7 DEVONIAN - 'OLD RED SANDSTONE' RIVERS & DESERT

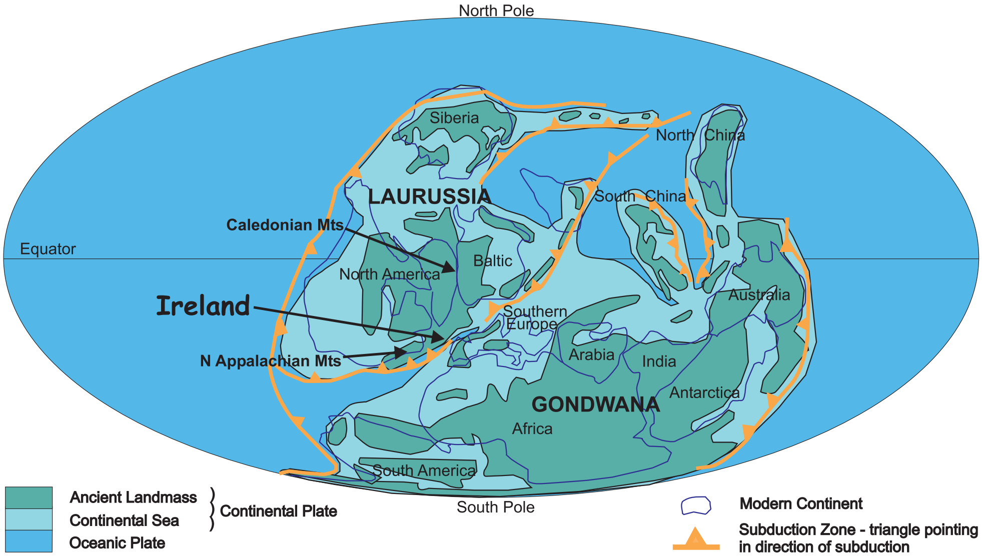

Figure 7.1 *Plate reconstruction for the Early Devonian (390 million years ago)*

7.1 CLIMATE & SETTING

During the Devonian Period, which lasted from 410 - 354 million years ago, Ireland was located on the southeastern margin of a large 'Old Red Sandstone' landmass that had formed from the final closure of the Iapetus Ocean during Silurian times (Fig. 7.1) (Chapters 5 & 6). This landmass on the Laurussian Plate covered most of what is now northern Europe and North America.

From the mid-Devonian onwards, Ireland, as part of the landmass, gradually moved from about 35^{O}S northwards towards the equator. The climate was semi-arid, with seasonal rainfall, Ireland being on the windward side of the continent, similar to the position of Zimbabwe today. Erosion of the Caledonian Mountains (Chapter 6) in northwest Ireland supplied sediment via large rivers to the extensive deserts of the alluvial plains.

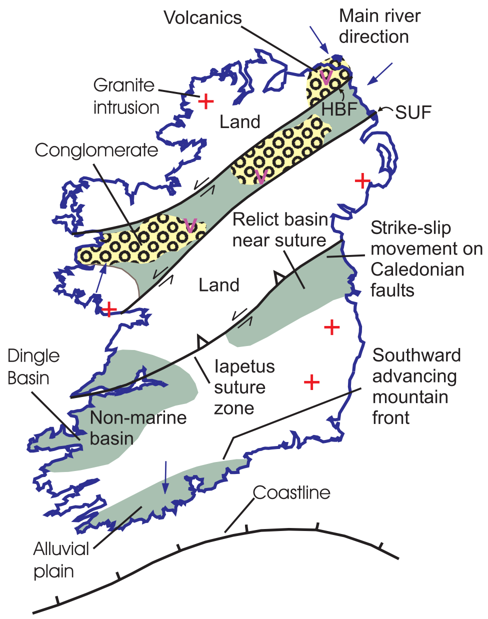

Figure 7.2 *Lower Devonian palaeogeography*

The predominantly red or purple colouration of the rocks, which gives rise to the name 'Old Red Sandstone' is due to the arid climatic conditions and low water table causing oxidation of the sediments (Study Box 7.2).

River processes dominated sedimentation in Ireland until the latest Devonian when the sea inundated most of Munster from the south. Evaporites and aeolian sediments were uncommon, compared to the later 'New Red Sandstone' deserts of the Permo-Trias (Chapter 11). Plants and trees flourished wherever the water table was high enough to prevent oxidation of the sediments. Bioturbation (Study Box 8.2) in mudstones from the Upper Devonian indicates that there was also an abundant fauna.

7.2 LOWER DEVONIAN BASINS

During the Lower Devonian, sedimentary basins (see section 1.4.2) were mostly restricted to the northern part of the country, exposed now near Clew Bay, the Curlew Mountains, Fintona, and Cushendall (Fig. 7.2). This was a mountainous area raised up in the last phase (Acadian) of the Caledonian Orogeny (Chapter 6, Fig. 6.1). The basins were internal basins (intermontane) within the mountain zone, that probably subsided between the Highland Boundary and Southern Uplands faults, which were active at this time (Figs 6.3, 6.4). These faults moved laterally by strike-slip displacement (see Fig. 1.35) as a result of the orogeny and extended into Ireland from the Midland Valley of Scotland, where there are similar Lower Devonian basins. They are characterised by conglomerates and sandstones and interbedded volcanic layers. Many of the conglomerate clasts are also derived from volcanic rocks. The conglomerates and sandstones were deposited in alluvial fans, playa lakes and associated fluvial deposits.

In the south of Ireland Lower Devonian rocks are preserved in another small basin on the Dingle Peninsula (Fig. 7.2). Here sedimentation was continuous from the Silurian into the Lower and Middle Devonian. The basin contains conglomerates and sandstones interpreted as lake sediments fringed by debris fans and later fluvial deposits.

At Inch, purple conglomerates contain clasts of metamorphic rocks that were probably derived from an area of now unexposed metamorphic rocks to the south (Fig. 7.3). This alluvial fan spread northwards down the southern slope of the Dingle Basin. Red sandstones and siltstones deposited between the conglomerate beds reveal sedimentary features, such as cross-bedding and ripple marks that are typical of an alluvial setting. Mud (desiccation) cracks formed on the surface of wet mud, indicate rapid drying-out of a playa lake in the hot desert environment.

Figure 7.3 *Conglomerates at Inch Strand, Co. Kerry*

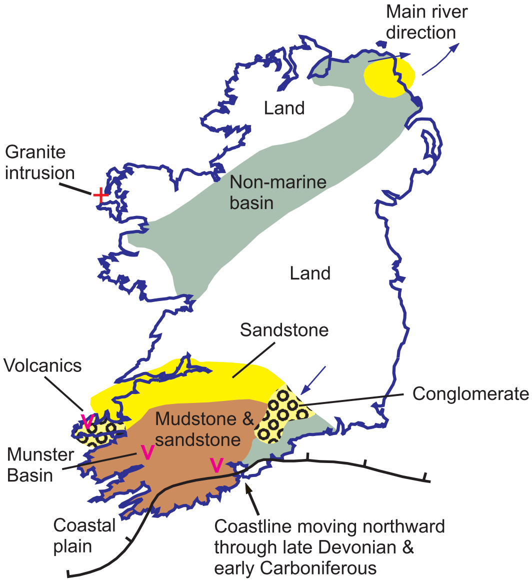

Figure 7.4 *Late Devonian palaeogeography*

7.3 MIDDLE & UPPER DEVONIAN

Most of the Devonian rocks preserved in Ireland today are of Upper Devonian age and rest unconformably on eroded Silurian rocks. Rocks of Middle Devonian age are generally absent, as this was a time of erosion marked by an unconformity (section 1.5.2; Fig. 1.34). However, rocks of Middle Devonian age have already been noted in the Dingle Basin. Rocks of late Middle Devonian age are also recorded from the Munster Basin.

7.3.1 THE MUNSTER BASIN

The Munster Basin (Fig. 7.4) was the site of the thickest non-marine Devonian sequence in Europe, with more than 6 km of sedimentary rocks deposited in the deepest part over the Iveragh Peninsula. It began in Middle Devonian times and continued throughout the Upper Devonian. The northern margin extended eastwards from Dingle Bay, through the Galtee and Comeragh mountains to the Waterford coast.

The basin is filled with conglomerates, sandstones, siltstones and mudstones. Two major river systems, that were eroding the mountainous source area to the north, dominated deposition in the Munster Basin. One entered the basin over the Iveragh Peninsula in the west and the other eastern river deposited its load over the Galtee Mountain region. Deposition from these rivers gave rise to the following four main packages of sedimentary rocks.

7.3.1.1 COARSE GRAINED FLUVIAL ROCKS – ALLUVIAL FANS & BRAIDED RIVERS

The coarse-grained conglomerates are found mostly on the margins of the basin, for example in the Comeragh and Galtee Mountains, where they represent alluvial fans (Study Box 7.1). These conglomerates can be seen in the back-wall of the corrie lake at Coumshingaun, Co. Waterford.

In the northern part of the basin, sedimentary structures in the pebbly sandstones and coarse sandstones show that the rivers were braided, that is, the channels split many times and joined up again as they flowed southwards across the alluvial plain (Study Box 7.1). The silt and mud sized material was carried away in suspension much further south.

7.3.1.2 AEOLIAN SANDSTONES

Sometimes, but not commonly, coarse alluvial fan deposits are interbedded with aeolian (wind-borne) sediments. This is seen on the northern margin of the Galtee Mountains, where fan conglomerates building outwards from the north interfingered with sands of an aeolian dune field (Study Box 7.2). Large-scale cross-bedding in the dunes (foresets of up to 15 m thickness) indicate that the main wind transportation was from the south. Similar juxtapositions of coarse alluvial deposits and aeolian sediments can be seen, for example, at Kilmurray Bay (Fig. 7.5) and Inch on the Dingle Peninsula.

Figure 7.5 *Aeolian Sandstones, Kilmurray Formation, Dingle.*

7.3.1.3 FINE-GRAINED FLUVIAL ROCKS – UNCONFINED SHEETFLOODS & LAKES

Further south, into the central part of the basin, the deposits are generally finer grained and result from unconfined sandy sheetfloods. In the hot, semi-arid climate, the mountains were periodically exposed to torrential rains, generating flash-floods in dry river valleys that caused rapid erosion. The rivers flowed mostly seasonally towards the south, ending in an extensive lacustrine area where the water seeped into the sediments. Drainage and evaporation far exceeded rainfall, and the lakes that formed on the plains, similar to those seen now in

South Australia, were short-lived. There were, however, a few perennial rivers. This finer grained predominantly purple coloured siltstone and mudstone (Fig. 7.6) makes up the great bulk of the Old Red Sandstone sequence, reaching several thousand metres in thickness along the peninsulas of West Cork and Kerry.

Figure 7.6 *Fine-grained floodplain deposits*

7.3.1.4 FLUVIAL COASTAL PLAIN SANDSTONES

Towards the top of the Old Red Sandstone succession, thick green and yellow sandstones appear and represent the transition from totally non-marine, well-oxygenated Old Red Sandstone fluviatile rocks, to the latest Devonian marine influx, marked by a higher water table and less oxygenated conditions. These sandstones were deposited by rivers on the coastal plain and can be seen at places such as Toe Head and Mizen Head in West Cork.

At around the same time micaceous white and yellow sandstones were being deposited in the eastern part of the basin, where they now crop out around the Galtee, Comeragh and Slievenamon Mountains. An interbedded green siltstone layer with beautifully preserved fossils of fish and plants (for example, *Archaeopteris* – Fig. 7.7) was discovered in the 19th century from a quarry at Kiltorcan, County Kilkenny. The siltstone was probably deposited by a highly sinuous river, on point bars and in adjacent swamps.

Figure 7.7 *Archaeopteris*

7.3.1.5 LATEST DEVONIAN MARINE SANDSTONES & SHALES

Tectonic rifting in latest Devonian times resulted in the formation of the smaller South Munster Basin, south of a line from Cork to Kenmare. In the uppermost Devonian, the sea encroached across this basin depositing dark-grey sandstone, siltstone and mudstone. Sedimentary structures show that there was wave and tidal current action (see Chapter 8; Study Box 8.1). The presence of brachiopod fossils also demonstrates their marine setting. This marked the beginning of a thick marine clastic sequence that continued uninterrupted in the South Munster Basin into Upper Carboniferous times. At the Old Head of Kinsale, these uppermost Devonian marine rocks are around 900 m thick and pass upward into dark-grey Carboniferous mudstones.

7.4 LATE DEVONIAN ROCKS IN THE MIDLANDS

On the map, rocks of Old Red Sandstone type surround the Silurian upland areas such as Slieve Bloom, Slieve Aughty and Slieve Phelim. These rocks comprise a widespread and relatively thin (generally less than 300 m) sequence of conglomerate, sandstone, siltstone and mudstone laid down to the north and east of the Munster Basin. The sandstones were mostly deposited from laterally migrating, low sinuosity rivers flowing southwards. Some of these rivers were of comparable size to the larger rivers in the British Isles today. Sandstone-mudstone interbeds are interpreted as deposits of vegetated floodplains beneath which the water table was rising. Conglomerates and pebbly sandstones, such as those found at Dunmore East (Fig.7.8) and Hook Head, were deposited in less sinuous, bedload dominated rivers closer to the higher ground of the Leinster Massif. This alluvial plain facies migrated slowly ahead of the northward advancing sea with uninterrupted fluvial deposition continuing upward into earliest Carboniferous times. In fact, most of the Old Red Sandstone in the north midlands is Lower Carboniferous in age.

Figure 7.8 *Old Red Sandstone conglomerate and sandstone at Dunmore East, Co. Waterford.*

7.5 DEVONIAN VOLCANOES & GRANITES

The presence of interbedded lava flows and ash fall deposits in the Old Red Sandstone, demonstrates that volcanic activity was contemporaneous with sedimentation. During the Lower Devonian in the Curlew Mountain area, thin andesitic lava flows (see Table 1.1) and pyroclastic layers alternated with sheetflood mudstone deposition on the downstream part of an alluvial fan.

Volcanic activity continued throughout the Middle and Upper Devonian in both northern and southern Ireland. The abundance of volcanic clasts and thin lava flows of this age (around 376 million years ago) in the Clogher Valley (Fintona) conglomerates, suggests that this alluvial fan was built up almost entirely from eroded contemporaneous volcanics.

Tuffs interbedded with the siltstones on the Iveragh Peninsula are dated at around late Middle Devonian (385 million years ago) and may be of similar age to the dolerites and gabbros intruded in the Valentia Island Harbour area. Southeast of Killarney, a similar-aged volcanic complex at Lough Guitane consists of mostly acid lavas and tuffs interbedded with alluvial fan channel sediments. Most of the volcanism and granite intrusion at this time appears to be related to the final stages of subduction of Iapetus oceanic crust. The rise of magmas was apparently controlled by strike-slip movement along major faults (see Chapter 6).

7.6 DEVONIAN LIFE

Major changes took place in the fauna and flora at the Silurian – Devonian boundary (Fig. 1.31). The changes were mostly in the terrestrial environment. Vascular plants continued to rapidly colonise the land, leading to dense forestation by the end of the Devonian, a time when seed-bearing plants (gymnosperms) also appeared. Heavily-armoured fish and primitive bony fish were abundant in the shallow fresh-water lakes of the Lower Old Red Sandstone, and sharks had evolved by mid-period. Later in the Devonian, 'tetrapod' amphibians (such as *Ichthyostega*) became the first animals to walk on land. Insects appeared in the early Devonian and the first winged type insect was reported from Upper Devonian rocks in Russia. Coral reefs and fish were abundant in the marine environments now recorded in southwest England and continental Europe. The goniatite group of ammonoids had evolved at the start of the Devonian and would become abundant in the Carboniferous seas that covered Ireland.

7.7 THE VALENTIA TETRAPOD TRACKWAY

Figure 7.9 *The tetrapod trackway on Valentia Island, Co. Kerry.*

A large number of fossil footprints (Fig. 7.9), forming several trackways, have been exposed on some of the bedding planes in the purple siltstones on Valentia Island. They were made by the first known tetrapod, a primitive amphibian that probably evolved from a type of lungfish, as it walked across the fluvial plain. From the two hundred or more footprints, complete with body and tail drag groove, it has been possible to calculate a body length of about one metre and to envisage a salamander-type gait. As the first discovery of this type in Europe and the oldest *in situ* record of an amphibian animal, the site is now protected as an important part of Ireland's heritage.

7.8 DATING THE ROCKS

Old Red Sandstone rocks are very difficult to date because of the paucity of fossils, due to the hostile conditions of deposition and preservation. They have been dated mainly on the basis of plant pollen (miospores), which evolved rapidly, but which are generally absent from all but the upper Old Red Sandstone. Radiometric dating of interbedded volcanic rocks have yielded absolute ages of late Middle to Upper Devonian (around 385 - 376 million years ago) for sedimentation in the Munster Basin.

STUDY BOX 7.1 - Alluvial Systems

A river is a dynamic system that constantly adjusts its flow (discharge), sediment transport and channel geometry in response to changes in slope and base level (Study Box 15.1). Debris that rivers carry as sediment is deposited as alluvium on the valley floor. When a mountain tributary stream moves from a steep gradient to a flatter gradient, where for example it joins the main valley, its velocity suddenly slows and its sediment load is dumped as an alluvial cone or alluvial fan. Coarser material, comprising boulders, cobbles and gravel, is deposited on the steeper upper slopes, while the finer sand, silt and mud are carried further onto the lower, gentle slopes.

Figure 1. *Alluvial fan, Andes, Argentina*

Fans from adjacent streams along the mountain front may coalesce into compound fans that can build up into a great thickness of sediment over millions of years. In a desert environment (Study Box 7.2), periodic torrential rainstorms produce flash floods which are highly erosive; the streams carry vast amounts of loose debris that add to the alluvial fans (Fig. 1). In the Mohave Desert, California, cone-shaped fans have built up at the foot of each narrow mountain valley, so that the lower slopes are totally covered.

Braided Streams - are typical of high-energy rivers (high load, low to variable slope and flow) flowing across the upper reaches of an alluvial valley plain.

The channel fill of braided streams is defined by a basal erosional surface, and cross- stratification from the downstream migration of bars. Fining-upwards of grain size is common (Figs. 2 & 3).

Figure 2. *Braided alluvial plain, Nazca, Peru*

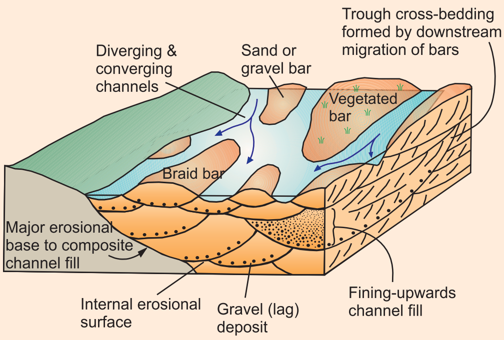

Figure 3. *Internal structure of a braided river*

Meandering Rivers - Low-energy rivers flowing across lowland plains carry a fine sediment load (sand, silt or mud) and develop a sinuous or meandering pattern. Some meandering rivers (Fig. 4) erode deeply into the bedrock during uplift (Study Box 15.1) and thereby become entrenched, for example, the Grand Canyon of the Colorado River.

The sideways movement of meanders is formed by erosion along the outside of the bend (where the current is strongest) and the deposition of a curved bar, known as a point bar (Fig. 4), on the inside of the bend (where the current is weakest). Some meanders on the Mississippi River migrate by as much as 20 m a year. As meanders migrate sideways and downstream, point bar and channel deposits of gravel, sand and silt accumulate across the valley floor, creating a wide flat floodplain.

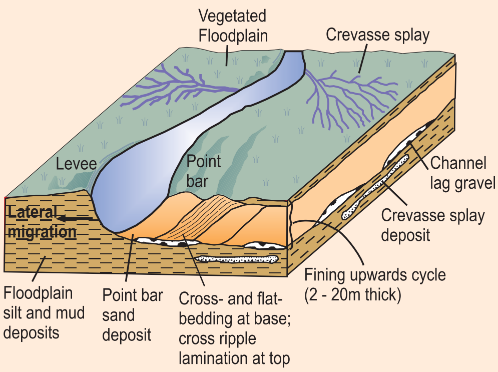

Figure 4. *Internal structure of a meandering river*

Point bars show cross-bedding in cross-section, and the downcurrent direction of these bedding patterns has been recognised in geological strata and used to determine flow directions of ancient river systems (palaeocurrent indicator).

If meander loops get too close together, the river may take a shortcut, leaving behind the abandoned bend as an oxbow lake. These fill with mud and silt and eventually support reeds and other vegetation. The floodplain also consists of finer grained overbank deposits of silts, clays and some sands, dumped across the floodplain in times of river flooding; such floodplain deposits are horizontally bedded and rippled. When a river breaches its banks, it suddenly drops its coarsest material along the sides, to form ridges that build up into confining levees after successive floods (see Study Box 10.1).

Study Box 7.2 Desert Processes - Erosion and Dunes

Desert areas form about one fifth of the world's land area and were as extensive, if not more so, in the geological past. Today, most of the great deserts lie in the tropics. The cold polar deserts, however, should not be forgotten. The main agents of erosion and deposition are water and wind (Fig. 1), with mechanical and chemical weathering helping to shape the desert landscape. However, rainfall is rare and sporadic, and temperature and wind power fluctuate dramatically on a daily and seasonal basis. The erosive and depositional power of water is described in Study Box 7.1.

Mechanical erosion predominates over chemical methods, involving splitting, exfoliation and disintegration of the rocks by the alternation of hot and cold extremes, forming steep scree slopes with angular rubble at the base and smaller rock fragments across the plains. Chemical weathering is extremely slow but plays an important role. Decomposition and solution weakens the rocks so that they are vulnerable to mechanical attack. Evaporation brings minute quantities of dissolved matter, including iron oxides (e.g. haematite), manganese and clay minerals, to the surface to form an oxidized red or brown film on rock and pebble surfaces, known as 'desert varnish'. It appears to take about 2000 years to 'varnish' a desert monument or artifact. Oxidation is a chemical weathering process where iron takes up oxygen, as when an iron bar goes rusty. Some of the rocks are green coloured and this reflects reduction, the opposite of oxidation, due to a high water table preventing air from reacting with the iron in the rocks.

Figure 1. *Alternating hard & soft rock layers in Jurassic rocks, Goblin valley, Utah, when joints & bedding surfaces are eroded by wind & water, result in differential erosion & the formation of 'goblins'.*

About one fifth of desert areas are covered by sand (Fig. 2). Much of the desert floor is bare bedrock strewn with coarse rock fragments, and only a sandy bedrock layer will yield sand on erosion. The sand grains are then whipped up by the wind, transported and shaped into a variety of mounds, ridges and dunes (Fig. 2). Form and pattern depend on many factors, including the grain size and type, the underlying rock surface and the strength and direction of the wind. Any obstacle to the wind, such as a rock or pebble, can be the starting point for dune formation. Sand accumulates downstream of the object, in the wind-shadow, which initially forms a sand drift. This may grow into a larger dune, given a constant sand supply and prevailing wind direction. Sand grains roll up the gentle windward slope and fall down the slip face, forming a foreset (in the same way as fluvially-formed cross-bedding Study Box 8.1) and thus advance the dune downwind (Fig. 3). Crescentic shaped dunes (barchans) occur as single units on bare bedrock where sand supply is limited, or as colonies that migrate across the desert like giant ripples. Consistent wind direction, as found in the Trade Winds areas, enables growth and stability in barchan colonies, as seen by their great procession through the Libyan Desert. Dunes often reach heights of 30 m and the mountainous dunes of the Saudi Arabian desert can reach 250 m. There is an inbuilt height limitation, as wind velocity increases higher up, thus removing sand from the top of the dune.

Figure 2. *Sand Dunes in the Sahara, Mauretania*

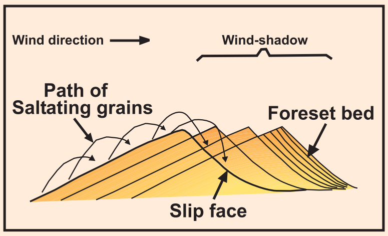

Figure 3. *Sand dune formation*

When the rock surface between irregularly spaced barchans and ridges is sprinkled with coarse sand and fragments, the wind disperses any loose sand into featureless sand sheets, rather than forming separate dunes. Sand sheets merge with other dune types to form an extensive dune field (or 'sand sea' or erg), often with smaller ripples developed on the dune surfaces, as seen in the Egyptian Desert.

Figure 4. *Aeolian cross-bedding, in Jurassic sandstones, San Rafael Swell, Utah*

In the geological record, large-scale cross-bedding is recognised as the product of ancient deserts, and gives direct evidence of palaeowind directions (Fig. 4).