Fig. 1.1 Hugh Miller, from a D. O. Hill calotype *c.*1843.

GEOLOGY AND LANDSCAPE OF EASTER ROSS AND SUTHERLAND

Con Gillen

GEOLOGY AND PHYSICAL LANDSCAPE

A look at the geological map [Fig. 1.2] shows that the firthlands are surrounded by a great V-shaped swathe of Old Red Sandstone rocks. Only the Dornoch Firth breaks through and penetrates into the older underlying harder Moine schists. The Old Red Sandstone, well-known in the east coast towns from Inverness to Dornoch as a useful and distinctive building stone, was made famous by the researches of Hugh Miller [Fig. 1.1], the Cromarty stonemason whose birthplace is preserved by the National Trust for Scotland. He was a meticulous worker who accurately described, catalogued and figured his remarkable finds of fossil fish from the Black Isle [Fig. 1.3].

Moine Schist and Lewisian Gneiss

The oldest rocks of the area, the Moine schists, occur in the hinterland of the firths. These rocks represent shallow-water sandstones and shales which were folded and altered by high pressures and temperatures deep within the Earth's crust during the Caledonian mountain-building period, some 500 million years ago. The resulting crystalline metamorphic rocks are granular feldspar-bearing quartzites and mica shists, which often break into slab-like flagstones at the surface. Ben Wyvis which dominates the scenery north-west of the Cromarty Firth is made of Moine schist of high metamorphic grade; the main rock type is coarse-grained garnet-mica schist or gneiss.

Along the Moray Firth shore of the Black Isle and at the south-east end of the Tarbat Ness peninsula, outcrops of Moine schists occur that contain narrow slivers of older Lewisian Gneiss which have been deformed with the Moine rocks (Harris 1977) [Fig. 1.2]. The main outcrop of Lewisian Gneiss is in north-west Scotland and the Outer Hebrides. This rock probably forms the basement underlying the entire Scottish highlands, and it has been brought up as slices along the Great Glen Fault and interleaved with the Moine schist during the Caledonian mountain building event. Similar slices of banded quartz–feldspar–hornblende gneiss occur elsewhere along the Great Glen, notably on the shore of Loch Ness opposite the Abriachan granite (NH 585365). The North and South Sutors are made of hard flaggy Moine schist, which is rather crushed and invaded by granite veins and sheets which in turn have also been milled down and recrystallized. Behind these bosses of metamorphic rocks occur the softer

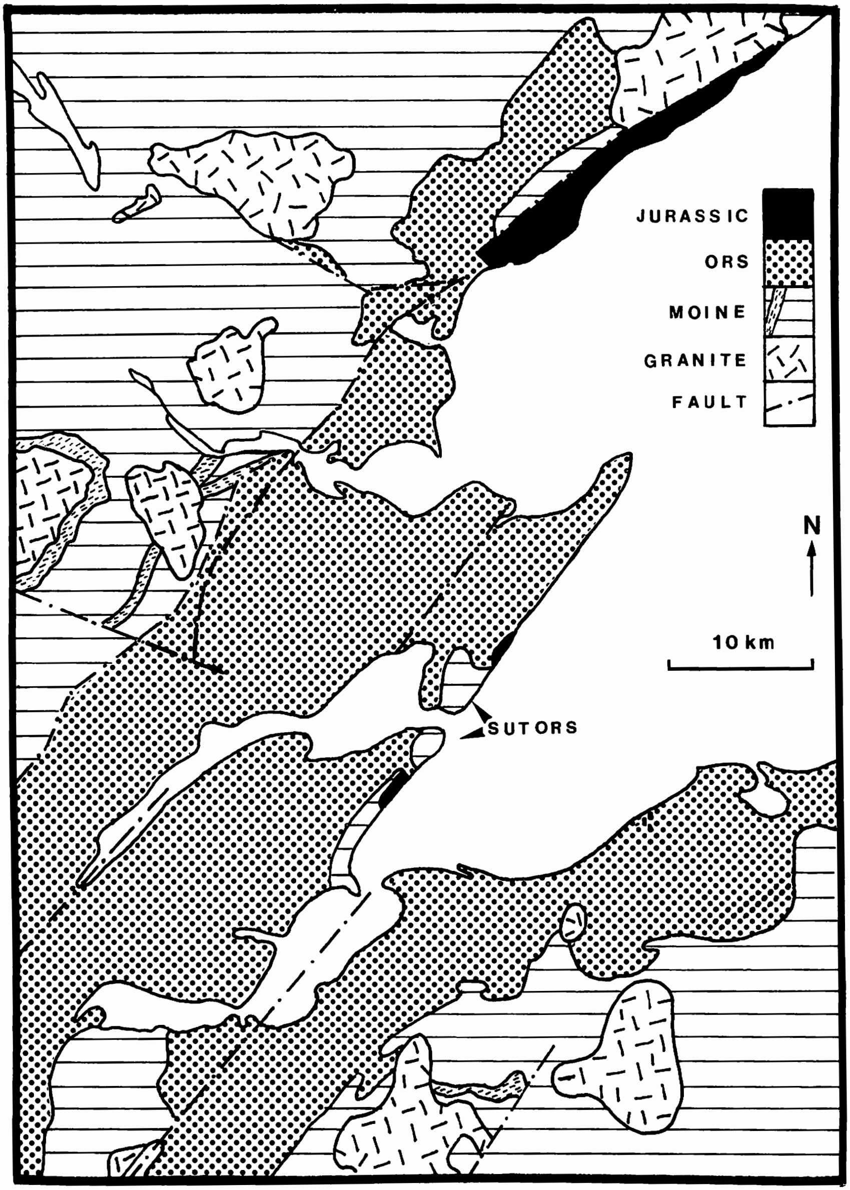

Fig. 1.2 General geological map of the firthlands.

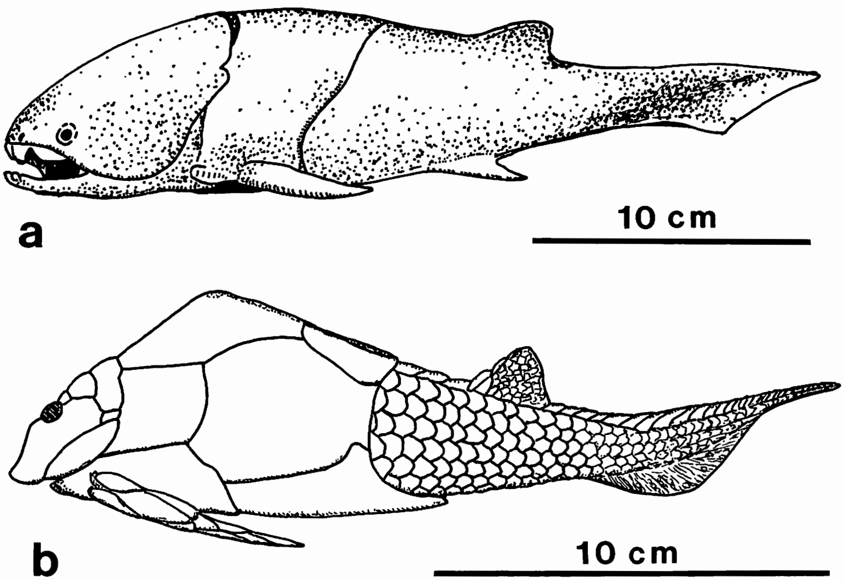

Fig. 1.3 Fossil fish, from the Old Red Sandstone (ORS) (a) *Coccosteus*, (b) *Pterichthys*.

sandstones of the Cromarty Firth. Reference will be made to the shape of this coastline in a later section.

Granite Intrusions

Large masses of molten granitic rock were intruded into the Moine schists at about 410 million years ago, just prior to the deposition of the Old Red Sandstone. The Fearn granite, for example, has supplied many boulders to the conglomerate at the base of the Old Red Sandstone. East of Bonar Bridge, the red colour of the Migdale granite is easily seen on crossing the bridge from the Ardgay side. The granite is made up of pink and white feldspar, clear quartz and black biotite. It is cut by many narrow (2–3 cm/1 in wide) veins of coarser granitic rock, referred to as pegmatite, which represent the last water-rich products of the cooling granite. Between Lairg and Rogart lies the Lairg or Rogart granite, the main mass of which forms rather low ground north of Strath Fleet. This rock is more properly referred to as granodiorite since it contains abundant dark minerals, biotite and hornblende, in addition to feldspar and quartz (see Brown 1983).

Old Red Sandstone

Rocks of Old Red Sandstone (or Devonian, 350–400 million years old) occupy a major NE–SW-trending synclinal fold, referred to as the Black Isle Syncline by Armstrong (1977) [Figs. 1.2; 1.4]. These sedimentary rocks

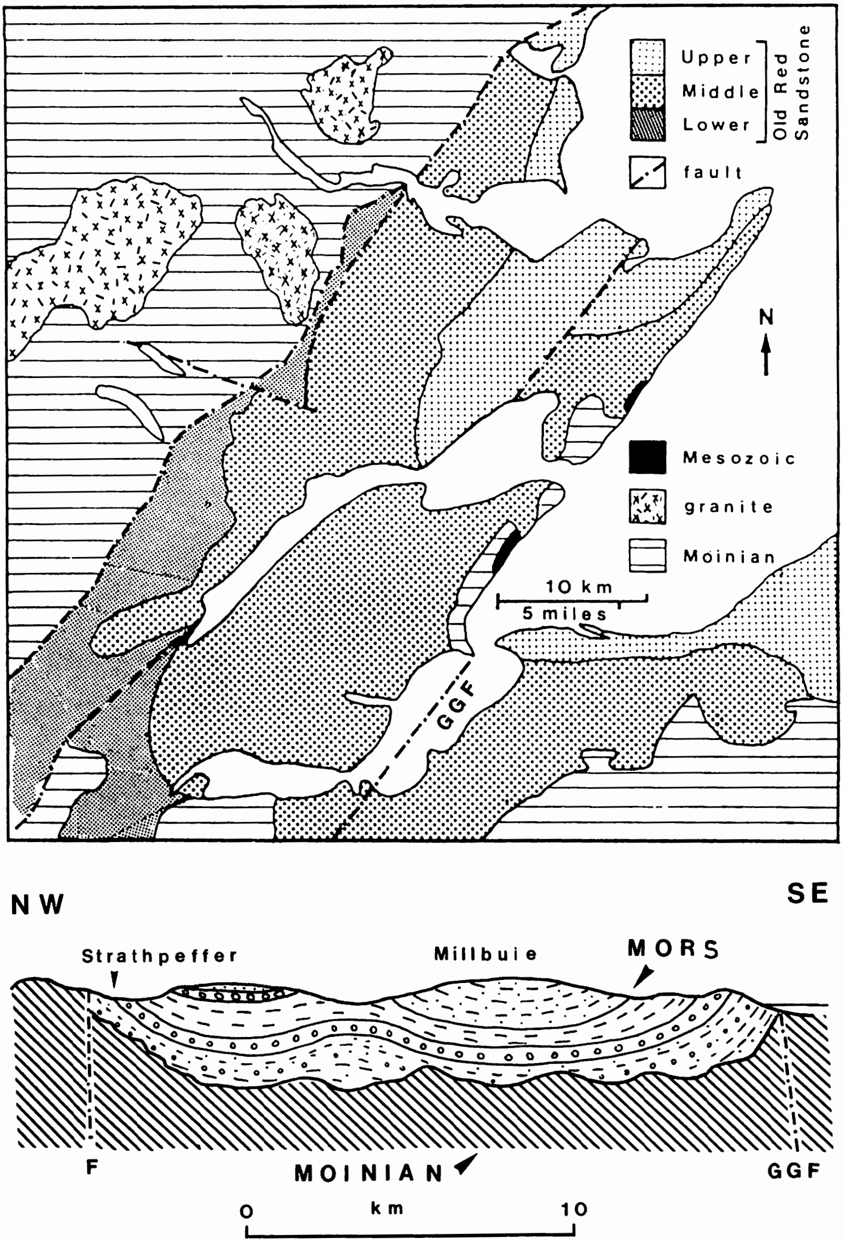

Fig. 1.4 Old Red Sandstone of the firthlands. Section shows Black Isle syncline (GGF: Great Glen Fault; MORS: Middle Old Red Sandstone).

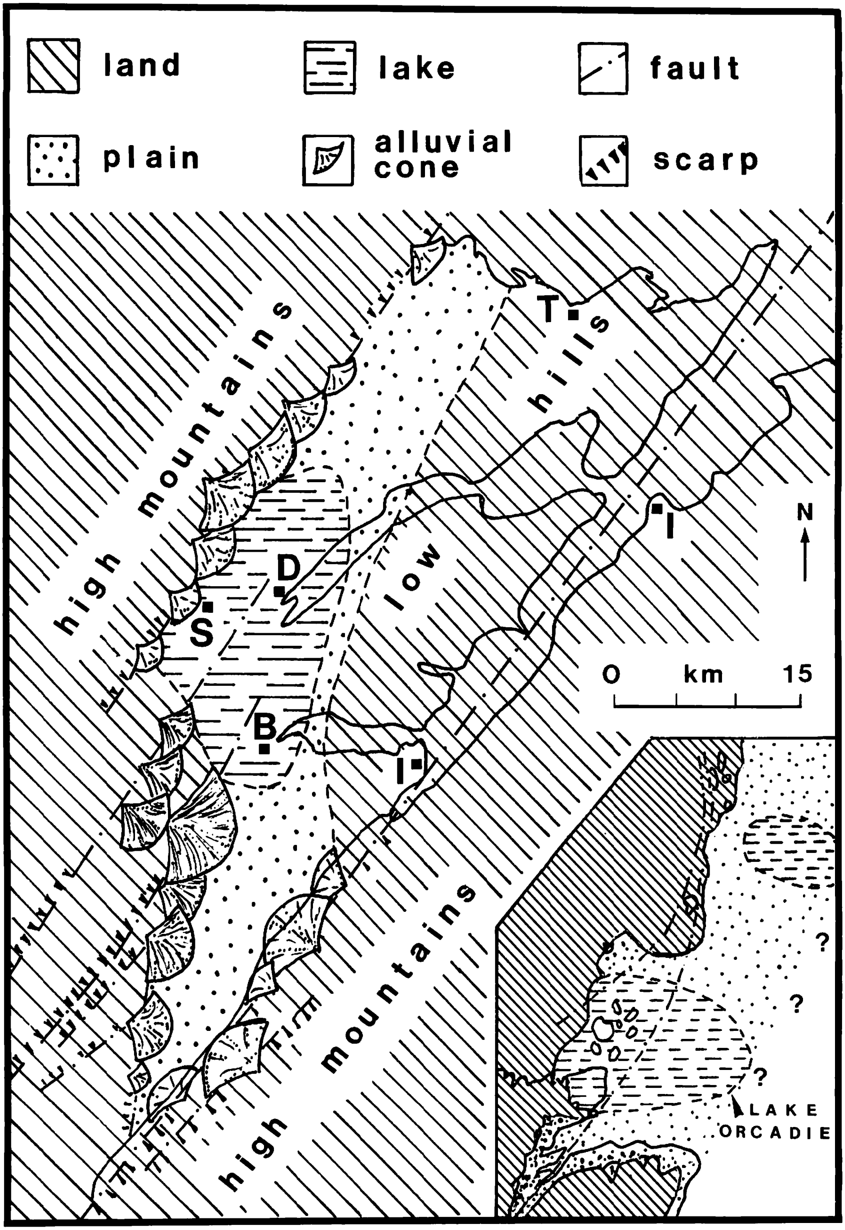

Fig. 1.5 Conditions of Old Red Sandstone (ORS) deposition. Post Devonian movement of 27 km on Great Glen Fault assumed (I: Inverness; B: Beauly; S: Strathpeffer; D: Dingwall; T: Tain). Inset shows extent of 'Lake Orcadie'.

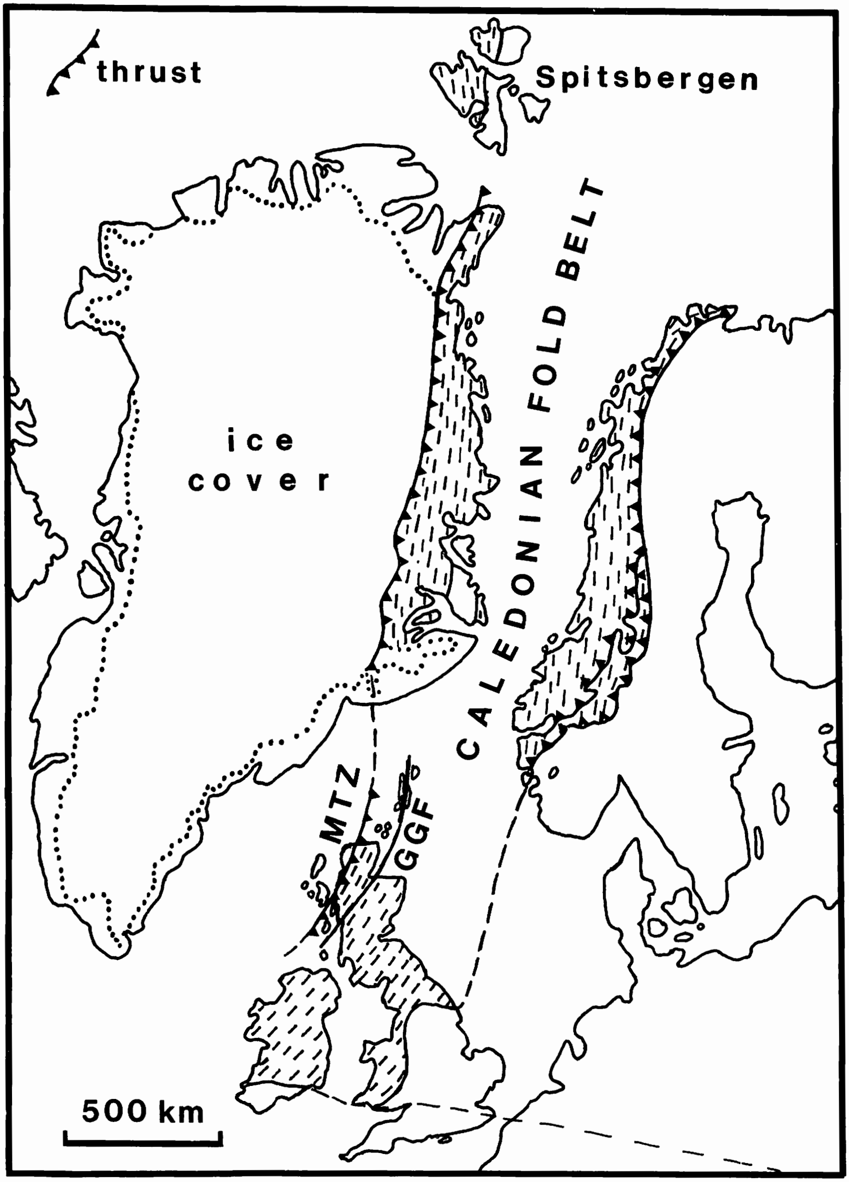

Fig. 1.6 Pre-drift reconstruction of the Caldonian fold belt.

became famous upon the discovery of fossil fish by Hugh Miller at Cromarty (NH 795673) and Ethie (NH 782642). Miller's various geological papers were collected and expanded into his book, *The Old Red Sandstone*, first published in 1841. The total thickness of the Old Red Sandstone succession in Easter Ross and the Black Isle is approximately 6,500 m (21,350 ft), made up of conglomerates, mudstones, sandstones and shales. The fish beds of Edderton, Cromarty and Balintore are Middle Old Red Sandstone calcareous shales, containing hard limey nodules with occasional fragments of primitive armour-plated fishes (mainly lustrous black scales) [Fig. 1.3].

The Old Red Sandstones are terrestrial in origin, having been laid down in the alluvial fans and on the floodplains of large meandering rivers which flowed off the young, high Caledonian mountains [Fig. 1.5]. Siltstones, shales and mudstones represent the deposits of shallow ephemeral lakes at the base of the mountain slopes. Some of these land-locked lakes became choked with sediment and decaying animal and vegetable matter. The Caledonian mountain range extended from Ireland and Wales through the Scottish Highlands, north to Shetland and north-east to Scandinavia, East Greenland and Spitzbergen [Fig. 1.6]. During the Lower Devonian, Britain lay at a latitude of 20°–30° S. Slow northward drift brought us to 10°–20° S by the end of the Devonian, some 350 million years ago (Mykura 1983). At that particular time, north-east Scotland lay in the lee of high mountains and had a hot dry climate, punctuated by torrential rainstorms which led to flash floods and the transport by intermittent rivers of the vast quantities of coarse sediment from the mountain scree slopes down onto the extensive plain at the foot of the mountain chain (Mykura & Owens 1983).

In Middle Devonian times the land sloped to the north-east and was cut by deeply incised rivers which flowed north-eastward onto the broad alluvial plains on the area in which today are found the firthlands (Mykura 1983). North of the firthlands lay the great land-locked lake or shallow inland sea known in the literature as the 'Orcadian' lake.

The Great Glen Fault

The Great Glen Fault is probably the single most important structural feature in the north of Scotland. The fault occupies a zone about a kilometre (0.6 mls.) wide along which considerable movement has taken place on several occasions during a long span of geological time, starting around 400 million years ago. Even today minor earthquakes are experienced in Inverness and other towns along the 90 km (56 mls.) of the Great Glen. During the last two centuries at least sixty earthquakes have been recorded along the fault (Wood 1978).

The Great Glen Fault is one of a set of near-parallel faults which cut the rocks of the highlands north and south of Glen More [Fig. 1.4]. The fault was initiated during the Caledonian mountain building event, long before the deposition of the Old Red Sandstone, and it remained a plane of weakness in the Earth's crust along which movement occurred in several different directions (Smith 1977; Mykura 1982, 1983). Crushing, fracturing and milling-down of rocks in the fault zone have resulted in material that has weathered more rapidly than the surrounding hard rocks, so that an early river valley was utilized by glaciers during the last ice age, and we are now left with a loch-filled long, narrow, deep valley.

While there are divergent opinions concerning movement on the Great Glen Fault, it is now accepted that the fault was initiated as a deep and fundamental structure before the deposition of Old Red Sandstone sediments. Basement rocks along the Great Glen display extensive shearing, cataclasis and recrystallization with the development of thick bands of mylonite (finely-banded fault rock, recrystallized from rock powder), indicating that the fault originated at deep levels within the crust (Smith 1977; Mykura 1983). Original attempts to determine the amount of movement on the fault were based on postulating a match between the Strontian granite at the south-west end and the Foyers granite at the north-east end of the fault. Other evidence includes matching structures, rock types and metamorphic grades in Moine schists, and when all this is taken into account we are left with the postulate that the Great Glen Fault is a sinistral (left-hand) transcurrent fault with a horizontal displacement of around 100 km (62 mls.). It should be emphasized, however, that the Great Glen follows not merely a simple transcurrent fault line, but a wide complex zone of thrusts and faults which were active at various times in the geological past.

In a recent study of the Old Red Sandstone rocks east of Loch Ness, Mykura (1982) draws attention to repeated differential vertical movements in the fault zone and along associated NE-trending faults during the deposition of the sediments, and to the existence of several compressive thrust faults and folds in the Foyers section. The conclusion is that there was a complex interplay of normal faulting, folding, thrusting and transcurrent movement in the Great Glen Fault zone in Devonian times. The Old Red Sandstone on Struie Hill, for instance, has been thrust over the underlying basement of Moine schists so that, looking up the hill from the 'Queen's View', the thrust plane can be clearly observed as a distinct near-horizontal break in slope. When the palaeogeography of Middle Old Red Sandstone rocks in the Moray Firth area is taken into account, the conclusion is reached that there was an overall dextral (right-hand) displacement along the Great Glen Fault of some 25–30 km (16–19 mls.) (Donovan et al. 1976; Smith 1977; Mykura 1982; Mykura & Owens 1983).

Evidence for movement along the Great Glen Fault zone in post-Devonian times is conflicting (Smith 1977). The concensus view, based on off-shore geophysical studies in the Moray Firth basin, is that during Mesozoic and early Tertiary times (190–55 million years ago), the Great Glen Fault behaved as one of a set of NE–SW fractures which partly controlled the location of sedimentary basins. The Jurassic sediments of the area have been affected by normal faults, with downthrow to the south-east (Bacon & Chesher 1975). Some reconstructions of the Great Glen Fault show it as continuing through the Walls Fault in central Shetland and on up to Spitzbergen, more than 1000 km (620 mls.) distant, but this correlation is uncertain and is disputed (Wood 1978; Mykura 1982).

The other major fault of the area is the Helmsdale Fault [Fig. 1.4], which brings Mesozoic rocks along the north coast of the Moray Firth down against older rocks (Old Red Sandstone, Moine schist and the Helmsdale Granite).

Mesozoic Rocks

Narrow outcrops of Mesozoic sediments occur along the coastal margins of the Moray Firth [Fig. 1.4]. An incomplete succession from Triassic (220 million years old) to Upper Jurassic (140 million years old) is found between Dunrobin and Helmsdale. Jurassic rocks are also present on the shore at Balintore and Ethie, while on the south coast of the Moray Firth a faulted succession of Permo-Triassic to Lower Jurassic sediments is exposed between Burghead and Lossiemouth.

The Jurassic rocks are mostly clays, shales, siltstones, sandstones and occasional beds of nodular limestone and ironstone. Fossils are fairly abundant, and include ammonites, lamellibranchs and plant fragments [Fig. 1.7]. At Brora, bituminous shales are overlain by a one metre (3.3 ft) thick coal seam which was worked for many years. Being a young coal, it is poor quality, with high water, gas and sulphur content. The depositional environment of these Middle to Upper Jurassic sediments is interpreted to have been a sandy shallow-water delta at Brora, and a deeper-water thin shaly sequence at Balintore (Chesher & Lawson 1983).

At Ethie and Balintore, the topmost Jurassic sediments consist of Kimmeridgian (around 137 million years old) carbonaceous shales, sandstones, grits and thin limestones. Between Brora and Helmsdale, the Kimmeridgian is represented by 60 m (20 ft) of thick sandstone units with shaly partings, overlain by 500 m (1,640 ft) of carbonaceous shales, flagstones and grits with many prominent boulder beds. Fossil evidence (the plants in the Brora coal beds for instance) indicates that the climate at the time was probably subtropical. These boulder beds contain large blocks of Old Red Sandstone, similar to rocks that occur *in situ* near Dunbeath, over 20 km (13 mls.) to the north. During late Jurassic times, large-scale normal faults developed during a period of rifting in the North Sea, with the formation of deep marine sedimentary basins. The margin of one such basin is defined by the Helmsdale Fault [Fig. 1.4]. Subsidence on the south-eastern side of this fault led to a fault scarp, down which masses of sediment flowed as debris accumulations, rock falls and mud-charged rapid turbidity currents (Pickering 1984). As the submarine slope built up, the uncompacted soft sediments were redeposited by sliding. Underwater channels were cut deeply into the slope and infilled with coarse-grained clastic sediments [Fig. 1.8]. The Helmsdale Fault continued to move as

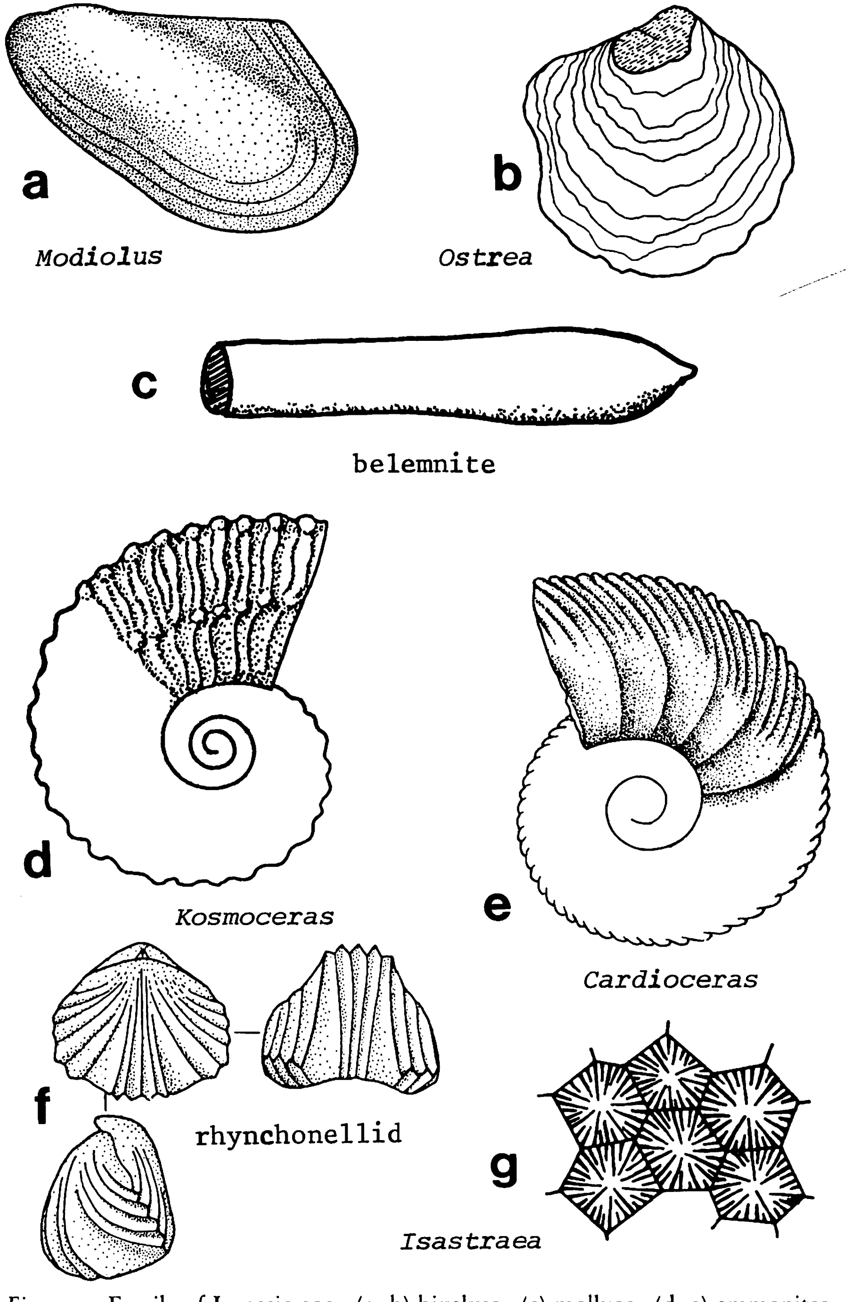

Fig. 1.7 Fossils of Jurassic age: (a, b) bivalves, (c) mollusc, (d, e) ammonites, (f) brachiopod, (g) coral.

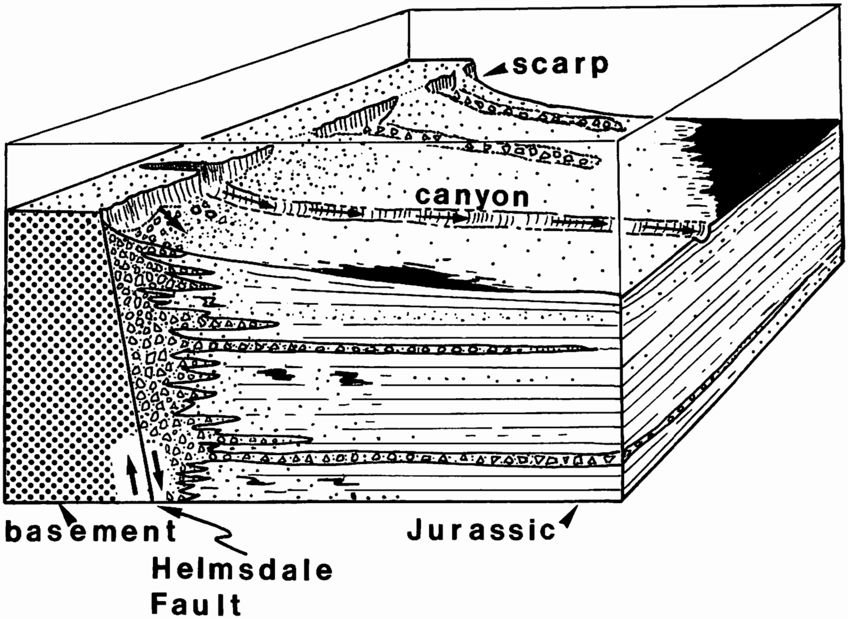

Fig. 1.8 Submarine fans along the Helmsdale Fault in Jurassic times (after Pickering, 1984).

sediment accumulated, and the regional structural pattern is of large-scale differential subsidence accompanied by the deposition of thick organic-rich muds which are locally interbedded with deposits of mass-flow and landslip origin, derived from adjacent rising fault-bounded blocks of crust (Anderton et al. 1979).

In the centre of the North Sea the Jurassic succession is some 2,300 m (7,550 ft) thick (Chesher & Lawson 1983), which is one of the thickest occurrences in the North Sea. The rock types there are alternating sandstones and shales, which overlie Permo-Triassic beds; they dip gently to the north-east. Black shales and siltstones of Lower Cretaceous age overlie Upper Jurassic Kimmeridgian beds in the North Sea. The Upper Cretaceous white chalk with flints is present in the east of the Moray Firth, where it extends over the entire width of the area. Upper Cretaceous chalk occurs on the sea bed north of Fraserburgh and east of Wick (Chesher & Lawson 1983).

The Moray Firth Basin

The Mesozoic basin of the Moray Firth was more or less coincident with the older Old Red Sandstone Orcadian basin. Mesozoic rocks are mostly marine and deltaic, whereas the Old Red Sandstone deposits are continental and lacustrine. The present-day coastline of the south Moray Firth marks the limit of the Mesozoic basin. Fault lines define the margins of the basin [Fig. 1.2], with Mesozoic strata being downfaulted against the Old Red Sandstone. Within the basin, sediments have been affected by normal faulting which was active during sedimentation, particularly in the Jurassic, and resulting in the formation of a series of fault-bounded rift valleys (grabens) and upstanding blocks (horsts). A major syncline (down-fold) is present along the line of the Great Glen Fault, which was active as a normal fault during the Mesozoic. Other major faults of the area moved during Mesozoic times along reactivated lines of weakness that were initiated in the Old Red Sandstone era, towards the end of the Caledonian orogeny (mountain-building period) or earlier (Watson 1984). Mesozoic sediments piled up thickly in the Moray Firth basin to the south of the Great Glen Fault, on its downthrow side (Chesher & Lawson 1983).

DEVELOPMENT OF THE LANDSCAPE

Tertiary Erosion

The present landscape which we see in the area of the firthlands began to be developed during Tertiary times, around 30 million years ago, when Scotland was repeatedly uplifted in a series of pulses and the land surface was deeply eroded. The drainage system of Scotland became established in the Tertiary, and great rivers flowed eastwards across the easterly-dipping tilted land surface of the highlands to the North Sea [Fig. 1.9]. During Tertiary and Quaternary times the area of the North Sea was subjected to deep and rapid subsidence (Anderton et al. 1979). Sediments of Tertiary age are absent from the land area of north-east Scotland, whereas large volumes of muddy, shaly and silty sediments were supplied to the subsiding trough of the North Sea in the form of large deltas and submarine fans. The Hebridean west coast of Scotland was an area of volcanic activity at the time, and humid tropical climatic conditions prevailed.

The long east-flowing streams cut discordantly across the major structures of the Moine schists, and for this reason the initial drainage pattern is considered to be superimposed on the geology due either to rapid uplift and the removal of a once-extensive cover of sediments (Sissons 1967), or to the emergence of a marine-planed surface from beneath the sea (George 1965). Dissection of the surface by rivers and later by the Pleistocene ice sheet resulted in the isolation of high residual hills, such as Ben Wyvis (1,047 m: 3,433 ft) from the main massif of the Scottish Highlands [Fig. 1.9]. West and north of Ben Wyvis the mountains are eroded into a dissected plateau, with erosion surfaces at different heights (George 1965; Sissons 1967).

Glacial Erosion

During the last two-and-a-half million years, cold waters have pushed southwards from the polar ice cap more than twenty times and large ice-sheets have built up on adjacent land masses in the North Atlantic region.

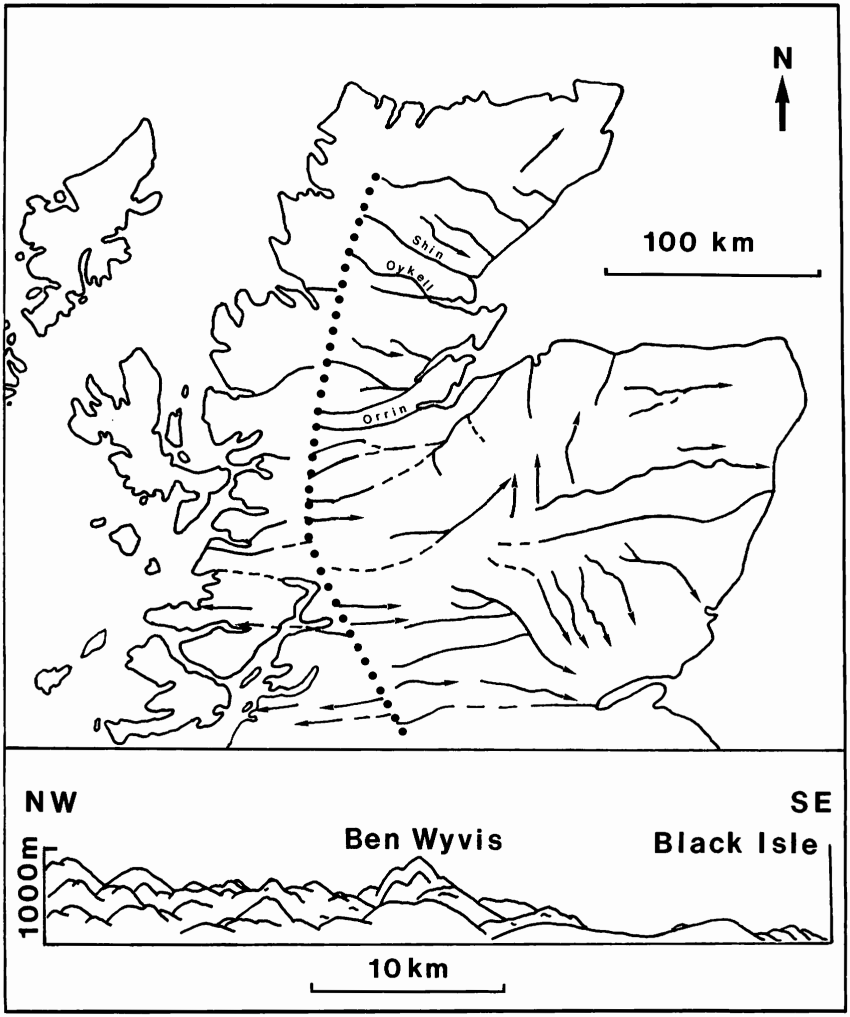

Fig. 1.9 Initial drainage and watershed of northern Scotland. Profile shows Ben Wyvis as a residual hill.

The mountainous areas of Britain became the centres of growth and as the climate deteriorated and arctic conditions set in, the mountain glaciers merged into an ice-cap and ice-sheets advanced over the lowlands. Ice-sheets well over 1,000 m (4,000 ft) thick covered most of Britain during the extensive early glaciations. The huge Scandinavian ice-sheet crossed the North Sea depression and came against the Scottish ice-sheet just off the north-east coast [Fig. 1.10]. It was not until a mere 10,000 years ago that the last ice-sheet melted from the Scottish Highlands.

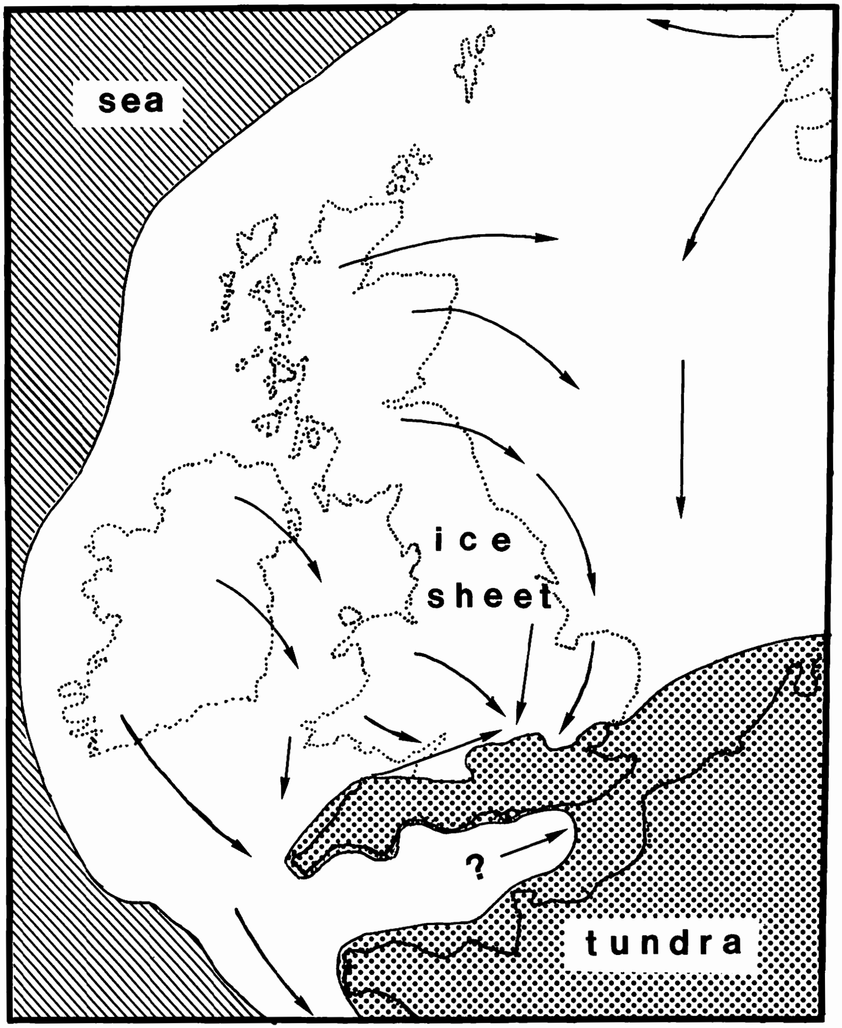

Fig. 1.10 Extent of the ice-sheet during the Pleistocene glaciation. Arrows show flow directions.

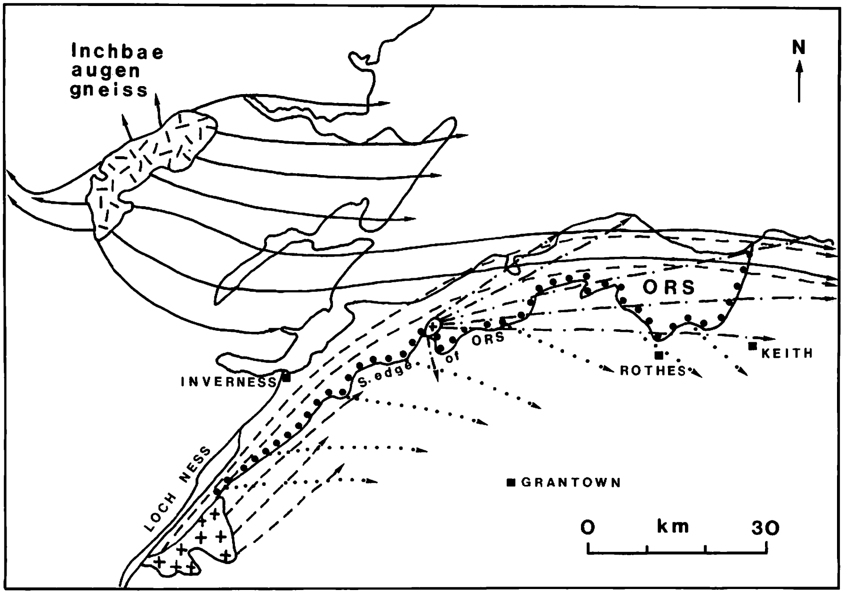

Fig. 1.11 Distribution of ice-carried erratics (ORS: Old Red Sandstone).

Many of the characteristic landscape features of the Highlands were produced by glacial erosion. As ice-sheets moved over the surface and down old river valleys, loose scree and alluvium were picked up and embedded in the base of the advancing glacier, which subsequently scraped, moulded and polished the bedrock. Glaciated valleys are now straighter than the original river valleys and tend to have steep sides and wide U-shaped profiles, in contrast to the more typical V-shaped valleys of mountain streams. The ice-sheets covered all but the highest areas of the Highlands and produced a smoother and more rounded landscape. It is not certain if Ben Wyvis was completely submerged beneath ice, though small semi-circular steep-walled corries are present on the mountain. These mark the birthplaces of glaciers which eventually outgrew their corries and flowed steadily down pre-existing river valleys. Glacial striae or scratch marks are not often preserved on the soft Old Red Sandstones, but some examples are to be found on rocks in the Black Isle, such as at Culbokie village, facing the Cromarty Firth.

Ice moved north-eastwards along the Great Glen and gouged out the rock basin of Loch Ness. Towards the Moray Firth this valley glacier was deflected eastwards on meeting a more powerful and larger ice-sheet that flowed eastwards from Ross-shire. Erratic boulders of the highly distinctive Inchbae augen gneiss were carried by the ice and are now widely distributed through Easter Ross, except on the summit of Ben Wyvis [Fig. 1.11].

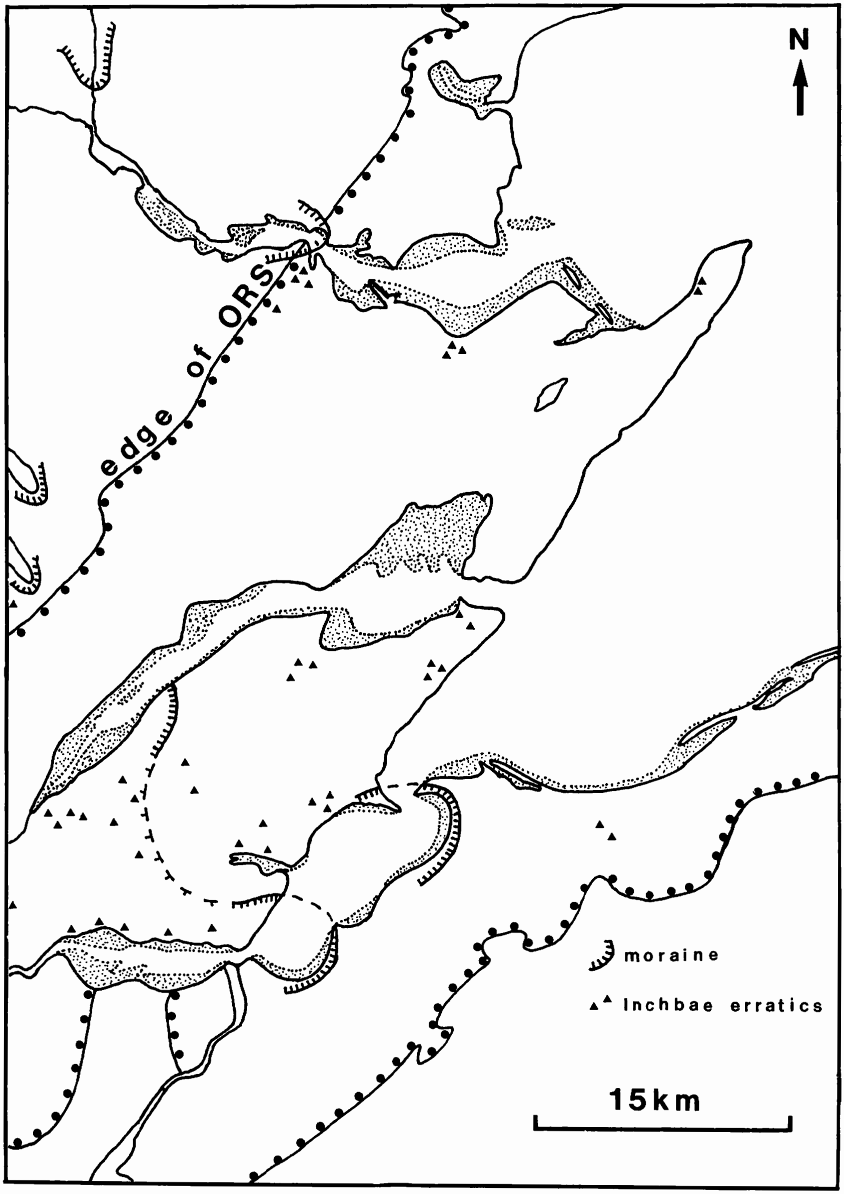

Fig. 1.12 Recent coastal forms, moraines and Inchbae augen gneiss erratics.

The Beauly, Cromarty and Dornoch firths are glacially over-deepened and drowned ancient river valleys. The presence of hard crystalline Moine schist and granite at the Sutors of Cromarty caused the ice to excavate more deeply into the softer Old Red Sandstone in the inner Cromarty Firth, which was considerably widened [Fig. 1.12]; eventually the ice broke through the Moine rocks and created a narrow entrance to the firth. An example exists at Balintraid [NH 744719], 6 km west of the Sutors, of deeply weathered sandstone similar in nature to other sites in north-east Scotland of deep glacial erosion (Smith 1977).

Fluvio-Glacial Deposition

Around the firths the low-lying land was scraped and smoothed by the ice-sheet, then largely covered by extensive sheets of glacial and fluvio-glacial drift (or moraine) deposited beneath and at the edges of the moving ice or left behind after the ice had melted and disappeared. Extensive sheets of fluvio-glacial material flank the shores of the Moray Firth.

The direction of meltwater flow on the northern side of the Moray Firth was controlled by the underlying shape of the topography. Near Dornoch and between Golspie and Brora are long sinuous mounds of fluvio-glacial sands and gravels termed eskers. Eskers record the courses of meltwater streams that flowed in tunnels beneath the ice. Systems of eskers run down Strath Brora along the northern shores of the Dornoch Firth towards Dornoch, while meltwater channels run parallel to the NE–SW strike of the Old Red Sandstone rocks in the coastal area around the firth [Fig. 1.12]. Large meltwater channels at Struie record meltwater flow from the Dornoch Firth into Strathrory, then into the Pitmaduthy esker system near Nigg Bay [NH 775765] (Smith 1977). The erosive effects of meltwater streams are well illustrated in the gorge of the River Beauly at the Falls of Kilmorack. The gorge has been cut into the basal conglomerates of the Old Red Sandstone and right down to Moine schist. The famous Black Rock gorge of Novar, near Evanton [NH 589668] is an extremely narrow, deep cleft in Old Red Sandstone conglomerate which formed in post-glacial times during a period of rapid uplift. Sediment-laden torrential meltwater cut swiftly through the rock like a saw.

An atypical landform between Ardersier and Chanonry Ness near Fortrose in the inner Moray Firth has been described by Smith (1977) as a glacial re-advance moraine, made of unsorted mixed boulders and cobbles overlain by beach deposits and formed at the front of a lobe of ice which locally advanced westwards from the retreating ice-sheet in a cold episode. The bluffs of the Ardersier-Fortrose moraine were subsequently washed by a late-glacial marine transgression and then extended by post-glacial seas to form the present-day cuspate shape of the foreland [Fig. 1.12]. Terraces at Edderton may represent the same phase in the Dornoch Firth. Smith (1977) reports that there is some morphological evidence for an ice margin in the area around Culbokie on the Black Isle.

Boulder clay was deposited directly by the ice and consists of boulders of mixed size, shape and rock type held together by a matrix of sticky grey, red or yellowish clay, the clay representing rotted and milled-down rock particles. The widespread covering of boulder clay throughout most of the Black Isle gives rise to smooth, undulating topography. The red to yellowish colour of much of the glacial and fluvio-glacial sediment indicates a local origin from the underlying Old Red Sandstone. Erratic blocks, however, are widespread throughout the north-east. These are ice-transported rounded boulders, cobbles and pebbles which have been moved some considerable distance and it is often the case that they can be matched with a unique rock outcrop, so allowing the path of ice movement to be traced. One such example is the Inchbae augen gneiss, referred to above, boulders of which have been found at Bonar Bridge [Fig. 1.11]. Erratics from Scandinavia have also been found around the coastline of north-east Scotland, indicating transport from at least 500 km (310 mls.) away by the Scandinavian ice-sheet.

Evidence for the decay of the ice-sheet is shown in the Black Isle in the form of successive moraine stripes and gravel ridges which run obliquely to the contours on the hillside overlooking the Cromarty Firth. These mounds and ridges slope gradually and increasingly towards the firth in a more or less concentric arrangement that marks successive stages in the retreat of the ice. The mounds are themselves truncated and form bluffs overlooking the 30 m (100 ft) post-glacial raised beach.

Raised Beaches

Well-marked terraces standing at heights up to about 30 m (100 ft) above sea level form a conspicuous feature along the shores of the northern firths. These terraces which skirt the shores mark the position of the sea at the end of the ice age. For when the glaciers had finally melted, the sea level rose for a time and drowned much of the coastal lowlands. At its maximum extent, the ice-sheet was over 1,000 m (4,000 ft) thick, and this enormous weight led to the land being somewhat depressed. Once the ice melted and the load was removed, the land surface began to adjust and started rising again (most rapidly where the ice was thickest) towards its pre-glacial level, so that the higher post-glacial seas began to retreat. Raised beaches with low cliffs, old caves and boulder deposits are well-preserved around the Beauly Firth and on the Tarbat Ness peninsula. Notable examples are at North Kessock and Hilton of Cadboll. Two levels at around 15 m (50 ft) and 30 m (100 ft) are seen at Munlochy in the south-east of the Black Isle. On the raised beach terraces are stratified deposits of marine sand, gravel and clay. Various levels between 15 m and 30 m have been recorded, particularly around the Beauly Firth, but usually they can be traced for only short distances and indicate a gradual uplift of the land, punctuated by occasional stand-stills when the sea was able to erode a more or less conspicuous notch into the boulder clay or the Old Red Sandstone.

The railway between Beauly and Muir of Ord crosses the wide terrace formed by the highest raised beach at the head of the Beauly Firth. The 30 m raised beach is also well-developed around the head of the Cromarty Firth, and it extends inland along the River Conon where it merges with a

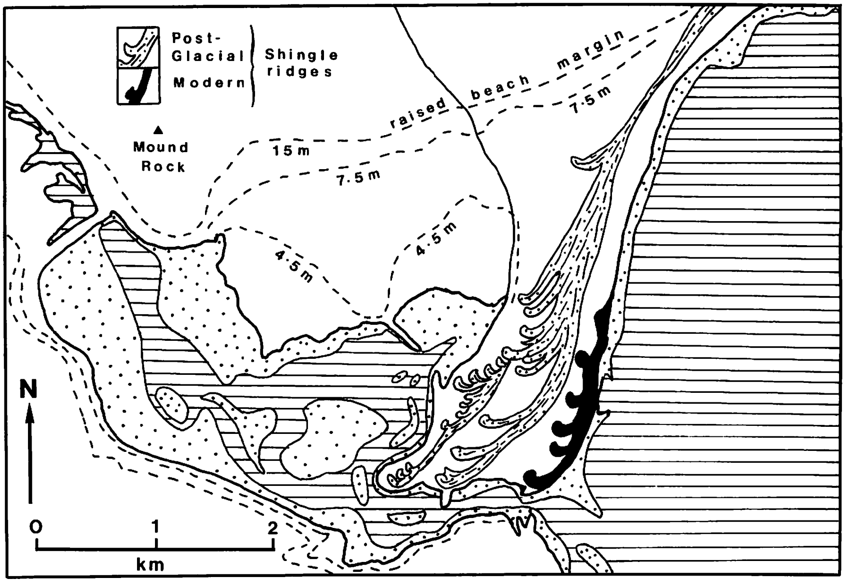

Fig. 1.13 Shingle ridges of Loch Fleet.

large ice-marginal delta (Synge 1977). On the Black Isle it forms a terrace about 500 m (1,640 ft) wide which increases in width inland. This particular terrace is made up of finely laminated light-brown clays and fine silty sand, giving rise to well-drained, good quality soils. On the north side of the firth the same beach terrace is much narrower. It extends up the valley almost as far as Strathpeffer itself, where again good arable land results. The glacial beach deposits at Strathpeffer contain sea shells (cockles, mussels and periwinkles) and whale bones. Raised beaches at 15 m (50 ft) and 7.5 m (25 ft) levels are found around the firths. Beauly stands on the wide 7.5 m terrace which is composed of marine alluvium: finely laminated grey and yellow clays with beds of sand and fine gravel. Shell banks occur within these sediments, containing remains of estuarine and shallow-water species that still exist today. Around Dingwall it is this same 7.5 m beach which gives rise to the widest extent of carse land. Raised beaches are discussed in greater detail in the paper by Synge (1977).

Loch Fleet, south of Golspie, was formed in post-glacial times when a shingle barrier was built up by wave action across the estuary of the River Fleet. The barrier is constructed of many shingle ridges, each 2–3 m (6.5–10 ft) high, which form a curved spit of land built out southwards from Golspie [Fig. 1.13]. Today the ridges are higher than and farther back from the sea, the highest parts being 10–11 m (33–36 ft) above sea-level. A number of other shingle spits are found a little to the south. Cuthill Links, Ferry Point and Ardjachie Point in the Dornoch Firth are raised post-glacial spit complexes made of well-rounded cobbles and pebbles with interlaminated lenses of coarse sand and occasional shell banks, now colonized by coastal plants and grasses. During the highest of the post-glacial sea levels there was a sea connection between the Cromarty and Dornoch Firths.

Formation of the Coast

The generally rectilinear north-east coast, in stark contrast to Scotland's highly indented west coast, depends for its origin on the underlying rocks. The NE–SW shape is parallel to the Caledonian 'grain' of the country rock, and in particular the coasts of the Black Isle and the Tarbat Ness peninsula facing the Moray Firth have been formed at the edge of the Great Glen Fault Zone [Fig. 1.4]. The eastern coastlands have been excavated from Old Red Sandstone in the main, a relatively uniform rock that extends from Orkney and Caithness southwards then eastwards along the Moray Firth. The relief around the firthlands is of a relatively uniform, low undulating plateau cut by broad valleys. Many of the shorelines are constructional, with wave action shaping the glacial deposits into long sandy beaches. Sand barriers erected by the wind since post-glacial times have caused the foreland of Morrich Mhor near Tain [NH 845855] to advance out into the firth as the higher post-glacial sea level fell; the Whiteness Sands have advanced and resulted in Tain harbour being silted-up (Whittow 1977; Ogilvie 1923); the landward margin of the Morrich Mhor is a sea-cliff cut in red boulder clay, and forms part of the 7.5 m (25 ft) raised beach.

Although some of his conclusions concerning post-glacial sea levels are questioned by Synge (1977), Ogilvie (1923) has presented a very detailed study of the coastal morphology of the Moray Firth. He considered the Dornoch Firth to be composed of three distinct segments:

(1) An 'inner firth' to the west of Struie Hill and Spinningdale. This 17 km (10.6 mls.) section consists of a steep-walled trough cut in Moine schist and overdeepened by glacial erosion. Five separate alluvial fans project into the firth, built out by stream deposition.

(2) The 'middle firth', bordered by dissected terraces, largely of glacial meltwater origin. The entire feature may have been a continuous surface of fluvio-glacial outwash.

(3) An 'outer firth', where the evolution of the coastline is mainly attributable to erosion of Old Red Sandstone rocks and the formation of marine constructions. At Cuthill Links, for example, much of the original shingle surface is overlain by recent sand dunes.

ECONOMIC GEOLOGY

The Old Red Sandstone of the area was once extensively quarried as a freestone for building construction, but this industry has now disappeared. Flagstones of Moine schist were once extracted at the Raven Rock, Strathpeffer, for local building purposes; quarries in the granites are also long abandoned. However, the extensive sand and gravel deposits are still being extracted on a massive scale for use as road metal and concrete aggregate.

The Brora coal has ceased to be worked, likewise the brick clays with which it was associated. Mineral veins are not of sufficient extent in the area to be commercially viable. Horne and Hinxman (1914) mention in their memoir that veins of silver-bearing galena, zinc blende, baryte and calcite occur in fault lines cutting the Moine schists in Strath Glass, and lead mines operated for a time during the first half of the last century.

It goes without saying that the greatest economic asset in the north-east is provided by the considerable deposits of oil and gas in the North Sea basin. Production is currently running at nearly 100 million tonnes per annum, with estimated recoverable reserves put at 2,000–4,300 million tonnes (Duff 1983). Most of the hydrocarbon deposits have been found within or around graben structures (down-faulted blocks containing thick accumulations of sedimentary rocks), though one exception is the Beatrice Field in the Moray Firth Basin where drilling platforms can be seen from the land north of Helmsdale. The source-rock for most of the oil seems to be the Kimmeridge Clay of Jurassic age, which is a black kerogen-rich mudstone. Oil occurs in traps beneath Jurassic to Tertiary shales, whereas gas is usually restricted to the Palaeocene (Lower Tertiary, 63 million years old). The source of the gas is also likely to be deeply-buried Kimmeridge Clay. Reservoir rocks are mostly sandstones of Jurassic or Tertiary age, with oil occurring in tilted fault-block traps.

Peat is another important fuel resource which is widespread as a blanket bog type of deposit in the upland areas adjacent to the firths. The Aultnabreac deposit is being exploited using mechanized methods, and there is renewed interest in the possible viability of small-scale peat-fired electricity-generating plants in various parts of the Highlands.

For over two hundred years Strathpeffer has been renowned as a spa resort on account of its natural mineral waters. Interest has declined of late, however, and the dozen or so springs which emerge from bedding planes of rocks or along fault lines at the surface are no longer of commercial use. The sulphurous spring waters, whose underground circulation is not very deep-seated (Horne and Hinxman 1914), emerge from fetid shales of Old Red Sandstone age; chalybeate springs (containing iron salts, especially carbonate) issue from glacial deposits and from muscovite-biotite gneiss in the Moine rocks (Phemister 1960).

Acknowledgement

Figure 1.1 is reproduced by kind permission of the Scottish National Portrait Gallery, Edinburgh.

References

Anderton, R., Bridges, P. H., Leeder, M. R. & Sellwood, B. W. *A Dynamic Stratigraphy of the British Isles — A Study in Crustal Evolution.* 1979.

Armstrong, M. The Old Red Sandstone of Easter Ross and the Black Isle, in Gill, G. ed. *The Moray Firth Area Geological Studies.* 1971: 25–34.

Bacon, M. & Chesher, J. A. Evidence against post-Hercynian transcurrent movement in the Great Glen Fault, in *Scott. J. Geol.* 1975. vol. 11(1): 79–82.

Brown, P. E. Caledonian and earlier magmatism, in Craig, G. Y. ed. *Geology of Scotland.* 2nd ed. 1983: 167–204.

Chesher, J. A. & Lawson, D. The geology of the Moray Firth, in *Rep. Inst. Geol. Sci.* 1983. no. 83/5.

Craig, G. Y. ed. *Geology of Scotland.* 2nd ed. 1983.

Donovan, R. N., Archer, A., Turner, P. & Tarling, D. H. Devonian Palaeogeography of the Orcadian Basin and the Great Glen Fault, in *Nature.* 1976. vol. 259: 550–51.

Duff, P. McL. D. Economic geology, in Craig, G. Y. ed. *Geology of Scotland.* 2nd ed. 1983: 425–54.

George, T. N. The geological growth of Scotland, in Craig, G. Y. ed. *The Geology of Scotland.* 1st ed. 1965: 1–49.

Gill, G. ed. *The Moray Firth Area Geological Studies.* 1977.

Harris, A. L. Metamorphic rocks of the Moray Firth district, in Gill, G. ed. *The Moray Firth Area Geological Studies.* 1977: 9–24.

Horne, J. & Hinxman, L. W. The geology of the country around Beauly and Inverness, including a part of the Black Isle (explanation of sheet 83), in *Mem. Geol. Surv. Scotland.* 1914.

Mykura, W. The Old Red Sandstone east of Loch Ness, Inverness-shire, in *Rep. Inst. Geol. Sci.* 1982. no. 82/13.

Mykura, W. Old Red Sandstone, in Craig, G. Y. *Geology of Scotland.* 2nd ed. 1983: 205–52.

Mykura, W. & Owens, B. The Old Red Sandstone of the Mealfuarvonie Outlier, west of Loch Ness, Inverness-shire, in *Rep. Inst. Geol. Sci.* 1983. no. 83/7.

Ogilvie, A. G. The physiography of the Moray Firth coast, in *Trans. Roy. Soc. Edinb.* 1923. vol. 53: 377–404.

Phemister, J. *Scotland: the Northern Highlands.* (British Regional Geology). 3rd ed. 1960.

Pickering, K. T. The Upper Jurassic 'Boulder Beds' and related deposits: a fault-controlled submarine slope, NE Scotland, in *Jl Geol. Soc.* 1984. vol. 141(2): 357–74.

Sissons, J. B. *The Evolution of Scotland's Scenery.* 1967.

Smith, D. I. The Great Glen Fault, in Gill, G. ed. *The Moray Firth Area Geological Studies.* 1977: 46–59.

Synge, F. M. Land and sea level changes during the waning of the last regional ice sheet in the vicinity of Inverness, in Gill, G. ed. *The Moray Firth Area Geological Studies.* 1977: 83–102.

Watson, J. V. The ending of the Caledonian orogeny in Scotland, in *Jl Geol. Soc.* 1984. vol. 141(2): 193–214.

Whittow, J. B. *Geology and Scenery in Scotland.* 1977.

Wood, R. M. *On the Rocks — a Geology of Britain.* 1978.