

when the two rock masses rubbed past each other, their surfaces got broken up and crushed into small pieces to form fault breccia and fault gouge (or rock flour) respectively, and both of these are seen in the cliff. On the north side there is also disrupted bedding, typical of faults. The normal limestone distinctive orangy brown colour. This alteration involves magnesium being substituted into the limestone and is related to hot fluids coming up from depth and reacting chemically with the surrounding rocks. Faults are often mineralised by hot fluids, and lead ore (galena), tin ore (sphalerite) and a coppery type of fools' gold (chalcopyrite) occur in small amounts here and are associated with two small faults (marked by a rust-stained breccia) just beyond the next small headland.

Stop 10. A short way beyond the Coastguard Fault, where a path descends from a lay by at the cliff top, well-preserved brachiopods of several species are seen in the rocks at the foot of the cliff. Between here and the concrete fishing jetty (where steps lead up to the road marking the end of this excursion) the rocks contain beautifully preserved bryozoans of at least four species, which weather out clearly on bedding surfaces. These are particularly clear on the lichen-covered rocks near the water's edge. Whole brachiopods and large fragments of crinoid columns can be seen in the darker, more shaly beds of the cliff.

EXCURSION 3: BALSADDEN & HOWTH

Ian Sanders

How to get there: DART to Howth station, then 10 minutes walk eastwards past the yacht club in the direction of the Martello tower. When you reach the King Sitric restaurant at the landward end of the East Pier turn right up a steep road (Balscadden Road) past a modern apartment block on the left, and a high, poorly vegetated embankment (supporting the Martello tower) on the right. Bus No. 31 (direct to Howth village) or 31B (scenic route via Howth Summit). Car parking is available beside the East Pier (below the Martello tower).

Geological horizon: Cambrian, Lower Carboniferous, & Quaternary. What to see: Faulted rocks, limestone, glacial deposits.

Duration: 1 hour or a little more.

Notes: Access is possible at any state of the tide, though half tide allows more to be seen in Balscadden Bay.

The Howth peninsula is composed of rocks of two ages. To the south, Cambrian quartzites, sandstones and mudrocks form the higher ground and can be seen in the cliffs and rocky foreshores. To the north, Carboniferous limestones lie beneath the lower ground and crop out in a few coastal and inland exposures. The two groups of rocks are separated by a fault the eastern end of which is exposed in Balscadden Bay, immediately to the east of Howth village. The western end emerges on the coast just south of Sutton Dinghy Club. Quaternary boulder clay, sand and gravel form deposits up to several metres thick resting on the older Carboniferous and Cambrian rocks in many places.

Balscadden Bay makes an excellent 'first geological visit'. In one small area it is possible to examine all three main groups of rock, Quaternary, Carboniferous, and Cambrian, that occur on the Howth peninsula.

Stop 1. The embankment opposite the Balscadden Road apartments. Observe that the embankment consists of buff-coloured sandy and pebbly material. These pebbly sands are believed to have been deposited towards the end of the last ice age. At that time Howth (and much of the rest of Ireland and Britain) was buried under a thick sheet of slowly moving ice, much as Greenland is today. The ice engulfed the original soil, stones and loose rocks in its path and carried them forward. With climatic warming, about 14,000 years ago, the ice sheet melted and the stony and muddy the

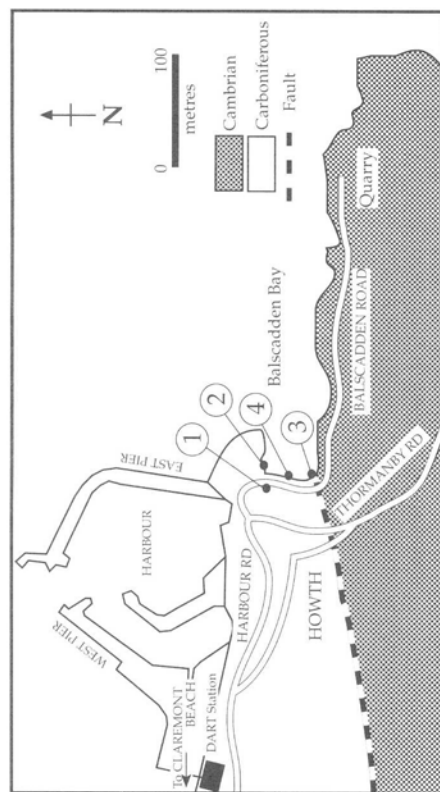


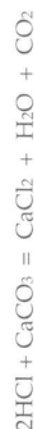
Figure 6. The geology of the Howth and Balscadden area.

material embedded within it was dumped as an unsorted layer draped over solid bedrock. This unsorted material is known as boulder clay or glacial till. Meltwater from the ice formed temporary rivers which eroded the loose boulder clay, transported it and redeposited it further downstream, possibly as a delta where the river entered a lake or the sea.

Roughly horizontal layers, some with more pebbles than average, can be seen over much of the embankment. These layered sands and gravels are material that has been transported and redeposited. The material near the top of the embankment, however, is not layered and contains some large boulders of rock. This is typical unsorted boulder clay. The presence of boulder clay on top of sorted sands and gravels suggests that the ice sheet first retreated, and the meltwater deposited the sands and gravels. Later the ice seems to have advanced again, over the sands and gravels, and when it finally melted the upper layer of boulder clay was left behind.

Stop 2. Foreshore below the apartments. Gain access down the concrete steps through a gate nearly opposite the sports club. On reaching the beach, turn left (north) and examine the rock exposures below the apartment block and (if the tide is low) beyond it - though take care since the seaweed covered foreshore is extremely slippery.

The rock here is grey limestone. It can be scratched by steel, and it fizzes if dilute acid is dropped onto it. These features distinguish limestone from other grey rocks. When acid is added the chemical reaction is:



Look carefully at the steep rock surfaces above the high tide mark and you may notice the protruding edges of fossils. Fossils may also be seen on the wave-worn surfaces. Do not try to remove them; they will only break up. Please leave them for others to see. Fossils may be found, and collected, from among the grey limestone pebbles on the beach.

The fossils are the shells and skeletons of organisms which lived on the sea floor in Carboniferous times, about 340 million years ago. The water was probably warm since coral fossils are present, and coral mainly grows in tropical latitudes today. (Geologists frequently make deductions about conditions in the past by making comparisons with what is seen to be happening today. This process of argument is sometimes called uniformitarianism and is summarised in the saying 'The present is the key to the past'.)

The shells are made of the mineral calcite (calcium carbonate, chemical formula CaCO_3). The limestone was formed by the gradual accumulation on the sea floor of millions upon millions of calcite shells and skeletons, whole and broken. With the passage of time, and the compression due to being buried, the loose calcite material became cemented together to form solid rock.

Notice that the limestone is layered. Each layer represents a batch of shelly material that was laid down on the sea floor. Geologists usually refer to the layers as beds or strata. If you look carefully you will see that the beds of limestone are separated from each other by layers of darker, muddy rock. This is shale, and it indicates that every so often suspended mud was washed into the sea, interrupting the accumulation of shell fragments.

If the beds of limestone were laid flat, on the sea floor, they would have been originally horizontal. Today they are no longer horizontal, but slope at a low, variable angle towards the west. Geologists refer to the slope of the beds as dip. Tilting of the beds must have occurred at some time after the limestone was deposited, probably at the end of Carboniferous time during a period of widespread earth movement and mountain building known as the Hercynian orogeny. Also, of course, a great thickness of rock must have been eroded away since then because the limestone formed, by burial and compression of shell fragments, at a considerable depth below the sea floor.

Dark, irregular protrusions, usually two or three centimetres across, may be seen on the wave-smoothed limestone. They are made of hard silica, known as chert. Skeletal material from some organisms, such as sponges, are made from silica (SiO_2) rather than calcite. Somehow this silica became concentrated into separate lumps within the limestone.

Stop 3. Southern end of Balcaddan Bay. From the apartments walk to the cliff on the far side of the beach. The rock here is not limestone. It is creamy brown in colour, it does not react with acid, and it cannot be scratched by steel. It is a rock known as quartzite. This quartzite probably began as ordinary (quartz) sand on the sea floor. It was buried under more and more layers of sand, and eventually the loose grains became squeezed and welded together to form solid rock. Of course, just as with the limestone, much rock must have been eroded away for the quartzite to be at the surface now.

Quartzite forms Howth Hill, Red Rock, the crags above Howth Castle, and the quarry about 1 km east of here. Being hard, quartzite is not easily eroded. When the land was rising, other less resistant kinds of rock were preferentially removed by erosion, leaving the quartzite standing proud as prominent topographical features.

The quartzite is much older than the limestone. Although it contains no fossils here, tiny fossils of Cambrian age (a little over 500 million years old) have been found in mudrocks associated with the quartzite elsewhere in the Howth area.

Notice that the rock at the base of the cliff seems to consist of broken pieces of quartzite embedded in a hard, dark brown material. The brown material is probably the mineral haematite (iron oxide). This broken and cemented quartzite is known as a breccia (pronounced 'brech'ya').

The breccia marks the place where a major fault plane separating Cambrian rocks from Carboniferous rocks appears on the coast. The fault extends right across the Howth peninsula to Sutton. A fault plane is the site of an ancient earthquake. The earthquake responsible for this fault probably happened many millions of years ago during the Hercynian orogeny, mentioned earlier. Earthquakes occur when enormous stresses build up within the earth's crust, and reach a level which the rocks can no longer withstand. Quite suddenly, the earth's crust breaks along a giant crack (a fault plane) and the rock on one side of the fault moves violently in the opposite direction to the rock on the other side of the fault. Rock lying close to the fault becomes broken up in the process, and the gaps between the broken pieces later become filled with other material - in this case by haematite - to form the fault breccia. Consider for a moment the direction in which the limestone and quartzite moved relative to each other. The limestone is younger than the quartzite, so it is likely that quartzite is buried beneath it. This would imply that the (hidden) quartzite beneath the limestone on the north side of the bay moved downwards relative to the exposed quartzite on the south side of the bay.

Solid rock is present only at either end of the beach. This is because fault breccia is a weak and easily eroded rock. The fault plane is really a broad fault zone, and the central part, where quartzite-rich breccia grades

into limestone-rich breccia, is extremely weak and lies beneath the beach. It has been eroded away leaving a gully which is now filled with the loose beach material.

Stop 4. Balcaddan beach. While returning to the steps take time to examine the pebbles on the beach. Most of the pebbles are either of hard, creamy white quartzite or of scratchable grey limestone. These are obviously from the local area. Also from nearby are occasional pieces of the fault breccia, and flat pebbles of greenish rock which is Cambrian sandstone and mudrock. Other pebbles are from outside the Howth area, and were presumably washed out of the boulder clay which had already been transported from far afield by the slow moving ice sheet. Look for coarse-grained rounded pebbles of grey granite with shiny flecks of mica. A rare, but very interesting rock type forms smooth creamy grey pebbles with millimetre sized dark blue-grey flecks. This is a special kind of granite found only on the island of Ailsa Craig which lies midway between Scotland and Northern Ireland. This granite provides evidence for the transport of rock fragments over great distances.

Some pebbles are not, in fact, rocks at all. A significant number of rounded blocks of brick, concrete, and roof tile may be found. These show that pebbles on a beach can become rounded in just a few decades.

Finally you may find pebbles of grey limestone which resemble Emmental cheese. The holes in them were bored by specially adapted shellfish which, using their own acid to dissolve away the rock, provided themselves with a safe home.

Additional stops in the Howth area:

Balcaddan quarry

If you have time, you might consider visiting the quartzite quarry about 1 km east of Balcaddan beach. Follow Balcaddan road to the car park at the end then double back up a track which leads into the disused quarry. In general the quartzite does not appear to form layers, but in some places thick layers can be seen. They are dipping (tilted) at a fairly high angle. Below the quarry, at the side of the track, the rock is dark greenish-grey and is obviously not quartzite. This rock is known as greywacke, and is formed when muddy sand becomes compressed and cemented into hard rock.

Claremont beach

A further place to visit in the area is Claremont beach to the west of Howth. Here pale grey limestone and boulder clay can be seen. Retrace your steps to Howth DART station, and take the path from the west pier on the seaward side of the railway. Walk along the sandy beach for a little over 500 m until

you reach grey limestone exposures at the head of the beach. This limestone is a much paler grey than that seen in Balcaddan Bay, and it is not possible to see layering. Further to the west the limestone appears to be stained brown in places. This is where the original calcite (CaCO_3) has been replaced by a new mineral, dolomite ($\text{CaMg}(\text{CO}_3)_2$). Further on it is possible to see boulder clay resting on the limestone. The top of the limestone, where the boulder clay has been washed away, locally appears to be scored by parallel grooves. These were gouged out by blocks of rock embedded in the base of the ice sheet as it moved slowly across the land surface. The grooves are called glacial striae, and they indicate the direction in which the ice sheet was moving.

EXCURSION 4: SUTTON

Ian Sanders

How to get there: DART to Sutton Station, and 25 minute walk to Sutton Dinghy Club on Strand Road. Bus No. 31B from Lower Abbey Street to Strand Road, followed by a walk of 10 minutes. Parking is possible for a few cars on the road.

Geological horizon: Cambrian, Lower Carboniferous, & Quaternary.

What to see: Carboniferous limestone; a raised beach.

Duration: about 1 hour.

Notes: Half or lower tide makes it easier to get around the rocks at Bottle Quay (Stop 2).

On the Sutton side of the peninsula, as at Howth, it is possible to examine Quaternary, Carboniferous and Cambrian rocks. The itinerary is complimentary to that at Howth, with somewhat different aspects of the rocks displayed.

Stop 1. Sutton Dinghy Club. Take the concrete steps down to the beach to the right of the club house. In the vertical rock face beside the steps note that the rock is yellowish brown in colour and does not show layering. One or two large (up to 1 metre) patches are conspicuously grey in colour. The grey rock is limestone. It fizzes when a drop of acid is placed on it. The surrounding brownish rock is dolomite. Dolomite is calcium magnesium carbonate ($\text{CaMg}(\text{CO}_3)_2$) and it also contains a trace of iron which gives it the brownish colour. Dolomite does not fizz with acid unless it is first powdered. Dolomite is formed when magnesium bearing water soaks through limestone, and half the calcium atoms are removed and replaced by Mg atoms. At this place virtually all the original limestone has been altered to dolomite. Only a few residual patches of the limestone survive. Earlier this century dolomite was extracted from a quarry about 150 m inland from here. It was shipped from a small harbour called Bottle Quay (Stop 2). The original limestone was formed from shell fragments which accumulated on the sea bed during the Carboniferous Period, about 340 million years ago.

Continue about 25 m north past a boat house to low, rounded outcrops of dolomite. Look closely at the rock surface where it emerges from beneath a covering of pebbly mud and sand at the head of the foreshore. You should find that it has been deeply scored by a series of parallel grooves. These grooves were carved into the rock surface during