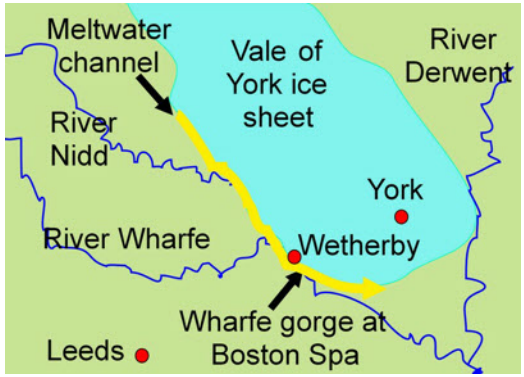
GLACIATION

During the last 30 million years, global climate has been cooling down and huge polar ice sheets have developed in the last 2.6 million years. Global temperature has fluctuated since then, resulting in many advances and retreats of ice sheets over northern Europe.

The last glacial stage, called the **Devensian**, was at a maximum about 17,000 years ago. Ice sheets covered the high ground in the Pennine area and moved down the Wharfe valley. As temperatures slowly rose, the ice melted and ice sheets became thinner.

In the final stages of the glacial period, glacial ice was confined to the valleys, as in the photo below. It would have been possible to stand near Boston Spa and see an ice sheet in the Vale of York. When the ice melted completely, around 12,000 years ago, it left behind extensive deposits of clay, sand and pebbles called **glacial till** (boulder clay). Meltwater streams filled the valley floors with sands and gravels. Some of the pebbles found in the Boston Spa area may have originated in Nidderdale and upper Wharfedale.

Solheimajökull, Iceland



The Vale of York ice-sheet in the final stages of the last glacial period

THE WHARFE GORGE

During late glacial times, water from the Yorkshire Dales was unable to flow to the east because of the ice in the Vale of York. Instead it ran southwards along the side of the ice sheet and carved through the soft dolostone rock, creating the gorge which stretches from Wetherby to Boston Spa. After the ice melted completely, about 12,000 years ago, the River Wharfe continued to flow in the gorge.

HOW TO REACH BOSTON SPA

Boston Spa is accessible by car using the map below. Public parking is available in Millennium Gardens, Boston Spa. There is limited parking at Deep Dale and in Thorp Arch. Buses connect the village with Wetherby, Leeds, Harrogate, Tadcaster, Otley, York and Wakefield.

This leaflet has been produced by a group of enthusiasts from Boston Spa and the West Yorkshire Geology Trust. It includes some technical terminology in bold type, though this has been kept to a minimum and the terms have been explained clearly. The leaflet can be downloaded as a pdf. from:

www.wyorksgeologytrust.org
www.bostonspapc.org.uk

West Yorkshire Geology Trust is part of a national network of groups which actively conserve important geological features. Details of three Local Geological Sites in the Boston Spa area can be found on the website.

www.wyorksgeologytrust.org

Boston Spa Archaeology and Heritage Group has produced "The Boston Spa Heritage Trail" for the Boston Spa Riverside Woods which covers various sites of archaeological, geological and historical interest .The trail can be found by logging on to the Boston Spa Parish Council website and following links to the Heritage Trail web-page.

www.bostonspapc.org.uk

Acknowledgements

Boston Spa Parish Council Woodland Management team has been very supportive in the development of some of the geological locations highlighted in the guide.

Written by Alison Tymon, Alan Rayner, Malcolm Barnes, Terry Gaussen and Jeremy Freeman.

Photographs by Malcolm Barnes, Alan Rayner, Alison Tymon

Layout and graphics by Barry Tymon and Alison Tymon

BOSTON SPA RIVERSIDE CLIFFS:

ROCKS AND LANDSCAPES

BOSTON SPA PARISH COUNCIL

W YORKSHIRE GEOLOGY TRUST

PERMIAN ROCKS

The rocks of the Boston Spa area are **Permian** in age. The Permian period followed the **Carboniferous** period about 290 million years ago. The continent, of which the UK was part, lay above sea-level in a hot, arid climate about 20°N of the equator.

The old name for the Permian rocks seen in this area was the Lower Magnesian Limestone but this has recently been renamed as the **Cadeby Formation.**

In late Permian times, 260 million years ago, the landscape around you would have looked very different, much more like the present Persian Gulf. The land was flooded by a shallow, salty sea called the **Zechstein Sea**. The sea dried out regularly under a tropical sun, leaving layers of limey mud containing carbonates and other salts. When small sand grains were washed in the lime mud by gentle wave action, they formed tiny spheres called **ooliths.**

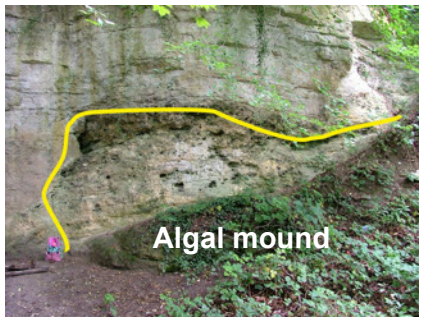
After the Zechstein Sea dried up, the carbonates were buried and compressed under later sediments and the water was squeezed out, leaving a limestone rock. Some of the carbonates in the rock contained magnesium as well as calcium and formed the mineral **dolomite**. This mineral is a cream or yellow colour. Geologists call this type of creamy-yellow limestone **dolostone**, to distinguish it from other limestones, such as the grey limestones of the Yorkshire Dales.

Small dolomite crystals, which have slightly curved faces, can sometimes be seen in holes called **vugs**.

LIFE IN THE ZECHSTEIN SEA

Fossils found in the dolostones are the remains of organisms which were able to cope with life in very salty seas. Worm burrows and shell fragments are found in some local rocks.

The Cadeby Formation includes unusual features called **algal mounds** (sometimes called **stromatolites**). In the shallow Zechstein Sea, algae could flourish. Sticky mats of algae grew on the sea bed amongst the limey mud, which stuck to the algal mats and formed fine layers. The algae were not eaten by invertebrates because there was very little life on the sea-bed, so the layers were able to grow into steep-sided mounds often several metres high. Similar mounds grow at present in Shark Bay in eastern Australia. An algal mound is shown on the front cover of this leaflet, in the rocks of the river cliff, just above the boat.



THE HAMPOLE BEDS

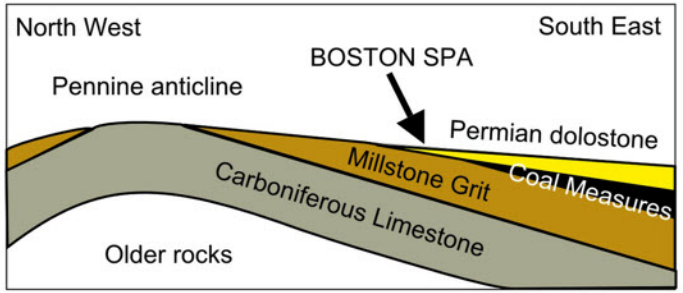
When the dolostones were being deposited, the sea was shallow. However, on one occasion, sea-level dropped to expose the sea floor. Very fine clay particles were blown across the shore and formed thin layers of mud. The mud and limey beds are called the **Hampole Beds**. Exposures of the Hampole Beds are very rare and difficult to identify. Older dolostones below the Hampole Beds (geologists call them the Wetherby Member) were deposited in quieter water than the younger dolostones above (Sprotborough Member), which were deposited where currents and waves were stronger.

Thin beds of dolostone and mud form the Hampole Beds in Front Quarry, Thorp Arch

ROCKS AROUND BOSTON SPA

A borehole drilled down through the Permian dolostone underneath Boston Spa would soon bore into different rocks. Sandstones and mudstones lie below the Permian rocks and are therefore older. Many of the mudstones include coal seams, so rocks of this age are called **Carboniferous** rocks. To the south west of Boston Spa, in the Leeds area, these rocks lie at the surface and the coal seams were mined in the past.

At the end of the Carboniferous period there was a major collision between two tectonic plates. This mountain-building period is called the **Variscan orogeny.** Northern England was pushed into an **anticline** (an upfold) which formed a range of hills trending north-south, the present Pennines. The cross-section shows the three main groups of Carboniferous rocks: Coal Measures, seen around Leeds; Millstone Grit, seen on Ilkley Moor; Carboniferous Limestone, the grey rock seen in the Yorkshire Dales. Great thicknesses of rock were removed by weathering and erosion before the Permian rocks were deposited.



AFTER THE PERMIAN PERIOD

Eventually, the Zechstein Sea dried up. Permian rocks were covered by later sediments, but in this area they have been weathered and eroded away in the last 250 million years, leaving the yellow dolostones we see today in the Boston Spa district.

BOSTON SPA ROCKS AND LANDSCAPES

1 TOP OF DEEP DALE **SE 421 462**

Here you will find an interpretation board which gives information about the geology and archaeology of this area.

This area was covered by ice until about 12,000 years ago. Mammoths, cave bears and woolly rhinoceros roamed the cold hills and valleys. Ice-sheets deposited stones and clay called glacial till (boulder clay). Large meltwater rivers from glaciers in Wharfedale flowed over frozen ground and deposited limestone blocks and sandstone pebbles on top of the glacial till. The fields at the top of Deep Dale are strewn with pebbles which were carried by ice or meltwater.

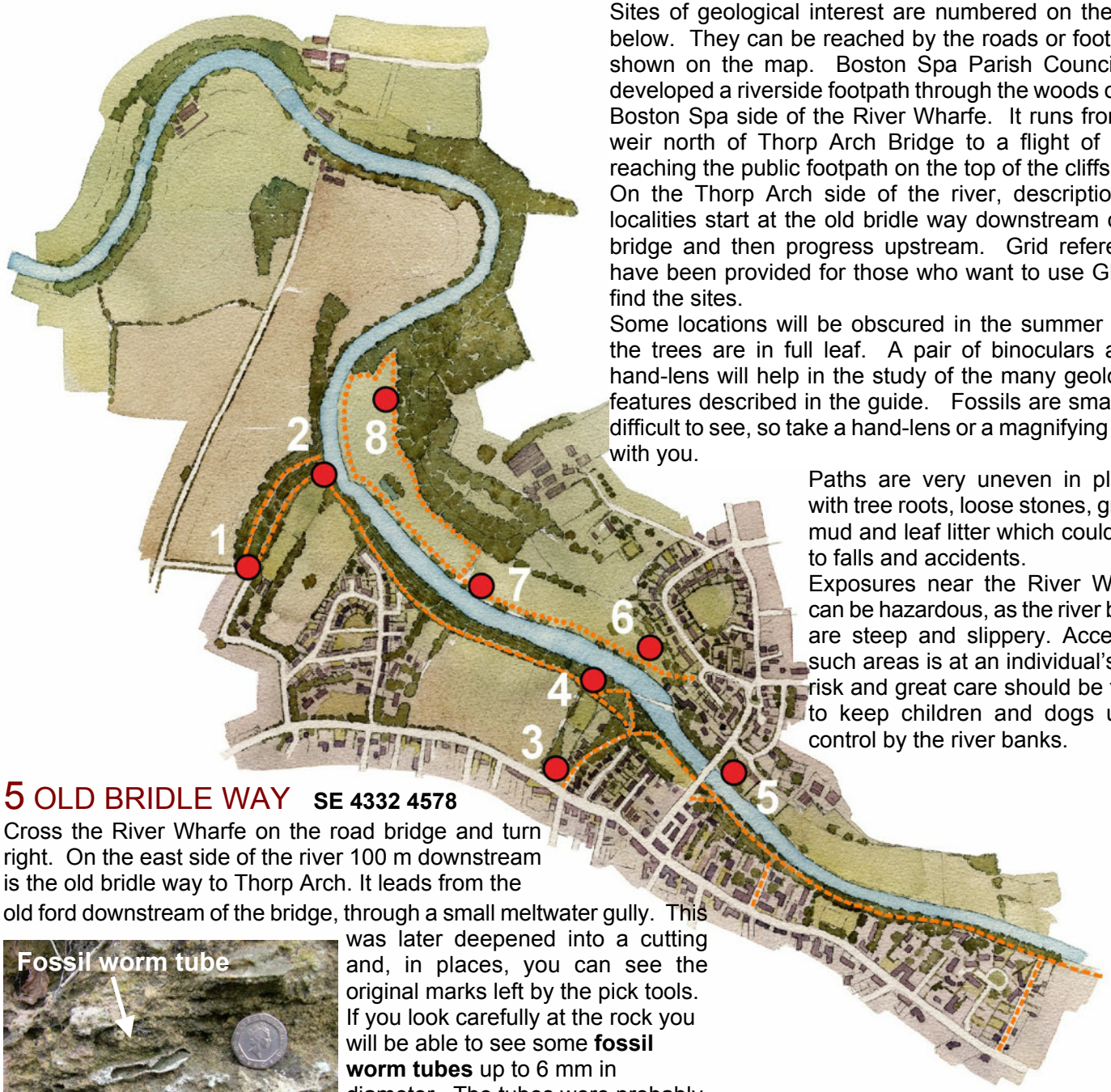
Deep Dale is an example of a **meltwater gully**. Several smaller gullies in nearby fields can be seen running into Deep Dale, which is now a dry valley.

2 JACKDAW CRAG **SE 422 465**

Jackdaw Crag and the Riverside Woods have been designated as a SEGI (Site of Ecological and Geological Importance). The crags on both sides of the stream are good examples of **algal mounds** (stromatolites), draped with bedded dolostone. The rocks are full of solution hollows called **vugs**.

3 ST MARY'S CHURCH **SE 428 458**

The church is a good example of the use of local dolostone for building. Fresh dolostone is a pale gold colour, though the colour may change after weathering. The regular horizontal beds made it easy for quarrymen to extract and move the heavy stone which came from local quarries. However, the rock is very susceptible to weathering. Water in weaknesses freezes during cold weather and then expands, breaking off flakes of rock.



Drawing by Stephen Huxley

Sites of geological interest are numbered on the map below. They can be reached by the roads or footpaths shown on the map. Boston Spa Parish Council has developed a riverside footpath through the woods on the Boston Spa side of the River Wharfe. It runs from the weir north of Thorp Arch Bridge to a flight of steps reaching the public footpath on the top of the cliffs.

On the Thorp Arch side of the river, descriptions of localities start at the old bridle way downstream of the bridge and then progress upstream. Grid references have been provided for those who want to use GPS to find the sites.

Some locations will be obscured in the summer when the trees are in full leaf. A pair of binoculars and a hand-lens will help in the study of the many geological features described in the guide. Fossils are small and difficult to see, so take a hand-lens or a magnifying glass with you.

Paths are very uneven in places, with tree roots, loose stones, gravel, mud and leaf litter which could lead to falls and accidents.

Exposures near the River Wharfe can be hazardous, as the river banks are steep and slippery. Access to such areas is at an individual's own risk and great care should be taken to keep children and dogs under control by the river banks.

5 OLD BRIDLE WAY **SE 4332 4578**

Cross the River Wharfe on the road bridge and turn right. On the east side of the river 100 m downstream is the old bridle way to Thorp Arch. It leads from the old ford downstream of the bridge, through a small meltwater gully. This was later deepened into a cutting and, in places, you can see the original marks left by the pick tools. If you look carefully at the rock you will be able to see some **fossil worm tubes** up to 6 mm in diameter. The tubes were probably made by worm-like creatures as they burrowed through the sea floor mud to feed.

4 TWO CLIFFS NEAR THE WEIR

Walk down Holgate, the track to the east of the Church, which is an old route down to the river following a glacial meltwater gully. When you reach the river, turn left along the riverside path. 150 m upstream of the weir, there are two very different cliff exposures of dolostone from the Permian Cadeby Formation.

St Mary's Cliff SE 4290 4598

The first cliff you meet shows bedded dolostones made of **ooliths** (tiny spheres of dolostone) and broken shells. These deposits were formed in the Zechstein Sea when there was gentle wave action. Despite the salty conditions, bivalves (with paired shells) and gastropods (with coiled shells) survived in the Zechstein Sea. Broken remains of their shells are scattered throughout these rocks, though you will probably need a magnifying glass to see them.


Fossil shells

Oxfield Cliff SE 4287 4599

The cliff a short distance upstream is an **algal mound** (stromatolite) which has been recrystallised into a dolostone shortly after it was deposited.

Dolostone takes up less volume than the original limey sediment and consequently fractures to form jointed blocks. The rock sometimes dissolves to form irregular holes or **vugs**, which are often lined with calcite or gypsum crystals. When water flowed over frozen ground, it found its way into crevices in the dolostone and developed potholes, caves and underground streams.


A vug with crystals

A small, smooth-sided, circular cave is seen at the right-hand of this exposure.

6 FRONT WOOD QUARRY SE 4310 4600

To reach the riverside footpath on the north-east side of the River Wharfe, walk to Thorp Arch village green. The gate for the footpath is on the right, 20 m down the Thorp Arch Park cul-de-sac at SE 432 459. The fields may contain sheep, cattle and calves so due caution is needed and dogs should be kept securely on leads at all times.

About 100 m down the footpath, look to your right to find a small, weathered dolostone cliff. See if you can see some small **vugs**, some of which have calcite crystals on the surfaces.

About 50 m beyond this cliff is a small quarry. Amongst the dolostone beds are two very thin clay layers which mark the **Hampole Beds**. They were formed when sea-level dropped and dust and clay blew across the dry shoreline. The Hampole Beds are an important marker band in the Permian Cadeby Formation. However, the two pale clay layers are very difficult to observe.

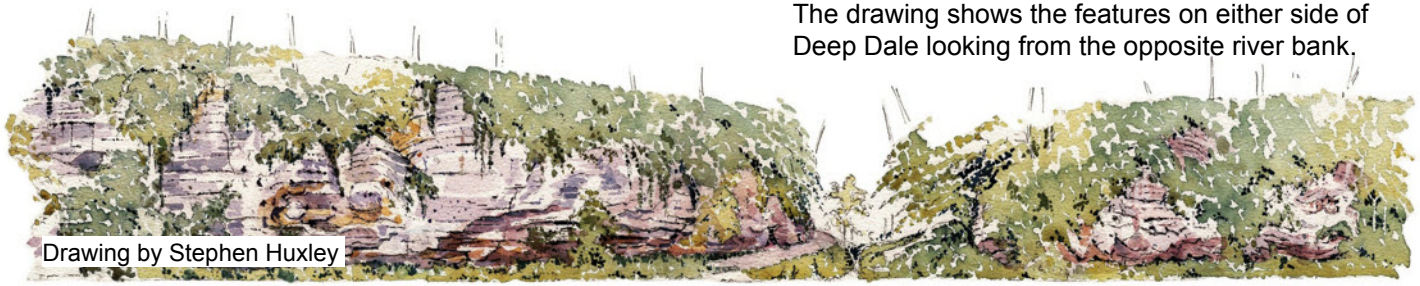
7 WHARFE GORGE CLIFFS

Continue upstream along the riverside footpath by for about 500 m. About 170 m before the stile, at SE 427 461, look at the cliff on the opposite side of the river.

Imagine that you are looking at the warm, shallow waters of a tropical sea.

The cliff shows horizontal beds of dolostone. As you walk further along the river bank, these give way to domed rocks, with more irregular bedding. These are **algal mounds** (stromatolites) which grew when **algae** and **bryozoa** (tiny colonial marine animals) thrived on the shallow sea bed, accumulating limey mud in sticky layers as they developed. As the patches of algal mounds built up on the shores of the Zechstein Sea, limey mud draped round the top and sides of the domes, which were enveloped by sloping beds of dolostone.

You can see several algal mounds in the cliffs opposite, though some are partly hidden by ivy and trees.

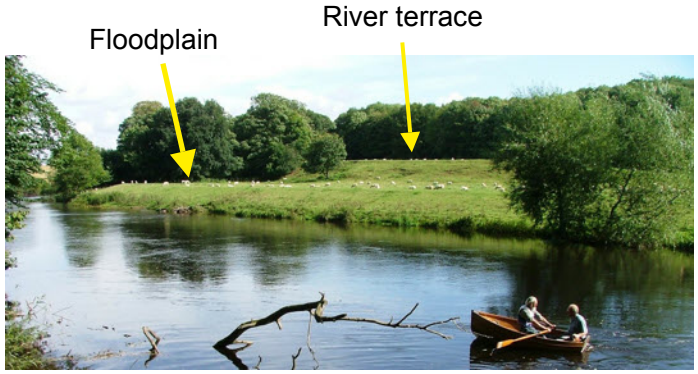

Drawing by Stephen Huxley

The drawing shows the features on either side of Deep Dale looking from the opposite river bank.

8 RIVER TERRACE SE 4245 4660

You have been walking along the river bank on the floodplain, which is underlain by clay and silt (**alluvium**), deposited when the river floods.

Continue for a further 250 m to see a **river terrace**, the steep bank to the right. Along its base, solid rock is exposed. This is overlain by a thin layer of silts, clays and scattered pebbles of sandstone and limestone, deposited by glacial meltwater. Occasional pieces of **chert**, a flint-like rock found in Carboniferous limestones, are also found. The material was washed out by meltwater from glacial till deposited when ice sheets covered the land. Some of the pebbles come from the upper Wharfedale area.



River terrace on the north-east bank of the River Wharfe