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Lime and Ice Project: an overview of the geology and geomorphology of part of the Hambleton and Howardian hills for the North York Moors National Park Authority

Geology and Landscape England

Commissioned Report CR/11/099

BRITISH GEOLOGICAL SURVEY

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J H Powell and J R Ford

Keywords

Lime and Ice; Jurassic; Quaternary; geology; landscape; Hambleton and Howardian hills; Sutton Bank; North York Moors National Park.

National Grid Reference

SW corner ^{4}50500 ^{4}78000
Centre point ^{4}570000, ^{4}81000
NE corner ^{4}62000, ^{4}84000

Map

1:50 000 scale Geological Sheets: 52 Thirsk; 53 Pickering; 62 Harrogate; 63 York.

Front cover

Roulston Scar and Hood Hill from Sutton Bank. © J H Powell (BGS)

Bibliographical reference

POWELL, J H AND FORD, J R. 2011. Lime and Ice Project: an overview of the geology and geomorphology of part of the Hambleton and Howardian hills for the North York Moors National Park Authority. *British Geological Survey Commissioned Report*, CR/11/099. 17 pp.

Keyworth, Nottingham British Geological Survey 2011

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Foreword

This report was commissioned by the North York Moors National Park Authority (NYMPA) to inform their 'Lime and Ice' Project centred on the North York Moors Visitor Centre at Sutton Bank, and encompassing the southern Hambleton Hills and part of the Howardian Hills. The report aims to inform the NYMPA and their interactive visitor exhibition at the Centre describing the geology, landscape and natural history of the area in a regional context.

The report was commissioned by Jill Renney, Information and Interpretation Manager and Jennifer Smith, of the North York Moors National Park Authority, Helmsley.

Acknowledgements

The authors would like to thank Henry Holbrook and Simon Ward for Figures 3 and 4. Additional figures were produced by Jon Ford.

We would also like to thank Jill Renney and Jennifer Smith (NYMPA) for their helpful comments and suggestions on an early draft of the report.

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Figures 10-21 (see digital CD file submitted to NYMPA). Oblique three-dimensional views of the Lime and Ice project area, including the Sutton Bank area from various viewpoints and at various scales; the topographical and geological bedrock maps are draped over a digital terrain model at various scales. NEXTMap Britain elevation data from Intermap Technologies.

PLATES

Frontispiece: Roulston Scar and the conical Hood Hill viewed from Sutton Bank. Note the cliff exposing the Lower Calcareous Grit (Corallian Group) at Roulston Scar, and the wooded slope, below, mostly comprising landslides. The boundary between the lowermost woodland and the arable fields marks the approximate level of the Middle Jurassic Dogger Formation overlying the softer Lias Group mudstones, below. The dry valley between Roulston Scar and Hood Hill was carved by ice and meltwater streams during the last ice-age.

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Plate 2. Boltby Scar; Corallian limestone and calcareous sandstone (Lower Calcareous Grit) exposed at the top of the escarpment with extensive wooded landslides, below.

Summary

This report provides an overview of the geology and landscape that characterises the Hambleton Hills and part of the Howardian Hills that together comprise the North York Moors National Park Authority (NYMNPA) ‘Lime and Ice’ project area. This outreach and community project is centred on the Sutton Bank Visitor Centre and aims to inform and excite visitors about the geology and landscape of this beautiful area. Underpinning an understanding of the natural history and the development of the area is an appreciation of the geological evolution of the Jurassic bedrock geology (‘lime’) and the impact of the last ice-age (‘ice’) that left a thin veneer of overlying glacial deposits over part of the area. A 200 million year geological history that records ancient shallow seas, rivers and deltas, major earth movements and the later impact of major glaciations, especially the last ice-age, is brought to life here to illustrate the dynamic Earth history and our more recent influence on the landscape.

The report covers the geographic scope of the ‘Lime and Ice’ Project area (Section 1) which includes part of the North York Moors National Park, an Area of Outstanding Natural Beauty, and the Coxwold-Gilling gap sandwiched between these designated areas. An overview of the geomorphology of the area (Section 2) comprising the upland moors of the Hambletons Hills, the low ground below the main escarpment and the rolling Howardian Hills sets the scene. The main part of the report (Section 3) describes the geological history and resources of the Jurassic rocks in the area in the context of the wider Cleveland (Yorkshire) Basin, with special reference to the local outcrops and landscape features. This is followed by a description of the influence of the last ice-age and subsequent post-glacial mass movement features that have sculpted and moulded the landscape that we appreciate today. The later sections cover the major Earth movements that have folded, faulted (displaced) and uplifted the rocks during the last 200 million years (Section 4) and the Section 5 provides an overview of our human exploitation of the natural geological resources of the area.

A bibliography of source material and further reading is provided. Technical and/or geological terms are highlighted by grey shading; these may require further explanation for the non-specialist in a Glossary depending on the knowledge of the intended audience and advice from the NYMNPA.

1 Geographic scope

The ‘Lime and Ice Project’ area (Figure 1) with its focus on Sutton Bank and surrounding area, covers about 225 square kilometres comprising the southern part of the Hambleton Hills and, to the south, the western Howardian Hills. These hilly areas are separated by the low ground of the E-W trending Coxwold-Gilling gap. The spectacular scenery and beautiful stone-built villages encompass part of the North York Moors National Park (i.e. the Hambleton Hills) and a designated Area of Outstanding Natural Beauty (i.e. the Howardian Hills). The visual character of this area is largely a result of the underlying Jurassic bedrock geology that records a history of shallow marine seas, rivers and deltas and ancient Earth movements. More recent events, such as the last ice-age, moulded and sculpted the landscape that has been subsequently exploited and adapted by us over the last 10,000 years, to form the steep escarpments, wide vistas, wooded valleys and picturesque stone-built villages that we see today.

2 Geomorphological interpretation

The landscape of the Lime and Ice Project area (Figure 1) is dominated by the steep west- and south-facing escarpment of the Hambleton Hills, that extends from Sneck Yate Bank, near Boltby, south-eastwards to Sutton Bank, and which then turns south-eastwards to encompass the famous Kilburn White Horse, and the less prominent escarpment between Oldstead and Oswaldkirk. The bold west–facing escarpment overlooks the lower ground of the Vale of York, which is underlain by softer, more easily eroded rocks covered by a thin veneer of glacial deposits. The low ground between cone-shaped Hood Hill and Sutton Bank was carved by ice during the last glaciation. Although the Hambleton Hills appear, at first glance, to be a flat-topped plateau, the underlying Jurassic rocks are inclined (or dip) gently to east, as seen when driving down this slope from Sutton Bank towards Sproxton, near Helmsley. This upland area is dissected by a number of steep-sided, wooded valleys such as Flassen Dale, Nettle Dale and Deep Gill whose streams flow, or used to flow, eastward the join the major south-east flowing River Rye in Rye Dale. Some of these steep-sided valleys are now 'dry' along part of their length, having been eroded (carved out) soon after the last ice-age; streams often disappear underground along fissures (karst) in the readily soluble limestone bedrock, to appear at springs at topographical lower levels.

The low ground occupied by the picturesque villages of Coxwold, Oldstead, Byland, Wass, Ampleforth, Oswaldkirk and Gilling East owes its character to ancient Earth movements that displaced (or downthrew) softer rocks in a narrow, parallel E-W orientated belt of geological faults that separate the Hambleton Hills from the Howardian Hills, located to the south (Figures 1 and 2); these softer rocks were subsequently more easily eroded by ice-sheets during glacial periods.

To the south of this E-W trending Coxwold-Gilling fault belt lie the more gently rolling Howardian Hills, which have a general east-west 'grain', again the result of similarly orientated geological faults that break up the same Jurassic rocks we see in the Hambleton Hills. The more varied bedrock geology in this area cut by many faults (Figure 2), is generally inclined to the north, and gives rise to small escarpments, steeply incised wooded valleys, rolling hills and large estates such as Gilling Park.

3 Lime and Ice – geological evolution of the area

The Jurassic sedimentary rocks in the area (Figures 2, 3, 4 and 5) record about 35 million years of the Earth's history. These rocks were originally deposited (laid down on the sea floor) as soft mud, limey mud and sand in either shallow warm seas or in rivers and deltas from about 185 to 150 million year ago, at a time when Britain lay much nearer the Equator, and when giant marine reptiles swam in the oceans and dinosaurs roamed the land. These Jurassic deposits were subsequently buried below thick piles of overlying younger rocks including the white Chalk that forms the Yorkshire Wolds, later to be gently folded, faulted and uplifted at around the time that the Alps were being formed in Europe some 58-23 million years ago. The overlying rocks, including the Chalk, were later eroded away to reveal the Jurassic limestone, mudstone, and sandstone strata that characterise the North York Moors of today. There was another major factor that determined the landscape in the region - the more recent glaciations. Although Britain was subjected to a series of glaciations over the last 2.6 million years, it was the last great glaciation that ended relatively recently, about 11,500 years ago, which had a profound effect on the character of the landscape of the area through the action of ice and glacial meltwater. Over the subsequent 11,500 years the landscape has been moulded by the action of wind, rain, rivers and landslips, and, of course, the impact of mankind through initially clearing virgin forest and then developing farming practices, damming rivers and quarrying stone.

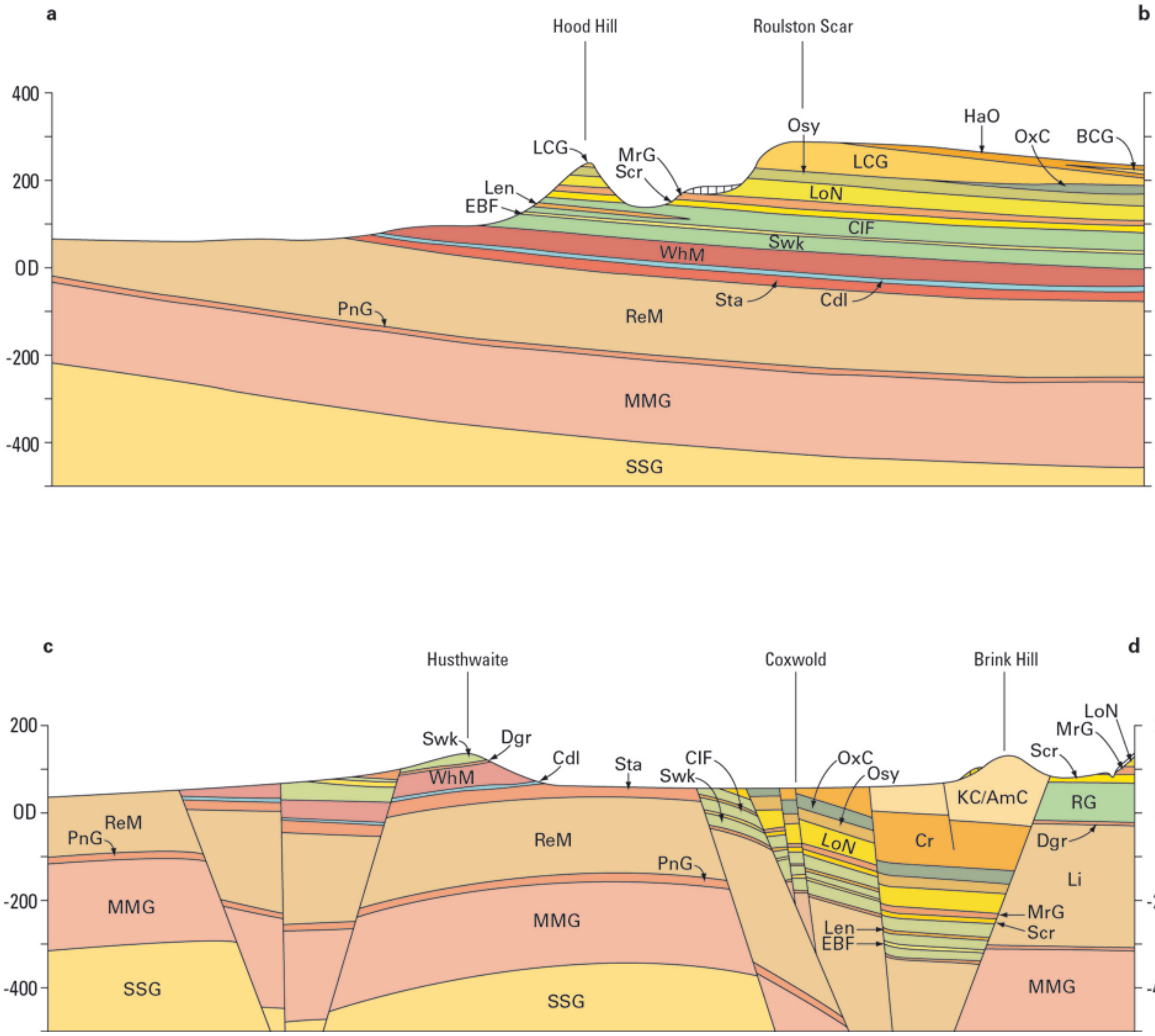

Figure 3. Geological cross-sections (vertical slices) illustrating the geology of the area at depth; (a) cross-section (a-b) on Figure 2 from the low ground in Vale of York (SW) to the Hambleton Hills; (b) cross-section (c-d) on Figure 2 from the Howardian Hills (S) to the Hambleton Hills including the highly faulted Coxwold-Gilling fault belt. Vertical exaggeration in both cross-sections is x 3 the horizontal scale, so the inclination (dip) of the rocks is slightly exaggerated. See Figure 4 for an explanation of the symbols.

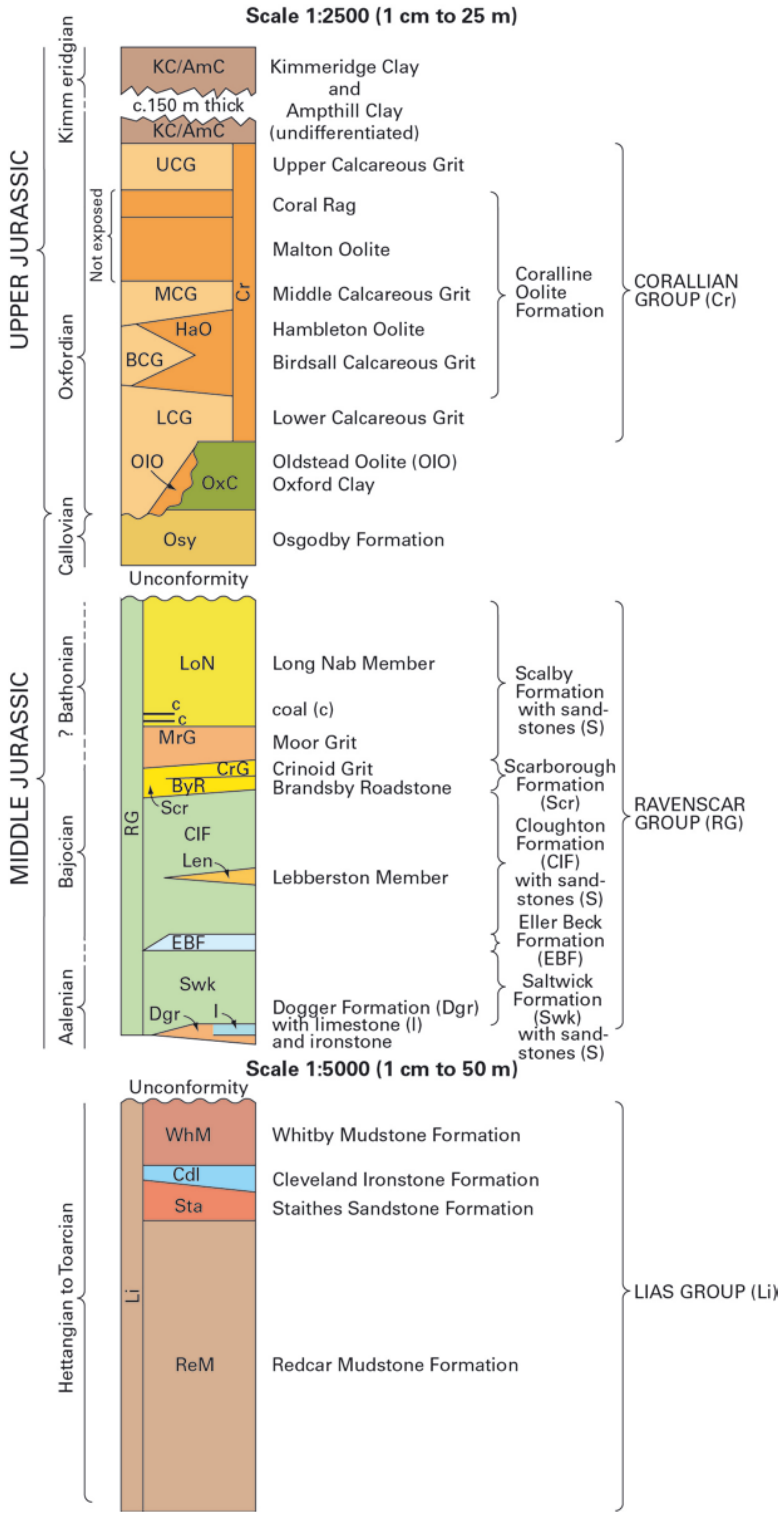

Figure 4. Generalised vertical section of the Jurassic bedrock in the Lime and Ice Project area.

3.1 BEDROCK GEOLOGY - THE ROCKS BENEATH YOUR FEET

As you climb the escarpment at Sutton Bank, Wass Bank or Sneck Yate Bank you are travelling up through time from older to younger rocks (Figures 2, 3 and 4). All the rocks in the 'Lime and Ice' area belong to a period of Earth history called the Jurassic, which dates from 200 to 145 million years ago, although the Jurassic rocks in this area range in age from about 185 to 150 million years. At this time, Britain lay closer to the Equator and our area was submerged from time to time by a wide sea that formed part of an ocean called 'Tethys', which stretched from

Europe to present-day India – the Mediterranean Sea is a remnant of this former ocean. Our area and the North York Moors generally, formed part of the Cleveland (Yorkshire) Basin that had a distinct geological history as compared to other parts of Britain such as the Cotswolds, where Jurassic sediments were also deposited. During Mid Jurassic times (about 175 to 165 million years ago) large rivers brought down sand and mud from the surrounding mountains (e.g. the present-day Pennines; Scotland and Scandinavia) to form extensive river floodplains, deltas and coastal plains.

Below the impressive west-facing escarpments such as Boltby Scar and Sutton Bank (Figure 2), the oldest rocks we see are the soft mudstones of the Lower Jurassic Lias Group that were laid down between 185 and 175 million years ago. Mud was deposited on the sea-floor, along with shelly sands that were periodically dispersed across the sea-floor by storms and hurricanes. These Lias seas supported a diverse marine animal life, including giant marine reptiles (Plesiosaurs), ammonites, bivalves and belemnites (bullet-shaped remains of a squid-like creature). At times iron-rich mud and sand known as the Cleveland Ironstone, exploited widely in North Yorkshire during the 19th century, was laid down in shallow coastal lagoons. At other times, the sea-floor was starved of oxygen so that black, organic-rich mud was deposited, along with fragments of wood that were subsequently compressed to form the semi-precious mineral 'jet', best known from Whitby on the Yorkshire coast where it was fashioned into jewellery. Disused workings or trials for jet mineral can occasionally be seen as small spoil tips below the escarpment west of Kilburn village. The uppermost Lias mudstones (Alum Shales) were formerly worked to produce the mineral 'alum', formerly used in the textile industry on Teeside to degrease sheeps' wool.

Following a period of gentle folding, uplift and erosion of the Lias rocks about 175 million years ago, iron-rich sands (Dogger Formation) were laid down in a shallow sea over much of the area, marking the base of the Middle Jurassic rocks. These rocks, predominantly sandstones, are much harder than the underlying Lias mudstone, and hence form the lowermost steep slopes of the main escarpment. As you drive eastward from Sutton-under-Whitestonecliffe to Cleaves you pass upwards from the Lias mudstone to the Dogger Formation at Cleaves Bank. Nearby, an unusual variety of the Dogger Formation, a coarse-grained limestone consisting of fragments of bivalves (sea-shells) and the limey remains of sea-lilies and bryozoa was quarried for lime. Elsewhere, along the escarpment between Felixkirk and Kirby Knowle, just north of the area, the Dogger Formation ironstone was worked in shallow drift (or adit) shafts dug into the hillside; small spoil tips attest to the former ironstone workings.

South of Cleaves the marine Dogger Formation is not seen (Figure 2). This is due to a subsequent major fall in sea-level and erosion of the Dogger Formation as sand, silt and mud were deposited over the area in rivers, estuaries and deltas. These terrestrial sediments (Ravenscar Group) were washed down by major rivers from the highland areas represented by the present-day Pennines, Scottish Highlands and Scandinavia. The harder sandstones form small crags and rocky outcrops along the main escarpment, and around Hood Hill, Oldstead and High Kilburn; they were quarried locally for building and walling stone. Plants and trees including cycads and *Ginkgo*, which survives today as a 'living Jurassic fossil', grew on the swampy land surface, producing peat, now preserved as thin coal seams that were formerly worked for use as a fuel in lime kilns to produce lime for agriculture and building mortar. Dinosaurs, both meat- and plant-eating, roamed the lowland coastal plains and, although no dinosaur bones have been preserved, they left their footprints in the sand and mud.

At times, the sea-level rose periodically to invade the land area, depositing thin marine ironstone (similar to the Dogger ironstone), mudstone, sandstone and limestone, along with marine fossils including bivalves, gastropods (marine snails) and occasional ammonites. These three marine incursions (Figures 2, 3 and 4) across the land surface were relatively brief. The lowermost marine bed (Eller Beck Formation) comprises thin sandy ironstone overlain by a thin, grey, platy limestone that can sometimes be seen around the southern shore of Lake Gormire. It was locally known as a 'hydraulic limestone' because of its hydraulic properties as lime in cement mortar. Higher up the escarpment, comes the Lebberston Member, better known in this area as the Whitwell Oolite on account of its thickest development near the village of Whitwell-on-the- Hill in the southern Howardian Hills, where it was used locally as a building stone. In the 'Lime and Ice' area it is best exposed near the Oulston where a pale grey, oolitic shelly limestone full of bivalves, crinoids (sea-lilies), bryozoa, corals and marine snails was formerly quarried for lime. The third lime-rich marine unit, the Scarborough Formation, represents a major ingress of the sea over the Jurassic land surface, when lime mud was laid down in shallow lagoons. This hard rock unit forms a less prominent ridge below the main escarpment, especially around Boltby Scar. In the 'Lime and Ice' area it comprises a pale grey, silica–rich thin-bedded limestone known as the 'Brandsby Roadstone' which takes its name from the village of Brandsby, located just south of the area, where it was quarried for hard road 'metal' before the advent of tarmac. Thin 'flaggy' beds, also quarried near the village of Oldstead, were also split into thin sheets for use as roofing slate. Overlying the limestone is yellow, coarse-grained sandstone called the 'Crinoid Grit' that was laid down in the near-shore zone of the sea; it contains the fossilized remains of bivalves (sea shells), gastropods (sea snails) and columnar stems of sea-lilies (crinoids).

Plate 1. Lake Gormire from Sutton Bank

Rivers and deltas advanced again from the north, laying down a fine-grained white sandstone (the 'Moor Grit') immediately above the Scarborough Formation (Figure 4). This distinctive sandstone is often seen as large white boulders across northern areas of the North York Moors, but in this area it is much less prominent, although it does cap some of the small hills between High Kilburn and Byland (Figure 2). As the rivers waned, the land surface became more subdued and was characterised by shallow lakes, muddy rivers and, in some areas, peat bogs; the latter are preserved as thin coals with underlying 'fossil soils' containing fossilised plant rootlets extending down from the coals. These so-called 'Moor Coals' were worked at Newburgh Park [SE 5538 7572], around Oldstead and Boar's Gill [SE5187 8085], and at the former Birdforth Colliery to the west of the area.

A major world-wide rise in sea-level about 165 million years ago resulted in the demise of the rivers and deltas as the sea 'flooded' the land a final time. In this area, the overlying marine sandstones (Osgodby Formation) are often covered by fallen rocks and landslide material, but can be seen below the prominent limestone escarpment, at Raven's Gill, Hell Hole and Roulston Scar (Figures 2 and 4). This yellow-brown, iron-rich sandstone contains abundant traces of the burrows of marine animals such as shrimps that buried themselves in the sand; it was used locally as a building stone in construction of the earlier buildings at Rievaulx Abbey. Above this lies the softer Oxford Clay, a deeper-water marine mudstone locally rich in small pyritised ammonites; it forms a topographical 'slack' below the harder Corallian limestone rocks that form the top of the main escarpment (Figures 2, 3 and 4). However, the area between Sutton Bank and Roulston Scar (Figure 3) has a special interest seen nowhere else in the North York Moors. Here, the soft Oxford Clay is missing as a result of the ancient sea-floor in the Roulston Scar area being uplifted about 160 million years ago so that the soft Oxford Clay was locally removed prior to the overlying Corallian limestone being laid down.

The most prominent landscape feature of the Hambleton Hills is the escarpment produced by the hard limestone and calcareous (lime-rich) sandstones of the Corallian Group; these rocks form the crest of the main escarpment that can be traced from Sneck Yate Bank, south-eastwards to Ampleforth. Corallian rocks form a near plateau, inclined gently to the east towards Rye Dale and Helmsley (Figures 2 and 5). The River Rye and its tributary streams cut down through these hard rocks to reveal the softer Oxford Clay and Middle Jurassic rocks (mudstone and sandstone) below. Within the east-west trending Coxwold-Gilling fault block these Corallian limestones form the higher ground around Kilburn Grange and Coxwold. South of the fault block, in the Howardian Hills, they form the east-west ridge between Gilling Park and Hovingham.

Corallian rocks range from pale grey, hard oolitic limestones to yellow calcareous sandstones (known as 'grits') full of minute siliceous sponge remains (giving their characteristic sandy appearance) and shelly fossils, laid down in a warm, shallow sea. Ooliths look like small fish roe, and were formed by concentric deposition of lime on small sand grains as they were rolled back and forth on the sea-floor – similar environments are seen today on the Bahamas Banks. At Shaw's Gate Quarry remarkable convoluted (disturbed) bedding in the Hambleton Oolite suggest mixing and injection of soft limey sands and muds, possibly a result of seismic (earthquake) shock generated by fault movements soon after it was laid down about 160 million years ago. Both rock types provided excellent building and walling stone that typifies the local villages and towns.

A further major rise in sea-level about 156 million years ago witnessed the deposition of mud at the bottom of a wide sea that covered much of Western Europe. In the 'Lime and Ice' area this event caused an abrupt end to the deposition of lime-rich sandstone and limestones that typify the landscape of the Hambleton Hills. These deeper water muds have been eroded (stripped off) the moors, but are preserved overlying the Corallian rocks in the down-faulted Coxwold-Gilling fault gap, and between Helmsley and the village of Sproxton. Microscopic marine plants collected on the sea-floor to produce an organic-rich mud known as the Ampthill Clay and overlying Kimmeridge Clay (Figures 2, 3, 4 and 5). In the North Sea, the organic remains in the Kimmeridge Clay would eventually be buried and heated, to be transformed into oil and gas that then became trapped in more permeable rocks such as the Middle Jurassic sandstones that we see lower down in the rock succession. These soft oil-shales are easily eroded and form the low ground in a downfaulted block between Byland Abbey and Stonegrave (e.g. Brink Hill) where they are generally covered by a thin veneer of glacial deposits.

3.2 SUPERFICIAL GEOLOGY: A LANDSCAPE SCULPTED AND MOULDED BY ICE

About 2.6 million years ago the Earth's climate entered a period of very cold 'glacial' phases interspersed with warmer temperate phases, the so-called 'interglacials'; we are currently within an interglacial period following the last great ice age that ended about 11,500 years ago. Our industrial production of greenhouse gases such as carbon dioxide and methane may make the climate even warmer over the coming centuries.

A pointer to former warm phases of Britain's climate are the remains of warm-climate mammals, including hyena, hippopotamus and elephant that were discovered in floor of Kirkdale Cave, east of Helmsley. These animal bones indicate a warmer, interglacial, climate in the region about 125,000 years ago, prior to the last ice-age.

During the last (Devensian) ice age that ended about 11,500 years ago, a major ice-sheet covered much of north-east England (Figures 6, 7 and 8). However, most of the North York Moors remained ice-free. About 25,000 years ago a major ice-sheet advanced southwards from the Tees plain to Eskdale (Figure 7); one arm of the ice-sheet was diverted to the west around the North York Moors and then southwards down the Vale of York as far as York and Eskrick where the front of the former ice-sheet is marked by ridges of glacial debris called moraines. This lobe of ice also pushed eastwards in our area along the low ground of the Coxwold-Gilling Gap as far as Ampleforth (Figure 7) at the western end of the Vale of Pickering, where mounds of rock debris formed another ridge-like moraine at the ice-margin. Similarly, an eastern arm of the ice-sheet occupying the North Sea moved down the coastal fringes to form another moraine, near Wykeham, west of Scarborough (Figure 7). Glacial meltwater emanating from the front of these two ice-sheet lobes, and also from melting snow on the moors, formed a vast lake - Glacial Lake Pickering – that occupies the low ground between the moraines (Figure 7). Glacial meltwater arising from the ice-sheet and small glacial lakes in Eskdake cut the spectacular south-flowing Newtondale channel (east of the area) down through the Jurassic rocks to spill out into the glacial lake at Pickering. Similarly ice and snow meltwater on the Hambleton Hills cut steep side valleys such as Rye Dale, Riccal Dale and Kirkdale that also drained south to Glacial Lake Pickering. The western end of the former glacial lake is marked in our area by flat-lying, glacial laminated clay and sand deposits between Thorpe Hall and Stonegrave. The ponded-up lake water eventually found an outlet by cutting a narrow gorge (Kirkham Gorge) through Jurassic bedrock near Kirkham Priory, south-east of the area (Figure 7).

The ice-sheet transported exotic rocks from far afield, including pebbles sourced from the Lake District (e.g. Shap Granite), Scotland and Scandinavia. The pebbles were deposited by the ice-sheet along with a fine-grained, grey-brown clay, essentially a ground up 'rock flour' known as 'till' or 'boulder clay', seen in the low ground of the Vale of York from Kirby Knowle to Oulston, and as far east as the end-moraine at Ampleforth (Figure 6). The top of the conical shaped Hood Hill (Frontispiece) probably protruded above the ice sheet as a 'nunatack'. Locally, sand and gravel was deposited from fast-flowing streams below, and at the margins, of the ice-sheet. These sandy gravels often form elongate ridges known as eskers, as seen near Carlton Husthwaite; elsewhere sand and gravel was deposited at the margin of the ice-sheet at its contact with the Jurassic rock escarpment, for instance around Kirby Knowle and Boltby (Figure 5).

Although the ice-sheet did not cover the Hambleton Hills and southern moors, meltwater from the snowfields covering these upland areas and from the ice-sheet margins had a profound influence on the landscape. Meltwater streams eroded deeply incised valleys such as Rye Dale and its tributaries (Nettle Dale, Flassen Dale and Deep Gill) which drained into Glacial Lake Pickering (Figure 7). An indication of the former erosive power of surface water is seen in the dry valleys between Cold Kirby and Murton Common – these valleys have no present-day streams and are part-filled by yellow-brown, silt overlying limestone bedrock. This wind-blown silt deposit, known as 'loess' (see below), is also widespread north of Murton Grange (Figure 6). Much of the present-day surface water finds its way down and along cracks and fissures called 'joints' in the limestone rocks; the slightly acidic nature of rainwater has gradually dissolved the limestone resulting in widening of the fissures and, in places, forming underground caves such as Fairies Parlour Cave, and Great Relief Pot along the escarpment; groundwater flowing in these underground streams often emerges as springs at lower topographical levels. The underground flow of water makes these rocks an excellent source of groundwater, which is exploited in the lower ground of the Howardian Hills. This type of limestone terrain is termed 'karst'.

In the Hambleton Hills the larger sub-vertical fissures are called 'windypits' – the name derives from air blowing through the open subterranean fissures in the limestone; these include Snip Gill, Antofts and Helmsley windypits located on the southwest flank of Rye Dale. There are records of sacrificial emplacement of bodies down some of the windypits during the Bronze Age (*check with archaeologists*). Loess sediments partially infilling some of the windypits indicates that they were probably formed after the late ice-age about 10,000 years ago during the subsequent post-glacial phase when fine-grained wind-blown silt was deposited; the fine silt was probably transported from the sandy glacial deposits exposed when the ice-sheet melted out in the Vale of York. Another factor controlling the location of the windypits and caves is the result of 'cambering' caused by limestone joints and fissures opening up along the escarpment edge so that the rocks incline towards the valley. This cambering effect is largely due to the overlying competent limestone bedrock effectively squeezing the softer underlying Oxford Clay - akin to the upper slab of a Victoria sponge cake squeezing out the softer jam and cream layer at the edge of the cake! Where cambering is most apparent, such as the escarpment between Boltby Scar and Sneck Yate Bank (Figure 2), cambering has formed natural 'en echelon' (side by side) gullies known as 'camber gulls', some of which are partly in-filled by wind-blown loess silt. At other places the bedrock has moved laterally away from the escarpment where a large fissure or cave has opened up behind the moved block, such as the rock pinnacle at Peak Scar. Much of this cambering took place soon after the waning and melting of the last ice-sheet when the undercutting and supporting ice melted along the escarpment thereby releasing vast quantities of meltwater from the ice–sheet itself and from the snowfields covering the moors (Figure 7). The subterranean water further widened the joints and fissures in the limestone (see windypits, above) and caused the underlying Oxford Clay to be softened along spring lines at the junction between the fissured limestone and the relatively impermeable Oxford Clay, below. In some of the deeply incised valleys such as Deep Gill, calcareous tufa (a soft porous limestone) has formed an apron-like deposit where subterranean streams flowing through the lime-rich Corallian rocks have dissolved lime and arise at the junction with underlying Oxford Clay to deposit mounds of lime.

A notable exception to the cambering effect at the edge of the escarpment is the prominent Roulston Scar area (Frontispiece), including the flat take-off area of the Hambleton Gliding Club. Why should this be so? Well, as noted above (Section 3.1) the soft Oxford Clay is locally absent below Roulston Scar, so the upper limestone slab of the 'Victoria sponge cake analogy' has not deformed toward the valley and 'sits up proud' displaying the Kilburn White Horse (Figures 9-20). The Kilburn White Horse owes its bright tone, not to the underlying bedrock, but to application of white chalk from time to time – without this it would be a very dull yellow colour of the underlying Corallian Lower Calcareous Grit!

3.3 MASS MOVEMENT (LANDSLIDES): POST-GLACIAL CHANGES TO THE LANDSCAPE

Undercutting of the North York Moors escarpment, especially erosion of the softer clays and mudstones of the Ravenscar Group and the Oxford Clay, by the advancing ice-sheet triggered extensive landslides, especially on the west- and south-facing slopes (Figures 9-21); this was exacerbated by the release of meltwater, as the climate became warmer. Some of the landslips (e.g. between South Woods and Sneck Yate Bank) cover many kilometres below the main escarpment (Plate 2). The landslides take many forms including rotational slips where large blocks fail and rotate downslope (e.g. Sutton Bank, Sneck Yate Bank); mudflows where the lower 'toe' of the landslip creeps gradually downslope (e.g. east of Boltby Village; Plate 2); rock falls where large blocks of Corallian rocks break away from the steep face (e.g. Roulston Scar) to translational slides where large areas of competent rock move laterally away from the main face (e.g. Peak Scar). At Sutton Bank the A170 road winds up rotated slip blocks (now stabilised!) until the final northwards ascent parallel to the escarpment, which exposes the Lower Calcareous Grit (Frontispiece). The discovery of a Bronze Age burial urn, *in situ*, part way up the Sutton Bank landslips suggests that the main landslide activity took place after the last ice-age and before the Bronze Age (about 4,500 years ago). The depression now occupied by Gormire Lake (Plate1; Figures 10-21) was carved into solid bedrock by ice and marginal streams between the ice-sheet and the main escarpment, although the present-day lake may be partly dammed up by a landslide at its southern end.

Plate 2. Boltby Scar; Corallian rocks exposed at the top of the escarpment with extensive wooded landslides below.

4 Structure: major earth movements that shaped the area

At around the time when the Alps were formed, about 58-23 million years ago during the Tertiary Period, the rocks of the North York Moors were uplifted from great depths and folded into a series of broadly east-west trending ridges known as anticlines or domes (upfolds), including the Cleveland Anticline, the axis of which extends roughly east-west from Chop Gate to Robin Hood's Bay (Figure 2), and complimentary synclines (downfolds). Some of the east-west trending faults displacing strata in the Coxwold-Gilling fault gap and in the Howardian Hills to the south (Figures 2 and 3), were probably initiated earlier in Jurassic and Cretaceous times, but they were subsequently reactivated during this later period of Earth movements during the Tertiary Period. During this phase of uplift, folding and erosion, the Kimmeridge Clay and overlying Cretaceous rocks such as the Speeton Clay and white Chalk (typical of the Yorkshire Wolds; Figure 5) which formerly covered the rocks of the North York Moors were stripped away to reveal the characteristic Jurassic limestone scenery of the Hambleton Hills.

An important event associated with these Tertiary Earth movements was the intrusion of hot molten lava (magma) from deep within the Earth's crust along a near-vertical WNW-ESE trending fissure, known as the Cleveland Dyke, which is located north of the 'Lime and Ice' area (Figure 5). The molten lava solidified as a hard dyke rock that was formerly exploited for road-stone; only deep worked-out trenches now bear witness to its former extent. The lava magma in the Cleveland Dyke emenated from a volcano on the Isle of Mull in western Scotland.

5 Human impact on the landscape

Numerous Late Neolithic and Bronze age burial mounds, earthworks and artefacts found on the moors, the latter including 'tanged and barbed' flint arrow heads, bear witness to human occupation since the last ice-age. Indeed, our influence on the landscape has impacted on plant life and biodiversity, which are, to a large extent, dependant on the nature of the underlying rocks. Some of the plant species (e.g. Alder; dwarf Juniper; Cloudberry) are relics of cold climate plants that grew here during, or immediately after, the last ice-age. In the northern moors, the Middle Jurassic sandstones (Figure 5) give rise to acidic peaty soils that formed following tree clearance by humans after the last ice-age. Peat bogs and heather-covered moors have evolved as nutrients were leached out of the soil. Heather moorland is now managed as a nesting habitat for grouse and other game birds. In contrast, the lime-rich soils that developed on the Corallian rocks of Hambleton and Howardian hills (Figure 5) support a rich and diverse lime-loving flora including varieties of orchids. Landslides and poor quality soils on the steep Jurassic escarpments are often planted with commercial conifers, which help to stabilise the slopes.

As noted above, local inhabitants have had a profound influence on the landscape of the 'Lime and Ice' area. Following clearance of the upland scrub forest, the limestone uplands have supported mixed arable and pastoral farming, with the limestone bedrock areas and loess deposits providing the best, albeit thin, soils in the Hambleton Hills. The mixed glacial 'boulder clay' (till) on the low ground in the Vale of York and around Coxwold (Figure 6) give rise to heavier soils, whilst the glacial sand and gravel deposits, and the lake clay and sand deposits between Thorpe Hall and Stonegrave provide good quality clay and loamy soils.

5.1 OUR EXPLOITATION OF THE NATURAL GEOLOGICAL RESOURCES

Pale grey and honey-coloured building stone typifies the picturesque village houses, farm buildings, churches, abbeys and country houses of the Hambleton and Howardian hills. Because stone was difficult and expensive to transport over large distances, the village building stone generally reflects the best locally available stone. The latter also worked in shallow pits for dry stone walling. The limestone was also quarried and burnt for the production of lime used to improve the quality of the more acidic sandy soils on the moors.

The pale-yellow, lime-rich Corallian sandstones were used in the construction of Byland Abbey and parts of Rievaulx Abbey, Ampleforth College and nearby towns such as Helmsley (Figure 1). On the moor tops the harder Hambleton Oolite was the most commonly used stone; this white to pale grey oolitic limestone was fashioned as small blocks and thin beds, and was often used as quoin (corner) stones. It was widely used for houses and farm buildings in villages such as Old Byland, Scawton and Cold Kirby. However, its thin 'flaggy bedded' nature also made it highly suited for dry stone walling on the moors. The purer oolitic limestones were burnt for the production of lime in larger quarries such as those at Boltby Scar, Scawton Moor and Byland Moor. During the Second World War the limestone quarried at Boltby Scar was transported by aerial ropeway to the low ground near Boltby village (Figure 1). The remains of lime kilns can be seen adjacent to some of the quarries (e.g. Old Byland); lime was used to improve the soils where the calcareous sandstone bedrock gave rise to more acidic soils, and as a cement mortar.

Some of the earliest monumental buildings in the area were constructed by the Cistercian monks on their estates at Rievaulx and Byland between the 12th and 14th centuries AD. At Rievaulx, some of the earlier buildings were constructed from the brown ferruginous Osgodby Formation sandstone quarried nearby, together with harder yellow-brown Middle Jurassic Ravenscar Group sandstones transported from Bilsdale to the north. Later buildings employed Corallian calcareous sandstones and limestones sourced from nearby quarries on the edge of the escarpment. Their Cistercian brothers at Byland Abbey utilised buff and yellow Corallian calcareous sandstone quarried nearby at Wass. Ampleforth College is built from similar stone quarried along the escarpment east of Beacon Bank. A variety of these building stones can be seen in the more recent vernacular buildings in Helmsley. Lower down the escarpment the tougher, yellow-brown, silica cemented sandstones of the Ravenscar Group were the favoured material, as can be seen in the villages of Boltby, Kilburn and Oldstead. Other limestone resources quarried nearby, mostly in the Howardian Hills, include the Dogger limestone at Cleaves and around Terrington (south of the area); the Brandsby Roadstone (road metal and roofing stone); the Whitwell Oolite (building stone), and a renowned, pale grey, fine-grained Corallian limestone quarried locally around Hildenley southeast of the area, the Hildenley Limestone, that has been used since Roman times for both monumental sculpture and high quality building stone.

Thin, poor quality Jurassic coals were worked in shallow adits and bell-pits mostly for fuelling lime kilns in the Howardian Hills. Small trial adits for ironstone in the Dogger Formation and jet mineral in the Lias shales near the base of the escarpment indicate that these mineral resources were considered to be of poorer quality and less abundant compared the main mining areas on the Yorkshire coast and in north Cleveland. Similarly, the Lias Alum Shales were not worked in this area although on the coast and in some of the inland valleys of north Cleveland the 'scars' of large quarries bear witness to extensive workings of the shale that provided the raw material (along with urine and wood ash) for the production of the mineral alum used in the wool textile industry as a de-greasant in the 18th and 19th centuries.

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