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Limestone plateaus of the Yorkshire Dales glaciokarst.

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Abstract: Landforms across the Yorkshire Dales were mapped by Marjorie Sweeting in 1950 and interpreted as a 1300-foot erosion surface, surviving from a past phase of planation. Re-appraisal of the field data shows that many of the surface features are stratimorphs or structural benches. The Malham Tarn basin may have erosional or geological origins. Other features of past erosion have long since been eroded away. Any concept of an old erosion surface surviving as elements within the modern Dales landscape is untenable.

Keywords: erosion surface, stratimorph, denudation, structural bench, Yorkshire Dales

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Marjorie Sweeting's 1300-foot erosion surface

A paper on the limestone landforms of the Yorkshire Dales (Sweeting, 1950) is one of the most frequently cited with reference to sequences of cave development and related surface features in a karst landscape. At the time of its publication in the hallowed pages of the *Geographical Journal* (published by the Royal Geographical Society), data from caves were rarely available, and Marjorie Sweeting made a great step forward in bringing underground features to the attention of geomorphologists who were not inclined to venture out of daylight. Marjorie was at the time an active caver; she is named among the explorers of Disappointment Pot (Gemmell and Myers, 1952). However, critical examination of the field sites reveals that the two main tenets of her paper, the erosion surface across the fells and the levels within the caves beneath, are both potentially unsound.

It is impossible to fit Marjorie's map of the erosion surfaces onto a current topographical map. Back in the 1940s, with neither good copying facilities nor any digital capacity, original field data were drawn on base maps lacking much of the modern detail and possibly distorted on unstable paper; this one was probably then traced over by hand, compiled as well as possible, redrawn in Oxford University's geography department, and then redrawn by the Journal's cartographer. In such a long trail of Chinese whispers, errors and distortions were bound to occur; Clapham village moved a kilometre to the south, and many parts of the mapped erosion surface cannot be identified reliably. The map of the 1950 data (Fig.1) has been adapted from the original, largely by fitting it locally to the major rivers and also by distorting detail so that the erosion surfaces relate sensibly with visible features and the contours on current maps.

Geographical thought in the 1940s was very much focussed on erosion surfaces and peneplains that could be seen as stages prior to phases of rejuvenation within a terrain's cyclic evolution. A cluster of hillside shoulders, benches and summit levels within a narrow band of altitudes, and recognizable within the modern topography, could be interpreted as a past erosion surface and become a clue to long-term landscape evolution. This was at a time when Davisian geomorphology (Davis, 1902, 1930) was the popular line, when geological factors were notoriously disregarded by most geographers, and when there was no possibility of absolute dating of any landforms.

Most of the limestone plateaus in the Yorkshire Dales region lie at altitudes close to 400m. In keeping with contemporary science, Marjorie therefore described them as the remnants of a peneplain, which has ever since been known by its historical name, the 1300-foot erosion surface (Sweeting, 1950, 1974). Its named altitude was an approximation. Marjorie described the mapped plateaus, benches and shoulders as having inner edges at 15 to 30m above that level and outer edges 15m below the nominal 1300 feet (396m). Unfortunately, Marjorie is no longer with us to explain how she acquired her "erosion surface" data. She probably walked many of the locations, but it is likely that others she interpreted from available contour maps; and those maps of the time were not up to the standards of modern mapping. It was very easy to over-interpret the evidence from both fieldwork and desk-study.

Finding no contemporary sediments on the "erosion surface", Marjorie admitted that it was impossible to date. She stated only that it was "pre-Glacial", and made the rather odd comment that the effects of glaciation had been insignificant. She hinted, by reference to marginal sea-cliffs, that the 1300-foot erosion surface within the Dales could have been a marine feature, but her association of the surface with a "level" of caves not far beneath it implied origins as a peneplain that was above its contemporary sea-level.

Early doubts about the erosion surface

The concept of the 1300-foot erosion surface was questioned, within a year of its publication, by Trevor Ford (1951), amid debate on Jean Corbel's comments on the Ingleborough plateaus. He wrote, *"I see the surface of the Great Scar Limestone as a structural surface of relatively resistant rock exposed by denudation of super-incumbent soft shales, rather than a surface conveniently planed off at a level roughly approximating to the top of the limestone"*, and later commented on the *"remarkable coincidence"* of sea-level planation at the top of the dominant resistant stratum. Unfortunately, his words were almost forgotten within the archives of the Cave Research Group [of Great Britain] Newsletter.

In his description of the Ingleborough benches, Trevor Ford almost defined the term "stratimorph". This denotes a topographical surface formed by an individual bed of strong rock, where weaker cover material has been stripped off by erosion. It can also be described as a structural bench, though this term is more commonly applied to narrower rock terraces across hillsides.

Nearly two decades later, the limestone plateaus of the Yorkshire Dales were described as stratimorphs at least in part (Waltham, 1970), though it was conceded that parts were also erosion surfaces. This was, however, little more than a side-issue in a paper describing the caves. It primarily invalidated Marjorie Sweeting's concept of cave levels, by relating the segments of sub-horizontal cave passages to shale beds within the limestone succession (Waltham, 1970), as is clear from the new generation of cave surveys that show more detail than those that Marjorie had to work with. Her three "levels" of cave development matched three zones that had rather more shale beds. Broad levels of development are still recognized in the Dales caves, but are interpreted more carefully with respect to geological influences and to their depths beneath contemporary water tables.

Concepts of erosion surfaces in the Yorkshire Dales survived in the literature for some years (King, 1969, 1976; Sweeting, 1974). Eventually, however, their reality came to be regarded with increasing scepticism, both locally (Clayton, 1981) and across the wider spectrum of geomorphology. Specifically within the Yorkshire Dales area, parts of the 1300-foot surface were mapped on Yoredale Group rock sequences that are dominated by weak shales, and it is difficult to see how fragments of marine erosion surfaces could have survived long periods of glacial and fluvial erosion of such weak materials. A fresh examination of the nature of Marjorie's supposed erosion surface finds its concept broadly untenable.

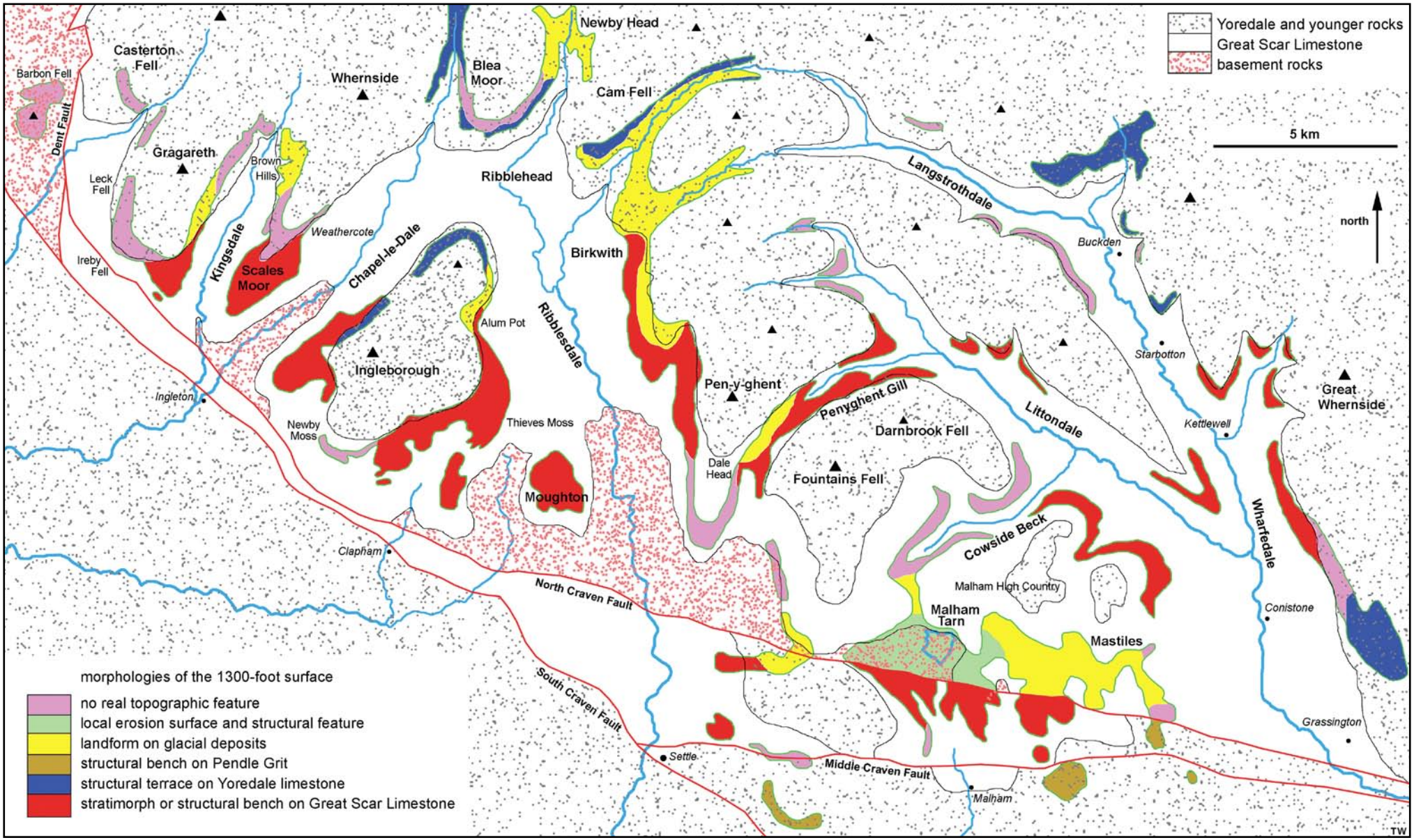

Figure 1: *Components of the supposed "1300-foot erosion surface" across the southern part of the Yorkshire Dales, with re-assessed origins and revised explanations of various landforms that were mapped by Marjorie Sweeting (1950). Labelled areas on the Great Scar Limestone include the prominent stratimorphs west of the Ribble, but east of the Ribble they are more poorly defined structural benches.*

The Malham Tarn basin is labelled as a local erosion surface but is at least in part a structural feature (see text).

Stratimorphs at the 1300-foot level

Large parts of the mapped erosion surface coincide with the wide and spectacular stratimorphic plateaus on top of the Great Scar Limestone Group. These are the surfaces with the extensive limestone pavements, notably around Ingleborough and on Scales Moor (Fig.2). Many are true stratimorphs on the top bed in the succession, but some plateau surfaces step down to one of a handful of thick beds of strong limestone, each capped by a thin shale bed that facilitated ice-plucking or fluvial erosion to a clean top surface. These upper beds include the Lower Hawes Limestone, which belongs stratigraphically to the Yoredale Group but in the southern dales is continuous lithologically with the Great Scar Limestone and locally forms a part of its landform.

Where the Great Scar Limestone stratimorphs are close to horizontal they were mapped by Marjorie as the erosion surface. This included the large surfaces alongside Chapel-le-Dale that straddle a vertical range of more than 50m (Fig.3). But the limestones have gentle northerly dips over much of the Askrigg Block, so that gently inclined stratimorphs continue below the 1300-foot level (396m). Notable are the massive inclined slab at the northern end of Scales Moor down from Twisleton to near Weathercote, the smaller inclined slab with the fine pavements above Southerscales Scar (Fig.3), and the very gently synclinal stratimorph between Moughton and Thieves Moss on the eastern side of Ingleborough. Marjorie's mapped erosion surface showed gaps at all these sites (Fig.1).

Other sections of the mapped 1300-foot surface lie on benches on the tops of the stronger limestone beds within the Yoredale sequence where the gentle regional dip towards the north brings their benches to around the 1300-foot level. Notable are the benches on the Hardraw Scar and Simonstone limestones north of Ingleborough, though like most of the Yoredale benches these are mostly narrow strips above their scars and cannot be described as significant stratimorphs. Some wider benches on the Middle Limestone above Wharfedale were also mapped as the 1300-foot erosion surface.

Some rounded shoulders and benches are developed largely on strong beds lower down in the Great Scar Limestone succession; though these landforms are clearly structural features, they do not warrant description as stratimorphs, but some were interpreted and mapped as elements of the erosion surface. The same applies to some small areas on the early Namurian Pendle Grit, south of the Craven Faults, but again these are structural features that are much more weathered and rounded on the sandstone than their counterparts on the limestone.

Figure 2: *Wide limestone pavements on the prominent stratimorph above Southerscales Scar on the plateau east of Ingleborough, with the Yoredale slopes of Whernside in the distance.*

Features mapped as the erosion surface

Fresh examination of the areas mapped as the 1300-foot erosion surface allows them to be explained as other features, or to be eliminated from consideration for a variety of reasons. Most of the mapped areas are stratimorphs, as outlined above. Other parts are on glacial sediments that happen to lie at the required altitude. In addition, some smaller flats within the terrain are features of localized erosion or sedimentation that developed in meltwater environments during glacial retreat, though distinguishing these would require sediment coring and more detailed mapping. At other sites, the mapped erosion surface is simply not recognizable in the field, where slopes show almost no changes of gradient from above to below the 1300-foot level; it has to be assumed that some were interpreted from wider contour spacings that were artefacts of the cartography on the maps of the 1940s.

The following review of the "erosion surface", as mapped in 1950, is in sequence broadly from west to east (Fig.1).

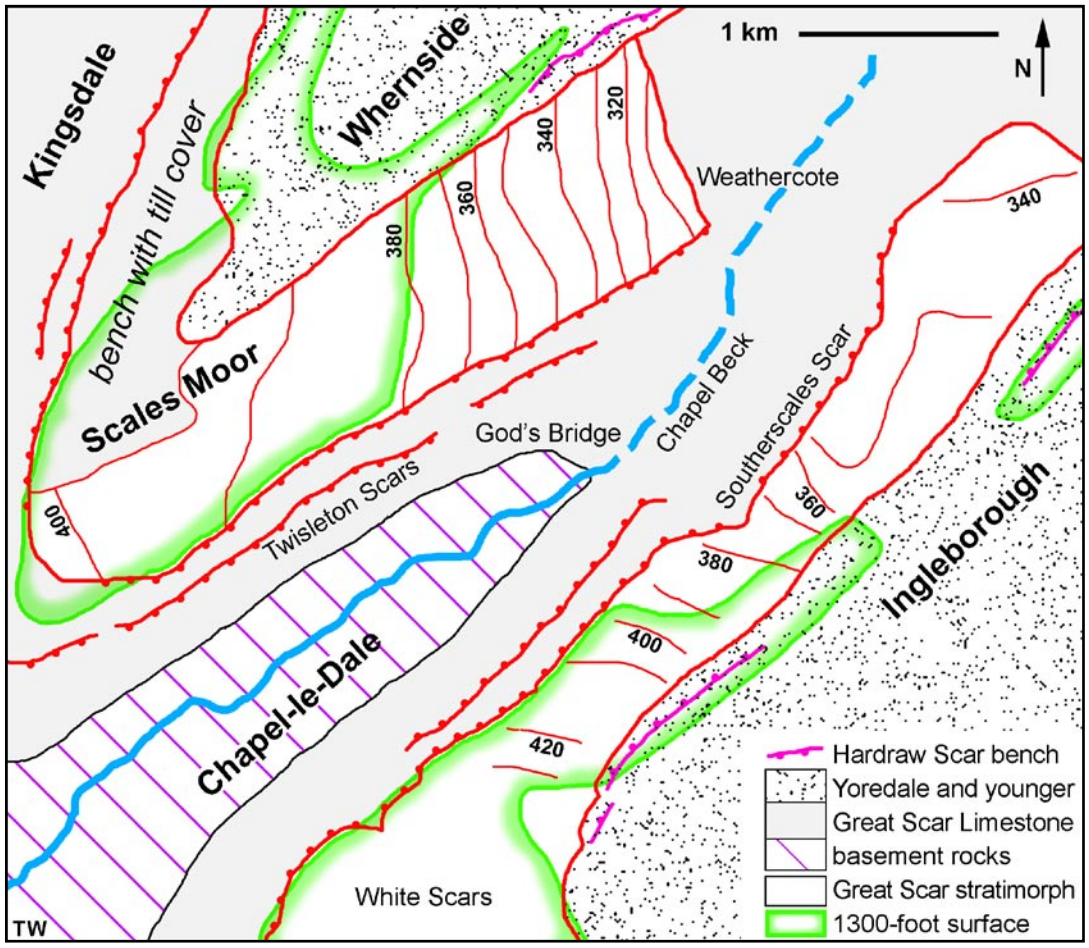

Figure 3: *Stratimorphs on each side of Chapel-le-Dale, with both the near-horizontal parts that were mapped as the 1300-foot erosion surface and also the inclined parts that dip below that level. Both stratimorphs are lost beneath veneers of till towards the northeast. Contours (in metres) on the stratimorphs are generalized, as various small faults are omitted.*

West of Ribblesdale

Mapped surfaces on the Lower Palaeozoic basement rocks of Barbon Fell are not recognizable in the field. Some topographical flats at around the 1300-foot level are on patches of sediment infill, and others are on the crests of landslip masses. Across Casterton, Leck and Ireby fells, the mapped surfaces are unrecognizable as they lie across slopes with almost uniform gradients on thick layers of glacial till. The more prominent landform on Leck Fell is the broad shoulder on the Great Scar Limestone, which is well below the 1300-foot level and slopes gently down through the upper beds.

At the southern end of Gragareth, the erosion surface was mapped across North End Scar on the slightly broken top of the Great Scar Limestone succession. From there, this stratimorph extends northeastwards, above Kingsdale, as a conspicuous landform that follows the dip to lower altitudes, until it is shrouded in till beyond Yordas Cave. The erosion surface was mapped over elongate mounds of glacial till higher on the fell, but becomes unrecognizable beyond a point above Kingsdale Head.

On the side of Whernside, the surface was mapped over the mounds of till that extend up the slopes of Kingsdale as part of the Brown Hills recessional moraine, but it becomes unrecognizable south of High Brown Hill. Farther south, the lower side of the erosion surface was mapped largely on the great Scales Moor stratimorph on the top of the Great Scar Limestone. East of the main interfluve, it is largely a bare pavement. To the northeast, this splendid stratimorph follows a local steepening of the dip as it descends towards Weathercote (Fig.3), while the erosion surface was mapped as tapering to nothing on the Yoredale slopes above.

On the eastern flank of Whernside, a narrow bench on the Yoredale Middle Limestone was mapped as the 1300-foot erosion surface, even though it lies at little over 350m altitude. The mapped surface continued across almost unbroken slopes on Blea Moor, picked up the narrow structural bench on the Simonstone Limestone and then reached on to an area of thick drift over Newby Head where no feature is recognizable in the field.

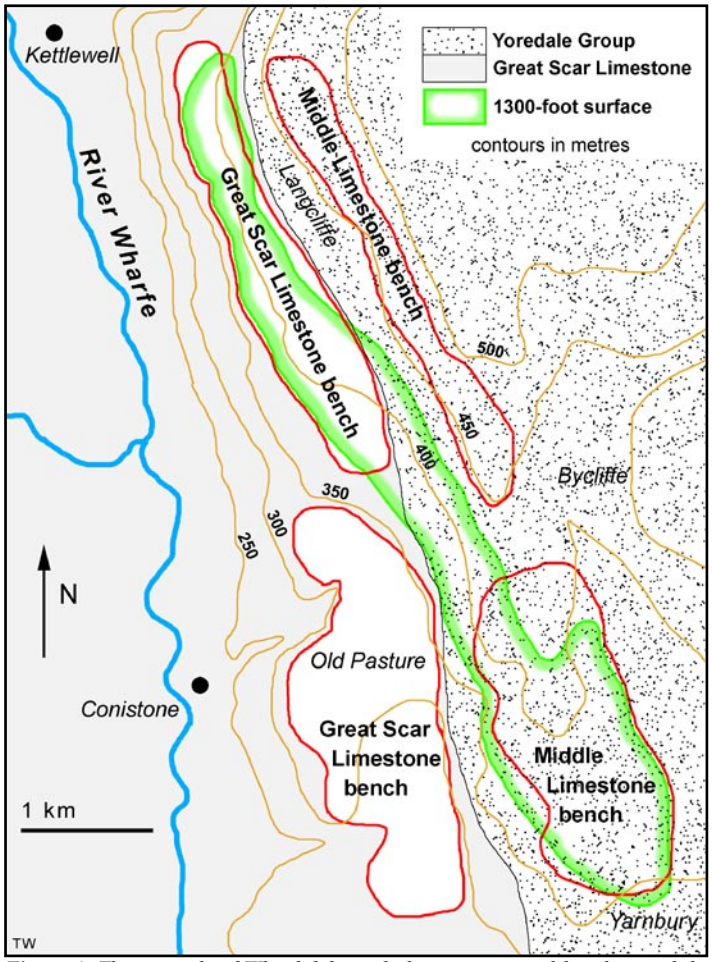

Figure 4: *The east side of Wharfedale, with the two structural benches, and the parts of them that were interpreted and mapped as the 1300-foot erosion surface. The map is generalized, particularly as it omits the Bycliffe and Mossdale fault systems, which break the stratimorphs above Conistone but are not mapped in detail. The floor of Wharfedale is at a general elevation of about 200m, and contours west of the river are not shown.*

On both the western and southeastern flanks of Ingleborough the wide stratimorphs on top of the Great Scar Limestone were mapped as the 1300-foot erosion surface (Fig.1). The pavements on these surfaces step across bedding planes about a metre apart, but the overall effect is of extensive stratimorphs. The mapped erosion surface is broken north of Moughton, where the plateau dips to a lower level, until it steps to a higher bed above Thieves Moss. On Newby Moss, at the southern end of Ingleborough, the mapped surface is unrecognizable across drift-covered slopes that lie below a gentle shoulder where the top of the Great Scar rises with the dip.

Alongside Chapel-le-Dale, the same regional dip eventually takes the stratimorph too low to be interpreted as the erosion surface, which was therefore mapped towards the northeast on the narrow terrace of the Hardraw Scar Limestone. On the eastern side of Ingleborough, the Great Scar stratimorph also dips too low north of Alum Pot, where the erosion surface was mapped across a cluster of drumlins and then onto the Hardraw Scar Limestone, which forms a narrow terrace close to the 1300-foot level round into Chapel-le-Dale.

East of Ribblesdale

The longest unbroken stretch of the mapped 1300-foot erosion surface reaches from the slopes of Cam Fell to and round the southern tip of Pen-y-ghent (Fig.1). Along the west side of Pen-y-ghent, and for part of its width northwards to Birkwith, the mapped surface follows on or close to the top of the Great Scar Limestone. Most of this hillside bench is at best a rather rounded shoulder, largely veneered with drift, and cannot be described as a stratimorph. The mapping also included the narrow structural bench on the Simonstone Limestone along the flank of Cam Fell. Between these two, the mapped surface lies across the edge of the great Ribblehead drumlin field. Any suggestion of an erosion surface would appear to be either an artefact of map contours or a coincidence of levels across a convenient selection of drumlin crests; nothing more is identifiable in the field.

Farther south, the mapped surface is unrecognizable round the shoulder of Pen-y-ghent, where a more conspicuous rock bench does lie on the top of the Great Scar Limestone about 50m higher than the 1300-foot level. Northeast of Dale Head, the tops of the Hawes and Great Scar limestones dip to lower altitudes and their stratimorphic benches along both sides of Penyghent Gill were mapped as part of the erosion surface, along with an area of undulating ground on till beneath Pen-y-ghent's summit.

Round the rest of Fountains and Darnbrook fells, there is little or nothing of the mapped surfaces that can be recognized in the field. There are low scars on strong beds of limestone south of Cowside Beck, a gently rounded shoulder on Nab End above Darnbrook House, and a thick blanket of glacial drift flooring the valley south towards Malham. Along the north side of the Cowside valley there are areas of structural bench on beds of the Great Scar Limestone at altitudes of 330m and 440m, with an almost uniform slope that straddles the 1300-foot level in between.

Above Settle, two areas on the Great Scar Limestone are best described as poorly defined and eroded structural benches, and a well rounded shoulder south of the Middle Craven Fault is broadly defined by the Pendle Grit. The mapped area astride the fault is not recognizable on thick drift with only a small flat at the 360m level. Farther east, the Malham area is a special case (see below).

Along the flanks of Littondale, the areas mapped as the erosion surface are largely structural features developed on strong beds of limestone at or near the top of the Great Scar Limestone succession. They cannot be described as stratimorphs as they are little more them local easings of the slope profiles above low rock scars that fringe narrow strips of limestone pavement across hillsides largely shrouded with soil and grass.

Across the head of Wharfedale, a large area mapped as the erosion surface straddles two well-defined structural benches on the Simonstone and Middle limestones. Two smaller mapped areas are defined by Yoredale limestone where their benches widen round shoulders above Buckden and Starbotton. Across the dale and extending into Langstrothdale, areas mapped by Marjorie as the erosion surface are barely recognizable except as gentle changes in slope from the top of the Great Scar Limestone onto the Yoredale shales. Above Kettlewell, on both sides of the dale and up towards Great Whernside, it is difficult to correlate the original mapping with the topography shown on current maps; the indicated areas of erosion surface all appear to coincide with structural features at the top of the Great Scar Limestone, though none warrants description as a true stratimorph.

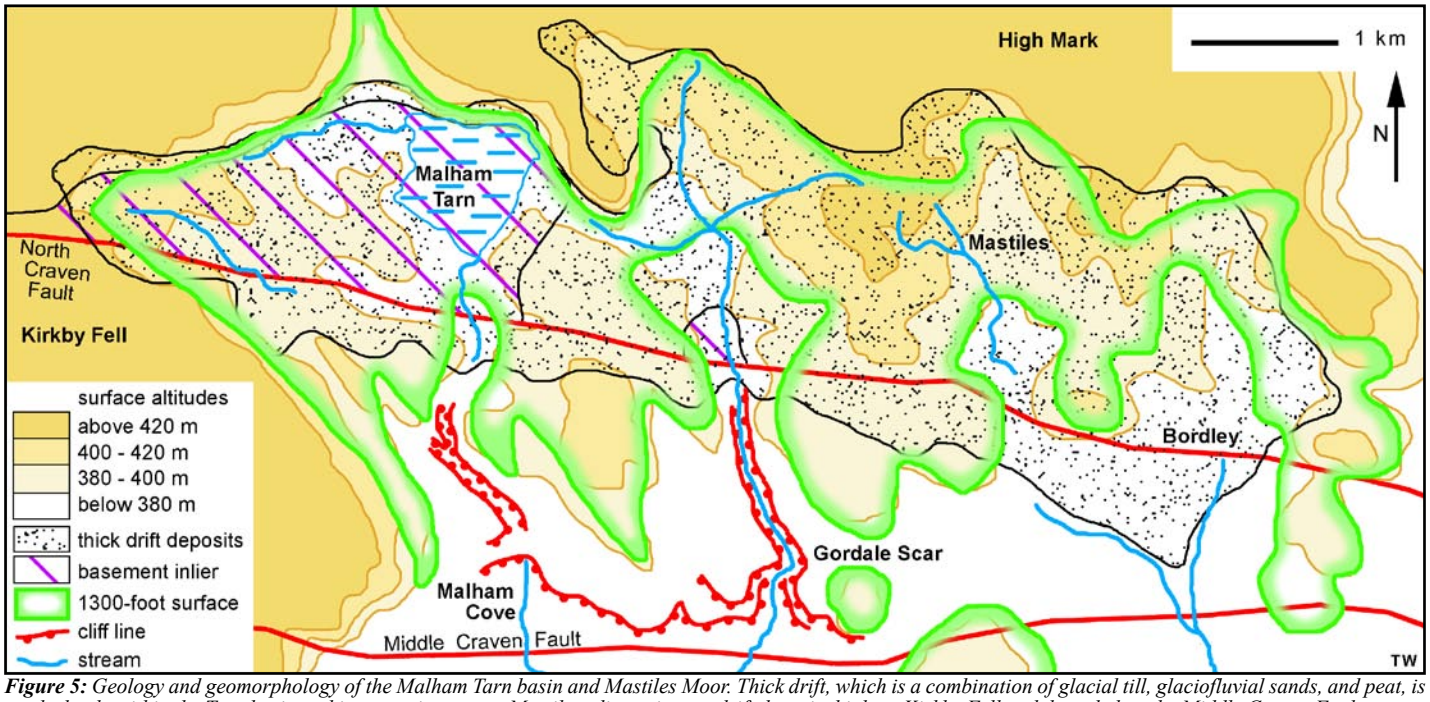

Figure 5: *Geology and geomorphology of the Malham Tarn basin and Mastiles Moor. Thick drift, which is a combination of glacial till, glaciofluvial sands, and peat, is marked only within the Tarn basin and its extension across Mastiles; discontinuous drift deposits high on Kirkby Fell and down below the Middle Craven Fault are not marked. Bedrock is Great Scar Limestone except south of the Middle Craven Fault, between the faults southeast of Bordley, and across the marked basement inlier.*

The large area mapped as the 1300-foot erosion surface on the eastern side of Wharfedale has three distinct components (Fig.4). Its northern end follows the bench on the Great Scar Limestone, but farther south the stratimorph at that horizon dips south, and steps down some faults, to the pavements of Conistone Old Pasture at altitudes lower than 340m. The southern end of the mapped erosion surface is a wide, poorly defined bench on the Middle Limestone; this is brought to the 1300-foot level by displacements on the mineralized faults of Bycliffe and Mossdale and by a local downturn of the dip in the approach to the Craven Faults. Between the two sections of limestone bench, the 1300-foot surface is simply not recognizable across steeper and unbroken slopes that appear to mask the faults within the shale-dominated Yoredale succession (Fig.4).

The Malham Tarn basin

The high-level basin that holds Malham Tarn, together with the large area of surrounding moor at close to the same altitude, gave Marjorie Sweeting the strongest evidence for the validity of her erosion surface concept. This was particularly so because it lies on contrasting rock types where it straddles the North Craven Fault (Fig.5), and her 1950 map even includes a small inset profile across it. However, the morphology of this area is more complex than a simple flat eroded into the terrain.

North of the fault, the Tarn basin is a conspicuous expanse of nearly level ground at an altitude close to 380m. It lies on an inlier of folded Lower Palaeozoic basement rocks, which are truncated at the unconformity where the Great Scar Limestone sits above and forms the inlier's northern perimeter slopes. The eastern half of the mapped erosion surface extends across the undulating grasslands of Mastiles. This area is on a thick blanket of glacial till that overlies the dark, thinly bedded Kilnsey Limestone in the lower part of the Great Scar Limestone succession. The erosion surface was mapped with its northern edge along the steeper limestone hills and with its southern edge almost along the 380m contour. It takes no account of the rolling terrain at altitudes ranging between 370 and 430m, though most of that is on till which would mask any erosion feature in bedrock. Its eastern extremities are barely recognizable and include an arm reaching across the North Craven Fault onto Pendle Grit, similar to another mapped area on a rounded grit crest south of Gordale.

South of Malham Tarn, the erosion surface was mapped across the North Craven Fault onto the benches, pavements and scars of the limestone between and on either side of the Watlowes and Gordale outlet valleys. These surfaces are at or close to the top of the Great Scar Limestone succession, but they could only be described as stratimorphs in the broadest sense. More significantly they rise, against a gentle northerly dip, to altitudes greater than 400m, more than 20m above Malham Tarn (Fig.6). The Tarn basin and these limestone benches do not combine to create a landform that can be described as either flat or unbroken.

There does appear to have been a measure of erosional planation within the Malham Tarn basin, but this is purely a local feature, and it does not imply any wider occurrence of an erosion surface. It probably originated where the thinly bedded and relatively weak Kilnsey Limestone was brought to outcrop north of the fault, where it was isolated behind the erosionally resistant limestones south of the fault. Its excavation could have been fluvial, with drainage through the gorge to Watlowes. Or it could have been modified by ice that scoured the Kilnsey Limestone and moved upwards over the stronger limestone beyond the fault. Whereas the Tarn flat could be described as a perched erosion surface, it could also be essentially a structural feature that was defined by the weaker limestones and then survived with a floor of basement rocks while protected by surrounding hills of more massive limestone.

Figure 6: *The Malham Tarn basin, seen from the west, with the higher ground on the limestone south of the fault on the right.*

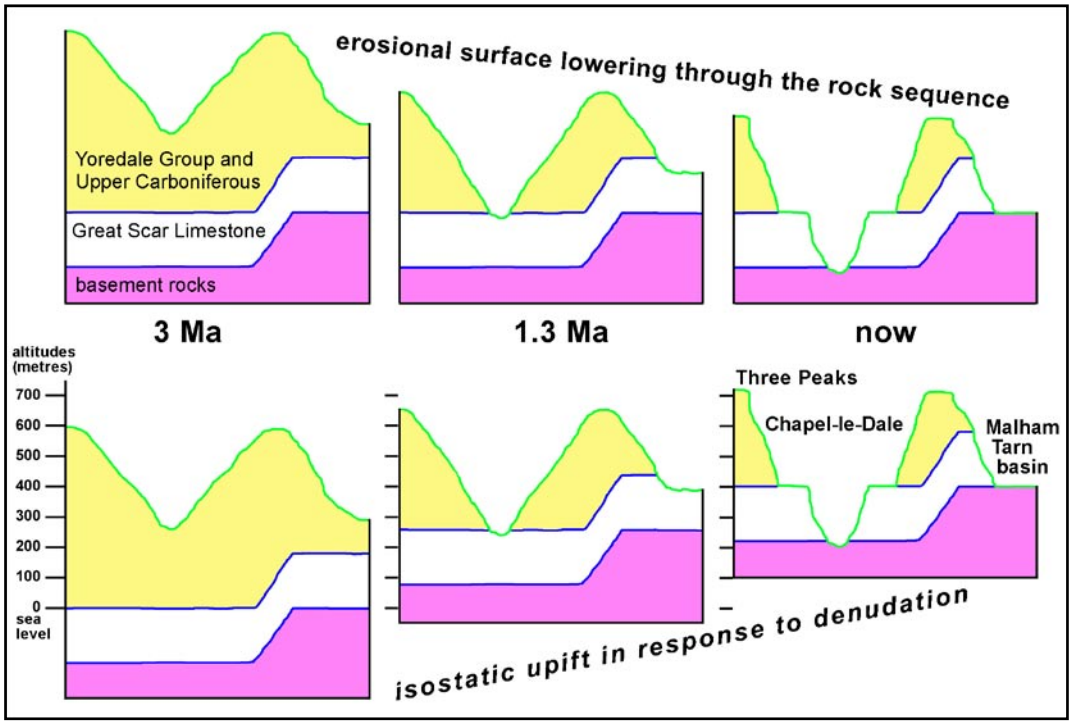

***Figure** 7: Diagrammatic profiles showing the evolution of the Dales landscapes. The model is based on incision rates in the western Dales interpreted from stalagmite dates in drained caves, combined with concepts that summit denudation is slower than valley floor incision and that isostatic uplift is a consequence of denudation. The upper profiles are tectonically static and therefore unreal, whereas the lower profiles are drawn relative to a constant sea level. Profiles are distorted to show the limestone benches of Chapel-le-Dale and also the high-level basin containing Malham Tarn; the monocline is therefore an artefact of the drawing, in place of a more uniform dip. About 1.3 Ma ago, Great Scar Limestone was first exposed in Chapel-le-Dale and doline karst was developing above Malham. When the top of the Great Scar Limestone in Chapel-le-Dale was at sea level about 3 Ma ago, it lay far below the eroding land surface.*

The Yorkshire Dales without their erosion surface

Models of valley incision showing the progressive excavation of the Yorkshire Dales are now based on an absolute chronology that was not available when Marjorie proposed her concepts. Measured ages of stalagmite have provided a framework for models that relate to caves progressively drained as valley floors were lowered (Atkinson *et al*., 1978; Gascoyne *et al*, 1983; Waltham, 1986).

A current best estimate of the mean rate of valley incision in the Yorkshire Dales is about 0.15 m/ka (Waltham, 2012). An inevitable consequence of denudation is isostatic uplift to compensate for the erosional loss. With typical crustal and mantle densities, uplift is likely to be about 85% of the surface lowering (Burbank and Anderson, 2001). The figures are only approximations, but long-term uplift at about 0.13 m/ka would place the widespread top level of the Great Scar Limestone (currently at 1300 feet or nearly 400m) at sea-level about 3 million years ago.

Any fragments of a base-level erosion surface that survived from 3 Ma would therefore be seen at around the 1300-foot level. But almost all elements of such an erosion surface, including those on top of the Great Scar Limestone, would then have been on slopes and benches that have long since been removed by erosion (Fig.7). The structural benches and stratimorphs in the modern landscapes would, at 3 Ma, have lain far beneath slopes of Yoredale shales that had not yet retreated to their present positions.

It is equally unreasonable to expect any planation surface around Malham Tarn to have survived since 3 Ma. Denudation rates over summits and interfluves are likely to have been lower than those in the dale floors, and karstic features on the high ground above Malham Tarn do indicate minimal or negligible erosion by Devensian ice (Marker and Goldie, 2007). But zero surface lowering through 3 Ma, and through multiple glaciations that included the major Anglian event, is hardly conceivable. Furthermore, if erosion over the interfluves was so limited, the total-area mean denudation rate would have been less than 0.15 m/ka, isostatic uplift would have been slower, and a 1300-foot erosion surface would be older, so would have had to survive even longer. The Malham Tarn flat has a Pleistocene history of fluvial and glacial erosion, but no evidence of marine origin during the Pliocene has been found.

While the dales were entrenched, through some millions of years, the main limestone benches were widened by retreat of the Yoredale slopes that rise above them. Marjorie herself recognized areas of shale retreat (Sweeting, 1974) and ascribed the process to Devensian glacial erosion. Some that she identified coincided with her mapped erosion surface, which would therefore have been buried beneath the shale until much later. It is significant that no marine, littoral or fluvial sediments directly associated with the erosion surface have ever been found. There is no place for the erosion surface within a credible model for the incision of the dales and the evolution of the limestone plateaus.

The concept of the 1300-foot erosion surface in the Yorkshire Dales should be allowed to die. It no longer has viability. With it goes the concept of the cave levels, at least within their original context. Marjorie Sweeting's 1950 paper was a classic of its time, very much in line with contemporary geomorphological thinking. However, re-appraisal of the field data, and of the concepts that they supported, shows that the paper should now be cited only within the context of the history of science.

Acknowledgements

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