Quaternary of Northern England

D. Huddart
Liverpool John Moores University,
Liverpool, UK

and

N.F. Glasser
University of Wales,
Aberystwyth, UK

With contributions from

Jim Innes
David Evans
John Boardman
Silvia Gonzalez
Richard Chiverrell
Wishart Mitchell
Andy Plater
Sarah Morriss
Cynthia Burek
Stephan Harrison
Richard Jones
Graham Wilson

GCR Editor: **G.S.P. Thomas**

JOINT NATURE CONSERVATION COMMITTEE

Chapter 3

Pre-Quaternary landscape development

D. Huddart

INTRODUCTION

The history of pre-Quaternary landscape development in northern England is difficult to establish because the area has been a successive source for regional ice sheets during the Pleistocene Epoch and glacial erosion has dominated the landscapes' development. Thus, much of the Pleistocene and pre-Quaternary record has been removed. Erosion too was prevalent during the Tertiary Sub-era and the area had been dominated by uplift and upland environments throughout Miocene and Pliocene times. Sediments and landforms from this geological Sub-era are rarely preserved in the area and difficult to interpret. A number of approaches have been used to fill this gap, however, including the examination of scattered Miocene and Pliocene sediments (Boulter *et al.*, 1971), weathering history (Walsh *et al.*, 1972), evidence from apatite fission-track analysis (Green, 1986; Lewis *et al.*, 1992; Holliday, 1993) and the erosional history of the uplands (Belbin, 1985).

TERTIARY SEDIMENTS IN NORTHERN ENGLAND

Relatively few Miocene or Pliocene sediments have been preserved on land in Britain (Figure 3.1), although extensive sequences have been recorded in the North, Irish and Celtic Seas (Anderton *et al.*, 1979). However, over sixty solution-subsidence hollows, or sinkholes, are known from the Derbyshire Peak District (Figure 3.2; Boulter 1971a, b), and they contain sequences of Tertiary clays, sands and gravels beneath Pleistocene deposits. These clays, the so called 'Pocket Deposits', belong to the Brassington Formation (Boulter *et al.,* 1971; Walsh *et al.*, 1972). They have been described by Pilkington (1789), Howe (1897), Kent (1957), Yorke (1961) and Ford and King (1968, 1969). At Kenslow Top they are up to 70 m thick and are divided into three members (Boulter *et al.*, 1971).

3. Kenslow Member: grey clays, containing plant remains.
2. Bees Nest Member: coloured clays, now mottled red and green, unfossiliferous.
1. Kirkham Member: sands and gravels, now much bleached and occasionally cemented into a soft sandstone, unfossiliferous.

The Brassington Formation contains pollen and spores of woody and herbaceous angiosperms, conifers and pteridophytes and macrofossils of angiosperms, conifers, fungi and moss. The vegetation probably included heath at higher elevations and woodland at lower levels. Some 30% of at least 75 genera in the flora are currently confined to warm, oceanic, tropical/subtropical climates and some of the plants are now restricted in distribution to either North America or East Asia. This climate was a good deal warmer than that of the present day, with smaller seasonal temperature variations and a temperature regime that did not fall below zero. Confirming the climatic implication, the mineral composition of a plant-bearing clay at Bees Nest shows a significant amount of gibbsite (Boulter, 1971b), a mineral resulting only from extreme tropical weathering. A Late Miocene to Early Pliocene age has been assigned to these sediments, mainly on the palynological evidence. The Brassington Formation formed in a terrestrial environment and represents one sedimentation cycle, passing upwards from alluvial sands and gravels, derived from Triassic bedrock, in the Kirkham Member, through a lacustrine environment in the Bees Nest Member, into paludal sedimentation, including lignite, in the Kenslow Member (Kent, 1957; Ford and King, 1969).

Walsh *et al.* (1972) considered the implications of this formation for the development of the Southern Pennines and other uplands in the British Isles. A land surface formed before either the Late Miocene or Early Pliocene at an altitude of about 450 m has been demonstrated in the Peak District. However, when the Neogene deposits for Britain are mapped they pass from this altitude to as deep as –300 m OD, and possibly –600 m (Walsh *et al.*, 1972), in the sedimentary basins offshore. This variation results from the interplay of several factors: differential erosion terminating at the time when sedimentation began in the different regions; the start of sedimentation on this composite surface at different times in different places; crustal movements during accumulation of the sediments and crustal movements after sedimentation. We cannot assess the impact of the first two factors but there must have been considerable Late Neogene and Pleistocene crustal movements that influenced the morphology of upland Britain. Uplift of the Southern Pennines, at the rate of about 1 m every 15 000 years since the main Alpine orogenesis in the mid-Tertiary, has

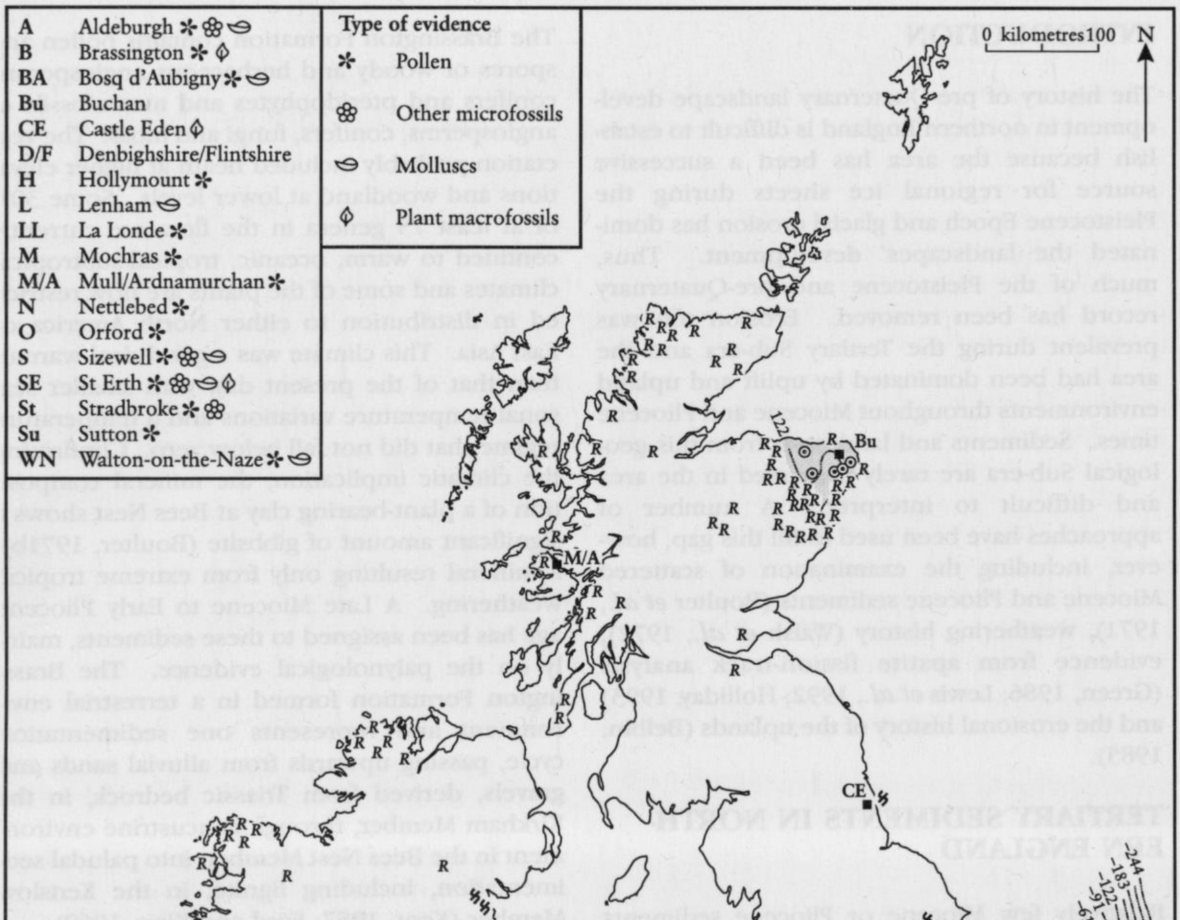

Figure 3.1 Location of Miocene–Pliocene (Neogene) sediments in Britain and the adjacent continental shelf (after Walsh *et al.*, 1972). See also Daley and Balson (1999) in the Tertiary stratigraphy volume of the GCR series.

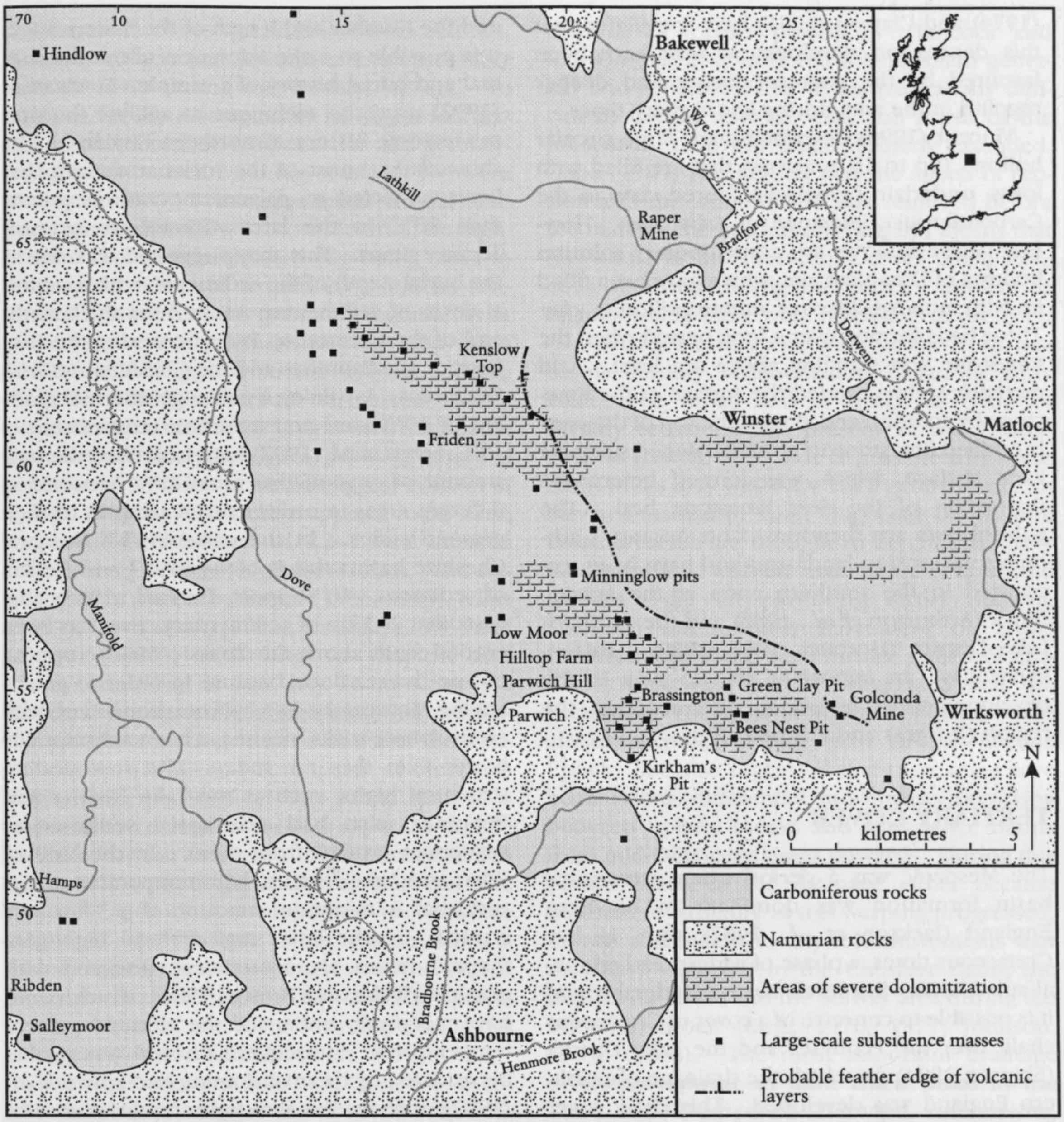

Figure 3.2 Location of large-scale subsidence features in Derbyshire, after Walsh *et al*. (1972).

been suggested, but the evidence is acknowledged as flimsy (Walsh *et al.*, 1972).

Similar deposits of sands and clays preserved in solution subsidence hollows in the Chalk of the Yorkshire Wolds were considered to be of pre-glacial age by Versey (1938a), although there has been much discussion as to their true origin and age (Bisat, 1940; Foster, 1986; Catt, 1991b). Similarly, over 20 solution-subsidence hollows of probable pre-glacial age have been preserved in the Carboniferous Limestone of Flintshire and Denbighshire (Maw, 1867; Strahan and De Rance, 1890; Walsh and Brown, 1971), many containing clays, sand and lignite. In the north-east, Reid (1920) considered that the species-rich macroflora from a fissure clay at Castle Eden (County Durham) was of Middle Pliocene age and Boulter (1971b) has suggested that there could be links between this flora and the Derbyshire floras. The largest closed depressions in the Pennine karst are the saucer-shaped landforms, 300–900 m in diameter and up to 100 m deep that are found to the north-east and south-west of Malham Tarn. Both Sweeting

(1974) and Clayton (1981) have speculated that this depression development may have been favoured by the warmer climate and deeper regolith in the area during late Tertiary times.

Vincent (1996) described many large circular hollows (up to 10 m across) that are filled with loess, underlain by ochre-coloured clays in the Carboniferous Limestone of Asby Scar. However, these hollows are contemporary solution hollows of Dinantian age, which have been filled in with non-fossiliferous montmorillonite clay. These beds formed over a long period when the limestone was standing above sea level. Acid meteoric waters eroded the surface of the limestone by solution and altered the top of the partly lithified limestone to give a hardened subshale karst surface, which was formed before the deposition of the next limestone bed. The palaeokarsts are therefore contemporary Carboniferous erosion landforms and have been recognized in the southern parts of the Askrigg Block (Arthurton *et al.*, 1988) and the southern Lake District (Horbury, 1987, 1989). Palaeokarsts have an important role to play in the development of limestone pavements in the region (Burgess and Mitchell, 1994).

TERTIARY COVER

The Mesozoic was a period when extensional basin formation was dominant in northern England (Jackson *et al.*, 1987) with, in late Cretaceous times, a phase of widespread regional subsidence. Sea levels rose considerably and it is possible to conceive of a cover of Cretaceous chalk over the Pennines and the Lake District (Skipsey, 1994) on which the drainage of northern England was developed. This chalk cover was subsequently eroded during the Tertiary Sub-era. Estimates of the amount of erosion of this chalk cover have been deduced from palaeotemperatures estimated from apatite fission track analysis (Green, 1986; Lewis *et al.*, 1992). The basis of this technique is that fission tracks (trails of radiation damage) are produced within apatite grains at a more or less constant rate through geological time as a result of the spontaneous fission of ^{238}U. These fission tracks are not preserved when the minerals have been heated subsequently, so that the number of tracks are related to the time intervals since the material was last at a certain critical temperature. Thus from the uranium content of the grains and the number and length of the fission tracks, it is possible to make inferences about the thermal and burial history of a sample. Lewis *et al.* (1992) used this technique to analyse the thermo-tectonic history of northern England. This showed that most of the rocks at outcrop had been subjected to palaeotemperatures greater than 90°C in the latest Cretaceous or early Tertiary times. This they suggested was due to the burial depth of the sediments, with a regional cover of sedimentary rocks 3 km thick at the end of the Cretaceous Period covering the Lake District, the Pennines and the Cheshire and Irish Sea basins. Assuming a palaeogeothermal gradient of 30°C km^{-1} and a surface temperature of 10°C, Lewis *et al.* (1992) have estimated the total amount of erosion that must have occurred in different areas in order to cool samples to their present values. In the eastern Irish Sea and Cheshire basins this is between 2.7 and 3.3 km of sediment. In support, Bushell (1986) suggests that 2–3 km of sedimentary cover has been eroded from above the Triassic rocks cropping out on the sea floor, because in order to generate the Morecambe Bay hydrocarbons, Carboniferous source rocks must have been substantially hotter than they are today. The surrounding structural highs, such as the Lake District and Pennines, also had substantial sedimentary sequences eroded from them. In the Vale of Eden and Lake District, high temperatures suggest that a minimum amount of 3.3 km was eroded. In the latter region, local high geothermal values are sometimes associated with granites (Webb and Brown, 1984), which could have marginally enhanced the elevated palaeotemperatures. Subsequent erosion was probably initiated by thermal doming and Lewis *et al.* (1992) note studies that indicate elevation of a dome with a 1000 km radius and central uplift of about 2 km and suggest that doming preceded rifting and spreading in the North Atlantic area.

This amount of erosion brought older crustal rocks back towards the surface and also led to further uplift by isostatic rebalancing and hence to prolonged erosion (Clark, 1994b). The influence of buried plutons on the pattern of compensatory uplift would become proportionately greater as erosion cut deeper and would affect differentiation of relief, as suggested by Clark (1994b) for the Skiddaw massif. Here the granite core exercised a growing independent influence on local relief as removal of the overlying sediment cover progressed.

In a review of the apatite fission track analysis, Holliday (1993) has arrived at a considerably thinner cover during the Tertiary Sub-era. To account for the discrepancies he suggested that the assumed surface temperatures and geothermal gradients used by Lewis *et al.* (1992) were incorrect. Early Palaeogene mean annual temperatures in Britain were considered to be higher than those of the present day, being close to subtropical values of around 20°C and he concluded that present-day geothermal gradients or palaeogeothermal gradients in preserved strata could not be applied to the eroded section. Holliday (1993) therefore suggested that a palaeotemperature of 20°C derived from apatite fission track analysis, and a palaeogeothermal gradient of 53°C km^{-1}, would suggest erosion of 1.7 km of strata. This value appears to be close to probable thicknesses of 1.2–1.7 km inferred from the regional geological evidence. The significance of papers by Green (1986, 1989), Hillis (1991), Lewis *et al.*, (1992), Holliday (1993) and Japsen (1997), according to Clayton and Shamoon (1999), is that they demonstrate the reality and magnitude of denudational unloading. So, commenting on the removal of the post-Palaeozoic sediments from parts of northern England, Lewis *et al.* (1992) stated that 'it is important to recognize that the apparent "uplift" indicated by the removal of 3 km of overburden is not all tectonically induced, but that the majority occurs in response to isostatic rebound.' In the case of the Alston Block a major negative gravity anomaly over the buried Weardale Granite supports the case for neotectonic movement and for a buoyancy that is not yet spent (Clayton and Shamoon, 1999).

The implications of this thick, Cretaceous sedimentary cover suggest an eroded, subdued, low-lying topography and it is clear that the Lake District core did not persist as a landmass throughout the Mesozoic Era and Tertiary Sub-era, buoyed up isostatically by the granite batholith. However, early Tertiary regional uplift and erosion was related both to the rifting in the North Atlantic and compression resulting from the Alpine orogeny. Skipsey (1994) illustrates the rapidity of this erosion for the Lake District, where he inferred erosion of 5–10 km of country rock around the Shap Granite in 43 million years. However, in such examples remnants of the eroded rocks can be found in the basal beds above unconformities. In the case of the hypothetical Chalk cover there are no traces at all to confirm its former presence. Hancock and Rawson (1992) considered this problem generally and concluded that it was particularly difficult to decide how far west and north of the present outcrop the Chalk formerly extended. Cope (1984) had argued that the speed of erosion and the amount of Chalk removed before the mid-Eocene in southern England means that the whole of the Cretaceous cover could have been removed during the Tertiary Sub-era in regions where there were no basalts to protect it (i.e. outside Northern Ireland). In the North Sea basins Tertiary sedimentation began in Early Palaeocene times and as much as 3 km of Tertiary sediments are present in the Central Graben (Lovell, 1990). It is possible that these basin infills may well have been eroded from an elevated mainland. Later Oligocene or Miocene erosion events are thought to be comparatively mild compared with the main phase of uplift and erosion in the early part of the Tertiary Sub-era, although undoubtedly movement on faults occurred and there were further pulses of erosion. King (1976, 1977) suggested that the Palaeozoic rocks of northern England were already exposed at the start of the Eocene Epoch. She also suggested that there must have been strong differential movements occurring between upland blocks and subsidence basins from mid-Oligocene times onwards. During this period much of the drainage either became adjusted to structure as this warping progressed, or was antecedent to any fold movements that may have occurred in the Cheshire basin, the English Midlands and the Solway area during the Miocene Epoch (King, 1976, 1977; Johnson, 1969, 1985a). The most important drainage diversions appear to have taken place in the Lune and Derbyshire Derwent catchments, where the exposure of Palaeozoic rocks provided structural conditions that allowed those favoured streams to extend their systems at the expense of those that had originated on the probable Chalk surfaces uplifted in early Tertiary times (Johnson, 1985a). This brief discussion on drainage changes allows the introduction of a consideration of the erosional history of the uplands in northern England.

EROSIONAL HISTORY

It has long been a central tenet of the geomorphology of the British uplands that they have experienced many phases of uplift and subsequent erosion and that as a result their geological structure has been truncated and planation surfaces formed. There is no doubt that this erosion took place, but how and when it took place, and indeed if such erosional landforms really can be recognized in the landscape at all, have been a matter of considerable speculation, dispute and discussion.

The problem has been reviewed comprehensively by King (1976), Straw and Clayton (1979), Belbin (1985) and Goudie (1990). The earliest phase of research was under the influence of Ramsay (1846) between 1846 and 1895, when marine planation was the vogue and an early planation surface was recognized on the moors of Crin Edge near Buxton (Plant, 1866), where an ancient marine beach at about 427 m was noted. Many flattened summits and spurs were interpreted as extensive marine planation surfaces at different heights, for example, the flattened summits visible from Helvellyn (De Rance, 1869a; Ward, 1870; Ramsay, 1872), and the accordant summits around 549 m in the Forest of Bowland (Tiddeman, 1872). The ages suggested for these marine terraces were variable. Whereas Plant's (1866) view was that they were post-glacial, Ward (1870) considered that the summits of the central Lake District were relics of a surface cut by the Carboniferous sea. Following Ward's Carboniferous incursion, younger marine transgressions were invoked to erode younger surfaces on younger rocks. For example, Goodchild (1889) suggested that Liassic and Upper Cretaceous Chalk seas had planed surfaces on the Carboniferous rocks of the outer Lake District and Pennines. Subaerial forces in Tertiary times were invoked to erode any subsequent sedimentary cover of Mesozoic or Tertiary age, to exhume and then to dissect the surface. By the end of the century a model of three ancient exhumed and dissected marine surfaces on the peaks of the Lake District and Pennines had been established.

In the later nineteenth century a subaerial origin was championed by Greenwood (1857), Jukes (1862) and Geikie (1865, 1868) and this origin was proposed for many areas in the Pennines and the Lake District. It did not develop to a widespread belief in subaerial planation until the influence of Davis (1895) held sway in the period 1895–1939. Reed (1901) interpreted the Pennine summits, from the Peak District to the Askrigg Block, as relics of one surface of early Tertiary, subaerial planation. This was because Davis (1895) had introduced to Britain a general model of landscape evolution that emphasized subaerial cycles of erosion. This model gradually resulted in a modification of the nineteenth century concepts by Davisian ideas in the papers of Marr (1906), Marr and Fearnsides (1909), Gibson *et al.* (1925) and Fearnsides (1932). In 1906 Marr still adhered to the idea of a pre-Tertiary age for any summit surface and suggested a subaerial, dissected, Devonian surface over the summits of the pre-Carboniferous, Lake District strata. This surface has been buried by Carboniferous strata, partly buried by deposits of Permian and Mesozoic age and then exhumed and dissected during Tertiary times. Marr and Fearnsides (1909) applied the same views to the Howgill Fells, where they recognized a subaerial, summit surface of Devonian age, which was exhumed from its marine cover of Palaeozoic, Mesozoic and Tertiary rocks and dissected during the Tertiary Sub-era. Gibson *et al.* (1925) and Fearnsides (1932) applied a similar logic to the Carboniferous Coal Measure summits and gritstone edges of the North Staffordshire uplands and Peak District, respectively. In this case they invoked a younger, but still pre-Tertiary period of subaerial erosion in the Permo-Triassic. Any later cover was removed and the surface dissected by subaerial processes in the Tertiary. Hudson (1933) re-emphasized the pure Davisian approach in the Pennines, where he suggested a subaerial surface formed in an early Tertiary cycle of erosion on the flattened summits of the Askrigg Block. Peaks such as Ingleborough were residuals above the peneplain. This surface had been tilted, initiating a second late Tertiary cycle, which had succeeded only in being dissected and differentially uplifted or warped. He also recognized on the lower summits a sub-Triassic subaerial surface near to extensive Triassic outcrops. Thus the late nineteenth century concept of the existence of exhumed pre-Tertiary surfaces in the landscape had not been brushed aside totally by the Davisian theory.

The work of Hollingworth (1935, 1938) in the Lake District reflected British geomorphologists' recognition of multilevel, polycyclical landscapes of marine and subaerial Tertiary planation surfaces. Hollingworth re-interpreted the topography of the western Lake District as a staircase sequence of marine and subaerial Tertiary erosion surfaces, all dissected to a greater or lesser extent. McConnell (1938), using projected profiles identified a staircase of seven surfaces in the southern Lake District from a summit level at 732–823 m, as on flattened spurs at High Street, to a 122–152 m level found as a prominent step in river valleys, such as at Troutbeck near Windermere. Miller (1938), using projected profiles, proposed a staircase sequence of three Tertiary marine surfaces preserved on the summits, spurs and valley benches of the Lancashire uplands and on hill summits above the Cheshire Plain at 244 m, 152 m and 61–76 m. So by this time there was a somewhat confused picture of supposed marine and subaerial Tertiary stepped sequences in the Lake District, Lancashire and Cheshire, and a mixture of ancient and Tertiary subaerial levels in the Pennines and Staffordshire Uplands. What was needed was a synthesis, which was provided by Linton using the denudational chronology model that had been constructed for south-east England (Wooldridge and Linton, 1939). Yet the approach represented by Hollingworth's work continued to be applied and Sweeting (1950) extended the approach into the Pennines by recognizing two surfaces in the Craven uplands at 457 m and 244–183 m, and Clayton (1953) extended it into the Peak District. He re-interpreted the summit surface at around 305 m on the limestone and gritstone north of the River Trent as a Tertiary subaerial surface and noted a stepped sequence at around 250 m, 168 m, 143 m and 98 m. The summit surface was suggested as late Tertiary and correlated with the mid-Pliocene summit surface of south-east England.

Wooldridge and Linton's (1939) work in producing a denudation chronology for south-east England had become tremendously influential, as their surfaces were correlated with some in northern England by many workers. Their surfaces included a chalk summit surface formed after the folding of the Weald in mid-Tertiary times (Wills, 1929); a sub-Eocene marine surface cut on the Chalk dip slopes exhumed from its Tertiary marine cover and a later Pliocene marine surface cut into the summit surface at 290 m. The result in northern England was a new model of planation levels, illustrated by the work of Gresswell (1953), who recognized four new surfaces in the Rossendale Anticline north of Manchester, at 396 m to 274 m at Anglezarke Moor, at 213 m to 152 m around Wheelton, at 76 m to 61 m around Skelmersdale, to the lowest at 31m to 8m at Scarisbrick. They were all regarded as marine, formed in stillstands as the sea fell to its present level. The highest was correlated with the Chalk summit surface, the second was the Pliocene–Early Pleistocene level and the later surfaces became Pleistocene in age. Yates (1956) extended the new approach into the Staffordshire Uplands, whilst Linton (1956) recognized three major surfaces in the South Pennines: an 'Upland Summit', between 480 and 600 m found only on the higher sandstone plateaux; the 'Upland Plain' was much less extensive, forming benches at lower levels, but on the limestone plateau it became the dominant element between 280 and 350 m OD; and the 'Upland Valley Surface', with suites of terraces and flats eroded during the Pleistocene Epoch. This model was based on the belief that subaerial processes would lower the landscape to one of low relief during prolonged stillstands and that uplift had occurred only intermittently during the Tertiary Sub-era. He also believed that the residual hills on the 'Summit Surface' marked the approximate position of a sub-Cretaceous unconformity that had once passed over most of upland Britain. This Chalk transgression marked the initial datum plane and its surface was thought still to be found on the highest summits, as in the Pennines, although it had largely been destroyed.

Parry (1960) extended this new conceptual framework to the Lake District, where he replaced the earlier step sequence with a staircase of ten surfaces from a 457 m level on Red Pike down to a largely drift-covered surface at 88 m. The 210 m surface found on valley benches he correlated with the Plio-Pleistocene marine level in south-east England and consequently the six lower surfaces, earlier regarded as Tertiary, now became Pleistocene in age. The three surfaces above he regarded as subaerial and tried to correlate them with south-east England.

The work of Moseley (1961), Sissons (1960a) and King (1969) all implied criticism of the existing school, a criticism that generally grew in the 1970s. From a detailed statistical analysis of slope data, Moseley (1961) produced an alternative to Tiddeman's (1872) model of a marine level at 549 m in the Forest of Bowland and he proposed a stepped sequence of three subaerial levels at 518–366 m, at 335–122 m and at 76 m, which he did not try and correlate with south-east England. At greater variance was Sissons' (1960a) planation model for the Pennines. He regarded the surfaces as Late Tertiary in age, but a combination of marine and subaerial in origin. A surface was cut by the sea during a particular stillstand but was then modified considerably by subaerial processes when it was exposed after the sea level fell to cut the next surface. Possibly the work most at variance was that of King (1969), who applied trend surface analysis to summit heights in the Pennines. The result suggested to her that there was one differentially uplifted summit surface rather than a stepped sequence as proposed by Linton. Attempts to consolidate ideas (for example, by Johnson, 1965b; King, 1976; Straw and Clayton, 1979) only fuelled more criticism of the approach. For example, Johnson (1965b) and King (1977) noted first the lack of evidence for these higher sea levels and also the general difficulties of altitudinal correlation of surfaces even in areas close to each other. The actual existence of surfaces on some summits was questioned, some of the flattened summits were suggested to result from the level inclination of the sedimentary strata and the lack of contemporary deposits made any interpretations of origin suspect. King also suggested that differential uplift over the Tertiary was an important factor that had not been considered by previous geomorphologists, who had emphasized the widespread changing base level. More fundamental than this, the idea of being able to correlate summits and flattened hillsides in a particular area to construct a planation surface was being questioned. For example, Smailes (1960) asked 'did any of these surfaces exist at all?'. Researchers were beginning to state the highly subjective nature of the multicyclic surface approach and the lack of hard evidence in putting so much erosion down to the late Tertiary and Early Pleistocene periods, when we had so little complementary stratigraphical evidence.

This means that we have to try and understand the current erosional history of the uplands in the light of certain fundamental concepts being discredited. For example, the marine origin of planation surfaces is doubted (King, 1963) and the previously accepted Davisian type of subaerial denudation is also now rejected (Belbin, 1985). However, Belbin (1985) summarizes persuasively the reasons why etchplanation might be one answer to understanding the erosion of the uplands in Tertiary times. The process takes place as the wash products of deeply decomposed rock weathered in a humid tropical or subtropical climate are removed to expose the weathering front as an etchplain. Another explanation might be that processes in a semi-arid climate, where erosion is at a maximum (Blatt *et al.*, 1972), would produce planation through the parallel retreat of hill-slopes by wash action, leaving low-angle rock slopes or pediments that then coalesce to form a large-scale erosion surface, or pediplain. A combination of both etchplanation and pediplanation has been suggested as possible in Britain (Thomas, 1978). In general the rejection of the threefold step-sequence model in the south-east of England (Hodgson *et al.*, 1967; Catt and Hodgson, 1976; Jones, 1981) also has thrown doubt on the step sequences of late Tertiary and Pleistocene surfaces in northern England.

Belbin (1985) suggests a new model where he emphasizes the need to recognize and use the basin–massif structure to establish the large-scale areal differentiation in northern England and the importance of post-orogenic plutons in maintaining this framework by isostatic uplift, as has been described already. There is also the need to recognize and date the initial surfaces in each of the subregions. The stratigraphical record suggests an initial Devonian age surface on the Lower Palaeozoic strata in the Lake District and the Howgill Fells and a Permian age for the initial surface on the Carboniferous strata of the Alston and Askrigg blocks, the Peak District, the north Lancashire uplands and the outer Lake District. There is the need to recognize the occurrence, location, age and structural control of the erosional and depositional events, including planation. The stratigraphical record would indicate the occurrence and age of these events, such as higher sea levels leading to major deposition on the initial surface, periods of etchplanation and pediplanation and what lithologies were being eroded, and consequently which subregions were being affected. The timing of these modifications would be ultimately related to major plate tectonic activity, such as the opening of the North Atlantic Ocean, early Tertiary hot-spot activity under western Britain and the repeated effects of the Alpine orogeny. Much information about these events may be gained from studies of the Mesozoic and Tertiary strata in southern and eastern England, although there is already some evidence for such modifications, especially etchplanation, from northern England. Corbel (1957) suggested the presence of humid tropical and subtropical karst landforms in the Furness area, and we have noted already the Brassington Formation in Derbyshire and similar deposits in north-east Wales and the Yorkshire Wolds. Arenaceous saprolite derived from the Millstone Grit, as in the Todmorden valley (Wright *et al.*, 1927) and from the Ennerdale granophyre in the Lake District (Ward, 1876), may be regarded as basal relics of such deeply weathered rock developed under tropical or subtropical conditions. The Millstone Grit and Dolomitic Limestone tors in the Pennines may be resistant sections of the weathering front exposed after the removal of this saprolite (see discussion of this later in the volume, and alternative explanations in the section 'The evolution of Tors', Chapter 7). However, it is clear that the key to understanding the erosional history of the uplands in northern England should rely more heavily on a combination of sedimentology and geomorphology of deposits rather than what is definitely now considered to be the controversial recognition of erosion surfaces from morphology alone.

CONCLUSION

This review of the pre-Pleistocene evolution of northern England poses as many questions as it answers and we are far from understanding the region's overall development during Tertiary times. There are only tantalizing clues as to its overall evolution and whereas some of the preceding discussion may well be helpful – such as the development of the Brassington Formation and similar deposits; the estimates of how much sediment has been eroded from the uplands; the likelihood of a Chalk cover; and the concepts of tropical deep weathering, etchplanation and pediplanation – other ideas that have been central bastions of the geomorphological development of the uplands, such as the development of marine and subaerial erosion stepped sequences – often based only on statistical manipulation of map data – have really proved to be far from useful in elaborating a sensible explanation of the pre-Pleistocene evolution. Of much greater influence are the broad-scale, plate-tectonic events in this time period, which controlled the overall development of the region, the underlying granite batholiths, and the differential movements along structural weaknesses. What is certain is that the upland and basin areas of northern England had achieved their current overall form by as early as mid-Tertiary times and that the effects of the major cold-climate processes of the Pleistocene Epoch have largely eroded any surviving evidence of warmer Tertiary events from the rock record in this region. This makes the unravelling of the pre-Pleistocene landscape an extremely difficult process.