

The Growth of Geological Knowledge in the Peak District

Trevor D. Ford

Abstract: The development of geological knowledge in the Peak District from the 18th century to the present day is reviewed. It is accompanied by a comprehensive bibliography.

Introduction

Geology has changed in the last two centuries from a largely amateur “gentleman’s” science to a professional vocation. The results of professional investigation in the Peak District have been built on the amateur foundation and the works cited in this review demonstrate the change in approach. The Geological Survey commenced a professional approach in the 1860-1880 period, continued during World War I and in the 1950s, but it was not until the 1970s that some intensive economic investigations were pursued. The Geological Survey’s activities in the 20th century were concurrent with the development of Geology Departments in the nearby Universities, where research grew slowly after World War I and more rapidly after World War II. However, there is still room for amateur investigation, as shown by the activities of such organizations as the East Midlands Geological Society.

As far as is known, the only previous attempts to survey the growth of geological knowledge in the Peak District were by Challinor (1949-1951), whose viewpoint was biased towards the western margins of the Peak District, and the present author, who gave an outline of research on the limestone massif in the introduction to his book on the Limestones and Caves of the Peak District (Ford, 1977). This review is an expanded version of a talk given at the Symposium held at the University of Derby on March 16th 1996, that date being the centenary of the first extra-mural classes in geology taught in Derby.

There are many published contributions to the geology of the Peak District which space precludes mentioning herein. Only those works representing significant advances are included. Readers are referred to Ford and Mason (1967) and Ford (1972) for comprehensive bibliographies up to those dates. Since then the pace of research has increased and a steady flow of publications has appeared since the above-mentioned bibliographies.

Historical perspective

The Pioneers. The principles of stratigraphy are often said to have been first formulated by William Smith in Somerset where there was an economic stimulus with a coalfield adjacent to lead mines in the limestones of the Mendip Hills, plus a sub-Triassic unconformity and overlapping Jurassic. Similar stimuli occurred elsewhere in other mining fields, particularly in the Peak District where the

lead miners made practical use of geological principles as early as the 17th century (Rieuwerts, 1984). In the 18th century the course of the initial part of Cromford Sough followed the strike of the limestone/shale contact where excavation was easier through shale. The position of the contact was obtained by down-dip projection from the outcrop showing that the soughers had some appreciation of concealed geology. The lead miners also used the basic principles of stratigraphy and structure to predict whether or not they would intersect toadstones in driving other soughs in the 18th century (Fig. 1).

Whilst most of the lead miners’ knowledge was never written down, some of it has been preserved in the appendix to “An Inquiry into The Original State and Formation of the Earth” by John Whitehurst (1713-1788) (see Craven, 1996). This appendix recorded the strata of limestone and interlayered toadstones on either side of the Derwent Gorge at Matlock by means of some of the first stratigraphical sections ever published (Whitehurst, 1778). The positions of some mines and mineral veins depicted on Whitehurst’s sections confirms that he acquired some of his knowledge about their disposition from the lead miners. However, he misunderstood the nature of the bouldery alluvium beneath the river bed and invoked a “gulf” full of boulders extending to an unknown depth (Fig. 2). Whitehurst realized that there was a syncline between Matlock and the Ashover inlier, but he found it difficult to show curvature of the strata on his sections and accommodated the axis with boulders filling another, downwards-expanding “gulf”.

A disciple of Whitehurst’s was White Watson (1760-1835). His geological tablets and Delineation books (1811; 1813) extended Whitehurst’s principle of a regular stratigraphical succession in the Matlock area throughout the Peak District and into the Derbyshire coalfield. He established a stratigraphical column of 36 units in Derbyshire, noting subtle differences in both lithology and palaeontology of limestones, shales and gritstones. White Watson’s inlaid marble tablets were at first diagrammatic representations of folded limestones and lavas, flanked by scarps of overlying shales and gritstones, but later he compiled detailed sections across much of the county, basing the first on drawings by Farey (Ford, 1960; 1995; Torrens, 1994). White Watson built up large fossil collections for sale, 500 at a time, and some of these form the basis of museum collections today. Watson and his colleague William Martin set out to produce an illustrated catalogue of Derbyshire fossils but it was eventually published by

Martin alone (Martin, 1810). Unfortunately Martin used a non-Linnean trinomial system of nomenclature so that his names were later declared invalid according to the Rules of Zoological Nomenclature, though some were adapted and are still used for some well-known species, e.g. "Conchylolithus Anomites Pugnus" is still known as *Pugnax pugnus*.

John Farey (1766-1826) inspired Watson's later more detailed sections. Farey was a polymath who published in various subjects, notably mathematics, music and geology (Ford and Torrens, 1989). He prepared long stratigraphical sections of various parts of Britain on rolls of paper: these unfortunately remained unpublished until discovered by Ford (1967). One such unpublished section lay across the Ashover anticline (Fig. 3). John Farey was a friend and disciple of William Smith and came to Derbyshire in 1807 to produce what was in effect the first district memoir (Farey, 1811). This catalogued the strata of Derbyshire in such a way that a simple stratigraphical map could have been produced, although his book contained only a simple outline geological map. Farey started work on a detailed geographical map of Derbyshire in the style of Smith's county maps but it was never completed and the manuscript has only recently been discovered by Hugh Torrens in a Californian library! Farey also drew a coloured, manuscript geological map of the Ashover inlier, recently published by Torrens (1994), which is comparable to modern maps. Perhaps more important is that Farey recognized the nature of faulting and his book contained fold-out sheets of explanations of different classes of fault. However, he overstated his arguments by assigning parts of the unconformable contact between limestones and Edale Shales to a Great Peak Fault. White Watson later corrected Farey in showing that the basset (outcrop) of the shale/limestone contact was without faults over much of its course (Watson, 1813).

These three pioneers, Whitehurst, Farey and White Watson, set geology on its feet in Derbyshire in much the same way as William Smith did around Bath, but they did not really get the credit they deserved as founders of the science of stratigraphy. Perhaps this was because three men were involved instead of one; perhaps the fact that they were not involved in canals as parts of a national transport system pushed them into the background. Even so, Farey was the first to publish William Smith's system of a stratigraphical succession and he helped Smith to extend his work over much of England.

All three pioneers also expressed ideas on the origins of toadstone, effectively supporting Hutton and Playfair in regarding toadstones as ancient volcanic rocks. Farey went so far as to suggest that it was satellite attraction which raised the Masson anticline at Matlock, but White Watson disagreed and argued that volcanic pressure from within the Earth was a much more likely cause of up-folding. Whitehurst and Farey published brief notes on the origin of mineral veins by lateral secretion. Watson also put forward ideas on the origin of the mineral veins from volcanic sources but only in unpublished lecture notes. White Watson was the first lecturer on geology in Derbyshire, delivering talks in Bakewell on a variety of geological topics for some 40 years until his death in 1835. A bound volume of printed sheets (effectively lecture notes) and sketches which he used as visual aids survives in Derby Reference Library.

Among the few other early geologists who may be considered alongside the pioneers is John Mawe (1766-1829) (Torrens, 1992). Mawe's book (1802) preceded both White Watson and Farey, but he was more concerned with mines and minerals. Even so, he provided an early stratigraphic account and section of the Castleton area. Profiles along several valleys showing the disposition and faulting of some of the toadstone outcrops were given in a little known private publication by Hopkins (1834).

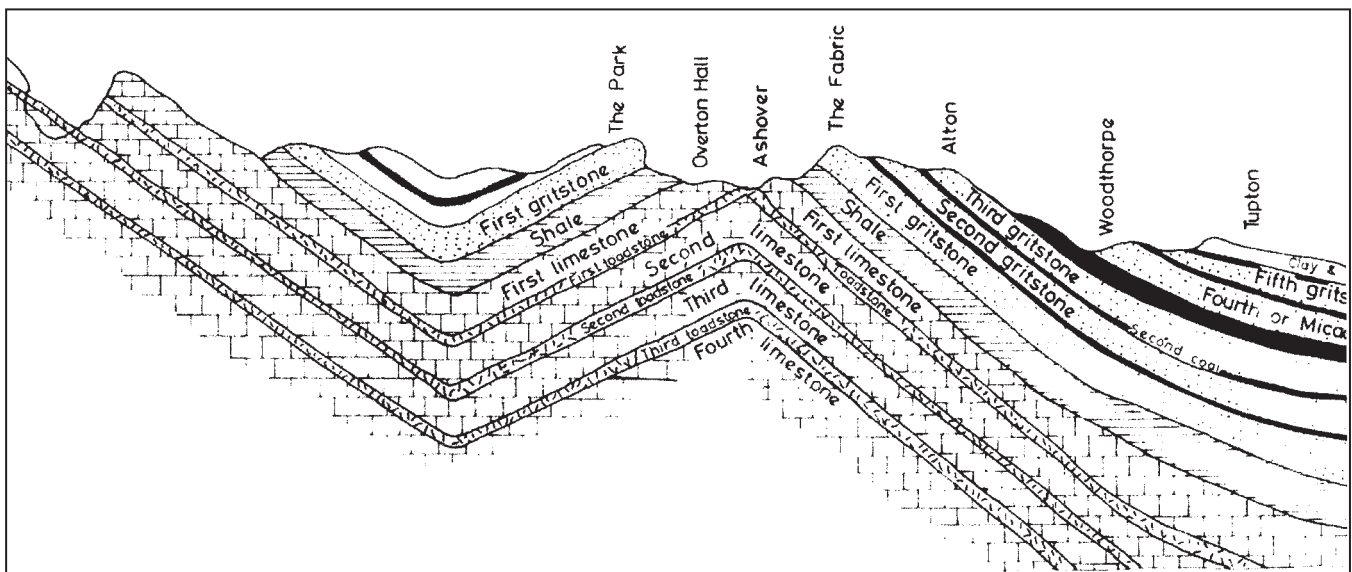


Fig. 3. A section of the strata from Matlock across the Ashover anticline from an unpublished diagram by John Farey (1808).

Mid to Late 19th century prehistory. Though White Watson mentioned the occurrence of bones of ancient animals in caves, e.g. an “elephant’s” skull in Ball Eye Cavern near Bonsall, it was not until the 1820s that the concept of antediluvian animals came to the fore through the work of Dean William Buckland at Oxford. One of his examples was the rhinoceros skeleton found by lead miners in the Dream Cave near Wirksworth (Buckland, 1823). Unfortunately the specimen has not survived so it is impossible to identify which species of rhinoceros was found there. Both Darwin’s “Origin of Species” in 1859 and the growth of prehistoric archaeology elsewhere had their spin-offs in the Peak District, where cave excavation reached a climax with the finding of Devensian faunas at Windy Knoll and other caves (Dawkins, 1874; 1875; Dawkins and Pennington, 1877; Pennington, 1874; 1875; 1877). Contemporary excavations at Creswell on the Derbyshire-Nottinghamshire border yielded both extinct mammals and human artefacts (Mello, 1876) and inspired a more intensive search in the Peak District, but it was not until the turn of the century that a “Pliocene” fauna was found in a fissure at Doveholes (Dawkins, 1903); it was later re-determined as Cromerian (Spencer and Melville, 1974). Some of the above writers and others speculated on the relationship of such deposits to early ideas of glaciation and denudation. The concept of denudation chronology, however, was slow to develop and little was published on the subject until the 1930s.

Mid 19th century Consolidation. The middle part of the 19th century was a period of consolidation rather than major advances in geological knowledge. There was much theoretical development of the subject elsewhere but the Peak District played little part in it.

Systematic knowledge of the fossils of the Peak District grew in the mid to late 19th century with the publication of several Palaeontographical Society monographs on brachiopods (Davidson, 1858-1863), corals (Milne-Edwards and Haime, 1852-1854), trilobites (Woodward, 1883), Foraminifera (Brady, 1876) and ostracods (Jones *et al.*, 1875). Numerous papers discussed less important groups of fossils. These and the early monographs have been superseded by later revisions but, to this day, there is no published, illustrated catalogue of the many Carboniferous fossils from the Peak District.

The growth of mineralogy as a science stimulated the catalogue of Greg and Lettsom (1858), which provided descriptions of some new minerals in Derbyshire, in particular matlockite and cromfordite (the latter now known as phosgenite).

Geological Survey officers commenced work in the Peak District in the mid-19th century and produced the early hachured 1 inch to 1 mile maps and memoirs (Green *et al.*, 1869). These collated geological knowledge, incorporating data from the lead mining industry. However, they failed to systematize Whitehurst, Watson’s and Farey’s

subdivisions of the limestone succession, and their maps coloured all the limestone outcrop in the same shade of blue, making no distinctions between the limestone formations that were to be named later.

Stokes’ (1879) review of the economic geology of Derbyshire provided a survey of a variety of mineral products with commercial potential, including lead and zinc ores, iron ore, fluorspar, baryte, calc-spar, chert, umber and coal. His later review of the then declining lead mining industry in 1880-83 included a map of the veins and a few geological observations.

20th century Geologists and Geological Institutions. Much of the early growth of geological knowledge in the Peak District can be put down to the work of amateurs or semi-professionals such as White Watson and Farey (1811). Professionals started to enter the area with early Geological Survey (Green *et al.*, 1869, 1887) and it was not until the early 20th century that academic geology was developed in the Universities of Sheffield and Manchester and later in Nottingham. Derby had to wait many years before an Earth Sciences Department was established in its College of Higher Education, recently established as the University of Derby. The small numbers of staff in the University Geology Departments before World War II meant that few had much opportunity for research either in the Peak District or anywhere else; post-graduate students were a rarity. Such research as was done was mostly concerned with practical geology in the coalfields either side of the Peak District. However, Fearnside (1933) gave an early structural analysis of the Peak District and its surroundings. His colleague in Sheffield University, Shirley (together with Horsfield) (1940, 1945) followed with detailed mapping of the Carboniferous Limestone. Of museum geologists, only Jackson (1925; 1926; 1927) made any significant addition to knowledge with his studies of Millstone Grit stratigraphy and palaeontology around Edale and Castleton.

While the general distribution of underground water resources was well known, it was not until 1929 that the data were collected in a Wells and Springs Memoir (Stephens, 1929). The geochemistry of these waters was later investigated by Downing (1967) and Edmunds (1971). The underground catchments were delineated by Christopher *et al.*, (in Ford, 1977) and the lead miners’ soughs catalogued by Rieuwerts (1987).

The search for oil resources during World War II was largely abortive but the oil seeps at Hardstoft maintained an interest in the Peak District (Falcon and Kent, 1960). Boreholes in Edale and Alport in 1938 and later at Gun Hill, Staffs (Hudson and Cotton, 1945), enabled detailed correlations and facies analyses but failed to yield hydrocarbon resources.

The Geological Survey started a re-survey of the Peak District in the late 1930s but it was put into abeyance during World War II and not continued until the 1950s. The set of maps and memoirs covering the whole Peak District was completed in the 1980s.

Re-investigation of mineral resources during World War II produced reports on fluorspar and baryte. Although an economic memoir on the lead mines and veins was started by C. A. U. Craven and J. V. Stephens of the Geological Survey in the 1950s, it was never completed and there is still no comprehensive overview comparable with the descriptive memoirs compiled for the North Pennines and Cornwall. Reviews of South Pennine baryte and fluorspar resources were compiled by Dunham and Dines (1945) and by Dunham (1952). Detailed studies of the limestone and dolomite resources were produced by the Geological Survey in the 1980s (see summary by Harrison and Adlam, (1985)).

Specific advances

Carboniferous Limestone. Whitehurst (1778) and Watson (1811) established a sequence of alternating limestones and toadstones, and Farey (1811) named these, in downward succession, the 1st Lime, 2nd Lime etc. Furthermore, Farey's simple outline map differentiated the 1st Lime as covering roughly the area of outcrop of Brigantian strata as known today. After these pioneer studies, little progress was made towards establishing a detailed stratigraphical succession within the limestones for another 50 years.

The early work of the Geological Survey (Green *et al.*, 1869, 1887) did not attempt to subdivide the Carboniferous Limestone. Soon after Vaughan's establishment of a zonal scheme based on corals and brachiopods in the Avon Gorge at Bristol, Sibly (1908) was able to show that most of the White Peak was composed of limestones belonging to Vaughan's uppermost zones (D₁ and D₂). This was restated in Fearnside's (1932) review.

In the pre-war run-up to the Geological Survey's remapping, Cope (1933, 1939) described and named the sequence in the most fully exposed section of the Wye Valley. Shirley and Horsfield (1940; 1945) followed with detailed stratigraphical

papers on the Castleton and Monyash-Wirksworth areas. Unfortunately, they misunderstood the relationships of massif and reef limestones around Castleton, regarding the latter as submarine scree banked against cliffs eroded into a massif of older limestones (Fig. 4). An alternative insight into facies relationships was provided by Hudson and Cotton's (1945) analyses and detailed stratigraphical sections derived from the deep boreholes in Edale, Alport and Gun Hill. The contrasts between massif, reef and basin facies were shown to have resulted from sedimentation on a block surrounded by deeper water. Soon afterwards, the rubber chemist and amateur geologist Parkinson (1947) reinterpreted the relationships at Castleton showing that the reef facies was contemporary with the massive facies, with a lateral passage between the two. Parkinson (1953) elaborated on the structure of the Castleton reef belt, providing palaeo-contours of the fore-reef slope. The palaeoecology of the specialized reef faunas reflected the facies changes both at Castleton and in the similar reef belt on the western margin of the limestone massif around Earl Sterndale (Wolfenden, 1958) (Fig. 5). The complex facies relationships in the Dovedale-Manifold Valley area were investigated by Parkinson (1950), and the adjoining Weaver Hills by Ludford (1951). Some revision became necessary as a result of joint studies in the intervening area (Parkinson and Ludford, 1964).

The "reef" facies, variously referred to as knoll-reefs, apron reefs and build-ups, are perhaps better called mud-mounds in view of their lack of an organic framework like modern coral reefs (Bridges and Chapman, 1988; Bridges *et al.*, 1995). Though the evidence is limited, it seems certain that the mud-mounds were built by microbial action (Gutteridge, 1995) particularly by algae and Cyanobacteria (Pickard, 1996). The shape of the mud-mounds was controlled by the depth of water at initiation and by the rate of subsidence. On ramps (sloping sea floors), contemporary mud-mounds could be wide and low in shallow water but narrow and highly domed at the margins of deeper water

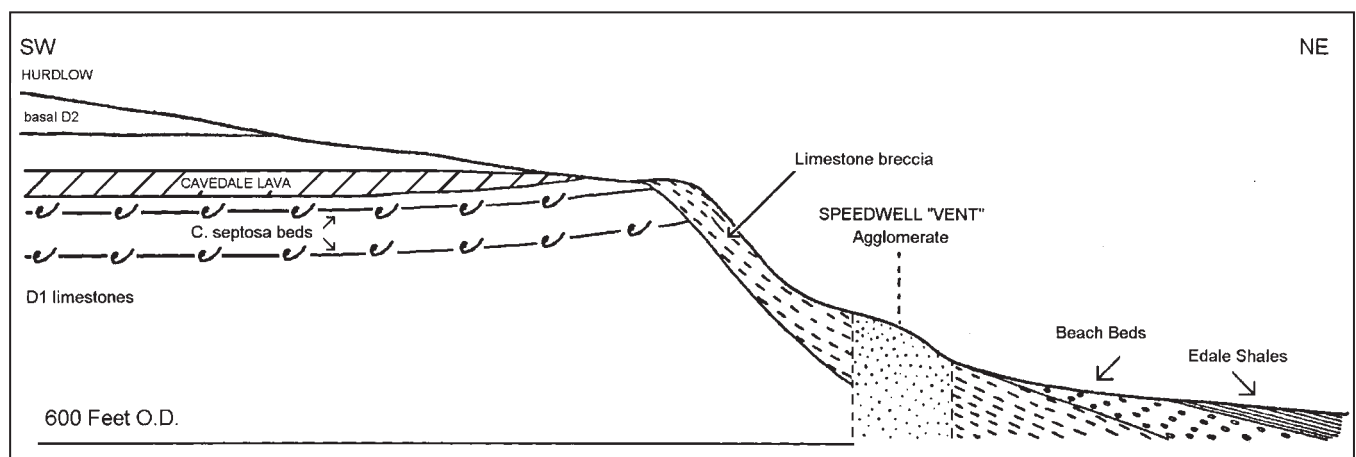


Fig. 4. Shirley's proposed relationship of the "reef" limestones lying unconformably against an eroded cliff of the massif limestones (modified after Shirley and Horsfield, (1940).

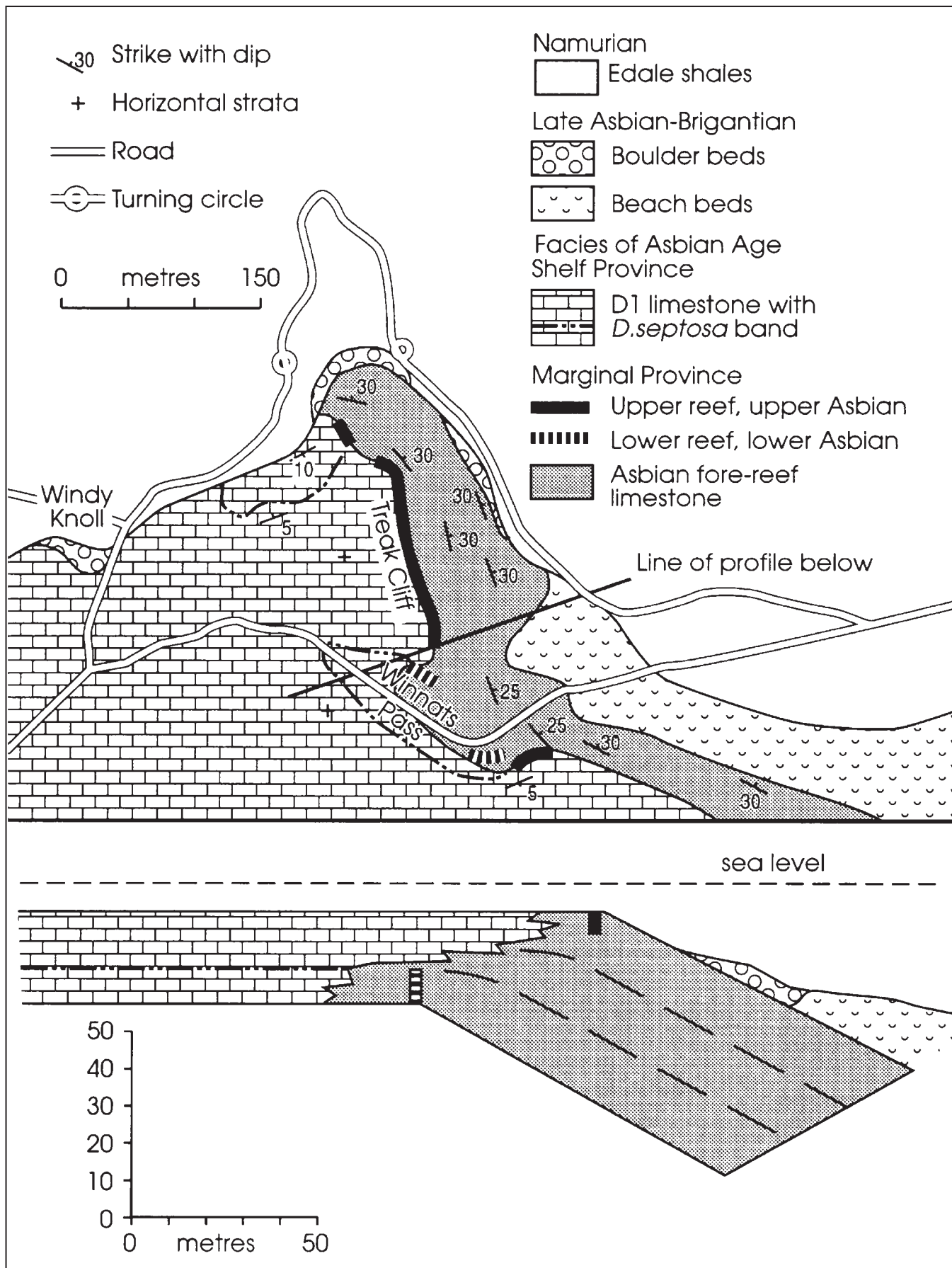


Fig. 5. Sketch map and section of the facies relationship of the reef and massif limestones at Castleton (modified after Wolfenden, 1958).

THE GROWTH OF GEOLOGICAL KNOWLEDGE IN THE PEAK DISTRICT

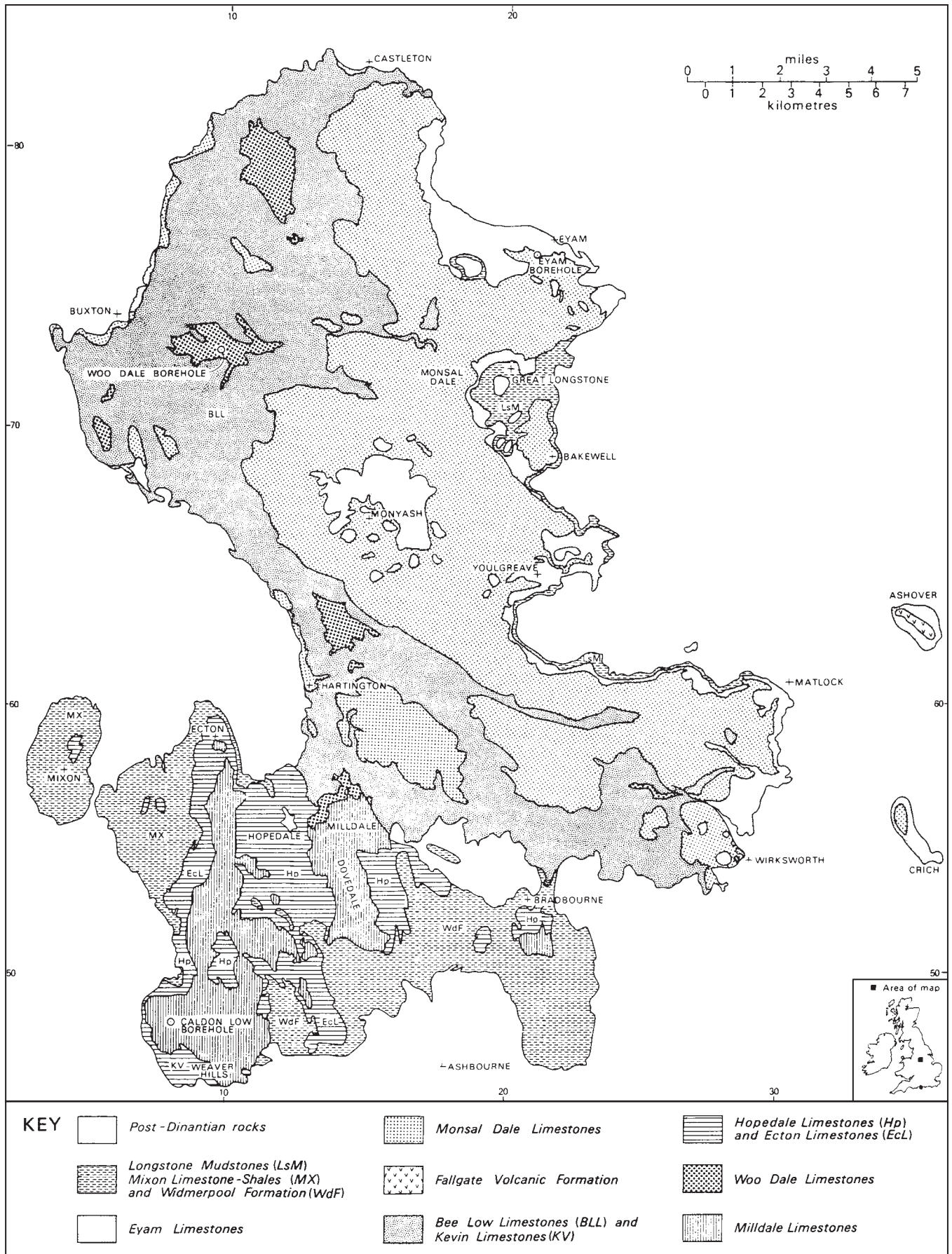


Fig. 6. Simplified map of the subdivisions of the Dinantian strata of the Peak District (reproduced from Aitkenhead and Chisholm, 1982, by permission of the Director of the British Geological Survey; © NERC).

basins (Gutteridge, 1995; Bridges *et al.*, 1995). Bioclastic limestones rich in crinoid debris both flanked the muds-mounds and accumulated on platform margins (Gawthorpe and Gutteridge, 1990). Some degree of water-depth control on the distribution of various species of brachiopods, molluscs and trilobites was deduced by the palaeobathymetric studies of Broadhurst and Simpson (1973).

The Woo Dale borehole extended knowledge of the concealed sequence beneath the lowest exposed beds (Cope, 1949; 1973). It penetrated 273m of largely dolomitic limestones resting on pre-Carboniferous volcanic rocks beneath the Wye Valley (Cope, 1949; 1973). The Woo Dale limestones themselves were shown to be partly dolomitized by Schofield and Adams (1985; 1986). The Eyam borehole, though starting at a higher horizon, penetrated over 1600m of limestones with anhydritic beds at the bottom before entering slates of probable Ordovician age (Dunham, 1973). This thick sequence demonstrated that transgression on to the Derbyshire massif started much earlier (Tournaisian?) than at Woo Dale, and that the basement surface was either sloping or faulted.

The higher (Brigantian) part of the sequence was investigated around the Hope cement quarry (Eden *et al.*, 1964) where the marginal complex is largely a series of mud-mounds and shoals of crinoidal calcarenite. Farther south, the Asbian-Brigantian sequence and accompanying lavas were mapped in Monsal Dale by Butcher and Ford (1973). A deeper-water facies with thin dark limestones, some of which are laminated with small slump structures, occurs in the mini-basin around Ashford-in-the-Water (Adams and Cossey, 1978). The flanking highs had contemporary mud-mounds near Monyash (Gutteridge, 1987; 1995). Microfacies in the Asbian marginal reefs and lagoonal limestones around Hartington were studied by Sadler (1966). The sequence in the main part of Dovedale, with its complex of "reef" limestones of two different ages, was described by Parkinson (1950). The marginal reefs in upper Dovedale were later shown to bear a close resemblance in both age and palaeontology to the marginal reefs of Castleton (Wolfenden, 1958). The sequence in the basinal facies of the Manifold Valley to the west, though much disturbed by both folding and faulting, was delineated by Prentice (1951). In the far southwest of the White Peak, the Weaver Hills stratigraphy was described by Ludford (1951). The earlier series of reefs in the Dovedale area were later shown to be relatively deep-water mud-mounds comparable to the Waulsortian facies of Belgium (Miller and Grayson, 1982; Bridges and Chapman, 1988; Bridges *et al.*, 1995). Across the Castleton-Bradwell margin of the massif, late Dinantian (Brigantian) sedimentation was shown to be an accumulation of migrating shoals of crinoidal calcarenite in contrast to the marginal "reef" complex in Asbian times (Gutteridge, 1989; 1990; 1995; Gawthorpe and Gutteridge, 1990).

Cyclic emergence of the carbonate-covered Derbyshire Block with the intermittent formation of palaeosols and palaeokarstic surfaces was deduced from sections along the Wye Valley (Walkden, 1974) and in the Wirksworth-Grangemill area (Oakman, 1984; Walkden *et al.*, 1981). At Crich, the cyclic nature of the Brigantian sequence was related to transgression-regression cycles (Bridges, 1982). The effect of this emergence on diagenesis, with resultant multiple generations of cementation, was subsequently discussed by Walkden and Williams (1991). Using cathodoluminescence to distinguish successive phases, the later phases of diagenesis have recently been related to mineralization and to hydrocarbon emplacement (Hollis and Walkden, 1996).

Dinantian sedimentation in the concealed Edale Basin was first investigated following drilling of the Edale borehole (Hudson and Cotton, 1945b). A more detailed interpretation was given by Gutteridge (1991), who also suggested that the adjacent limestone massif might be bounded by concealed basement faults.

Dolomitization is widespread in the upper limestones of the southern Peak District (Parsons, 1922). Although commonly attributed to the sub-surface effects of a Permian transgression, it is usually regarded as an early phase of mineralization (see later section on mineralization).

Silica is common in some limestone formations in the form of chert nodules, authigenic quartz, silicified fossils or as quartz rock. On the other hand, some limestones, particularly mud-mounds, are almost devoid of silica. Whilst some of the distribution in Brigantian beds has been ascribed to mobilization of silica from altered volcanics (Orme, 1974) no full study is yet available. Massive cherts in the highest beds around Bakewell were once mined for use in the Potteries (Bowering and Flindall, 1998).

Palaeontology has been incidental to most of the stratigraphical and sedimentological studies. Lists of fossils were given in many publications but there were few illustrations and no guide to identification. Parkinson (1954), however, laid some of the foundations of statistical palaeontology with studies of brachiopod populations and community growth patterns based on collections from the fore-reef limestones of Treak Cliff, Castleton. Facies control of faunal distribution around Castleton and upper Dovedale was noted by Wolfenden (1958) and in the Brigantian mud-mounds near Monyash by Gutteridge (1990; 1995 and Bridges *et al.*, 1995). Tilsley (1988) noted that, at Castleton, trilobite remains seemed to be concentrated at intermediate depths on fore-reef slopes. The Eyam borehole enabled Strank (1985) to describe the Tournaisian to Brigantian evolution of foraminifera and other faunas.

The Geological Survey returned to the Peak District during the 1950-1970 period, as a result of which maps at 1:50,000, 1:25,000 and 1:10,000

(or 10,560) scales are now available. Descriptive memoirs also cover the whole Peak District (Smith *et al.*, 1967; Stevenson and Gaunt, 1971; Aitkenhead *et al.*, 1985; Chisholm *et al.*, 1988). Nomenclature was standardized and a summary map produced by Aitkenhead and Chisholm (1982) (Fig. 6). The series of formational names produced

in different parts of the Peak District was also systematized by Aitkenhead and Chisholm (1982) (Fig. 7), although some revision became necessary owing to the later recognition of subtle facies changes around Matlock (Chisholm *et al.*, 1983). Although not usually listed among the main authors, the Geological Survey's biostratigraphers, notably

DINANTIAN STAGES	REGIONAL FORMATION NAMES	LOCAL AND EARLIER CLASSIFICATIONS					
		Wye valley <i>(Cope 1933, 1937 & 1958)</i>	Matlock area <i>(Smith and others 1967)</i>	Wirksworth area <i>(Frost and Smart 1979)</i>	Monyash and Wirksworth <i>(Shirley 1953)</i>	North-east of Hartington <i>(Sadler and Wyatt 1966)</i>	Wolfscoate Dale & Alsop Moor <i>(Parkinson 1950)</i>
BRIGANTIAN	LONGSTONE MUDSTONES		Cawdor Group	Cawdor Shale		Wolfscoate Dale & Alsop Moor Limestone	
	EYAM LIMESTONES	Ashford Beds		Cawdor Limestone	Cawdor Limestones		
	MONSAL DALE LIMESTONES	Monsal Dale Beds	Matlock Group	Matlock Limestone	Lathkill Limestone		
		Priestcliffe Beds					
Upper Lava Station Quarry Beds							
ASBIAN	BEE LOW LIMESTONES	Miller's Dale Beds	Hoptonwood Group	Hoptonwood Limestone	Via Gellia Limestone	Upper Limestones	
		Lower Lava					
		Chee Tor Rock					
HOLKERIAN	WOO DALE LIMESTONES	Daviesiella Beds	Griffe Grange Bed			Lean Low Beds	
						Hard Dale Beds	
						Vincent House Beds	

DINANTIAN STAGES	REGIONAL FORMATION NAMES		LOCAL AND EARLIER CLASSIFICATIONS			
	<i>(Aitkenhead & Chisholm, 1982)</i>		Mixon & Manifold Valley <i>(Hudson in Hudson and Cotton 1945a)</i>	Manifold Valley <i>(Prentice 1951)</i>	Dovedale & Swinscoe <i>(Modified from Parkinson 1950 and Parkinson and Ludford 1964)</i>	Weaver Hills <i>(Ludford 1951)</i>
BRIGANTIAN	MIXON LIMESTONE - SHALES and WIDMERPOOL FORMATION	KEVIN LIMESTONES	Mixon Limestone - Shales	Posidonomya Beds	Hollington End Beds	Waterhouses Limestone
ASBIAN			ECTON LIMESTONES and HOPEDALE LIMESTONES	MIXON LIMESTONES and Ecton Limestones	Brownlow Mudstones	
HOLKERIAN	MILLDALE LIMESTONES	MILLDALE LIMESTONES			Manifold Limestones with Shales	Manifold Limestone-with-Shales
ARUNDIAN			Calton Limestones	Massive Series	Milldale Limestone	Manifold Limestone-with-Shales
CHADIAN						Cementstone Series
COURCEYAN			RUE HILL DOLOMITES	REDHOUSE SANDSTONES <i>(Carboniferous or Devonian)</i>		

Fig. 7. Stratigraphic tables of Dinantian subdivisions in the Peak District: a. Central, northern and eastern Peak District; b. southwestern Peak District (Stage boundaries are uncertain in the southwest) (reproduced with modifications from Aitkenhead and Chisholm, (1982), by permission of the Director of the British Geological Survey; © NERC).

M. Mitchell, W. H. C. Ramsbottom, N. J. Riley, and A. R. E. Strank identified thousands of fossils listed in the Memoirs and contributed much to understanding of the stratigraphical and structural relationships. The Survey also published 1:25,000 scale maps of educationally important areas (Edale and Castleton, Millers Dale, Matlock and Wirksworth) with concise descriptions in their margins. Almost the whole White Peak area was covered at the latter scale in maps accompanying the limestone resources assessment reports noted below.

As part of the general systematization of chronostratigraphy and nomenclature in the Lower Carboniferous (Avonian, later Dinantian), a series of stages were defined in accordance with the rules of stratigraphic nomenclature (George, 1972; George *et al.*, 1976). Based on fossil assemblages from type-sections in various parts of Britain, the stages seemed to correlate with transgression-regression cycles identified by Ramsbottom (1973). The stages Courceyan, Chadian, Arundian, Holkerian, Asbian and Brigantian (Fig. 7) replaced the old coral-brachiopod zones, K, Z, C, S and D, which could only be applied to the shallow water shelf facies. The first of these stages (Courceyan) appears to have little or no representation in the Peak District, though some of the Rue Hill Sandstones at the bottom of the Cauldon Low borehole in the Weaver Hills (Chisholm *et al.*, 1988) may be of this age or possibly even late Devonian.

Substantial surface and subsurface lithological detail was provided by the surveys of limestone and dolomite resources carried out by the Institute of Geological Sciences for the Department of the Environment by Cox and Bridge (1977), Cox and Harrison (1980), Harrison (1981), Bridge and Gozzard (1981), Gatliff (1982) and Bridge and Kneebone (1983). Many shallow boreholes yielded both lithological and stratigraphical detail for almost the whole limestone outcrop. The results were summarized by Harrison and Adlam (1985).

The Toadstones. The assemblage of basalt lavas, tuffs and ashes commonly known as toadstones intrigued early geologists in view of the late 18th century controversy between Werner, who thought that all ancient basalts were precipitates from a primaeval sea, and Hutton, who correctly regarded them as volcanic outpourings. As noted above, Whitehurst, Watson and Farey were adherents of the Huttonian theory. They thought that there were two principal horizons of toadstone in most of the Peak District, but Hopkins (1834) argued that there might be three toadstones in some locations but only one in others (Fig. 8). Later, as many as seven toadstone horizons were identified in Mill Close Mine at Darley Dale (Traill, 1939; Shirley, 1949).

The end of the 19th century and early 20th saw a major advance in knowledge with the publication of Allport's (1874) and Bemrose's (later Arnold Bemrose) works on the petrography of the lavas and ashes (Bemrose, 1894). Bemrose later mapped the

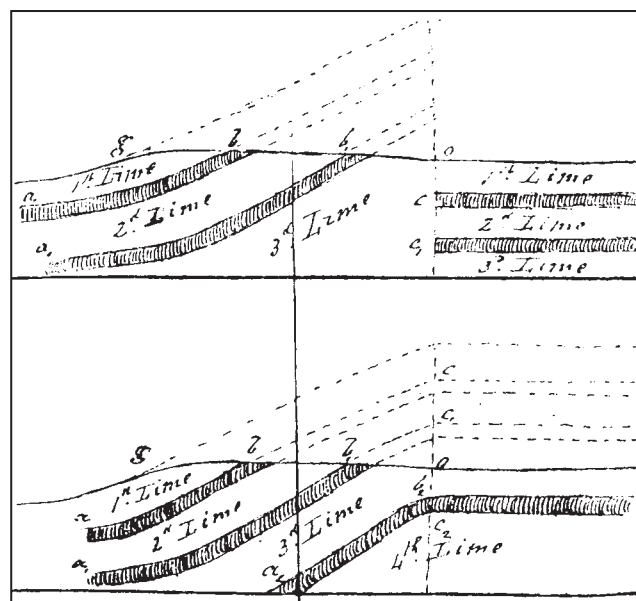


Fig. 8. Alternative sections with of two or three toadstones, near Aldwark (from Hopkins, 1834).

distribution of toadstones throughout the White Peak (1907). His mapping demonstrated the presence of several main lava flows as well as sheets of tuff and patches of vent agglomerate. A few sills were also recognised. Although there are two main lavas in both the Castleton-Millers Dale and the Matlock areas, they lie at different horizons and later work showed that a simple correlation of the lavas in those areas was misleading. Bemrose's studies could have provided the basis for a detailed stratigraphical map of the White Peak's limestones, but he was content with mapping the toadstones and giving a general review of the area (Bemrose, 1910a). Wilcockson (in Fearnside, 1932) and later Macdonald *et al.* (1984) added petrographical detail showing that the basalts ranged in composition from olivine-rich alkaline basalts to olivine-poor tholeiites. Detailed studies of the lavas in the Matlock area arising from the limestone resources investigations noted above led to the Lower Matlock Lava being recognized as multiple lava flows, intercalated with thick tuffs (Chisholm *et al.*, 1983). Webb and Brown (1989) provided both a new map of the toadstone outcrops (Fig. 9) and a digest of geochemical data.

Interbedded with the limestones both above and below the main lavas are thin greenish clay layers known as wayboards. Their origin as volcanic ash falls, sometimes accompanied by soil-forming processes, was described by Walkden (1972), who found that some ash falls were sufficient to result in temporary emergence above sea level.

The basalts of Calton Hill, near Taddington, were found to include the unusual feature of olivine nodules (Bemrose, 1910b). The opening of a quarry there in the 1920s, in what appeared to be a volcanic neck, stimulated research into these basalts, particularly by the Russian emigré Tomkeieff (1928). The basalts included massive, columnar and vesicular varieties, and there was secondary

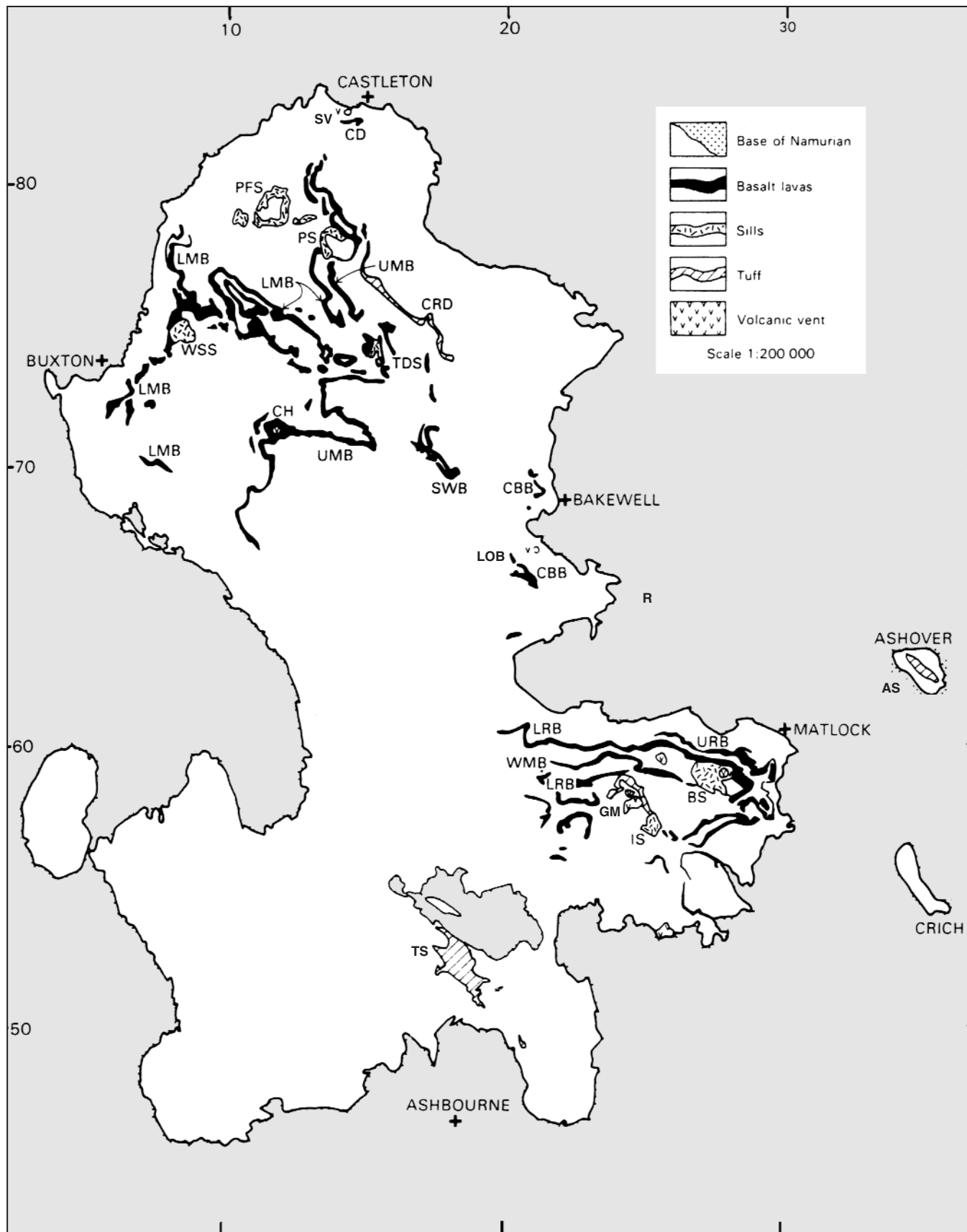


Fig. 9. Distribution of Carboniferous lavas, vents and sills. LAVAS: UMB, Upper Millers Dale; LMB, Lower Millers Dale; CD, Cave Dale; CRD, Cressbrook Dale; SWB, Shacklow Wood; CBB, Conksbury Bridge; LOB, Lathkill Lodge; LRB, Lower Matlock; WMB, Winster Moor; URB, Upper Matlock; R, Rowsley Boreholes. VENTS: SV, Speedwell; CH, Calton Hill; GM, Grangemill. SILLS: PFS, Peak Forest; PS, Potluck; WSS, Waterswallows; TDS, Tideswell; BS, Bonsall; IS, Ible; TUFFS: TS, Tissington; AS, Ashover (reproduced from Webb and Brown, 1989, by permission of the Director of the British Geological Survey; © NERC).

mineralization with many quartz veins containing hematite inclusions. A pattern of boreholes sunk by the quarry company to prove resources showed that the whole pile had a saucer-shaped base; no feeder pipe was detected. Olivine nodules within the massive basalt were shown by Hamad (1963) to contain a small proportion of pyroxenes. It is still debatable whether the nodules represent concentrations of ferro-magnesian minerals brought up from deep in the magma chamber or whether they might have been derived from the Earth's mantle. The former seems to be the favoured hypothesis at present.

A borehole beneath the cement works at Hope revealed an unexpected pile of mostly pillow lavas (Fearnside and Templeman, 1932). These appear to be marginal to a tuff mound later found beneath the adjacent quarry (Eden *et al.*, 1964; Stevenson and Gaunt, 1971).

In 1933 Cope described tholeiite dykes in Great Rocks Dale. In 1997 he proposed that these might represent feeders for the lavas. Elsewhere the lavas were thought to emanate from scattered vents, though demonstrating the physical connection has not generally been possible.

As noted in the Carboniferous Limestone section above, the officers of the Geological Survey re-surveyed the Peak District after World War II, thereby providing the first detailed maps of toadstone outcrops since Bemrose (1907). During this resurvey, boreholes near Ashover demonstrated a thick volcanic pile beneath that anticline (Ramsbottom *et al.*, 1962). Later, Walters and Ineson (1981) provided a detailed analysis of the volcanic history.

Millstone Grit. At the base of the Millstone Grit succession, the thick marine Edale Shales were at first correlated with the Yoredale Beds of the North Pennines until palaeontological work showed that this was partially incorrect and that the lower Yoredales were of Dinantian age. The basal contact of the shales with the limestone, regarded as due to a fault complex by Farey (1811) and the early Geological Survey (Green *et al.*, 1869; 1887), was shown to be at least partly a buried-landscape type of unconformity by Jackson (1925) and Hudson (1931); they demonstrated that the shales were banked against eroded fore-reef beds largely of Asbian age. A massive boulder bed at the shale/limestone contact around Treak Cliff, Castleton, indicated that perhaps 100m thickness of Brigantian limestones had been removed in latest Brigantian to earliest Namurian times (Simpson and Broadhurst, 1969). Their implication was that uplift of comparable magnitude had taken place and that the limestone had been eroded subaerially.

The thick sequences of alternating shale and coarse sandstone (gritstone) noted by Watson (1811) and Farey (1811) forms the Millstone Grit frame around the White Peak, culminating in the plateau of Kinderscout in the north — the so-called Dark Peak. Farey's unpublished section of 1808

numbered Grit horizons in upward order (Fig. 3). The beds were mapped by early officers of the Geological Survey (Green *et al.*, 1869; 1887) who laid the foundations of the sandstone nomenclature used today, namely Shale Grit, Kinderscout Grit, Chatsworth Grit, Ashover Grit and Rough Rock. However, the equivalent beds in northeast Staffordshire were unfortunately referred to as First Grit, Second Grit, etc., leading to mis-correlation (Fig. 3) until it was sorted out by the palaeontological work of Hind (1897, 1898), Jackson (1926, 1927) and particularly Bisat (1924). Bisat notably established the Namurian age of the Millstone Grit by goniatite correlation with the Belgian sequence. A series of mainly proto-quartzitic sandstones in the lower part of the Millstone Grit was later named the Minn Beds in north Staffordshire (Holdsworth, 1963; Ramsbottom *et al.*, 1978).

In post World War II times the details of the Namurian strata have been mapped and described in Geological Survey Memoirs (Eden *et al.*, 1957; Smith *et al.*, 1967; Stevenson and Gaunt, 1971; Aitkenhead *et al.*, 1985; Chisholm *et al.*, 1988). The mapping stimulated sedimentological studies by contemporary academics, notably Allen (1960), Holdsworth (1963) and Collinson (1968; 1969). Bisat's (1924) notation of goniatite zones E₁, E₂, H, R₁, R₂, and G was replaced by a sequence of stages named after type areas; Pendleian, Arnsbergian, Chokerian, Alportian, Kinderscoutian, Yeadonian and Marsdenian. The relationship of local successions to these stages was discussed by Ramsbottom *et al.* (1978) (Fig. 10). These chronological stages were regarded as almost synchronous with a series of transgression/regression cycles referred to as mesothems (Ramsbottom, 1977). Eleven mesothems were recognized, but the concept was later regarded as too simplistic by Holdsworth and Collinson (1988). Applying the hypothesis of sequence stratigraphy, Read (1991) referred the lower parts of each sandstone/shale cycle to a low-stand system tract, whilst the massive sandstones represented high-stand system tracts and the whole package was explained as due to glacial-eustatic sea-level oscillations. The concept of sequence stratigraphy now proposes that the simple early idea of repeated rises of sea-level should be replaced by one involving both rises and falls.

The sedimentology of the Millstone Grit was outlined as early as 1859 by Sorby, and enlarged upon much later by Gilligan (1919), who explained the Millstone Grit as the deposit of a massive delta, building out southwestwards into the Pennine Basin. The coarse sandstones of the north and east flanks of the Peak District exhibit current-bedding that indicates derivation from the north and northeast. Preceded by the deep-water Edale Shales, the deltas did not build out into the Peak District until Kinderscoutian times. Remnants of the Edale Shales on top of the limestone massif show condensed sequences which contrast with the thick

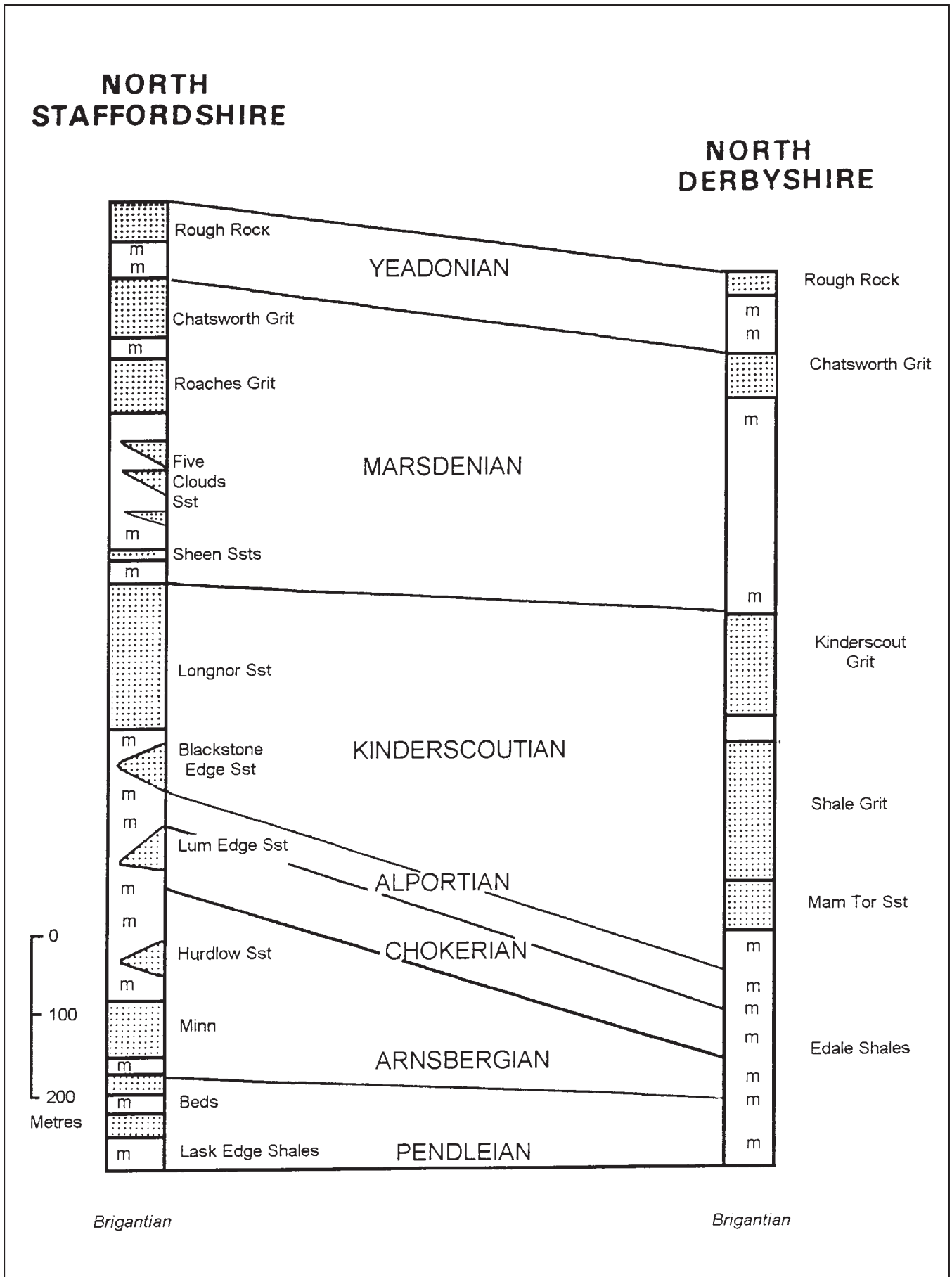


Fig. 10. Namurian correlation between North Staffordshire and North Derbyshire (after Ramsbottom *et al.*, 1978).

mudstones of the Edale and North Staffordshire 'Gulfs'. The deltaic sandstones have a variable content of feldspar and mica indicating a source in metamorphic rocks like those of the Scottish Highlands.

By contrast the earliest sandstones, the Minn Beds of the Staffordshire Gulf, were proto-quartzitic turbidites of Pendleian to Kinderscoutian age. They were deficient in feldspar and mica and were derived from a southerly source, the Midlands land-mass (Trewin and Holdsworth, 1973). From Kinderscoutian times onwards, deltas with coarse feldspathic sandstones derived from the north also built out into the Staffordshire Gulf.

The sedimentological studies of Allen (1960), Walker (1966), Collinson (1968, 1969), Morris (1969), Trewin and Holdsworth (1973), Chisholm (1977), Jones (1980), Jones and Chisholm (1997) and Hampson (1997) have distinguished such features as delta-top aggradation, prograding slope sheets, overbank splays, channel-fills, proximal turbidite fans, distal aprons, offshore muds and growth faults (Fig. 11). Most importantly, a change of view has emerged from simple stacking of deltas one on top of the other to a concept of laterally prograding fluvio-deltaic systems. For example, Jones (1980) showed that the Ashover Grit was fed into the South Pennine basin from a southeast direction, by-passing the thick pile of Kinderscout and Chatsworth Grits and reaching far enough westwards to form the Roaches Grit. Recent studies have shown that the Ashover Grit and its correlative Roaches Grit in Staffordshire filled a palaeo-valley up to 80m deep cut across the southern margins of the preceding Kinderscout delta complex (Jones and Chisholm, 1997).

The Tertiary Silica Sand Pocket Deposits.

Worked for refractory brick manufacture to a limited extent in the late 18th century, and also tested unsuccessfully for china clay, the silica sand pockets did not attract much attention from geologists until Brown's (1867) and Maw's (1867) descriptions. Their economic importance was investigated by Howe (1897; 1918; 1920) but the deposits in the sixty or so pits (Fig. 12) were not described in any detail until Yorke's private publications (1954-61). Long regarded as Triassic outliers (Kent, 1957), the late Cenozoic age of the Pocket Deposits was not established until much later when Walsh *et al.* (1972) formally named the sands and clays as the Brassington Formation. They showed that there was once a continuous sheet at least 45m thick over much of the southern part of the Peak District, composed of three members:

3. Kenslow Member: grey clays with fossil plants;
2. Bees Nest Member: coloured clays;
1. Kirkham Member: white and yellow sands with pebble bands.

In spite of the former extent of the Brassington Formation, these three members are now preserved only as a result of sagging into subsidence collapse "pockets" (Fig. 13), but a continuous sheet of these fluvial sediments is thought to have once formed a braided river plain across much of the southern Peak District (Walsh *et al.*, (1972).

The fossil plants in the Kenslow Member were listed by Boulter (1971), who deduced a late Miocene to early Pliocene age. Quartzite pebbles in the sands were deduced to have been derived from the Triassic Sherwood Sandstones which now occur as a low, north-facing escarpment around Hulland Water, some 8km south of Brassington. The

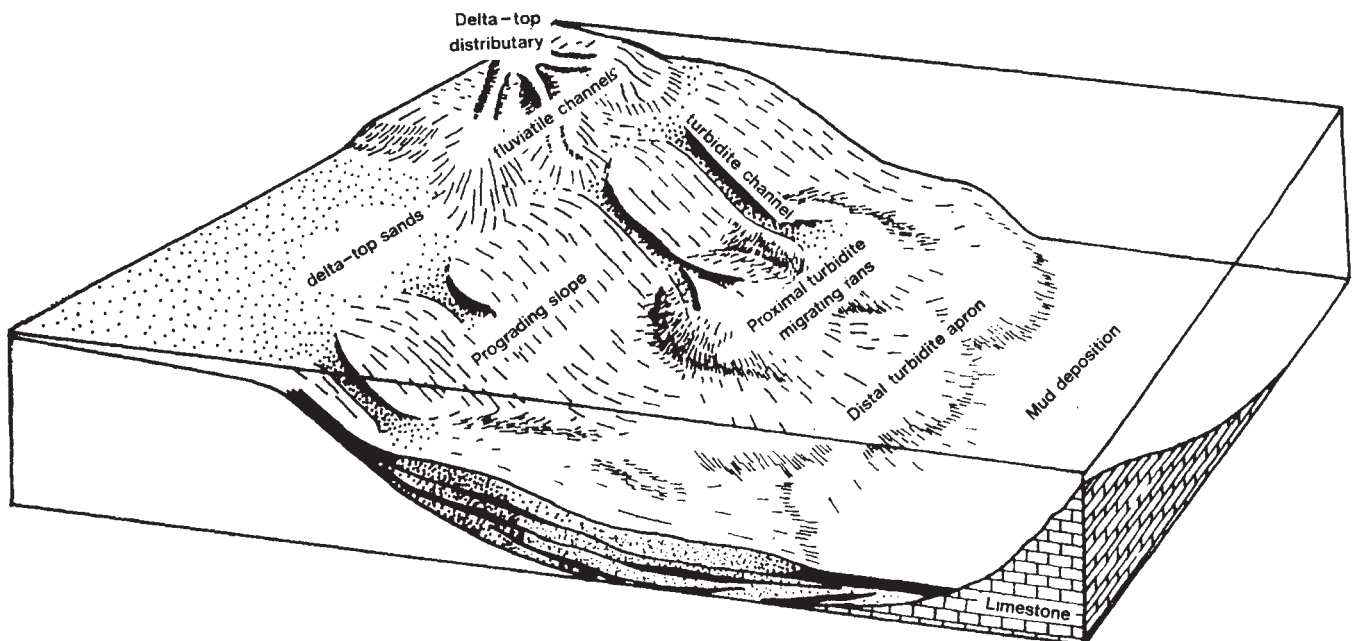


Fig. 11. Block diagram of the different facies of Millstone Grit deltaic sediments in the Peak District (modified after Collinson, 1968).

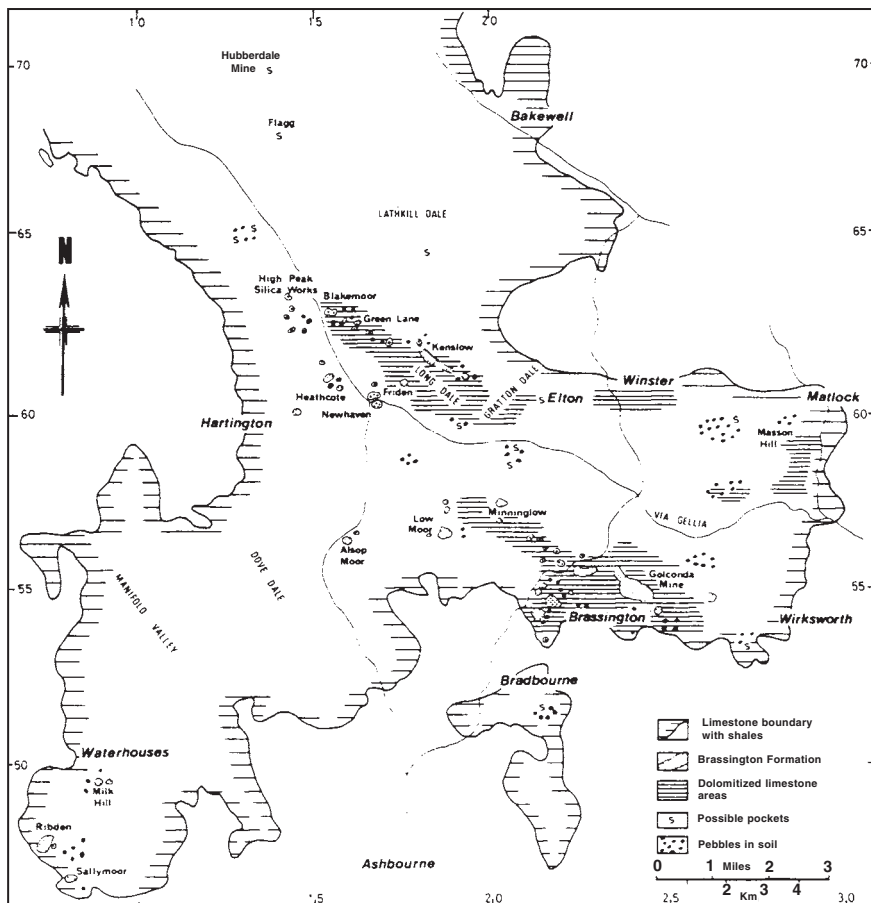


Fig. 12. Sketch-map to show the distribution of the Neogene Brassington Formation in the Peak District (from Ford, 1977).

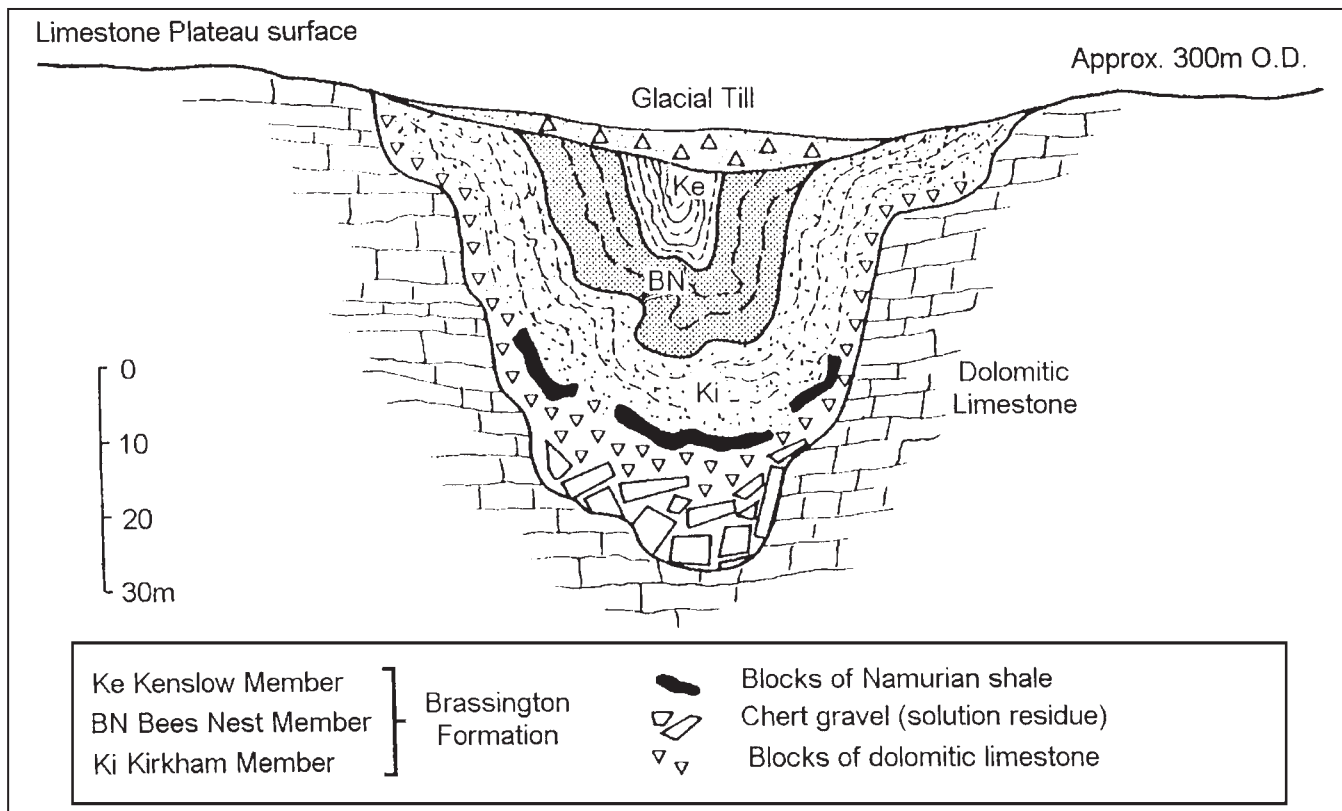


Fig. 13. Diagrammatic section through a typical pocket deposit (modified after Dalton *et al.*, 1988, with permission from the Geographical Association).

escarpment appears to have retreated from a former extent covering the southern part of the limestone massif. The fact that the escarpment is now at a lower altitude than the silica sand pockets suggests that there has been differential uplift of the limestone plateau since the early Pliocene (Walsh *et al.* 1972).

The Quaternary. Often regarded by 19th century geologists as “the muck” on top of the real geology, Quaternary deposits are thin and patchy over most of the Peak District and have received comparatively little attention.

Passing remarks concerning Pleistocene mammal remains in caves were made by White Watson (1811), who recorded an elephant skull alleged to have been found in Ball Eye cave near Bonsall. A rhinoceros skeleton was found in the Dream Cave near Wirksworth (Buckland, 1823). It was not until the 1870s that systematic digging started (Dawkins and Pennington, 1877). A Pliocene fauna found at Doveholes (Dawkins, 1903) was later re-determined as probably Cromerian in age, perhaps one million years younger (Spencer and Melville, 1974). From the 1930s onwards, Elderbush Cave and other caves in the Manifold Valley and Dovedale area yielded important, later Pleistocene sequences and faunas (Bramwell, in Ford, 1977).

The early Geological Survey (Green *et al.*, 1869; 1887) commented on the patchy representation of glacial drift in the Peak District, and little further advance was made until Jowett and Charlesworth (1929) analysed the directions of ice streams across the White Peak and found little evidence of more than a single glaciation. However, an analysis of river terraces along the Derwent valley by Waters and Johnson (1958) showed that there were ‘high’ and ‘low’ level deposits which could be related to “Older” and “Newer” Drifts, suggesting at least two episodes of glaciation. Further discussion on the relationship of tills, terraces and drainage diversion and their implications for glacial chronology, was put forward by Straw and Lewis (1962) and by Straw (1968). Drainage patterns and terraces in the Buxton — Chapel-en-le-Frith area were also inferred to support two glacial episodes (Johnson and Rice, 1961; Johnson, 1967; Burek, 1977) (Fig. 14). Burek (1991) has more recently shown that two distinct tills can be distinguished by their clay mineralogy.

Widespread yellowish silty clays on the limestone plateau were interpreted as bioturbated loess by Pigott (1962). Representing wind-blown detritus from the surrounding Millstone Grit areas, they are probably largely Devensian in age, though there may be earlier deposits of unproven age. Material apparently derived from these is intermixed with outwash sands in cave sediments (Noel *et al.*, 1984; Ford, 1986).

A starting point for a chronological sequence of Pleistocene events was provided by the recognition of the Mio-Pliocene age of the Brassington Formation (Walsh *et al.*, 1972). Noting the work of

Beck (in Ford, 1977), Burek (1977) was able to build up a tentative history of Pleistocene events as they relate to cave formation. The chronology was developed further by Ford’s (1986, 1996) analysis of the evolution of the Castleton cave systems, based partly on morphology and partly on uranium disequilibrium dates on stalagmites (Ford *et al.*, 1983). The caves’ relationship to the evolution of such landforms as the Winnats Pass has also been discussed by Ford (1987).

Cave sediments around Matlock have yielded palaeomagnetic evidence of a pre-Anglian glaciation at around 780,000 years BP (Noel *et al.*, 1984). The glacial/interglacial history is critical in the analysis of the evolution of the Derwent Gorge at Matlock (Ford, 1997) and further dating and research are needed. Similar glacial-related sediments in ancient caves intersected by quarrying at Eldon Hill, near Castleton, still await a full description.

The problem concerning whether the high level drifts represent a different glaciation (Anglian?) from the low level drifts on terraces (Wolstonian?) highlights the deficiencies in knowledge. The high level drifts, at least in the southern part of the limestone area, contain a high proportion of material derived from the Trias via the Brassington Formation, whilst the low level till has a high proportion of Carboniferous material with rare Lake District erratics. In short, the details of the Pleistocene glacial history of the Peak District still await full analysis and understanding.

Landforms such as gritstone tors (Palmer and Radley, 1961), dry valleys (Warwick, 1964), landslides (Skempton *et al.*, 1989), dolomite tors (Ford, 1963), caves (Ford, 1977, 1986), outwash sheets (Johnson, 1967) and anomalous gorges (Ford and Burek, 1976) such as the Winnats Pass (Ford, 1987) and Derwent Gorge at Matlock (Ford, 1997), demonstrate the diversity of geomorphology in the Peak District. Useful summaries of the geomorphological history have been provided by Dalton *et al.* (1988; 1990; 1999).

Structure. The general structural pattern of the “Derbyshire Dome” and its subsidiary folds was known early in the 19th century with simple sketch maps produced by Farey (1811) and Watson (1811). The general wrench fault nature of the mineral veins was established later, but the structural history of the Peak District drew little early attention until Fearnside’s (1933) astute observations. From the fault pattern, he deduced the possibility that the Peak District limestones had been deposited on a block of buried Precambrian (Charnian) rocks and that this had been pushed northwestwards so that folds in the Millstone Grit country were bent round it, as around the prow of a ship. Fearnside’s compilation, however, combined different phases and types of folds and faults as though one single episode of tectonic movement was responsible.

The nature of the pre-Carboniferous basement below the limestone massif remained unknown until

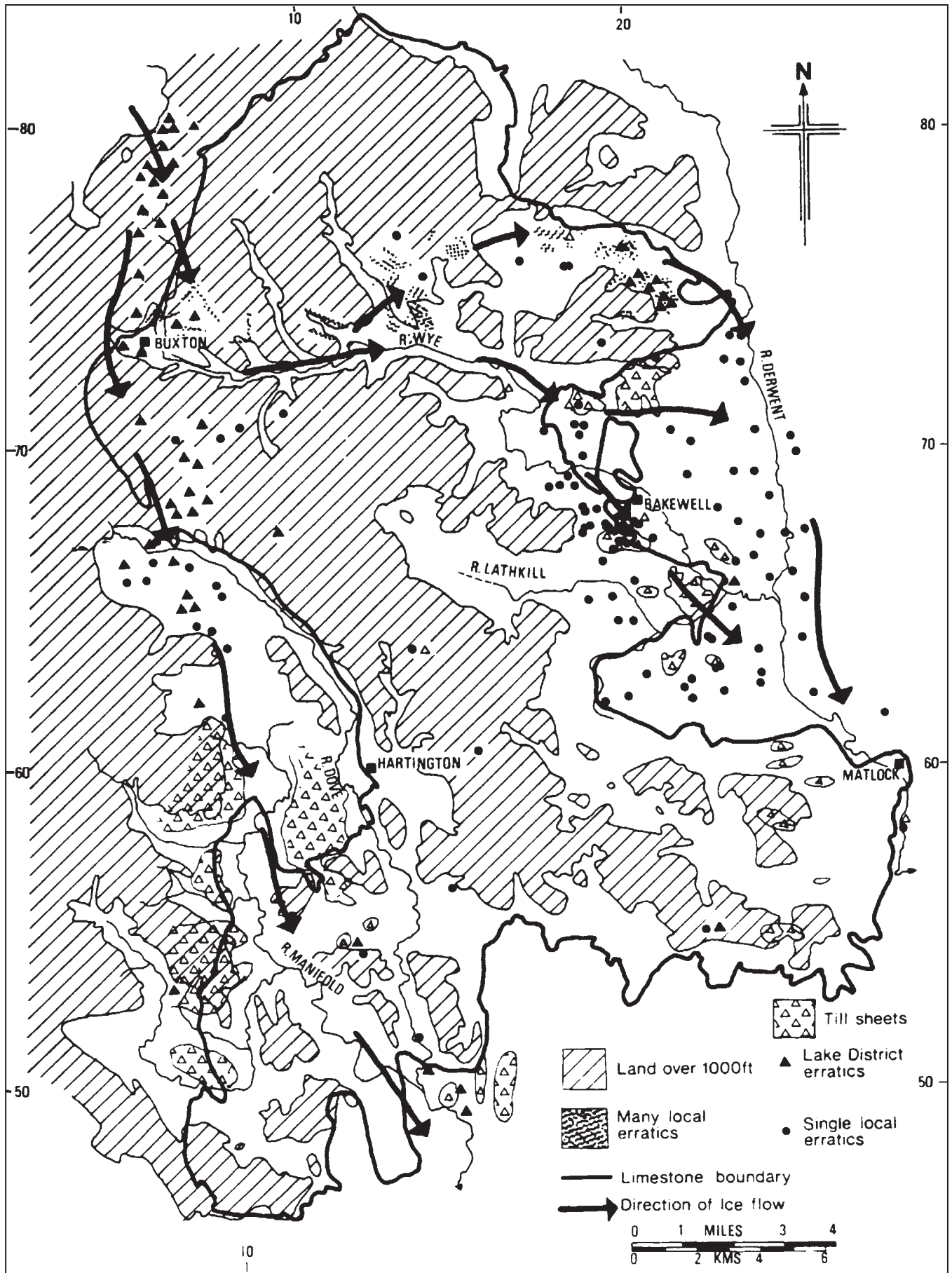


Fig. 14. Sketch-map of the distribution of glacial deposits, erractic boulders and suggested lines of ice flow (from Burek, 1977).

the Woodale borehole demonstrated a volcanic foundation only 273m down (Cope, 1949; 1973). The age of these volcanics is still uncertain. Cope (1979) reported a K/Ar date of 382 ± 6 Ma, i.e. Devonian, though this may reflect a Caledonian overprint on Precambrian (Charnian) or Ordovician volcanics (Webb and Brown, 1989). In contrast, the deep borehole at Eyam (Dunham, 1973) proved basement at more than 1600m, composed of Ordovician pelites. This indicated that the basement was not a northerly extension of the Precambrian rocks of Charnwood Forest. The thick sequence of carbonates in this borehole threw some doubt on the buried massif concept. No boreholes in the adjacent deep basins have proved basement. A borehole at Cauldon Low in the Weaver Hills of Staffordshire penetrated 170m of early Dinantian and possibly late Devonian sandstones beneath the carbonates (Aitkenhead and Chisholm, 1982). The borehole terminated at a depth of 535m, probably not far above the basement.

Geophysical studies of the sub-Carboniferous basement (Maroof, 1976; Rogers, 1983; Colman *et al.* in Plant and Jones, 1989) suggested that the basement is faulted and that the carbonates are draped over tilted fault blocks, thereby covering a series of half-grabens. The positions, trends, directions and amounts of throw on these buried faults remain controversial, with the faults downthrowing west according to Miller and Grayson (1982) or northeast according to Smith *et al.* (1985). Gutteridge (1987) agreed with the latter but proposed a rather more complex pattern of largely concealed listric faults (Fig. 15). The pattern of blocks and half-grabens was discussed further by Plant and Jones (1989). Some of the bounding faults appear to have become inactive during Dinantian times so that they have little or no expression in the higher beds. Others were reactivated as wrench faults by later movements and may also have been mineralized. Buried faults around the Derbyshire block comparable with the Craven Faults bounding the Askrigg Block to the north have not yet been demonstrated, though Gutteridge (1991) suggested that such basement faults outlined the northern end of the limestone massif. The results of oil company vibroseis traverses in the 1980s have largely remained confidential though may ultimately yield a solution if they are ever released into the public domain.

The Derbyshire block thus appears to be a local uplift within a much wider South Pennine basin which suffered inversion as a result of the Variscan compression at the end of the Carboniferous.

Within the orefield, the major veins or rakes are characterized by lateral movement and Firman's (1977) intriguingly titled paper on "Wrenches and Ores, the Rake's Progress" suggested how mineralized faults might have been propagated. However, analysis of mineral vein patterns indicates that the stress field changed intermittently through middle and late Carboniferous times, with both

compressional and extensional phases operating with varying orientation (Fig. 16). These stress patterns evolved during episodic mineralization mainly in late Carboniferous times (Quirk, 1986; 1993).

The structure of the orefield was related to a much wider study of metallogenesis in Eastern England by Plant and Jones (1989). They extended the concept of the Widmerpool and Edale Gulfs bounding the Derbyshire Block, first proposed by Falcon and Kent (1960), to suggest that there were other blocks and basins beneath the East Midlands. Any or all of these basins could have held the Carboniferous mudstones that yielded the metals, fluorine, barium and sulphur ions necessary for mineralization during diagenesis and could thus represent a buried equivalent of the South Pennine Orefield.

The relationship of the different types of fault patterns in the White Peak, the adjoining Millstone Grit country and the coalfields to a history of changing stress regimes still awaits full analysis.

The burial history of the Peak District has given rise to some debate. Though formerly portrayed on some palaeogeographic maps as a series of islands, the South Pennines are now thought to have been covered by Jurassic and Cretaceous strata (Cope *et al.*, 1992), before being denuded again in Tertiary times.

Mineral Deposits and Mineralisation. The galena in the mineral veins of the Peak District (also known as the South Pennine Orefield) attracted attention from prehistoric times but its origin was considered a matter of divine provenance: indeed tithes were once claimed on the basis that ores regenerated in the same way as crops grew on the surface. The lead miners used elementary principles of geology as early as the 16th century in predicting the strata which would be penetrated in shafts and drainage levels (Rieuwerts, 1984) (Fig. 1). However, little appeared in print until the end of the 18th century when brief ideas on ore genesis were put forward. Whitehurst (1778) and Farey (1811) both argued that the ores had been concentrated from surrounding rocks, i.e. by some form of lateral secretion. White Watson elaborated on this a little in an unpublished lecture sheet, advocating origin of the mineral veins by volcanic effects.

After these early comments there was little written on ore genesis until the early 20th century when a consensus seemed to regard the Peak District mineral veins as being comparable with the Cornish veins and therefore fed from a concealed granite.

Mineral veins were long categorized by lead miners into four types: rakes (major fracture fills), scrins (minor fracture fills), flats (along the bedding), and pipes (cavity linings) (Fig. 17). The mineral veins themselves were catalogued by Farey (1811) with notes on their mineral content and on the stratigraphy of the host rocks, such as 1st lime, 2nd lime etc (Fig. 3). The early Geological Survey Memoirs (Green *et al.*, 1869, 1887) added some

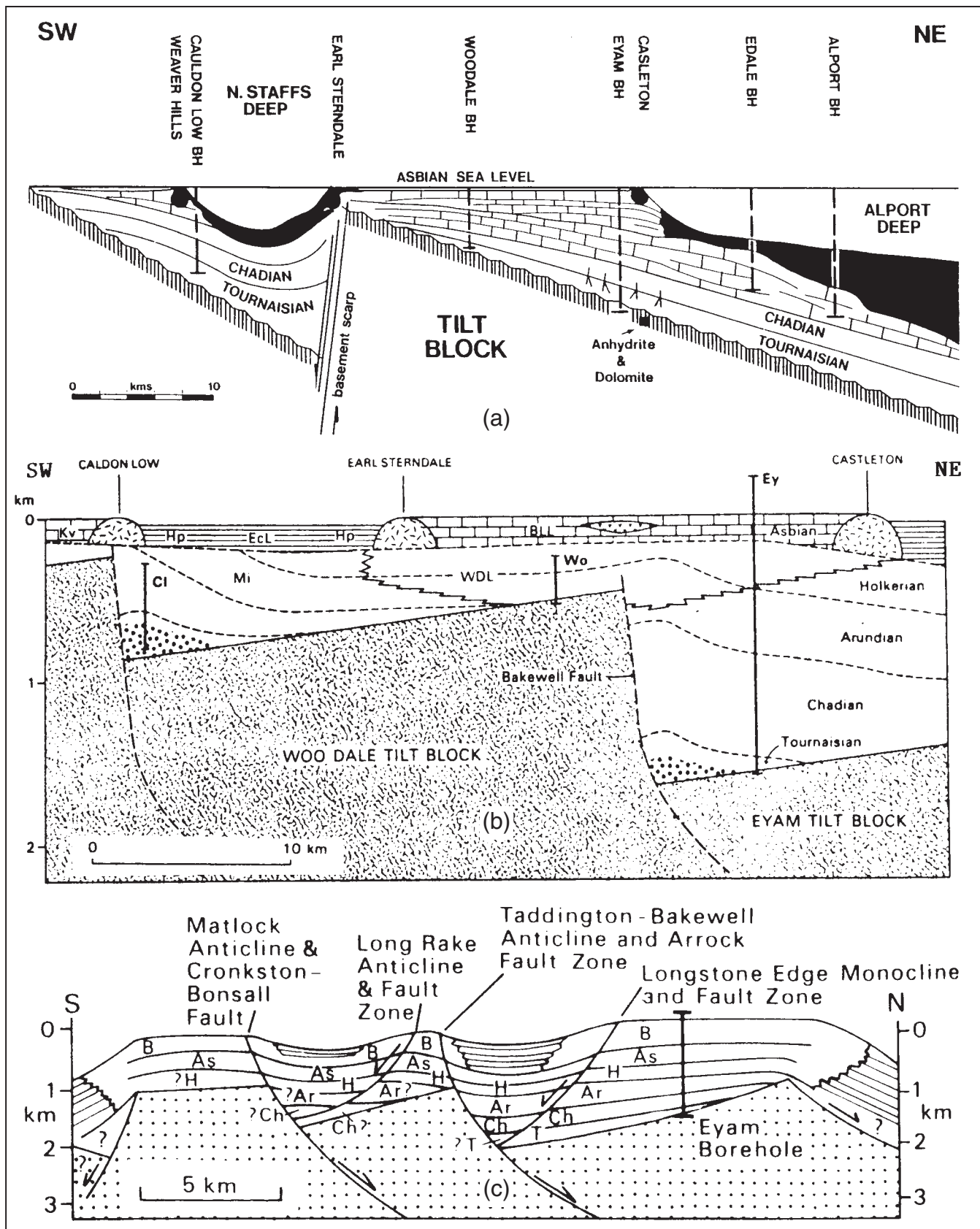


Fig. 15. Different interpretations of the basement structure beneath the Peak District:
 a. single tilt-block and half-graben with a major fault system throwing down to the west (after Miller and Grayson, 1982);
 b. two tilt-blocks and half-grabens with faults throwing down to the northeast (reproduced with permission from Smith *et al.*, 1985; © John Wiley & Sons Ltd.).
 c. three tilt-blocks with half-grabens bounded by listric fault systems (reproduced with permission from Gutteridge 1987; © John Wiley & Sons, Ltd.).

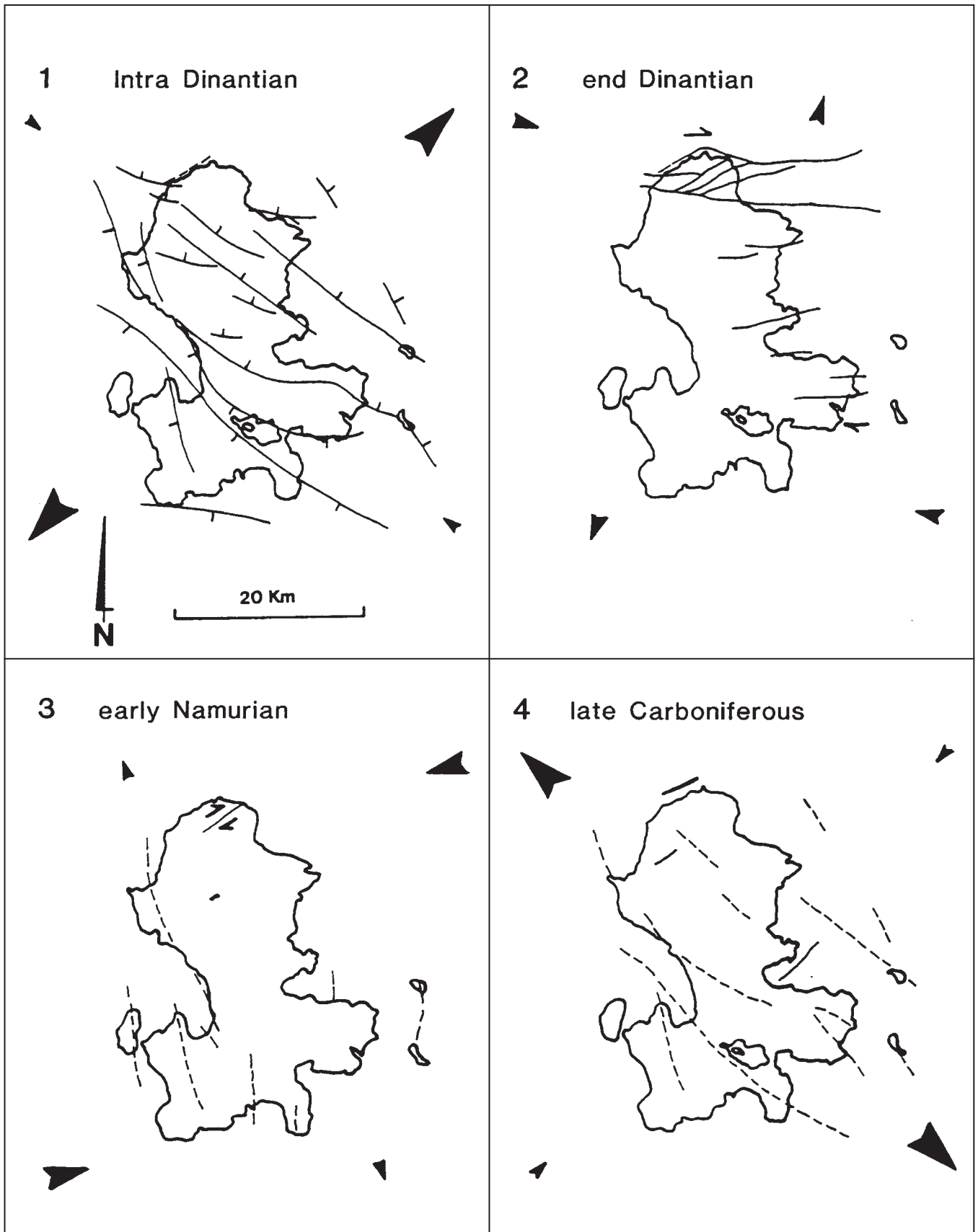


Fig. 16. Outline maps of the changing stress fields affecting the Peak District mineral deposits (after Quirk, 1993):
 1. Intra-Dinantian NE-SW extension results in NW-SE faults above basement structures.
 2. End-Dinantian: stress field rotates anticlockwise resulting in dextral wrench faults.
 3. Early Namurian: stress field continues to rotate with some uplift and erosion, and the development of NNW-SSE faults.
 4. Late Carboniferous: thermal subsidence with maximum extension NW-SE resulting in faulting along the same trend.

information on both individual mines and on production but said little on ore genesis. The Inspector of Mines, A. H. Stokes, provided a comprehensive survey of mineral deposits of economic potential (Stokes, 1879) and a map of the veins with an account of the history of mining and of the associated legal system (Stokes, 1880-83). However, he was writing during the declining years of the lead mining industry and it was not until the early 20th century that interest was renewed owing to the rise of the fluorspar industry (Wedd and Drabble, 1908). World War I brought new investigations of resources needed for the war effort and the rebuilding of industry afterwards. The Geological Survey published Special Reports on lead and zinc (Carruthers and Strahan, 1923), copper (Dewey and Eastwood, 1915), fluorspar (Carruthers and Pocock, 1916), barytes (Carruthers *et al.*, 1915), fireclay and other refractories (Howe, 1918; 1920). Though giving useful descriptions of the deposits, it is doubtful if these reports provided much stimulus to home production. None of the reports had much to say on genetic theories. World War II brought a more complete survey of baryte resources (Dunham and Dines, 1945) and, later, of fluorspar resources (Dunham, 1952). The fluorspar mining potential was reviewed again by Ford and Ineson (1971).

While the distribution of the mineral deposits was well-covered, little was written on the economics of

exploitation and matters such as stratigraphical and structural relationships were left until later (Varvill, 1937; Traill, 1939; Dunham and Dines, 1945; Dunham, 1952). The Pb-Zn-F-Ba veins occupy a dominantly E-W wrench fault system and its offshoots in the limestone massif. Local controls of the position of strata-bound orebodies are afforded by toadstone and tuff horizons with their limited permeability (Traill, 1939; Shirley, 1949). In spite of a widely-held belief that there was no ore in the toadstones, Walters and Ineson (1980) were able to list many such occurrences. The dominant minerals were shown to be zoned with fluorspar common in the east, baryte in the centre and calcite in the west (Dunham, 1952; Mueller, 1954a). Subsequent research (Firman, 1977; Quirk, 1986, 1993) has shown the distribution of gangue minerals to be considerably more complex owing to episodic, sometimes overlapping, phases of mineralization.

A summary map of the veins was compiled by Quirk (1993) (Fig. 18) as part of an analysis of the genesis of the orefield (Fig. 19). An accompanying annotated catalogue of nearly a hundred minerals was compiled by Ford *et al.* (1993).

A small, separate orefield dominated by copper minerals occurs at Ecton in the Manifold Valley and was worked as far back as Bronze Age times. Hosted in folded basal limestones, the ore-pipes are vertical bodies said to be formed at the intersections

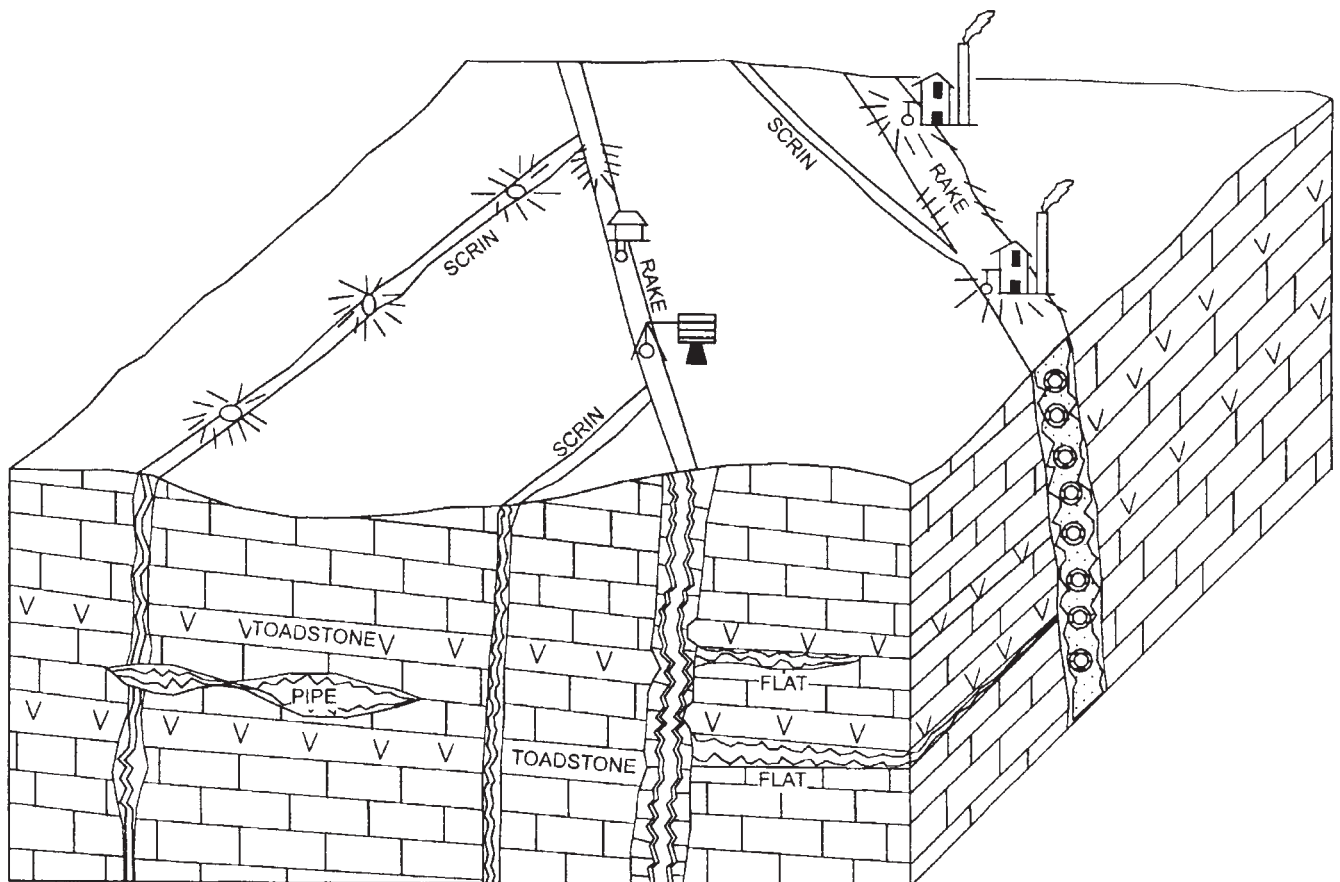


Fig. 17. Block diagram of the types of mineral vein in the Peak District: two rakes (one brecciated) have scrins branching from them: two flats underlie volcanic horizons: a pair of strata-bound pipe veins are cavities lined with minerals.

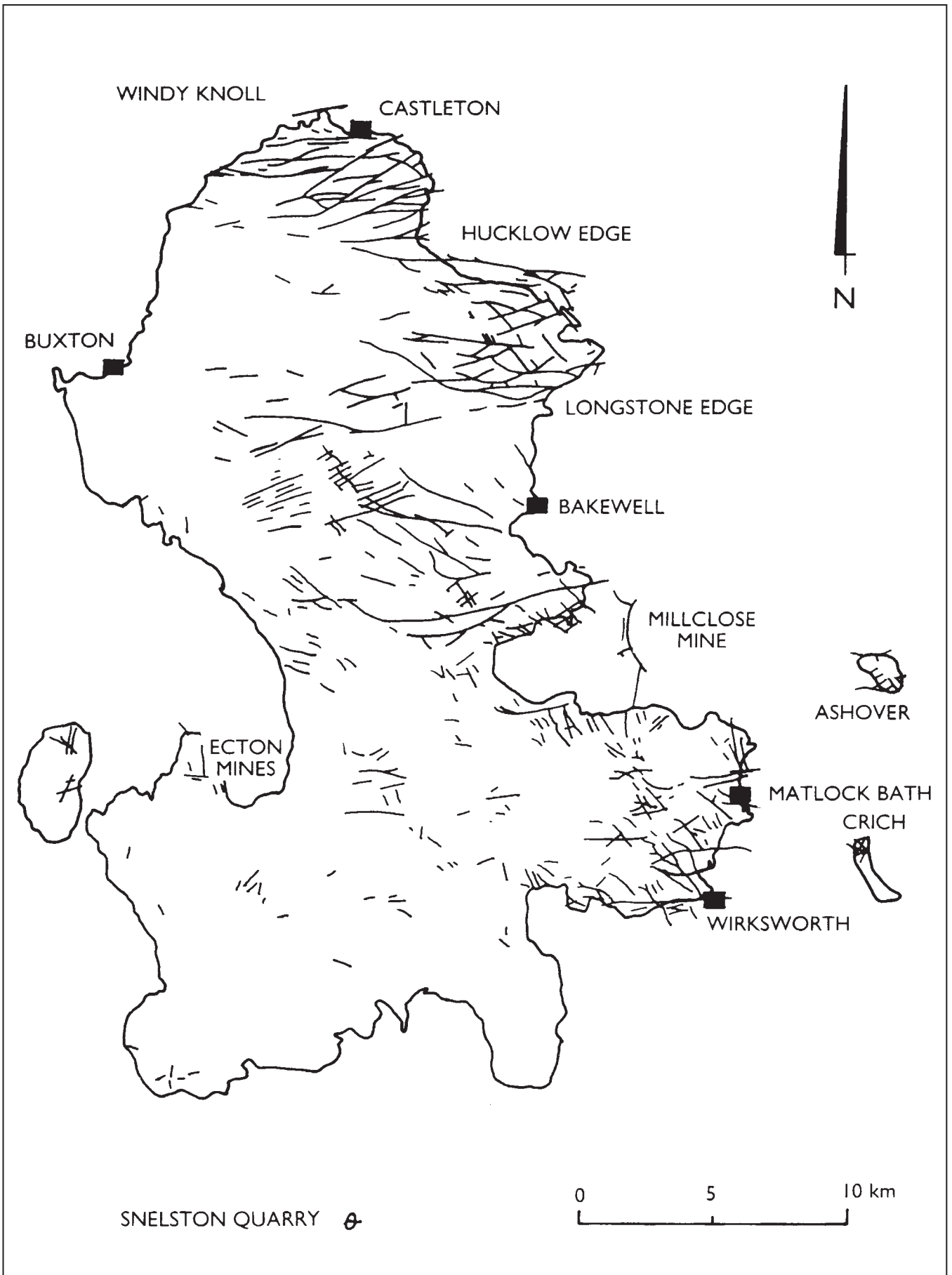


Fig. 18. Sketch-map of the principal mineral veins of the Peak District (from Quirk, 1993).

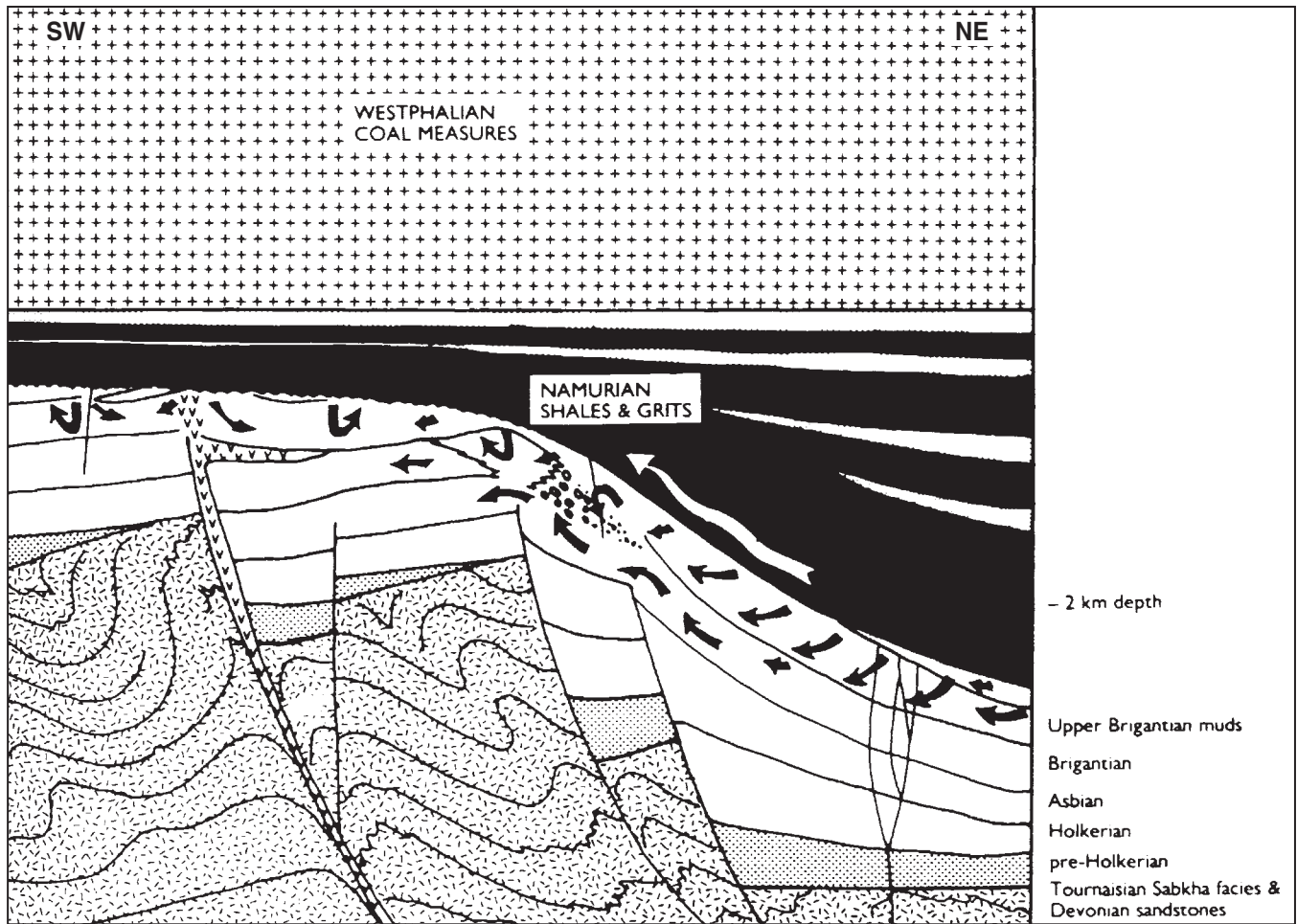


Fig. 19. Diagram of the fluid flow pattern resulting in mineralization (from Quirk, 1993).

of N-S and E-W veins (Critchley, 1979) though these are difficult to delineate. On the basis of fluid inclusion studies, Masheder and Rankin (1988) argued that the ores at Ecton had been derived from fluids expelled from the Cheshire Basin, in contrast with the rest of the South Pennine orefield, which had been sourced from the east.

A unique fluorite-baryte deposit alongside Dirlow Rake, south of Castleton, was found to be hosted in a pre-Namurian palaeokarstic collapse structure (Butcher and Hedges, 1987).

Unusual pervasive mineralization was found in the only areas where Triassic sediments rested directly on Carboniferous Limestone, at Snelston and at Limestone Hill, near Ashbourne (Cornwell *et al.*, 1995). Although some mining of both lead and copper occurred the deposits were only of limited extent.

Dolomitization has affected the higher parts of the limestone sequence (Asbian-Brigantian) over about a quarter of the limestone outcrop (Parsons, 1922) though it is still uncertain whether it resulted from a phase of the mineralization process or to a former cover of Permian Magnesian Limestone. No evidence has yet been found to prove that the Magnesian Limestone was ever deposited over the limestone plateau (Cope *et al.*, 1992) though it is

possible that there could have been a transgression westwards from the main Permian escarpment of east Derbyshire and Nottinghamshire. Projection westwards of the east Derbyshire scarp would take the Magnesian Limestone only a hundred metres or so above the White Peak's limestones. However, the Magnesian Limestone is late Permian in age and much of the mineralization was in place by the late Carboniferous which raises a chronological problem, adding weight to the hypothesis of dolomitization being an early phase of mineralization.

Dolomitization also affected older (Arundian-Holkerian) limestones in the Woodale and Eyam boreholes (Schofield and Adams, 1985; Dunham, 1973). This earlier phase of dolomitization probably resulted from restricted circulation in the lagoon in pre-Asbian times and is perhaps related to the anhydrites at the bottom of the limestone sequence in the Eyam borehole.

The dolomite resources were described during the Geological Survey's survey of limestone resources of the 1980s, summarized by Harrison and Adlam (1985). Once worked for refractory materials, dolomite is no longer exploited today. A commercial attempt to extract magnesium metal near Wirksworth in the 1960s proved uneconomic. Small

amounts of manganese pigment materials, umber and wad, were once extracted from the dolomite areas (Stokes, 1879).

In post World War II years there was a marked change from hypotheses concerning a buried granite origin for Pennine orefields to sedimentary sources. Derivation of the ions from the host limestones during diagenesis was considered but did not find favour. Comparison with overseas orefields soon concentrated ideas onto sources in adjoining shale basins (Dunham, 1983; Ford, 1976; Quirk, 1986; 1993; Colman *et al.*, 1989; Plant and Jones, 1989; Ixer and Vaughan, 1993). Dunham (1983) viewed Pennine mineralization as a fluorine-rich variant of the Mississippi-Valley-type of mineralization. Dating of fault gouges by K/Ar methods (Ineson and Mitchell, 1972) showed that phases of mineralization probably ranged from late Carboniferous to late Triassic times, though the validity of the method later raised some doubts. Fluid inclusion studies indicated that the mineralizing fluids were highly saline with palaeo-temperatures indicating an easterly source with the zoning effected by westward fluid migration with falling temperatures (Dunham, 1952; Mueller, 1954a; 1954b). However, more recent work on fluid inclusions (Atkinson *et al.*, 1982; Masheder and Rankin, 1988; Quirk, 1993) has found more uniform palaeotemperatures across the orefield with little evidence of a thermal gradient. Discoveries of metasomatic fluor spar deposits west of the so-called fluor spar zone again indicate that the zoning hypothesis is too simplistic.

The consensus of opinion at present is that the South Pennine Orefield is a local variant of Mississippi-Valley-Type mineralization. The saline mineralizing fluids originated by expulsion from neighbouring Carboniferous shale basins, transported during the changing stress regimes of mid- to late Carboniferous times into the limestone high of the White Peak. Precipitation was effected by mixing with local oxygenated formation waters, by the oxidation of organic catalysts and by cooling. Fluid inclusions bearing hydrocarbons have been described by Moser *et al.* (1992) and their light hydrocarbon gases by Ferguson (1991). Hydrocarbons carrying uraniferous inclusions have been noted by Parnell (1988). Ewbank *et al.* (1995; 1996) have argued that there is evidence of three phases of fluid migration from the adjoining basins into the Peak District high; an early high temperature mineralizing fluid, and two later low temperature hydrocarbon-bearing fluids. The Ecton copper mineralization has been regarded as a slightly lower temperature variant with a different source (Masheder and Rankin, 1988). In the discussion of Ewbank *et al.* (1966), Quirk argued that the mineralizing and hydrocarbon phases may have been pene-contemporaneous. Hollis and Walkden (1996) have related mineralization to calcite cementation in the limestones; the sixth and last phase of cementation appears to have been contemporaneous with the main episode of mineralization and with late Carboniferous extensional tectonics at the onset of the Variscan orogeny.

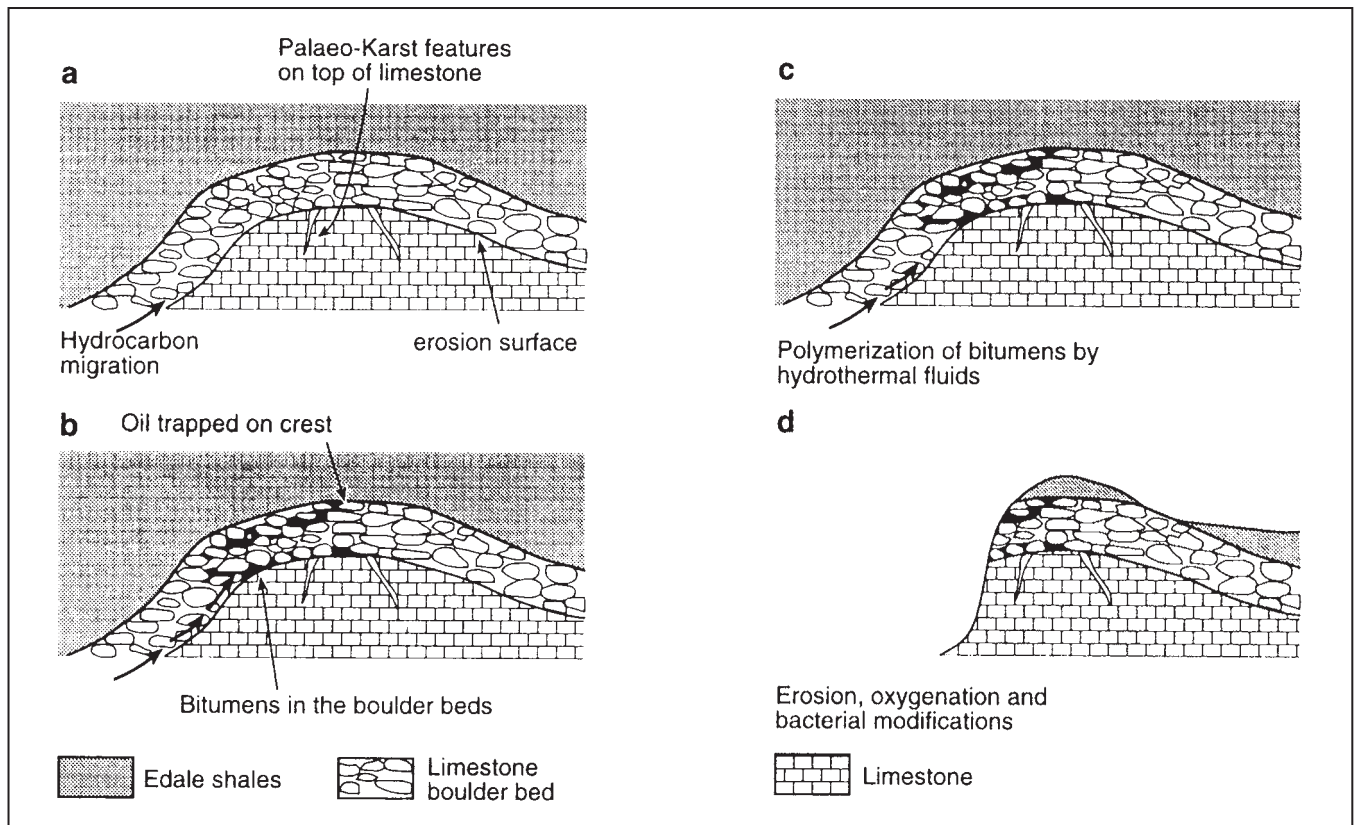


Fig. 20. The sequence of events in the development of the bitumen deposits at Windy Knoll, near Castleton (after Pering, 1973).

The cause of the colouring of the Blue John variety of fluorite found in Treak Cliff, near Castleton, has been the subject of much investigation, summarized in Ford *et al.* (1993). The colour was initially attributed to a small manganese content (Adam, 1843) but analysis failed to confirm this. Blount and Sequira (1919) and Mueller (1954a) argued that hydrocarbon inclusions were the cause, but Braithwaite *et al.* (1973) deduced that the colouring was mainly due to crystal dislocations induced by the radiation from uranium in surrounding rocks. Uranium is present in uraniferous collophane nodules near the limestone/shale contact (Peacock and Taylor, 1966), and has been absorbed within hydrocarbon inclusions in the Blue John fluorite crystals. The blue and white colour banding is thought to be due to the vagaries of changing flow rates and pressures through a complex plumbing system in voids in the pre-Namurian Boulder Bed, leading to a varying supply of uraniferous hydrocarbons (see also Ford, 2000).

The Bitumens of Windy Knoll. Though known since the 17th century, the bitumen (elaterite) deposits of Windy Knoll, near Castleton, were not studied in any detail until the early 1950s (Mueller, 1954b). He distinguished some 30 hydrocarbon "mineraloids" (listed in Ford *et al.*, 1993) and argued that their relationship to the hydrothermal mineral suite demonstrated that the heat of the mineralizing solutions had been enough to polymerize the original hydrocarbons. Subsequent fluid inclusion work (Atkinson *et al.*, 1982) threw doubt on Mueller's arguments. The space race in the 1960s attracted the attention of NASA to the possibility that the bitumens were abiogenic and thus representative of extra-terrestrial processes. However, NASA's investigations showed conclusively that the Windy Knoll bitumens are biogenic (Pering, 1973) (Fig. 20). In spite of more recent investigations by Xuemin *et al.* (1987), Parnell (1988), Moser *et al.* (1992) and Ewbank *et al.* (1995; 1996) the genesis of the Windy Knoll bitumens is still incompletely known and the part played by hydrocarbons in mineralization is still uncertain.

Radio-activity studies. A pre-war advertisement once alleged that the therapeutic properties of the Buxton thermal springs was due to their radio-activity! No supporting evidence was presented.

The search for uranium resources in post-war years revealed its presence in trace proportions in Carboniferous sediments in Derbyshire, particularly in shale partings in the reef limestones of the Castleton area (Ponsford, 1955). Uranium was also found in Derbyshire's underground waters, with concentrations in the karstic waters of Russet Well at Castleton being close to those of the thermal springs at Buxton (Peacock, 1961). The source was thought to be uraniferous collophane clasts in Neptunian dykes in the pre-Namurian weathered limestone surface (Peacock and Taylor, 1966).

The gaseous daughter of uranium decay, radon, has been found in sufficient quantities to be a potential health hazard in several mines, caves and houses in the Castleton and Ashover areas (Ball *et al.*, 1992; Hyslop, 1993). In these areas, mineral veins and joints provided conduits for radon emanations originating from the upper limestones, particularly from uraniferous hydrocarbons in stylolites. Sediments washed into caves also yielded radon from uranium in transported material (Gunn *et al.*, 1991; Bottrell, 1993).

Economic Geology. Apart from limestone quarrying and the lead-zinc-fluorspar-baryte deposits noted above, many other materials have been exploited in the Peak District. These include chert, tufa, dolomite, calc-spar, "marble", copper and iron ores, gritstone, refractory clays and sands, brick clays, umber and wad. Site investigations and constructional materials for dams, assessments of underground water resources and the abortive search for oil have also been important. Each has contributed in its own way to geological knowledge in the Peak District but a comprehensive review is beyond the scope of this paper.

Conclusions

Whilst not exhaustive, this review of the state of knowledge of the Peak District's geology should provide future researchers with a background for their studies. It also clarifies where research and/or publication are still deficient. Future research or data acquisition is needed in several areas.

1. Much more needs to be known about the basement beneath the Peak District. It is to be hoped that some unpublished geophysical studies will see the light of day soon.
2. The details of the formation of many of the mud-mounds are still imperfectly understood, particularly the marginal reefs of the Castleton and upper Dovedale areas.
3. An atlas of Carboniferous fossils is desirable at least as a teaching aid.
4. There is as yet no full catalogue of the mineral veins and their minerals comparable with those published for the North Pennines and Cornwall.
5. The structural history in relation to basin inversion and the formation of the mineral veins is still imperfectly known.
6. In spite of research on the bitumens of Windy Knoll, there is still no complete analysis of what hydrocarbons are present or of their genesis.
7. The denudation chronology in relation to one, two or even three glacial advances is far from clear and correlation with other areas is uncertain.
8. Many cave deposits await the application of modern dating techniques, and promising cave sites such as Peak Cavern entrance remain unexcavated.

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Trevor D. Ford, OBE
Geology Department
University of Leicester
Leicester
LE1 7RH