REVISION OF THE CRACOEIAN STAGE (Lower Carboniferous) IN THE BOWLAND-CRAVEN BASIN (U.K.) OF SEDIMENTATION

by

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Summary

Much geological research has been conducted by various workers in different parts of the Clitheroe-Slaidburn-Skipton region of Northeast Lancashire and the West Riding of Yorkshire. An attempt is made here to compare the results of these investigations, so far as they are concerned with the strata of *Beyrichoceras* (B_1 B_2) age and their relation to the older and younger beds. Among the matters discussed is the position of the boundary between B_1 and B_2 and also that between Lower and Upper B_2. It is argued that the available evidence necessitates unconformities, both below and above the Upper B_2 sub-zone. The latter break results from the Sudetian I earth movement of post early P_{1a} and pre-P_{1b} age. The break below Upper B_2 is of later date than the Cravenian movement (S_2/S_2D_1) which has not been proved south of Skipton and precedes Sudetian I. It follows a simple uplift, to denote which the name "Bowlandian" is suggested.

Introduction

The Cracoeian Stage of the Lower Carboniferous comprises the former *Beyrichoceras* (B) zone, which spans the interval from the *Bollandoceras hodderense* Beds (base of B_1) to the *Goniatites crenistria* (P_{1a}) zone at the base of the Bollandian. It approximates to the S_2 and D_1 zones (Middle Visēan). The Beds of B_1 and B_2 age have not proved amenable to subdivision into a sequence of goniatite zones which have the precision of those of the overlying Bowland Shales. Goniatites, though everywhere rare, are (except in the *hodderense* Beds) commoner in B_2 than in B_1, and, within B_2, more abundant in the upper than in the lower part. Attempts have been made with only partial success to subdivide the B_2 zone into Lower, and Upper B_2. sub-zones. In the Geological Survey Memoir, "Geology of the country around Clitheroe and Nelson" (Earp et al, 1961) the B_2 zone was treated as a single unit.

The present communication discusses the more important features of the Cracoeian Stage in the area covered by Sheet 68 (Clitheroe) and districts to the north and west of it (text-fig. 1).

The *Bollandoceras hodderense* Beds (lower B_1)

The basal 15 to 30 feet of the B_1 beds, where typically developed, are readily recognized in the field. They consist of very hard cementstone bands interbedded with calcareous shales. The lithology, which has been fully described in various papers, is unusual, the cement-stones in some of the bands displaying blotches of various colours. The goniatite species include *Bollandoceras hodderense* (Bisat), *Merocanites applanatus* (Frech) and at least one species of *Nomismoceras* (Bisat, 1924, 1934; Parkinson, 1926, 1936; Earp et al., (1961). *Merocanites henslowi* (J. Sowerby) has been collected from this horizon (J. Miller *in litt.*). and Earp et al. (1961, p. 180) record it from "shales at the top of the (*hodderense*) band in Porter's Brook, Grindleton.".

North of a line from Croasdale House near the southern end of the Stocks Reservoir through Barnoldswick to the south of Lothersdale the *hodderense* Beds are not typically

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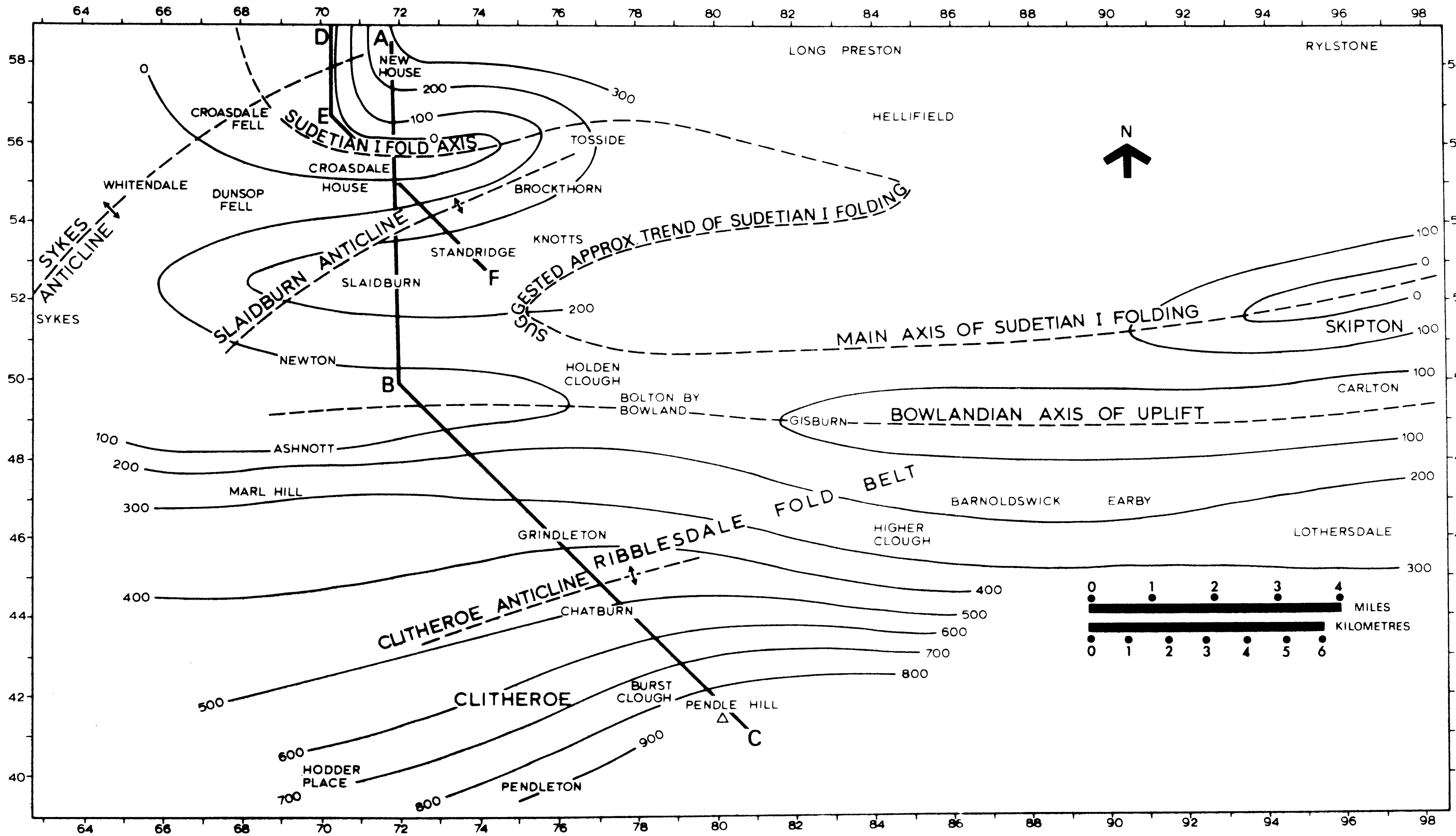


Text-fig. 1. Isopachyte map of the Bowland-Craven basin of sedimentation. The isopachs, which are drawn at 100 ft. intervals on the beds of Cracoeian age, although only approximately placed, are indicative of the relationship between the Bowlandian and Sudetian earth movements and the post-Millstone Grit folding.

developed, but the horizon has been recognised in an exposure between Carlton and Earby (Earp et al, p. 74). In the Skipton Anticline (Hudson and Mitchell, 1937, p. 14) beds in the Upper Skibeden Shales-with-Limestone, displaying green chloritic patches and yellow weathering, are probably of *hodderense* age.

The *Merocanites henslowi* Beds (Upper B_1)

In a zonal table, Hudson (1938, p. 308) placed *M. henslowi* as the index fossil for Upper B_1 and equivalent to higher S_2. As noted above, this species also occurs in Lower B_1 and it has been found in beds higher than B_1 on Buttershaw Knoll, Cracoe, Yorkshire (Bisat, 1934, p. 306). The location is a little north of the northeastern corner of the map (text-fig.1) and the horizon according to Bond (1950, p.167) is middle D_1. Nevertheless, *M. henslowi*, though not common, is the dominant and most widespread goniatite in the higher parts of B_1, notably in the Isle of Man. Within the area under consideration it is best known at the northeastern corner near Rylstone. The associated fauna consists largely of corals of *Cyathaxonia*-zaphrentid phase, whilst the goniatites recorded (apart from some species which Hudson and Cotton, (1945, pp. 280-1) suggested should be renamed) are *Beyrichoceras mutabile* (Phillips) *Beyrichoceratoides* aff. *implicatus* (Phillips) and *Nomismoceras* sp.. The type locality of *B. implicatus* is Black Hall Quarry, near Chipping, Lancashire, eight miles west of Clitheroe (just outside the limits of the map, (text-fig.1). This quarry is certainly higher than S_2 and the Rylstone form is apparently an early variety.

M. henslowi, identified by Bisat (1934, p. 306) was collected from an exposure near New House in the north-eastern part of the Sykes Anticline, 3½ miles north of Slaidburn (Parkinson, 1936, p. 308) which yielded an extensive fauna, including *Lithostrotion sociale* (Phillips) and *Stroboceras sulcatum* (J. de C. Sowerby).

In Burst Clough, northeast of Little Mearley, on the lower scarp of Pendle Hill, shale specimens of a form recorded as *Prolecanites compressus* (J. Sowerby) (Parkinson, 1926, p.214) were found at intervals from 10 feet above the *hodderense* limestone to the *Lithostrotion arachnoideum* Beds 400 feet higher in the sequence. *Merocanites compressus* is a C_2 (or C_2S_1) form and it is probable that the Pendle specimens should be referred to *M. henslowi*.

The Pendleside Limestone and the boundary between B_1 and B_2

In the type area of Pendle Hill the Pendleside Limestone proper is about 250 feet thick between Hookcliffe and Little Mearley, with its base some 400 feet above the *Bollandoceras hodderense* Beds. To the southwest it is largely replaced by shales and mudstones; to the northeast and northwest it thins out, partly by shale replacement and partly by reduced sedimentation. In some localities it loses its identity; in others it lies directly on the *hodderense* Beds. Thus in the Marl Hill Tunnel (Earp et al., p. 68 and Pl. VI) 294 feet of limestone rest, apparently conformably, on 21 ft. 4 ins. of the *hodderense* Beds, and in Clough Wood, Holden, the Pendleside Limestone, 84 feet thick, lies on 27 ft. 10 ins. *hodderense* Beds (*op. cit.*, pp. 72-73).

Among the fossils collected from the lower beds of the Pendleside Limestone (*Lithostrotion arachnoideum* Beds) in and near Burst Clough (Parkinson, 1926, p.215), *Stroboceras sulcatum*, *Lithostrotion sociale* (recorded as *L. affine*) and *M. henslowi* (recorded as *P. compressus* ?) were later found, as noted above, in the New House Bed.

Some species, not known on Pendle, were collected by the Rev. G. Waddington (1927) from the section in the River Hodder at Hodder Place, 3½ miles southwest of Clitheroe. Hudson and Cotton (1945, p.298) referred this assemblage, which includes *Rylstonia benecompacta* Hudson and Platt and *Rhopalolasma bradbournense* (Vaughan) - and elsewhere *M. henslowi* - to passage beds between S_2 and D_1. The re-survey did not add to existing knowledge and no opinion was expressed in the memoir (Earp et al., 1961) as to age, but the comment was made (p.180) that "the beds in the Hodder are of a faunal phase distinct from that of the true Pendleside Limestone, and a considerable fauna has been found there, including *Lithostrotion* (Waddington, 1927, p.40)". It is further stated (Memoir, p.180) that "owing to the rarity of goniatites the position of the boundary between B_1 and B_2 is not known".

A single goniatite from a few feet below the base of the Pendleside Limestone in Burst Clough, Pendle, was referred by Bisat (Parkinson, 1926, p.215) to *Beyrichoceras micronotum* (Phillips). This was a poor specimen, which according to a revised opinion of Bisat (in litt. to Earp et al, p.180) may have affinities with *Girtyoceras*. This solitary specimen and *M. henslowi* are the only goniatites which are known in that part of the sequence where the boundary between B_1 and B_2 might be expected to be found. The numerous species of *Girtyoceras* described by E.W.J. Moore (1946) were all collected from beds above the Pendleside Limestone, so it is possible that the Burst Clough specimen is a B_2 rather than a B_1 species. The evidence, such as it is, suggests that the junction between B_1 and B_2 is a little below the base of the massive Pendleside Limestone. In the Hodder Place section, assuming the usually accepted view of the equivalence of the goniatite B_1B_2 and the coral - brachiopod, S_2D_1 stages, the junction can be taken at the level of the *Rylstonia* fauna, the position of which is shown in text-fig. 3. (See Waddington, 1927, p.37 and Earp et al, 1961, p.69).

In the Skipton Anticline, although the rocks of Cracoeian age are much thinner than those in the Pendle area, many more fossils are recorded from them. The fauna is a coral-brachiopod phase. The species listed by Hudson and Mitchell (1937, pp.19-21) from the Draughton Limestone indicate a D_1 age, though some forms from the lower beds suggest S_2. Among these, according to the authors, many specimens are probably derived from the underlying Intake Limestone, a local deposit in the Upper Skibeden Shales-with-Limestone. No goniatites are named. The most probable horizon of the B_1-B_2 boundary is the base of the Draughton Limestone. This limestone is a greatly condensed equivalent of the Pendleside Limestone and displays two horizons of breccia-conglomerate, the higher of which, up to six feet thick, is known as Tiddeman's Breccia (*op. cit.* p.17).

Strata of Lower B_2 age

The B_2 beds were subdivided by Hudson (1938, pp.312-3) into Lower B_2 and Upper B_2. In his 1945 paper with Cotton (p.257), Hudson proposed as index fossil for the whole of B_2 *Goniatites maximus* Bisat, whilst for Lower B_2 he suggested *Beyrichoceras vesiculiferum* (de Koninck) and for Upper B_2 *B. delicatum* Bisat. Within the area of text-fig.1 the only goniatite which can with some confidence be assigned to Lower B_2 is *Bollandoceras* cf. *phillipsi* (Bisat) which was recorded by Earp et al. (p.180) from the Pendleside Limestone of Pendleton Brook, a quarter of a mile southeast of Pendleton Church. This horizon is at least 200 feet above the *Girtyoceras* bed in Burst Clough (Parkinson, 1964).

Strata of Upper B_2 age

Along the Pendle Range there are many stream sections and some of them have yielded Upper B_2 goniatites. The sudden increase in the number of goniatite species is coincident with the widespread occurrence of the trilobite *Phillibole* aff. *aprathensis* R. and E. Richter (Earp et al., pp. 89, 180), and the entry of this species seemed the obvious horizon to place the base of Upper B_2 (Parkinson, 1964). The Upper B_2 beds, which consist largely of shales and mudstones, with occasional bullions, overlying the Pendleside Limestone, thin out towards the northeast from 150-175 feet at Little Mearley Clough to 54 feet at Higher (Cowdale) Clough southwest of Barnoldswick. The combined records of these and other localities by Moore (1936, 1941, 1946), Bisat (1952), Earp et al., (1961) and Miller and Grayson (unpublished work) suggest the existence of the following sequence, in descending order, below the *Goniatites crenistria* - *Beyrichoceratoides truncatus* beds of P_{1a}.

Dimorphoceras gilbertsoni (Phillips)

Bollandites castletonenis (Bisat),
Beyrichoceras delicatum Bisat.

Goniatites crenistria Phillips, *Girtyoceras platiforme* Moore, *Girtyoceras deani* Moore, *Bollandoceras globosum* Bisat

Goniatites maximus-wedberensis group, *Bollandoceras* cf. *excavatum* *Beyrichoceras* aff. *vesiculiferum* (de Koninck), *Beyrichoceras* cf. *micronotoides* Bisat, *Prolecanites hesteri* Moore, *Epicanites* aff. *bowlandensis* Moore, *Nomismoceras* sp.

Bollandites castletonensis (Bisat).

Goniatites hudsoni Bisat, *Girtyoceras simplex* Moore *Cowdaleoceras difficile* Bisat, *Prolecanites hesteri* Moore

Bollandites castletonensis (Bisat), *Nomismoceras rotiforme* (Phillips)

The lowest of these three levels of *Bollandites castletonensis* was found in Limekiln Clough, Pendle, southwest of Little Mearley Clough, by Miller and Grayson. Mr. Miller has kindly provided me with details of this section which was earlier studied by Moore (1936) and Earp et al (1961, pp. 89, 181). The Upper B_2 beds here are about 150 ft. thick and consist mainly of shales and mudstones. The upper leaf of the Pendleside Limestone, 8 ft. thick, is 80-90 ft. below the bullion bed containing the highest horizon of *B. castletonensis*. The new horizon of this species is near the base of the measured section and some 110 ft. below the bullion bed. It thus appears to be much lower than the *B.* aff. *castletonensis* horizon in Little Mearley Clough (Earp et al, Fig. 8, p. 90) which is about 20 ft. below the bullion bed (*op cit*, p. 181). Messrs Grayson and Miller collected a varied fauna from Limekiln Clough, including *Phillibole aprathensis*, which here ranges through the lower 80 ft. of the sequence.

Below the Bowland Shales in the Slaidburn and Sykes Anticlines, the Slaidburn Breccia (Parkinson, 1935, 1936, 1964; Moseley, 1962) is widespread. It thins out towards the south from about 100 ft. to zero. In the northeastern part of the Sykes Anticline, where it is thickest, it approximates to a reef facies with both brecciated and unbrecciated limestone which has yielded many species of brachiopods, together with a fair number of corals and a few goniatites. It has been argued (Parkinson, 1964) that these beds could be as old as Lower B_2. Among the goniatites recorded, (Parkinson, 1936, p. 312), *Girtyoceras discus* (Roemer), *Prolecanites serpentinus* (Phillips) and *Beyrichoceras parkinsoni* Bisat do not differentiate between the lower and higher parts of B_2, but *Beyrichoceras* cf. *micronotum* (Phillips) suggests Upper B_2, since there is apparently no reliable record of this goniatite at lower horizons. The corals (*op. cit*, p. 311) include a number of D_1 forms, some of which survive into D_2. The most important of these is *Lithostrotion maccoyanum* Edwards & Haime, which is dominant in lower D_2 (P_1) and apparently does not appear below the middle of D_1. It was found (*op. cit*, p. 315) on the northern slopes of Knotts Hill, associated with the D_2 coral *Lonsdaleia floriformis* and other fossils. In the Clitheroe Memoir the only occurrence noted (p. 83) of *L. maccoyanum* is in the P_{1a} beds of Grindleton Back Brook. In Derbyshire this species ranges, with varieties, from the upper part of the Chee Tor Rock to the top of the

Lower Monsal Dale Beds (middle D_1 to Lower D_2), the typical form being characteristic of the higher horizons (Chapel-en-le-Frith Memoir, 1971. Note in particular the table on p.129).

This evidence appears to justify the assignment of the Slaidburn Breccia to Upper B_2 (higher D_1). The earlier suggestion of Lower B_2 (Parkinson, 1964, p.163) was based largely on the relation of the breccia to the *Michelinia* cf. *tenuisepta* - *Emmonsia parasitica* fauna which is characteristic of Upper B_2-P_{1a} in the Pendle and Cracoe areas. The *Michelinia-Emmonsia* Beds of Bond (1950) were assigned to Upper D_{1-2}. This fauna is apparently absent from the Slaidburn Breccia, though occurring in the beds above it. However, this does not necessarily mean, as will be shown, that the breccia predates Upper B_2.

In the Skipton Anticline the limits of Upper B_2 are problematical owing to lack of goniatite evidence. The lower limit might be as low as Tiddeman's Breccia, which, like the Slaidburn Breccia, is below the beds containing the *Michelinia* - *Emmonsia* fauna. The Slaidburn Breccia has erosive effects on the beds below, whilst, as stated by Hudson and Mitchell (1937, p.19), the irregular base of Tiddeman's Breccia cuts down locally into the lower beds by as much as one foot in six feet. But, as further noted by these authors, the higher beds of the Draughton Limestone display several erosional surfaces, and the base of Upper B_2 could well be higher than Tiddeman's Breccia, though not in my view so high as the base of the Draughton Shales. This opinion is based on the suggestion of Hudson and Mitchell (1937, p.23) that the Draughton Shales (which did not yield any diagnostic fossils) are possibly of P_{1a} age. However, it is also possible that Upper B_2 might range into the Draughton Shales. The top of B_2 therefore would appear to be either at the base of, or within, the Draughton Shales.

North of the Skipton Anticline in the Craven Reef Belt the base of Upper B_2 is usually taken at the level of an oolitic conglomerate, which is a deposit also recognized in the Castleton area of Derbyshire (Hudson and Cotton, 1945, pp.302-5; Parkinson, 1947, pp.103-4, 108).

Earth Movements

The name "Cravenian" was proposed by Hudson and Mitchell (1937, p.30) for a crustal movement in the Skipton Anticline of $S_2/S_2/D_1$ age. This may be equivalent to the Selkian phase of the early Variscan folding. These authors (p. 31 and Figs. 3 and 6) adduced evidence of a stratal break at the base of the Draughton Limestone with some transgression of the underlying Skibeden Shales. The Draughton Limestone with its two breccia-conglomerate horizons is a "condensed sequence deposited over an area relatively uplifted or stable when compared with the belts of Craven Reef Limestone and Pendleside Limestone deposition to the north and south of it". The authors agree with Tiddeman that the upper and lower breccias were formed of material denuded by wave action on adjoining deposits.

The Cravenian break may have existed, locally at least, in the Craven Reef Belt where Bond (1950, p.164) suggested a possible non-sequence between S_2 and D_1 in Swindon Quarry near Cracoe.

No evidence of unconformity of this age has been reported from the Pendle area, but work as yet unpublished by Miller and Grayson has disclosed the existence of mudstone conglomerates below the Pendleside Limestone.

Within the Draughton Limestone, as noted above, there is evidence of a minor unconformity at the base of Tiddeman's Breccia. A major unconformity (Sudetian I) was demonstrated in the Skipton Anticline by Hudson and Mitchell (1937, p. 32) and attributed to an earth movement of D_1/P_{1b} age. Later movements caused minor unconformities of P_{1c}/P_{2a} (Sudetian II) and E_{1a}/E_{1b} (Sudetian III) age.

In the Slaidburn paper (1936) I submitted evidence indicating an unconformity below the Bowland Shales in the Ashnott, Slaidburn and Sykes Anticlines. Earp et al (1961) disputed this conclusion, partly on their work near Ashnott (p. 67) where I had inexcusably misinterpreted an exposure. The Survey officers concluded (p. 19) that all the standard zones were present, the thickness changes being related to different rates of subsidence.

In my 1964 paper the stratal break was placed at the base of the beds with the *Phillibole* aff. *aprathensis* fauna, though no unconformity had been found on Pendle itself. In the Ashnott area Upper B_2 was interpreted as following Lower B_1, the equivalent of some 750 beds in the Pendle sequence being absent. I agree with the Survey officers that the subsidence rate was greatly reduced between Pendle and Ashnott, but still believe that this does not account for the apparent absence of Lower B_2 and most of B_1. North of Ashnott, above a thin development of Pendleside Limestone there is an exposure of the *P.* aff. *aprathensis* shales (Memoir, p. 68). These shales have not been seen north of Slaidburn. At Standridge and Knotts Hill the Pendleside Limestone is succeeded by the Slaidburn Breccia, which is in turn followed by the Bowland Shales. If, as argued above, the breccia is of Upper B_2 age it must postdate the Lower B_2/ Upper B_2 earth movement (which was at a maximum near Ashnott) instead of predating it as was formerly supposed (Parkinson, 1936, 1964). This involves the existence of two unconformities, since further north the Bowland Shales are transgressive over the breccia and lower beds. The higher unconformity followed the Sudetian I crustal movement. In the Carlton district the beds of *Beyrichoceras* age are a little more developed than those near Ashnott, but whereas P_{1a} is present around and north of Ashnott it has not been found near Carlton, unless 10 feet of sandy micaceous shales with two hard sandstone bands are of this age, a possibility suggested by Gill (1940, p. 259), who compared them with the Draughton Shales in the Skipton Anticline. Elsewhere in the area Gill found shales of P_{1b} age resting on the very thin Cat Gill (Pendleside) Limestone. He postulated an unconformity of Sudetian I age (Gill 1940, p. 262), but admitted that "wherever the junction can be seen the Bowland Shales rest on the limestone with no apparent disconformity." Earp et al (p. 78) discovered B_2 fossils above the Cat Gill Limestone in two localities. This evidence is consistent with a break below Upper B_2 and another one below P_{1b}.

On the north side of the Lothersdale Anticline the Pendleside Limestone is well developed, and a section (Earp et al., p. 74) shows it to be "abruptly overlain by dark grey shales containing *Goniatites maximus* of B_2 age, assigned to the Bowland Shale group." On page 99 of the memoir it is suggested that "the shales are possibly unconformable to the underlying Pendleside Limestone."

The post-Cravenian (pre-Sudetian I) earth movement is of sufficient importance to merit a distinctive name and I suggest "Bowlandian". Evidence of uplift about the same time has been found in Derbyshire and Staffordshire. (Parkinson, 1947, 1953, 1965, 1973; Parkinson and Ludford, 1964).

In text-fig. 1 isopachs at 100 ft. intervals are drawn for the beds of Cracoeian age. In the Sykes Anticline, where the *Bollandoceras hodderense* Beds have not been recognized, the base of the Cracoeian is placed immediately above the massive chert bed, presumed to be near the top of S_1 (Moseley, 1962; Parkinson, 1936, p. 306; 1964, Fig. 2, p. 160).

The isopachs illustrate the Bowlandian movement as a simple uplift along an east-west axis stretching from north of Ashnott to Carlton. It seems possible, however, that some incompetent small-scale folding in the southern part of the Slaidburn Anticline (Parkinson, 1936; Earp et al, 1961, p. 68) may be associated with the movement.

The influence of the Bowlandian uplift may have been small north of the Skipton Anticline, but there is some evidence of it in the Rylstone area where the Middle Visêan strata are very thin. At Clints (Rylstone Railway) Quarry, Booker and Hudson (1926) recorded, below beds with *Michelinia tenuisepta* and *Emmonsia parasitica* at the top of the quarry, 20 feet of finely brecciated limestone with an extensive fauna, including *Lithostrotion arachnoideum*. Below these beds are 10 feet of limestone with an abundant fauna of zaphrentid phase referred to on earlier pages as the *Rylstonia* fauna. The lowest 24 feet are the *Merocanites henslowi* (then recorded as *M. applanatus*) Beds of S_2 age. Although Bond (1950, p. 171) suggested that in this Quarry the whole of lower D_1 and perhaps the top of S_2 are missing, the faunal succession does not support such a view. There may be a non-sequence below the *Michelinia-Emmonsia* Beds corresponding to the higher part of the Pendleside Limestone, but the *L. arachnoideum* Beds are of Pendleside Limestone (Lower D_1) age and the *Rylstonia* fauna below them is paralleled in the Hodder Place section, which, as we have seen, can be regarded as passage beds from S_2 to D_1. In the discussion on Bond's paper (1950, p. 185) Hudson stated that the suggestion of a mid-Viséan uplift at Rylstone was an error. My own suggestion is that around Rylstone the greatly condensed succession resulted primarily from a very slow rate of subsidence (accompanied possibly by small non-sequences) which was halted at the onset of the Bowlandian uplift, the effects of which extended northwards with diminishing intensity as far as Rylstone.

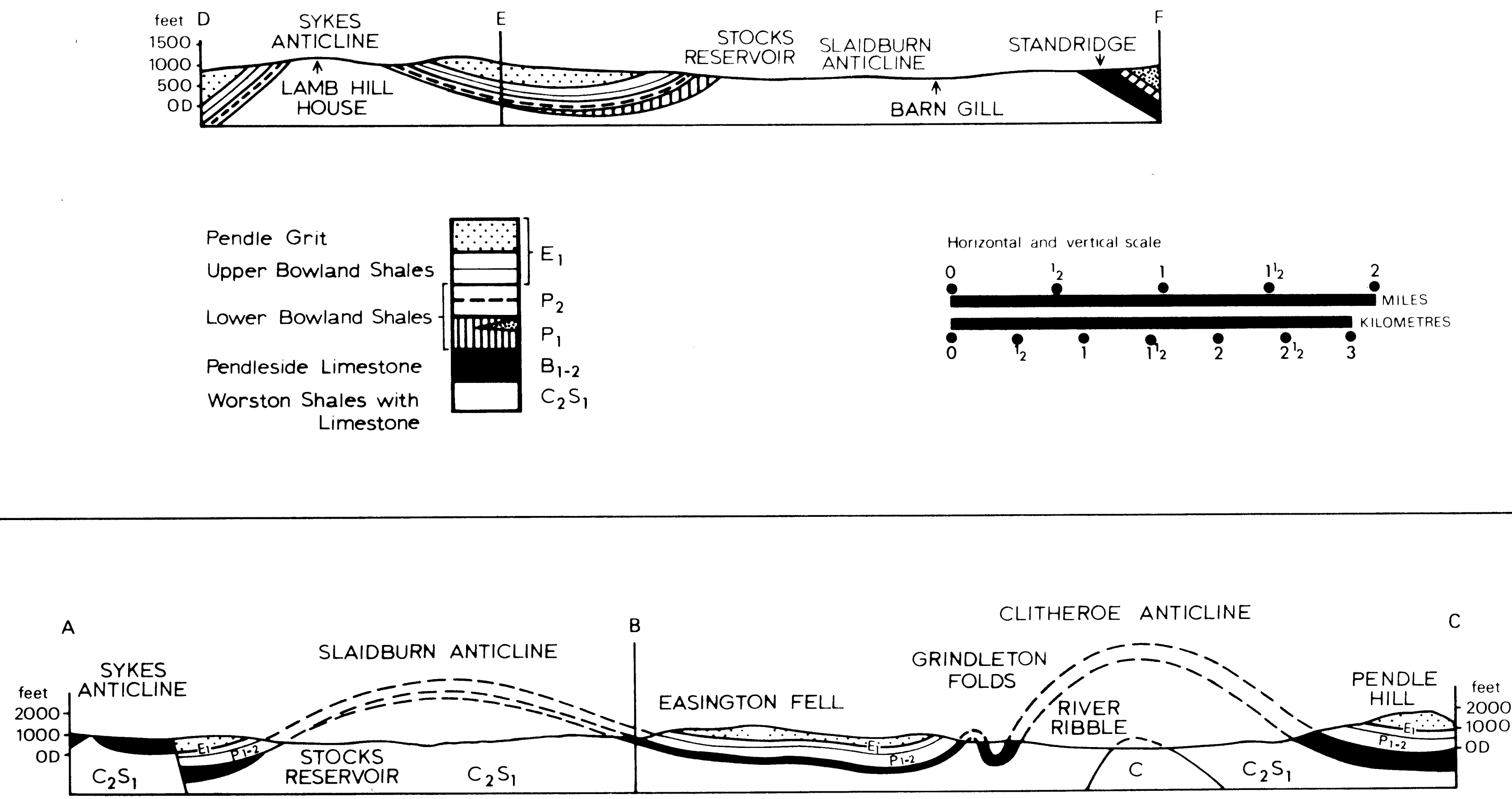
The Sudetian I movement was more powerful than the Bowlandian, and Hudson and Mitchell have made a good case that the Skipton Anticline itself was initiated by it. These authors state (1937, p. 32) that the Sudetian I folding gave rise to a "main axis to the south of which were numerous sharp folds of small amplitude arranged *en échelon*" They envisage a rock mass to the north "against which the rocks were pushed, buckled and packed from the south". The beds above the unconformity, beginning with P_{1b}, are much less severely folded than those below. The folding of the Draughton Shales conforms to that of the Draughton Limestone. Similarly, in the northeastern part of the Sykes Anticline, P_{1b} forms the base of the Bowland Shales (Parkinson, 1936, 1964). Westwards, P_{1b} is overlapped by higher beds almost to the base of E_1, and the shales are transgressive over the Slaidburn Breccia and Pendleside Limestone down to beds of S_1 age. (See generalized horizontal sections, text-fig. 2 and vertical sections, text-fig. 3). As in the Skipton Anticline the beds below the unconformity display many sharp small-scale folds, but the crustal movement as a whole does not appear to be related to the initiation of the Sykes Anticline unlike events in the Skipton Anticline.

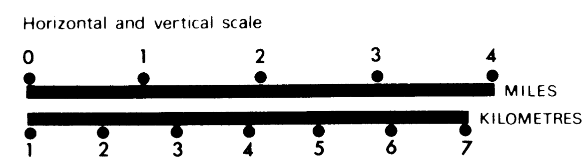
In the Sykes, Brennand and Whitendale areas which constitute the southwestern part of the Sykes Anticline, the Slaidburn Breccia is followed by P_{1b} beds. If P_{1a} is present it is no more than 5 feet thick (Moseley, 1962, p. 295). The intense folding, unlike that of the Skipton Anticline, is not confined to the rocks below the Bowland Shales. Moseley (1962 p. 300) found no evidence of an angular unconformity below P_{1b}, and he notes that the lower beds of the Bowland Shales dip at the same angles as the limestones. Higher beds generally dip at lower angles in conformity with the overlying Pendle Grit. The southwestern part of the Sykes Anticline is interpreted by Moseley (p. 306) as a "concentric fold modified by disharmonic folding of the incompetent Bowland Shales."

In the Bowland Forest Tunnel, beneath the grit of Dunsop Fell (Earp, 1955), where the succession was fully exposed, there is apparent conformity between the Bowland Shales and lower beds. The Pendleside Limestone with the *hodderense* Beds at its base is about 100 feet thick.

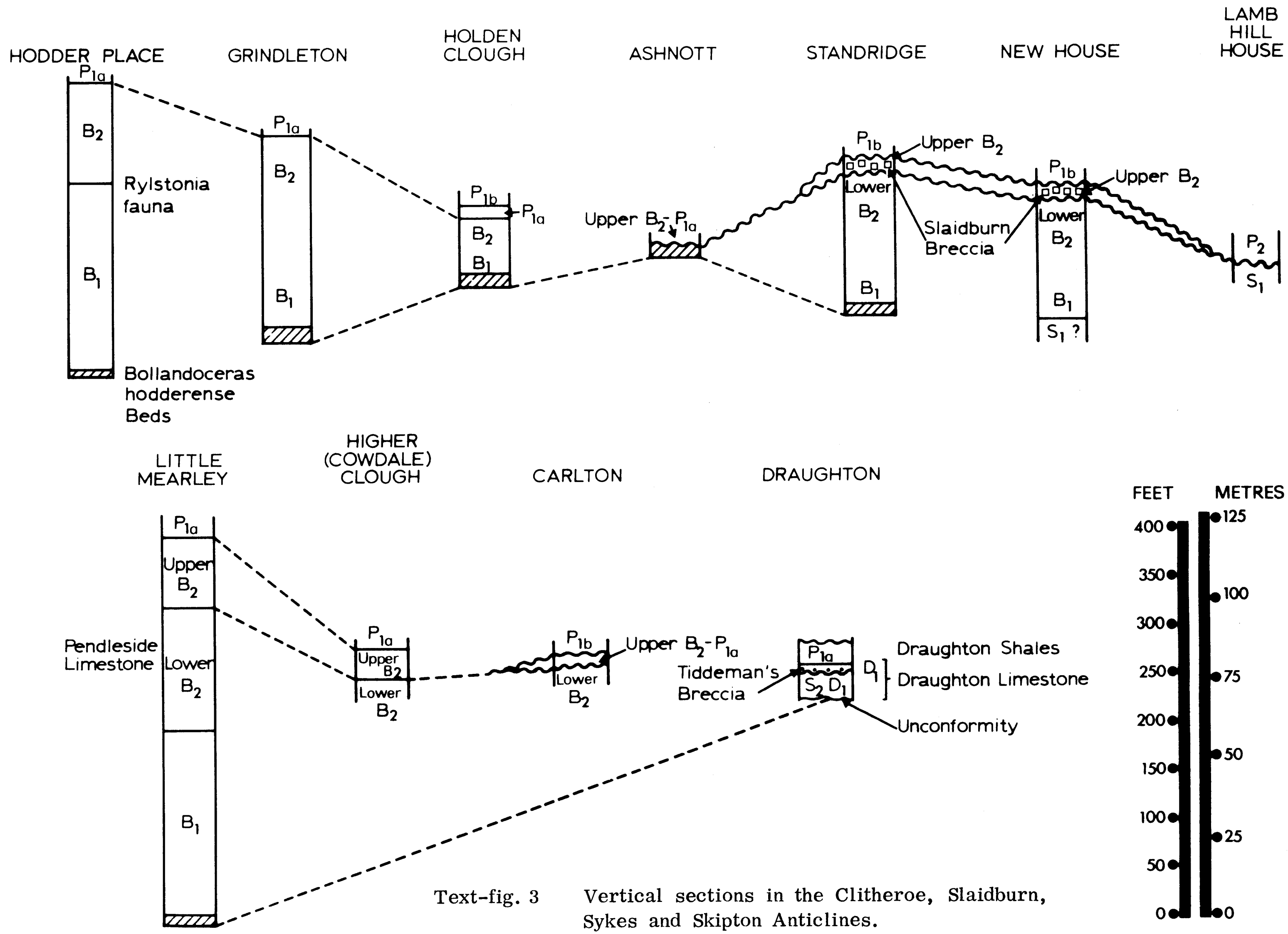
Along the northern limb of the Slaidburn Anticline, P_{1b} beds rest on sharply folded flaggy limestones, some beds being probably of pre-*hodderense* age. Many exposures are now buried in the Stocks Reservoir (Parkinson, 1936, Plate XXVI). The only section of proved P_{1a} beds is in Croasdale Brook, near Croasdale House (*op cit.*, pp. 314-5), where some 35 feet of shales and conglomeratic limestones underlie the *Nomismoceras* Band at the top of the zone. It is possible that the lower part of the succession may belong to Upper B_2, since southwards across the anticline both P_{1a} and Upper B_2 are very thin; otherwise the Upper B_2 beds may have been overlapped. Anyhow, the shales rest on a very thin development of Pendleside Limestone at the base of which are the *hodderense* Beds. About 20 feet above the *Nomismoceras* Band (Parkinson, 1936, p. 315) is a *Goniatites falcatus* Band, with another one 12 feet higher, within a P_{1b} sequence of shales and crinoidal limestones. Thus there is no evidence of a significant break below P_{1b}, as in the exposures northeastwards along the anticlinal limb. The Croasdale Brook section apparently lies just outside the influence of the Sudetian I unconformity.

It should now be re-iterated that in Moseley's view any earth movements prior to the post-Millstone Grit folding were of little significance. He suggested (Moseley 1962, pp. 308-9) that disharmonic folding had probably occurred in the northeastern part of the Sykes Anticline





Text-fig. 2 Generalized and simplified horizontal sections across the Slaidburn-Clitheroe area which are based primarily on the author's own work, but also, to some extent, on the one inch to one mile Geological Survey map of the Clitheroe district, Sheet 68.



Text-fig. 3 Vertical sections in the Clitheroe, Slaidburn, Sykes and Skipton Anticlines.

and in the Slaidburn Anticline, outside his mapped area. In the discussion of his paper he suggested similar disharmonic folding in the Skipton Anticline. Though he did not deny the possibility of minor unconformities or non-sequences, he thought a major unconformity below the Bowland Shales to be unlikely, and made the point that Hudson and Mitchell's map showed the Lower Bowland Shales to rest invariably on either the Draughton Shales or Draughton Limestone (together only about 250 feet thick). He thought that in an outcrop 12 miles long these formations should have been overstepped. But on Hudson and Mitchell's theory, any appreciable overstep would lie *across* the trend of the Skipton Anticline and not along it, and, in fact, these authors show, in their diagram (Fig. 6) illustrating the evolution of the anticline, that along its axis the Bowland Shales rest on beds well below the base of the Draughton Limestone. Because of recent denudation the full extent of overstep remains an assumption, but it need not have gone far below the Draughton Limestone to justify the authors' conclusions.

Along the Craven Reef Belt, as was demonstrated by Hudson (1930) and by later authors, Bowland Shales overlap on the reef limestones, the summit beds of which (in the Cracoe-Burnsall area) are of low $D_2(P_{1a})$ age (Bond, 1950; Black, 1958). The overlap extends from P_{1b} to E_1 and thus involves several goniatite zones, but the actual break below P_{1b} is small.

The Sudetian II movement in the Skipton Anticline (Hudson and Mitchell, 1937, p. 33) was preceded by the deposition of the Nettleber Sandstone "which suffered erosion in the final period of movement." (See also *op. cit.*, p. 24 and Hudson and Versey, 1935). Evidence of this uplift was noted along the north limb of the Slaidburn Anticline by the presence of boulder beds in P_{1c} (Parkinson, 1936, pp. 316-7; 1964, pp. 164-5).

The isopachs of text-fig. 1 indicate, as already noted, the position of the axis of Bowlandian uplift, which trends east-west from north of Ashnott to Carlton. They also illustrate, little more than a mile north of Carlton, the roughly parallel trend of the Sudetian I main axis of the Skipton Anticline. Westwards, pre-B_1 rocks are at outcrop over a wide area and the trend of the axis is lost. It is again shown following the northern limb of the Slaidburn Anticline in a more northerly position than near Skipton. The axis then swings round to the northwest to cross the axis of the Sykes Anticline. The suggested approximate trend of the folding is indicated in text-fig. 1, but alternative explanations are equally possible.

The Pendle area has produced no direct evidence of Bowlandian and Sudetian crustal movements, but it seems unlikely that sedimentation was continuous. It may be significant that on Pendle the D_1 Zone (i.e. the Pendleside Limestone and overlying Upper B_2 shales) is little more than 400 feet thick compared with some 1300 feet along the Derbyshire-Staffordshire border (Parkinson and Ludford, 1964). In North Wales the maximum thickness of the *Dibunophyllum* Zone may approach 3000 feet. This estimate (George, 1958, p. 281) includes D_2 (equivalent to the P_1P_2 beds of the basin areas.) In view of the 600+ feet of Lower Carboniferous shales and limestones in the Clitheroe-Pendle area, a mere 400 feet of D_1 is rather surprising if sedimentation was uninterrupted.

Conclusions

This analysis has clarified some important aspects of the stratigraphy of Middle Viséan age in an area which has claimed the attention of geologists and palaeontologists over many years.

It seems justifiable, mainly on structural evidence supported by lithology and fauna to separate the beds of *Beyrichoceras* age into four subdivisions, namely Lower B_1, Upper B_1, Lower B_2 and Upper B_2. Upper B_1 and Lower B_2 cannot satisfactorily be defined by goniatites alone. The junction of B_1 and B_2 on Pendle Hill is taken a little below the Pendleside Limestone and the corresponding horizon elsewhere can be recognized by a distinctive coral fauna.

The separation of B_2 into lower and upper sub-groups by means of the goniatite faunas, as these are at present understood, is of doubtful validity as was recognized by authors of the Chapel-en-le-Frith Memoir (Earp *et al.* 1971, p.141). The goniatites in themselves are inadequate to sustain such a subdivision in the Bowland-Craven region and the boundary between Lower and Upper B_2 is taken at the level of the Bowlandian unconformity.

Three periods of earth movement affecting the rocks of Cracoeian age are now, in my view, recognizable. Of these the Cravenian (S_2/S_2D_1) may not have extended far south of the Skipton Anticline. However, below the passage beds on Pendle Hill from B_1 to B_2 (S_2 to D_1) the undescribed mudstone conglomerates discovered by Miller and Grayson may be related to the Cravenian movement.

The Bowlandian uplift (Lower B_2/Upper B_2) which is at a maximum along a west-east line from near Ashnott to Carlton, extended northwards to the northeastern part of the Sykes Anticline where it is evidenced by the eroded base of the Slaidburn Breccia, though the break there may be small. The equivalent horizon in the Skipton Anticline may be the eroded base of Tiddeman's Breccia. South of the Ashnott-Carlton line the Bowlandian unconformity diminishes and there is no direct evidence of it on Pendle Hill, where its position is probably the base of the *Phillibole* aff. *aprathensis* beds.

The Sudetian I movement (P_{1a}/P_{1b}) was more intense and more complex than the Bowlandian, though its effects were only felt (southwards at least) over a smaller area. The southern limit of its influence apparently follows a line running southeast from north of Croasdale House and then east to south of Carlton.

Acknowledgment

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