Brown End Quarry, Staffordshire

[SK 090 502]

Introduction

This disused quarry [SK 0902 5024] at Waterhouses, 10 km south-east of Leek, shows an outstanding section of the marine Milldale Limestones and Hopedale Limestones, formed towards the foot of a gently sloping carbonate ramp in the North Staffordshire Basin in early Carboniferous times. The succession includes a spectacular array of features including varied macrofossil and trace-fossil assemblages, reworked microfossil assemblages and a significant amount of re-sedimented material including turbidites, debris-flow deposits and an allochthonous (transported) carbonate mud-mound block. A late Chadian age has been suggested for the bulk of the sequence but unequivocal evidence for the age of the Hopedale Limestones at this site has yet to be determined. Early reference to the site was made in the stratigraphical studies of Ludford (1951), Prentice (1951) and Parkinson and Ludford (1964). More detailed accounts of the site geology are presented by Chisholm *et al.* (1988) and Cossey *et al.* (1995). Aspects of the palaeontology are detailed by Morris (1970a,b, 1994). Pioneering conservation work by the North Staffordshire Group of the Geologists' Association in collaboration with the Staffordshire Wildlife Trust resulted in the development of this quarry as Staffordshire's first geological nature reserve in the late 1980s (Cossey *et al.,* 1995).

Description

At this site, the Milldale Limestones comprise a steeply dipping sequence (88 m) of mainly dark, thinly bedded and fine-grained crinoidal wackestones and packstones with some coarser crinoidal rudstone and floatstone beds. A log of the succession is shown in (Figure 7.28). Besides the ubiquitous crinoid remains (represented by rare calices, stem ossicles and current-orientated stem lengths), the macrofauna from these beds includes corals, brachiopods, gastropods, bryozoans, the occasional goniatite, trilobite and echinoid (Beasley, 1969) and a possible holothurian (Morris, 1970a, but see Cossey *et al.,* 1995). Rich microfaunas including Chadian foraminifera and Tournaisian conodonts (Chisholm *et al.,* 1988), and a trace-fossil assemblage with Zoophycos*, Anconichnus horizontalis, Scalarituba missouriensis* and *Planolites* are also reported from this part of the sequence (Cossey *et al.,* 1995).

Prominent at the base of the section are two 'Waulsortian' carbonate mud-mounds (Figure 7.29). Geopetal cavity fills in the younger of these structures has indicated that it is, most probably, a detached and inverted allochthonous block derived from the principal area of Waulsortian outcrop in the Manifold Valley–Dovedale area to the north-east (Cossey *et al.,* 1995; and see Wetton to Berseford Dale and Dovedale GCR site reports, this chapter). Higher in the sequence an erosion surface at the base of a massive (4.6 m), poorly sorted, fossiliferous crinoidal grainstone–rudstone unit (possibly a gravity-flow deposit) cuts into the underlying laminated peloidal grainstone unit with minor angular discordance. The upper part of the formation comprises laminated and sharp-based graded limestone beds (turbidites) with rare flute casts on their under surfaces. These beds are overlain in turn by the Hopedale Limestones. This formation is represented by another massive (8 m) and composite, intraclast-bearing crinoidal rudstone unit (debris-flow deposit) characterized internally by ill-defined erosion surfaces separating a number of vertically stacked and graded channel-fill beds, each up to 3 m in thickness (Cossey *et al.,* 1995).

Interpretation

The Milldale Limestones (Aitkenhead and Chisholm, 1982) at this site were originally referred to as part of the Weaver Beds by Ludford (1951) and as part of the Cementstones Series by Prentice (1951). A C_1 (Chadian) age was ascribed to them by Prentice (1951), but other authors (Ludford, 1951; Parkinson and Ludford, 1964) referred them to the C2 Zone (Chadian–Arundian). The original suggestion that part of the formation might be of Courceyan age (George *et al.,* 1976; Aitkenhead *et al.,* 1979) was based on the discovery of the Tournaisian conodont *Scaliognathus anchoralis* in the middle part of the sequence (Morris, 1970b). This view was rejected by Riley (in Chisholm *et al.,* 1988) because the beds

containing *S. anchoralis* occur stratigraphically above those in which a younger Chadian microfauna (*Koninckopora inflata, Eoparastaffella* cf. *simplex*)occurs. These same authors attributed this anomolous microfossil distribution to the reworking of the older conodont elements (Chisholm *et al.,* 1988), a view that is consistent with the recognition of several re-sedimented beds in the sequence (Cossey *et al.,* 1995). The currently accepted view, based on foraminiferal evidence (see above) and macrofaunal evidence (*Clisiophyllum ingletonense, Siphonophyllia* sp. *cylindrica* group, *Lamdarina manifoldensis, Eomarginifera derbiensisis* and *Weania* '*Gitarra*' *colei*), is that these beds are of Chadian (Chisholm *et al.,* 1988; Cossey *et al.,* 1995) or, more specifically, late Chadian age (N. Riley, pers. comm., 2002).

Age determinations for the Hopedale Limestones (= Waterhouses Limestone of Ludford, 1951) at the site are equally problematic because of conflicting macrofaunal and microfaunal evidence (Chisholm *et al.,* 1988). Early suggestions of a D_1 or Asbian age for these beds (Ludford, 1951; Parkinson and Ludford, 1964; Aitkenhead *et al.,* 1979) appear to have been based, at least partly, on the presence of corals such as *Palaeosmilia murchisoni* and *Clisiophyllum* cf. *rigidum* — taxa formerly regarded as typical of the late Viséan and whose stratigraphical ranges are now known to extend down to the Chadian (for *P. murchisoni*)and to the Chadian or Holkerian (for *C.* cf. *rigidum*) (Mitchell, 1989; Riley, 1993). The association of these taxa with a foraminiferal assemblage that includes *Pseudolituobella multicamerata* appears to support the 'probable Chadian age' assigned to these beds by Chisholm *et al.,* (1988). Since the Hopedale Limestones overlie the Milldale Limestones with 'apparent conformity' (Chisholm *et al.,* 1988), the slight angular discordance noted between these two formations in the Waterhouses area, by Prentice (1951) and by Parkinson and Ludford (1964), cannot be regarded as stratigraphically significant. This feature most probably represents a minor erosion surface associated with the deposition of gravity-flow deposits (coarse rudstones) at the base of the overlying Hopedale Limestones.

Regional geological investigations in the north Staffordshire area (Maroof, 1976; Bridges, 1984; Smith *et al.,* 1985; Gutteridge, 1987; Chisholm *et al.,* 1988; Gawthorpe *et al.,* 1989; Fraser and Gawthorpe, 1990) indicate that the Milldale Limestones were deposited towards the foot of a W- or SW-sloping carbonate ramp (Ahr, 1973) and above a similarly orientated 'tilt-block' in the underlying basement. The occurrence (at this site) of the classic 'Waulsortian' subfacies (= phase A of Lees and Miller, 1985) from a detached carbonate mud-mound block at the base of the Milldale Limestones indicates that this part of the sequence may have accumulated at water depths in excess of 280 m (Cossey *et al.,* 1995). Furthermore, trace-fossil assemblages typical of either the *Nereites* or *Zoophycos* ichnofacies reported by Cossey *et al.* (1995) indicate that conditions on the ramp may have been dysaero-bic and that deposition most probably took place below storm wave-base.

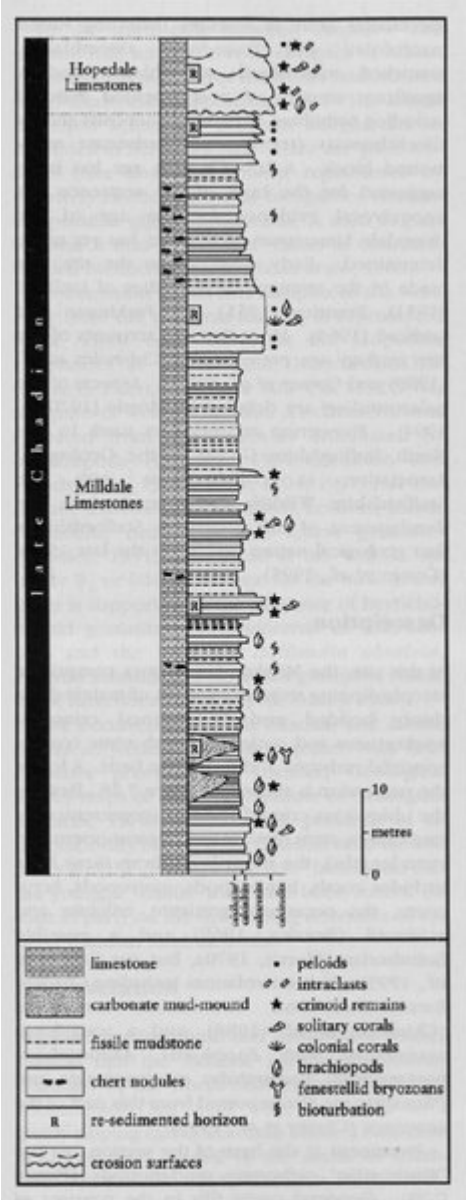
Evidence of re-sedimentation in the form of gravity-flow deposits and reworked microfossil assemblages, lends support to the view that sedimentation during early Dinantian times (and especially during Chadian times) was strongly influenced by the activity of as yet imprecisely defined growth faults at the margins of the North Staffordshire Basin and smaller, possibly antithetic fault systems such as the Manifold Valley Fault plexus (Chisholm *et al.,* 1988; Cossey *et al.,* 1995; and see Wetton to Beresford Dale GCR site report, this chapter). Although the source of the re-sedimented material has yet to be securely established, Cossey *et al.* (1995) suggested it may have been derived from the developing Staffordshire Shelf to the south-west, or, as in the case of the detached Waulsortian mud-mound block, from the proximal up-slope parts of a carbonate ramp to the north-east. A further suggestion by these same authors is that the upward transition from thinly bedded turbidites at the top of the Milldale Limestones to thickly bedded debris-flow deposits at the base of the Hopedale Limestones forms part of a coarsening-upward sequence and part of a prograding fan system that spread across a sea floor of irregular topography, infilling depressions between contemporaneous 'knoll reefs' and older carbonate mud-mound structures (Aitkenhead and Chisholm, 1982; Chisholm *et al.,* 1988).

Conclusions

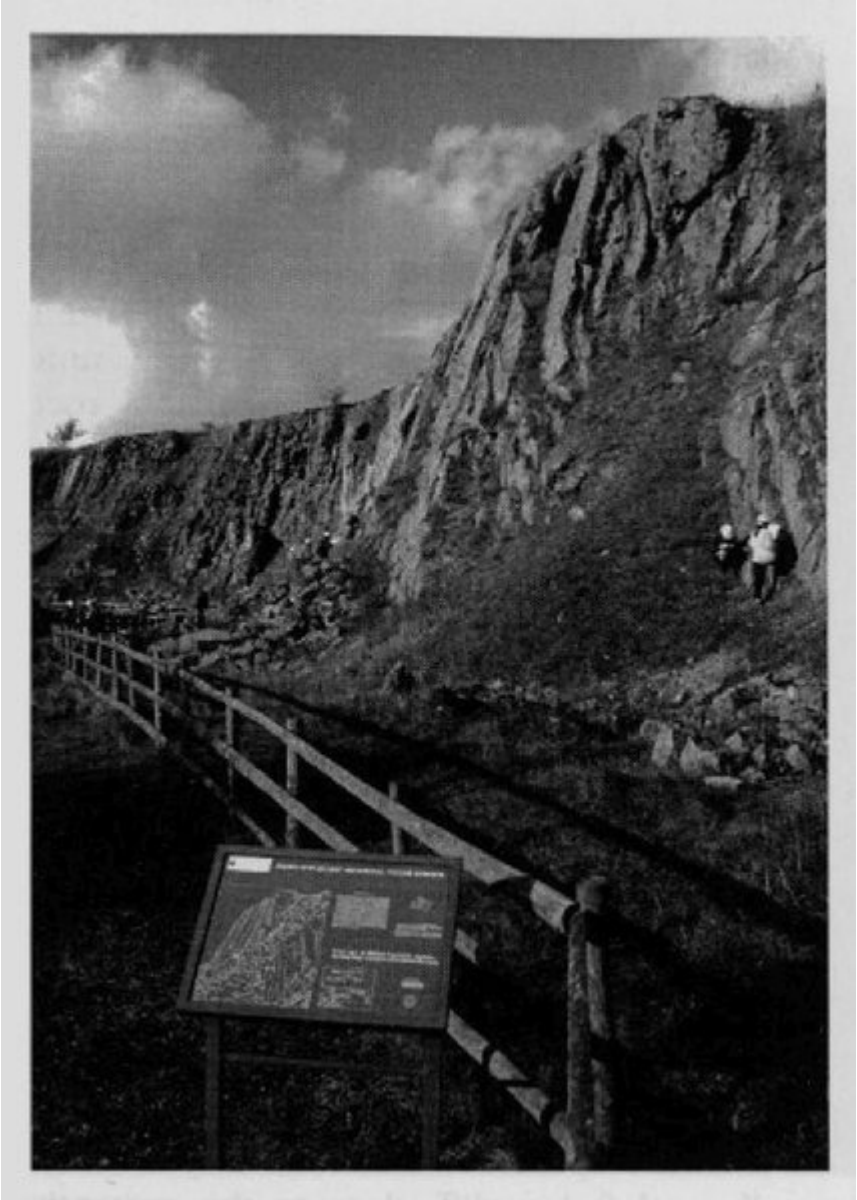
As the type locality (in part) for both the Milldale Limestones and the Hopedale Limestones (Aitkenhead and Chisholm, 1982), Brown End Quarry is one of the most important geological sites in north Staffordshire. The site is critical to the understanding of the tectono-sedimentary evolution and palaeogeography of the North Staffordshire Basin–Widmerpool Gulf area during early Dinantian times. The marine succession formed in the relatively deep waters of the North Staffordshire Basin at water depths of around 300 m. Although the precise age of parts of the sequence remains uncertain, a late Chadian age for the bulk of the section is now generally accepted. The contentious nature of the

stratigraphy and the diverse array of rock features make this a promising site for biostratigraphical and sedimentological research work in the future.

References



(Figure 7.28) Sedimentary log of the late Chadian Milldale Limestones and the Hopedale Limestones succession at Brown End Quarry, Waterhouses. Based on Chishom et al. (1988) and Cossey et al. (1995).



(Figure 7.29) General view of the steeply dipping Milldale Limestones at the Brown End Quarry GCR site showing the position of the inverted mud-mound block (top right) referred to in the text. (Photo: P.J. Cossey.)