

## CARBONIFEROUS GONIATITES, TECTONIC STRUCTURE AND STRATIGRAPHY IN BONHAY ROAD, EXETER, DEVONSHIRE



N. E. BUTCHER AND F. HODSON

Butcher, N.E. and Hodson, F. 1998. Carboniferous goniatites, tectonic structure and stratigraphy in Bonhay Road, Exeter, Devonshire. *Geoscience in south-west England* 9, 151-156.

Studies of the now much degraded natural river cliff in Bonhay Road, Exeter and adjacent exposures over 40 years show that this is the key inland section for the understanding of the tectonic structure and stratigraphy of the Upper Carboniferous sediments of southwest England. On the basis of the critical Namurian goniatites, about 75 m of distal marine turbidite deposits of the Crackington Formation possibly from the top of the Arnbergian stage E<sub>2</sub> up into the Kinderscoutian stage R<sub>1a</sub> are involved in folds overturned to the south. A complex fault pattern, representing both late Carboniferous north-south compression and suggested late to post New Red Sandstone north-south extension, further complicates the tectonic structure.

N.E. Butcher, 22 Drum Brae Walk, Edinburgh EH4 8DQ.  
F. Hodson, 54 Park Road, Chandler's Ford, Hampshire S053 2ES.

### INTRODUCTION

An earlier Review of the Carboniferous Goniatite Zones in Devon and Cornwall (Butcher and Hodson, 1960), based on then existing museum specimens, focussed attention on three goniatites from Bonhay Road, Exeter, in the Vicary Collection at the Natural History Museum in London. These indicated the presence of the Visean P<sub>1c</sub> subzone as well as the Namurian H<sub>2b</sub> subzone and the base of the R zone in this locality. It thus raised the possibility of the presence of both Lower and Upper Carboniferous sediments, the Lower and Upper Culm Measures of Sedgwick and Murchison (1840), in close proximity. Accordingly, a detailed investigation of the locality was begun by the first-named author in January 1958. All identifications of goniatites collected in the course of this investigation are by the second-named author.

William Vicary (1811-1903) was an English tanner and amateur geologist who retired in 1856, moving to Exeter where he was one of the founders of the Devonshire Association for the Advancement of Science, Art and Literature in 1862. He bequeathed his large and valuable collection of fossils to the Natural History Museum in London.

Bonhay Road in Exeter leads south from St. David's Railway Station on the east bank of the River Exe (Figure 1). To the south of the loop railway line curving eastwards to Exeter Central Station, a natural river cliff [SX 9142 9273 to SX 9146 9254] exposing Carboniferous strata rises to a maximum height of 17 m and extends some 170 m in a north-south direction. It is shown on an early view of Exeter, printed by Hogenburg in 1587, just outside the ancient walled city. This natural river cliff section has become somewhat degraded over the years and is in places supported, and thereby obscured, by masonry walling. However, a detailed drawing of the section has been attempted, on which all the critical goniatite localities have been plotted (Figure 2).

In addition, small rock exposures occur behind some of the houses in Bonhay Road to the north of the natural river cliff, and in the adjoining Looe Road to the north. A critical locality occurs behind No. 37 Looe Road [SX 9132 9315].

Carboniferous goniatites have been collected from 17 localities in the generally near-vertical and east-west striking sediments over a north-south distance of 170 m in the natural river cliff since 1958. With the addition of the No. 37 Looe Road locality some 400 m to the north, it

is possible to draw some conclusions regarding the tectonic structure and stratigraphy at this key inland locality in the Crackington Formation recognised by Cleal and Thomas (1996, pp. 44-45). Inevitably, given the complexity of the geology, some uncertainties remain.

### CARBONIFEROUS GONIATITES

All the Carboniferous goniatites collected from the Bonhay Road cliff face and the nearby Looe Road exposure since 1958 occur in generally small decalcified and somewhat iron nodules as internal moulds. These nodules, often called bullions in the Carboniferous sediments, occur in the shale - siltstone parts of the stratigraphical succession of cyclic sediments. In some instances, only one goniatite specimen has been found, but a few bullions have been recovered crammed full of many individuals. The best and identified material is shown in Plate 1. All of these specimens are accurately located in Figures 2 and 4.

The Vicary Collection specimens in the Natural History Museum are not specifically located but the present work confirms the presence of the Namurian forms. It has not been possible to confirm Vicary's P<sub>1c</sub> goniatite (Butcher and Hodson, 1960, Plate 18 Figure 3). In Exeter Museum, the F.G. Collins Collection contains one unidentifiable goniatite from Bonhay Road. The collections in the former Department of Geology, University of Exeter, contain a piece of bullion with *Homoceras undulatum* (Brown) and a dimorphoceratid which, according to D.L. Dineley (personal communication 21 April 1958) came from the cliff face immediately south of the main masonry walling (Figure 2) at some date prior to 1958.

During 1958, sufficient material was collected to demonstrate that the bulk of the natural cliff section was to be referred to the H zone. In fact, for some time it was thought that the whole of the main section, north and south of the central masonry walling, belonged to a single Namurian subzone, H<sub>1g</sub>. A single fragment of *Homoceras heyrichianum* (de Kon.) emend. Haug (Plate 1.1) in a small bullion AB1 at the northern end of the section (Figure 2) was apparently matched with a large bullion ST1 crammed full of individuals of the *H. beyrichianum* group (Plate 1.5) and *Brachycycloceras* at the southern end of the section (Figure 2). Further collecting at intermediate points in the section, however, revealed the true situation.

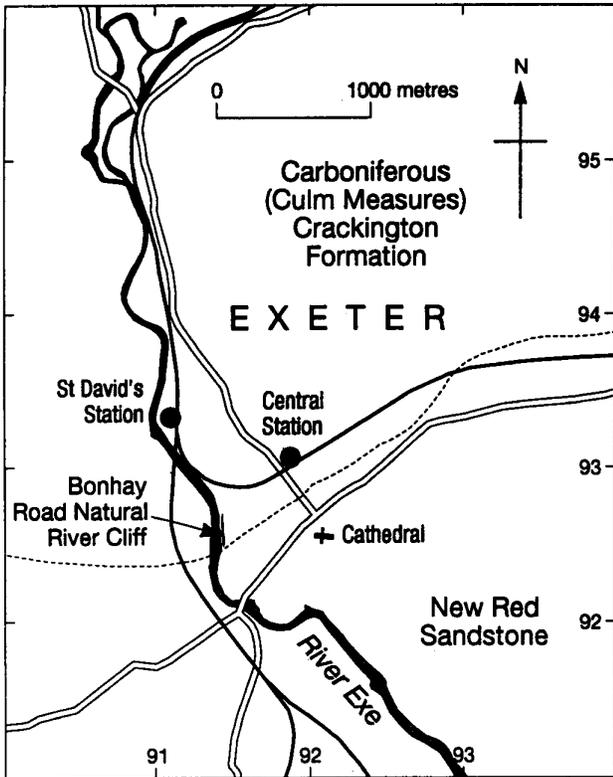


Figure 1. Map showing the location of the natural river cliff in Bonhay Road in Exeter.

Although poorly preserved, the distinctive *Hudsonoceras proteum* H<sub>2a</sub> subzone goniatite is suggested by a single fragment (Plate 1.2) from a bullion LM1 from the northern part of the section (Figure 2). Further south, but still in the northern part of the section, a single specimen of *Homoceras undulatum* (Plate 1.3) was collected from a bullion TU1b high up in the rock face (Figure 2), thus indicating the H<sub>2b</sub> subzone. In the southern part of the section, low down in the rock face immediately south of the central masonry walling, a small bullion

ABI yielded a poor fragment suggestive of *Cravenoceratoides* sp. or *Nuculoceras* sp. and thus the E<sub>2</sub> subzone (Plate 1.4). Unfortunately, this identification has not been confirmed, but, if correct, this would indicate the oldest Namurian horizon present in the Bonhay Road section.

In contrast, the youngest Namurian horizon present in the Bonhay Road section was discovered on 30 March 1961 when a bed of bullions was found in the rock face above the low wall to the south of the main natural river cliff (Figure 2). This distinctive, reddened horizon yielded *Reticuloceras* aff. *circumplicatile* R. *pulchellum* (Plate 1.6 and 1.7) as well as *Calamites* sp., a dimorphoceratid and ?*Vallites* sp., thus indicating the R<sub>1a</sub> subzone.

With Vicary's P<sub>1c</sub> goniatite (Butcher and Hodson, 1960 Plate 18 Figure 3) thus unconfirmed, opportunities for further collecting in Bonhay Road and adjoining exposures did not present themselves until 23 June 1973. On that day, during examination of poor rock exposures to the north of the main natural river cliff section, behind several houses in Bonhay Road and the adjoining Looe Road to the north (Figure 6), a large bullion was found in the low rock face behind No. 37 Looe Road (Figure 4). Crammed full of goniatite individuals, in addition to a dimorphoceratid, they are some species of *Homoceras* as follows:

The collection is dominated by nuclei, 6-9 mm, of a widely umbilicate *Homoceras*, cadicone with sharp umbilical edge. There are thin ribs on the inner area which thicken across the umbilical edge to become strong ribs rectilinear across the venter. There is no hyponomic sinus and may be even a slight forward bow over the venter. Some ribs bifurcate near the umbilical edge and occasional new ribs arise by intercalation. Up to two constrictions may occur on the internal mould which follow the direction of the ribs.

They belong to the ribbed group of *Homoceras*, the *beyrichianum* - *smithi* - *undulatum* group but differ from these species in the early appearance of rib bifurcation. Were better preserved and larger specimens available, it might be named as *Homoceras* sp. nov. Although dangerous to determine geological horizon from evolutionary trends, the suggestion is that they indicate a H<sub>2b/c</sub> level of the Namurian. The best preserved specimen is figured in Plate 1.8.

Note added by N.J. Riley: The *H. beyrichianum* assemblage is very complex and does include forms with bifurcation which might be attributable to *Ramosites* sp.

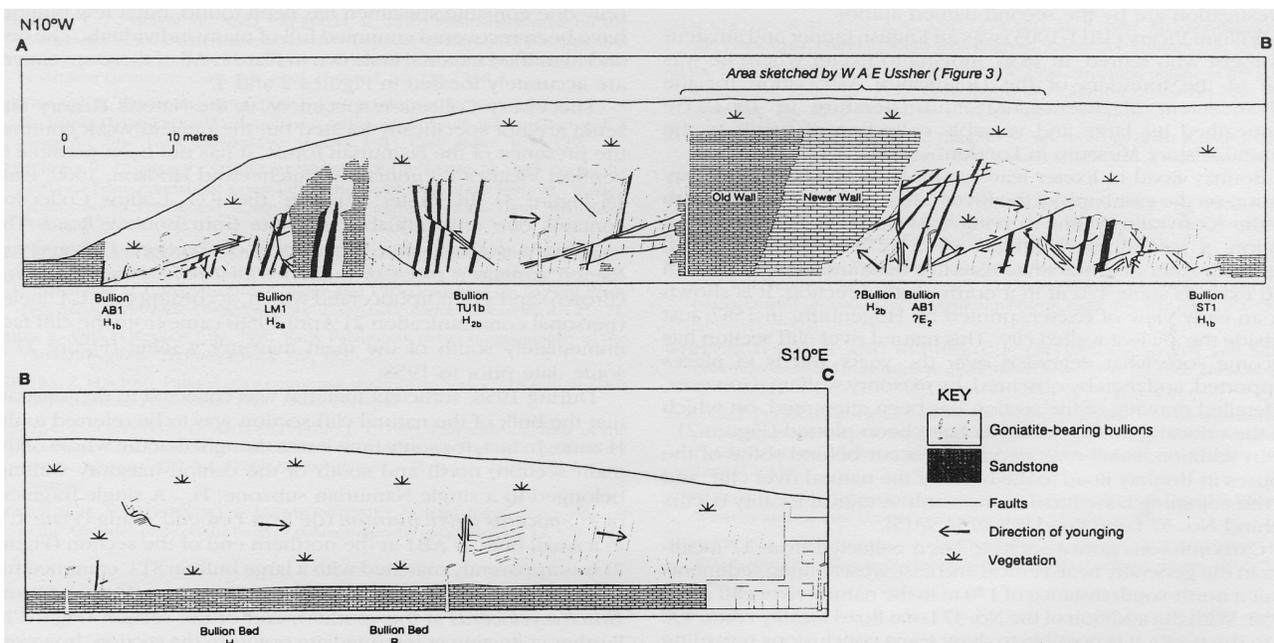
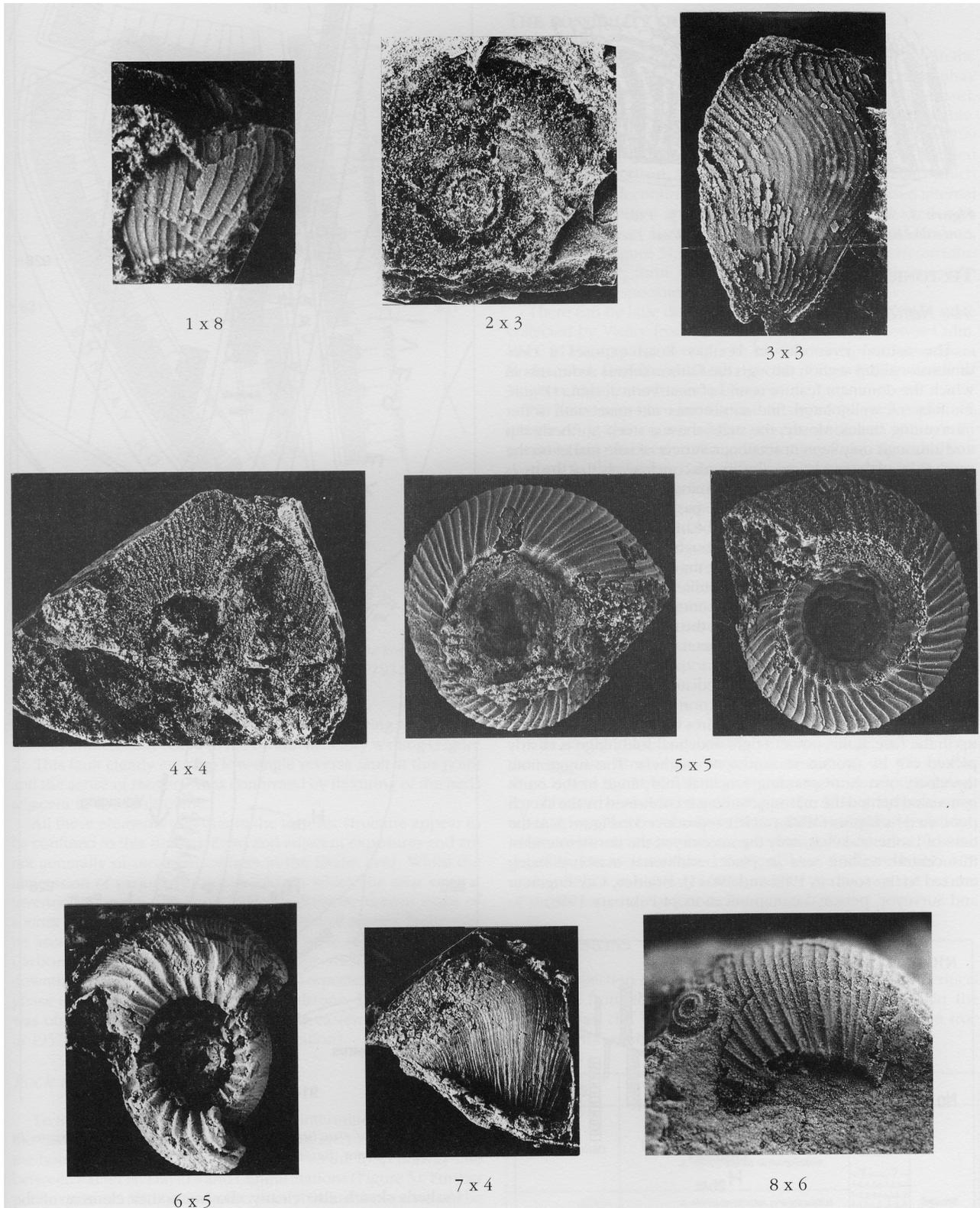


Figure 2. Detailed drawing of the natural river cliff section in Bonhay Road, Exeter. Based on photographs 1958-61. By N.E. Butcher 25 February 1998.



**Plate 1.** Critical goniatites collected by N.E. Butcher 1958-73 in Bonhay Road and Looe Road, Exeter. 1. *Homoceras beyrichianum* (de Koninck) emend. Haug. 2. *Hudsonoceras proteum* 3. *Homoceras undulatum* (Brown). 4. *Cravenoceratoides* sp. or *Nuculoceras* sp. 5. *Homoceras beyrichianum* (de Koninck) emend. Haug. 6. *Reticuloceras circumplicatile* 7. *Reticuloceras pulchellum* 8. *Homoceras* sp. nov or ?*Ramosites* sp.



Figure 3. Sketch by W.A.E. Ussher (1892, p. 138) of cliff face now concealed behind masonry wall in Bonhay Road, Exeter.

**TECTONIC STRUCTURE**

*The Natural River Cliff*

The natural river cliff in Bonhay Road exposes a two-dimensional dip section through the Carboniferous sediments in which the dominant feature is one of near-vertical strata (Figure 2). Ribs of well-jointed fine sandstones alternate with softer intervening shales. Mostly, the strata show a steep northerly dip and although only seen in section, a variety of sole marks on the north sides of the sandstone ribs proves conclusively that the beds are indeed inverted. Weak cross lamination occurs within the sandstones which are fine-grained, passing through siltstones into shales, in which the goniatite-bearing nodules commonly occur. Plant debris is common. Although no petrographic work has been done, these sediments have the character of cyclic units and probably represent distal turbidites. The sandstones are variable in thickness, from very thin stringers to beds of about 1/2 m which act as prominent markers in the cliff face (Figure 2). The shales commonly bear a near horizontal cleavage which has the effect of producing tectonic pencils.

Low down in the cliff face, immediately south of the central masonry walling, the sediments dip north at only 45° and these can be proved by sedimentary structures to be right way up. High up in the face at this point, a tight anticlinal fold hinge is clearly picked out by prominent sandstone markers. The suggestion, therefore, of a corresponding synclinal fold hinge to the north concealed behind the masonry walling is confirmed by the sketch published by Ussher (1892, p. 138), reproduced in Figure 3. At the time of Ussher's sketch, only the masonry at the northern end of this central walling was in place, additional masonry being erected to the south in 1902 and 1904 (J. Brierley, City Engineer and Surveyor, personal communication 24 February 1958).

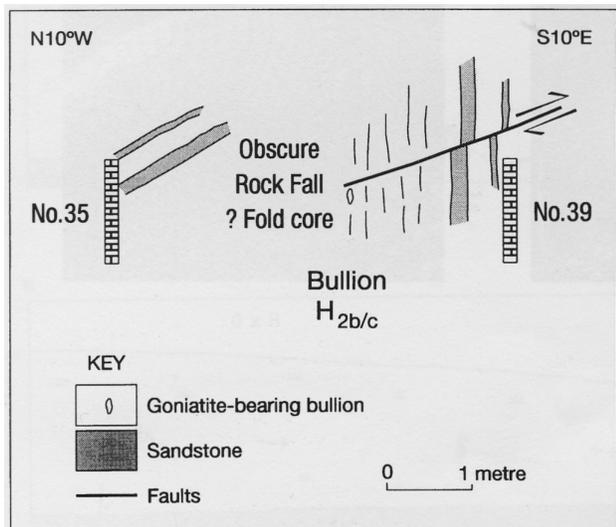


Figure 4. Sketch of section behind No. 37 Looe Road off Bonhay Road, Exeter. Based on survey by N.E. Butcher 23 June 1973.

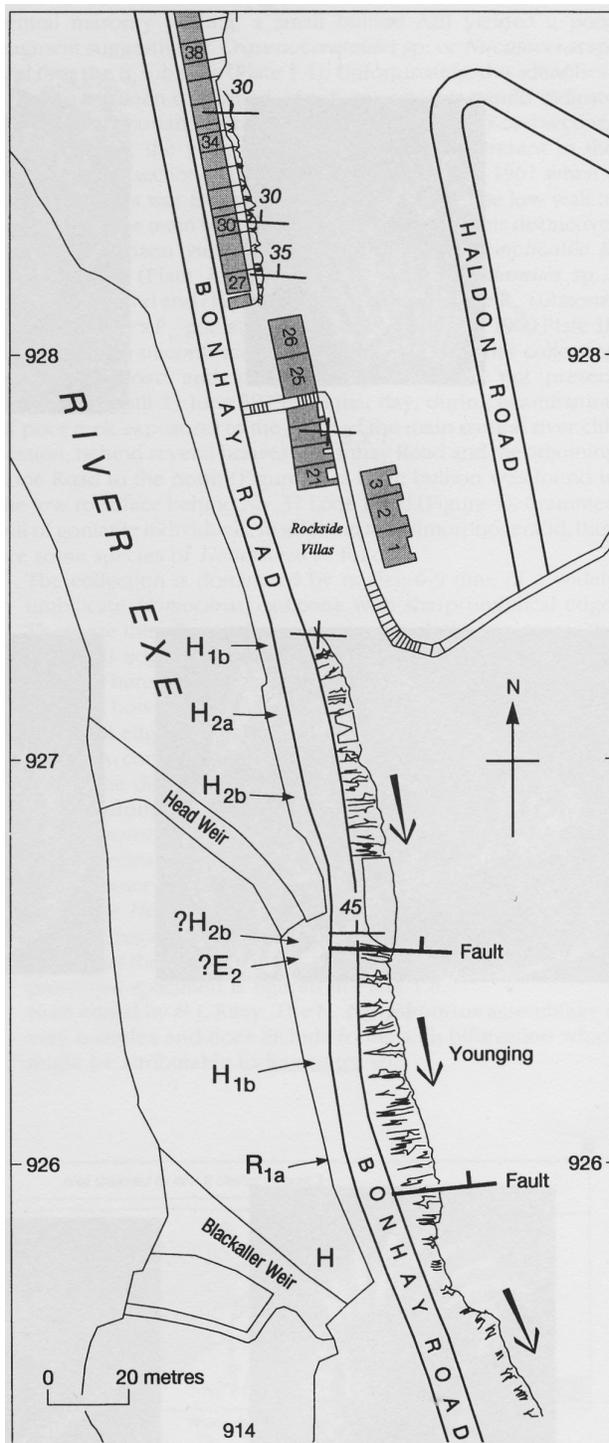


Figure 5. Plan of structural data and critical goniatite horizons in Bonhay Road, Exeter. Based on OS Plan SX 9192 NW 1: 1 250

Ussher's sketch also clearly shows another element of the tectonic structure - the presence of low northerly-clipping reverse faults. These are to be seen throughout the length of the cliff face and clearly post-date the folding, as one is to be seen cutting both limbs of the tight anticlinal hinge mentioned above (Figure 2). A complementary set of southerly-clipping reverse faults is also present, though these tend to be at a higher angle (Figure 2). Some flexuring of adjacent strata on both sets of reverse faults confirms the sense of movement.

Finally, another important and clearly the latest element in the tectonic structure is the presence of near-vertical east-west faults

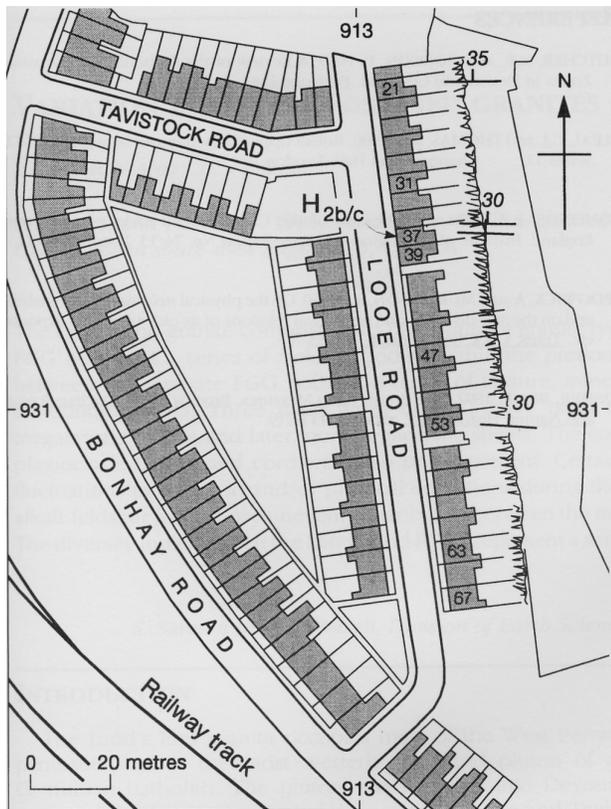


Figure 6. Plan of structural data and critical goniatite horizon in Looe Road off Bonhay Road, Exeter. Based on OS Plan SX 9193 SW 1: 1 250.

downthrowing to the north, the best example being that cutting the fold immediately south of the central masonry walling (Figure 2). This fault clearly cuts the low-angle reverse fault at this point and the sense of movement is confirmed by flexuring of the beds adjacent to the fault plane.

All these elements together in the tectonic structure appear to be confined to this Bonhay Road and adjacent exposures and are not generally observed elsewhere in the Exeter area. Whilst the impression of major overturned folds in which the near vertical inverted limbs are dominant, with subordinate normal limbs of shorter length, cut by complementary sets of reverse faults, can be ascribed to the north-south compressive regime of the late Carboniferous, the near vertical east-west normal faults downthrowing to the north are thought to represent an extensional phase either late or post New Red Sandstone. Evidence for this was observed at Pinhoe Brick Pit on the eastern edge of Exeter in 1957 (Butcher and House, in preparation).

#### Rock Exposures to the North

To the north of the natural river cliff, intermittent exposures of the Carboniferous sandstones and shales are to be seen behind the houses in Bonhay Road as far north as the loop railway line between Exeter St. David's and Central Stations (Figure 5). Further poor exposures also occur further north behind the houses on the east side of Looe Road (Figure 6). In every case, the nature of the exposures is in keeping with what is to be seen in the natural river cliff. Where it can be obtained, structural data is plotted on the large scale plans (Figures 5 and 6).

Clearly, from this data, further fold hinges can be inferred. A key locality is that behind No. 37 Looe Road (Figure 4). An anticlinal fold hinge is presumably present here and the goniatite-bearing nodule obtained from the southern vertical limb confirms a stratigraphical horizon within the range of the succession exposed in the natural river cliff to the south.

#### THE POSSIBILITY OF A LOWER CULM INLIER

In fact, there are four goniatites in the Vicary Collection in the Natural History Museum in London said to come from Bonhay Road. BM C 9108 is a solid, pyritised specimen with some hard, black shaly limestone matrix, but unfortunately not identifiable. It bears the original label "Goniatite Bonhay Road". BM C 9109 and BM C 9110 are the two Namurian forms already identified (Butcher and Hodson, 1960 Plate 19 Figures 1 and 2) and which the present work confirms. BM C 9111 is a solid, pyritised internal mould with sutures and small patches of original shell with ornament and has already been figured (Butcher and Hodson, 1960 Plate 18 Figure 3), identified as *Goniatites sphaericostriatus* Bisat, a Visean  $P_{1c}$  form. A small amount of dark, greyish limestone attaches to the specimen.

There can be little doubt that BM C 9108 and BM C 9111 were collected by Vicary from limestones typical of the Lower Culm. BM C 9111 compares closely with limestones exposed near Spara Bridge and Daddiscombsleigh in the Teign Valley north of Newton Abbot, south-west of Exeter.

No limestones have been found in any of the rock exposures examined in the course of the present work and Vicary's  $P_{1c}$  goniatite has not been confirmed at Bonhay Road. Structurally, it is possible that Lower Culm limestones are present in Bonhay Road, in close proximity to the Namurian sandstones and shales, due to anticlinal folding and/or faulting. The most likely locality for this would be behind Nos. 25 and 26 Bonhay Road [SX 9142 9280], high up on the bank immediately north of the steps leading to Rockside Villas (Figure 5). It is conceivable that Vicary collected here from the foundations for these two houses when they were under construction in the 19th century. However, on the present evidence, it seems better to conclude that Vicary's specimen BM C 9111 was mislabelled and in fact came from the known Teign Valley exposures of the Lower Culm.

#### STRATIGRAPHY

The stratigraphical succession at Bonhay Road extends from the top of the Arnsbergian stage  $E_2$  zone through the Chokierian stage  $H_1$  and the Alportian stage  $H_2$  into the Kinderscoutian stage  $R_{1a}$  subzone of the Namurian (Figure 7). It is a succession of repeated cycles of subordinate fine sandstones passing through siltstones into dominant shales, representing distal marine turbidite deposits. The total measured stratigraphical thickness is about 75 m. It is only a partial succession, neither the top nor the bottom of the sedimentary sequence being seen.

#### CONCLUSIONS

The collection and identification of accurately located critical goniatites from the Carboniferous sediments exposed in the natural river cliff in Bonhay Road and nearby allows the true nature of the stratigraphy and the tectonic structure to be established.

STAGES	ZONES	SEDIMENT	
Kinderscoutian	$R_1$ c <i>Reticuloceras reticulatum</i> b <i>Reticuloceras nodosum</i> a <i>Reticuloceras circumplicatile</i>		Repeated cycles of distal marine turbidite deposits
Alportian	$H_2$ c <i>Homoceras prereticulatus</i> b <i>Homoceras undulatum</i> a <i>Hudsonoceras proteum</i>		
Chokierian	$H_1$ b <i>Homoceras beyrichianum</i> a <i>Isohomoceras subglobosum</i>		
Arnsbergian	$E_2$ c <i>Nuculoceras nuculum</i> b <i>Cravenoceras nitidus</i> a <i>Eumorphoceras bisulcatum</i>		
			0 20 metres

Figure 7. Idealised stratigraphical succession of Crackington Formation exposed in the natural river cliff in Bonhay Road, Exeter.

This north-south section appears to be the key inland section in the Crackington Formation (Cleal and Thomas, 1996, pp. 44-45), representing perhaps the oldest Namurian strata exposed in the Exeter area.

It is recognised that this study presents only a two-dimensional picture of the tectonic structure, but this Bonhay Road section may be the core of a larger structure. Both north-south compressive, late Carboniferous and extensional, late to post New Red Sandstone elements are present.

The thin stratigraphical succession of the Namurian sediments may be an indication of the wider picture and throw doubt on the claim in BGS 1: 50 000 Sheet 325 Exeter 1995 that the Crackington Formation is up to ? 1 000 m thick. Without close palaeontological control, it is not clear how the true nature of the tectonic structure and the stratigraphical thickness can be determined.

#### **ACKNOWLEDGEMENTS**

This work was commenced in January 1958 when both authors were employed by the University of Reading and continued whilst the second author held the Chair of Geology in the University of Southampton. The first author thanks the Research Board of the University of Reading for financial support, which was added to by the Geological Society of London through its Gloyne Outdoor Geological Fund.

M.R. House and W.R. Dearman have particularly encouraged the first author over many years. E.N.K. Clarkson is thanked for photographing the goniatite specimen in Plate 1.8. S. Horsburgh of the Drawing Office of the British Geological Survey, Murchison House, Edinburgh kindly provided the text figures. N.J. Riley kindly advised on goniatite nomenclature.

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