Keele UNIVERSITY

THE PALAEONTOLOGY, SEDIMENTOLOGY AND STRATIGRAPHY OF THE UPPER ARNSBERGIAN, CHOKIERIAN AND ALPORTIAN OF THE NORTH STAFFORDSHIRE BASIN

by

THOMAS BOLTON

VOLUME II

Thesis submitted for the degree of Doctor of Philosophy at the University of Keele

1978

CHAPTER 3

MICROPALAEONTOLOGY

THE MICROFAUNA OF THE BULLION HORIZONS IN THE NORTH STAFFS. BASIN

Introduction

During the course of this work the microfaunas of several of the faunal horizons occurring in the North Staffordshire Basin were examined. The microfaunas present in these horizons include Radiolaria, spat molluses and sponge spicules.

The Radiolaria are only found in limestone bullions, (Holdsworth, 1964a, 1966a, b, c, 1967 and 1969a), which are considered by Holdsworth (1966b) to be early diagenetic calcareous concretions in which the original skeletal radiolarian framework has been selectively replaced by ankeritic dolomite (Holdsworth, 1967). The preservation of the Radiolaria within the limestone bullions is very variable. At some localities the process of dolomitisation has completely destroyed the microfauna and also in several instances the microfauna has largely been obliterated. For example, the well preserved radiolarian content of the E_2b_2 limestone bullion horizon at Loc. 126 in the Wiggenstall Stream, appears to have been completely obliterated by dolomitisation in the Blake Brook Section. Examination of specimens of limestone from the E_2b_2 Subzone in the Ashover Boreholes also indicated that dolomitisation had destroyed the microfauna at a level thought to be equivalent to that of the faunal band present at Loc. 126 in the Wiggenstall Stream.

Commonly the bullion material examined has a dolomitic or pyritic and dolomitic rim which may extend into the limestone for several centimetres and within this zone the microfauna is usually completely destroyed.

The microfaunas of the bullions investigated reveal that in all cases the most abundant forms present are entactiniid spumellarians of the genera Entactinia, Entactinosphaera and Polyentactinia. Detailed taxonomic work has not been attempted on the Spumellaria but examination of bullion material from several horizons within the range E_2b_1 to H_1a indicates that no apparent marked change occurs from horizon to horizon in the spumellarian species present. Holdsworth (1966a) commenting on the radiolarian faunas present in the North Staffordshire Basin in the range E_2b_1 to low R_2b states, in connection with the spumellarian population, "......There is no obvious regular change in species present from horizon to horizon comparable with the marked and irreversible trend of the successive goniatite faunas." There are however a number of non-spumellarian Radiolaria which are of relatively sparse occurrence in the microfaunas, but which display distinct differences which may be of evolutionary significance. These are largely members of the Suborder Albaillellaria and in particular include the Genera Ceratoikiscum Deflandre and Albaillella Deflandre. Previous work on the radiolarian content of some of the faunal bands in the North Staffordshire Basin by Holdsworth (1966a) indicated that the Albaillellaria displayed significant evolutionary changes and that as with the Namurian goniatites they could be used as index fossils of the faunal bands. In the course of the present work detailed examination was confined to genera belonging to the Suborder Albaillellaria. During the course of this work, three new subspecies of Ceratoikiscum were recorded from limestone bullion horizons in the North Staffordshire Basin. In the following account details are given of the microfauna present at the localities examined in the basin in the interval E_2b_1 - H_2c. Systematic descriptions of the three new subspecies of Ceratoikiscum are also given and the notation and nomenclature of the basic skeletal frame of Ceratoikiscum spp., as developed by Forman (1963) and elaborated by Holdsworth (1969a, text - figure 1) is used in the descriptions (see Fig.3.A.).

Preparation of Specimens for examination

The bullion material was cut into thin slabs, 0.5-1 cm thick, and one side of the slab was etched in a 50% solution of hydrochloric acid for approximately 30 seconds, the time interval is variable depending on the solubility of the limestone. The effect of the etch is to remove a sufficient thickness of soluble material so that one layer of microfossils can be examined. Too deep an etch produces a confusing mass of specimens, whilst too shallow an etch reveals insufficient detail. A trial etch will usually indicate the primary sedimentary stratification of the bullion material which is picked out by the clay sized detrital fraction, usually comprising only a minor portion of the limestone. Once the orientation of the sample is ascertained sections of the bullion material are cut normal to the bedding, as this orientation of the material is found to provide the most suitable surface for examination of the microfauna, since selectively dolomitised areas or clay laminae form only a small part of the etched surface. Hydrocarbons are commonly present in the limestone, and are released when the material is etched; this is proposed as a further indication of the early diagenetic origin of the bullions in which preservation of the fragile skeletal radiolarian structures has taken place without any distortion of the specimens. Following the initial examination of the etched surface, the slab was mounted in a dust proof box with a transparent lid, on which the position of the specimens identified was recorded.

Microfauna of a limestone bullion occurring at Loc. 130 present in the Wiggenstall Stream Section 11T. Horizon $E_{2}b_{2-1}$.

This is the highest of three horizons present in this section each containing Ct.edalense. In Namurian bullion material examined to date the frequency of occurrence of Ceratoikiscum sp. is low in comparison with associated Radiolaria.

The bullion material at Loc. 130 is no exception, and is in fact remarkable for the high concentration of Entactinidae which exhibit excellent perservation. Sponge spicules are much less numerous in occurrence than the Radiolaria, although both isolated hollow megascleres and small sponges are present. Mature and rare spat goniatites are present and the mature forms are identified [1.] as Cravenoceras edalense, (Bisat). Lamellibranch spat is sparsely represented on the etched surfaces.

The Ceratoikiscidae present in the bullion material at Loc. 130 are represented by a single new subspecies Ceratoikiscum aff. tricancellatum A, the vertical range of this subspecies is unknown, but on the basis of the occurrence of Ceratoikiscum bicancellatum sp. nov (Holdsworth, 1969) is thought to terminate below the level of Ct. nitidus. The lateral extent of C. aff. tricancellatum A in the North Staffordshire Basin is unknown.

Systematic description of Ceratoikiscum aff. tricancellatum A

Subclass Radiolaria Muller, (1858).

Order Porulosida Haekel, (1887).

Suborder Albaillellaria Deflandre, (1953) emend. Holdsworth, (1969).

Family Ceratoikiscidae Holdsworth, (1969).

Genus Ceratoikiscum Deflandre, (1953).

Species Ceratoikiscum tricancellatum Holdsworth (1969), n.sp.

Subspecies Ceratoikiscum aff. tricancellatum A

1. Identification by B. K. Holdsworth.

Fig.3.A.

Anatomical notation of the Ceratoikiscum frame.
(after Holdsworth, 1969).

Figs.3.B. - 3.F.

Ceratoikiscum aff. tricancellatum A.

Fig.3.B. Specimen 291. Mag. x 180 Left lateral view.

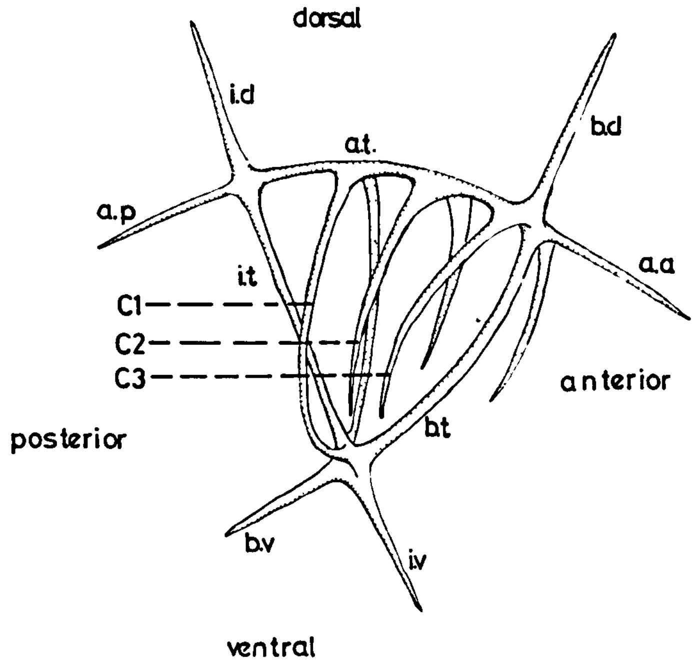
Fig.3.C. Specimen 279. Mag. x 180 Left lateral view.

Fig.3.D. Specimen 294. Mag. x 180 Posterodorsal view.

Fig.3.E. Specimen 256. Mag. x 180 Anteroventral view.

Fig.3.F. Specimen 275. Mag. x 180 Ventral view.

Fig. 3.A



Anatomical notation of the <u>Ceratoikiscum</u> frame.

Fig. 3. B.

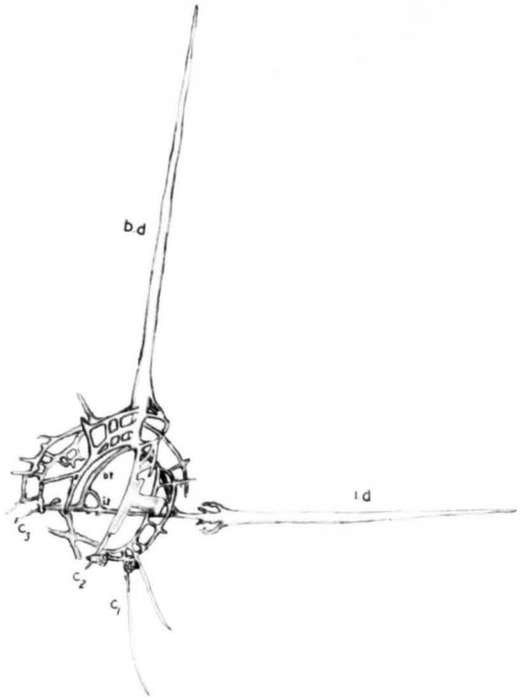
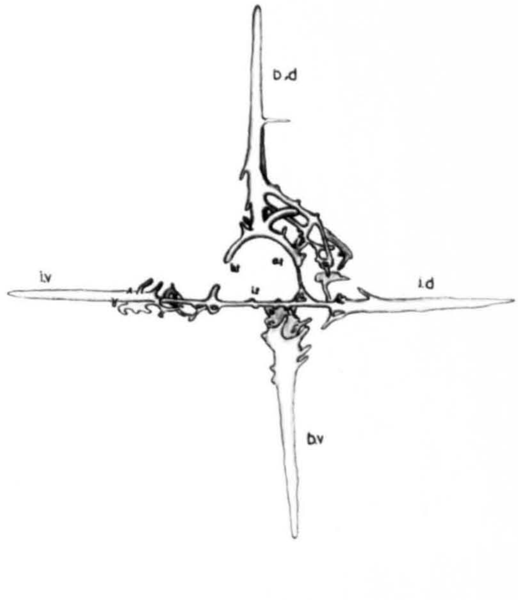


Fig. 3.C.



Description of the typical form of Ceratoikiscum aff. tricancellatum A.

(Figs.3.B.,C.,D.,E., and F.)

The basic frame of C. aff. tricancellatum A consists of three delicate rods, diameter 2-3 microns, forming an approximate equilateral triangle, the a.t and b.t rods are curved, the i.t rod is straight. Four extra-triangular tapered spinose extensions are present, i.v, i.d, b.v and b.d. The i.v and i.d spines thin abruptly to the diameter of the i.t rod some 25-35 microns prior to the i.t - b.t and a.t - i.t junctions, and are supported by perforate patagial vanes which are linked in turn to the b.t and a.t rods and to the b.d spine.

The b.d spine is attached to the basic triangle at the a.t - b.t junction, whilst the b.v spine is linked to the i.t rod by several patagial attachments. The b.v spine is not medially located with respect to the i.t rod but occupies a position between the medial point and the a.t - i.t junction.

Three paired caveal ribs are present, the anterior rib pair C3, arises at the a.t - b.t junction and forms a forwardly concave crescent which terminates ventrally. The C2 rib pair is attached to the a.t rod posteriorly to the C3 junction and form a slightly posteriorly concave crescent which terminates ventrally. The Cl rib pair form a saucer shaped loop which is concave posteriorly and is linked ventrally to the b.v spine. Dorsally the caveal ribs bear perforate vanes, the pore walls being extended into spines.

The pore pattern of the Cl rib vanes consists of a single row of subquadrate pores ventrally, with a second row of subquadrate to subtriangular pores commencing laterally and continuing dorsally. The C2 rib vanes contain mainly subquadrate pores but irregularities occur in the pore pattern in some specimens, a maximum of three pore rows has been observed although usually only the first pore row is clearly defined.

The C3 rib vanes are attached dorsally to the b.d spine, pores are subquadrate and form one distinct pore row with a poorly developed second and third row of mainly irregular pores formed dorsally to the rib spine.

Dimensions of Ceratoikiscum aff. tricancellatum A

Specimen 291, (Fig.3.B.) chord to b.t 56 u, chord to a.t 56 u, i.t 64 u, i.d 202 u, b.d 230 u, thin portion of i.d 29 u.

Specimen 279, (Fig.3.C.) chord to b.t 53 u, chord to a.t 56 u, i.t 60 u, b.d 157 u, b.v 165 u, i.d 160 u, i.v 155 u, thin portion of i.d 29 u, thin portion of i.v 31 u.

Specimen 294, (Fig.3.D.) b.d circa 234 u (distorted).

Specimen 293, (Fig.3.E.) b.d circa 160 u (incomplete).

Specimen 256, thin portion of i.v 34 u, b.d 223 u.

Specimen 257, chord to b.t 57 u, chord to a.t 51 u, i.t 56 u, thin portion of i.v 27 u, b.v 173 u, b.d 165 u.

Specimen 258, i.v circa 170 u.

Specimen 259, chord to b.t 58.5 u, chord to a.t 52 u, i.t 60 u, thin portion of i.d 29 u, thin portion of i.v 27 u, b.v 234 u.

Specimen 261, i.d 173 u.

Specimen 262, b.d 197 u, b.v circa 181 u, internal diameter C1 loop 64 u.

Specimen 264, chord to b.t 53 u, chord to a.t 51 u, i.t 56 u, thin portion of i.d 27 u.

Specimen 265, thin portion of i.v 27 u.

Specimen 266, b.d 149 u (probably incomplete).

Specimen 267, i.t 53 u.

Specimen 272, chord to b.t 62 u, chord to a.t 62 u, i.t 64 u, b.d 309 u, b.v 230 u.

Specimen 273, b.d 170 u.

Specimen 280, chord to b.t 56 u, chord to a.t 51 u, i.t 56 u, thin portion of i.d 27 u, i.d 162 u.

Specimen 292, i.v 181 u.

Specimen 295, chord to b.t 56 u, chord to a.t 53 u, i.t 56 u, b.d 157 u, b.v 192 u, i.v 162 u.

Specimen 296, b.d circa 239 u.

Distinguishing features

The most marked distinction between C. aff. tricancellatum A and C. tricancellatum is seen in the occurrence in the former of two fragile connecting rods, circa 3 microns in diameter by 25-35 microns long, one linking the i.v spine and the other the i.d spine to the i.t rod. In well preserved specimens the thick bases of the i.v and i.d spines bear the remnants of roughly radially disposed patagial attachments which are thought to have strengthened the junctions of these rods with the basic triangle. In C.tricancellatum however, the two fragile connecting rods are absent and the i.v and i.d spines are attached at their bases directly to the basic triangle.

Variants of Ceratoikiscum aff. tricancellatum A

One specimen only (271) possesses an additional spine, $b.v_{ii}$, which is located to the left of b.v and is linked to it by small patagial rods. Non-systematic variations occur in the pore pattern of the caveal vanes but due to incomplete preservation they are difficult to define. In the majority of specimens the pore rows are composed of subquadrate pores which persist throughout the vane, on the other hand, some specimens display a completely random pattern of irregular pores, this is frequently common in vane areas proximal to the a.t rod.

Figs.3.G. - 3.P.

Ceratoikiscum aff. bicancellatum A.

Fig.3.G. Specimen 207. Mag. x 180 Right lateral view.

Fig.3.H. Specimen 208. Mag. x 180 Anterior view.

Fig.3.I. Specimen 216. Mag. x 180 Anterodorsal view.

Fig.3.J. Specimen 217. Mag. x 180 Anterior view.

Fig.3.K. Specimen 226. Mag. x 180 Right lateral view.

Fig.3.L. Specimen 233. Mag. x 180 Left lateral view.

Fig.3.M. Specimen 239. Mag. x 180 Anterolateral view.

Fig.3.N. Specimen 242. Mag. x 180 Anteroventral view.

Fig.3.0. Specimen 255. Mag. x 180 Left lateral view.

Fig.3.P. Specimen 244. Mag. x 180 Anteroventral view.

Fig. 3.G.

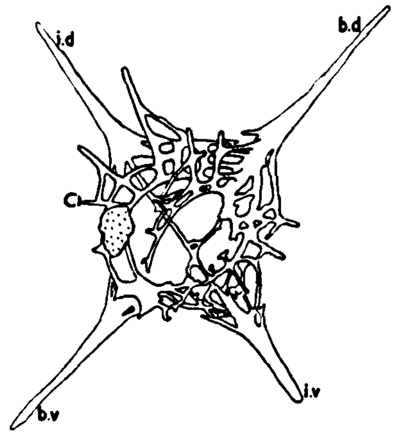


Fig. 3.H.

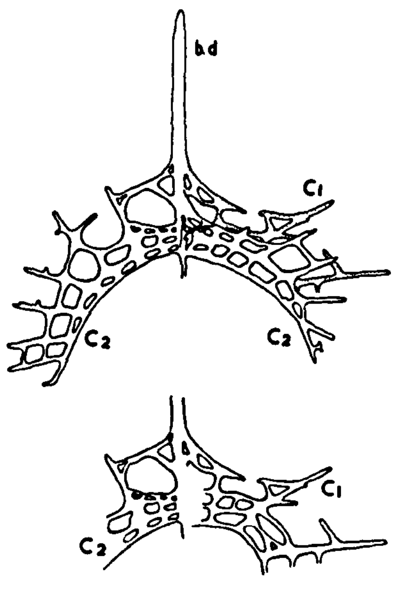


Fig. 3.I.

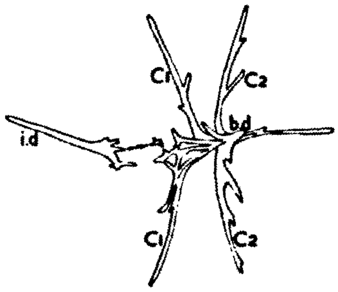


Fig. 3.J.

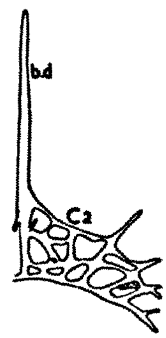


Fig. 3.K.

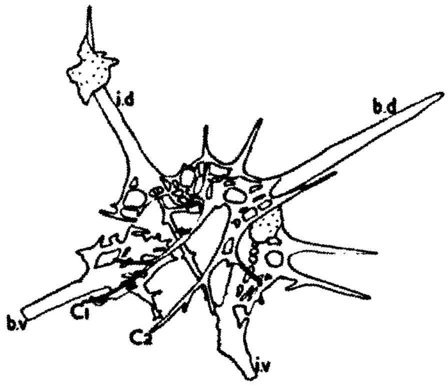


Fig. 3. L.

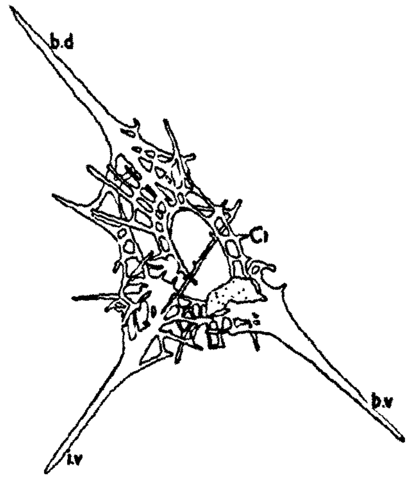


Fig.3.M.

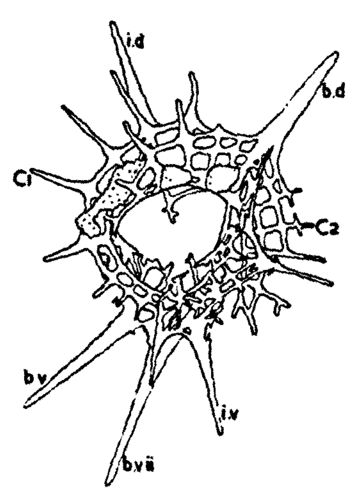


Fig. 3.N.

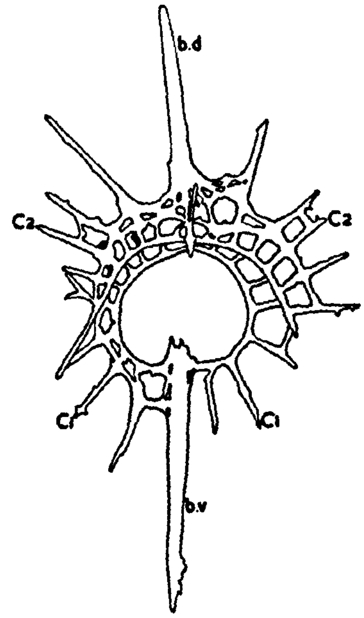


Fig. 3.P.

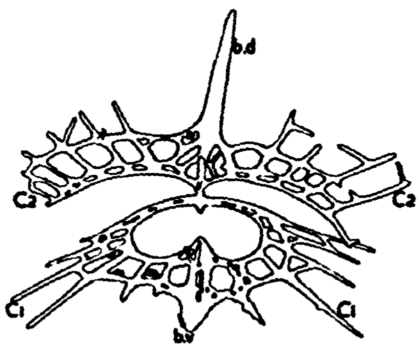
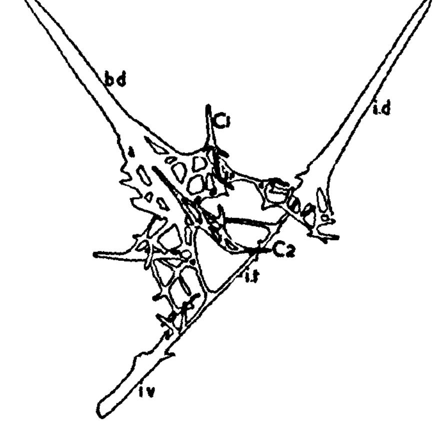


Fig. 3.O.



Microfauna of the limestone bullion occurring at Loc. 126, present in the Wiggenstall Stream, Section 11T. Horizon E_2b_2, 3.66m below the horizon of C.holmesi and 9.45m above the Stannery Limestone.

The etched surfaces of the bullion material at this locality display rare detached hollow sponge spicules, megascleres and occasional small sponges. Goniatite spat occur extremely rarely and when present they are discoidal to subglobose and possess a small deep umbilicus, external ornament is absent. Radiolaria, exhibiting exquisite perservation, occur in profusion on the etched surfaces, the Suborders Albaillellaria and Spumellaria are represented with members of the Family Entactiniidae being the most numerous. The Ceratoikiscidae are represented by a single distinct form which occurs very infrequently in the bullion material and is identified as a new subspecies, Ceratoikiscum aff. bicancellatum A. This new subspecies appears to be restricted in occurrence to an horizon below the level of C.holmesi Loc. 125, and above the Stannery Limestone, Loc. 127, the lateral extent of this horizon is unknown.

Description of typical form of Ceratoikiscum aff. bicancallatum A.

(Figs.3.G.,H.,I.,J.,K.,L.,M.,N.,0 and P.)

The basic frame of C. aff. bicancellatum A consists of three delicate rods, diameter 2-3 microns, forming an approximate equilateral triangle, in which the a.t and b.t rods are curved and the i.t rod is straight. Four extra-triangular tapered spinose extensions only are present, i.v, i.d, b.v and b.d. Where i.v and i.d are attached to the basic triangle, there is a marked thinning of these spines, which are also attached at their bases to perforate circlets of patagial tissue. The b.d spine is attached to the basic triangle at the a.t - b.t junction; whilst the b.v spine arises from a medial position on the i.t rod and in specimen 213 is seen to be joined to this rod by patagial tissue. Perforate patagial vanes are present between b.d and i.d, and between b.d and i.v, the vanes are attached to the b.d, i.v and i.d spines and to the a.t and b.t rods. A random pore pattern is displayed by these vanes, two rows of pores may be present, the pores varying in shape from sub-rounded to subquadrate to subtriangular, size is variable. The pore walls are produced to form a patagial spine, in some specimens two spines per vane are present. C. aff. bicancellatum A possesses two rib pairs, C1 and C2 which arise from the a.t rod. The anterior rib pair C2 arises at the a.t - b.t junction, whilst the C1 rib pair are attached to the a.t rod posteriorly to the C2 junction. The junction of the C2 ribs with the a.t rod is not symmetrical, the left hand rib being slightly off-set dorsally and the right hand rib junction off-set ventrally. The C2 rib pair form a forwardly concave crescent which terminates ventrally. The C1 rib pair form a saucer shaped loop which is concave posteriorly and is linked ventrally to the b.v spine. Dorsally, the caveal ribs bear perforate vanes, the pore walls being extended into spines, the vane spines. Considerable variation exists in the pore structure of the vanes and in the development of the vane spines, and due to their delicate structure these features are not always completely present in the etched preparation. Asymmetry of the C2 rib vanes is marked by variations in the pore pattern and vane spines. A maximum of six pores is present in the first and second pore rows. The first pore row, C2 vane, tapers to the a.t junction, i.e. proximally, and also tapers ventrally merging with the rib prior to the distal termination of the rib. The pores are subquadrate and are usually smaller than the pores in the second row. The second pore row, C2 rib vane, is composed of subrounded to subquadrate pores which display unequal development on the right and left C2 rib vane, are usually only fragmentarily preserved and consist of large subquadrate pores.

The pore pattern of the C1 rib vanes consists of a single row of subrounded to subquadrate pores, ventrally, with a second row of subquadrate to subtriangular pores commencing laterally and continuing dorsally.

Dimensions of Ceratoikiscum aff. bicancellatum A

Specimen 207, (Fig.3.G.) chord to b.t 53 u, b.d 202 u, b.v 181 u measured from the i.t rod to the tip of b.v, thin portion of i.v circa 56 u, i.v incomplete.

Specimen 242, (Fig.3.N.) b.d 175 u.

Specimen 233, (Fig.3.L.) chord to a.t 53 u, i.t circa 51 u, chord to b.t 53 u, b.d 194 u, b.v 207 u measured from the i.t rod to the tip of b.v, i.v 160 u measured from the b.t - i.t junction.

Specimen 239, (Fig.3.M.) b.v 181 u, measured from the i.t rod to the tip of b.v.

Specimen 255, (Fig.3.O.) chord to a.t 55 u, i.t 58 u, chord to b.t 53 u, b.d 218 u, i.d 200 u measured from the a.t - i.t junction, thin portion of i.v circa 48 u, thin portion of i.d circa 32 u.

Distinguishing features

C. aff. bicancellatum A possesses four extra-triangular spines, and the presence of the four spines in this subspecies clearly distinguishes it from C. bicancellatum in which the b.v spine is absent. Whilst another major distinctive feature of C. aff. bicancellatum A is seen in the asymmetrical junction of the C2 rib pair with the a.t rod.

Variants of Ceratoikiscum aff. bicancellatum A

On three specimens 239, 234 and 254, a spine of the same magnitude as b.v occurs in close proximity to b.v and is termed $b.v_{ii}$, (Fig.3.M.) this spine occupies a position to the left of the plane containing b.d and b.v. Specimen 239 (Fig.3.M.) possesses a perforate trough-like structure composed of patagial tissue which bears spinose extension at its four corners, the spine at the left ventral corner is i.v, the other corners bear patagial spines. The long axis of the trough bisects the angle between b.v and $b.v_{ii}$ and continues dorsally to b.d eventually merging with this spine and the caveal rib C2.

Microfauna of the limestone bullion bed occurring at Loc. 306B (Holdsworth, 1963), present in the Swallow Brook. Horizon E_2c_{2-2i}

This bullion bed is the lowest of four in situ bullion beds present in this section, each containing N.nuculum.

Bullion material from Holdsworth's 1963 Locality 306B was not recovered on re-examination of the Swallow Brook Section. Holdsworth (1969a) records N.nuculum at this locality and states that this horizon is the lowest E_2c_2 horizon in this succession. Holdsworth (1969a) records the presence of C.tricancellatum, C.lorum and Albaillella aff. pennata within the limestone at Loc. 306B and correlates this horizon on the basis of the occurrence of C.lorum with his bullion horizon at Loc. 269 in the Stannery Farm Section.[1.]

1. Bullion 269 (Holdsworth, 1963) from the Stannery Farm Section. This material was re-examined and the presence of C.tricancellatum, C.lorum and Albaillella sp. was confirmed at this level, and on the basis of the distribution of the microfauna in the Swallow Brook section, there is little doubt that this bullion horizon at Loc. 269 correlates with the bullion material from Holdsworth's Loc. 306B in the Swallow Brook.

Microfauna of a single limestone bullion (loose) occurring at Loc. 306 (Holdsworth, 1963), present in the Swallow Brook.

Position

In the E_2c_2 Subzone, the bullion is thought to have been initially located near the base of the Subzone, but its occurrence as a loose bullion 60 ft down-stream from the lowest E_2c_{2i} horizon does not enable it to be accurately placed. The bullion at Loc. 306 has a deeply dolomitised rim, 5-6 cm deep, and contains a high proportion of clay sized detrital particles. A poorly preserved microfauna is present including entactiniid spumellarians rare specimens of Ceratoikiscum aff. tricancellatum, Holdsworth, and rare specimens of Albaillella sp. Mollusc spat is of rare occurrence. Although the lithology and faunal content of the single loose bullion recovered from Holdsworth's Loc. 306 differ, the contained microfauna tends to suggest that the stratigraphic level of the bullion is close to that of the bullion horizon at 306B. (E_2c_{2i}).

Microfauna of a single loose bullion occurring at Loc. 308 (Holdsworth, 1963), present in the Swallow Brook.

Position

In the E_2c_2 Subzone - as the bullion is loose it cannot be accurately placed, but on the basis of its microfauna it is thought to have originated at the 306B horizon (E_2c_{2i}).

The bullion at Loc. 308 is the type material of C.tricancellatum, C.triangulatum and C.lorum. This limestone also contains Albaillella aff. pennata and abundant entactiniid spumellarians.

Microfauna of the limestone bullion bed occurring at Loc. 309 (Holdsworth, 1963), present in the Swallow Brook.

Horizon

In the upper part of the E_2c_2 Subzone.

This bullion material contains abundant and well preserved entactiniid spumellarians. The very rare Albaillellaria include *Albaillella sp.* and a very small poorly preserved fragile species identified as *Ceratoikiscum sp.* This minute Ceratoikiscid displays two paired caveal ribs, the C1 rib pair form a loop and possess one row of quadrate pores. Rare spat goniatites and lamellibranchs are also present together with rare isolated sponge spicules.

Microfauna of the limestone bullion bed occurring at Loc. 210, present in the Swallow Brook.

Horizon E_2c_{2iii}.

The bullion material at this location exhibits a narrow dolomitised margin and contains numerous clay rich laminae. The presence of such marked lamination is unusual in association with a well preserved microfauna. Entactiniidae are numerous and well preserved, their delicate spines forming an interlocking felt on deeply etched surfaces. Sponge spicules though present are rare in comparison to their occurrence in other bullion material and the small sponges observed in the highest E_2c_2 horizon in the Swallow Brook are significantly absent. The suborder Albaillellaria is represented in the bullion material by a new subspecies of *Ceratoikiscum* *Ceratoikiscum* aff. *bicancellatum* B, and in addition by *Albaillella sp.*, and *Albaillella* aff. *pennata.* The association of *Ceratoikiscum sp.* and *Albaillella sp.* has previously been recorded by Holdsworth (1969a) from the E_2c_2 Subzone in bullions 306B and 269 (Locs. of Holdsworth, 1963) where the species *C.tricancellatum* and Albaillella aff. pennata occur in association.

Also encountered in the bullion material at Loc. 210 is what appears to be an analogue of Albaillella sp., a conical form identified as Corythoecia Foreman sp. A previously undescribed form having some similarities to Ceratoikiscum sp. is also present and is readily identified by a complex development of spongy patagial tissue and the absence of a basic triangular frame.[1.] Relatively rare goniatite and lamellibranch spat occur although larger immature goniatites are present and are identified as Nuculoceras nuculum and Eumorphoceras bisulcatum.

Stratigraphical position of the limestone bullion horizon at Loc. 210

The limestone bullion containing C. aff. bicancellatum B is present in the bed of Swallow Brook, a tributary of the River Dove, and occurs circa 6.00m vertically below the level of bullion 284 (Holdsworth, 1963) which contains Nuculoceras nuculum and Eumorphoceras bisulcatum aff. mut.b. Two bullion horizons 307 and 306B and two loose bullions 308 and 306 occur in the section below the bullion horizon at Loc. 210 all carry the zone fossils of the E_2c_2 Subzone. A bullion horizon carrying Homoceras subglobosum is present circa 30.00m above bullion 284 (Holdsworth, 1963) and on this and the foregoing evidence, the C. aff. bicancellatum B horizon is placed in the upper part of the E_2c_2 Subzone.

1. This form is probably Radiolaria Genus B, first encountered by Forman (1963) from the Upper Devonian, Ohio Shale, and laterly recognised by Holdsworth (1973) from the Lower Carboniferous, (Baltalimani Formation, whose figured specimen (P.14., plate 1) corresponds closely with specimens from Loc. 210.

Figs.3.Q. - 3.U.

Ceratoikiscum aff. bicancellatum B.

Fig.3.Q. Specimen 321. Mag. x 180. Anteroventral view.

Fig.3.R. Specimen 300. Mag. x 180. Left lateral view.

Fig.3.S. Specimen 330. Mag. x 180. Lateral view.

Fig.3.T. Specimen 331. Mag. x 180. Left lateral view.

Fig.3.U. Specimen 322. Mag. x 180. Anterior view.

Figs.3.V. and 3.W.

Radiolaria Genus B.

Fig.3.V. Specimen 315. Mag. x 180. Lateral view.

Fig.3.W. Specimen 314. Mag. x 180. Lateral view.

Fig. 3.Q.

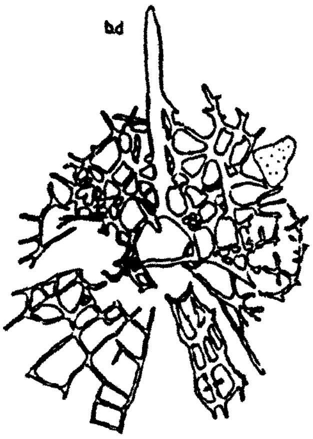


Fig. 3.R.

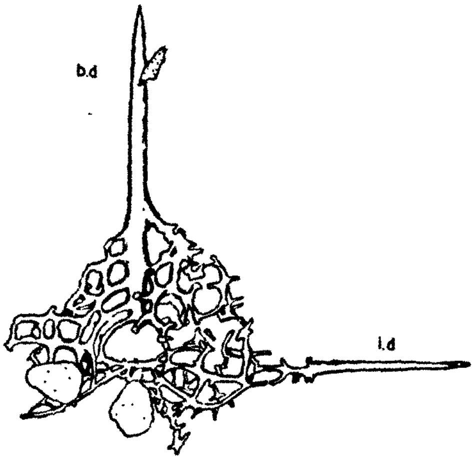


Fig. 3.S.

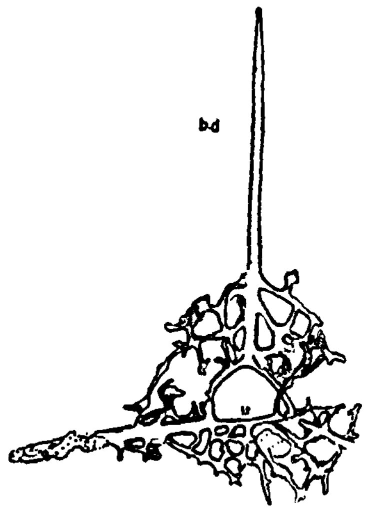


Fig. 3.T.

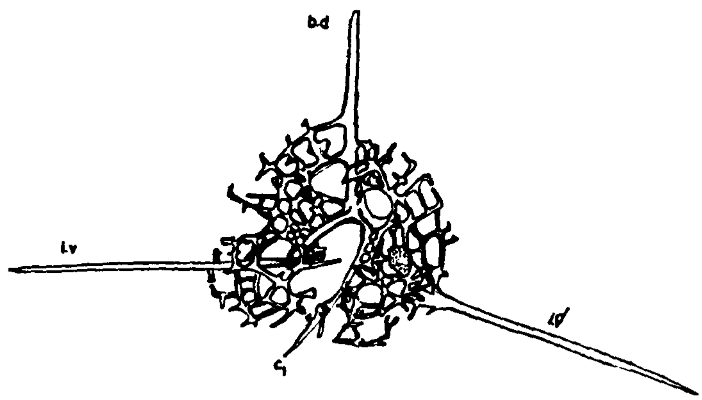


Fig. 3.U.

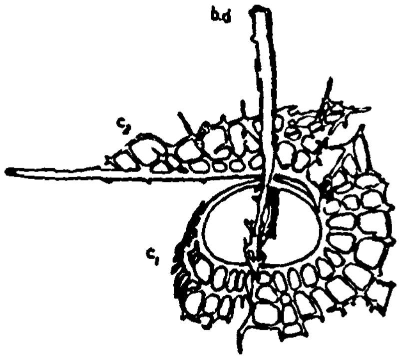


Fig. 3.V.

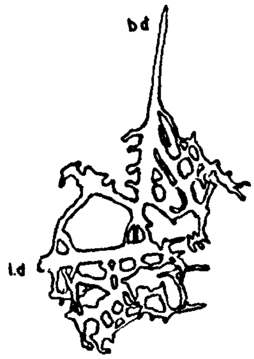


Fig. 3.W.

Description of typical form of Ceratoikiscum aff. bicancellatum B

(Figs.3.Q.,R.,S.,T. and U.)

This subspecies is characterised by a basic triangle bearing three extra-triangular spines embedded in an intricate framework of patagial tissue. The basic triangle is approximately equilateral and consists of three delicate rods, i.t which is straight and a.t and b.t which are slightly curved, the rods have a diameter of 2-3 microns. The three extra-triangular spines are positioned as follows; the b.d spine arises at the a.t - b.t junction, the i.d spine at the i.t - a.t junction and the i.v spine at the b.t - i.t junction. These junctions are not as clear as those in the previously described Namurian Ceratoikiscids since they are assimilated in an intricate mesh of supporting patagial tissue.

A characteristic of this subspecies is the absence of the b.v spine, in its place occurs an arcuate zone of perforate patagial tissue which fuses with the C1 caveal rib and rib vane. Perforate patagial tissue occupies the sectors between the three extra-triangular spines and in some specimens perforate pouches are present, opening dorsally in the patagial zone between i.d and b.d, and ventrally in the zone between b.d and i.v.

Two paired caveal ribs are present, both are strongly developed,the C2 rib pair exceptionally so. The C2 ribs arise at the base of b.d on the a.t - b.t junction, the ribs bear perforate vanes containing three rows of subquadrate pores which taper to zero laterally, prior to the distal termination of the ribs.

The C1 rib pair arise from the a.t rod and form a loop which passes below the i.t rod. The perforate C1 rib vanes are concave posteriorly and contain three rows of regularly arranged subquadrate pores, with a fragmentary development of an outer fourth row. The extensive pore development is notable in this Subspecies when compared to the single pore rows of the C1 rib vanes exhibited by C. aff. bicancellatum A and C. aff. tricancellatum A.

Dimensions of Ceratoikiscum aff. bicancellatum B

Specimen 321, (Fig.3.Q.) chord to a.t 44 u, chord to b.t 40 u, i.t 53 u, b.d 152 u.

Specimen 300, (Fig.3.R.) chord to a.t 42.5 u, chord to b.t 40 u, i.t 53 u, b.d 223 u, i.d 213 u.

Specimen 323, chord to a.t 42.5 u, chord to b.t 48 u, i.t 43 u, b.d 250 u.

Specimen 324, i.d 192 u.

Specimen 330, (Fig.3.S.), chord to a.t 48 u, chord to b.t 48 u, i.t 56 u, b.d 261 u, i.d 253 u, i.v 226 u.

Distinguishing features

C. aff. bicancellatum B can clearly be distinguished from all the other known Namurian Ceratoikiscids, by the possession of an extensive development of filamentous patagial tissue surrounding the basic triangle. In addition this subspecies possesses a very strongly developed C2 rib pair, whilst the pore pattern of the C1 rib vanes is remarkable for its extensive regular development.

Variants of Ceratoikiscum aff. bicancellatum B

Slight variations in the pore pattern of the rib vanes and patagium are present in the specimens examined, but it appears unlikely that any marked variation of the basic framework is possible, since the caveal ribs and extra-triangular spines are strongly developed and are well supported in the intricately developed patagium.

The microfauna associated with Ceratoikiscum aff. bicancellatum B at Loc. 210

Members of the Suborder Albaillellaria are probably more abundant in the bullion material from Loc. 210 than in any other bullion material examined to date. In addition to C. aff. bicancellatum B the etched limestone surfaces display Albaillella sp. (specimens 303, 306 and 307) and Albaillella aff. pennata (specimens 301 and 302) and Corythoecia Foreman sp. (specimens 316 and 317). A genus, with many similarities to Ceratoikiscum sp, which is identified as Radiolaria Genus B Foreman (1963) is also present and has a frequency of occurrence in this material similar to that of C. aff. bicancellatum B. Eight specimens of this genus have been examined in detail and the resemblence to C. aff. bicancellatum B is so close that in fragmentary specimens it is sometimes impossible to differentiate between the two forms, which are both characterised by an extensive development of patagial tissue.

Description of Radiolaria Genus B (Figs. 3.V. and 3.W.)

The nomenclature applied to the skeletal frame of Ceratoikiscum spp. (Foreman 1963, Holdsworth 1969a) is adopted for this genus. A triangular frame, consisting of three rods forms the central part of the animal. The base of the triangle is formed by the i.t rod which is much thicker than the other two, and dorsally and ventrally is produced into spines, i.d and i.v. A spine which is termed b.d arises from the b.t rod near to its junction with the i.t rod. The a.t and b.t rods are slightly curved and like the i.t rod they appear to form an anchorage for the abundantly developed extra-triangular patagial tissue. All the extra-triangular spines appear to be contained in the plane of the basic triangle. The absence of caveal ribs and the off-set position of the b.d spine are the most useful characteristics for differentiating between Ceratoikiscum sp. and Radiolaria Genus B.

Dimensions of Radiolaria Genus B.

Specimen 315, (Fig.3.V.) i.t 42 u, chord to a.t 32 u, chord to b.t 32 u, b.d 150 u.

Specimen 311, chord to b.t 50 u, i.v 220 u.

Specimen 312, i.d 220 u, i.t 60 u, chord to b.t 50 u, chord to a.t 50 u.

Specimen 313, i.v or i.d 212 u.

Specimen 319, i.t circa 60 u, chord to b.t circa 50 u, chord to a.t circa 50 u.

Specimen 325, i.d circa 200 u.

Specimen 326, i.d 230 u.

The microfauna of a limestone bullion bed occurring at Loc. 284 (Holdsworth, 1963), present in the Swallow Brook.

Horizon

This is the highest E_2c_2 faunal band in this section and is present below an H_1a faunal band exposed at Loc. 211. This bullion material contains well preserved and abundant entactiniid spumellarians and rare Albaillella sp. Sponge spicules are common and include cross and T-shaped megascleres, and microscleres, small sponges are also present. Spat goniatites and lamellibranchs are of common occurrence.

A loose bullion containing an identical microfauna was present 2 ft upstream from the bullion limestone at Loc. 284, the two are considered to be at the same stratigraphic level.

The microfauna of a limestone bullion bed occurring at Loc. 211, present in the Swallow Brook.

Horizon - H_1a_i.

This bullion bed containing H. subglobosum possesses a sparse fauna of entactiniid spumellarians. Sponge spicules together with spat goniatites and spat lamellibranchs are of common occurrence. Rare small sponges are also present.

The microfauna of the H_1a Bullions

In the North Staffordshire Basin outside the Dove Valley area, the majority of faunal horizons did not reveal a recognisable microfauna mainly due to the ankeritic recrystallisation of the limestones which has completely destroyed the microfauna. The H_1a bullion horizons are an exception and at some localities display a limited amount of selective dolomitisation of the microfauna. Within the H_1a Zone in the Dingle Brook limestone bullions at Locs. 030, 030a and 030b contain a poorly preserved microfauna of entactiniid spumellarians, sponge spicules and small oval shaped sponges (1-2 cms maximum diameter) together with spat goniatites and lamellibranchs. The H_1a bullion horizons at Locs. 061a and 061b in the Hurdlow Section contain a similar microfauna to the equivalent horizons in the Dingle Brook, in both cases, however, the preservation of the fragile radiolarian structures is insufficient to enable any detailed work to be done on them.

A Discussion of the Namurian Ceratoikiscidae

A comparison of the Upper Devonian Ceratoikiscidae from the Huron member of the Ohio Shale Foreman (1963) with the Namurian species of Ceratoikiscum from Staffordshire and Derbyshire, reveals several marked morphological differences in the skeletal frame which are diagnostic. Generally speaking there is a reduction in extra-triangular spines from a maximum of six in Devonian forms, to a minimum of three in Namurian forms. The most marked difference occurs in the caveal ribs which, with the exception of the single sturdy rodlike rib of Ceratoikiscum bujugum evolve from simple and often weakly developed rib pairs in the Ohio Shale specimens, to two, three or four strongly developed rib pairs bearing complex perforate spinose rib vanes in the Namurian forms. Patagium is characteristic of some Namurian species, forming perforate spinose vanes between the extra-triangular spines, this development was foreshadowed in the Devonian by Ceratoikiscum planistellare, which possesses an irregularly perforate and spongy lamellar patagium between the extra-triangular spines.

Basic differences in the skeletal frame of the Namurian Ceratoikiscidae enable identification of the different species to be made, provided sufficient well preserved specimens are available to be examined.

Ceratoikiscum aff. tricancellatum A , the earliest Namurian form as yet described has in common with C. aff. bicancellatum A an abrupt thinning of the i.d and i.v spines prior to their junction with the i.t rod. The length of this thin portion of extra-triangular spine is 30-50u, having a diameter similar to that possessed by the i.t rod. A reduction in paired caveal ribs from three, C. aff. tricancellatum A to two, C. aff. bicancellatum A, serves to distinguish the two subspecies. The fragile attachment of the i.v and i.d spines to the basic triangle is also seen, though less clearly so, in C. aff. bicancellatum B, in this subspecies the spines merge with perforate patagial tissue and are weakly joined to the i.t rod. The absence of the b.v spine is characteristic of this subspecies its place being occupied by patagium. C. bicancellatum and C. tricancellatum are two species which are distinguished as is implied by their names by the number of paired caveal ribs they possess.

The distinction between C. bicancellatum and C. aff. bicancellatum A, both possessing two pairs of caveal ribs, may be made in some cases on the basis of differences in rib vane pore pattern. C. aff. bicancellatum A may display a random pattern of irregularly shaped rib vane pores in contrast to the more regular rib vane pore pattern of C. bicancellatum (Holdsworth, 1969a). A distinction between C. bicancellatum and C. aff. bicancellatum A may also be made on the basis of the number of extra-triangular spines that they possess, four extra-triangular spines are a feature of C. aff. bicancellatum A and although C. bicancellatum has normally three extra-triangular spines, a variant possessing a b.v spine was figured by Holdsworth (1969a). However, the most marked distinction between the two is in the abrupt thinning of the i.d and i.v spines prior to their junctions with the i.t rod a characteristic of C. aff. bicancellatum A, whilst these spines in C. bicancellatum possess their maximum diameter at the junction with the basic triangle (Holdsworth, 1969a) (P.1., Fig.11.) A similar thinning of the i.d and i.v spines serves to distinguish C. aff. tricancellatum A from C. tricancellatum, in addition the b.v spine of C. tricancellatum is off-set ventrally on the i.t rod, whilst a dorsal off-set of this spine occurs in C. aff. tricancellatum B. At the type horizons of C. aff. tricancellatum A and C. aff. bicancellatum A the associated radiolaria are all members of the Family Entactiniidae. Entactiniid spumellarians are common at the horizon of C. aff. bicancellatum B, and in addition a form with Ceratoikiscid affinities, Radiolaria Genus B is present together with Albaillella sp., Albaillella aff. pennata and cf. Corythocecia Foreman sp.

C. tricancellatum has been identified in the Swallow Brook by Holdsworth (1969a) at Locs. 308 and 306B and in the Upper Dove by Holdsworth (1969a) at Loc. 269, bullion material from these locations was re-examined during the course of this research. At location 308 (Holdsworth, 1963), the genus Ceratoikiscum triangulatum also occurs and is distinguished from other Namurian Ceratoikiscidae by the presence of a basic frame in the shape of a straight sided isosceles triangle and by the possession of four pairs of caveal ribs. Also present at this location and at Locs. 269 and 306B is Ceratoikiscum lorum, which possesses six twig like extra-triangular spines and three paired extensive, strap-like caveal ribs which are characteristic of this species the latter enabling the identifcation of incomplete specimens to be made.

C. tricancellatum has been identified from the Dove at the level of H.smithi (Holdsworth, Loc. 250) but the associated Ceratoikiscid fauna of C.lorum or C.lorum and C. triangulatum found at E_2c_2 localities is absent. At the R_1a horizon of Reticuloceras circumplicatile (Loc. 179, Holdsworth, 1963) in the Upper Dove, Holdsworth (1969a) identified minute specimens referable to C. tricancellatum. This occurrence of the same form of Ceratoikiscid at three different stratigraphic horizons is unique in the Namurian as is demonstrated by the species and subspecies identified at other levels referred to in this account.

Evolution and Distribution

The evidence provided by the Namurian Ceratoikiscidae identified to date, does not appear to provide a sufficiently detailed basis from which to determine their evolutionary history. However, it is possible that the evolution of independant stocks may be represented by the fauna present in the area studied. For example, one major stock may be represented by bicancellate and the other by tricancellate forms, although it is possible to propose other morphological characteristics which may form the basis for stocks which are not defined on caveal rib pair numbers. For instance, two separate stocks may be proposed on the basis of the differences in attachment of the i.v and i.d spines to the basic triangle. In one case the attachment of the i.v and i.d spines to a fragile extension of the i.t rod is apparent and is suggested as the basis of a stock containing C. aff. tricancellatum A, C. aff. bicancellatum A and C. aff. bicancellatum B. Whilst a second stock may be proposed in which the i.v and i.d spines join directly to the basic triangle, as in C.bicancellatum and C. tricancellatum.

The absence of any intermingling of representatives of the proposed Ceratoikiscid stocks at any one horizon plus the juxtaposition in the succession of completely morphologically distinct forms as illustrated by the occurrence of C. aff. bicancellatum B and C. tricancellatum in the Swallow Brook exposures may indicate that the Ceratoikiscidae originated from more than one oceanic environment.

It has been proposed by Holdsworth (1966b) that the spumellarian Radiolaria lived at shallower depths than the non-spumellarian genera Albaillella and Popofskyellum. It also appears possible, on the basis of the association and non-association of Albaillella and Ceratoikiscum in the North Staffordshire succession, that the Albaillellids lived at shallower depths than the Ceratoikiscids. Water depth during faunal band genesis may also be suggested as being a possible factor regulating the distribution of the Ceratoikiscids in the Basin succession. However from the associations of Albaillella and Ceratoikiscum in the succession, together with the occurrence of C. tricancellatum both above and below the horizon of C. aff. bicancellatum B, it would appear that neither water depth nor evolutionary processes can account for the distribution of all the species and subspecies of Ceratoikiscum. A possible alternative to account for the distribution of the Ceratoikiscidae may be that their distributions are related in part to their origins which are proposed as being located in different water masses. These water masses, as previously implied, cannot be equated with different depth zones in a single environment, but are suggested as having originated in geographically distinct oceanic environments. It is proposed that differences in the physical and chemical properties of the water masses existed between the different oceanic locations,and it is thought probable that they were differences in temperature and salinity similar to those which occur between modern oceanic zones from different latitudes. The distribution of some of the Ceratoikiscids in the E_2b_1 - H_2a succession is thought to imply that some species/subspecies preferentially colonised a water mass which was unsuitable for other species/subspecies whilst the presence of some key species/subspecies, which are not intermingled in the faunal bands appears to indicate that the influence of at least two distinct major palaeo-oceanic water masses or currents can be detected in the succession.

It is possible that the Ceratoikiscid stocks, previously referred to, were evolving in separate parts of the Namurian Ocean and that the processes of evolution and palaeo-oceanic movement or distribution of water masses are largely responsible for their occurrence and distribution in the faunal bands of the North Staffordshire Basin.

Correlation with other areas

The occurrence of the Ceratoikiscidae from the English Namurian at localities outside the Staffordshire Derbyshire area is as yet unproven; during the course of research examination of core samples from Geological Survey boreholes in the

Ashover area of Derbyshire was undertaken, at an horizon thought to be equivalent to that of C. aff bicancellatum A in the Wiggenstall Stream Section. The probable relevant horizon in the Highoredish Borehole, occurring in the Cravenoceratoides nitidus Zone was an 18" band of calcareous 'cank' from which sample No. BN 5601 was taken at 236' 1½". Examination of an etched surface of this sample displayed coarse dolomitisation, the dolomite crystals occurring in spherical clusters, each group of crystals being bounded by a thin rim of mud-sized detrital material. This lithology is thought to be indicative of a radiolarian rich horizon into which only a small amount of fine detrital material found its way. The frequency of the spherical forms is suggested as being representative of a high density of spumellarians, as is seen in selectively dolomitised bullion material from other sources within this Zone. Another core sample, BN 7395, examined was from the Tansley Borehole at 905' 2" taken from an 18" 'cank' band. An etched surface of this sample displayed a lithology similar to that seen on sample BN 5601, and although the dolomitisation was less coarse,the fine structure of the microfauna was completely destroyed.

Examination of E_2b bullion material from Caton Brook in the Lancaster Fells, at Mosley's horizon of Cravenoceratoides lirifer (Loc. 29 Greenholes Beck), also proved disappointing. The outlines of undolomitised spumellaria were well displayed on the etched surface which consisted of a finely granular mass of dolomite crystals. This material also contains sponge spicules, spat lamellibranchs and goniatites together with mature goniatites tentatively identified as Cravenoceratoides sp.

A bullion from near the base of the Lower Coal Measures, 1 ft above the Union Seam in the Hapton Valley Colliery, of the Burnley Coalfield, was also examined. This material was a pyritic margin 1 cm thick, and on etching of cut surfaces proved to have a dolomitic interior. A feature of this bullion was the presence of undistorted cellular coalfield plant material and in addition numerous spat goniatites and lamellibranchs. Rare sponge spicules were also present. The presence of the undistorted cellular plant material is thought to confirm the early diagenetic origin proposed for limestone bullions by Holdsworth (1966b). Mature goniatites present in this material were tentatively assigned to *Gastrioceras sp.*

CHAPTER 4

PALAEONTOLOGICAL DISCUSSION

PALAEONTOLOGICAL DISCUSSION

Distribution of faunal elements

The distribution and the variations in distribution of some of the faunal elements in the faunal bands of the North Staffordshire Basin in the interval E_2b_1 - H_2c is now examined, and the possible controls affecting the distribution of the fauna will be discussed.

The Goniatites

Within the Basin succession in the interval E_2b_1 - H_2c no discernable lateral variations in goniatite population density occurs in any one faunal band. This phenomenon of constant population density is well displayed in the H_1a Subzone. Here limestone bullions at the level of H.subglobosum are particularly well exposed, at, for example, Locs. 030, 061 and 211. They contain a prolific fauna of mature and immature goniatites which show no apparent variation in population density[1.] at the several localities where the identical type of preservation occurs. However, it should be noted that variations in density of concentration can occur due to differences in diagenesis. Thus, dense concentrations of goniatites occur at the horizons of H.beyrichianum and H.smithi in both the proposed shelf and basinal areas (these areas are defined on p.282) in faunal bands of black shale/ mudstone lithology, whilst less dense concentrations occur at these horizons in faunal bands of the limestone bullion type. However, these differences are to be expected since as Holdsworth (1966b) points out, faunal bands of the black shale type, rich in crushed goniatites, are not the result of relatively rapid concentrations of goniatites in a small amount of sediment, but are rather the slow addition of shells to a large volume of extremely compressible clay, often richly radiolarian.

1. Holdsworth, 1966b, plate 18, Fig.3 illustrates the density of H.subglobosum in faunal bands of this type.

Diagenesis of such a deposit appears to have resulted in the removal of much or all of the shell material and compaction has produced the characteristic "Thin goniatite seams". On the other hand, faunal bands of the limestone bullion type which are proposed by Holdsworth (1966b) to have an early diagenetic origin commonly contain faunal elements which show little sign of crushing and in such lithologies it is thought that compaction was minimal. Differences in density due to differences in diagenesis can sometimes be observed in faunal bands exhibiting more than one lithology at a single locality. Thus, in the Hurdlow Section at the E_2c_{2iii} level, goniatite densities in an ankeritic limestone (Loc. 066) are much less than in the overlying mudstone. A similar variation in goniatite densities is seen at the H_2a level in the Fairthorn Farm Section,here an ankeritic limestone bullion at Loc. 181 containing a sparse population of Hd. proteum is directly overlain by black shale exhibiting a dense concentration of specimens of H. smithi.

Taking into account the variations in goniatite densities produced by differences in diagenesis, it is however apparent, when the vertical succession is examined, that variations in goniatite population densities do occur when different faunal bands are compared. For example, limestone bullions at the level of N. nuculum display a much lower concentration of specimens of N. nuculum than that exhibited by specimens of H. subglobosum in the H_1a bullion limestones. This low concentration of specimens of N. nuculum in limestones is evident in all the E_2c_2 faunal bands in the North Staffordshire Basin and it is proposed that this feature reflects an original low population density of specimens of N. nuculum in the area. In addition to the E_2c_2 levels, low goniatite densities are displayed by limestone bullions at the levels of Ct. nitidus, C. holmesi, Hd. proteum and

Hmct. prereticulatus. For example, in the E_2b_2 Subzone in the Wiggenstall Stream at Loc. 125, only a single specimen of C.holmesi was recovered, after an extensive search. This low concentration is thought once again to reflect an original low population density. At Loc. 126, also in the E_2b_2 Subzone in the Wiggenstall Section, a faunal band of the limestone bullion type is present which although possessing an abundant fauna of spumellarian and less abundant non-spumellarian Radiolaria, has not, even after extensive examination, yielded a mature goniatite. On the basis of the latter evidence it would appear that there are some type/types of environment, obviously of a truly marine character, which were not suited to, or relatively unfavourable to, colonisation by thicker-shelled goniatites, whilst at other levels in the succession conditions were such that thicker-shelled goniatites proliferated.

Faunal bands of the limestone bullion type displaying dense concentrations of goniatites, such as those present at H.subglobosum horizons exhibit a marked association of mature and immature goniatites at all localities in the Basin. In faunal bands of the black shale type at the H_1a level the same association of mature and immature goniatites, as is present in the limestone bullions at this level, also occurs.

Faunal bands in the Basin, although not necessarily of the limestone bullion type, containing both mature and immature goniatites are present at the levels of E.rostratum, N.stellarum, H.subglobosum and H.beyrichianum.

Faunal bands of the limestone bullion type which have low goniatite densities do not exhibit the marked association of mature and immature goniatites but are instead characterised mainly by the presence of mature goniatites.

The Brachiopods

Brachiopods occur sporadically in the faunal bands of the North Staffordshire Basin in the E_2b_1 - H_2c interval, and are no more frequent in other parts of the column. They are present in the E_2b_3 Subzone in the Cherts faunal band where they occur in the thicker-shelled goniatite phase in association with crinoids and trilobites. Ramsbottom et al. (1962) record a brachiopod fauna, from the Cherts - equivalent[1.] level in the Ashover Boreholes, consisting of Chonetids, Productids, Rhynchonellids and Spiriferids, whilst Sheldon (1961) records a similar fauna for this band at localities in the Edale area. A benthonic fauna consisting mainly of Chonetids, Productids and crinoids is present in the H_2a faunal band at Loc. 010. This is the only faunal band in the North Staffordshire Basin which has been observed in a paralic situation. Brachiopod faunas have also been recorded from the North Staffordshire Basin in the R_1a_2 Subzone by Holdsworth (1966b), and in the E_2a Zone at the level of E.erinense by Trewin (1969), whilst in the Ashover Boreholes, Ramsbottom et al. (1962) record a brachiopod-crinoid fauna in the E_1c Subzone at the probable level of C.malhamense.

The Porifera

Limestone bullions in which a microfauna is preserved may contain detached scattered sponge spicules, the majority being megascleres which have a hollow cylindrical tapering form. Rare small sponges 5-10mm in diameter, containing both megascleres and microscleres may also be present and have been observed at the level of Ct.edalense, Ct.nitidus, N.nuculum, H.subglobosum and Hmct. prereticulatus, whilst isolated small sponges lacking microscleres are

1. In the Ashover Succession this faunal band although having the characteristic fauna does not exhibit the cherty lithology characteristic of this band in the Basin Succession.

present at the level of H.subglobosum (Holdsworth, 1966b). Holdsworth (1966b) also records the occurrence of sponges and sponge spicules from his Loc. 173b in the Manifold Valley, which occurs at the highest R.paucicrenulatum level. (Previously identified as the R.nodosum level (Holdsworth, 1963), but reidentified as R.paucicrenulatum (Ashton, 1974)). At Loc. 173b Holdsworth indicates that flat-lying sheets of spicules occur in clusters with sufficient abundance to mottle the limestone even in unetched specimens.

In the bullion material examined, sponge spicules are of variable occurrence and are present in abundance at some levels but have a very sparse distribution or are absent at others. In the Wiggenstall Stream Section a limestone bullion, Loc. 130, at the level of Ct.edalense contains both small sponges and numerous detached spicules.[1.] A similar concentration of sponges and spicules occurs in the highest N.nuculum horizon in the Swallow Brook at Loc. 211. In the three H_1a faunal bands, sponge spicules are abundant occurring both as isolated detached spicules and as clusters of detached spicules. Holdsworth (1966b) records the occurrence of dense clusters of spicules at the highest R.paucicrenulatum horizon, and above this level, at an R_1b horizon, he indicates that flat-lying sheets of spicules occur in clusters with sufficient abundance to mottle the limestone even in unetched specimens.

The Spat

Other elements of the microfauna are the goniatite and lamellibranch spat. The complete areal distribution of spat in the faunal bands of the Basin is only partly known since they have not been recovered from faunal bands of the black shale/mudstone type, whilst faunal bands which have suffered extensive dolomitisation

1. Spicules, frequency of occurrence 1-10 per cm^2.

display a complete absence of microfauna. In the vertical succession goniatite and lamellibranch spat have been recorded from etched surfaces of limestone bullions in the interval E_2b_1 - H_1a inclusive, and as with the other faunal elements they display a variable frequency of occurrence. Concentrations of lamellibranch spat are present in the H_1a horizons. They occur either in isolation or in flat clusters present on etched surfaces cut normal to the bullion lamination. Goniatite spat are also present at the level of H. subglobosum occurring with frequencies of one or more per cm^2, and as previously indicated, they are associated with immature and mature specimens of H. subglobosum.

Spat goniatites are present at the level of Ct. edalense in the Wiggenstall Stream Loc. 130, occurring with a frequency of approximately one per cm^2, whilst spat lamellibranchs although present are very sparsely represented. Also in the Wiggenstall Stream, at Loc. 126, goniatite spat are present in a faunal band of the limestone bullion type, although mature goniatites have not been recovered from this material. The frequency of occurrence of the goniatite spat at Loc. 126 is less than one per cm^2, that is very sparse, and lamellibranch spat have not been recorded at this level.

Spat goniatites and spat lamellibranchs have been recorded from E_2c_2 horizons in the Swallow Brook and with the exception of the highest N. nuculum horizon, their frequency of occurrence is very low, less than 0.5 per cm^2. At the highest N. nuculum horizon in the Swallow Brook spat goniatites and lamellibranchs are of common occurrence and are present in excess of one per cm^2. Thus, in addition to the highest N. nuculum horizon relatively dense concentrations of goniatite and lamellibranch spat have been recorded at H_1a levels in land proximal situations e.g. Dingle Brook, Locs. 030, 030a, 030b, in proposed shelf areas, e.g. Hurdlow

Locs. 061a, 061b and in the proposed land remote parts of the North Staffordshire Basin in the Swallow Brook at Loc. 211.

The Radiolaria

Radiolaria have been recorded from all limestone bullions in which dolomitisation has not obliterated the microfauna. Entactiniid spumellarians are present in all cases whilst non-spumellarian Radiolaria occur only at certain levels. The abundance of Radiolaria in faunal bands contained in limestone bullions appears to be antipathetic to that of mollusc spat, sponge spicules, and goniatites. Thus, at the H_1a levels the Radiolaria are only sparsely represented, whilst in the E_2b_1 Subzone at the level of Ct.edalense abundant Radiolaria are present on the etched surfaces. Spumellarian Radiolaria are abundant at all the N.nuculum horizons in the Swallow Brook exposures and at the lowest E_2c_2 horizon, Loc. 269, in the Dove. In the Wiggenstall Stream at the level of Ceratoikiscum aff. bicancellatum A (Loc. 126) and at the level of Ct.nitidus (Loc. 128) similar concentrations occur and at these localities mature goniatites are respectively absent and rare. Trewin's (1969) Waterhouses locality, tentatively placed at the level of Ct.nitidus also contains abundant Radiolaria (Ceratoikiscum bicancellatum type locality), although mature goniatites have not been recovered from this locality.

Non-spumellarian Radiolaria, Albaillella and Ceratoikiscum are present at several levels in the succession and in all cases they occur in association with a much more abundant spumellarian population. The first known Namurian occurrence of Ceratoikiscum is at the Ct.edalense level in the Wiggenstall Stream, Loc. 130 where it is the sole representative of the Albaillellaria. The next recorded occurrence is at the probable level of Ct.nitidus, Loc. of Trewin (1969) (SK 02705054), where

Holdsworth (1966b) states, "At its type horizon C.bicancellatum is the commonest non-spumellarian form and is associated with two other Ceratoikiscids, one a common large lamellose species of an undescribed genus better known from the high Visean,the other a rare species very incompletely seen and of uncertain genus, but with clearly Ceratoikiscid characteristics." Above the level of Ct.nitidus at Loc. 126 in the Wiggenstall Stream is the type horizon for Ceratoikiscum aff. bicancellatum A, this is the only member of the Albaillellaria present at this horizon. A dolomitised bullion at the level of C.holmesi in the Wiggenstall Stream Loc. 125, contains outlines of spumellarian Radiolaria, whilst Holdsworth (personal communication) indicates that spumellarian Radiolaria are present below the level of the Cherts in the Dove in a bullion horizon containing C. aff. holmesi.

In the Swallow Brook Section all the N.nuculum faunal bands present contain an abundant population of spumellarian Radiolaria and non-spumellarian Radiolaria, although less abundant, are also present (see Micropalaeontology Chapter). The non-spumellarian genera include species of Ceratoikiscum and Albaillella which are present at all N.nuculum horizons except the highest where rare Albaillella are the only non-spumellarian representatives.

At Loc. 211 the lowest H.subglobosum horizon in the Swallow Brook is exposed and contains a sparse fauna of spumelline Radiolaria; Albaillellaria are absent at this horizon. Holdsworth (personal communication) records the presence of Albaillella sp. from the level of Hd.proteum in the Mam Tor area, however in the Basin succession, the Albaillellaria re-appear at the level of H.smithi, Loc. 250 of Holdsworth (1963) and are represented by C.tricancellatum, whilst a very rare small variant of C.tricancellatum is present at the level of R.circumplicatile.

Although non-pylomate spumellarian Radiolaria occur abundantly in the microfauna of the North Staffordshire Basin in the interval E_2b_1 - H_2c pylomate

Spumellaria appear to be absent.

Pylomate and non-pylomate Spumellaria have however been recorded in association in faunal bands from the Devonian Ohio Shale by Forman (1963), from the Visean by Deflandre (1963) and from the Baltalimani Formation of Tournaisian age by Holdsworth (1973a).

In the North Staffordshire Basin at the level of R.paucicrenulatum (re-identified as R.circumplicatile, Ashton, 1974) Holdsworth (1966b) identified Popofskyellum undulatum[1.] Deflandre, although members of the family Popofskyellidae have not however been encountered in the E_2b_1 - H_2c succession.

Also apparently absent from the E_2b_1 - H_2c Basin succession is the genus Palaeoscenidium Deflandre, which has been recorded from the Visean (Deflandre, 1960), the Upper Devonian (Forman, 1963) and from the Baltalimani Formation (Holdsworth, 1973a).

The reason for the absence of the Palaeoscenidiidae and the pylomate Entactiniidae from the Basin succession is unknown, however it is thought probable in the light of the abundance of species, particularly the pylomates, present in the Tournaisian Baltalimani Formation (Holdsworth, 1973) that they had not become extinct by Namurian times. It is tentatively suggested that their distribution was controlled by physico-chemical water mass characteristics and that the hydrodgraphic regimes established in the Basin in E_2b_1 - H_2c times were not conducive to the colonisation of the area by these particular Radiolaria.

1. Namurian species originally thought to belong to P.undulatum (Holdsworth, 1966b) are now believed to represent a separate species (Holdsworth, 1973).

The implications of the variations in distribution of the faunal elements

It is proposed that the variations occurring in the abundance and type of faunal elements present in faunal bands of the bullion type in the North Staffordshire Basin are direct reflections of environmental variations. As previously discussed, mature thicker-shelled goniatites may have relatively high or low densities in bullion limestones and in some instances are apparently absent from these limestones, whilst immature thicker-shelled goniatites are usually associated with faunal bands containing relatively high densities of mature specimens.

The density of concentration of goniatites in some bullions is extremely low, and even at the highest concentrations encountered, adjacent specimens may be separated by a thickness of sediment which commonly has a dimension greater than the shell diameter. Holdsworth (1966b) suggests an extremely slow rate of accumulation for bullion sediments, approximately comparable with that for modern pelagic globigerina ooze. Thus, in view of this very slow rate of accumulation it would seem that the goniatite densities in the bullions reflect very low population densities in the Namurian seas.

Very dense concentrations of cephalopods have however been described by several authors and are commonly referred to as "shell beds". Opinions differ as to the origin of such beds; Reyment (1957) refers to dense concentrations of Tertiary nautiloids from the Japanese succession and suggests that they accumulated in coastal embayments, floating into these areas after death. However, Ruzhencev (1962) commenting on the occurrence of an upper Palaeozoic "shell bed", containing goniatites in all stages of growth, suggests that the goniatites had accumulated in an estuarine environment and he implies that they were killed off by an influx of fresh water. The association of goniatites, in all stages of growth, in such a "shell bed" may indicate that the goniatites had actually colonised the near shore area only to be killed en masse by an abnormal event.

Ashton (1974) proposes a shallow water origin for a "shell bed" of R_2a age which is present in the North Staffordshire Basin at Oakamoor (Locs. 144 and 113, Ashton, 1974). She points out that the shells of R.gracile present in this bed show good preservation and lack any marked abrasion which may have indicated littoral accumulation and concentration. However, limited evidence of current action is present suggesting a shallow water environment. Ashton further proposes that the absence of features associated with rapid fossilisation after death, suggests that the R_2a goniatites were not all killed, buried and preserved by the same episode. She suggests that the goniatites present in the R_2a "shell bed" lived in or near the area of deposition, and states, "..... within the R.gracile ankerite, large shells of goniatites are relatively abundant (compared with the typical black shales) and numerous goniatite spat occur." Heptonstall (1964) has indicated that the average size of goniatites decreased as the G.cancellatum marine band was traced out into the Basin away from the proposed shoreline. Ashton points out that the occurrence of large specimens of R.gracile is in an area proximal to encroaching deltaic sediments. She states "Bottom conditions may have been more suitable in nearer-shore areas compared with the soft muds of the typical black shale marine bands, or food more abundant nearer to estuarine waters." Concerning the abundance of goniatite spat in the "shell bed", Ashton proposes that the spat may have drifted after death, although it is thought unlikely that they would have accumulated in such dense concentrations. Ashton is of the opinion that spat are not commonly found in the typical black shale marine bands; this may be a feature of non-preservation. However, the spat content of some of the proposed land distal bullion limestones in the E_2b_1 - H_2c interval is very sparse and it appears most likely that spat which are present in these areas have been drifted in for long distances.

Migration to coastal waters for breeding is proposed by Ashton as one reason for the concentration of goniatites in the R_2a "shell bed", she points out that the mortality rate for spat would be high and that the mature shells could have been derived from individuals which died within the area and were incorporated within the sediments in the littoral or shallower neritic zones. Examination of Plate 5.2a (Ashton, Thesis 1974) reveals the presence of not only mature and spat forms but also of a range of intermediate sizes, classed as immature goniatities, corresponding to the deposit described by Ruzhencev (1962) in which occurred, "goniatites in all stages of growth."

All the evidence discussed so far appears to indicate that mature, immature and spat goniatites colonised "shallow water" environments and that faunal bands with high goniatite densities had a "shallow water" genesis. The low density of concentration or absence of goniatites from some faunal bands in the E_2b_1 - H_2c interval in the North Staffordshire Basin appears to indicate that a discernable lateral variation in population density, although not observed in the area studied, should occur over a much wider area of the Basin than is exposed and is thought to be related to variations in water depth and possibly to bottom conditions.

H_1a faunal bands at Heath Hay Loc. 020, Thorncliffe Loc. 101a and Crowborough Loc. 027 are associated with overlying fluvial deposits and palaeogeographical evidence indicates that in this interval deltaic sediments were prograding into the North Staffordshire Basin from the west to south. These deposits can be traced from Heath Hay in the north, southwards through Endon and Stanley and are equated with similar deposits at Combes and Ipstones. The eastern extent of this fluvial deposit stretched at least to the Thorncliffe area, whilst to the west the paralic margin is thought to have been in the Astbury area. Ashton proposes that the goniatites needed extensive areas of shallow water (e.g. over inundated delta tops) for breeding grounds. It is suggested that in the North Staffordshire Basin the relatively high density of goniatites in all stages of growth in the H_1a faunal bands is related to the establishment of an extensive area suitable for their breeding and development. Such an area would appear to be associated with the prograding deltaic area in the west and south. In this area it is thought that very high goniatite densities such as are found in the R_2a "shell bed", will occur in the H_1a faunal bands.

Ashton describing the faunal elements present in the R.gracile "shell bed" comments on the absence of a brachiopod fauna and suggests that variable salinity due to fluctuating discharge of fresh water would inhibit the colonisation of the area by brachiopods, whilst the more mobile goniatites were presumably able to cope with variations in salinity. The absence of brachiopods from the H_1a faunal bands at all known localities may then indicate that the water mass was subject to fluctuations in salinity and is proposed as further evidence of shallow water conditions and associated contraction of the North Staffordshire Basin during H_1a times.

Falling sea level with exposure of delta tops and consequent destruction of breeding grounds are proposed by Ashton to have contributed as much towards the disappearance of the goniatite fauna as changes in salinity. At the level of the R.gracile faunal band in the North Staffordshire Basin, Ashton records that Radiolaria are absent or extremely rare whilst spat goniatites and lamellibranchs are abundant at two localities and small sponges are recorded from this band in the Shell Brook (Loc. 108).

The antipathetic relationship of the Radiolaria to the relatively dense concentration of goniatites, exhibiting all stages of growth, occurring in the H_1a bullion horizons has previously been described (ibid) and is thought to indicate that the "shallow water" environment in which the goniatites developed was unsuitable for colonisation by Radiolaria. Varying salinity and possibly shallowness of the environment are proposed as being the causes for the "absence" of Radiolaria, and it is thought that the few individuals which are present would inevitably be present due to their planktonic mode of life and occasional distribution in shallow water by wave or current action.

Shrock and Twenhofel (1953) indicate that Radiolaria are exclusively marine organisms. Holdsworth (1966a) suggests that the non-spumellarian genera Albaillella and Popofskyellum may have lived at greather depths than the spumellarians.

Non-spumellarian Radiolaria are absent from all the H_1a faunal bands in the North Staffordshire Basin, whilst spumellarian genera are only sparsely represented. At an R.paucicrenulatum horizon (Loc. 173 of Holdsworth, 1963) and also at a higher Rla_2 horizon (Loc. 173B), Holdsworth indicates that non-spumellarian genera are absent and spumelline genera are only sparsely represented. At Loc. 173B, Holdsworth (1966b) records the presence of dense clusters of sponge spicules which are associated with a brachiopod fauna.

Trewin (1969) records the presence of a benthonic fauna consisting of crinoids and brachiopods from the E.erinense (E_2a_2) faunal band and Holdsworth (personal communication) indicates non-spumellarian genera are absent at this level and that spumellarian Radiolaria are only sparsely represented. He also indicates a similar distribution for the Radiolaria at the level of C.subplicatum (E_2b_1), although a benthonic fauna with the exception of a single productid has not been recorded from this faunal band. This absence of non-spumelline Radiolaria and the low densities of spumellarian genera in faunal bands exhibiting high goniatite densities which have previously been equated with a "shallow water" genesis, is thought to emphasise that a shallow water environment was unsuitable for colonisation by the Radiolaria.

The distribution of Radiolaria in the faunal bands of the North Staffordshire Basin has previously been discussed (ibid) and it is thought that this variable radiolarian content is indicative of different depositional environments. A "shallow" near shore environment is proposed in which a sparse fauna of only spumellarian Radiolaria may be present in association with abundant goniatites, in all stages of growth and possibly with a benthonic crinoid-brachiopod fauna. Dense concentrations of sponge spicules or small sponges may also be present, suggesting a shallow benthonic mode of life for the Namurian Porifera.

Faunal bands representative of a "deep water" environment contain in addition to spumellarian, non-spumellarian genera; crinoids and brachiopods are absent and sponge spicules are rare. Goniatite densities are low and in some cases mature specimens appear to be absent. Spat goniatites and spat lamellibranchs can generally be found after prolonged search in this type of faunal band although their density is extremely low. The latter feature tends to confirm the proposal that the "shallower waters" of the North Staffordshire Basin were a breeding ground for the goniatites. The rare presence of spat and detached sponge spicules in faunal bands of "deep water" genesis is probably due to their transportation into this environment by weak currents.

Holdsworth (1966b) commenting on the association and non-assocation of spumellarian and non-spumellarian Radiolaria from bullions at the level of R.paucicrenulatum (re-identified as being at the level of R.circumplicatile by Ashton 1974, Ph.D Thesis, p.33.) in the Upper Dove suggests, "The appearance of the two non-spumelline species could have been the result of several kinds of influence, of a minor change in salinity or temperature, or possibly a slight alteration in speed of water movement. Such explanations presuppose that the spumellines were less sensitive to their immediate environment than A.pennata and P.undulatum. A rather more satisfactory explanation is that the two non-spumellines are relatively deep water forms...."

In the North Staffordshire Basin in interval E_2b_1 - H_2c the variations exhibited by the faunal elements in the faunal bands appear to indicate that a variety of depositional environments existed. A faunal band of the "deep water" type occurs for example at the level of N.nuculum (Loc. 210) whilst faunal bands of "shallow water" genesis occur at the level of H.subglobosum. Between these two extremes intermediate types exist, the subdivision being based on the presence or absence of particular radiolarian genera. Thus, at the level of N.nuculum (Loc. 210) abundant spumellarian Radiolaria occur and are associated with the less abundant non-spumellarian genera Albaillella and Ceratoikiscum, this faunal band is classed as a "deep water" type (ibid). Rare specimens of Albaillella sp. are present in the highest N.nuculum horizon (E_2c_{2iii}) in the Swallow Brook Loc. 284 (Holdsworth, 1963) associated with an abundant spumellarian population. In the Swallow Brook at Loc. 210, and Locs. 309, 308, 306 and 306B of Holdsworth (1963) spumellarian and the non-spumellarian genera Albaillella and Ceratoikiscum occur. The absence of Ceratoikiscum at Loc. 284 is thought to imply a deeper water habitat for this genera than for Albaillella. Thus, faunal bands such as that at Loc. 284 represent an environment in which maximum water depth is intermediate between the two extremes. Faunal bands containing spumellarian Radiolaria but from which non-spumellarian Radiolaria are absent occur at the level of C.holmesi, C. aff.holmesi and R.paucicrenulatum and they are thought to represent environments in which maximum water depth never extended to the zone colonised by the non-spumellarian genera.

On the basis of the previously discussed variations displayed by the faunal elements in the North Staffordshire Basin succession in the interval E_2b_1 - H_2c, it is suggested that two types of faunal band exist:-

(1) a "shallow water" type characterised by relatively dense concentrations of mature and immature goniatites, sponge spicules and small sponges and goniatite and lamellibranch spat

(2) a "deep water" type characterised by the presence of abundant spumellarian Radiolaria and particularly by the presence of Radiolaria of the Suborder Albaillellaria, and by a low density or apparent absence of goniatites.

Faunal bands which may be of slightly less "deep water" genesis than those of type 2 are also present, they contain abundant spumellarian Radiolaria, although members of the Albaillellaria are either very rare or absent.

The apparent intervals present in the North Staffordshire Basin succession

In the Basin succession it is suggested (ibid) that the distribution of faunal elements in the faunal bands present reflects the depth of water which obtained during their period of genesis. On examination of the succession it is proposed that a well defined grouping of faunal bands occurs, the groups being characterised by the presence of either "deep water" or "shallow water" types of faunal bands. Thus, "deep" groupings are present in the Ct. edalense to C.holmesi, lower to upper N.nuculum and Hd.proteum to R.circumplicatile intervals, whilst "shallow" groupings are present in the E.rostratum to N.stellarum and H.subglobosum to H.beyrichianum intervals.

Examining the groupings in more detail it is seen that the lowest group in the E_2b_1 - H_2c interval contains Radiolaria rich faunal bands which are proposed (ibid) as being of the "deep water" type. The lowest band, the Ct.edalense faunal band contains abundant spumellarian Radiolaria and less abundant Albaillellaria, which are represented by Ceratoikiscum aff. tricancellatum A. The next band in this "deep" group, the Ct.nitidus band also contains a prolific spumellarian population together with the less abundant non-spumellarian Ceratoikiscum bicancellatum.

The Stannery Limestone, which is present in the E_2b_2 Subzone contains a fauna of P.corrugata which is crowded into one parting plane. Goniatites are normally absent but one specimen of a small globose thicker-shelled goniatite was collected from the fossiliferous parting plane at Loc. 147 in the Blake Brook exposure. The majority of the Stannery Limestone is dolomitised and the micro-fauna have been destroyed. However, less dolomitised portions display the abundant outlines of spumelline Radiolaria, rare spat goniatites and lamellibranchs together with rare detached sponge spicules of densities less than 1 per cm^2. The presence of the P.corrugata horizon in the Stannery Limestone is difficult to interpret, since laterally persistant concentrations of lamellibranchs are not found elsewhere in the E_2b_1 - H_2c interval. Ramsbottom et al. (1962) consider the Namurian posidonids, Posidonia and Caneyella to be free living benthonic forms, whilst Holdsworth (1966b) suggests that the distribution of these lamellibranchs can be most satisfactorily explained by supposing them to have been benthonic in the adult stage. A possible explanation to account for the presence of the laterally persistant P.corrugata horizon in the Stannery Limestone may be that bottom conditions developed which allowed for the extensive colonisation, at a single horizon only, of a benthonic fauna, these conditions which appear to be unique in the succession may have been produced by a water turn-over inducing temporary oxygenation of the anoxic bottom.[1.] However, the presence of abundant Spumellarian Radiolaria and the almost total absence of mature goniatites are suggested as evidence that during the genesis of the Stannery Limestone "deep water" conditions were established in the North Staffordshire Basin.

At Loc. 126 in the Wiggenstall Stream a faunal band, which is present in the succession between the Stannery Limestone and the C.holmesi faunal bands, is proposed as being of a "deep water" type. The band contains a fauna of spumellarian Radiolaria and the less abundant non-spumellarian Ceratoikiscum aff. bicancellatum A. Thicker-shelled goniatites, other than spat which occur extremely rarely are absent from this band, although small indistinctly preserved, possibly thin-shelled specimens, were observed on the rim of the bullion.

A dolomitised bullion horizon at Loc. 125 in the Wiggenstall Stream at the level of C.holmesi yielded only a single mature goniatite and whilst the microfauna have largely been destroyed by dolomitisation,traces of spumellarian Radiolaria have been observed. The extremely low density of goniatites in this band is thought to indicate that "deep water" conditions existed during its genesis.

The first "shallow" grouping to occur in the E_2b_1 - H_2c interval contains two faunal bands. The lowest of these bands, the Cherts, occurs in the E_2b_3 Subzone and contains a relatively prolific fauna of mature and immature thicker-shelled goniatites together with infrequently occurring thin-shelled goniatites. The density of occurrence and the size range of the goniatites present in this faunal band is

1. An analogous occurence is recorded by Hülseman and Emery (1961) from recent sediments in the Santa Barbara Basin, California; they suggest that periodically oxygenated water reached the Basin floor, which was normally anoxic, and enabled a benthic fauna including Macoma sp. and Cardita sp. to colonise the floor of the Basin.

thought to indicate a "shallow" water genesis whilst the presence of a rich brachiopod and crinoid fauna is thought to further confirm that a "shallow" sea was present in the North Staffordshire Basin area during this interval.

The upper of the two faunal bands occurring in the first "shallow" group occurs at the level of N.stellarum, this band which is present in a thin dolomitised muddy limestone contains a prolific fauna of mature and immature thicker-shelled goniatites together with rare specimens of Dimorphoceras. The size range of the goniatite population present in this E_2c_1 band is proposed as being indicative of its "shallow water" genesis.

Faunal evidence for the occurrence in the succession of a second grouping of faunal bands of the "deep water" type is seen in the E_2c_2 Subzone. Throughout the North Staffordshire Basin faunal bands characterised by the presence of N.nuculum exhibit low densities of mature thicker-shelled goniatites, a feature which has previously been proposed as being indicative of "deep water" conditions.

In the Swallow Brook, faunal bands in the E_2c_2 Subzone are exposed at five and possibly six horizons. The lowest horizon at Loc. 306B of Holdsworth (1963) is proposed as being of typical "deep water" genesis since in addition to a low density of mature goniatites it exhibits an abundant population of spumellarian Radiolaria, and the less abundant non-spumellarians Albaillella and Ceratoikiscum.

A loose bullion, containing N.nuculum, from the Swallow Brook section at Loc. 306 (Holdsworth 1963), which on the evidence of its radiolarian microfauna is thought to have originated near to the horizon of 306B (see Micropalaeontology Section), is proposed as being of "deep water" genesis. The absence of sponge spicules and the extremely rare occurrence of mollusc spat in this bullion may indicate that due possibly to the water depth which obtained during the genesis of this band, that environments suitable for colonisation by spat and Porifera were not present in the North Staffordshire Basin at this time.

A faunal band at the E_2c_{2ii} level, which was recorded by Holdsworth (1963) at his Loc. 307 contains spumellarian Radiolaria (Holdsworth personal communication), and is proposed as being of the "deep water" type. During a re-examination of the Swallow Brook section, this horizon was not located and the original bullion material although listed, has been lost and additional information relative to the microfauna is not available. An E_2c_2 horizon containing thin-shelled goniatites occurs at the Swallow Brook Loc. 309 of Holdsworth (1963). This horizon which is present in the upper part of the E_2c_2 Subzone is thought on faunal evidence to have had a shallower water genesis than is proposed for the faunal band at Loc. 306. Abundant spumellarian Radiolaria occur at Loc. 309 but the non-spumellarians occur very rarely and include Albaillella sp. and a minute bicancellate ceratoikiscid; rare spat goniatites and lamellibranchs are present together with isolated sponge spicules. The type and densities of faunal elements present in this band are thought to indicate that its genesis took place in "deep water" although the absence of the mature thicker-shelled goniatites poses a problem. It may be that the genesis of the bullion horizon at Loc. 309 occurred in an environment unsuited to colonisation by the thicker-shelled goniatites, although the presence of abundant spumellarian Radiolaria is interpreted as evidence of maximum marine conditions. The rare occurrence in this bullion material of the Albaillellaria is thought to imply that water depth although "deep" was shallower than that indicated by the preceding E_2c_2 faunal horizons. The N. nuculum band at Loc. 210 (above Loc. 309) contains faunal elements which are thought to be representative of the existence of deeper water conditions in the North Staffordshire Basin than those represented by the faunal band at Loc. 309. Spumelline Radiolaria are abundantly represented whilst the less abundant non-spumelline genera include Ceratoikiscum aff. bicancellatum B, Radiolaria genus B and two species of Albaillella.

The depth of water during which the genesis of the faunal band at Loc. 210 occurred is thought to be slightly less deep than that associated with Loc. 306, since rare goniatite and lamellibranch spat occur in the band together with isolated sponge spicules.

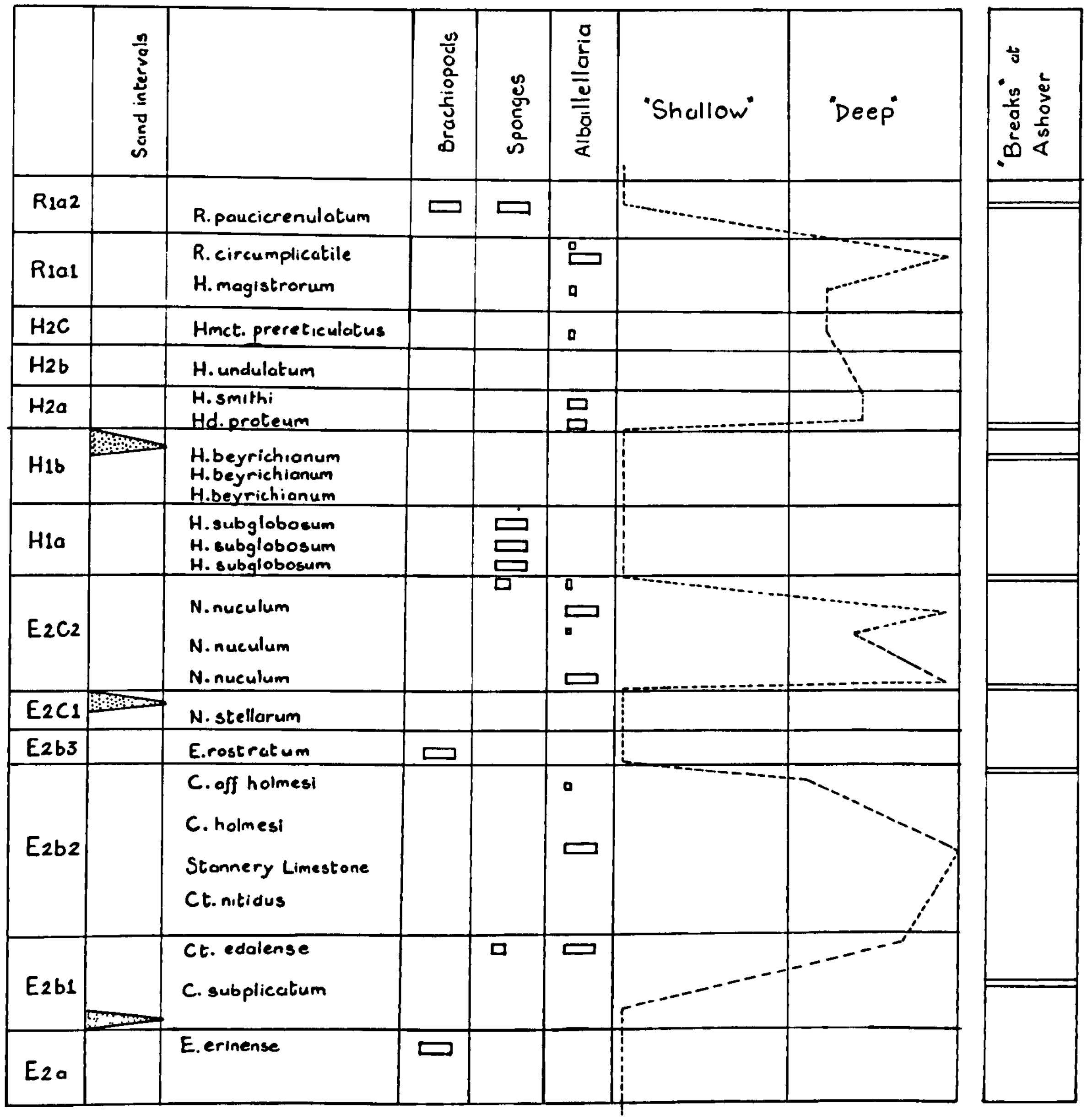
The next faunal band in the succession is thought to be transitional between the "deep" group of faunal bands of the E_2c_2 Subzone and the succeeding "shallow" group of faunal bands. This transitional faunal band is exposed in the Swallow Brook at Loc. 284 of Holdsworth (1963),and contains abundant spumellarian Radiolaria but only very rare examples of the non-spumellaria genera Albaillella, whilst the Ceratoikiscidae are absent. Sponge spicules are of frequent occurrence and rare small sponges are present. Spat goniatites and lamellibranchs are of relatively common occurrence in this band having a frequency in excess of 1 per cm^2. Thus, all the evidence of the microfauna at Loc. 284 points to an "intermediate water depth" genesis for this faunal band.

The second "shallow" grouping of faunal bands already initiated at the closure of E_2c_2 times becomes firmly established in the H_1a Zone. In the Swallow Brook a bullion bed at Loc. 211 contains the first H. subglobosum horizon and is characterised by mature and immature goniatites and small sponges occurring with densities similar to those indicated by Holdsworth (1966B) from an H_1a horizon in the Manifold Valley. Spumellarian Radiolaria are of sparse occurrence when compared with the Radiolarian content of faunal bands formed during "deep water" conditions. Goniatite and lamellibranch spat and detached sponge spicules occur with frequencies in excess of 1 per cm^2. H_1a faunal bands in the Dingle Brook, Hurdlow and Gun End sections are thought to be typical of "shallow water" genesis, they possess an abundant fauna of spat and sponge spicules and relatively dense concentrations of mature and immature goniatites, whilst Radiolaria are only sparsely represented.

Undolomitised limestone bullions at the level of H.beyrichianum have not been encountered in the North Staffordshire Basin and no record of the microfauna is available. A thin ankeritic bullion horizon occurring in the Gun End Stream at Loc. 042 contains mature and immature goniatites exhibiting densities greater than those displayed by specimens of N.nuculum similarly preserved in ankerities. The majority of H_1b faunal bands are of black shale type in which specimen densities are thought to have been increased during diagenesis (Holdsworth 1966b). However, a size range of specimens from 30mm down to 5mm median diameter has been recorded from these bands and this together with the evidence of the relatively high goniatite density at Loc. 042 is thought to indicate a "shallow water" genesis for the H_1b faunal bands.

A third "deep" grouping of faunal bands occurs in the Basin succession in the H_2a to R_1a interval. The Hd.proteum faunal band is present in this group, it is ankeritic at all localities and a microfauna is not preserved, however, it is proposed that the low densities of thicker-shelled goniatites present at this level are indicative of a "deep water" genesis for this band. Evidence from succeeding faunal horizons is thought to further confirm the "deep water" origins proposed for this group. Thus, at an H.smithi horizon in the Dove (Loc. 250 of Holdsworth, 1963) Holdsworth (1969) records the presence of Ceratoikiscum tricancellatum together with abundant entactiniid spumellarians. Whilst at the level of Hmct. prereticulatus ankeritic bullion horizons occur at several locations and yield a sparse "deep water" type fauna of thicker-shelled goniatites. A "deep" type of faunal band occurs at the level of R.circumplicatile in the Dove at Loc. 179

FIG. 4.A. Megarythmic Cycles in the North Staffordshire Basin.



(Holdsworth, 1963) which is Holdsworth's (1969) type locality for A.pennata. Holdsworth (1969) also records from the Dove at an R_1a_1 locality near to Loc. 179 an abundant fauna of entactiniid spumellarians, together with rare specimens of a minute variant of C.tricancellatum and a single specimen of Albaillella sp. This faunal band possesses characteristics similar to those displayed by the E_2c_2 faunal band at Loc. 309 (Holdsworth, 1963) which were proposed as evidence of "shallowing" of the second "deep" group of faunal bands.

The third "deep" group of faunal bands is replaced by a "shallow" group in the R_1a_2 Subzone. Evidence for this "shallow" grouping is seen in R_1 times by the incoming of benthonic faunas including abundant sponges and sponge spicules (Holdsworth, 1966b) and brachiopods and crinoids (Holdsworth, 1966b and Ashton, 1974), whilst non-spumellarian Radiolaria are significantly absent from faunal bands in this interval.

On the basis of the evidence outlined above, it is suggested that there are parts of the North Staffordshire Basin succession in which repeated "deep water" conditions occurred during faunal band genesis and that these parts of the succession alternate with parts which contain only faunal bands of "shallow water" genesis (Fig.4.A.).

The position of coarse clastic sediment in the succession

Further confirmation of the proposed "shallow" and "deep" conditions, which have so far been suggested on the basis of faunal evidence, is thought to be indicated by the position of the coarse clastic sediment in the Basin succession. In the interval E_2b_1 - H_2c coarse clastic sediment occurs only twice in the succession in palaeoland-remote parts of the Basin.[1.] It is present between the E_2c_1 and E_2c_{2i}

1. Excluding the Gawsworth area, where palaeontological control is lacking.

faunal horizons and between the highest H.beyrichianum level and the level of Hd.proteum. Thus, the sand intervals occur at those parts of the succession where an interval containing a "shallow water" type group of faunal bands is succeeded by an interval containing a "deep water" type group of faunal bands (Fig.4.A.). It should be noted that coarse clastic sediments are not present in palaeoland-remote parts of the succession above or within intervals containing faunal bands of the "deep water" type.

It is suggested that during the time of genesis of a part of the succession containing a "shallow" group of faunal bands, that coarse clastic sediment prograded into the Basin from the paralic margins. It is envisaged that this sediment was derived from the fronts of advancing deltas and was delivered to land-distal parts of the Basin via turbidity currents. However, during the genesis of the succeeding interval containing a "deep water" group of faunal bands, the supply of sand from the paralic areas was discontinued. This may imply that deltaic regression was occurring at the paralic margin during a "deep water" interval. Thus, it is suggested that the sand intervals in addition to emphasising the junctions between "shallow" and "deep" groups of faunal bands in the succession, may also provide independent evidence relating to water depth in the Basin since the evidence indicates that only after the establishment of shallowing conditions was coarse clastic sediment able to prograde to palaeoland-remote parts of the Basin.

In conclusion, it seems that the position of the sand intervals in the succession, together with the previously discussed faunal evidence, indicate that the succession in the North Staffordshire Basin shows alternating megacycles of "deep" and "shallow" water nature throughout the E_2b_1 - H_2c (inclusive) interval.

Fig.4.B.

A comparison of "Deep" and "Shallow" intervals in the North Staffordshire Basin succession with the distribution of faunal phases in the Ashover Boreholes.

North Staffordshire Basin	Ashover Boreholes	
"Shallow"	B	
		R. dubium
"Deep"	A	
		Hd. proteum
"Shallow"	C	
		H. aff. beyrichianum (Highest H_1b) Horizon
	A	
		H. subglobosum (H_1a_i)
"Deep"	B ↑ A	
		N. nuculum (E_2c_{2i})
"Shallow"	C	
The Cherts		Ct. nititoides
"Deep"	A ↑ B	
		Ct. edalense

Key:

A phases present 4, 5 and 6 (5 infrequent)
B phases present 1, 2, 3, 4, 5, 6 and barren intervals.
C phases present 1, 2, 3, 4 (+ Naidites sp.)
Arrow indicates a gradational change.

The "breaks" in the Ashover Succession

Detailed analysis of the Ashover Borehole records indicates that variations occur in the distribution of the faunal phases. For example, a "pattern" is established in the H_2c - R_1a interval which consists of repetitions of alternating spat and goniatite phases. Whilst in other parts of the Ashover succession, for example, in the E_2c_2 and E_2b_2 Subzones the "pattern" of phases present consists or repetitive cycles which display a gradual transition from barren strata through to the thicker-shelled goniatite phase and then a gradual return to barren strata. A third type of faunal phase "pattern" is evident in the Ashover succession. In this "pattern" the maximum marine conditions of the thicker-shelled goniatite phase are absent. The phases present alternate between fish phases to spat phases or Planolites phases to spat phases. In rare instances the A/D phase, is present in this "pattern".

Marked vertical changes in faunal phase "pattern" in the Ashover succession occur at the following positions: at the level of Ct.nititoides (The Cherts), immediately below the level of N.nuculum (E_2c_{2i}), at the level of H.subglobosum (H_1a_i), immediately below the level of Hd.proteum and immediately above the R_1a_2 level of R.dubium.

Therefore, on the basis of the palaeontological evidence it appears that the marked changes or "breaks" in the faunal phase "patterns" in the Ashover succession are synchronous with the interval junctions which occur in the North Staffordshire Basin succession between parts of the succession containing "shallow" groupings of faunal bands and parts containing "deep" groupings of faunal bands (Figs.4.A.&4.B.). Thus, it seems likely that the broad cyclicity occurring in the Basin succession may not be a purely local phenomenon, and that the North Staffordshire and Ashover successions were influenced by synchronous variations in water depth. It should be noted however, that the "deep" Ashover "pattern" need not indicate absolute depth comparable with "deep" of the Basin.

Tectonic versus general eustatic theory of Carboniferous control

In the Carboniferous, rhythmic or cyclic lithological sequences have been explained by several authors in terms of environmental alterations produced by either tectonic or eustatic mechanisms.

Considering firstly the tectonic mechanism; Bott and Johnson (1967) propose a mechanism of tectonic control for Carboniferous sedimentary cycles which they suggest are the product of subsidence of the crust taking place in rapid steps separated by longer periods of relative quiesence. In particular, they suggest that cyclicity of the type present in the Yoredale facies in the Craven area is closely controlled by tectonic subsidence. However, Ramsbottom (1973) indicates that during the deposition of the Yoredale cycles in the Craven area, there are indications of synchronous cyclicity in areas remote from the Craven area a phenomenon which seems to be best explained by a mechanism other than that of repeated local subsidence. This mechanism is proposed by Ramsbottom (1973) to be one of widespread uniform eustatic change in sea level. He cites evidence from the Dinantian in Britain where he proposes that eustatic changes in sea level are reflected by major cycles in the succession and that junctions between cycles are synchronous with similar junctions in the succession in Ireland and Belgium. He also indicates that comparisons can be made between the British and United States successions as, for example, in respect of the major non-sequence occurring at the top of the British Tournaisian which is equated with a non-sequence of the same age in the Mississippian of the United States. Moore (1935) indicates that this non-sequence in the Mississippian is due to a lowering of sea level and Ramsbottom (1973) is of the opinion that the evidence in Britain leads to the same conclusion.

Eustatic changes in the sea level may be either transgressive with either rising levels of sea and shoreline or regressive when these levels fall. Ramsbottom (1973) states "...in the United States (in the Dinantian) the same major transgressions and regressions affect the sedimentation as in Britain..." and also that "...widespread minor cyclicity begins at similar horizons in both countries."

Trewin and Holdsworth (1973) discussing cyclicity in the E_1a - E_2a (inclusive) succession of the North Staffordshire Basin indicate that the faunas of the E_1c, E_2a and E_2b marine bands present in the cycles are so widespread that they imply virtually synchronous marine transgressions in areas as far apart as Eire (Yates, 1962) and Belgium (Van Leckwijck, 1964). They suggest that eustatic control appears to be the only mechanism competent to effect synchonous faunal and sedimentary changes over such extensive areas.

In the North Staffordshire Basin in the E_2b_1 - H_2c interval a megacyclic sequence of alternating "deep" and "shallow" intervals has been proposed (ibid and Fig.4.A.). The interval junctions in the Basin have been proposed as being synchronous with the marked "breaks" or changes of faunal phase "pattern" in the Ashover succession (Fig.4.B.) and the two are proposed as being the product of a single controlling mechanism.

It appears that a eustatic control is the only mechanism competent to produce the major synchronous features referred to above. However, it will be shown later in the discussion that the effects of local epeirogenic movements which cannot be correlated with similar movements in adjacent areas have also influenced the character of local Namurian successions.

Faunal phases related to eustatic fluctuations in sea level

In the E_2b_1 - H_2c interval in the North Staffordshire succession faunal bands are present separated by considerable thicknesses of strata which yield no macrofauna. It was suggested by Holdsworth (1966b) that these "barren intervals" represent periods of reduced salinity and reduced water depth, and it was thought that such conditions may equate with eustatic low periods. Ashton (1974) suggests that the "barren intervals" in the Basin may be due to acid bottom conditions such that all the organic carbonate was dissolved or that bottom conditions were oxygenating and encouraged bacterial attack and concomitant solution of shell material. Ashton proposed that faunas were preserved, when carbonate precipitation was sufficiently rapid, or that in black shale areas where oxygen levels and bacterial activity were low giving time for impressions to be formed before solution of shell material. Analysis of the Ashover Boreholes (Ramsbottom et al. 1962) reveals that barren intervals are extremely rare in the succession. Thus it appears that either conditions of preservation were different in the two areas, or that differences of environment between the two areas significantly affected faunal colonisation.

Ramsbottom et al. (1962) indicate that the succession of the faunal bands in the Ashover area is marked by a gradual build-up of faunal phases, which can be correlated with gradual increases in salinity and possibly with increased depth of water accompanying a eustatic rise in sea level. In particular, palaeontological data from the Ashover Boreholes is interpreted by Ramsbottom et al. as indicative of a gradual transition of faunal elements within a faunal band in response to increasing salinity, in strata of Reticuloceras, Homoceras and Upper Eumorphoceras ages. They state, "The principal faunal phases encountered are: (1) Fish phase; (2) Planolites phase; (3) Lingula phase; (4) mollusc spat phase; (5) Anthracoceras or Dimorphoceras phase; and (6) the typical thicker-shelled goniatite phase. The order in which these phases are numbered is that in which they are found in cyclic succession, though not all these phases are necessarily found in any one cycle of faunal phases. The view taken here is that it is also the order of increasing salinity of the environment, though increasing depth of water may have been another factor." Trewin and Holdsworth (1973) concur with the findings of Ramsbottom et al. (1962) when they state "...the thicker-shelled goniatite phase most probably records periods of maximum water depth and maximum extension of fully saline water in the Central Province." However, they suggest that it would be unwise to assume that only the thicker-shelled goniatite faunas of the typical marine bands represent truly marine conditions. Trewin and Holdsworth also believe that faunal phase change is most likely to be controlled by eustatic change of sea level, although they indicate that minor eustatic fluctuations could have produced profound faunal changes in one environment whilst producing no recognisable change in others.

Considering the implications of eustatic control on the distribution of faunal phases in the faunal bands of the North Staffordshire Basin in the interval E_2b_1 - H_2c, the sequence of phases within any one faunal band can be expected to correspond to that proposed by Ramsbottom et al. (1962). Thus, with rising water level the phases in the vertical sequence would be expected to occur in the order 1-6 or in any other progression within this sequence, depending on the initial phase, for example, 3-6. In that part of each eustatic cycle where falling water level occurs the vertical order of phases would be expected to be reversed. With a eustatic rise in sea level Ramsbottom (1973) suggests that in the Dinantian, a transgressive phase developed in which progressive faunal changes occured in response to environmental changes. In the North Staffordshire Basin, particularly in the marginal areas, it is presumed that any environmental changes initiated by a eustatically controlled transgression, would include change in salinity and water depth. Thus moving laterally into areas of increased salinity the phases would be expected to occur in the order 1-6. However, the majority of faunal bands (circa 80%) examined in the North Staffordshire Basin during the course of this work contain only thicker-shelled goniatite phase faunas. Of the remainder, approximately half contain the thicker-shelled goniatite phase and one other phase. The latter can be either a phase containing Posidonia sp. or Posidoniella sp., or a phase containing Anthracoceras sp. or Dimorphoceras sp., with or without Dunbarella sp. The remaining 10% of the faunal bands in the Basin contain faunal elements which belong to the A or D phase. Some contain thin-shelled goniatites only, whilst others contain either Posidonia sp. or Posidoniella sp. only.

Thus, at first sight, due to the absence of vertical or lateral variation in the faunal bands, it appears that faunal evidence for eustatic rise and fall of water level during faunal band genesis is lacking in the Basin area. If however, the influence of environment on the character of the faunal bands is considered, it is still possible to explain the faunal record of the Basin in terms of eustatic fluctuations of sea level with variable maxima. In order to do this, the absence of phases 1, 2, 3, 4 and the occurrence in only 20% of the faunal bands of phase 5 requires explanation. Holdsworth (1966b) suggests that the barren intervals present in the Basin succession record periods of depth reduction such as to inhibit the thicker-shelled goniatites but without sufficient reduction in salinity to favour Anthracoceras or Dimorphoceras and without the establishment of a bottom environment favouring the development of thin-shelled lamellibranchs. It is proposed that the absence of phases 1, 2 and 3 may also be due to insufficient reduction in salinity, and in particular the absence of the "brackish water" lamellibranchs from the Basin succession, which are however present in the Ashover succession, appears to confirm this proposal.

A possible explanation for the absence of phase 4, the spat phase, from the Basin succession may be deduced from an examination of parts of the Ashover succession. In the Ashover Boreholes, the spat phase is extremely well developed with countless numbers of spat shells present in the succession. Ramsbottom et al. (1962) identified both gasteropod and lamellibranch spat from the Ashover succession although they rarely identified goniatite spat with any certainty. They recognised three types of lamellibranch spat, types a, b and c which they tentatively identified as: type (c) Posidoniella and types (a) and (b) which they suggest may be Caneyella, Posidoniella or Nuculids. Ramsbottom et al. state, "In rare instances examples of the so called non-marine lamellibranch genera Naiadites and Curvirimula occur in the spat phase." Careful examination of the Ashover logs reveals however, that in the majority of instances the non-marine lamellibranchs occur in segments of the succession which display the spat phase, but from which the maximum marine phase is absent. Thus, on the evidence of the Ashover succession, together with the absence of the "brackish water" lamellibranchs from the Basin, there appears to be some indication that the absence of the spat phase from the Basin succession is due, as were phases 1, 2 and 3 to insufficient reduction in salinity which did not allow adult lamellibranchs, the source of the spat, to colonise areas of the Basin or areas adjacent to the Basin, even in periods of falling sea level.

Goniatite and lamellibranch spat are however present in the thicker-shelled goniatite phase in the Basin which it has been suggested represents conditions of maximum salinity. Their presence in this phase plus the absence of goniatite spat from the spat phase in the Ashover Boreholes may imply that the mollusc spat in the spat phase are different from those in the thicker-shelled goniatite phase. The absence of non-marine lamellibranchs from the Basin and their occurrence in the spat phase in the Ashover succession may also imply that the spat in the spat phase are the spat of non-marine species.

The presence of goniatite and lamellibranch spat in the thicker-shelled goniatite phase in the Basin is thought to indicate that at some stage during the development of a eustatic cycle environments became established in the Basin which were suitable breeding grounds for goniatites and lamellibranchs. In the case of the goniatites in particular, all the previously discussed evidence indicates that they needed extensive areas of shallow water for breeding grounds and it is thought that only at a certain stage in the development of a eustatic rise in sea level was this type of environment established in the Basin, or, more probably at its margins. For example, Ashton (1974) proposed that an environment suitable as a breeding ground would, with rising water level, become established over inundated delta tops. Thus, with the establishment of such an environment in the Basin area both mature and spat forms would occur in a single phase in the faunal bands. The co-existence of lamellibranch spat and goniatite spat in the faunal bands of the Basin appears to indicate that they originated from the same or closely comparable environments, which it is suggested developed at or near to the eustatic maximum. The presence of spat of this type in faunal bands in all parts of the Basin is thought to indicate that the spat were planktonic and were distributed, possibly by wave and current action, throughout the Basin. In the case of lamellibranch spat, Holdsworth (1966b) suggests that they sank into areas of excessive water depth where bottom conditions were unfavourable for their development, whilst as previously suggested (p.251) the goniatite spat content represents the accumulation of shells due to natural mortality rates.

It has been suggested (ibid) that the variations in the character of the faunal bands (i.e. "deep" and "shallow" types) present in the Basin can be explained if a mechanism of eustatic fluctuations of sea level with variable maxima is considered. Thus, the "deep" type of faunal band with its sparse goniatite population is thought to be representative of a eustatic maximum which either pushed back the goniatite breeding grounds to remote parts of the Basin or markedly reduced such breeding areas within the Basin. On the other hand, the "shallow" type of eustatic rise in sea level, typified by faunal bands containing relatively dense goniatite concentrations is thought to have been favourable for the development of extensive goniatite breeding grounds covering much of the "shallower" areas of the North Staffordshire Basin.

The influence of eustatic fluctuations in sea levels with variable maxima and local epeirogeny on the faunal phases in the Ashover succession.

The marked changes of faunal phase "pattern" occurring in the Ashover succession which correlate with interval junctions in the Basin succession has previously been described as being the result of a general overal eustatic control in the two areas. The presence of the various types of faunal phase "pattern" occurring in the Ashover succession has also been noted and remains to be explained. Three main types of faunal phase "pattern" occur. The first is a "pattern" restricted to alternating spat and goniatite phases and is seen for example in the H_2a - R_1a interval. It is proposed to equate this type of "pattern" with "deep" water conditions in the Ashover area when, even during eustatic low periods, water depth in this interval is thought to have been too great to allow other phases, which are regarded as less marine by Ramsbottom et al. (1962), to develop. In other parts of the Ashover succession, for example, in the E_2c_2 and E_2b_2 Subzones, the "pattern" of faunal phases present in each eustatic cycle indicates a gradual transition from barren intervals through to the thicker-shelled goniatite phase and then a gradual return to barren strata. This type of "pattern" is thought to indicate that in the Ashover area the water depths and salinity conditions occurring in each eustatic cycle were favourable for colonisation of the area by the faunal elements present in the successive Fish to thicker-shelled goniatite faunal phases. This type of "pattern" will subsequently be referred to as the "sensitive condition" since the environment was apparently water depth sensitive and subject to marked changes during the complete eustatic cycle. A third type of faunal phase "pattern" is evident from analysis of the Ashover Borehole records. In this "pattern" the maximum marine conditions of the thicker-shelled goniatite phase are absent. Such a pattern is present in the succession between the highest H.beyrichianum and Hd.proteum levels. The phases present alternate between Fish or Planolites phases to spat phases and in rare instances have the A/D phase as the maxima. Also present in this third type of phase pattern are the non-marine lamellibranchs, Naiadites sp. and or Curvirimula sp. In a phase "pattern" of this type above the R.gracile horizon in the Upper-town Borehole specimens of Naiadites sp. with adherent Spirorbis sp. are recorded and in the same interval at Tansley the non-marine ostrocod Carbonita sp. is present. It is thought that this type of "pattern" which even at the eustatic maxima was not conducive to the development of the thicker-shelled goniatite phase, represents a "shallow water" or "shoal" environment. The frequent presence of a non-marine fauna in this type of pattern is thought to indicate that salinity levels varied and it is suggested that even during eustatic highs that conditions were not always truly marine.

Analysis of the faunal phases in the Ashover succession reveals that in some parts of the succession it is possible to detect the influence of synchronous fluctuations in sea level which have produced the same response in both the Basin and the Ashover area, that is both areas are characterised by "deep" or both by "shallow" conditions, whilst in other parts of the succession this correspondence does not occur. (N.B. Absolute depths in the two areas need not be comparable). Thus, the first "deep" interval which occurs in the Basin in the E_2b_1 and E_2b_2 Subzones, does not immediately produce the expected "deep pattern" of faunal phases in the Ashover succession, although by the C.holmesi level a "deep pattern" is evident. An explanation for this may be that the Ashover area had become stable in this period or was even a positive area and the average rise in sea level produced only the "sensitive condition."

A change to a "deep pattern" in the upper part of the E_2b_2 Subzone may indicate the establishment of renewed subsidence relative to the North Staffordshire area, since a deepening of the average sea level is not indicated on faunal evidence from the Basin succession.

The "shallow" interval containing the E.rostratum and N.stellarum faunal bands in the Basin correlates with a "shoaling" type of environment in this interval in the Ashover area. Above the Cherts-equivalent horizon at Ashover, three barren intervals are present in the succession below the first E_2c_2 horizon which are separated by Fish, Lingula and Spat Phases. It is proposed that the N.stellarum level equates with a portion of this succession and its absence in the Ashover succession is thought to indicate that the eustatic maximum associated with N.stellarum did not produce "deep water conditions" in the area and that an environment suitable for colonisation by thicker-shelled goniatites was not developed.

The "deep" interval seen in the Basin in the E_2c_2 Subzone, produces a distinct change in the "pattern" of faunal phases in the Ashover succession. A "deep pattern" is seen in the lower half of the Subzone which near to the top of the Subzone changes to the "sensitive" type. The change may be due in part to falling average sea levels as the transition to the succeeding "shallow" interval occurs or may indicate that uplift had produced a shallowing of the area leading to the "sensitive condition."

The "shallow" interval occurring in the H_1a and H_1b Zones is well defined in the North Staffordshire Basin and it was expected that a "shallow/shoaling pattern" of faunal phases would result in the Ashover succession. However, this is not the case and for most of the interval a "pattern" of faunal phases is present which is of the type associated with a "deep water" environment. In the light of this evidence it is assumed that subsidence in the Ashover area produced the "deep water" environment. The proposed subsidence is most marked from the H_1a_{ii} horizon to the highest H.beyrichianum band and is followed by a "shallowing" which is indicated by a repetitive "pattern" of spat and Planolites phases in which the non-marine lamellibranch Naiadites occurs.

The succeeding "deep" interval which commences in the H_2a Zone produces in the Ashover succession a "pattern" of alternating spat and goniatite phases thought to be indicative of "deep water" between the horizons of Hd.proteum and R.dubium. A corresponding "deep" grouping of faunal bands is present in the Basin succession in this interval. The "shallow" interval which follows results in a return to the "pattern" of faunal phases described as the "sensitive condition", with a brachiopod and crinoid fauna at the levels of H.ornatum and R.reticulatum, and has the non-marine lamellibranchs Naiadites and Curvirimula occurring mainly in the spat phases. This interval also corresponds with the "shallow" grouping of faunal bands present in the Basin succession at this level.

Thus, the influence of the eustatic fluctuations and the variable maxima they exhibit can be detected in both areas although the modifications produced by the local epeirogenic movements in the Ashover area relative to the Basin area have produced significant modifications in the "pattern" of faunal phases within the major intervals. These differences are not detectable in the Basin succession where the faunal evidence indicates that only limited environmental variation occurred in each eustatic cycle.

APPENDIX TO CHAPTER 4

Recapitulation

The characteristic features of the thicker-shelled goniatite bands which are present in Namurian basinal facies appear to indicate that they resulted from abrupt widespread and synchronous establishment of marine conditions. Such changes seem most likely to have been produced by eustatic sea level fluctuations, rise in sea level having allowed essentially synchronous establishment of very similar thicker-shelled goniatite populations over extensive areas.

In the North Staffordshire Basin succession the individual goniatite bands have been shown to differ one from the other, the nature of the differences, it has been suggested, being related to the depth of deposition and distance from the palaeoshore line (p. 252). It has been suggested that the genesis of some bands was in "shallow" and others in "deep" conditions (p. 257) and an examination of the succession (Fig. 4A) reveals the presence of an alternating sequence of groups of "shallow" and groups of "deep" bands.

On the evidence of the goniatite bands four "shallow" intervals have been recognised in the succession, from the base upwards they are as follows:- 1st. "shallow" interval pre- E_2b_1, 2nd. "shallow" interval E_2b_3 - E_2c_1 (inclusive), 3rd. "shallow" interval H_1a - H_1b (inclusive), 4th. "shallow" interval post R_1a_2. Interspersed with the "shallow" are "deep" intervals which occupy the following positions in the succession:-
1st. "deep" interval E_2b_1 - E_2b_2 (inclusive), 2nd. "deep" interval E_2c_2, 3rd. "deep" interval H_2a - R_1a_2 (inclusive).

Further examination of Fig. 4A reveals that the sand units in the Basin [1] succession occur in segments of the column where "shallow" goniatite bands predominate.

The evidence of the grouping of the two "types" of goniatite bands and the position of the coarse clastic sediments in the column is suggested to be indicative of "megacyclicity" in the history of the Basin (p. 265) which is characterised by periods of time when successive goniatite bands developed in "deep" conditions with negligible sand deposition alternating with periods of time marked by deposition of successive "shallow" water goniatite bands and relatively abundant sand deposition.

It must be emphasised that the evidence from the Basin succession does not indicate that "shallow" goniatite band genesis resulted from shallowing due to sand deposition but rather that the genesis of "shallow" goniatite bands preceded the entry of coarse clastic sediment into the Basin succession. Evidence bearing on this point is present for example in the E_2b_3 and E_2c_1 Subzones, where establishment of the "shallow" type goniatite bands *E. rostratum*, (*Ct. nititoides*) and *N. stellarum* precedes the entry of the Hurdlow Sandstone (p. 265). Similarly the abrupt "deep" to "shallow" change of goniatite band types across the E_2c_2 - H_1a boundary (p. 262) occurs prior to the deposition of the first Chokierian sands, whilst evidence is present for marine band "shallowing" from R_1a_1 to R_1a_2 (Holdsworth, 1966c; Ashton, 1974) immediately preceding the deposition of R_1b turbidites (Holdsworth, 1963; Ashton, 1974).

1. The term "Basin" is frequently used in this account as an abbreviation for North Staffordshire Basin.

Thus it appears evident that the megacyclicity of the North Staffordshire succession although emphasised by the position of the sand units was not produced by the variation in the supply of coarse clastic sediment to the Basin and some other explanation must be sought. Two obvious mechanisms may have operated; (a) Average water depth within the Basin changed at the initiation of successive megacycles due to epeiric rise or fall of the North Staffordshire area relative to the contemporaneous world sea level; (b) World sea level itself was subject not merely to the relatively "brief" fluctuations which controlled the genesis of the goniatite bands (this section paragraph 1) but also to a longer term pattern of variation in sea level which is evidenced in the megacyclicity present in the North Staffordshire succession.

Clearly, if the second mechanism, that of major eustatic cyclicity, was the fundamental control then its influence should be detectable in Namurian successions outside the area of the North Staffordshire Basin. Evidence from extra - Basinal [1] Namurian areas in the British Isles will be examined in this section.

<u>Criteria for the recognition of megacyclicity in extra-Basinal areas</u>

In the Basin succession the criteria for distinguishing between "deep" and "shallow" intervals is on the basis of the faunal and lithological evidence. In extra-Basinal areas detailed palaeontological evidence of the type previously discussed in this thesis is largely unobtainable and in these areas it appears that only lithological evidence is available against which to test the possibility of widespread megacyclicity. It is proposed (p. 265) that the entry of coarse clastic sediment into the Basin took place as a consequence of "shallowing"

1. The term "extra-Basinal" is used in this account with reference to any area outside the North Staffordshire Basin.

and it is suggested that the presence of sand in extra-Basinal successions may likewise be indicative of "shallow" intervals in these successions. However in some areas the whole of the Namurian succession, in the E_2b_1 - H_2c (inclusive) interval, is sand free. Such areas, on the basis of contemporary palaeogeography, are seen to be situated in land-distal localities. This is the case in the Edale area, and that part of the Edale Shales representing this interval is a completely argillaceous sequence. The Sabden Shales of the Rossendale area are also seen to have been deposited in a land remote area and likewise are sand free in the interval under consideration. In the Upper Dove Valley, a palaeo-land - remote area of the North Staffordshire Basin, the succession in the E_2b_1 - H_2c (inclusive) interval, with the exception of a single very thin bed of sandstone of turbidite origin occurring below the Hd. proteus horizon, consists of basinal mudstone. In this case however, the absence of sand may also be partly due to the proposed slope reversal in the area marginal to the Dinantian massif (p. 281). Thus it is apparent that in some basinal areas lithologies cannot be used as indicators of megacyclicity since coarse clastic sediments may not have reached them even in "shallow" periods.

In paralic areas, where faunal evidence is frequently lacking (c.f. Astbury) the interpretation of megarythmic sequences on the basis of lithological evidence may again not be possible, and the possibility that faunal evidence may have been removed by erosion during "shallow" intervals must also be considered.

The detection of a megacyclic sedimentation pattern, in abnormal areas which appear to have received a continuous supply of coarse sediment such as the Gawsworth area may also be virtually impossible, whilst the interpretation and correlation of the sedimentary events in such areas with those in other areas may be further complicated by the consequent limited development of faunal bands.

Bearing in mind the possible influence of the above sedimentary controls in any particular succession, the sedimentary evidence from extra-Basinal areas is now assessed with reference to the possibility of eustatically controlled megacyclicity.

However, as is very well established, the Namurian successions of the North of England "blocks or massifs" differ markedly in overall lithologic nature from the basinal sequences of the Central Province. Nevertheless, if the interpretation of the North Staffordshire megacycles is correct and if, fundamentally, this megacyclicity is of a eustatic nature, it must be predicted that "basinal" characteristics will be more apparent across the blocks in portions of the record contemporaneous with "deep" sequences of the North Staffordshire Basin.

Evidence from extra-Basinal areas

(a) Basinal Facies

In the Central Province evidence of cyclicity synchronous with that of the Basin succession is referred to by Trewin and Holdsworth (1973). They indicate that the "deep" conditions which marked the end of their "shallow" *E. bisulcatum erinense* cycle can also be detected in the Lancaster Fells (Moseley, 1954) Slieve Anierin (Yates, 1962) and Rombalds Moor (Stephens *et al.*, 1942). In these areas they propose that the "deep" conditions in the E_2b_1 Subzone which culminated in the Ct. edalensis maximum produced a marine succession in what had previously been an autochthonous intra-basinal coal bearing sequence.

The above mentioned areas were particularly well documented by their respective authors and these and others will now be discussed in detail.

In the Lancaster Fells the Roeburndale Grit Group occurs entirely within the 1st. "shallow" megarythmic interval, since Moseley (1954) places the base of the group above the level of E. bisulcatum and the top below the level of Ct. lirifer [1.] (Ct. edalensis). The Group displays a broad coarsening upwards sequence and contains several sand units including the Long Crag Grit and the Lower and Upper Roeburndale Grits. The Roeburndale Grits which attain a maximum thickness of 180' in the Ward's Stone area contain persistent coal seams and gannisters which clearly indicate their paralic nature.

The 1st. "deep" megarythmic interval is represented in the Lancaster Fells by the Caton Shales which, as Moseley points out, everywhere succeed abruptly the Upper Roeburndale Grit, and in places the lowest marine band in the Caton Shales, the first Ct. lirifer (Ct. edalensis) band, often rests directly on the undulating surface of this paralic grit. Moseley also noted that Anthracoceras sp. was present in the black shales above this thicker-shelled goniatite horizon but was almost completely absent below, a feature which appears to indicate that the paralic Roeburndale Grit Group was inundated only at the E_2b_1 maximum.

The argillaceous sequence displayed by the Caton Shales attains a thickness of 180' in the type locality and contains in addition to a maximum of four Ct. lirifer (Ct. edalensis) horizons, the horizons of Ct. nitidus and C. holmesi.

1. The species identified by Moseley (1954) as Ct. lirifer is now known to be Ct. edalensis (Personal communication B.K. Holdsworth)

Towards the top of the Caton Shales, 17 ft above the level of C. holmesi, Moseley records at his Loc. 39 an inch thick highly calcareous band containing Ct. ? stellarum (N. stellarum) and he indicates that Hudson (1944) recorded a similar band from Greenholes Beck (a locality near Caton) from which were obtained specimens of "Ct. stellarum" (N. stellarum).

Above his "Ct. ? stellarum" (N. stellarum) level Moseley indicates that the shales become micaceous and above at the incoming of sandy shales and thin sandstones, he places the lower boundary of the Claughton Flags. (From personal observation in Greenholes Beck the succession above Loc. 39 (Moseley, 1954) shows an upward passage from dark basinal mudstones (Caton Shales), to turbidites of distal aspect (Claughton Flags), culminating in a thick fluvial sandstone succession (Claughton Sandstone).)

The Claughton Flags Group in the Caton area contains two sandstones, the Claughton Sandstones (10 - 30 ft thick) which lie 30 - 50' above the level of "Ct. ? stellarum" (N. stellarum). Whilst in the east, in the Mewith area, an arenaceous unit the Oak Bank "Grit" (100 ft max.), lies directly above the E_2c_1 faunal band. From personal observation the Claughton Sandstone displays evidence of shallow water origin, and Moseley indicates that a 12 ft thick gannister overlain by a thin coal is present in the Lower Claughton Sandstone in the Claughton area.

The evidence of the lithologies in the upper part of the Claughton Flags Group appears to be indicative of the accummulation of sediment in shallow water and on the basis of the palaeontological evidence the Claughton Flags Group, up to and including the Claughton Sandstones, equate with the 2nd. "shallow" megarythm in the North Staffordshire Basin succession.

Above the Claughton Sandstones are circa 50 ft of micaceous shales and flags which Moseley (1954) places in the upper part of the E_2c_2 Subzone. This interval is overlain by a sandstone unit the Crossdale Grit which Moseley correlates with the Lower Follyfoot Grit of the Northern Pennines. Both occur below the H. beyrichianum Subzone, and in the Rombalds Moor succession (Stephens et al., 1942) the base of the Lower Follyfoot Ridge Grit is clearly defined above an argillaceous interval carrying N. nuculum at Locs. 29, 40 and 50 of Stephens et al., 1954.

Between the Rombalds Moor and Lancaster Fells areas lies the Keasden district. Here Moseley (1956) describes a sandstone unit, the Silver Hills Grit, which has a marked erosive base. This arenaceous unit he equates with the Crossdale Grit to the west and the Lower Follifoot Grit to the east. The Silver Hills Grit lies above a group of sandy micaceous shales and flags some 120 ft thick which in part Moseley correlates with the micaceous shales and flags of the upper part of the Claughton Flags of the Lancaster Fells. Moseley (1954, 1956) is of the opinion that the equivalent part of the succession to the west in the Rombalds Moor area is an argillaceous interval carrying marine horizons with N. nuculum. In the Keasden area the only fauna recorded from this interval is that of land-derived plant fragments, whilst in the Lancaster Fells area lamellibranchs though rare in occurrence are also present. The lithologies and faunas present in this interval in the Lancaster Fells and Keasden areas appear to indicate that during E_2c_2 times this depositional area was proximal to a landmass which although not supplying the coarse detrital sediment characteristic of the "shallow" Claughton Sandstone or Crossdale Grit times was, despite a rise in average sea level still basically a non-marine area which precluded E_2c_2 goniatite colonisation. An alternative to this is that erosion by the overlying grit units removed the faunal evidence although this seems less likely than the former explanation. It is thought that the apparent lack of E_2c_2 marine conditions in the Lancaster Fells - Keasden area may be attributed to contemporaneous local epeirogenic movement to the north or north west of the area, this appears to be a reasonable proposal in view of the proximity of the Craven Fault Zone which Ramsbottom (1974) indicates was still associated in R_1 times with the continuing positive nature of the underlying structure.

Thus although palaeontological control is less precise in the Lancaster Fells than in the Rombalds Moor area, it is probable that the argillaceous succession between the Claughton Sandstones and the Crossdale Grit is, as Moseley suggests, of E_2c_2 age.

It is suggested therefore that the argillaceous sediments occupying the top 50' of the Claughton Flags represent "deep" water conditions and correlate with the second "deep" megarythm in the North Staffordshire Basin succession.

A return to "shallow" conditions is evidenced by the lithologies of the Crossdale Grit which Moseley indicates contains units of coarse and pebbly false bedded sandstone, thin coal seams, with seatearths and flaggy sandstones. These lithologies appear to indicate a paralic environment in which it is suggested the "shallow" faunal bands of the H_1a Subzone were either not deposited or were removed by penecontemporaneous erosion. A similar situation is thought to have existed in the southern parts of the North Staffordshire Basin during the deposition of the Sharpcliffe Sandstone which occurs above an argillaceous succession containing three N. nuculum horizons, whilst the otherwise commonly occurring H. subglobosum horizons appear to have been suppressed in this area.

An H. beyrichianum horizon occurs 25' above the Crossdale Grit, and in the Bentham area is immediately overlain by the Bentham Grit. To the south of High Bentham this grit is known as the Clintsfield Grit and contains gannisters and thin coal seams (the Clintsfield Coal).

The position of the Clintsfield Grit above the H. beyrichianum faunal horizon is thought to be equivalent to that of the Lum Lady Edge Sandstone which is present at the top of the 3rd. "shallow" megacycle in the North Staffordshire Basin. In the Lancaster Fells area it is suggested therefore that the shallow water paralic sediments forming both the Crossdale Grit and the overlying Bentham or Clintsfield Grit were deposited during the 3rd. "shallow". megarythmic interval.

Above the Clintsfield Grit, Moseley indicates that shales of up to 100' max. occur and at the base carry an horizon with Homoceras sp. This shale interval above the paralic Clintsfield Grit appears to be very variable, in the Crossdale area. It is described as being a fine grained black shale containing goniatites, whilst to the north in the Mewith district Moseley indicates that a silty shale with a benthonic fauna occurs at this level. The benthonic fauna of the Mewith district containing Productus sp., Chonetes cf. hardrensis, Crurithyris sp., Schizophoria sp. and crinoid stems is reminiscent of the H_2a benthos of the Astbury succession and although Hd. proteus has not been recorded from the area it seems very likely that the abrupt termination of the paralic conditions which obtained in Clintsfield Grit times was produced by the H_2a rise in sea level which as in other areas (see Fig. VIIA) saw the abrupt cessation of coarse clastic sedimentation.

Above the 100' argillaceous interval Moseley (1954) states, ".... there is a gradual transition from marine to sandy shale. This is succeeded by medium-grained massively bedded sandstone, which become rather calcareous and contain brachiopods near the top." The massively bedded sandstones referred to by Moseley are overlain by an horizon containing R. reticulatum.

Thus although palaeontological control is poor in the upper part of H and R_1 in the Lancaster Fells there is, however, evidence of cyclicity which may be correlated with the megacycles in the Basin, in particular the argillaceous interval above the Clintsfield Grit is equated with the 3rd. "deep" megacycle whilst the shallowing succession above this is equated with the 4th. "shallow" interval in the Basin succession.

The work of Stephens et al. (1942) in the Rombalds Moor area of North West Yorkshire is now examined. Palaeontological control is good in this area and on this basis the position of the sand intervals in the succession can be accurately determined. The base of E_2 is taken as the Edge Marine Band which contains E. bisulcatum. Above this horizon is a group of sandstones and shales 600 ft thick which is terminated by a massive sandstone the Marchup Grit. A shale interval, the Weeton Shales some 200 ft thick, occurs above the Marchup Grit. At the base, where they contain bullions, the shales are referred to as the Marchup Marine Beds.

These beds are exposed at several localities and Stephens et al., suggest that they contain several distinct marine bands. Although the exposures of the various faunal bands are scattered the upward order of succession according to Stephens et al., appears to be C. subplicatum, C. aff. edalense (Ct. edalensis), C. aff. holmesi and C. stellarum (N. stellarum).

At or near the horizon of C. stellarum (N. stellarum) the presence of Cravenoceras nititoides (early form) was recorded by Hudson (1933). A sandstone unit, the Nesfield Sandstone occurs above the C. stellarum (N. stellarum) horizon whilst above this is an E_2c_2 shale succession carrying faunal bands with N. nuculum. From the above evidence it appears that the influence of the 1st. and 2nd. "shallow" megarythms together with the intervening 1st. "deep" interval recognised in the Basin succession can also be recognised by a similar response in the Rombalds Moor succession.

In the Basin the E_2c_2 succession has been suggested as being indicative of "deep" conditions. Similarly a thick shale succession in the Rombalds Moor area carrying faunal bands at four localities each with N. nuculum and E. bisulcatum, is thought to confirm that the 2nd. "deep" megacyclic interval recognised in the Basin also produced a "deep" response in this area.

Above the E_2c_2 succession occurs a sand interval, the Middleton Grit, which is succeeded by a mudstone succession apparently containing four faunal bands which in upward sequence carry H. subglobosum, H. subglobosum var., H. beyrichianum and H. beyrichianum together with a form identified as H. aff. undulatum. Thus it appears in this area that the entry of coarse clastics, as in the Combes area of North Staffordshire, took place at an early stage in the post E_2c_2 shallowing. The Brocka Bank or Upper Follifoot Ridge Grit is present above the highest H_1b horizon and is succeeded by a shale sequence in which the only faunal band recorded lies 30 - 110 ft above the Grit and contains H. eostriolatum.

It is suggested that the Middleton Grit and the Brocka Bank Grit lie within the 3rd. "shallow" megacycle discernable in the Basin succession, and that the presence of these coarse clastic sediments in the Rombalds Moor area also indicates a shallowing broadly synchronous with that in the Basin. However, the presence above the Middleton Grit particularly of the H. beyrichianum faunal bands suggests a rise in sea level of sufficient magnitude to temporarily terminate the supply of coarse clastics to this area. This "deepening" is not discernable in the North Staffordshire Basin, although it has been noted in the Lancaster Fells and also occurs in the Bradford and Skipton area (Stephens et al., 1953). In the Leeds area (Edwards et al., 1950) the equivalent grits to the Middleton Grit and the Brocka Bank Grit are the Lower and Upper Follifoot Ridge Grits, which in the vicinity of Leeds form practically a single unit being separated in places by only 10' of mudstone carrying Lingula sp. It is suggested therefore that although the H_1b bands represent relatively "deep" conditions within a "shallow" megacyclic period that they were not of sufficient "depth" or duration to significantly change the "shallow" nature of the 3rd. "shallow" megacycle.

Above the level of H. eostriolatum a shale sequence is present with faunal bands exposed at several localities from which have been obtained Hmct. prereticulatus (loose block), H. aff. henkei, and species of Reticuloceras thought to be of R_1a age, whilst to the east of the area a shell bed, the Cayton Gill Shell Bed is present in this interval. The shale sequence is terminated by the Addlethorpe Grit which is in turn succeeded by a shale sequence which carries near the base a faunal band containing R. reticulatum. It is thus apparent that the megacyclic pattern continues in the area and it is suggested that the influence of the 4th. "shallow" megarythm in this area can be equated in part with the deposition of the Addlethorpe Grit whilst the shale sequence between this Grit and the preceding Upper Follifoot Ridge Grit corresponds to the 3rd. "deep" megacyclic interval in the Basin succession.

The presence of the brachiopod rich shelly sandstone, the Cayton Gill Shell Beds, occurring within the proposed 3rd. deep megarythmic interval, (above the horizon of H. eostriolatum and below an horizon from which H. aff. henkei was recorded) appears to be anomalous. However Ramsbottom (1974) is of the opinion that the Cayton Gill Shell Beds and other shell beds of shallow water origin present in the Kinderscoutian of the Wharfedale - Nidderdale area were developed close to the area of maximum movement of the Craven Fault in the Dinantian and early Namurian and that the presence of the shell beds indicates the continuing positive nature of the underlying structure. In the localised area of occurrence of the Cayton Gill Shell Beds it thus appears possible that eustatic influence on at least part of the succession has been subject to modification by local epeirogenesis.

The Geological Survey Memoirs for Leeds (Edwards et al., 1950) and Bradford and Skipton (Stephens et al., 1953) describe successions which are closely comparable with that in the adjacent Rombalds Moor area and in addition provide detail of the sand intervals in these areas.

In the Leeds area the Almscliffe Grit [1.] is described as being a coarse massive sandstone 150-400 ft thick, with individual beds 3-10 ft thick some displaying current bedding. The overlying Weeton Shales 650-800' thick contain faunal bands with C. subplicatum and C. stellarum (N. stellarum).

1. The Almscliffe Grit is now placed in E_1 immediately below the horizon of C. cowlingense (Ramsbottom, 1974)

A thin sandstone which occurs 400-500 ft above the base of the shales at Swarth Hill and Healthwaite Hill occurs, on the basis of strata thicknesses, at or about the level of C. stellarum (N. stellarum) and probably equates with the Nesfield Sandstone of Rombalds Moor. The shales above this sandstone contain the Owl Head Marine Band, which carries N. nuculum, and occurs 60-70 ft below the Lower Follifoot Ridge Grit, a medium to coarse grained massive sandstone 50-150 ft thick which lenses out to the south.

Above, the Upper Follifoot Ridge Grit is of similar lithology to the lower grit and is separated from it in places by 10 ft to a maximum of 50 ft of mudstone. This mudstone in the Leeds area has yielded only Lingula although to the north in the Harrogate area H. beyrichianum has been recorded from this interval.

In the north east of the Leeds area shales above the Upper Follifoot Grit carry ? H. eostriolatum. Also present and restricted to the north east are the Caton Gill Shell Beds which occur above the ? H. eostriolatum level. These beds which consist of a succession of siltstones and cherts, the latter containing abundant brachiopod moulds, have more recently been placed by Ramsbottom (1974) above the level of H. magistrorum. Thus their presence in the upper part of R_1a_1 may equate with the onset in this area of the 4th. "shallow" megarythmic interval although the influence of local epeirogenic control, as previously mentioned cannot be discounted.

The overlying Addlethorpe Grit, containing units of coarse to pebbly cross-bedded sandstone, also lies within the 4th. "shallow" megarythm occurring as it does below the Eccup Marine Band which contains R. reticulatum.

It is suggested that the lithologies and position of the sand intervals in the above succession, which correlates closely with the Rombalds Moor succession, are indicative of conditions of megacyclic sedimentation which, within the limits of the available palaeontological control, are broadly synchronous with - and of the same pattern as - those proposed for the North Staffordshire Basin.

The geology of the Bradford and Skipton area (Stephens et al., 1953) is similar to that of the Leeds area. However, some of the details of the succession and the lithologies present are worth further discussion since they provide additional evidence relating to the nature of the megacyclicity and the position of the coarse clastics. The Marchup Grit, present in the first "shallow" megarythm, displays lithologies variable from fine (burrowed) to coarse pebbly sandstone which may be ripple-bedded, the base of the Grit has been observed to channel into the underlying shales, whilst some of the sandstones carry an abundance of carbonaceous material and lenses of coal. The Nesfield Sandstone the equivalent of the Hurdlow Sandstone (2nd. "shallow" megarythm) is described as a fine grained sandstone with many thin shale partings (? turbidite origin).

It is present in the succession 30 ft above an exposure from which was obtained C. stellarum (N. stellarum) and Ct. cf. nititoides, the precise positions of the two goniatites are not given, together with a benthonic fauna similar to that described from the Cherts in the Basin succession.

The Middleton Grit (3rd. "shallow" megarythm) varies from coarse to fine grained and in some places is described as strongly current-bedded (cross-bedded) a feature which is thought to imply a fluvial origin.

The Addlethorpe Grit is present in only part of the area and is thinly developed. It occurs above the horizons of R. adpressum and R. aff. dubium and below R. cf. nodosum a position which fixes it within the 4th. "shallow" megarythmic interval.

From the Slieve Anierin district of Southern Ireland, Yates (1962) describes a P_1 to E_2b succession which displays evidence of cyclicity which correlates exactly with the megacyclic succession of the North Staffordshire Basin.

In the E_2a Subzone the succession, above the highest E. bisulcatum horizon, consists of about 100 ft of shales with clay-ironstone bands increasing in abundance upwards, overlain by a massive quartzitic grit. The grit unit, which is about 200 ft thick, contains two persistent coal seams (3 ft and 1 ft maximum thicknesses) and is present in the succession 20-40 ft below a faunal band containing Ct. edalense (Ct. edalensis). Commenting on the occurrence of the grit unit Yates (1962) states:
"It is clear that a great influx of fairly coarse arenaceous material entered the Namurian seas in the area at this time, associated with advancing delta fronts which periodically allowed a coal swamp vegetation to flourish."
The succession described above displays quite markedly evidence of shallowing and on the basis of the fauna present can be positively equated with the first "shallow" megarythmic interval in the Basin.
In the succession above the grit unit occurs a shale interval (circa 110 ft thick) which contains in ascending order the Ct. edalense (Ct. edalensis), C. holmesi and Ct. nititoides faunal bands.

The succession above the Ct. nititoides horizon is interpreted as a "shallowing" sequence consisting of 40 ft of barren sandy shales with clay-ironstone bands becoming more numerous towards the top and passes upwards on the summit of Slieve Anierin into 12 ft of pale coloured flagstone with plant fragments.

From the evidence of the succession on Slieve Anierin it appears that the 1st. "deep" megarythm of the Basin is represented by the 110 ft shale interval carrying E_2b_1 and E_2b_2 faunal bands whilst the shallowing succession above Ct. nititoides equates with the 2nd. "shallow" megarythmic interval in the Basin. At the E_2b_3 level it is interesting to note that Yates (1962) records the presence of a tough, pale brown, decalcified band (? chert) containing a benthonic fauna including Weberides cf. shunnerensis, Productus hibernicus, Orbiculoidea nitida and crinoid debris in addition to Ct. nititoides and E. rostratum.

A similar benthonic fauna is recorded from the Ct. nititoides level at other localities including: several localities in the Millstone Grit shales of Derbyshire (Ramsbottom et al., 1962); The Bradford and Skipton area (Stephens et al., 1953); The Edale Valley (Stevenson and Gaunt, 1971); at several localities in the Basin (p. 20) and is also recorded by Schwarzbach (1936) from Upper Silesia.

It is realised that in near-shore areas many faunal bands contain benthonic elements. However, the Ct. nititoides band also contains a benthonic fauna in land distal localities as seen for example at the Geological Survey's E_2b_3 locality in the Edale Valley and at the Wiggenstall and Blake localities in the Basin.

Yates (1962) was of the opinion that the occurrences of a benthonic fauna at the level of Ct. nititoides is striking proof of the widespread nature of this horizon, a feature which is interpreted by the writer as being indicative of eustatic control producing a "shallowing" of world sea level during the genesis of this faunal band.

A recent Geological Survey borehole three miles north of Derby at Duffield (Aitkinhead, 1977) is located in the Widmerpool Basin, marginal to the edge of the Central Province. The borehole penetrated a thick succession of B, P, E and H strata.

In the E_2a Zone sand of turbidite origin is present for some 55 metres between the horizons of E. bisulcatum and E. yatesae. This sand interval is bounded at the base by a well defined mudstone interval (25m) and similarly above by an argillaceous interval, circa 65m thick. From the evidence of this succession there is little doubt that the first "shallow" megarythm recognised in the Basin also produced a "shallow" response in this area which resulted in a supply of coarse clastics reaching the northern side of the Widmerpool Basin.

The first "deep" megarythmic interval of the Basin is seen to have produced a similar "deep" response in the Duffield area, where a sand free argillaceous interval (circa 55m) is present between the horizons of E. yatesae and E. rostratum. The faunal horizons recorded from this interval in order of succession are as follows:- C. subplicatum, Ct. edalensis, C. cf. holmesi, C. cf. subplicatum, Ct. nitidus and E. leitrimense, and C. holmesi.

Sand (turbidites) again enters the succession approximately 1m above the horizon of N. stellarum and is present in the succession for circa 10m. It is of interest to note that ironstone bands or nodules are present in the succession both above and below the sand unit, a feature which in the Basin succession is thought to indicate the entry of less saline water (p. 214). It is suggested then that the influence of the second "shallow" megarythmic interval is apparent in the Duffield succession and is indicated by the entry of sand immediately above the N. stellarum horizon, a feature which is strikingly constant throughout much of the British Namurian.

Above the second "shallow" megarythmic interval occurs 35m of strata containing four N.nuculum horizons.

At the base a sand free argillaceous succession 21m thick which contains the lowest N.nuculum horizon, is thought to equate with the onset of the second "deep" megarythm. However, below the 3rd. N.nuculum horizon a sand interval (turbidites) 5m thick is present in the succession. This sand unit is thought to equate with the minor "shallowing" which develops in this interval (see Fig. 4A) and appears to have triggered off turbidity currents supplying sand to the area. In the upper part of the E_2c_2 succession a 5m argillaceous interval containing two N.nuculum horizons is thought to indicate a return to "deep" conditions.

A sandstone (turbidite) unit 10m thick is present in the Duffield succession 10m above the highest H.subglobosum horizon, although the maximum thickness of this unit is unknown since the borehole was commenced in this formation. It is proposed that this sand unit is evidence in the Duffield area, of the 3rd. megacyclic "shallow" interval recognised in the Basin succession.

From the above evidence it is apparent that the thick megacyclic sand and mud intervals present in the Duffield succession are synchronous with those of the Basin. The presence of the sand interval in the E_2c_2 Subzone is anomalous when compared with other successions in the Central Province and its occurrence, although correlating with the mid - E_2c_2 minor "shallowing" proposed on faunal evidence from the Basin succession (see p. 227 - Microfauna of the limestone bullion at Loc. 309 (Holdsworth, 1963) present in the Swallow Brook.), could also be explained by some other mechanism occurring in the southern paralic margin of the Widmerpool Basin.

In some successions sand units are absent, even in the proposed "shallow" intervals and it is reasonable to believe, as has previously been indicated, that this is due to the distal nature of the area relative to the palaeo-shoreline. One such area is the Rossendale area where an argillaceous succession, the Sabden Shales (circa 800 ft thick), present between the horizons of E. bisulcatum and R. reticulatum, contains the majority of goniatite horizons characteristic of E_2, H and R_1.
The Wilpshire Grit present in the succession 30 ft below the E. bisulcatum, horizon appears to indicate that "shallow" conditions existed, but the deposition of coarse clastic sediment did not continue into the Sabden Shales. The sand intervals of the 2nd. and 3rd. "shallow" megarythmic intervals, which are seen to the north in the Lancaster Fells and Skipton areas are not present in this area and it appears that any "shallowing" which may have developed in the Central Province during the deposition of the Sabdén Shales was not established for a sufficiently long duration or of sufficient magnitude to enable sand to prograde to this land distal area.

A similar sand free succession occurs further south in the Edale area (Stevenson and Gaunt, 1971) where the argillaceous succession of the Edale Shales is again suggested to have been deposited in a land distal area. Likewise the Clare Shales of South West Ireland (Hodson and Lewarne 1961) which display a completely argillaceous sequence in the E_1a - R_1b interval, are thought to have been deposited in a land distal environment. In areas such as these listed above it is not possible to detect megacyclicity on the basis of lithology.

In the Rossendale area the Parsonage Sandstone occurs in the succession above the horizon of R. reticulatum and may be a late expression of the R_1

"shallow" interval. This sand interval is equated by Ramsbottom (1965) with the Mam Tor Beds and Shale Grit of the Southern Pennines, and in this case, it seems likely that "shallow" conditions become more marked throughout the Central Province in post R_1a times. During this marked "shallowing" it is thought that the supply of coarse clastic sediment was greatly increased and that sand was able to prograde to land distal areas. It is suggested that the increase in supply of coarse clastic sediment was associated with increase in the rate of erosion in the source area consequent on the establishment of a lower base level of erosion during the proposed marked "shallow" interval.
An alternative would be uplift of the source area.
However, the former is thought to be most likely since an equivalent "shallow" response is present to the north and to the south of the Midland Barrier. On the northern margin of the Midland Barrier southerly derived coarse clastic sediments of late R_1 age are described by several authors including Holdsworth (1963), Evans et al., (1968) and Ashton (1974), these sediments are thought to be the expression of the R_1 "shallowing" in the Basin. In the south, Ramsbottom (1969) indicates that in the land distal parts of the South Wales Basin the only thick sandstone is in R_2 whilst sandstones at other levels in the succession are almost confined to the edges of the Basin.

In the South Wales Basin Ramsbottom (1969) indicates that Namurian deposition in the centre of the Basin was probably continuous from the Visean although on the margins of the Basin higher stages rest on pre-Namurian rocks. In the Pontypridd and Maesteg area, Woodland and Evans (1964) indicate that beds of ? E_2 age overly a ? P_2 succession. Two sand intervals are present in the succession, the lower (30-40 ft thick) is present below a faunal band containing ? Cravenoceratoides which is suggested as indicating a possible high E_2 age. A shale interval (circa 100') overlying the lower sandstone contains H and R_1 faunal bands and is succeeded by a 90 ft sand unit which is present above a faunal band containing Reticuloceras cf. reticulatum. Thus in this area it appears that only the 4th. "shallow" interval of the Basin succession can be recognised although it is possible that the lower sandstone equates with the 1st. "shallow" megarythm. Faunal evidence is, however, insufficient for this to be certain. The influence of the 2nd. and 3rd. "shallow" intervals is not apparent in this succession and their absence may once again indicate that the proposed shallowing associated with them was less marked than that of the 1st. and 4th. "shallow" intervals.

To the north west of Swansea in the Gwendraeth Valley (Archer, 1969) the succession in the Basal Grit consists largely of sandstones with thin fossiliferous shale intervals. A thicker argillaceous interval occurring to the east of the area carries N. nuculum and is equated with a thin shale interval carrying horny brachiopods in the Gwendraeth area. The character of the Basal Grit Group, which in addition to the massive sandstones and thin shale intervals also contains thin coal partings and rootlet beds, appears to be that of a paralic deposit which at intervals was inundated by short lived marine episodes. The extent to which the character of this succession was controlled by either being in a land proximal situation or by being influenced by local epeirogenic movement is unknown. However it is evident that many of the faunal bands between N.nuculum (equivalent horizon) and H.henkei are either not recorded or what appears to be more likely are not present

(i. e are represented by sand intervals) and in a paralic environment such as this with only a fragmentary faunal record the influence of megacyclicity on the succession need not necessarily be immediately apparent.

(b) The North of England Blocks

An analysis of the stratigraphy of the "basinal successions" previously investigated in this research appears to confirm that in many areas outside the North Staffordshire Basin a megacyclicity exists which can be correlated with that which is evident in the Basin succession. It is probable that this megacyclicity reflects a eustatic control of Namurian sea level and therefore should also be present in uplifted or block successions.

In Northern England a marked facies change, from a basinal to a block character, occurs along a line coincident with the Craven Fault Zone. Ramsbottom (1974) states, "Most, but not all, of the major Millstone Grit sandstones are represented by thin sandstones in the northern part of the country and thus arenaceous deltaic advances into the basin also evidently covered the block areas." It thus seems probable that sandstone units equivalent to those present in "shallow" megacyclic intervals of basinal areas should also be present on the blocks and therefore it should also be possible to detect megacyclicity in block successions.

In the area of the blocks an almost continuous Namurian succession was recorded by Owens and Burgess (1965) from the Stainmore Outlier. Between the Mirk Fell Ironstone (C. cowlingense equivalent level [1.]) and the Mousegill Marine Beds which carry H.henkei, Owens and Burgess recognise, in the 600ft of strata which comprises this section, at least eight

1. Block limestone correlations and equivalent goniatite horizons are taken from Ramsbottom, 1974.

sedimentary cycles each containing a coarse clastic unit and an overlying "marine" interval. The sandstones are frequently coarse massive cross-bedded units which may grade upwards into gannisters with in some cases overlying autochthonous coal seams such as the High Wood and Holme Wood coals. The Stainmore succession appears to be predominantly a shallow water paralic/deltaic succession in which bioturbation is common, the coal seams present clearly indicating stable or even slightly emergent conditions although their restricted lateral extent suggests that this may be a localised phenomenon.

On the southern margin of the Alston Block a cyclic succession of a similar character to that of the Stainmore area was recorded from the Woodland Borehole by Mills and Hull (1968). In this succession between the Lower Fell Top Limestone (C. cowlingense equivalent level) and the H. henkei horizon it is possible to detect six cycles. Sand, however, is present in only three of the cycles and these lie between the Lower Fell Top Limestone and the Grindstone Limestone (Ct. nitidus equivalent level), the succession above up to the level of the Whitehouse Limestone (R_1b) having a predominantly argillaceous character.

It is apparent when the successions in the Stainmore area and Woodland Borehole are compared that marked differences in lithology exist between some of the equivalent cycles in the two areas. Also, the number of cycles present in each area differs. These variations are even more marked in the Namurian successions of North-eastern England (vide Hull, 1968, p.300), between which a viable correlation of even the major coarse clastic units in seven successions depicted between the Colsterdale and Falkirk areas is difficult to achieve.

On the basis of the Northern England records it is evident that each succession exhibits a cyclic character which is, however, dissimilar to that of adjacent successions, a situation, it is suggested, which is markedly different from the supposedly eustatically controlled cyclicity evident in basinal successions.

The Namurian of the blocks is referred to by Ramsbottom (1974) as a Modified Yoredale Facies. Within the successions many small scale cycles occur and as previously suggested it does not seem possible on the basis of the available lithological evidence to detect a megacyclicity comparable with that of basinal areas. Even within the broad correlations which have been effected there are anomalies which do not fit into a pattern of eustatic control. For example, in the North Staffordshire Basin and in many Central Province successions, coarse clastics of the 3rd. "shallow" megacycle are present in the H Zone. However, in the Woodland Borehole (Mills and Hull, 1968) the succession in H is mainly argillaceous, displaying no marked evidence of "shallowing" comparable with basinal areas. In the Stainmore area (Owens and Burgess, 1965) the 1st. "deep" megarythmic interval, so well displayed as a sand free cycle in basinal areas, cannot be recognised in a succession containing repetitive sandstone units in the appropriate interval. Consequently due to the markedly different lithological character of block and basinal successions it does not seem possible from the evidence examined to date to recognise features common to both areas which may be interpreted as being of eustatic origin.

It is suggested, however, that if the variations in the Namurian sea level were subject to eustatic control, that the relatively elevated paralic/deltaic environment of the blocks may possibly have been below mean sea level during periods of eustatic maxima. Therefore in an attempt to identify features of eustatic origin those intervals present in block successions which are thought to be representative of marine conditions of deposition will now be considered.

Thin limestones are present in the block successions which Ramsbottom (1974) indicates were the products of marine transgressions. He states (p. 87), "In the block areas of north Yorkshire such marine transgressions led to the deposition of limestones and the water of these seas there was evidently shallow or very shallow. At the same time in the basin to the south mudstones with a non-benthonic fauna of goniatites and bivalves were being laid down." The block limestones commonly carry a brachiopod-crinoid fauna present in lithologies of the calcite mudstone or cementstone type, some of which show evidence of mud-cracking and are proposed by Ramsbottom (1974, p. 84) to have frequently been deposited in somewhat hypersaline, shallow water environments.

In these block marine intervals thicker-shelled goniatites are absent or of rare occurrence and precise stratigraphic control such as is afforded by the goniatite faunas of basinal successions is not available. However, several authors notably Mills and Hull (1968) and Owens and Burgess (1965) indicate that a complete Namurian succession is present on the blocks although Ramsbottom (1969) is of the opinion that there may be small non-sequences in E_2c to G_1.

Goniatites which have so far been identified in block successions are from the E_2, H_1 and R_1 Stages.

In E_2, C. cowlingense is present in the Cockhill Marine Band Limestone of the Nidderdale area (Wilson and Thompson, 1959) and also in the north west of the Askrigg Block in a silty sideritic limestone termed the Mirk Fell Ironstone (Hudson,1941). There is however no record of C. cowlingense from the proposed equivalent block limestone of the Alston area nor from the Midland valley of Scotland. Higher in the succession in the south eastern part of the Askrigg Block the Colsterdale Limestone carries Ct. nitidus (Wilson and Thompson, 1959) although the species has not been recorded to the north in the probable correlative, the Shunner Fell Limestone (Rowell and Scanlon, 1957). On the Alston Block Ct.nitidus has not been recorded from the limestones and "marine bands" thought to be at this E_2b_2 horizon, although in the Midland Valley of Scotland Currie (1954) identified a single poorly preserved specimen from the Castlecary Limestone as Ct. cf. nitidus.

The next known goniatite occurrence in the succession is a single exposure at the H_1b level from the southern part of the Askrigg Block in the Colsterdale area (Wilson, 1960). At this locality Wilson indicates that H. beyrichianum occurs in a black shale immediately above a thin limestone containing crinoid ossicles, gastropods and pelecypods.

Apparently the earliest thicker-shelled goniatite bearing horizon to be established on the Alston Block is that of H. henkei present in the Woodland Borehole succession (Mills and Hull, 1968), this species is also present in the adjacent Stainmore Trough occurring in the Mousegill Marine Beds (Owens and Burgess, 1965).

The H. henkei marine transgression also appears to have reached the Midland Valley of Scotland since Homoceratoides sp. from about the same stratigraphic level as H. henkei (Ramsbottom, 1965) has been recorded from the No. 3 Marine Band of the Passage Group by Neves et al. (1965).

The next thicker-shelled goniatite horizon to occur on the Alston Block is in R_1b in the Woodland Borehole succession (Mills and Hull, 1968), here Reticuloceras stubblefieldi occurs in a shale sequence above the Whitehouse Limestone.

On the basis of the available evidence, it is difficult due to the limited and sporadic occurrence of the thicker-shelled goniatites to the north of the Craven Faults, to achieve any detailed palaeogeographical reconstruction relating to the extent of goniatite colonisation of the Alston and Askrigg areas. It is possible that future examination of block "marine" beds may reveal the presence of more goniatites, but it is thought likely that frequencies will be low in areas remote from block margins. The latter situation is probably indicated by the work of Wilson and Thompson (1959) in which they show that the relative frequency of thicker-shelled goniatites in the Colsterdale Marine Band (Ct. nitidus) decreases as the band is traced northwards from the southern margin of the Askrigg Block. They suggest that environmental differences particularly of depth and salinity between the southern margin of the Askrigg Block and the area to the north are the reasons for this variable distribution. On the basis of the above evidence it is probable that many block limestones and "marine" beds from which thicker-shelled goniatites are absent are however the equivalents of goniatite horizons of basinal areas. Whilst the previously mentioned rare occurrences of thicker-shelled goniatites in the North of England successions confirm that at least some of the block marine intervals can be positively correlated with basinal marine episodes. Thus it appears possible to identify some eustatic features in block successions and therefore it seems that in these successions it should also be possible to detect a megacyclicity correlatable with that present in basinal successions. Ramsbottom (1969) indicates that there are nearly 60 diagnostic goniatite horizons distributed throughout the succession in Namurian basinal areas. Thus in the known absence of any major block non-sequences (Ramsbottom, 1969), it must be predicted that a similar number and similar stratigraphic distribution of "marine" intervals will occur in the Northern England area. This however is not the case, there being in parts of the succession significantly fewer marine intervals on the blocks than in basinal areas. For example, in the interval C. cowlingense to Ct. nitidus, where palaeontological control is good in block successions, it is evident that the horizons of C. subplicatum and Ct. edalensis are not represented by equivalent block marine intervals.

In the Ct. nitidus to H. henkei interval, which carries more than twelve diagnostic goniatite bands in basinal areas, only five "marine" intervals are recorded from the Woodland Borehole succession (Mills and Hull, 1968) and four in the Stainmore succession (Owens and Burgess, 1965).

It must also be predicted, if the block "marine" intervals are the products of eustatic rises in sea level, that the individual marine transgressions should be represented throughout the whole of the Northern England shelf area. In some instances this appears to be the case as for example at the level of the Colsterdale Limestone (Ct. nitidus) where, as previously indicated, proposed correlative block limestones and "marine" beds can be traced from the southern margin of the area across the blocks and into the Midland Valley. Extensive lateral persistence of many of the "marine" intervals on the blocks is however not always a feature of the area.

Lateral variability of block lithologies has been noted by Ramsbottom (1969) who states, "There are, however, considerable local variations in the succession in the E_1 and E_2ab cyclic beds and correlation can be difficult." This variation is evident for example in E_2a at the level of C. aff. cowlingense where the Hearne Beck Limestone present in Upper Wensleydale (Burgess and Ramsbottom, 1970) is on the evidence of the succession of Wilson and Thompson (1959) absent in the south-eastern portion of the Askrigg Block.

It has previously been indicated that the eustatic rises in sea level proposed for basinal areas did not always result in synchronous transgressions in block areas and it is now evident that in some instances when transgressions did take place that the resulting "marine" environments had a restricted block development.

Palynological evidence from the Stainmore succession Owens in Owens and Burgess (1968) indicates that there are several horizons at which marked changes occur in Namurian microspore assemblages. Similar marked changes in microspore assemblages are present in Westphalian successions (Butterworth and Millot, 1954) and are most evident at levels which coincide with the major Ammanian marine transgressions such as those represented by the Katarina (A. vanderbeckei) and Aegir (A. hindi) marine bands; horizons which are generally accepted as being the products of major eustatic rises in sea level.

The most marked changes in the Namurian spore assemblages in the Stainmore succession occur at the levels of the High Wood Marine Beds (Ct. nitidus equivalent level) and the Mousegill Marine Beds (H. henkei).

At the E_2b level the upper limit of at least five microspore species occurs synchronously and prior to the marine horizon, whilst the synchronous entry of at least four new microspore species takes place above it. At the H. henkei level, although a less sharp floral division occurs, at least three new microspore species immediately appear, to be followed by four more at a slightly higher level. In discussing the stratigraphical distribution of numerous and easily recognisable microspores with restricted ranges, Owens in Owens and Burgess (1968) indicates that at the level of the High Wood Marine Beds low Namurian forms are replaced by a series of higher forms and at the level of the Mousegill Marine Beds still higher Namurian forms appear in the succession. These changes in microspore assemblages are not restricted to the Stainmore area alone since Owens indicates that palynological correlations are possible between this and other Namurian successions. Of particular interest is the occurrence of an influx of large numbers of Crassispora kosankei at the H. henkei level in the Stainmore succession, a form which also first appears at this level in the Southern Pennines (Neves, 1961).

In other parts of the Stainmore succession, although changes in microspore assemblages are evident, they are less marked than those previously discussed. For example at about the C. cowlingense (equivalent) level a minimum of three microspore species die out but apparently are not succeeded by new species (plate III, Owens and Burgess, 1965), whilst between the horizons of Ct. nitidus and H. henkei there appears to be little or no change in microspore distribution, even at the level of the Peasah Wood Limestone (The highest P. corrugata horizon) which on palynological evidence is thought to be high E_2 and may together with its correlative limestone in the Alston Block, represent an E_2c_2 horizon.

The widespread geographical distribution of the Ct. nitidus and the H. henkei horizons in both block and basinal areas has previously been referred to as possible evidence of eustatic control. Palynological evidence indicates that at these levels significant changes in Namurian microspore assemblages occurred and by analogy with Westphalian microspore distribution patterns (Butterworth and Millot, 1954) it appears that changes of this type took place at well defined marine levels. On the evidence of their geographical extent and associated significant microspore variations, such levels are proposed to be the products of major eustatic rises in sea level. It must be predicted, if, as has previously been indicated, the blocks were positive uplifted areas, that the eustatic rises in sea level most likely to inundate the Northern England area would be those of the greatest magnitude. These same eustatic highs would also be expected to produce maximum "deep" conditions in the Central Province and on the evidence of North Staffordshire successions this proves to be the case since the Ct. nitidus and H. henkei horizons are seen to occur at or near maximum "deep" conditions in their respective "deep" megacycles.

The spread of C. cowlingense on to the Askrigg Block appears to be contrary to the proposed model of eustatic megacyclicity since on Central Province evidence there is little doubt that the C. cowlingense horizon, which is present below sand intervals in several successions has "shallow" affinities, and thus would not be expected to occur in positive/uplifted block situations. However the broad lithological character of the successions on the blocks and in the Stainmore Trough displays a marked change at or about the Pendleian - Arnsbergian junction. The numerous block limestones which are present in the Pendleian tend to become less frequent in the Arnsbergian whilst sand intervals become more evident in the higher Stage. These characteristics are taken to indicate that the blocks had a lower elevation in E_1 than in E_2 and the relatively "shallow" C. cowlingense rise in sea level was thus able to establish "marine" conditions across the Askrigg Block and Stainmore areas and also probably onto the Alston Block where the Lower Fell Top Limestone may be its equivalent. Above the C. cowlingense level the succession shallows, sand enters more frequently and with the exception of the previously referred to localised occurrence of limestone at the C. aff. cowlingense level, limestone with block coverage does not appear again in the succession until the eustatic "deep" sea level of Ct. nitidus times.

If the above hypothesis is correct it implies that block environments, in addition to eustatic influences, were also subject to tectonic influences and in particular uplift of this Northern England area appears to have taken place in post C. cowlingense times. Evidence of the occurrence of this tectonic movement can also be deduced at the E_1 - E_2 boundary in the Midland Valley of Scotland where it is suggested that the low energy environment which allowed the coals of the Limestone Coal Group (E_1) to accummulate was succeeded, presumably due to uplift of this northern area by a high energy environment in Upper Limestone Group (E_2a, b) times in which coal seams are less frequent and are of limited lateral occurrence.

On the basis of palaeontological and lithological evidence in the North Staffordshire Basin and on lithological evidence in other Central Province successions, E_2c_2 horizons have previously been proposed to occupy "deep" positions in the 2nd. "deep" megacyclic interval and as such are to be expected to occur in block successions. However N. nuculum has not yet been identified in block successions although as previously stated the Peasah Wood Limestone, carrying P. corrugata may be a N. nuculum equivalent horizon in the Stainmore succession as may be a thin limestone also carrying P. corrugata in the Woodland Borehole. Ramsbottom (1969) also indicates that P. corrugata which is not known to occur higher than E_2 is also present in the No. 1 marine band of the Passage Group in the Scottish succession. Palynological evidence (Owens in Owens and Burgess, 1965) does not however indicate any marked change in block microspore assemblages in E_2c_2 whilst Neves (1961) is of the opinion that in many respects Sabdenian assemblages are comparable with those of the Arnsbergian in the Southern Pennines area. It must therefore be concluded that the eustatic rises which produced the "deep" N. nuculum horizons in basinal areas were not of as great a magnitude as those which produced the Ct. nitidus and H. henkei "deeps".

If as is suggested eustasy is the control, the "shallow" intervals of the North Staffordshire Basin would not generally be expected to be represented in predominantly paralic/deltaic block environments. This appears to be the case since E_2b_3, E_2c_1 and H_1a marine intervals have not been recorded from block successions. It is also apparent that microspore assemblages are unchanged at such levels, which is thought to indicate that these "shallow" eustatic rises in sea level were of insufficient magnitude to produce any significant variations in microspore assemblages such as are associated with those "deep" eustatic rises which achieved block coverage. Other marine intervals, which on North Staffordshire Basin evidence are proposed to be "deep" intervals are unrecorded on the blocks. For example the widely recognised Hd. proteus marine interval which was of sufficient magnitude to abruptly terminate the supply of Chokierian sand to the North Staffordshire Basin is apparently not present. Thus despite the extensive basinal occurrence of this marine interval it appears that the magnitude of this H_2 eustatic rise was not as "deep" as the "deep" conditions of E_2b and R_1a times when block areas were inundated.

The occurrence on the blocks of H. beyrichianum (Wilson, 1960) and Reticuloceras sp. from the R. stubblefieldi level (Mills and Hull, 1968) both present in "shallow" Basin intervals initially appears to be a contradiction of the proposed pattern of eustatic megacyclicity. However these goniatites have only been recorded from solitary locations, and elsewhere on the blocks equivalent "marine" intervals, such as those present at the Ct. nitidus level, are not apparent in the successions. For example at the H_1b level Wilson (1960) shows that there are numerous H. beyrichianum localities bordering the southern margin of the Askrigg Block but the species has been found at only one locality on the Block in the south east in the Nidderdale area. Thus although detailed palaeogeographical reconstruction is at best tentative it is reasonable to suggest in view of the solitary occurrence and apparently limited lateral extent of this H_1b block marine interval that access to the area may have been gained via a shallow gulf or inlet, temporarily allowing restricted access of H_1b goniatites on to the Askrigg Block.

It is presumed that the formation of such a gulf or inlet may have resulted from contemporary localised epeirogenic movement occurring within a faulted area of the block margin.[1] In discussing the structure of the Askrigg Block Wilson (1960) states, "Faults are local and of small throw except in the extreme south. Here a plexus of dislocations is dominated by the Lofthouse Moor Fault which downthrows about a hundred feet to the north."

The block locality of H. beyrichianum, Woo Gill in Nidderdale, is situated adjacent to and on the downthrow side of the W.S.W. trending Lofthouse Moor Fault complex. Thus it appears possible, providing contemporary movement occurred, that a connection between the upper Nidderdale area and the H. beyrichianum populations known to be present in basinal areas bordering the southern margins of the Askrigg Block, could have been effected via a gulf positioned in the area of the Lofthouse Fault complex.

In the North Staffordshire Basin the horizons of H. beyrichianum and H. subglobosum are placed in the third "shallow" megacyclic interval and occur in the succession below the Lum Lady Edge sand interval. Elsewhere in the Central Province two sand intervals occur in this "shallow" interval although in the Leeds area they are depicted as one unit partly separated by a Lingula horizon which is proposed (Fig. VIIA) to be the equivalent of the single H. beyrichianum horizon present in the Lancaster Fells between the Crossdale Grit and the Clintsfield Grit. On this evidence it appears likely that one of the H_1b eustatic rises was higher than either those at other H_1b horizons or those at the H. subglobosum levels.

1. Mills and Hull (1976, p.161) indicate that some of the thickness variations occurring in Carboniferous sediments, especially on the margins of the blocks, are associated with faulting, this appears to indicate that contemporaneous movement took place.

This relatively "high" H_1b rise in sea level may inpart explain the isolated occurrence of H. beyrichianum at the Woo Gill locality, although in the absence of other H_1b block localities, particularly on the southern margin of the Askrigg Block, access via a fault controlled gulf appears to be the most reasonable explanation for the solitary block occurrence of H. beyrichianum.

R. stubblefieldi is present in a shale succession overlying the Whitehouse Limestone in the Woodland Borehole (Mills and Hull, 1968).

The borehole which is situated on the south eastern margin of the Alston Block occurs in the vicinity of a fault complex forming the Block boundary. The Hett fault, to the north west of the Woodland area, has been intruded by the Hett Dyke which is proposed to be of early Stephanian age (Fitch and Miller, 1967). Mills and Hull (1976, p. 164) suggest that faulting in this Alston Block boundary zone, which "overlaps" with the northern part of the Cotherstone (Stainmore) Trough, took place in late Westphalian times, although they indicate that fault movement must also have occurred at earlier dates, probably along pre-existing Caledonide lines.

In the Woodland area the Eggleston-Woodland and Butterknowle - Wham faults are major faults along which throws of plus 400 feet are common. Mills and Hull (1976) indicate that there is evidence that these faults, which lie in the "hinge zone" between the Alston and Askrigg Blocks, were in an area in which Namurian fault movement took place. The Woodland area also lies in the axial zone of an eastwardly pitching syncline which continues in association with the Butterknowle Fault into the Durham Coalfield. The Whitehouse Limestone which is brought to the surface by this folding crops out in the Eggleston Whitehouse area to the west of Woodland. This limestone, which ranges in thickness from one inch to one foot six inches, but locally may be up to five feet thick, apart from its outcrop at Crag Gill (adjacent to Whitehouse) and presence in the Woodland and Roddymoor borehdes, has not been positively identified elsewhere in the Cotherstone (Stainmore) Trough or on the blocks, although Mills and Hull (1976) suggest it may be present at two more localities in the Trough. The Alston and Askrigg Blocks are proposed by Mills and Hull (1976) to have been subsiding at a lesser rate than the Cotherstone Trough in Namurian times, and it is thought that the localised occurrence of the Whitehouse Limestone is indicative of the establishment of "marine" conditions which were restricted to a subsiding area in which contemporaneous faulting and possibly folding took place. These conditions become even more marine at the horizon of R. stubblefieldi, which is present in a shale succession immediately above the Whitehouse Limestone, and it appears that at this time the effects of subsidence and eustatic rise in sea level were sufficient to produce a "deep" water connection with the R_1b goniatite population of the Central Province. R. stubblefieldi has been identified at outcrop near to Whitehouse and in the Woodland Borehole just over four miles to the north east. In the Roddymoor Borehole some six miles to the north east of the Woodland Borehole, the R. stubblefieldi horizon appears to be "dying out" since re-examination of the cores of this borehole (Mills and Hull, 1968) revealed the presence of juvenile goniatites above the Whitehouse Limestone. (Note. Horizons of this type have been encountered in paralic situations in the North Staffordshire Basin).

Thus it is concluded that the basinal characteristics occurring at restricted localities in the Northern England area at the H. beyrichianum and R. stubblefieldi levels are primarily the result of tectonic rather than eustatic control. A situation is envisaged in which marginal areas of the blocks were at times at critical levels relative to the sea level of adjacent basinal areas and that during these times even "shallow" eustatic rises in sea level were of sufficient magnitude to produce maximum marine conditions in areas of the block margins which had been subject to localised tectonic control.

In summing up the evidence it is suggested that a megacyclicity synchronous to that present in the North Staffordshire Basin succession is present in many Central Province successions, whilst in Northern England it is apparent that those rises in sea level which were of sufficient magnitude to produce total block and Midland Valley coverage also occur at or near the maximum of marked "deep" intervals in the Basin. However "shallow" basinal "marine" horizons (excluding those subject to tectonic control to which reference has previously been made) are absent from block successions. Thus there is also evidence of a megacyclicity in block successions which can be correlated with that present in basinal successions. In addition the tectonic histories of block and basinal areas are markedly different and so it must be concluded that this megacyclicity was subject to a common control which is thought to have been of eustatic origin. Perhaps the most striking evidence of eustatic control in Namurian successions occurs above the E_2b_3 - E_2c_1 interval. In the North Staffordshire Basin succession immediately above the level of N. stellarum turbidity currents introduced sand into a sequence which formerly had exhibited an argillaceous sand free character. Above the level of Ct. nititoides in the Slieve Anierin area the existence of a "shallowing" sequence has been demonstrated (Yates, 1962), whilst in the South West Province, the earliest described Namurian sediments, turbidites of the Crackington Formation, appear to have entered the Boscastle - Oakhampton - Exeter Basin in late E_2b or early E_2c times (Edmonds et al., 1969). In the Namurian shelf succession north of the Craven Fault line Ramsbottom (1969) indicates that a marked thinning commenced in late E_2b times. Whilst on the American continent, which in Namurian times probably bordered the same continental area as Scotland and Northern England, he indicates that a similar thinning occurs with beds of E_2b age overlain by a thin succession of R_1R_2 and G_1 beds (E_2c and H have not been recognised.).

In conclusion the writer is of the opinion that the correlations which exist between the cyclic succession of the North Staffordshire Basin and successions in extra-Basinal areas are the direct response of a eustatically controlled megacyclicity which was produced by long-term patterns of rise and fall of world sea level. The origin of these megacyclic eustatic fluctuations is beyond the scope of this work.

Footnote to the Appendix

The appendix, in which the "megacycle" theme has been examined further, was added at the request of the examiners. The major part of this research was completed prior to the publication of Ramsbottom's 1977 paper (Major cycles of transgression and regression (mesothems) in the Namurian) in which there are some areas of similarity and others which conflict with this thesis. Both authors recognise the existence of major eustatically controlled cyclicity in the Namurian and their proposed cycle boundaries are frequently in the same stratigraphical position. However, there are some differences in boundary positions and it is also evident that different criteria have been used by Ramsbottom for cycle recognition than have been used in this thesis.

Considering the differences in positioning of the cycle boundaries it is evident from Fig. VIIA that the 3rd."deep" megacycle equates with mesothem N5 and the sand free part of N6. Concerning N5, Ramsbottom (1977) states, "Sandstones at the top of this cycle are poorly developed in the north of the basinal area, but are widespread in Staffordshire, where at least part of the Stanley Grit is at this level (Evans et al., 1968)". In the writer's opinion however, field evidence in North Staffordshire indicates that the supply of sand to the Basin was terminated by the Hd. proteus transgression and the sand free H_2a - H_2b (inclusive) interval (N5) together with the overlying H_2c and R_1a_1 intervals exhibit "deep" characteristics and constitute a single cyclic unit. All the remaining mesothem boundaries in the interval E_2b_1 - R_1b are coincident with boundaries proposed in this thesis although not all megacycle boundaries are accounted for. Thus the interval between the base of the Ct. edalensis beds and the base of the N. nuculum Subzone is considered by Ramsbottom to be one cyclic unit (N2), however, in this thesis it is seen to incorporate both the 1st."deep" and 2nd."shallow" megacycles, a difference which is due to the use of different criteria in the recognition of the respective cyclic intervals.

Another conflicting area concerns mesothem N3 which incorporates the greater part of the E_2c_2 Subzone and equates stratigraphically with the 2nd."deep" megacycle. Faunal evidence in North Staffordshire and the absence of any major sand unit in this interval in the Basin and Duffield successions is thought to be indicative of the persistence of "deep" conditions throughout this megacyclic interval. Above this interval the character of the H_1a faunal bands indicates a return to "shallow" conditions leading eventually to sand deposition in basinal areas as deltas prograde. However, in some paralic areas for example Sharpcliffe (Loc. 086), sand deposition is seen to have commenced with the onset of the H_1a "shallowing" and the rapidly prograding sand bodies appear to have prevented H_1a goniatite colonisation at this Basin margin.

On the evidence of the character it displays it must be assumed that the sediments and fauna of the 2nd."deep" megacycle would be present not only in basinal areas but also in shelf and paralic areas and this is the case in North Staffordshire. However, Ramsbottom (1976) is of the opinion that mesothem N3 is absent from the shelf/paralic succession of the Lancaster Fells and also from the North of England blocks. However, although N. nuculum horizons have yet to be found in the Lancaster Fells, it has previously been suggested that the argillaceous interval (circa 50 ft) between the Claughton Sandstone (= Oak Bank Grit) and the Crossdale Grit [1.] is indicative of the establishment of E_2c_2 "deep" conditions in this paralic and possibly tectonically active area, whilst on the blocks an unnamed limestone carrying P. corrugata occurring 56 ft below H. henkei in the Woodland Borehole may be an E_2c_2 horizon. Thus it is suggested that the E_2c_2 interval displays characteristics consistent with a "deep" episode although it appears that the magnitude of this "deep" was less than was initially envisaged since unlike the 1st. and 3rd. "deep" megacycles the rise in sea level producing it apparently was not of sufficient magnitude to allow thicker shelled goniatites to colonise the North of England Blocks.

Further differences are apparent if the regular mesothemic pattern proposed by Ramsbottom is compared with the megacyclic pattern in which non-systematic variations occur. For example the position of the "deep" maxima in the "deep" megacycles is variable as is seen in the 1st. "deep" where the maximum occurs near to the middle of the megacycle, whilst in the 3rd. "deep" it occurs near the top. A variation of a different type occurs in the 2nd. "deep" megacyclic interval which on the basis of faunal evidence in the North Staffordshire succession appears to exhibit a "shallowing" in its central portion. This "shallowing" is also evident in the Duffield Borehole where sand enters the succession between the middle and upper N. nuculum horizons.

1. Note: Moseley (1952) places the Crossdale Grit 25 ft below the horizon of H. beyrichianum and 50 ft above the Oak Bank Grit which he equates with the Claughton Sandstone. Ramsbottom (1977) places the Crossdale Grit in E_2 b below the Oak Bank Grit.

Differences in interpretation also occur, thus although the stratigraphic boundaries of the 3rd "shallow" megacycle are the same as those of mesothem N4, the interpretations of this interval are markedly different. Ramsbottom (1977) indicates that N4 consists of an episode of transgression followed by one of regression and the deposition of sand. In this thesis it is suggested that the "shallowing" that followed the "deep" E_2c_2 interval enabled the already established land proximal sand deposition zone to prograde into basinal areas, thus in some successions, depending on their palaeogeographic location, the deposition of sand commenced earlier than in others. However the basically "shallow" character of the interval was interrupted by an H_1b "deepening" evidenced in some successions by the presence of an H. beyrichianum horizon with sand units above and below. Thus in the Lancaster Fells the Crossdale Grit and Clintsfield Grit are separated by a 40 ft (max.) argillaceous interval containing a single H. beyrichianum horizon, whilst in the Leeds area (Edwards et al., 1950) the equivalent sandstones the Lower and Upper Follifoot Grits[1.] form almost a single unit underlain by N. nuculum horizons and separated by a Lingula horizon, the local equivalent of the H_1b horizon. A similar sequence is seen in the Bradford/Skipton area (Stephens et al., 1953) where a single H. beyrichianum horizon separates the Brocka Bank Grit from the Middleton Grit which overlies horizons with N. nuculum although in the Rombalds Moor area (Stephens et al., 1942) the deposition of sand in Marchup Grit times appears to have been prematurely terminated by an H_1a rise in sea level as is indicated by the presence of two H. subglobosum horizons overlying this unit.

1. Note: Ramsbottom (1974a) Fig. 27 shows the Lower Follifoot Grit to be the equivalent of the Middleton Grit, both occurring between E_2c_2 and H_1 a horizons.

Concerning the distribution of fauna, Ramsbottom (1977) indicates that in the Namurian the most marked faunal changes and renewals always occurred immediately subsequent to the major regressions. He suggests that these changes, as in the Dinantian, can best be explained by faunal extinctions which took place during major regressions whilst the major transgressions which initiated each cycle brought in a new fauna containing genera or species groups not present earlier. Thus there appears to be little doubt that the proposed major cyclic boundaries present in Namurian successions are also horizons of faunal change, though it is difficult to envisage how the mechanisms proposed for Dinantian faunal change can be applied to Namurian change there being fundamental palaeoecological differences between the respective faunas.

In conclusion it is evident that although there are some relatively minor points of issue between Ramsbottom's 1977 paper and this thesis, such as for example the difference of opinion as to the stratigraphic position of some of the sand units in the succession, it is apparent however that the major difference between the two works lies in the difference in character of the cyclicity. Ramsbottom's thesis proposes that the cyclicity consisted of repetitive episodes of transgression and regression. In this thesis however it is suggested that for marked periods in the Namurian "deep" water conditions existed, whilst at other times "shallower" conditions were established. Superimposed on this broad eustatically controlled cyclicity are eustatic rises in sea level which in the "shallow" megacyclic intervals may or may not have terminated sand deposition. In the "deep" megacyclic intervals eustatically controlled regression did not lead to sand deposition, and further it appears that only in the "deeper" of the "deep" megacycles was it possible for widespread goniatite colonisation of the North of England Blocks and the Midland Valley of Scotland to take place.

CHAPTER 5

LITHOFACIES RELATIONSHIPS AND ENVIRONMENTAL INTERPRETATIONS

LITHOFACIES RELATIONSHIPS AND ENVIRONMENTAL INTERPRETATIONS IN THE NORTH STAFFORDSHIRE BASIN IN THE INTERVAL E_2b_1 - H_2c (INCLUSIVE)

Introduction

Several authors including Hudson (1945), Holdsworth (1963), Kent (1967), Trewin (1969), Trewin and Holdsworth (1973) and others have indicated the existence of a Basin of deposition, present in North Staffordshire in Namurian times. The Basin is suggested to have been bounded on the east by the western edge of the Carboniferous Limestone Massif, whilst its western margin is largely conjectural, although litholigical evidence indicative of the proximity of a western paralic margin to the Basin is present in the Congleton Edge area. The line of the Red Rock Fault striking southwards from the Macclesfield area through Congleton and continuing southwards on the west side of Stoke-on-Trent may have formed the effective western margin of the North Staffordshire Basin, although this is not verifiable. It has been suggested by Trewin and Holdsworth (1973) that the unpublished geophysical data of G. Rowbotham (Keele) indicates a rapid and substantial eastern thickening of the Carboniferous beds at the Red Rock Fault.

The southern limit of the Basin is thought to have been the Midland Barrier or St. Georges land, although the presence of Coal Measures resting unconformably on Lower Palaeozoic rocks in Shropshire, South Staffordshire and Warwickshire (Trewin, 1969), suggests that in the Namurian period the southern margin of the Basin was further north than in the succeeding Westphalian. Thus, its southern margin appears to have been within the Potteries Coalfield, possibly to the south of Stoke-on-Trent although no confirmatory borehole evidence is available.

The North Staffordshire Basin is bounded on the south east by a barrier which separates it from an adjacent Namurian Basin of deposition, the Windmerpool Gulf

(Kent, 1967; also figured in Trewin and Holdsworth 1973, P.391, Fig.8.). The barrier which stretches from the Carboniferous Limestone Massif to St. Georges Land, probably assumed in Namurian times the form of a submarine ridge which is thought to have effectively prevented easterly derived sediment from entering the North Staffordshire Basin. A similar barrier is thought to have existed to the north of the Basin running roughly west to east in the Macclesfield area. Trewin (1969) indicates that in Pendleian and Arnsbergian times, north moving turbidites were not able to surmount this barrier and from evidence gathered during the course of this research it appears that the same conditions apply in Alportian and Chokierian times.

Data relating to the source of the sediments deposited in the North Staffordshire Basin in the E_2b_1 - H_2c interval indicates a west to south sector of origin. This source area of sediment supply fits neatly into the areal situation described above, as the south and west margins of the Basin are, with the exception of the Carboniferous Limestone Massif in the east, the only possible source of detrital sediment. However, on the evidence of a pelitic succession in the north east in the Wardlow Mires borehole (Stevenson and Gaunt, 1971) and also in the east in the Ashover boreholes (Ramsbottom et al. 1962) it is thought most unlikely that coarse clastic sediment entered the Basin from the Massif. The presence of paralic sediments of Chokierian age coincident with the proposed western margin of the North Staffordshire Basin in the Astbury-Congleton area further agrees with the areal situation envisaged for the Basin margin, whilst fluvial sediments also of Chokierian age, are present on the southern margins in the Endon and Ipstones areas, and adjacent to the proposed western margin in the Biddulph Moor to Lask Edge vicinities.

On the east of the North Staffordshire Basin the succession is thinner than in the west and consists mainly of mudstones with thin southerly and south westerly derived source distal turbidites. The turbidites thin to zero before the Carboniferous Limestone Massif is reached, a feature which may be evidence of a reversal of slope. The actual Namurian Visean contact is exposed in the Upper Dove Valley where Visean (B_2) reef limestones are overlain unconformably by E_2a - R_1c Shales (Trewin and Holdsworth, 1973). The records of the Ashover Boreholes (Ramsbottom et al. 1962) and the Wardlow Mires Borehde (Stevenson and Gaunt, 1971) show a conformable, if somewhat attenuated Namurian succession over the massif. Further to the east the Lower Namurian is thinly developed in the Ironville No. 2 Borehole (Smith et al., 1967) whilst the Eakring Boreholes (Falcon and Kent, 1960) indicate an unconformable contact with Namurian sediments of R1 age resting on the Upper Visean. The nature of the Namurian/Visean contact on the east of the North Staffordshire Basin appears to be of minor importance when discussing the origin of sediment in the Basin, and what is of more significance is the fact that easterly derived coarse detrital sediment is absent from the Basin. It is thought that this fact lends support to the assumption that the Carboniferous Limestone Massif formed the eastern boundary of the North Staffordshire Basin and that adjacent parts of the Massif, which on the evidence of the Ashover and Wardlow Mires Boreholes was submerged for most of the period, was never-the-less an effective barrier preventing easterly derived detrital sediment from entering the Basin in Upper Arnsbergian to Alportian times.

As the coarse detrital sediments in the North Staffordshire Basin are followed westwards and southwards they tend to increase in thickness within the E_2b_1 - H_2c interval. Distal turbidites become source proximal in character and near the proposed western and southern margins of the Basin their chronostratigraphic equivalent facies are of fluvial origin.

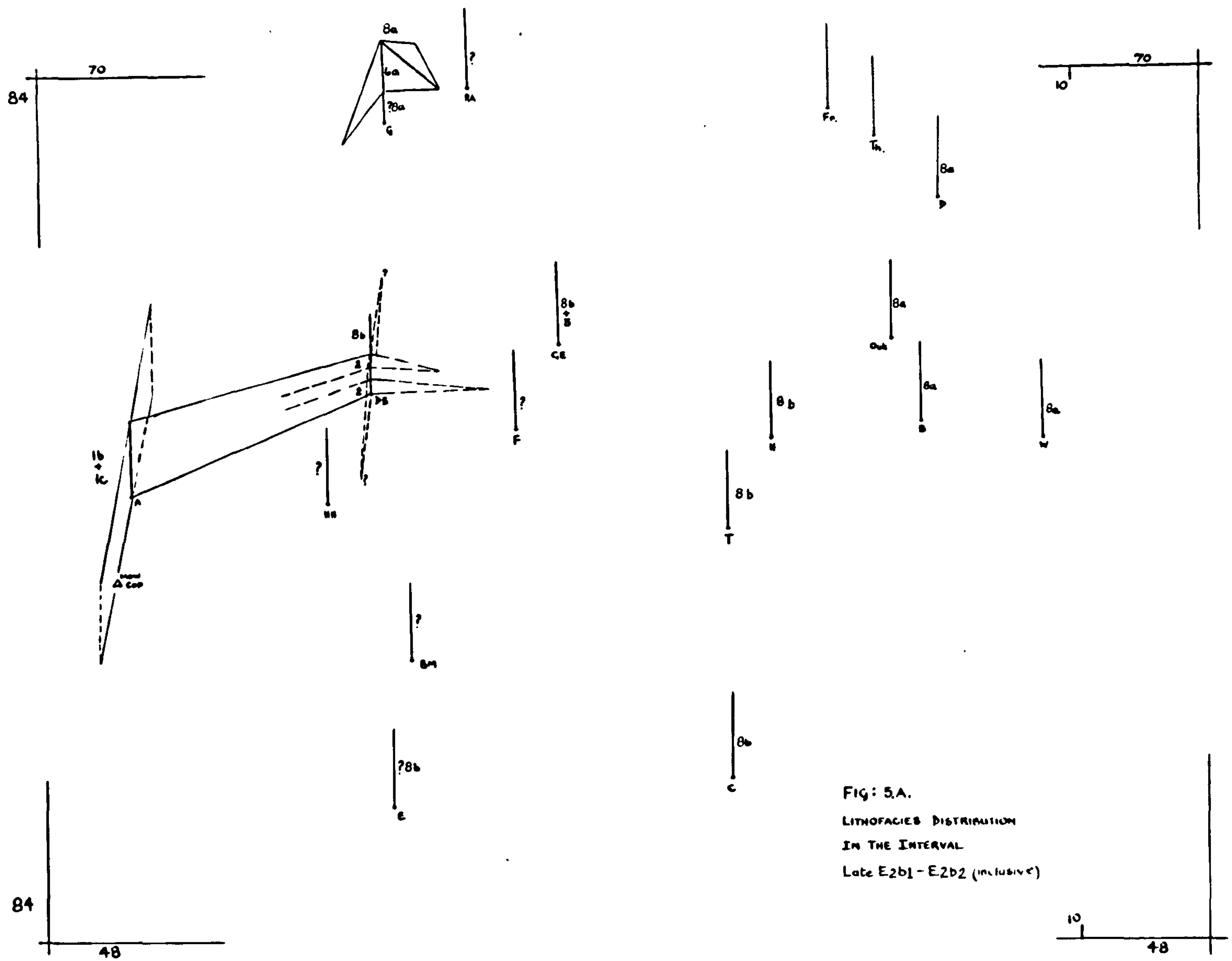


Fig: 5.A.
Lithofacies Distribution
In The Interval
Late E2b1 - E2b2 (inclusive)

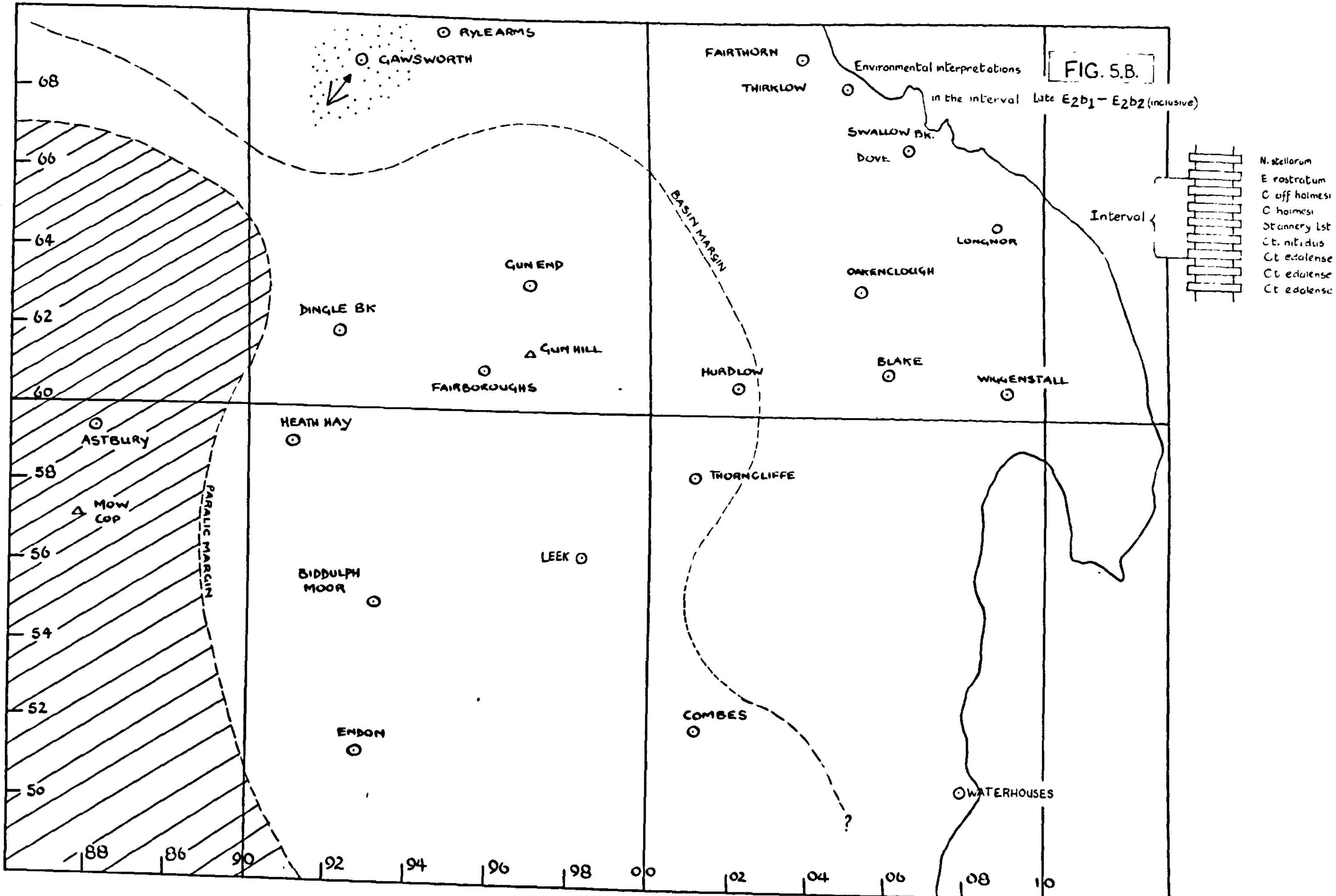


FIG. 5.B.

Environmental interpretations in the interval Late E_2b_1 – E_2b_2 (inclusive)

Lithofacies Relationships

The relationships of the various Lithofacies upon which both the palaeogeographical and palaeoenvironmental interpretations are based is depicted in Figs.5.A. to 5.H. and for convenience the following discussion on the Lithofacies relationships is sub-divided on a chronostratigraphic basis into five intervals.

Note.

In the account the term "Basin" is used to denote the "Stratigraphic Basin of North Staffordshire." Whilst the term "basin" is used in an environmental sense to define areas of the Basin in which sediments including silt-free muds and coarse clastic sediments transported by turbidity currents were deposited. Bordering the basinal area is the "shelf" area, the two being linked by the "slope". The "shelf" is defined as that area of the Basin in which sediments including sands of fluvial origin, silts and silty mudstones were deposited in essentially a shallow subaqueous environment. On the landward side of the shelf is the margin of the Basin which in this account is referred to as the paralic margin. The sediments of the paralic margin are mainly fluvial sands, silts and muds frequently interbedded with seatearths of the gannister and fireclay type often underlying thin coal seams. Deposition at the paralic margin is thought to have taken place in a deltaic environment, in particular in distributary channels, interdistributary swamps and at the delta front.

Lithofacies relationships and environmental interpretations in the interval late E_2b_1 - E_2b_2 (inclusive) (Refer to Figs.5.A. and 5.B.)

Sandstones, with the possible exception of the Gawsworth area occur infrequently in this interval and in particular are absent from the succession in basinal areas.

This absence of sandstones from the land remote parts of the succession has previously been cited, as has the faunal evidence in this interval, to be indicative of the establishment of average "deep water" conditions in the North Staffordshire Basin during this period.

Sandstones are however present in some marginal areas, for instance in the Dingle Brook section, Evans et al.(1968) record the presence of two sandstone units occurring between a conjectured horizon of Ct.edalense and an horizon of Ct.nitidus (Loc. 52 Evans et al. 1968) only the upper unit is exposed and consists of fluvial sandstones of Lithofacies 2 character, which are proposed to have been deposited in a broad shallow shelf located channel. It is thought probable that these fluvial sandstones equate with part of the succession at Astbury where deltaic sandstones of Sublithofacies lb and lc aspect occur in the Limekiln Stream Section. Much of this section is poorly exposed and the zonal goniatites characteristic of the late E_2b_1 - E_2b_2 (inclusive) interval are absent. However, the whole of the section exposed in this stream, between an horizon of H.beyrichianum (Loc. 108, Evans et al. 1968) and an horizon of Posidoniella variablis Hind (Loc. 23 Evans et al. 1968) which was tentatively assigned to E_2b by Trewin and Holdsworth (1973), consists of Lithofacies 1 sandstone units separated by mudstones.

To the east of the Dingle Brook locality, part of the succession at Gun End, between the lowest E_2c_2 faunal band and the Minn sandstones of the Gun Hill anticline is thought to equate with the late E_2b_1 - E_2b_2 (inclusive) interval. This section includes a minimum of 30m of sediments largely shelf mudstones of Sublithofacies 8b aspect with rare thin shelf "sheet" sands and silts of Lithofacies 3 type which are thought to be the products of land distal shelf deposition. The Hurdlow section, to the east of Gun End displays Sublithofacies 8b shelf mudstones only for much of the interval late E_2b_1 - E_2b_2 (inclusive) and this locality, together with the adjacent Thorncliffe section in the south, is thought to be close to the land distal shelf margin, since at localities to the east sediments of a basinal character are present.

In the south, shelf mudstones of Sublithofacies 8b character such as those associated with the sandstone units in the Dingle Brook section and with the thin sandstones in the Gun End Stream are present in the Combes Brook. In this section, shelf mudstones are present below the base of the Cherts (Loc. 084) for much of the assumed late E_2b_1 - E_2b_2 (inclusive) interval. Due west of the Combes locality shelf sediments are thought to be present in the Endon area. The lowest faunal band exposed in this area is an E_2c_2 horizon present in the Roughwood End Quarry (Loc. 023) and in the assumed late E_2b_1 - E_2b_2 (inclusive) interval the sediments present are probably mudstones since where sandstones do occur, above Loc. 023, they form marked topographic features on the steeply sloping hillside.

Basinal sediments are present in this interval in the Dove, Oakenclough, Blake and Wiggenstall localities, here although sandstone are absent dark basinal mudstones of Sublithofacies 8a aspect occur in the succession.

In the north west, basinal sediments of Sublithofacies 6a aspect are present in the Gawsworth area where they form a thick sequence of source proximal turbidites which on the basis of palaeocurrent evidence have been derived from the south and south west. A source proposed for these sediments is the Astbury - Cloud End area, and as has been previously suggested the sediments may have accumulated at the distal mouth of a submarine canyon which connected the basinal area of Gawsworth with the paralic area of Astbury-Cloud End. The proposed palaeogeography (see Fig.1) indicates that the shelf is narrow in this area, a feature which probably implies a steepening of the slope and although the presence of a submarine canyon system is only conjectural it would appear that the area was a favourable one for its initiation and for the continuation of a supply of sediment throughout the majority of the late E_2b_1 - H_2c (inclusive) period of deposition. The presence of pencontemporaneous large scale slump structures at discrete horizons within the proximal turbidites (6a) at Gawsworth may be associated with tectonic activity along the line of the adjacent present day Red Rock Fault. The slump structures are however, limited in lateral extent and it is thus suggested that the basin floor in the Gawsworth area was relatively flat.

Contemporaneous tectonic activity along the line of the Red Rock Fault may in part have also triggered off the supply of material in the source area of the Sublithofacies 6a proximal turbidites' whilst in addition the sandstone units in the Gawsworth area are separated by intervals of sand free basinal mudstone of Sublithofacies 8a type, varying in thickness from 2-8m, which it is suggested may represent periods of quiesence along the fault. Alternatively these mudstones may represent the normal accumulation of basinal sediment occurring when the supply of coarse clastic sediment was temporarily suspended. This fluctuation in supply of coarse clastic sediment to the Gawsworth area may also have been due to periodic deltaic regression in the source area and it is suggested that the occurrence of deltaic sandstone units (1b and 1c) in the Astbury succession which are separated by mudstone intervals (8b) is evidence of this variation in the position of the delta front.

The source distal limits of the proximal turbidites (6a) present in the Gawsworth area are not accurately known although a sandfree succession is present to the north east at Ryle Arms (SJ 94816939) containing in the upper parts the faunal horizons of H. subglobosum and N. nuculum (Locs. 80 and 35 respectively of Evans et al. 1968). The extent of the northern distribution of these proximal turbidites is also unknown since the beds are not exposed due to the northerly pitch of the folding in the northern part of the Gawsworth area. On the basis of the distribution of the Lithofacies present it is possible to suggest the following tentative disposition for the shelf, basinal and paralic areas of the North Staffordshire Basin in the interval late E_2b_1 - E_2b_2 (inclusive). The Astbury - Cloud End area appears to have been located in the paralic margins of an alluvial coastal plain which was bordered on its eastern margin by a broad shelf area extending to the Hurdlow-Thorncliffe area. A river system prograding eastward across the land proximal part of the shelf deposited coarse clastic sediment at least as far as Dingle Brook, whilst further to the east the fine sand and silt shelf deposits in the Gun End section are probably the source distal deposits of this fluvial system. To the north of the Astbury - Dingle Brook latitude, the margin of the coastal plain appears to have assumed an east-west orientation and was bordered by a narrow shelf and steep slope zone, to the north of which lay a flat basin floor in the Gawsworth area.

In the south of the area of study a land distal part of the shelf covered the Combes Valley area and probably the Endon area too. The absence of coarse clastic sediment on this southern shelf area is thought to indicate that the paralic southern margin of the Basin is not represented in the area studied, probably lying further to the south.

A basinal area including the Dove, Oakenclough, Blake and Wiggenstall localities is present in the east and the absence of coarse clastic sediments from this area is thought to be indicative of its land distal situation. Trewin and Holdsworth (1973) indicate that this area also had a basinal character in E_1a - E_2a times although the type and distribution of sediments is quite different from that occurring in the

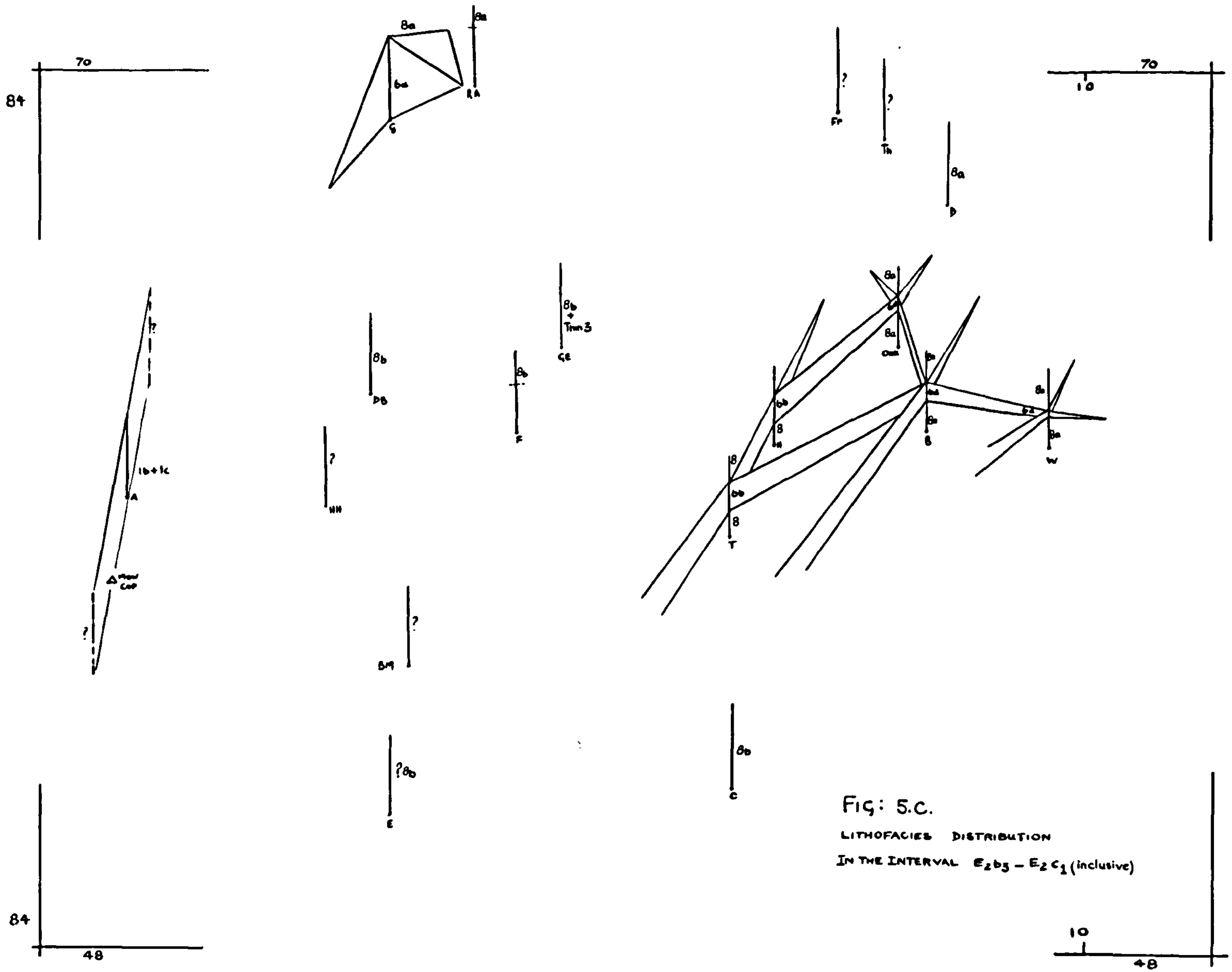


Fig: 5.C.

Lithofacies Distribution

In the Interval $E_2b_3 - E_2c_1$ (inclusive)

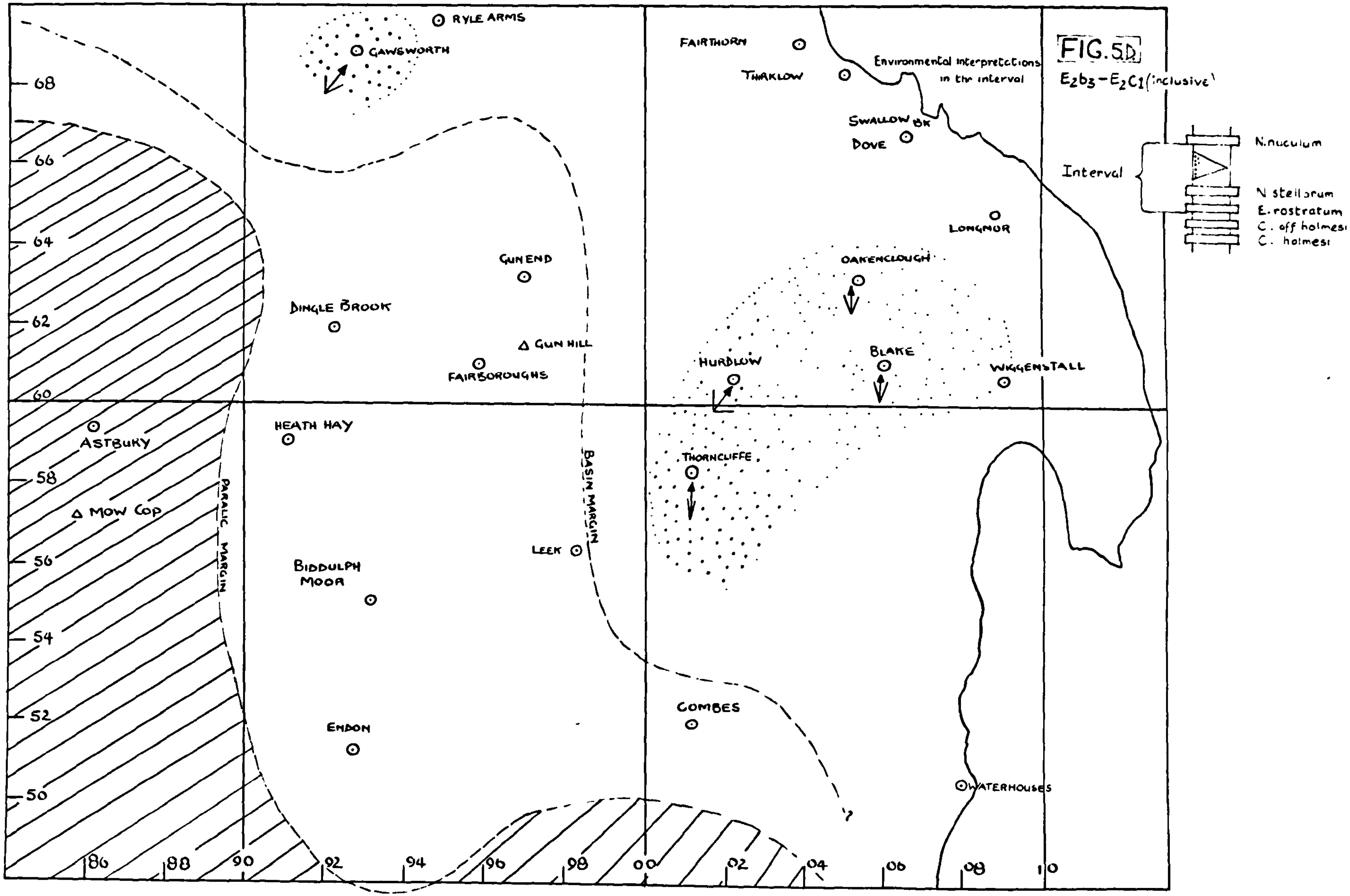


FIG. 5D
Environmental interpretations in the interval
$E_2b_3 - E_2C_1$ (inclusive)
Interval
N. nuculum
N. stellarum
E. rostratum
C. aff holmesi
C. holmesi
RYLE ARMS
GAWSWORTH
FAIRTHORN
THIRKLOW
SWALLOW BK
DOVE
LONGNOR
OAKENCLOUGH
GUN END
DINGLE BROOK
GUN HILL
FAIRBOROUGHS
HURDLOW
BLAKE
WIGGENSTALL
ASTBURY
HEATH HAY
THORNCLIFFE
MOW COP
PARALIC MARGIN
BASIN MARGIN
LEEK
BIDDULPH MOOR
COMBES
ENDON
WATERHOUSES
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late E_2b_1 - E_2b_2 (inclusive) interval. The northern part of the eastern basinal area is adjacent to the basinal area of Gawsworth. However, the absence of coarse clastic sediment in the Dove and Ryle Arms localities,together with the palaeocurrent evidence in the Gawsworth area appears to indicate a lack of connection between these two basinal areas. It is suggested that this may be due to the existence of a positive area forming a submarine barrier or ridge following the line of the axis of the present day Gun Hill anticline and as such may be interpreted as evidence of incipient contemporaneous folding activity[1.] in the North Staffordshire Basin in the interval late E_2b_1 - E_2b_2 (inclusive).

Lithofacies relationships and environmental interpretations in the interval E_2b_3 - E_2c_1 (inclusive). (Refer to Figs.5.C. and 5.D.)

In this interval, in direct contrast to the previous interval, coarse clastic sediments are present in basinal localities at Hurdlow, Thorncliffe, Oakenclough, Blake and Wiggenstall, in addition to their continued presence in the Astbury and Gawsworth areas. The widespread geographical distribution of the sandstones in this interval together with the presence of faunas, which it has previously been suggested are indicative of "shallow water" environments, is thought to imply that "shallow water" conditions obtained in the Basin throughout the E_2b_3 - E_2c_1 (inclusive) interval.

The sandstones in the basinal areas are all characteristically turbidites. In the Hurdlow and Thorncliffe sections, mature turbidites of Sublithofacies 6b aspect are present in this interval above the level of N. stellarum at Locs. 069 and 109 respectively. Their lateral equivalents are distal turbidites (6d) present in the Oakenclough and Blake sections above the horizon of N. stellarum, occurring

1. Ashton (Ph.D thesis 1974) suggests that tectonic activity along the line of the present day Gun Hill anticline may have already been exerting some degree of influence on the distribution of sediments in R1 and R2 times.

in association with basinal muds of Sublithofacies 8a. A similar succession occurs in this interval in the Wiggenstall section although the N.stellarum band is not exposed. These source distal turbidites (6d) display their maximum development in the Blake Brook, but are poorly represented in the Wiggenstall stream where only a thin development of this Sublithofacies occurs, whilst in the Oakenclough stream, although well exposed, they are less extensive than in the Blake. The implications of this distribution are thought to be that the Blake area was closer to the main axis of the turbidite cone of deposition covering the basin floor, than either Wiggenstall or Oakenclough and as a consequence received sediment more frequently than these two areas. The very thin development of sediment at Wiggenstall is also thought to imply that this locality was near to the outer limit of turbidity current influence. The northern limit of the turbidite apron is thought to lie between the Oakenclough and Dove localities, since in the Dove area, as in the previous interval, the succession consists of basinal sand free mudstones of Sublithofacies 8a character.

The mature turbidites (6b) present in the Hurdlow and Thorncliffe localities, which were termed the Hurdlow sandstones by Aitkinhead (1974), terminate their outcrop roughly a mile and a half to the north of the Hurdlow Stream Section. This termination is thought to occur near to the margin of the turbidite apron in this locality. To the south of the Thorncliffe section the Hurdlow Sandstones, although not exposed, form a continuous strike feature in the Easings area (SK 014576) whilst further to the south they are concealed by drift. Palaeocurrent evidence indicates an origin from a sector between west and south for the Hurdlow Sandstones, whilst the distribution of their distal equivalents (6d) in the Oakenclough, Blake and Wiggenstall localities, which on the basis of their primary current structures have a southern origin, together with the proposed position of termination of the turbidite apron to the north of the Hurdlow area is thought to imply that a north easterly curving path was taken by the turbidity currents in this interval.

A source area for the turbidites of the eastern part of the Basin in the E_2b_3 - E_2c_1 (inclusive) interval is not immediately apparent. A possible source is the Astbury area where, as in the previous interval, deltaic sediments of distributary channel (lb) and prodelta (lc) character were deposited. However, the presence, to the east, of shelf mudstone (8b) in the Dingle Brook, Fairboroughs and Gun End localities together with only thin developments of fine grained shelf sands and silts (3) in the Gun End section, is thought to indicate that the majority of the coarse clastic sediment derived from the Astbury deltaic terrain was contributed, as in the previous interval, to the Gawsworth area and very little, if any, accumulated on the eastern parts of the shelf. This absence of coarse clastic sediment in the Dingle Brook and Gun End sections also appears to indicate that the shelf in this area was not the source area for the mature turbidites (6b) comprising the Hurdlow Sandstones. There is however, a possibility that strike faulting in the Gun End section which was described by Evans et al. (1968) as having cut out the upper part of the Minn Beds and the lower part of the Lower Churnet Shales, may also have suppressed in this area sandstones of equivalent age to the Hurdlow Sandstones. However, on the basis of palaeocurrent evidence it is suggested that sediments, if contributed from the shelf in the Gun End vicinity to the slope or basin in the Hurdlow and Thorncliffe localities, consisted of only a minor contribution and that the major source of sediment supply lay further to the south.

In the southern part of the area, the presence of shelf mudstones (8b) is inferred for this interval in the Endon area (see note for the preceding interval) whilst further to the east, in the Combes section, shelf mudstones occur which towards the top of the interval contain a marked abundance of siderities. Sandstones are, however, absent from this succession. Holdsworth and Trewin (1973) suggest that the appearance of siderities in parts of the North Staffordshire Basin succession in the E_1 - E_2a interval could have been effected by the periodic entry of large quantities of fresh water from a deltaic area to the south. They also indicate that in the E_1 - E_2a interval, siderite nodules present in the shale successions at the basin margin in the Waterhouses and Upper Dove areas occur at levels equivalent to the protoquartzite units of the main basin succession. In the E_2b_2 - E_2c_1 (inclusive) interval it is suggested that the abnormal concentration of siderities in the Combes Brook shelf succession may also be associated with a major influx of fresh water into the Basin and further, that the siderities in this locality are the lateral equivalents of sand intervals in adjacent parts of the succession. The absence of coarse clastic sediment in the Endon and Combes sections suggests that the source of the Hurdlow Sandstones and their distal (6d) equivalents in the Wiggenstall, Blake and Oakenclough areas lay to the south east of the area studied, whilst the presence of the siderities in the Combes section may indicate the proximity of a zone of entry of these turbidites into the basin. Despite a lack of positive evidence it is thought probable that the turbidites entered the basin along a zone to the east of the Combes locality and appear to have been channelled in from a south easterly source along a subsiding part of the shelf margin, which was roughly aligned north-south. The presence of two structural features, the Ecton Anticline and the Fernyford Syncline, the former marginal to and the latter within the envisaged subsiding area, may be only a coincidence. Possibly, however, contemporaneous incipient folding was taking place along the line of these fold axes. It is suggested that this movement could have produced a north-south subsiding area which was traversed by successive turbidity currents, and also that further into the basin the previously referred to north eastern curve of the turbidite axis, was also associated with contemporaneous warping. It is possible that this curved axis had resulted from being aligned along a subsiding north-east south-west trending depression in the basin. However, it is thought more likely that it was produced by the deflection of the turbidity currents meeting an uplifted or positive area slightly to the west of a line between Thorncliffe and Hurdlow. If the latter is correct, it would partly explain the diverse palaeocurrent directions encountered in the basin and is also thought to reinforce the previous assertion that coarse clastic sediment did not enter the basin from a westerly source.

All the previously discussed evidence implies that the source area for the coarse clastic sediments of the basin lay to the south east of the area studied in an area which is thought to have been part of the southern paralic margin of the North Staffordshire Basin.

The disposition of the shelf and basinal areas in the E_2b_3 - E_2c_1 (inclusive) interval appears to be only slightly different, despite a different sediment distribution pattern, than in the previous interval. However, a major difference is thought to have been a northern advance of the terrestrial-deltaic terrain forming the southern margin of the North Staffordshire Basin, the main evidence for this being the presence of the southerly derived turbidites in the basin area which were absent in the preceding interval. It is suggested that with the onset of "shallowing" in E_2b_3 times, that this southern deltaic area was able to prograde northwards across a shallowing shelf area to reach a position where in E_2c_1 times it was able to contribute coarse clastic sediment to the basinal area.

In the north-west the continued accumulation of proximal turbidites (6a) in the basinal area of Gawsworth is thought to imply continuity of position for the Astbury coastal plain area and the associated narr ow shelf and steep slope to the north.

The "shallow" period proposed for the North Staffordshire Basin in the E_2b_3 - E_2c_1 (inclusive) interval, which, as has previously been suggested, produced a northward advance of the southern paralic margin does not, on Lithofacies evidence, appear to have produced an easterly advance of the western paralic margin. A possible reason for this may be that the shelf to the east of Astbury was, like the southern margin of the Basin, influenced by contemporaneous tectonic movement in this interval which induced a predominantly northward movement of coarse clastic sediment from the Astbury area, possibly along the line of the Bosley Syncline.

Further evidence indicating the occurrence of contemporaneous incipient local folding movement is thought to be present in the Hurdlow and Thorncliffe sections. Here the sediments in this interval have a basinal character whilst the succession in the previous interval suggests that these two areas were situated on the eastern margins of the shelf. This apparent westward expansion of the basinal area may have been the result of contemporaneous local down folding of an area, which was marginal to an upfolded area. It has previously been suggested (ibid) that this upfolded area had modified the distribution of the turbidites of the main basinal area in this interval.

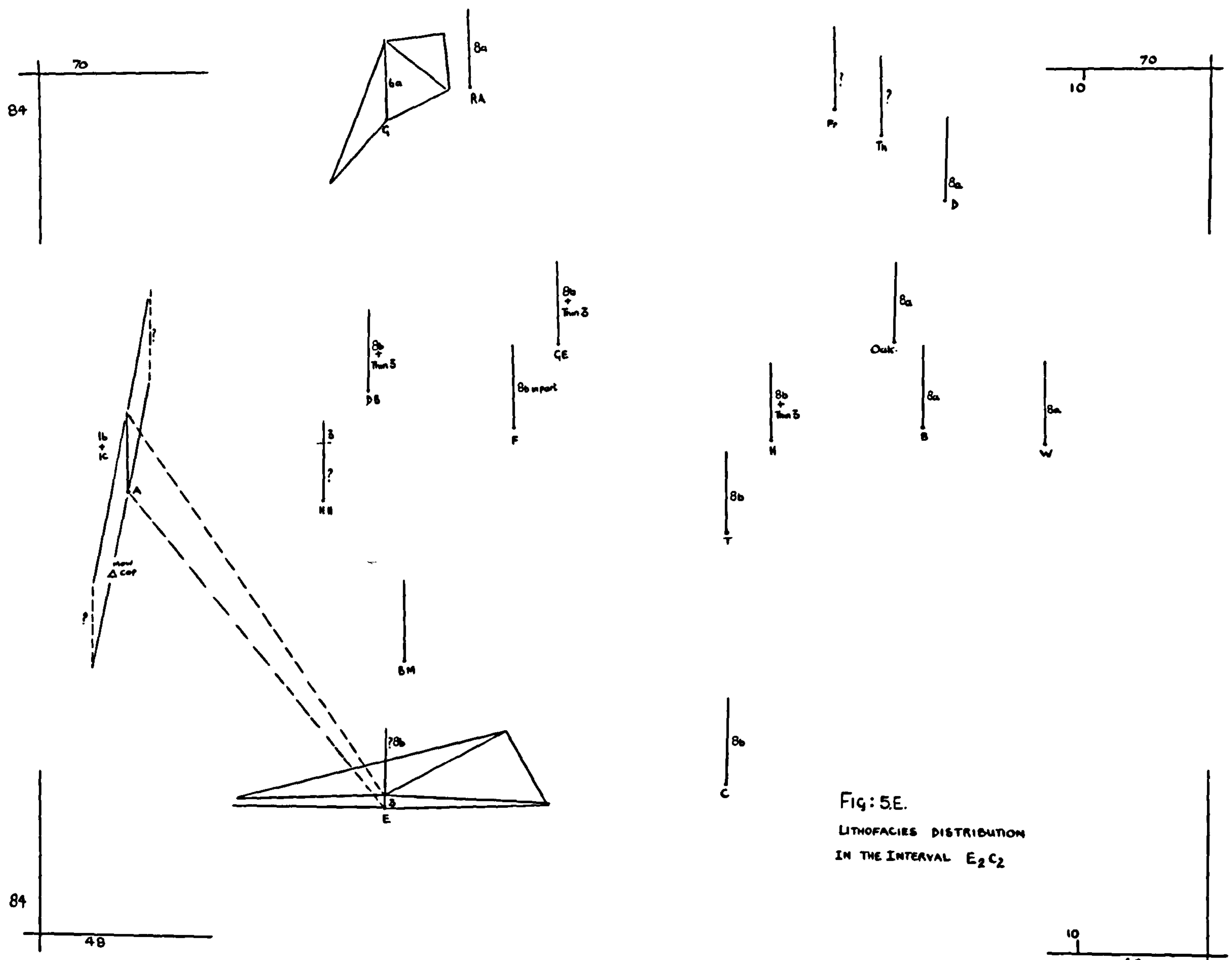


Fig: 5.E.
LITHOFACIES DISTRIBUTION
IN THE INTERVAL E_2C_2

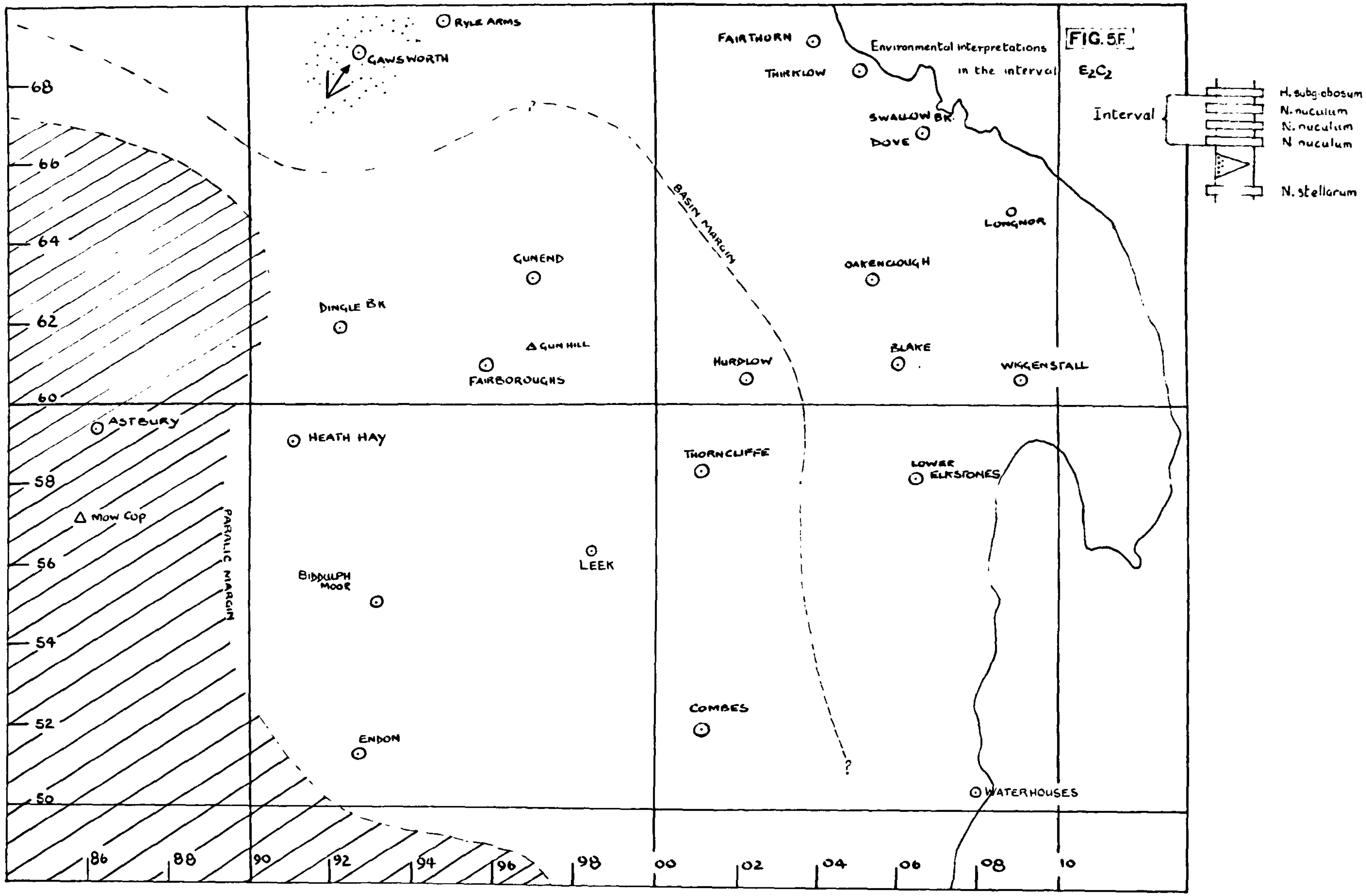


FIG. 5F

Environmental interpretations in the interval E_2C_2

In conclusion, it is proposed that the E_2b_3 - E_2c_1 (inclusive) interval, which on the evidence of the faunas of the Cherts and N. stellarum faunal bands is suggested to be a "shallow" interval, did not produce any major palaeogeographic change apart from a significant northern advance of the southern Basin margin, but did however, produce very marked changes in sediment distribution which are most apparent in the basinal areas.

Lithofacies relationships and environmental interpretations in the interval E_2c_2 (refer to Figs.5.E. and 5.F.)

In this interval coarse clastic sediments, with the exception of those in the Gawsworth area, are present only at or adjacent to the paralic margins of the Basin. This type of distribution plus the complete absence of sand from eastern basinal areas,together with the comprehensive faunal evidence previously discussed, is thought to imply that "deep water" conditions existed in the North Staffordshire Basin throughout much of the E_2c_2 interval.

In the Astbury area sands and silts of Sublithofacies lb and lc type persist as deposits of a deltaic coastal plain which, as was suggested in the interval late E_2b_1 - E_2b_2 (inclusive), is close to the point of supply of the southerly derived proximal turbidites (6a) present in this interval in the Gawsworth area.

To the south east of Astbury fine grained shelf sands and silts of Lithofacies 3 type are present at Endon and are overlain by the E_2c_{2iii} faunal band occurring in this area at Loc. 023.

To the east of Astbury, thin fine grained shelf sands and silts (3) occupy that part of the succession exposed immediately below the lowest H_1a horizon in the Heath Hay and Dingle Brook sections. Whilst even further to the east thin developments of Lithofacies 3 sediments are also present in the Gun End and Hurdlow exposures, although the greater part of the succession in these two areas consists of shelf mudstones (8b).

In the south of the area the succession in the Combes Brook consists of shelf mudstones (8b) which are probably continuous northwards as is evidenced by their occurrence in the Thorncliffe succession.

The Oakenclough, Blake and Wiggenstall areas are all characterised by basinal mudstones (8a) in this interval, as is the area adjacent to the Carboniferous Limestone Massif in the north, on the evidence of the Swallow Brook Section. A mudstone succession (8a) is also present in this interval in the Ryle Arms Stream and as in previous intervals effectively provides a maximum north westerly limit for the development of the proximal turbidites (6a) of the Gawsworth area.

In the area studied the disposition of the basinal, shelf and paralic areas in the E_2c_2 interval is similar to that in the previous interval. However, marked differences in the distribution of the Lithofacies present are thought to indicate that broad palaeogeographic changes had occurred in the Basin as a whole. In particular, the Lithofacies 6 turbidites characteristic of the eastern basinal area in the preceding interval are absent from this area in E_2c_2 times. The absence of this Lithofacies is thought to imply that the source of the coarse clastic sediment had for much of the interval moved southwards, due probably to deltaic regression associated with a high average sea level, to a position where it was unable to contribute sand to the basinal area. The more distal nature of the shelf in the Combes Brook area in this interval when compared with the previous interval, also tends to confirm this observation.

A slight change in the position of the paralic margin is thought to have occurred in the south west in the upper part of the E_2c_2 interval. This is evidenced by the infilling of a minor embayment which existed in the Endon area in the previous interval, and the fine grained shelf sands and silts deposited in the area in this interval may be indicative of a general "shallowing" of the Basin thought to have taken place in Upper E_2c_2 times.

To the east of the Endon area it is thought probable that the paralic margin turns southwards at a more westerly point than in the previous interval. This assumption is based mainly on the evidence of the succession in the Combes area which has a distal shelf character, whilst the abnormal concentration of siderities present in this area in the previous interval which were suggested to have been deposited in a land proximal situation is absent from the E_2c_2 succession.

On the basis of Lithofacies evidence, it is thought probable that an eastward extension of the distal margin of the shelf occurred in this interval to incorporate the Hurdlow and Thorncliffe localities, which in the previous interval were situated in the basinal area. A possible reason for this minor change in the disposition of shelf and basinal areas is thought to be the occurrence of contemporary tectonic movement, possibly along the line of the present day Mixon anticline, producing the elevation of an area previously lying within the basin.

In the north west of the Basin the continued presence of a steep slope and narrow shelf area to the north of Astbury seems likely on the evidence of the proximity of the basinal deposits in the Gawsworth area. The absence of coarse clastic sediment from the shelf to the east of Astbury is thought to indicate, as in the previous interval, that sediments from an Astbury source area were again directed northwards along a subsiding trough into the Gawsworth area. Thus, it seems probable that this continuity of sediment supply into this northern basinal area may be further evidence of contemporaneous tectonic activity in the North Staffordshire Basin in the E_2c_2 interval.

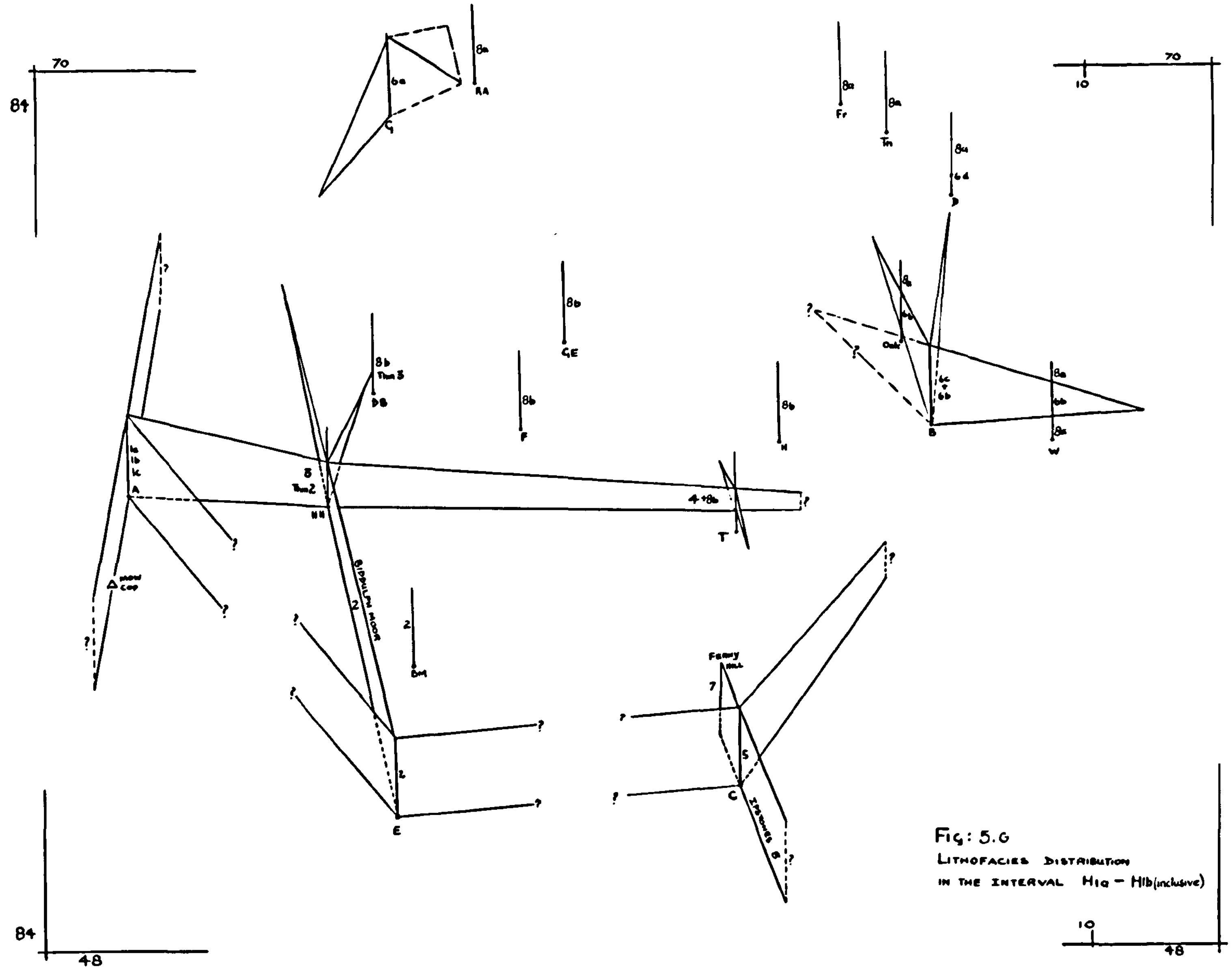
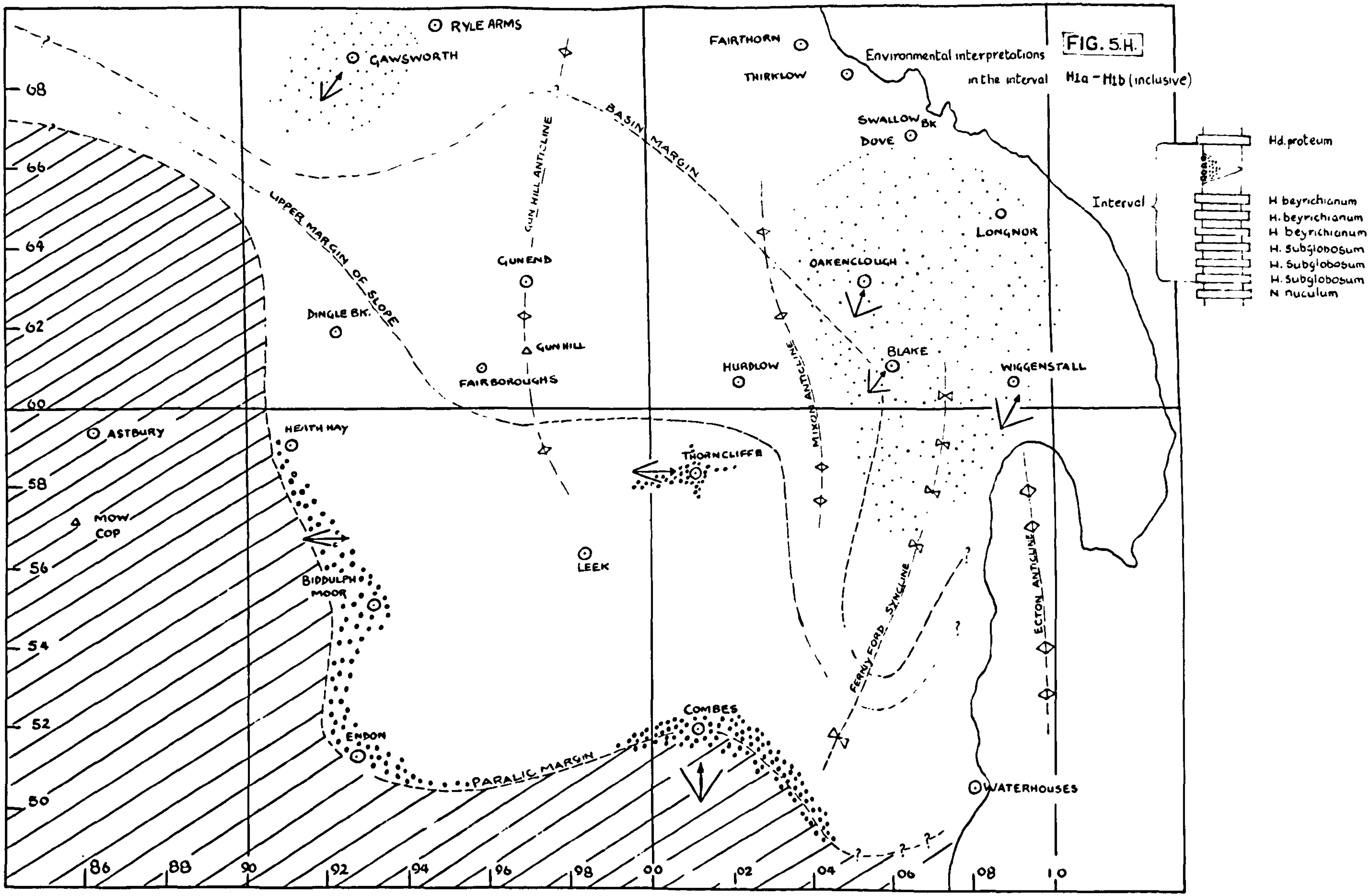


Fig: 5.6
Lithofacies distribution in the interval H1a – H1b (inclusive)



Environmental interpretations in the interval H1a - H1b (inclusive)
RYLE ARMS
GAWSWORTH
FAIRTHORN
THIRKLOW
SWALLOW BK
DOVE
LONGNOR
OAKENCLOUGH
BLAKE
WIGGENSTALL
HURDLOW
GUNEND
GUN HILL
GUN HILL ANTICLINE
DINGLE BK.
FAIRBOROUGHS
UPPER MARGIN OF SLOPE
BASIN MARGIN
MIXON ANTICLINE
ASTBURY
HEITH HAY
MOW COP
BIDDULPH MOOR
LEEK
THORNCLIFFE
ENDON
COMBES
PARALIC MARGIN
FERNYFORD SYNCLINE
ECTON ANTICLINE
WATERHOUSES
Interval
Hd. proteum
H beyrichianum
H. beyrichianum
H beyrichianum
H. subglobosum
H. subglobosum
H. subglobosum
N nuculum

FIG. 5.H.

Lithofacies relationships and environmental interpretations in the interval H_1a - H_1b (inclusive) (Refer to Figs.5.G. and 5.H.)

Sandstones in this interval are more widespread in the North Staffordshire Basin than in any other interval in E_2b_1 - H_2c (inclusive) succession. Mature turbidites occur in all but the most land remote basinal areas, whilst sand bodies are present in some shelf locations which in the previous interval contained only shelf mudstones and were thought to be situated in land distal shelf situations. The previously discussed faunal evidence, provided in particular by the numerous exposures of the H_1a faunal bands, together with the distribution of coarse clastic sediment especially in the eastern basinal area is suggested to indicate that "shallow water" conditions were characteristic of the North Staffordshire Basin in the H_1a - H_1b (inclusive) interval.

In the Astbury area units of deltaic sediment of Lithofacies 1 type are present in the succession at Loc. 011. At the base, Sublithofacies 1b sediments representing the infillings of minor distributary channels are present, grading upwards into sediments of Sublithofacies 1c type which are thought to be the products of deposition in the immediate pro-delta area or in an inter-distributary environment. The sandstone development at Astbury in this interval culminates in Sublithofacies 1a type sediments which characteristically also contain coal seams and seat earths.

To the east a thin development of fluvial channel sandstones of Lithofacies 2 and shelf sands and silts of type 3 is present in the Heath Hay succession. Southwards these sediments thicken up and are interpreted as sands of fluvial origin infilling broad shallow subaqueous shelf channels. These thick sandstones form a marked topographic feature in the Biddulph Moor area, and at Crowborough crossroads, Loc. 027, are directly underlain by a faunal horizon containing H. subglobosum.

Southwards from Biddulph Moor the feature continues along Brown Edge and is well exposed in an old quarry at Endon Edge, Loc. 022 where current directional data indicates a westerly to south westerly origin. These Lithofacies 2 sandstones continue across the Endon Valley and crop out at Roughwood End Loc. 025 and in the vicinity of Stanley Pool. Evans et al. (1968) refer to the thin development of the Lithofacies 2 sediments exposed in the Heath Hay stream as being the correlative of the Stanley Grit, which is the sandstone exposed at Loc. 025, and also forms an arcuate outcrop around Stanley Pool. The paralic nature of the sediments exposed at Astbury, plus the proximity of the westerly to south westerly source proposed for the Biddulph Moor and Brown Edge channel fill sandstones (2) is thought to imply a close association of the two Lithofacies which presumably interdigitate in the intervening area. Whilst the absence of coarse clastic sediment in the Hurdlow, Bent End and Dingle Brook sections, together with the northern termination of the channel fill sandstones (2) in the Heath Hay area, which may be due to the presence of an elevated or positive area of the shelf on the northern margin of the proposed channel, is thought to further reinforce the evidence for a westerly or south westerly origin for these Lithofacies 2 sediments.

To the east the Lithofacies 4 sediments of Thorncliffe, consisting of fine grained sands and silts forming a channel bank deposit, are of the same age as the Heath Hay - Biddulph Moor - Brown Edge channel fill sandstones and their westerly origin strongly indicates a lateral passage between the two.

In the south of the area coarse to pebbly sandstones (5) thought to be the deposits of a braided river system are exposed in the Combes Brook and adjacent areas. The directional evidence relating to the source of these sediments is barely adequate, but an average southerly origin can be adduced. This thick development of Lithofacies 5 sandstones also outcrops, on strike, in the Sharpcliff area Locs. 086, 087 and 089 and presumably forms the high ground to the south east known as Ipstones Edge.

Sandstones of turbidite origin (6) are present in the east in the Oakenclough, Blake and Wiggenstall Streams, well defined tool markings in the Blake Brook slope turbidites (6c) indicate a south to south westerly origin,a direction which may indicate a connection with the Combes Brook-Ipstones area. However, on the basis of palaeocurrent evidence it is possible that some sediment may have entered the Blake area from a more westerly source, possibly the adjacent Thorncliffe area. Further evidence supporting this westerly origin may be the presence of horizons containing plant debris which, although absent from the Combes succession, are present in some of the sandstones in both the Blake and Thorncliffe successions. In the Wiggenstall section, mature turbidites (6b) show marked evidence of transport from a southerly source, although near to the top of the succession the orientation of current induced directional structures becomes variable and may indicate a westerly source for some of the beds. Alternatively this variation in orientation may be due to the differences in the travel paths of successive turbidity currents (Bouma, 1962, P.100). This may be because not all currents had the same starting point and also in this case may have been influenced by local changes in the topography of the basin floor. Another possibility is that as the succession built up turbidity currents were successively deflected by the accumulation of sediment deposited by previous currents. In the Oakenclough stream the mature turbidites (6b) at Loc. 160 display evidences of both southerly and westerly origins for reasons, it is suggested, similar to those described above.

In the north east sediments of basinal mudstone (8a) type are present in the Fairthorn and Thirklow exposures whilst in the Dove at Loc. 250 of Holdsworth (1963) a single thin sandstone bed of Sublithofacies 6d aspect is proposed as the distal equivalent of the mature and slope turbidites (6b and 6c) present in the Blake, Oakenclough and Wiggenstall streams in this interval, and as such marks the northern limit of southerly derived coarse clastic sediment. Thus, from the evidence outlined above, it would appear that the sediments of turbidite origin present in the eastern basinal area were derived from areas to the south and west where fluvial sandstones of Lithofacies 2, 4, 5 and 7 aspect are present in the succession.

In the Gawsworth basinal area, as in previous intervals, proximal turbidites (6a) continue to be deposited and a persistent southerly derivation is recorded for these sediments.

In the H_1a - H_1b (inclusive) interval both the disposition, of shelf, basinal and paralic areas, and the distribution of sediments in the Basin is markedly different from that in any of the preceding intervals and the most striking change is probably the marked northern advance of the southern paralic margin.

On the western margins the alluvial coastal plain extends over the Astbury area as is evidenced by the coal swamp conditions of the Sublithofacies la sediments in this locality. The paralic margin is now thought to be situated further to the east than was previously the case, and probably occupies a position adjacent to the Biddulph Moor - Brown Edge area swinging tightly to the west in the vicinity of Cloud End, and passing eastward in the Endon area and through the Combes-Ipstones area.

Minor variations in the position of the paralic margin during this period may be indicated by the nature of the Lithofacies 1 deltaic sediments in the Astbury succession. Initially the sands and silts infilling minor channels (lb) are thought to represent the deposits of a fluvial system prograding eastward across the shelf. These sediments are succeeded by prodelta sands (lc) which it is suggested may represent a minor regression of the delta. Inter-distributary swamp (la) sediments are present in the upper parts of the succession and are thought to represent a further eastward advance of the paralic margin. It is recognised however, that the same sequence could have been achieved by lateral migration of the delta, similar to that described from the Lafourche area of the Mississippi Delta by Frazier (1967). A deltaic complex of this type could be expected to occur in an environment where sediment was allowed to build up without being removed by tidal scour or by oceanic currents. In a partially enclosed situation such as is proposed for the North Staffordshire Basin, it is thought unlikely that strong currents would obtain, and the Lithofacies present in the Astbury area appear to indicate that only minimal tidal variation took place.

To the east of the Astbury area the Lithofacies 2 sediments of Biddulph Moor, Brown Edge and Endon are thought to be the product of subaqueous deposition in the pro-delta area, and in particular, are thought to represent the infilling of broad shallow channels on a shelf, which had a very limited tidal scour. The eastward extension of the sandstone deposits on the shelf probably reached an area in the vicinity of Leek, whilst in some cases delta front distributaries are thought to have extended even further to the east, and it is suggested that the Lithofacies 4 sediments present in the Thorncliffe stream consititute a channel bank deposit of an easterly prograding delta front distributary of this type.

The embayment in the shelf present in the Combes area in E_2b_1 - E_2c_2 (inclusive) times is now thought to have migrated northwards as fluvial sediments are seen to have reached the northern margin of the shelf and also to have contributed sediment, via turbidity currents, into the basin taking the form of a broad cone of deposition which had the Blake succession at or near its geographical centre. Whilst the less proximal mature turbidites (6b) at Wiggenstall and Oakenclough are thought to have been situated on the flanks of this cone of deposition. Fine grained sediment discharged into the basin area from rivers prograding across the shelf from the west, such as the distributary identified in the Thorncliffe section, is thought to have reached the basin area and is recognised in the slope (6c) and proximal (6a) turbidites present in the Blake Brook. Some of this material appears to have been partially eroded after deposition possibly by the turbidity currents which entered the area from the south, so that many very thinly bedded to medium bedded fine grained beds are lenticular in form at this locality. Slump structures are also present within the turbidite succession in the Blake Brook and it is suggested that these rapidly accumulating beds would have been particularly susceptible to slumping in the area forming the apex of the cone of deposition.

In the interval E_2b_1 - E_2c_2 (inclusive) it has been suggested that only coarse clastic sediment derived from the south of the area was able to reach the eastern parts of the basin. It was only in the H_1a - H_1b(inclusive) interval that westerly derived coarse clastic sediment prograding across the shelf was in a position to contribute material to this part of the basin. This situation implies the existence of a broad shelf and a very gentle eastward inclined slope into the basin on the west whilst on palaeocurrent evidence the slope in the south appears to have been periodically more favourable for the initiation and development of turbidity currents.

In the north west part of the basin, sediment continues to be supplied to the Gawsworth area and the incidence of instability, as evidenced by the presence of slump structures, becomes more frequent in that part of the succession equated with the

H_1a - H_2b (inclusive) interval. The presence of these slump structures may be equated with an increase in the rate of deposition which may imply a northward approach of the source area, or, as previously mentioned may be associated with contemporaneous tectonic activity on the line of the adjacent Red Rock Fault complex. Despite the contraction of the North Staffordshire Basin there is no evidence to suggest that the proximal Sublithofacies 6a turbidites of the Gawsworth area are represented by distal equivalents in other localities. On the north east in the Fairthorn, Thirklow and Dove localities basinal muds are present, which are thought to have been the characteristic sediments accumulating in this area throughout the whole of the E_2b_1 - H_2c (inclusive) interval. The absence of westerly derived distal turbidites in these areas tends to suggest that coarse clastic sediments derived from the Astbury area, were as in previous intervals restricted to the Gawsworth area of deposition.

The evidence of the increased amount of coarse clastic sediment being deposited in the Basin in this interval suggests either an uplift and rejuvenation of the land areas to the south and west or a lowering of the average sea level in the North Staffordshire Basin area. Both situations it is suggested would have produced conditions favourable for a northerly and westerly advance of the paralic margin. The presence of the coarse pebbly Lithofacies 5 sandstones in the Combes - Ipstones area, thought to be associated with a braided river system, strongly suggests that uplift and rapid erosion was operative in the southern land areas. In addition to the proposed uplift it has previously been suggested that a marked lowering of average sea level occurred in the H_1a - H_1b (inclusive) interval which is thought to have produced a shallowing of the shelf area, thus allowing coarse sediment to accumulate in hitherto more distal portions of the shelf. This contraction of the Basin is also evidenced by the nature of the turbidites which in the Blake, Wiggenstall and Oakenclough sections exhibit a more proximal character in the H_1a - H_1b (inclusive) interval than do the source distal turbidites occurring at the same localities in the E_2b_3 - E_2c_1 (inclusive) interval.

Lithofacies relationships and environmental interpretations in the interval H_2a - H_2c (inclusive)

In marked contrast to the preceding interval the previously discussed faunal evidence for the H_2a - H_2c (inclusive) interval has been suggested to be indicative of the establishment of "deep water" conditions in the North Staffordshire Basin at this time. The complete absence of sandstones in this interval from all the localities examined in the Basin is thought to be further confirmation of the existence of "deep water" conditions.

Pelitic sediments are characteristic of the succession in this interval and in the Blake, Wiggenstall and Oakenclough sections basinal mudstones (8a) are present and also occur in the north in the Fairthorn, Thirklow and Dove exposures.

In the Astbury area sediments above the level of Hd.proteum, the first "deep" faunal horizon in this interval, are shelf mudstones (8b) and although there is an absence of palaeontological control it is suggested on the absence of sand in the paralic western margin that the deposition of the proximal turbidites characteristic of the Gawsworth area in previous intervals may have ceased prior to the deposition of the Hd.proteum faunal band. In the Gawsworth area basinal muds of Sublithofacies 8a aspect are present at Loc. 114 of Evans et al. (1968) which contains an R1 fauna and it is thought that the low ground between this location and the upland area formed by the proximal turbidites of Gawsworth Common, is composed of similar basinal sediments.

Basinal mudstones (8a) are also present in the Thorncliffe, Hurdlow, Fairboroughs and Bent End Sections, areas which in the previous interval were located on the shelf. Whilst the Dingle Brook and Heath Hay exposures to the west contain shelf mudstones of Sublithofacies 8b type. In the Endon and Combes Brook areas the fluvial sandstones of Lithofacies 2 and 5 aspect present in the preceding interval are replaced in the succession in this interval by shelf mudstones (8b).

The implication of the above Lithofacies distributions in this interval is that a marked change particularly in the disposition of the paralic margins and shelf areas occurred which apparently took the form of a westward and a southward expansion of the basin area. The shelf area, with the exception of the previously land proximal localities of the Dingle Brook and Heath Hay, now became an area where basinal muds accumulated. Whilst the paralic sediments of Astbury were replaced by shelf deposits and it is suggested that the same situation occurred in the Endon and Combes areas.

The deposition of proximal turbidites (6a) in the Gawsworth area is suggested (ibid) to have ceased in this interval and the implications are that coarse clastic sediment was no longer available for this Sublithofacies in the Astbury source area, probably due to both the westerly and southerly regression of the paralic margin.

The situation in the North Staffordshire Basin as outlined above is thought to have persisted throughout the H_2a - H_2c (inclusive) interval and to have continued at least into the lower parts of the R_1a Zone. The presence of basinal deposits on areas previously receiving shelf sediments, and of shelf deposits on areas previously forming part of the alluvial coastal plain in addition to the previously discussed faunal evidence, is thought to confirm that a "high" average water level obtained in the North Staffordshire Basin during this period. The marked increase in depth of water which is proposed to have commenced with the advent of the Hd.proteum faunal band was not only confined to the North Staffordshire Basin and the associated Namurian Provinces of Great Britain (Ramsbottom, 1969), but also extended into Western Ireland and continental Europe (Hodson and Van Leckwijck, 1958).

It appears that following the Hd.proteum - H.smithi eustatic maxima, any shallowing of the waters of the North Staffordshire Basin that may have occurred did not develop sufficiently to produce any discernable effects in the area since the sediments accumulating in H_2b and H_2c times have the characteristic of either shelf or basinal pelites.

APPENDIX I

THE SUCCESSION IN THE INTERVAL LATE E_2b_1 - H_2c (INCLUSIVE)

The following details of the succession are taken only from localities where a continuous section of strata is exposed, isolated exposures unless of particular significance are not documented in this section. Parts of the succession have been examined in greater detail than others and are referred to more fully in the palaeontological account. Similarly the lithology of parts of the succession is figured in more detail in the account of the various Lithofacies (ref. Figs.C-J).

The Congleton Edge - Astbury succession

The sediments seen in the Astbury area are exposed at two localities. The upper part of the succession is exposed at the southern end of an old gannister quarry (SJ 86935929), and the lower part of the succession is exposed in the nearby Limekiln Stream Section. (SJ 86405855). In addition, exposures in old gannister workings are present at several localities below Congleton Edge and although palaeontological control is lacking in these areas, they are placed within the interval H_1a - H_2c on the basis of their structural relationships with adjacent localities (Evans *et al*. 1968).

The Limekiln Stream Succession (SJ 86405855) Section IT

The characteristic marine horizons containing *H.subglobosum* are absent at this locality and the first definite marine horizon is that of *H.beyrichianum* (Loc. 108a, of Evans *et al*. 1968). The writer was able to locate the Survey position of *H.beyrichianum*, occurring in a thin bed of dark grey shale, but was unable to positively identify the poorly preserved immature goniatites recovered from this bed as *H.beyrichianum*. Never-the-less, the section logged at this locality corresponds closely with that recorded by the Geological Survey, and the position of H.beyrichianum in the succession can be fixed quite accurately.

In the absence of palaeontological control the base of the Middle Churnet Shales is difficult to fix in the Astbury area. From evidence elsewhere in the North Staffordshire Succession, the interval H_1a - H_1b is seen to be circa 15m, a figure which is compatible with the Survey estimates for this portion of the succession. ("Beds of the Homoceras subglobosum Zone (H_1a) are about 90ft in thickness, ..." Evans et al. 1968).

The following succession was recorded in the Limekiln stream:-

Limekiln Stream, Section 1T (SJ 86405855)

	ft in	m
Drift.		
Mudstone, grey, brown at base, abundant brachiopod fragments. (Loc. 109a, Evans et al. 1968).	10'6"	3.05
Sandstone, medium grained, light grey, with plant fragments.	2'0"	0.60
Not exposed, probably sandstone on basis of G.S. record.	11'0"	3.35
Sandstones, medium grained, pale grey to white.	4'0"	1.22
Not exposed.	4'0"	1.22
Mudstone, grey, thin sandstone laminae at top, poorly exposed at base.	13'0"	3.96
Sandstone, medium grained, light grey with plant fragments.	3'10"	1.16
Mudstone, silty.	0'6"	0.15
Sandstone, fine grained, grey, coaly partings at base.	2'0"	0.60
Fireclay, blue grey clay, soapy feel, plant rootlets.	0'2"	0.05
Brown clay.	0'6"	0.15
Mudstone, blue grey, soft, clayey.	0'11"	0.28
Clay, red-yellow, soft.	0'1"	0.025

	ft in.	m
Mudstone, blue grey, soft clayey.	4'0"	1.22
Mudstone, blue grey, poorly exposed.	1'1½"	0.34
Mudstone, blue grey.	0'9"	0.225
Sandstone, fine grained, with mudstone partings, passing upwards into	0'3"	0.075
Sandstone, medium grained, yellow-buff, plant fragments and coaly partings.	0'6½"	0.16
Shale, dark grey, goniatites at base, (Loc. 108a, Evans et al. 1968) H.beyrichianum Loc. 001.	0'0½"	0.013
Sandstone, medium grained, grey, coaly partings.	0'1½"	0.038
Shale, dark grey, coaly streaks, with plant fragments.	0'1½"	0.038
Sandstone, medium grained, light grey, with plant fragments.	7'0"	2.13
Silty mudstone, light grey.	2'0"	0.60
Not exposed.	11'0"	3.35
Sandstone, fine grained, pale yellow, with pink spots.	14'0"	4.27
Not exposed, probably mudstone, estimated position of the top H_1a faunal band at the base.	16'0"	4.88
No exposure.	4'0"	1.22
Sandstone, pale grey to yellow, only partly exposed upper contact not seen, this bed forms a ridge in the bank side.	8'0"	2.44
No exposure. circa	100'0"	30.48
Nodular mudstone to siltstone with micaceous sandstone streaks.	24'0"	7.32
No exposure, probably shale/mudstone.	50'0"	15.24
Sandstone, light grey to white, carbonaceous partings and plant rootlets.	5'0"	1.52
Mudstone, grey, plant fragments.	0'6"	0.15
Sandstone, light grey, plant fragments.	0'6"	0.15

	ft in.	m
Mudstone.	0'4"	0.10
Sandstone, grey, plant fragments.	0'5"	0.125
Mudstone.	0'6"	0.15
Sandstone.	0'3"	0.075
Mudstone.	0'6"	0.15
Mudstone, grey, silty, plant fragments.	0'6"	0.15
Mudstone, grey, silty.	0'9"	0.225
Mudstone, partially exposed, weathered yellow.	10'0"	3.04
No exposure.		

Old gannister quarries to the north east and south west of the above section are on strike with the sandstones exposed in the upper part of th Limekiln Stream Section. In the old gannister quarry to the north east, Pot Bank Quarry (SJ 86935929), it appears likely that the beds exposed there overlap, in part, the succession observed in the Limekiln Stream. The sandstone units seen in the upper part of the Limekiln Stream are more fully exposed at the southern end of Pot Bank Quarry. The overlying mudstones contain a prolific fauna of brachiopods, lamellibranchs and gasteropods which are probably the equivalent of the brachiopod horizon (Loc. 109a Evans et al.) seen in the Limekiln Stream.

The beds below the horizon of H.beyrichianum Loc. 001, in the Limekiln Stream form part of the lower Churnet Shales in this area. The fragmentary exposures, mainly of the sandstones in this section below the level of H_1b indicate that almost identical lithologies typify both the Lower and Middle Churnet Shales in the Astbury-Congleton Edge region.

The following succession was recorded at a mid-point on the eastern face in the Pot Bank Quarry (SJ 86935929) Section 2Ta.

	ft in.	m
Drift.		
Mudstone, dark grey, with ironstone nodules.	20'0"	6.10
Limestone, shelly, decomposed, *Schizophoria sp.*	4'4"	1.32
Sandstone, medium grained, light grey, plant fragments.	1'2"	0.35
Mudstone, dark grey, plant rootlets.	0'6"	0.15
Mudstone, grey, silty with siltstone laminae.		
Mudstone, grey passing upwards into-	2'6"	0.755
Mudstone dark grey.	0'4"	0.10
Ironstone nodules.	0'4"	0.10
Mudstone, grey with ironstone nodules at base, *Chonetes sp.*	1'7"	0.475
Mudstone, grey, with ironstone nodules at base, *Chonetes sp.*	1'9"	0.525
Mudstone, grey, with three horizons of ironstone nodules, *Productus sp.*	0'11"	0.275
Mudstone grey.	0'11"	0.275
Mudstone, grey, with three horizons of ironstone nodules, *Chonetes sp.*	0'7"	0.175
Mudstone, grey, with ironstone nodules at base, *Chonetes sp.*, *Nuculopsis gibbosa*.	0'7"	0.175
Mudstone, grey with ironstone nodules at base, *Chonetes sp.*, *Nuculopsis gibbosa*, *H.smithi*, Loc. 010a	0'6"	0.15
Mudstone, soft clay like, brown to blue grey, *Chonetes sp.*, *Productus sp.*, *Orthis sp.*, *Orbiculoidea sp.*, *Bellerophon sp.*	1'0"	0.305
Mudstone, dark grey, calcareous, hard, *Hd.proteum* in bottom 10", *H.smithi* in top 2". Loc. 010.	1'0"	0.305

	ft in.	m
Mudstone, grey, calcareous, Lingula sp., Orthis sp.	0'10"	0.25
Mudstone, grey, with ironstone nodules at base passing upwards to-	1'8"	0.50
Mudstone, grey, with ironstone nodules at base.	1'4"	0.46
Mudstone, grey.	1'0"	0.305
Gannister, medium grained, light grey, thin coal at 6" from top. Stigmaria sp. and plant fragments throughout.	3'0"	0.915

The beds in the Pot Bank Quarry have been extracted along the strike and at the southern end of the quarry a succession of unworked sandstones occurs, lying directly below the succession given above.

Succession from southern end of Pot Bank Quarry (SJ 86865918) Section 2Tb.

	ft in.	m
Mudstone, with brachiopods, lamellibranchs, gasteropods. (Loc. 109a Evans et al.)	3'0"	0.915
Gannister, fine grained, rootlets increasing towards base, brachiopod impressions on top surface.	5'8"	1.7
Fireclay, black, with rootlets.	1'1½"	0.34
Gannister, fine grained, with rootlets.	0'5"	0.12
Coal, dirty, gradational contacts.	0'2½"	0.06
Fireclay, black, with rootlets.	1'0"	0.30
Gannister, fine grained, rootlets throughout, top surface irregular with impressions of Stigmaria sp. base erosive.	1'4"	0.70
Shale, black, coaly, silty, Coal trace at base.	2'0"	0.60
Gannister, fine grained, rootlets throughout, top surface irregular with impressions of Stigmaria sp., base erosive.	1'5½"	0.44
Mudstone, black.	0'1½"	0.04
Coal, bituminous, cleated.	0'0½"	0.01

	ft in.	m
Gannister, fine grained, rootlets throughout, upper surface irregular with impressions of Stigmaria sp. base erosive, Loc. 011.	5'8"	1.70
Gannister, buff, fine grained, rootlets throughout.	1'8"	Max. 0.50
Fault.		
No exposure.	6'8"	2.00
Sandstone, medium grained, grey, drifted plant material throughout.	0'2"	0.05
Sandstone, medium grained, grey, drifted plant material throughout.	0'4"	0.10
Sandstone, medium grained, grey, drifted plant material throughout.	0'2½"	0.06
Siltstone, grey.	0'8"	0.20
Sandstone, medium grained, grey, drifted plant material throughout. Load cast.	0'2"	0.05
Sandstone, medium grained grey, drifted plant material. Load cast.	0'3"	0.08
Sandstone grey, medium grained, drifted plant material throughout. Load cast.	0'5"	0.12
(This bed tends to split along a bioturbated layer).		
No exposure.	14'4"	3.30
Sandstone, buff, medium grained.	0'8"	0.20
Siltstone, grey.	0'4"	0.10
Sandstone, quartzitic, coarse grained, gradational to siltstone. Trailmarked base.	0'10½"	0.26
Siltstone.	0'5"	0.12
Sandstone, medium grained, parallel laminations throughout. Load cast base.	0'8½"	0.21
Silstone, grey. Base gradational to sandstone.	0'7"	0.18

	ft in.	m
Sandstone, coarse laminae at base fining upwards.	0'5½"	0.13
Sandstone, fine grained, parallel laminae, drifted plant debris, contacts gradational.	1'2"	0.35
Mudstone, grey, silty, contacts gradational.	0'0½"	0.01
Sandstone, fine grained.	0'2"	0.05
Mudstone, grey, silty.	0'3"	0.07
Sandstone, fine grained.	0'2"	0.045
Mudstone, grey, silty.	0'1"	0.03
Sandstone, fine grained.	0'2"	0.05
Mudstone, grey, silty.	0'0½"	0.015
Sandstone, fine grained.	0'1"	0.03
Mudstone, grey, silty.	0'1½"	0.035
Sandstone, fine grained.	0'0½"	0.05
Mudstone, black, shaley.	0'1"	0.025
Sandstone, fine grained, organic laminae, base load cast. Mud parting at base.	0'1"	0.03
Sandstone, fine grained, organic laminae, base load cast.	0'1½"	0.04
Mudstone.	0'0¼"	0.005
Sandstone, fine grained, organic laminae parallel to bedding. Load cast, burrows at base.	0'2½"	0.06
Sandstone, fine grained, organic laminae. Load cast base.	0'2"	0.05
Sandstone, fine grained, organic laminae.	0'1½"	0.04
Sandstone, medium grained, lenticular, crossbedded, foresets picked out by organic remains, inclined towards 110°.	0'7½"-0'3"	0'19-0.08
Sandstone, medium grained, lenticular.	0'4"- 0'0"	0.10-zero
Sandstone, medium grained, parallel lamination picked out by plant debris.	0'1½"	0.04

	ft in.	m
Sandstone, grey, massive, coarse grained gradational to fine grained at base with drifted plant debris. Load cast.	2'0½"	0.62
Mudstone, with thin coal at base.	0'1"	0.03
Sandstone, medium grained, grey, finely divided plant debris. Parallel laminae in top 0.20m. Lenticular. Base erosive.	1'8"-1'4"	0.50-0.40
Sandstone, medium grained, grey. Base erosive.	2'11"-0'10"	0.90-0.25
Sandstone, medium grained, grey. Base erosive. Coarse plant debris.	1'4"-0'0"	0.00-0.40
Sandstone, medium grained grey. Base erosive. Abundant coarse plant debris.	0'6"	0.15
No exposure.		

The Heath Hay Stream (SJ 90915932)

The base of this succession is well defined by the occurrence of the H.subglobosum marine horizons which are associated with a mudstone siltstone succession which coarsens upwards to a sandstone unit Loc. 028, displaying vertical burrows with off shoots parallel to the bedding. Above the sandstone unit a strike fault occurs cutting out the Hd.proteum marine horizon. The top of the succession is marked by the occurrence of Hmct.prereticulatus occurring in a bedded ankeritic limestone. When comparison of this succession with the equivalent levels in the Astbury area is made, there is seen to be a marked absence of fireclays, gannisters and associated thin coal seams, whilst rootlet beds of the stigmarian type, much in evidence in the Pot Bank Quarry, do not occur.

Heath Hay Stream, Section 8T (SJ 90915932)

	ft in.	m
Limestone, grey, ankeritic, Hmct.prereticulatus, Loc. 029. H_2c.	0'6"	0.15
Mudstone, shaley, dark grey.	0'9"	0.23
Faulted ground.	6'0"	1.83
Silstone, grey, laminated.	11'0"	3.35
Faulted ground.	2'0"	0.60
Sandstone, fine grained, grey, vertical burrows. Loc. 028.	4'6"	1.36
Silty shale, grey.	1'3"	0.38
Sandstone, very fine grained, grey.	0'0¾"	0.02
Silty shale, grey.	0'6"	0.15
Sandstone, very fine grained, grey.	0'2"	0.05
Silty, shale, grey.	0'4"	0.10
Sandstone, very fine grained, grey.	0'2"	0.05
Silty shale, grey.	0'8"	0.20
Sandstone, very fine grained, grey.	0'1½"	0.04
Silty shale, grey.	0'4½"	0.11
Sandstone, very fine grained, grey.	0'1"	0.025
Silty shale, grey.	0'4"	0.10
Sandstone, very fine grained, grey.	0'1"	0.025
Silty shale, grey.	0'2"	0.05
Sandstone, very fine grained, grey.	0'1"	0.025
Silty shale, grey.	0'3½"	0.09
Sandstone, very fine grained, grey.	0'1"	0.025
Silty shale, grey.	0'2½"	0.06

	ft in.	m
Sandstone, very fine grained, grey.	0'3"	0.075
Silty sandstone, grey.	0'6"	0.15
Silty shale, grey.	0'2"	0.05
Sandstone, very fine grained, grey.	0'1½"	0.04
Silty shale, grey.	0'2"	0.05
Sandstone, very fine grained, grey.	0'2"	0.05
Silty shale, grey.	0'1½"	0.04
Sandstone, very fine grained, grey.	0'1¼"	0.03
Silty shale, grey.	8'0"	2.44
Sandstone, fine grained, variable to silty mudstone.	3'0"	0.914
Silty shale.	1'6"	0.45
Sandstone, coarse grained.	0'5"	0.12
Silty shale, grey.	6'0"	1.83
Sandstone, shale laminae.	0'3½"	0.09
Shale, dark grey.	10'6"	3.20
Sandstone, fine grained, grey.	0'2"	0.05
Shale, dark grey.	1'4"	0.40
Sandstone, fine grained, lensing to zero.	0'8" Max.	0.20
Mudstone, bl ue grey.	12'0"	3.66
Limestone, blue grey, silty, ankeritic. H.subglobosum, Loc. 020, H_1a_{iii}.	0'5"	0.13
Mudstone, blue grey.	1'0"	3.66
Sandstone, fine grained, buff.	0'2½"	0.06
Mudstone, blue grey.	0'8½"	0.21

	ft in.	m
Limestone, silty, ankeritic, well jointed. H.subglobosum, Loc. 020a, H_1a_{ii}.	0'3"	0.08
Shale grey.	11'0"	3.35
Shale, dark grey, H.subglobosum. Survey Loc. 97.	4'0"	1.22
No exposure.		

Those sediments in the above succession which coarsen upwards to the sandstone unit at Loc. 028 are equated with a thicker sandstone outcropping to the south on Biddulph Moor which can be traced, by a mapped feature and a series of old quarries, southwards to the Endon area, where it is termed the Stanley Grit. At the crossroads north of Crowborough Farm the following exposure is recorded:-

Crowborough Crossroads Exposure (SJ 90685693)

		ft in.	m
Sandstone unit in Old quarry. (Stanley Grit).		unknown	
No exposure.	circa	16'6"	5.0
Silty shaley mudstone.		1'8"	0.5
Limestone, ankeritic, blue grey. H.subglobosum, Dunbarella sp., Dimorphoceras sp., Loc. 027.		0'4½"	0.12
Silty shaley mudstone.		1'8"	0.5

South of the above exposure the sandstone unit is well exposed near to Morris House in an old quarry (SJ 91455425) Loc. 026,and can be traced southwards to the Endon area by feature mapping and by outcrops.

Section at Loc. 026 Morris House Quarry (SJ 91455425)

	ft in.	m
Sandstone, coarse grained, buff, burrows at base. (appears to be massive)	2'0"	0.6
Sandstone, medium grained, parallel lamination, burrows throughout, normal to bedding and branching.	0'6"	0.15

	ft in.	m
Sandstone, coarse grained, buff, massive.	4'4½"	1.30
Sandstone, coarse grained, buff, massive.	0'9"	0.23
Sandstone, coarse grained, buff, massive.	0'8"	0.20
Sandstone, massive, base erosional cutting out bed below.	0'10"	0.25
Sandstone, medium grained, buff, parallel lamination, burrowed throughout.	0'5½"	0.14
Sandstone, coarse grained, buff, massive, base erosive into bed below.	2'6½"	0.76
Sandstone, medium grained, buff, parallel laminations, thinly bedded, burrowed throughout, trails or burrows on bedding planes.	1'6½"	0.46
Sandstone, coarse grained, buff, massive, base irregular erosive.	1'3½"	0.39
No exposure.	0'5½"	0.14
Sandstone, medium grained, buff, massive, base erosive into bed below.	0'10½"	0.26
Sandstone, medium grained, buff, parallel laminations thinly bedded burrowed throughout, trails/burrows on bedding planes.	1'4"	0.40
Sandstone, coarse grained, buff, channels into bed below, tool marks on base of channel indicate S.W. derivation, axis of channel N.E. S.W.	1'8"	0.50
Sandstone, medium grained, buff, parallel laminations.	0'5½"	0.14
Sandstone, medium grained, buff, parallel laminations.	0'8"	0.20

The sandstone unit at Loc. 026 thins northwards to Heath Hay and appears to die out north of this area. Southwards the sandstone unit of Loc. 026 can be traced across the Endon Valley to Stanley Moor where it forms a ridge outcropping above Roughwood (SJ 92005139) Loc. 025.

The Section at Roughwood End Loc. 025 (SJ 92005139)

	ft in.	m
No exposure.		
Grit unit, (very coarse sandstone) red to buff, bedding planes at 0.20 - 0.40m intervals, some of these bedding planes are erosive and channel into the underlying sediment, primary current lineation is present on parting planes in some of the beds.		
Parallel lamination and cross lamination were observed on loose blocks.		
Upper surfaces display impressions of brachiopods, and mudflakes. Loc. 025.	19'8"	6.0
No exposure.	49'3"	15.0
Sandstone, fine grained, buff.	0'4"	0.10
Silstone, grey.	0'3"	0.07
Sandstone fine grained, buff.	0'5"	0.12
Sandstone/siltstone laminations.	0'5"	0.13
Thin sandstone separated by siltstone intervals. Prod marks S.W. derivation.	0'9½"	0.19
Sandstone, fine grained, buff.	0'3"	0.08
Sandstone, fine grained, buff, trace of burrowing.	0'3"	0.07
Silstone, grey.	0'0¼"	0.0025
Sandstone, fine grained, buff. Burrows, branching and normal to bedding. Loc. 624.	0'2½"	0.06
Silstone, grey.	0'1"	0.02
Sandstone, fine grained, buff, small scale cross bedding in top 0.02m southerly derivation.	0'10"	0.25
Sandstone, fine grained, with silty parallel laminae, cross bedding in top 0.02m southerly derivation.	0'9½"	0.20

	ft in.	m
Sandstone, fine grained, with silty parallel laminae.	1'0"	0.30
Sandstone, fine grained, buff.	0'2½"	0.06
Siltstone, grey.	0'1"	0.02
Sandstone, fine grained, buff, gradational contacts.	0'1"	0.02
Silstone, grey, gradational contacts.	0'1"	0.03
Sandstone, fine grained, buff.	0'2"	0.05
Sandstone, alternating with siltstone.	0'10½"	0.27
Sandstone, parallel lamination in top 0.02m.	0'3½"	0.09
Shale, black. P.corrugata.	1'3"	0.35
Limestone, dark grey, ankeritic, bedded. N.nuculum, E.bisulcatum. Loc. 023, E_2c_2.	1'5½"	0.43

No exposure.

The grit unit (Loc. 025) at the top of the above succession is overlain by a mudstone succession carrying a fauna of R1 age. Loc. 036 of C. Ashton. The grit can be traced northwards and at Crowborough Farm, Loc. 027 is underlain by an H.subglobosum marine horizon.

The Dingle Brook Section 14T

Two localities occur in the Dingle Brook separated by faulted ground, the stratigraphically highest beds seen are poorly exposed silty mudstones containing a bullion horizon outcropping downstream from a small weir (SJ 92736128). The main exposure (SJ 92076175) occurs upstream from the above locality and is separated from it by an unknown thickness of strata.

Section at (SJ 92736128)

	ft in	m
Limestonebullion. Hmct.prereticulatus, Loc. 039, H_2c, with silty mudstone above and below.	2'0"	0.60
No exposure, faulted ground, estimated interval between H_1a_{iii} and H_2c from adjacent sections is	90'-100'	29.00

Section at (SJ 92076175)

Drift.		
Silty mudstone, grey.	10'0"	3.05
Sandstone, fine grained, grey.	0'3½"	0.09
Silty, mudstone, grey.	0'4"	0.10
Sandstone, fine grained, grey.	0'2"	0.05
Silty mudstone.	0'1"	0.025
Sandstone, grey, fine grained.	0'1½"	0.04
Silty mudstone, grey.	1'4"	0.40
Limestone, bedded, silty/muddy, Homoceras sp., Posidonia sp.	0'4"	0.10
Silty mudstone.	2'0"	0.60
Calcareous mudstone, dark grey.	0'6"	0.15
Silty mudstone.	7'6"	2.28
Sandstone, grey, fine grained.	0'3½"	0.09
Silty mudstone.	8'0"	2.44
Limestone bullions, not ankeritic. H.subglobosum, Loc. 030, H_1a_{iii}.	0'4"	0.10
Silty mudstone, grey, with one isolated limestone bullion at base (3½" x 1'0") containing sparse immature goniatites.	6'6"	1.98
Silty mudstone, grey.	6'0"	1.83
Calcareous mudstone, dark grey, Posidonia sp.	0'3"	0.07

	ft in.	m
Silty mudstone, blue grey.	11'6"	3.50
Calcareous mudstone, dark grey.	0'6"	0.15
Silty mudstone, blue grey.	6'0"	1.83
Limestone bullions, not ankeritic. H. subglobosum, Loc. 030a, H_1a_{ii}.	0'4"	0.10
Silty mudstone.	1'0"	0.31
Shaley silty mudstone, blue grey.	10'0"	3.05
Silty mudstone, grey.	7'0"	2.13
Sandstone, fine grained, grey.	0'2"	0.05
Shale, blue grey.	0'5"	0.12
Sandstone, fine grained, grey.	0'2"	0.05
Shale, blue grey.	0'4"	0.10
Sandstone, coarse grained, grey.	0'0¾"	0.02
Silty shale, blue grey.	3'6"	1.06
Limestone bullions, not ankeritic, H. subglobosum, Loc. 030b, H_1a_i.	0'6"	0.15
Mudstone, silty, blue grey.	3'0"	0.91
No exposure.	4'6"	1.37
Blue grey, silty mudstone, with silty sandy streaks.	1'6"	0.45
No exposure.	2'0"	0.60
Siltstone with alternations of fine sandstone.	14'0"	4.27
Fine grained sandstone doggers in contorted strata (slumped).	0'5"	0.13
Silty mudstone.	5'0"	1.52
Sandstone, fine grained, grey.	0'3½"	0.09
Silty mudstone with sandstone doggers.	8'0"	2.44

	ft in.	m
Mudstone, poorly exposed.	45'0"	13.72
Geological Survey location 47 estimated position of N.nuculum.		
Mudstone, poorly exposed.	135'0"	41.15
Calcareous siltstone, dark grey.	1'0"	0.31
Geological Survey location 48 N.nuculum		
Mudstone poorly exposed.	145'0"	44.20
Sandstone, fine to medium grained, quartzitic.	50'0"	15.24
Mudstone, alternating with thin fine grained sandstone.	180'0"	54.86
Estimated position (Evans et al.,1968) of Ct.nititoides.		
Mudstone poorly exposed.	60'0"	18.29
Shale dark grey. Ct. cf. nitidus Geological Survey location 52 (Evans et al., 1968)	6'0"	1.83
Mudstone, poorly exposed.	60'0"	18.29
Sandstone, coarse grained, massive. Loc. 038.	20'0"	6.10

The Gun End Stream Succession (SJ 96406330)

Palaeontological control is good in this succession, an H.subglobosum horizon Loc. 043, occurs 25' above the highest N.nuculum horizon at Loc. 044, and is taken to be H_1a_1 by comparison with this interval in adjacent sections. The upper two H.subglobosum horizons are faulted out by a strike fault immediately downstream from Loc. 043. The Hd.proteum, Loc. 041, and H.smithi, Loc. 040, horizons are present in this section as two distinct horizons separated by an interval (3'4") of unfossiliferons strata. A fault cuts out the Hmct.prereticulatus level, but 25' above Loc. 043 black shales with mudstones and bentonites occur containing R.circumplicatile. The closure of the Gun Hill anticline brings the Hmct.prereticulatus horizon, Loc. 045, to outcrop in a small stream to the north east of the main stream section where the characteristic goniatite occurs in a grey mudstone succession. The Gun End section is predominantly composed of silty argillaceous sediments, the thin sandstone and siltstone intervals characteristic of the Dingle Brook and Heath Hay successions are absent in this locality.

Gun End Stream, Section 7T (SJ 96406330)

	ft in.	m.
Shale, black, with jarosite, R.circumplicatile, Loc. 013 of C. Ashton.		
No exposure.	21'0"	6.4
Fault zone		
Dark grey shale.	4'0"	1.22
Mudstone, black, with siderite, H.smithi, Loc. 040, H_2a.	0'8"	0.20
Shale, grey.	3'4"	1.01
Limestone bullions, ankeritic, Hd.proteum, Loc. 041, H_2a.	0'8"	0.20
Shale, grey.	6'0"	1.83
Bentonite, soft, yellow.	0'0½"	0.01
Shale, grey.	3'0"	0.91
Shale, light grey, silty.	3'7½"	1.10
Siltstone, grey.	0'1½"	0.04
Shale, light grey, silty.	0'1½"	0.04
Siltstone, grey.	0'1½"	0.04
Shale, light grey, silty.	4'0"	1.22
No exposure.	21'0"	6.4
Shale, blue grey, silty.	1'9"	0.53
Ankeritic limestone, dark grey, muddy.	0'4"	0.10
Shale, with poorly preserved goniatites.	0'4"	0.10

	ft in.	m
Limestone bullions, ankeritic, H.beyrichianum. Loc. 042, H_1b.	0'6"	0.15
Shale, silty.	7'0"	2.13
No exposure.	6'0"	1.83
Silty shale, blue grey.	3'0"	0.91
No exposure.	9'0"	2.74
Silty shale, blue grey.	4'0"	1.22
No exposure.	9'0"	2.74
Fault, clay gouge. (change of strike).		
Shaley, mudstone, ironstained.	7'6"	2.28
Shale, grey, hard.	1'0"	0.31
Shale grey calcareous, Posidonia sp., plant fragments.	0'6"	0.15
Limestone, black, not ankeritic,abundant H.subglobosum. Loc. 043, H_1a_i.	1'0"	0.31
Calcareous, shale (partly exposed).	2'0"	0.60
Blue grey silty shale, with thin sandstones, Posidonia sp. and Dunbarella sp. in upper 6".	16'0"	4.88
Silty sideritic concretions 'doggers'.	0'6" Max.	0.15
Shale with rare thin silty sandstone.	7'6"	2.28
Grey ankeritic limestone, abundant Posidoniella sp.,in upper levels.N.nuculum, E.bisulcatum. Loc. 044, E_2c_{2iii}.	1'0"	0.31
No exposure.	10'0"	3.05
Shale.	8'0"	2.44
Hard siltstone band.	0'3"	0.07
Shale.	14'0"	4.27
Dark grey silty limestone, Posidoniella sp. (?E_2c_{2ii})	0'6"	0.15
Shale, blue grey.	6'0"	1.83

	ft in.	m
Silty sideritic concretions.	0'3" Max.	0.07
Blue grey shale.	10'0"	3.05
Hard silty calcareous mudstone.	0'4"	0.10
Blue grey shale.	16'0"	4.88
Poorly exposed faulted ground.	6'0"	1.83
Blue grey shale.	24'0"	7.32
Sandstone, fine grained.	0'1"	0.03
Shale.	0'4"	0.10
Sandstone, fine grained.	0'1"	0.03
Shale.	2'4"	0.71
Limestone, grey ankeritic, N.nuculum. Loc. 046, E_2c_{2i}.	0'10"	0.24
Mudstone with rare thin beds of fine silty sandstone.	100'0"	29.00
Sandstone [1.] - fine to medium grained quartzitic.	6'0"	1.83

A section in a similar situation to the Gun End Stream Section is found on the western flanks of Gun Hill in a stream flowing through Fairboroughs Wood (SJ 96106100). The exposures are limited but consist largely of mudstones with rare thin limestones carrying goniatites of Homoceras sp. Loc. 90 and 91 Evans et al. (1968). A six inch thick ankeritic limestone at Loc. 59 (SJ 96186112) of Evans et al. (1968), carries N.nuculum and is suggested by the Survey to be the highest of the E_2c_2 horizons. The lack of continuous exposure between this Loc. 59 and the R1 shales at Loc. 145 (Evans et al. 1968) makes it impossible to estimate the actual thickness of the interval, however it is apparent that succession is considerably

1. This Sandstone occurs in the core of the Gun Hill anticline and is placed by the Geological Survey (1968) in the upper part of the Minn Beds. Faulting parallel to the main fold axis is thought to have cut out much of the succession in the upper part of the Minn Beds and the lower part of the Lower Churnet Shales.

attenuated presumably by faulting. Discontinuous exposures of blue grey silty mudstone were observed in the stream bed, and adjacent tributaries, throughout the interval E_2c_2 to R_1. Evans et al. (1968) state, "Higher beds of the Middle Churnet Shales seem to be thinner than elsewhere and they may in part be faulted out, no fossils were obtained." Despite the suspected occurrence of faulting, it seems likely that the succession is entirely argillaceous,there is no evidence to the contrary in adjacent streams and tributaries.

The Hurdlow Stream Succession (SK 02326085)

This section is exposed in two tributaries of the Churnet, the smaller forms a steep sided valley to the east of Hurdlow Farm, whilst the larger tributary, north east of the farm, occupies a valley which is mainly drift covered and carries a major tributary of the Churnet. Isolated exposures occur elsewhere in the vicinity and their exact position is indicated on the map, Fig.III.A. Many of the marine horizons in the interval E_2b_1 - H_2c are represented in this succession but due to faulting and lack of exposure it is not possible to observe one continuous exposure especially within the interval H_1a - H_2c.

Hurdlow Stream, Section 10T (SK 02326085) exposures in tributaries of the Churnet to the east and north east of Hurdlow Farm House.

	ft in.	m
Shale, blue grey.	7'6"	2.28
Bentonite, yellow.	0'0½"	0.01
Shale, blue grey.	1'0"	0.31
Bentonite, yellow.	0'0¼"	0.005
Shale, blue grey.	0'6"	0.15
Limestone bullion, R.circumplicatile, Loc. 007of C. Ashton, R_1a.	1'3" Max.	0.37

	ft in.	m
Mudstone, grey with jarosite. H.henkei at base. R_1a.	3'7"	1.08
Shale, silty, blue grey at base. Hmct.prereticulatus. Loc. 060, H_2c.	4'0"	1.22
Silty shale, blue grey.	42'0"	12.80
Fault.		
No exposure.	34'0"	10.36
Fault.		
Clay, grey soft lenticular.	0'5" Max.	0.12
Limestone bullion horizon, ankeritic, brecciated, H.subglobosum. Loc. 061, H_1a_{iii}.	0'5" Max.	0.12
Mudstone, shaley, blue grey.	3'0"	0.91
No exposure.	5'0"	1.52
Shale, black with jarosite, passing upwards to blue grey shale.	8'0"	2.44
Shale, black, H.subglobosum.	1'6"	0.45
Limestone bullion horizon, H.subglobosum. Loc. 061a, H_1a_{ii}.	0'6" Max.	0.15
No exposure.	5'0"	1.52
Shale, blue grey, silty.	5'0"	1.52
Isolated ankeritic bullion 5" x 12".	0'5"	0.12
Shale, blue grey, silty.	8'0"	2.44
Shale, blue grey, H.subglobosum.	0'6"	0.15
Limestone bullion horizon, H.subglobosum. Loc. 061b, H_1a_i.	0'4½"	0.12
Shale, blue grey, plant fragments.	12'5"	3.78
Shale, blue grey, Posidoniella sp.	2'0"	0.61
Mudstone, grey.	1'0"	0.31
Mudstone, black, N.nuculum.	0'8"	0.20
Mudstone, blue grey. N.nuculum.	1'2"	0.35

	ft in.	m
Limestone, ankeritic, greenish grey, N.nuculum, E.bisulcatum. Loc. 066, E_2c_{2iii}.	1'0"	0.31
Shale, grey, silty, with rare thin fine grained sandstones.	82'3"	25.06
Limestone, ankeritic, greenish grey, N.nuculum, E.bisulcatum. Loc. 067, E_2c_{2i}.	1'0"	0.31
Mudstone, blue grey, only partially exposed, containing rare thin sandstone and siderite nodules.	150'0"	45.72
Sandstone.	5'0"	1.52
Mudstone, poor exposure.	60'0"	18.29
Sandstone/Mudstone unit, partially exposed. Loc. 069[2].	15'0"	4.57
Mudstone partially exposed. Loc. 068. Ct.edalense[1]. (at base)	60'0"	18.28

North of the above section and to the north of Swainsmoor Farm (see Fig.A1.A.), isolated exposures occur in a stream bed as follows:-

Bullion ankeritic with Hmtprereticulatus in shale above Loc. 062, H_2c. A stream (see Fig.IIIA.) to the south of Hurdlow farm shows scattered exposures of blue grey silty shale with a bullion horizon containing Homoceras sp. Loc. 063. The highest N.nuculum Loc. 064 is exposed in a stream entering Blackshaw Moor Reservoir (see Fig.III A.) outcrops of mudstone in this vicinity are assumed to be within the interval H_1a - H_2c.

The Thorncliffe Stream Succession (SK 01265848)

Palaeontological control is adequate to position the sediments outcropping in the Thorncliffe Stream within the interval E_2c_2 - H_2c. However, the H_1b and H_2a marine horizons were not found in the main stream section due to lack of exposure but they are represented, in part, in a small stream to the south of the village of Thorncliffe.

1. Location of N. Aitkinhead at (SK 02596064) Ct.edalense.
2. To the north of this section the N.stellarum band outcrops at Strines, Loc of N. Aitkinhead (SK 03036170) and is present 0.47m below the Hurdlow Sandstone which is also exposed at Loc. 069.

The Thorncliffe Stream, Section 9T

	ft in.	m
Shaley mudstone, blue black, jarosite, Hmct.prereticulatus, Loc. 100, H_2c.	1'0"	0.31
No continuous exposure, mainly mudstone.	20'0"	6.10
Sandstone, contains mud flakes and abundant drifted plant fragments.	4'0"	1.22
No exposure.	19'0"	5.79
Sandstone unit with interbedded siltstone, Loc. 104, (for details see Fig.2.C.).	36'0"	11.135
No exposure.	10'0"	3.01
Sandstone, white, quartzitic.	6'0"	1.83
Shaley, mudstone, poorly exposed.	5'0"	1.52
Shale, dark calcareous H.subglobosum.) Loc. 101a, H_1a_{iii}.	1'9"	0.53
Shale, dark blue grey. H.subglobosum.) Loc. 101a, H_1a_{iii}.	2'0"	0.61
Shale, dark blue grey.	1'6"	0.45
Calcareous, mudstone, blue grey, passing into bullions in stream bed H.subglobosum. Loc. 101.	1'0" Max.	0.31
Shale, blue grey silty, poorly exposed.	20'0"	6.10
Sandstone, coarse grained buff, drifted plant fragments.	5'0"	1.52
Fault.		
Shale, blue grey, silty.	5'0"	1.52
Limestone bullions, ankeritic, H.subglobosum, Loc. 102, H_1a_{ii}.	0'6"	0.15
Shale, blue grey, silty, poorly exposed.	19'0"	5.79
Shale, blue black, H.subglobosum at base.	1'0"	0.31
Limestone, ankeritic, bedded. H.subglobosum, Loc. 103, H_1a_i.	0'4½"	0.09
Shaley mudstone, blue grey silty, solitary ankeritic bullion 16'0" below Loc. 103.	25'0"	7.62

	ft in.	m
No exposure.	59'0"	17.98
Mudstone, blue grey, silty.	6'0"	1.83
Limestone, ankeritic, bedded, Anthracoceras sp.	1'0"	0.31
Mudstone, blue grey, silty.	6'0"	1.83
Limestone, ankeritic, N.nuculum, E.bisulcatum, Posidoniella sp., Loc. 105, E_2c_{2i}.	0'6"	0.15
Mudstone, blue grey, Isolated ankeritic bullion at 15m from top.	196'0"	60.0
Sandstone/Mudstone unit. Loc. 109.	12'0"	3.66
Mudstone, blue grey.	10'0"	3.04
Sandstone (forming waterfall).	5'0"	1.52
No exposure, probably mudstone.	65'0"	20.0

Inferred position of Ct.edalensis[1].

To the south of the village of Thorncliffe, sediments within the H_2c - H_1a interval are again exposed and are represented by mudstones, sandstones and siltstones are notably absent, especially when the succession is considered in the light of the adjacent Thorncliffe Stream Section, 300m to the north, which contains a considerable thickness of sandstone at Loc. 104.

The stream to the south of Thorncliffe Village (SK 01165812), Section 9TA.

	ft in.	m
Mudstone, black, with iron carbonate cement Reticuloceras sp. R. (Loc.080 of C. Ashton).	0'5"	0.12
Mudstone, black, soft.	2'0"	0.61
Mudstone, blue grey, with jarosite.	6'6"	1.98
Mudstone, blue grey, calcareous.	1'0"	0.31

1. Location of N. Aitkinhead (SK 01755860)

	ft in.	m
No exposure.	14'0"	4.27
Mudstone, blue grey, Dimorphoceras sp., Dunbarella sp. at base.	3'0"	0.91
Mudstone, blue grey.	4'0"	1.22
No exposure.	30'0"	9.14
Mudstone, black, H.smithi. Loc. 106a, H_2a.	4'0"	1.22
Mudstone, blue grey.	5'0"	1.52
Mudstone, black with jarosite, H.smithi. Loc. 106b, H_2a.	2'0"	0.61
Mudstone, blue grey.	1'0"	0.31
Mudstone, cemented with iron carbonate, abundant Posidoniella sp.	1'0"	0.31
Mudstone, blue grey, rare Posidoniella sp.	4'0"	1.22
Mudstone, dark blue calcareous, H.beyrichianum. Loc. 107, H_1b.	1'0"	0.31
No exposure.	60'0"	18.29
Mudstone, blue grey, silty.	6'0"	1.83
No exposure.	18'0"	5.49
Mudstone, blue grey, silty.	6'0"	1.83
No exposure.	18'0"	5.49

The Combes Brook Succession (SK 00645285)

The Combes Valley and adjacent Ferny Hill, and Ipstones Edge areas display a series of isolated exposures in the E and H Zones. Marine bands from the H_1a - H_2c interval are not exposed in the area, but the position of sediments within this interval can be estimated by reference to the highest E_2c_2 horizon, and the R_1a marine horizon. The area has been mapped on a scale of 25" to 1 mile and the thicknesses of some parts of the succession have been calculated on the basis of dip, constant strike and map position. (Fig. IVA.).

The Combes Brook, Section 16T (SK 00645285)

		m	ft in.
Mudstone containing Dunbarella sp., Reticuloceras sp., partially obscured by landslip debris, (Loc. 9, Morris 1967). (Loc.038,C. Ashton) Loc. 080, R_1a..		2.0	6'6"
No exposure.		15.00	49'0"
Mudstone, grey, silty, with thin sandstone laminae.		1.00	3'4"
No exposure.		89.00	292'0"
Medium grained sandstone, burrowed, ripple marked. (This is the highest exposure of the sandstone unit which forms the prominent ridge in the valley side, and continues to Ipstones Edge).		1.00	3'4"
No exposure, probably sandstone continuous from above.		63.00	207'0"
Sandstone, coarse grained, conglomerate in part.	circa	1.0	3'4"
No exposure, probably sandstone.		15.00	49.0"
Sandstone, white coarse grained, conglomerate in part.	circa	1.00	3'4"
No exposure, probably sandstone.		12.00	39'0"
Conglomerate, large scale cross bedding, forsets inclined due east.	circa	1.0	3'4"
Partially exposed blue grey silty mudstone.		30.00	98'0"
Limestone, ankeritic, blue grey, N.nuculum. Loc. 081, E_2c_{2iii}.		0.07	0'3"
Partially exposed, blue grey silty mudstone.		19.00	62'0"
Limestone, ankeritic, blue grey. Dimorphoceras sp.		0.10	3'4"
Partially exposed, blue grey, silty, mudstone.		14.00	46'0"
Limestone, ankeritic, blue grey, N.nuculum. Loc. 082, E_2c_{2ii}.		0.10	3'4"

	m	ft in.
Partially exposed blue grey silty mudstone, with thin siderite bands. Loc. 083.	8.00	26'0"
Limestone, ankeritic, blue grey, plant fragments, N. nuculum. Loc. 083, E_2c_{2i}.	0.60	2'0"
Mudstone, blue grey, silty.	5.0	16.0"
Limestone bullion, ankeritic, blue grey.	0.14 Max.	0'5½"
Mudstone, blue grey, silty.	0.47	1'7"
Siderite nodule horizon.	0.04 Max.	0.1½"
Mudstone, blue grey, silty.	0.47	1'7"
Siderite, nodule horizon.	0.03	0'1"
Mudstone, blue grey, silty.	0.31	1'0"
Siderite nodule horizon.	0.03	0'1"
Mudstone, blue grey, silty.	0.40	1'4"
Siderite nodule horizon.	0.02	0'1"
Mudstone, blue grey, silty.	0.09	0'3½"
Siderite nodule horizon.	0.01	0'0½"
Mudstone, blue grey, silty.	0.35	1'2"
Siderite nodule horizon.	0.015	0'0½"
Mudstone, blue grey, silty.	0.45	1'6"
Siderite nodule horizon.	0.015	0'0½"
Mudstone, blue grey, silty.	0.48	1'7"
Siderite nodule horizon.	0.01	0'0½"
Mudstone, blue grey, silty.	0.135	0'5½"
Siderite nodule horizon.	0.005	0'0¼"
Mudstone, blue grey, silty.	0.10	0'4"

	m	ft in.
Siderite nodule horizon.	0.02	0'1"
Mudstone, blue grey, silty.	2.90	9'8"
Siderite nodule horizon.	0.07	0'3"
Mudstone, blue grey, silty. Faulted.	1.46	4'10½"
Siderite nodule horizon.	0.02	0'1"
Mudstone, blue grey, silty.	0.39	1'3½"
Siderite nodule horizon.	0.035	0'1½"
Mudstone, blue grey, silty.	1.47	4'11"
Siderite nodule horizon.	0.10	0'4"
Mudstone, blue grey, silty.	2.40	8'0"
Partially exposed mudstone, blue grey, silty.	55.00	180'0"
Limestone, ankeritic, blue grey.	0.30	1'0"
Mudstone, blue grey, silty.	9.70	31'9"
Cherts, laminated, E.rostratum, Loc. 084, E_2b_3.	1.00	3'4"
Mudstone, blue grey, silty.	7.00	23'0"
Limestone, ankeritic, blue grey.	0.20	0'8"

The three E_2c_2 marine horizons and the Cherts have not previously been recorded from this section of the Combes Valley. Morris 1967, positions the whole of the succession recorded above as, "R_1 or possibly of Homoceras (H) Age." In the light of palaeontological evidence, this must now be revised and the succession placed within the E and H Zones. The position of the base of the sandstone unit which incorporates the Sharpcliffe Conglomerate (Morris, 1967) occurs 30m above the highest N.nuculum horizon whilst the top of this unit, which is 93m thick, occurs 105m below the R_1a marine horizon Loc. 080 (Loc. 9, Morris 1967). On this evidence it is proposed to place the whole of the sandstone unit in the H Zone. This unit forms the lower of two sandstones which outcrop to the south east forming Ipstones Edge and are termed the Ipstone Edge Sandstone (Morris, 1967). The upper sandstone unit is correctly placed in the R Zone, occurring above the R_1a marine horizon Loc. 080. To the south east the sandstone unit in the H Zone is exposed at three localities near Sharpcliffe Loc. 086, Loc. 087 and Loc. 089 near to the north west termination of Ipstones Edge. Below the Edge in Blackhill Wood stream a 63cm thick ankeritic limestone containing N.nuculum is exposed, Loc. 085. On consideration of its distance below the lower sandstone unit of Ipstones Edge this horizon must be the equivalent of the lowest of the three N.nuculum horizons exposed in the Combes Stream bed.

Ipstones Edge Section (SK 01415205)

	m	ft in.
Sandstones and conglomerates of the Ipstones Edge Sandstone occurring at Locs. 086, 087 and 089. Maximum thickness exposed.	12.00	40'0"
Base of sandstone estimated from topography.		
(For details see Fig.2.E.).		
No exposure, probably mudstone seen on strike in Blackhill Wood stream.	174.00	567'0"
Limestone, ankeritic, blue grey, N.nuculum. Loc. 085, E_2c_{2i}.	0.63	2'1"

The H Zone sandstone unit of Ipstones Edge, strikes across the Combes Valley and outcrops on the flanks of Ferny Hill Loc. 088.

The Ferny Hill Section (SK 00424271)

	m	ft in.
Sandstone and grit unit, with infrequent thin siltstones, Loc. 088 (For details of this interval see Fig.2.M.).	11.00 Max. exposed	36'0"
No exposure.	142.00	466'0"
Limestone, ankeritic, blue grey, N.nuculum Loc. 081, E_2c_{2iii}.	0.07	0'3"

The thicknesses recorded in the three sections in the Combes area for the interval between the N.nuculum horizons and the Sandstone unit correspond closely, thus, on the basis of this evidence, and on the palaeontological control in the Combes Brook, both the Ferny Hill Sandstone Loc. 088 and the Ipstones Edge Sandstones Locs. 086, 087 and 089 are correlated with the H Zone sandstones of the Combes Brook section.

The Wiggenstall Stream Succession (SK 09226078)

The presence of the H.subglobosum and Hd.proteum marine horizons provides effective control of the main sandstone exposures in this succession. Drift partially masks the exposures above the Hd.proteum horizon but on the basis of adjacent sections the position of Hmct. prereticulatus can be estimated. The interval between H_2a and H_2c is circa 6m, consisting of low lying marshy ground, and in the absence of any feature which might indicate a sandstone unit in the succession it is probable that argillacious sediment occupies the unexposed intervals. This proposal is supported by the examination of this interval in adjacent sections which display a succession of dark grey to black mudstones.

The Wiggenstall Stream, Section 11T

	ft in.	m
Estimated position of Hmct. prereticulatus horizon.		
No exposure.	2'6"	3.81
Mudstone, blue grey.	3'0"	0.91
No exposure.	3'6"	1.06
Limestone bullions, blue grey, ankeritic, Hd.proteum. Loc. 120, H_2a.	2'0"	0.61
No exposure.	4'6"	1.37
Mudstone, blue grey, silty.	4'0"	1.22
No exposure.	21'0"	6.40
Mudstone, dark grey with jarosite, coaly streaks in lower 1ft.	3'0"	0.91
Mudstone, blue grey, silty.	1'0"	0.31
Sandstone, fine grained, load cast base.	0'1"	0.025
Mudstone, blue grey, silty.	0'9"	0.23
Sandstone, fine grained, light grey load cast base.	0'11"	0.28
Mudstone, blue grey, silty.	2'0"	0.61
Siltstone with coarser sandy laminae.	0'5"	0.13
Sandstone, fine grained.	0'1"	0.025
Silty mudstone, with layers of fine sandstone.	0'6"	0.15
Sandstone, grey, fine grained.	0'5"	0.13
Mudstone, blue grey, silty.	0'1½"	0.04
Sandstone, fine grained, grey.	0'5"	0.13
Mudstone, blue grey, silty.	3'0"	0.91
No exposure.	2'0"	0.61

	ft in.	m
Mudstone, blue grey, silty.	8'0"	2.44
Mudstone, dark grey with jarosite, Lamellibranchs cf. Posidonia sp.	5'0"	1.52
Mudstone, blue grey, silty.	3'4"	1.01
Sandstone/Mudstone alternations, Loc. 121 (Details in Fig.2.F.)	13'0"	3.96
Mudstone, blue grey, silty.	7'0"	2.13
Sandstone, greenish grey, fine grained, plant and lamellibranch fragments.	0'1"	0.025
No exposure.	11'0"	3.35
Limestone bullions grey, ankeritic, brecciated, H.subglobosum. Loc. 122, H_1a_{iii}.	1'0"	0.31
No exposure.	8'0"	2.44
Mudstone, blue grey.	5'0"	1.52
No exposure.	3'0"	0.91
Limestone bullion, grey ankeritic, ? in situ. H.subglobosum. Loc. 122a, H_1a_{ii}.	1'0"	0.31
Partial exposure of mudstone.	13'0"	3.96
Mudstone, dark grey, shaley.	6'0"	1.83
Mudstone, dark grey, shaley. H.subglobosum. Loc. 123, H_1a_i.	0'6"	0.15
Mudstone, dark grey, shaley.	6'6"	1.97
Fault.		
No exposure.	121'0"	36.88
Mudstone, blue grey, silty.	9'0"	2.74
Sandstone, fine grained, quartzitic.	0'1"	0.025
Mudstone.	1'9"	0.52
Sandstone fine grained, quartzitic, bioturbated lower bedding plane.	0'1½"	0.04

	ft in.	m
Silty mudstone with thin sandstone laminae.	6'0"	1.83
Bentonite, yellow, soft.	0'0½"	0.01
Mudstone, blue grey, silty.	7'0"	2.13
No exposure.	6'0"	1.83
Sandstone, fine grained, sideritic cement, base ripple marked.	0'10"	0.01
Mudstone, grey, silty.	0'3"	0.07
Sandstone, fine grained, grey, base bioturbated.	0'3½"	0.09
Mudstone, silty.	0'9"	0.23
Sandstone fine grained, base bioturbated.	0'3"	0.07
Mudstone, blue grey, silty, with rare fine sandstone streaks.	12'0"	3.66
Cherts. E.rostratum. Loc. 124, E_2b_3.	2'0"	0.61
Mudstone, blue grey, silty.	10'0"	3.05
Limestone bullion horizon, ankeritic, C.holmesi. Loc. 125, E_2b_2.	0'5" Max.	0.12
Mudstone, blue grey, silty.	12'0"	3.66
Limestone bullion horizon, blue grey calcitic, small goniatites. Ceratoikiscum sp., Loc. 126,	0'5½" Max.	0.14
Silty mudstone, ankeritic lens 7'0" above base with P.corrugata.	31'0"	9.45
Limestone, ankeritic, (Stannery Limestone), on bedding plane 2" from top abundant P.corrugata. Loc. 127.	1'2"	0.35
Mudstone, partially exposed.	23'0"	7.01
Limestone bullion horizon, Ct.nitidus. Loc. 128, E_2b_2.	0'8" Max.	0.20
Mudstone, partly exposed with Ct.edalense at base.	21'0"	6.40

Wiggenstall Stream tributary, Section 11TA

	ft in.	m
Mudstone, dark grey, shaley, H.subglobosum. Loc. 123, H_1a_i.	0'6"	0.15
Mudstone, dark grey, shaley.	1'6"	0.45
Mudstone, grey.	6'6"	1.97
No exposure.	5'6"	1.67
Fault.		
Silty mudstone.	10'0"	3.05
Ankerite, decomposed, lenticular (? E_2c_{2iii}).	0'6" Max.	0.15
Silty mudstone.	10'0"	3.05
Siderite band.	0'1"	0.025
Mudstone, blue grey, silty.	8'6"	2.59
Ankerite, decomposed, soft, black P.corrugata (? E_2c_{2ii}).	0'2"	0.05
Mudstone, blue grey, silty.	14'0"	4.27
Ankerite, decomposed, soft black P.corrugata and fragments of a smooth shelled goniatite (? E_2c_{2i}).	0'4½"	3.05
Mudstone, silty.	10'0"	3.05
Mudstone, dark grey silty calcareous ? Lingula sp.	0'4"	0.10
Silty mudstone blue grey.	74'0"	22.56
Sandstone, fine grained,buff.	0'2"	0.05
Silty mudstone.	0'7"	0.17
Sandstone, fine grained, buff.	0'9½"	0.24
Mudstone, silty.	0'3½"	0.09
Sandstone, fine grained, buff.	0'4½"	0.11
Mudstone, silty.	2'0"	0.61
Sandstone, fine grained, buff.	0'1½"	0.04
Silty mudstone.	12'0"	3.66

	ft in.	m
Silty mudstone with siltstone streaks.	1'7"	0.48
Sandstone, fine grained, quartzitic.	0'3"	0.07
Sandstone, fine grained, quartzitic, coated with siderite.	0'3"	0.07
Silty mudstone.	5'0"	1.52
No exposure.	16'0"	4.88
Silty mudstone.	9'0"	2.74
No exposure.	3'0"	0.91
Silty mudstone.	7'0"	2.13
Mudstone, poorly exposed, containing three Bentonites.	3'0"	0.91
Cherts. E.rostratum. Loc. 129, E_2b_3.	2'0"	0.61
No exposure.		

The Blake Brook Succession (SK 06206119)

This succession is well exposed in the bed of the stream, the stratigraphic position of the main sandstone unit at Loc. 142 being well defined by the presence of H.subglobosum at its base, and Hd.proteum above its upper limit. Only one H.subglobosum horizon Loc. 142 is exposed occurring 3.5m below a distinctive green coloured sandstone. A similar sandstone occurs 3.5m above the highest H_1a marine horizon in the Wiggenstall succession and on this basis it is proposed to equate the H.subglobosum horizon in the Blake with the H_1a_{iii} horizon in the Wiggenstall stream.

The H_1b marine horizons are not present in the succession and it is believed that conditions conducive to their formation did not occur possibly due to a rapid and continuous supply of detrital material into the area during the H_1a_{iii} - H_2a interval.

The Blake Brook, Section 5T

	ft in.	m
Mudstone, black, shaley, Hmct. prereticulatus. Loc. 140, H_2c.	1'6"	0.45
Limestone, bullions, ankeritic.	1'0" Max.	0.31
Partially exposed, black shaley mudstone.	19'0"	5.79
Limestone bullions, ankeritic, blue grey, Hd.proteum. Loc. 141, H_2a.	1'0" Max.	0.31
Mudstone, black shaley, Dunbarella sp., Posidoniella sp.	5'0"	1.52
Mudstone, grey, silty. (gradational to above).	2'6"	0.75
Sandstone/silty mudstone succession Loc. 142 (for details see Fig.II.A.).	105'0"	32.00
No exposure (concrete of Bridge) probably mainly sandstone.	50'0"	15.24
Sandstone, as Loc. 142.	3'9"	1.14
No exposure.	19'0"	5.79
Sandstone, fine grained, blue grey.	0'6"	0.15
No exposure.	3'9"	1.14
Sandstone, medium grained, dark green.	2'0"	0.60
No exposure.	11'6"	3.50
Limestone bullions, ankeritic, septarium, H.subglobosum. Loc. 143, H_1a_{iii}.	1'0" Max.	0.31
Mudstone, blue grey, silty.	16'3"	5.03
No exposure.	10'2"	3.10
Mudstone, blue grey, silty.	1'6"	0.45
No exposure.	2'6"	0.75
Mudstone, blue grey shale.	1'6"	0.45
No exposure.	102'0"	31.09

	ft in.	m
Thin sandstones, fine grained, grey, alternating with thin grey silty mudstone Loc. 144. (details in Fig.2.G.).	10'0"	3.05
No exposure.	5'0"	1.52
Mudstone, blue grey.	1'0"	0.31
Blue grey silty, sandstone, with plant fragments.	0'0½"	0.01
Mudstone, blue grey.	3'4"	1.00
Sandstone, fine grained grey.	0'3"	0.08
Shale.	0'1½"	0.04
Fine grained sandstone with shale partings.	0'2"	0.05
Poorly exposed, probably all silty mudstone with thin fine grained sandstone streaks.	5'0"	1.52
No exposure.	62'0"	19.00
Mudstone, blue grey, siderite nodules at base max. 2".	0'5"	0.12
Mudstone, blue grey, siderite nodules at base max. 2".	1'8"	0.50
Mudstone, blue grey.	1'0"	0.30
Limestone, grey, ankeritic.	0'2"	0.05
Mudstone, blue grey.	0'2"	0.05
Limestone, blue grey, ankeritic, N.stellarum. Loc. 145, E_2c_1.	0'2½"	0.06
Mudstone blue grey, siderite nodules max. 2" at 2'0" from top.	8'2"	2.50
No exposure.	5'3"	1.60
Cherts. E.rostratum. Loc. 146, E_2b_3.	3'4"	1.00
No exposure, probably mudstone.	32'0"	10.00
Limestone bullion horizon, blue grey, ankeritic.	0'5" Max.	0.13

	ft in.	m
Mudstone partly exposed.	28'6"	9.00
Blue grey ankeritic limestone (Stannery Limestone) on bedding plane 2½" from top abundant P.corrugata, also rare immature, globose goniatites. Loc. 147.	0'7"	0.18
Mudstone, blue grey.	0'10"	0.25
Blue grey, ankeritic limestone.	0'4½"	0.11
Mudstone, blue grey.	4'7"	1.40
No exposure.		

The Oakenclough Stream Succession (SK 05246360)

Palaeontological control is poor in the upper part of this succession, a decomposing bullion horizon containing H.subglobosum, Loc. 161, is the only marine horizon present in the H_1a - H_2c interval. The interval between this horizon and E_2c_{2iii} is 15.85m, and using adjacent sections as a basis for comparison, it is most likely that the H_1a horizon present in the Oakenclough Stream is the highest H.subglobosum horizon in the succession. Sandstones are present in the succession immediately above the level of H_1a_{iii} and thus the succession corresponds closely with the observed sections in the Blake and Wiggenstall Streams.

The Oakenclough Stream, Section 15T

	ft in.	m
Shales blue grey, containing an R_1a fauna C. Ashton 1974 no location number given.		
No exposure.	67'0"	20.42
Sandstone, grey coarse grained.	5'0"	1.52
No exposure.	46'0"	14.02

	ft in.	m
Sandstone/Mudstone unit. Loc. 160. (See Fig.2.F.b. for details).	13'0"	3.96
Mudstone, blue grey, shaley.	8'0"	2.44
Limestone bullions, partly decomposed, ankeritic, brecciated, H.subglobosum. Loc. 161, H_1a_{iii}.	0'7" Max.	0.18
No exposure.	30'0"	9.14
Mudstone, blue grey.	22'0"	6.71
Limestone, ankeritic, well jointed, N.nuculum, E.bisulcatum. Loc. 162, E_2c_{2iii}.	0'9"	0.23
Mudstone, blue grey.	1'8"	0.50
No exposure, ? fault.	5'0"	1.52
Mudstone, blue grey.	8'0"	2.44
Partially exposed blue grey mudstone.	54'0"	16.46
Mudstone, black, N.nuculum.	0'6"	0.15
Blue grey ankeritic, decomposed limestone, iron stained, N.nuculum. Loc. 163, E_2c_{2i}.	0'8"	0.20
Mudstone, blue grey, with ½" streak of fine grained quartzitic sandstone 9" from top.	7'0"	2.13
No exposure.	50'0"	15.24
Sandstone, fine-medium grained, quartzitic, burrows on sole. Loc. 164.	0'0½"	0.01
Silty mudstone.	0'7"	0.18
Sandstone, fine-medium grained, quartzitic.	0'0¼"	0.01
Silty mudstone.	0'5"	0.13
Sandstone, fine-medium grained, quartzitic.	0'1½"	0.04
Silty mudstone.	0'7"	0.18
Sandstone, fine-medium grained, quartzitic.	0'0½"	0.01

	ft in.	m
Silty mudstone.	0'4"	0.10
Sandstone, fine-medium grained, quartzitic.	0'2"	0.05
No exposure.	5'0"	1.52
Sandstone, fine-medium grained, quartzitic.	0'3"	0.08
Silty mudstone.	0'11"	0.28
Sandstone, fine-medium grained, quartzitic.	0'4"	0.10
Silty mudstone.	1'0"	0.31
Sandstone, fine-medium grained, quartzitic.	0'1½"	0.04
Silty mudstone.	0'2"	0.05
Sandstone fine to medium grained, quartzitic.	0'1"	0.02
Silty mudstone.	0'10"	0.25
Sandstone, fine-medium grained, quartzitic.	0'3½"	0.09
No exposure.	50'0"	15.24
Sandstone, blue grey, micaceous, plant fragments.	0'10"	0.25
No exposure.	10'0"	3.05
Sandstone, blue grey.	0'3½"	0.09
Mudstone, blue grey, silty.	5'0"	1.52
No exposure.	15'0"	4.57
Mudstone, blue grey, silty.	2'3"	0.68
Sideritic nodules, with poorly preserved lamellibranchs.	0'3" Max.	0.08
Mudstone, blue grey, silty.	0'8"	0.20
Limestone, muddy, ankeritic, grey, N.stellarum. Loc. 165, E_2c_1.	0'3"	0.08
Mudstone, blue grey, silty.	1'5"	0.425

	ft in.	m
Sideritic nodules, with poorly preserved lamellibranchs.	0'4" Max.	0.10
Shaley mudstone passing into shale.	8'0"	2.44
Siderite band.	0'1½"	0.04
Shale.	4'0"	1.22
Cherts. E.rostratum. Loc. 166, E_2b_3.	3'10"	1.16
Mudstone, blue grey, silty.	0'8"	0.20
Siderite.	0'03"	0.02
Mudstone, blue grey, shaley.	8'1"	2.46
Ankeritic limestone bullion E_2b_2, Loc. 167.	0'6" Max.	0.15

Cravenoceras sp. and an orthocone nautiloid.

At this location Holdsworth (1963) collected C.holmesi (specimen 206b).

No exposure.

Upper Dove, Fairthorn Farm Succession

The succession at this locality is close to the limestone massif of the Southern Pennines, and the pelitic nature of the sediments is thought to indicate a land remote environment of deposition. At Loc. 250 of B. K. Holdsworth (1963) on the Upper Dove, a thin sandstone occurring below the Hd.proteum horizon is interpreted as being the equivalent of the sandstone units occurring below this horizon in the Wiggenstall, Blake and Oakenclough sections.

Fairthorn Farm Succession, Section 3T

	ft in.	m
Mudstone, black shaley, R.paucicrenulatum.	2'6"	0.75
Mudstone, black shaley, Reticuloceras sp.	1'0"	0.31
Limestone bullion, ankeritic.	1'0" Max.	0.31
Limestone, ankeritic.	0'6"	0.15
Mudstone, black, shaley.	2'6"	0.75
Bentonite.	0'0¼"	0.01
Mudstone, black, shaley.	3'6"	1.06
Fault.		
Mudstone, black, shaley.	4'6"	1.37
Mudstone, black, shaley, jarosite. H.smithi.	1'0"	0.31
Mudstone, black, shaley, jarosite, abundant H.smithi. Loc. 180.	0'6"	0.15
Mudstone, black, shaley, jarosite. H.smithi.	2'6"	0.75
Limestone bullion, ankeritic, Hd.proteum. Loc. 181, H_2a.	2'0" Max.	0.61
Mudstone, black, shaley, Dunbarella sp.	2'0"	0.61
Mudstone, black, shaley.	10'0"	3.05
Limestone, ankeritic.	0'6"	0.15
Mudstone, black, shaley.	1'0"	0.31
No exposure.		

The Gawsworth Common Succession, Section 18T (SJ 92306830)

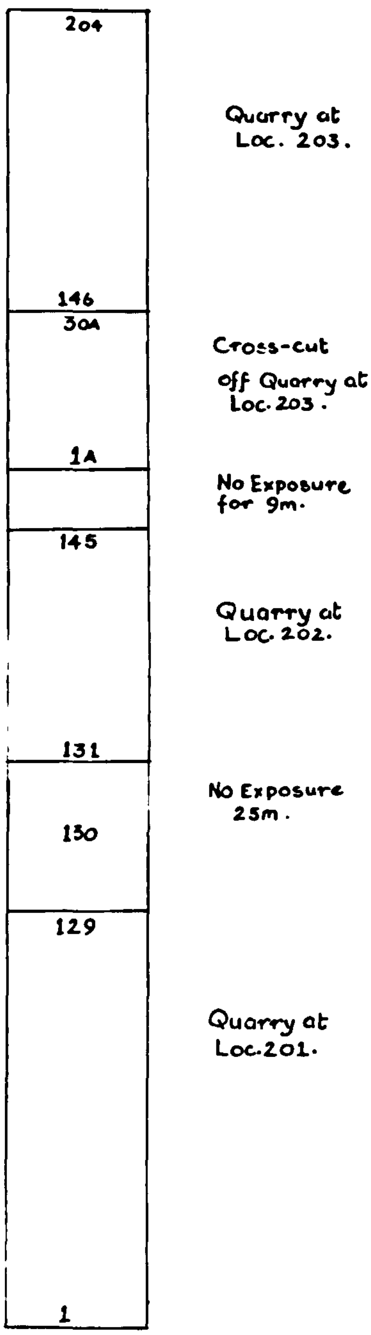
The succession in this area is represented by a sandstone mudstone sequence (Fig.I.A.), and is almost continuously exposed in a series of stone quarries on Gawsworth Common. Palaeontological control in this area is very poor and is limited to isolated exposures which give a very loose stratigraphical control. Evans et al. (1968) place the Gawsworth succession in the Lower and Middle Churnet Shales and suggest a total thickness of more than 600 ft for this interval of which some 450 ft they assign to the Middle Churnet Shales.

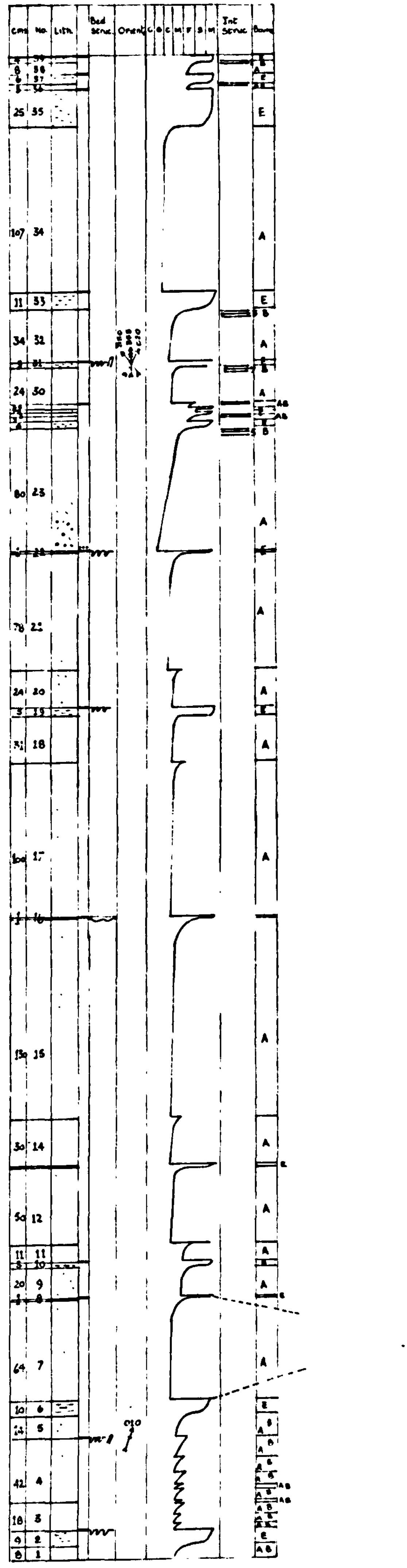
The top of the succession is delineated by dark mudstones of a basinal character carrying fauna of R_1 age, Loc. 114 of Evans et al. (1968). Within the sandstone mudstone sequence at Gawsworth the only palaeontological horizon present occurs on the north side of the hill at Stoneyfold where H. beyrichianum was recorded at Loc. 81 (Evans et al. 1968) in weathered material. The base of the Gawsworth succession is marked by low ground to the north around Rough Hay (SJ 92106900) and Ratcliff Wood (SJ 92206930) in which isolated outcrops of mudstone occur. To the north of Oakgrove, a small stream section exposes a shale mudstone sequence with isolated ankerite horizons which at Loc. 34 (Evans et al. 1968) yielded Ct. edalensis.

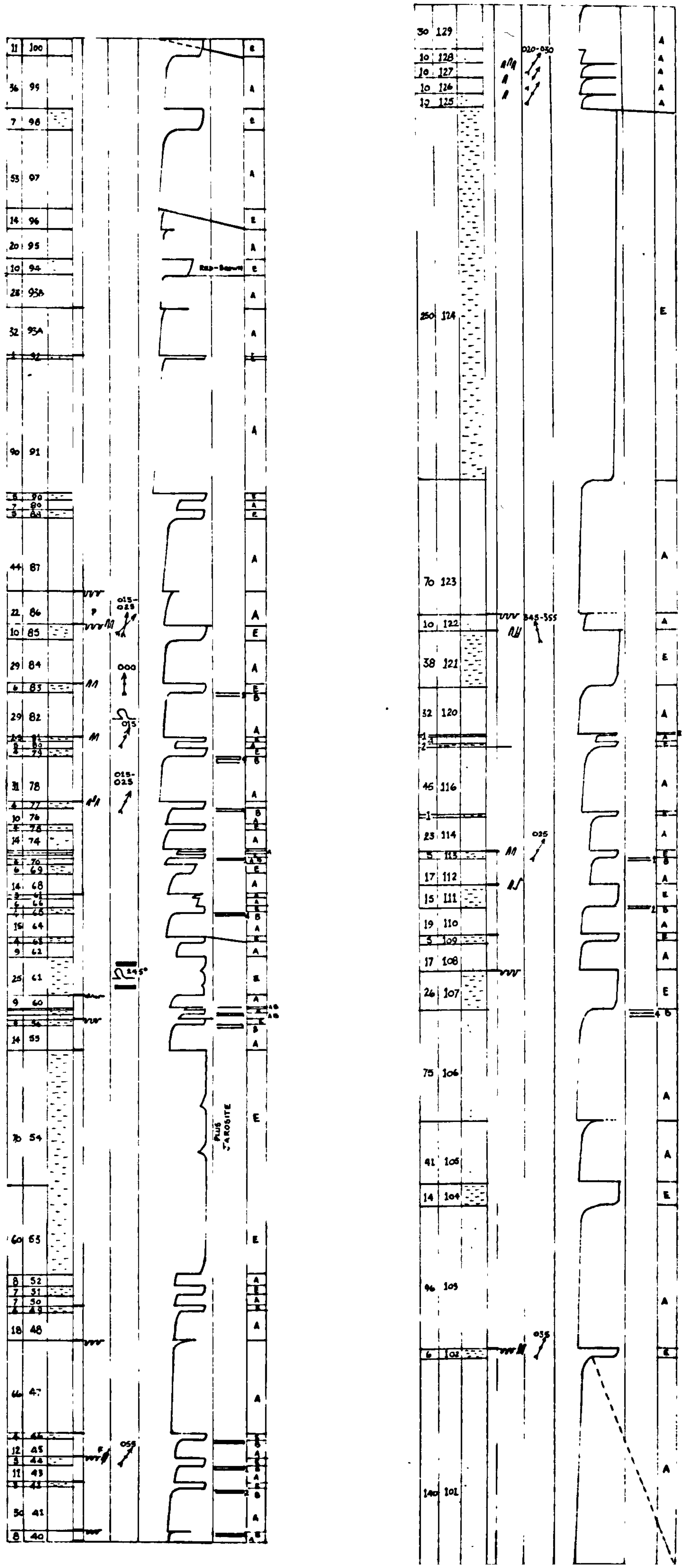
FIG. IA.

Lithofacies 6a sediments present in the Gowsworth Area, section 18T.

Key to the succession

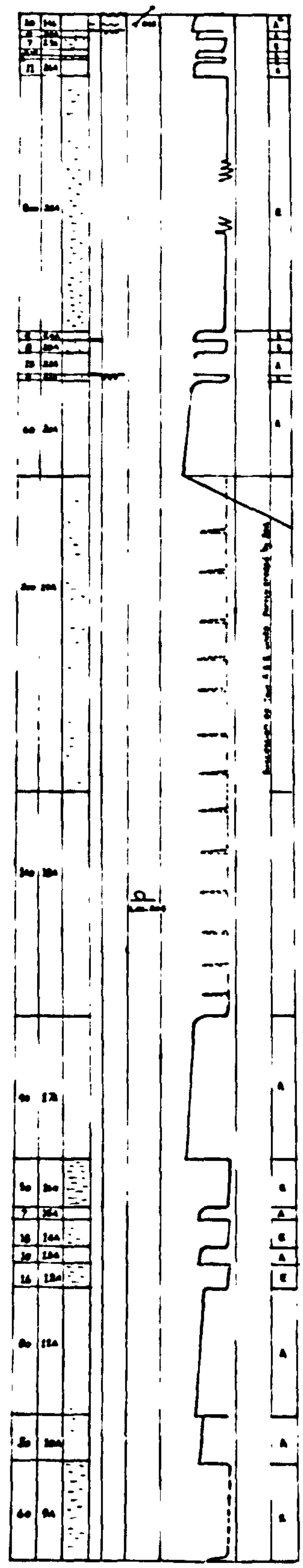


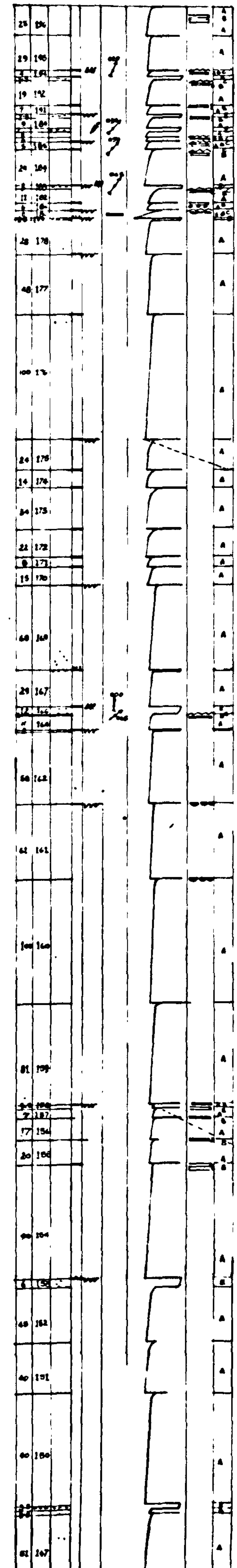


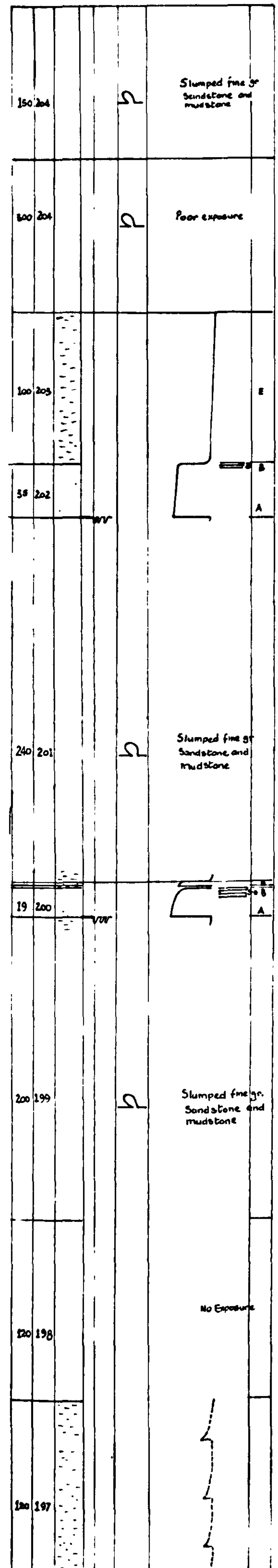


RED-BROWN
PLUS JAROSITE

17 145 A
No Exp.
120 144 E
30 143 A
30 142 A
21 142A A
48 140 A
24 139 A
124 137 A
8 136 A
25 135 A
60 134
127 132 A
158 131 A
200 8A
250 7A A
30 6A E
200 5A A
40 4A E
60 3A A
40 2A E
118 1A A
9m no Exposure to No.14-5






150 204
Slumped fine gr Sandstone and mudstone
300 204
Poor exposure
100 203
E
B
35 202
A
240 201
Slumped fine gr Sandstone and mudstone
19 200
B
A
200 199
Slumped fine gr. Sandstone and mudstone
120 198
No Exposure
120 197

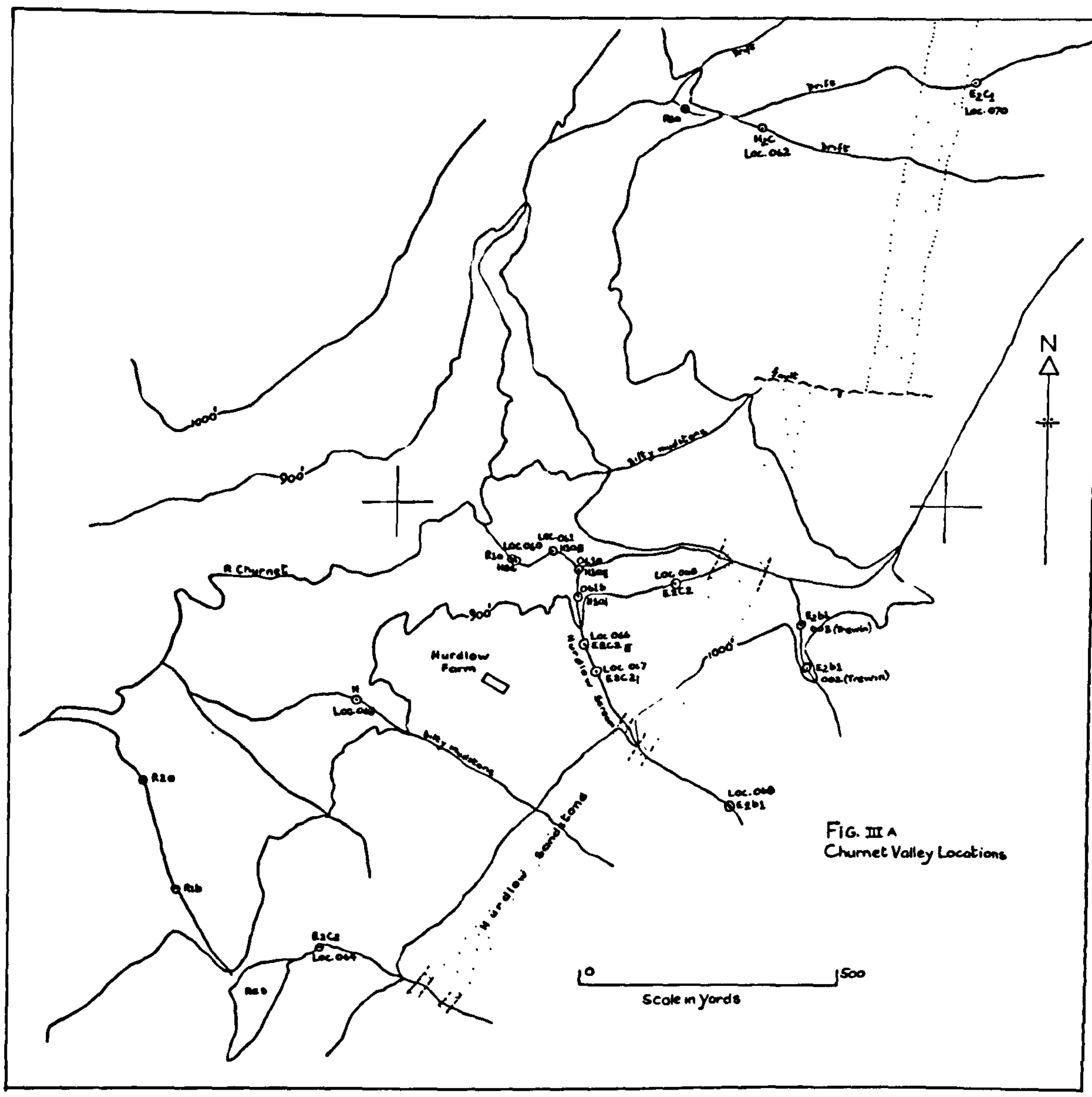


FIG. III A
Churnet Valley Locations

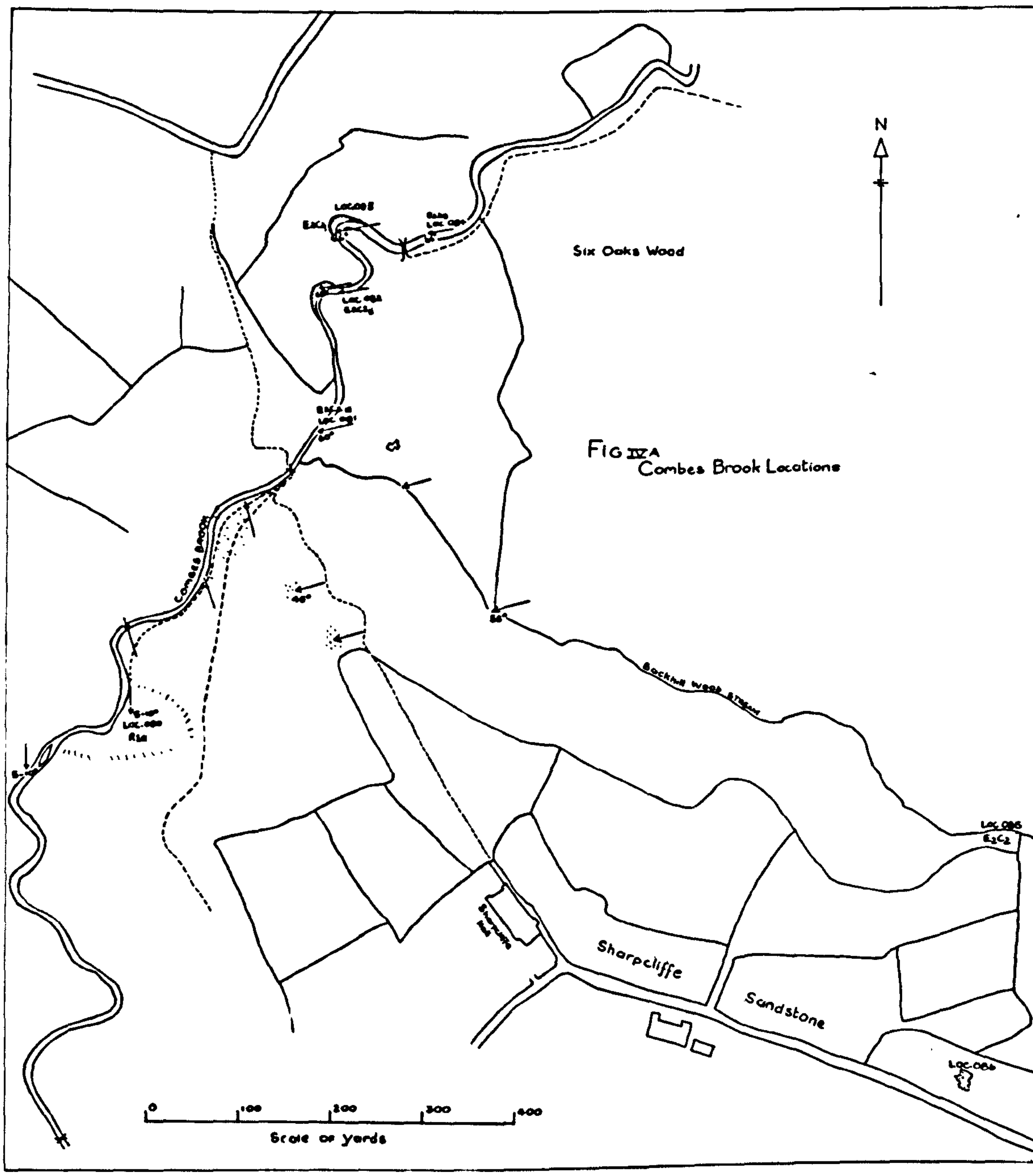


FIG IVA
Combes Brook Locations

APPENDIX II

LIST OF LOCALITIES

001 Shale, dark grey, ½" thick, H.beyrichianum, Limekiln Stream, Geological Survey Loc. 108a. (Evans et al.,1968) (SJ 86405855)

010 Calcareous mudstone, Hd.proteum and H.smithi, Pot Bank Quarry. (SJ 86935929)

010a Mudstone containing H.smithi, Pot Bank Quarry. (SJ 86935929)

011 Gannister, with rootlets. Southern end of Pot Bank Quarry. (SJ 86875918)

020 Calcareous mudstone, 5" thick, H.subglobosum (H_1a_{iii}), Heath Hay Stream. (SJ 90935932)

020a Limestone, silty, ankeritic, 3" thick H.subglobosum (H_1a_{ii}), Heath Hay Stream. (SJ 90935932)

022 Sandstone unit of Endon Edge Quarry. (SJ 91935288)

023 Limestone, ankeritic, decomposed, N.nuculum, E.bisulcatum, Roughwood End, Old Quarry. (SJ 92105145)

024 Burrowed Sandstone unit, Roughwood End Old Quarry. (SJ 92105145)

025 Sandstone unit (Stanley Grit) of Roughwood, Endon. (SJ 92005139)

026 Sandstone unit of Morris House Quarry, Brown Edge. (SJ 91455425)

027 Limestone, ankeritic, blue grey, H.subglobosum, in ditch at Crowborough crossroads. (SJ 90685693)

028 Sandstone, fine grained, grey, 4'6" thick, burrowed, Heath Hay Stream. (SJ 90925932)

029 Limestone, ankeritic, grey, 6" thick, Hmct.prereticulatus, Heath Hay Stream. (SJ 90905931)

030 Limestone bullion bed, H.subglobosum (H_1a_{iii}), exposed in the bed of the Dingle Brook. (SJ 92076175)

030a Limestone bullion bed, H.subglobosum (H_1a_{ii}), exposed in the bed of the Dingle Brook. (SJ 92076175)

030b Limestone bullion bed, H.subglobosum (H_1a_i), exposed in the bed of the Dingle Brook. (SJ 92076175)

038 Sandstone unit of Dingle Brook in the interval late E_2b_1 - E_2b_2 (inclusive). (SJ 91936173)

039 Limestone bullion bed, Hmct. prereticulatus, exposed in the bed of the Dingle Brook. (SJ 91726128)

040 Mudstone, black, H.smithi, exposed on the north bank of the Gun End stream. (SJ 96316340)

041 Limestone bullion bed, ankeritic, Hd.proteum, exposed on the north bank of the Gun End stream. (SJ 96316340)

042 Limestone bullion bed, ankeritic, H.beyrichianum, exposed on the north bank of the Gun End stream. (SJ 96366335)

043 Limestone bullion bed, abundant H.subglobosum (H_1a_i), exposed in the bed of the Gun End stream. (SJ 96396333)

044 Limestone, grey, ankeritic, N.nuculum (E_2c_{2iii}), exposed on the north bank of the Gun End stream. (SJ 96406331)

045 Mudstone, grey, calcareous, Hmct.prereticulatus, exposed in stream north of Bend End farmhouse. (SJ 96606388)

046 Limestone, grey, ankeritic, N.nuculum (E_2c_{2i}), exposed on the north east bank of the Gun End stream. (SJ 96466320)

050 Limestone, grey, ankeritic, N. nuculum, exposed in the stream bed in Fairborough Wood. (SJ 96176112)

051 Limestone bullion bed veined by calcite with H. subglobosum, in the shale above a small stream on the eastern margin of Fairborough Wood. (SJ 96106099)

052 Limestone bullion, veined by calcite, Homoceras sp., Loc. 91 of Evans et al. (1968), Fairborough Wood. (SJ 96076100)

053 Limestone bullion veined by calcite, Homoceras sp. (H_1), Loc. 90 of Evans et al. (1968), Fairborough Wood. (SJ 96146109)

060 Shale, 8 feet below R_1a bullion bed, Hmct. prereticulatus, exposed on the south bank of the River Churnet. (SK 02206092)

061 Limestone bullion bed, decomposed, ankeritic, brecciated, H. subglobosum (H_1a_{iii}), exposed at a sharp bend on the north bank of the River Churnet. (SK 02266094)

061a Limestone bullion bed, ankeritic, H. subglobosum (H_1a_{ii}), exposed in a small waterfall at the confluence of the Hurdlow and Churnet streams. (SK 02316090)

061b Limestone bullion, H. subglobosum (H_1a_i), exposed on the east bank of the Hurdlow Farm stream. (SK 02326084)

062 Limestone bullion, ankeritic, Hmct. prereticulatus, exposed in the stream bed to the north of Swainsmoor. (SK 02656171)

063 Limestone bullion, ankeritic, Homoceras sp., exposed in the stream to the south of Hurdlow Farm. (SK 01916065)

064 Limestone, grey, ankeritic, N. nuculum, exposed on the north bank of the stream which enters Blackshaw Moor Reservoir. (SK 01856020)

065 Decomposed ankeritic, N.nuculum, exposed in Big Wood on the south side of the Churnet Valley. (SK 02456090)

066 Limestone, grey, ankeritic, N.nuculum (E_2c_{2iii}), exposed on the east bank of the Hurdlow stream. (SK 02316084)

067 Limestone, grey, ankeritic, N.nuculum (E_2c_{2i}) exposed on the east bank of the Hurdlow stream. (SK 02356072)

068 Exposure at Location of N. Aitkinhead (1974), right bank of Hurdlow stream . Cravenoceratoides sp. (E_2b_1). (SK 02596046)

069 Sandstone unit of Hurdlow stream, above Loc. 068. (SK 02446056)

070 Location of N. Aitkinhead (1974) N.stellarum, 46 cm below Hurdlow Sandstone north west of Strines. (SK 03036170)

080 Mudstone with loose bullions, below landslip on south side of Combes Valley (Loc. 9 of Morris, 1967) Reticuloceras sp. (R_1a). (SK 00425239)

081 Limestone, grey, ankeritic, N.nuculum (E_2c_{iii}) exposed in the bed of the Combes Brook. (SK 00635269)

082 Limestone, grey, ankeritic, N.nuculum (E_2c_{2ii}), exposed in the bed of the Combes Brook. (SK 00665285)

084 The Cherts, E.rostratum (E_2b_3) exposed in the bed of the Combes Brook. (SK 00765292)

085 Limestone, ankeritic (0.63m), N.nuculum, exposed in a mudstone sequence below a culvert in Backhill Wood stream. (SK 01385228)

086 Cross-bedded sandstone and conglomerate unit exposed near Sharpcliffe on Ipstones Edge. (SK 01415204)

087 Cross-bedded sandstone and conglomerate unit exposed near Sharpcliffe on Ipstones Edge. (SK 01555204)

088 Sandstone unit of Ferny Hill, north west side of Combes Valley. (SK 00425271)

089 Cross-bedded sandstone and conglomerate unit exposed near Sharpcliffe on Ipstones Edge. (SK 01635193)

100 Mudstone cliff, 20 feet above Thorncliffe Stream on the south bank, Hmct. prereticulatus. (SK 01235845)

101 Calcareous mudstone in the cliff on the south bank of the Thorncliffe Stream, passing laterally into ankeritic bullions exposed in the stream bed, H.subglobosum. (SK 01315848)

101a Shale, dark grey, calcareous, overlying Loc. 101, Thorncliffe Stream, south bank, H.subglobosum (H_1a_{iii}) (SK 01315848)

102 Limestone bullion bed, ankeritic, H.subglobosum (H_1a_{ii}), exposed in a cliff on the north side of the Thorncliffe Stream, adjacent to a sharp bend in the stream. (SK 01345848)

103 Limestone blue grey ankeritic, H.subglobosum (H_1a_i), exposed on the south bank of the Thorncliffe Stream. (SK 01355848)

104 Sandstone unit of Thorncliffe Stream (in the interval H_1a - H_1b inclusive) exposed in the stream bed. (SK 01265848)

105 Limestone, blue grey, ankeritic, N.nuculum (E_2c_1), exposed on the south bank of the Thorncliffe Stream at its confluence with a small tributary flowing from the vicinity of the Methodist Church. (SK 01445849)

106a Black mudstone, H.smithi, exposed in a cliff on the south bank of a stream located south of Thorncliffe. (SK 01195812)

106b As above, occurring 5 feet below Loc. 106a. (SK 01195812)

107 Mudstone, dark blue, calcareous, H.beyrichianum, occurring 6 feet below Loc. 106b. (SK 01195812)

108 Sandstone unit with abundant plant fragments occurring in the bed of the Thorncliffe Stream 6m below the horizon of Hmct.prereticulatus. (? in situ) (SK 01285858)

109 Sandstone unit of Thorncliffe Stream (E_2b_1 - E_2c_2), exposed at the Waterfall. This unit is termed the Hurdlow Sandstone by Aitkinhead (1974), and is present above the conjectured horizon of Ct.edalensis at Loc. 110. (SK 01605855)

110 Inferred horizon of Ct.edalensis Loc. (SK 01755860) of Aitkinhead (1974). (SK 01755860)

120 Limestone bullion bed, grey, ankeritic, Hd.proteum, exposed in the bed of the Wiggenstall Stream. (SK 09356081)

121 Sandstone unit of Wiggenstall Stream (within the interval H_1a - H_1b inclusive), exposed in a cliff on the south bank of the stream. (SK 09286081)

122 Limestone bullion bed, ankeritic, brecciated, H.subglobosum (H_1a_{iii}), exposed in the bed of the Wiggenstall Stream. (SK 09226078)

122a Limestone bullion bed, H.subglobosum (H_1a_{ii}), exposed in the bed of the Wiggenstall Stream. (SK 09206080)

123 Mudstone, dark grey, H.subglobosum (H_1a_i) bank on south side of Wiggenstall Stream. (SK 09156076)

124 The Cherts, <u>E.rostratum</u> (E_2b_3), exposed in the bed and on the south bank of the Wiggenstall Stream. (SK 09036078)

124a The Cherts, exposed below the road bridge crossing the Wiggenstall Stream. (SK 08936088)

125 Limestone bullion bed, <u>C.holmesi</u>, exposed in the bed of the Wiggenstall Stream. (SK 09016079)

126 Limestone bullion bed containing <u>Ceratoikiscum sp.</u>, exposed in the bed of the Wiggenstall Stream. (SK 09016079)

127 Stannery Limestone, exposed in the bed of the Wiggenstall Stream. (SK 09006080)

128 Limestone bullion bed, <u>Ct. nitidus</u>,exposed in the bed of the Wiggenstall Stream. (SK 09026078)

129 The Cherts, exposed on the south bank of the southern tributary of the Wiggenstall Stream. (SK 09106064)

130 Limestone bullion bed, <u>Ct.edalensis</u>, <u>Ceratoikiscum sp.</u>, exposed in the bed of the Wiggenstall Stream. (SK 08886083)

140 Mudstone, black, <u>Hmct.prereticulatus</u>, exposed on the north bank of the Blake Brook. (SK 06256119)

141 Limestone bullion bed, ankeritic, <u>Hd.proteum</u>, exposed in the bed of the Blake Brook. (SK 06246119)

142 Sandstone unit of Blake Brook, in the interval H_1a - H_1b, exposed downstream from the road bridge. (SK 06206119)

143 Limestone bullion, ankeritic, septarium, <u>H.subglobosum</u>, exposed in the bed of the Blake Brook, upstream from the road bridge. (SK 06096114)

144 Sandstone unit of Blake Brook present in the interval E_2b_3 - E_2c_1 (inclusive) exposed on the north bank upstream from the road bridge. (SK 06016111)

145 Thin ankeritic limestone, N. stellarum, exposed on the south bank of the Blake Brook. (SK 05956106)

146 The Cherts, E. rostratum, exposed on the south bank of the Blake Brook and in the stream bed. (SK 05936103)

147 The Stannery Limestone, exposed on the north bank of the Blake Brook. (SK 05906102)

160 Sandstone unit of the Oakenclough Stream, in the interval H_1a - H_1b (inclusive). (SK 05286361)

161 Limestone bullion bed, partially decomposed, septarium, H. subglobosum, present in bed of the Oakenclough Stream. (SK 05286361)

162 (Loc. 127 of Holdsworth, 1963) Well jointed ankeritic limestone, present in the south bank of the Oakenclough Stream N. nuculum. (SK 05196358)

163 (Loc. 284b of Holdsworth, 1963) Rotten limestone (decalcified), present in the south bank of the Oakenclough Stream N. nuculum. (SK 05606357)

164 Sandstone unit of the Oakenclough Stream in the interval E_2b_3 - E_2c_1 (inclusive) exposed on a cliff on the south bank of the stream. (SK 05136361)

165 (Loc. 206c of Holdsworth, 1963) Decalcified rotten siltstone with N. stellarum. (SK 05046368)

170 H. beyrichianum exposed in a mudstone succession on the south bank of the Wiggenstall Stream upstream from the road bridge. (SK 08776098)

170a	H.beyrichianum exposed in a mudstone succession on the south bank of the Wiggenstall Stream.	(SK 08716099)
170b	H.beyrichianum exposed in a mudstone succession on the south bank of the Wiggenstall Stream.	(SK 08686099)
180	Mudstone, black, H.smithi, exposed on cliff above the Fairthorn Farm Stream.	(SK 69160430)
181	Limestone bullion bed, blue grey ankeritic, Hd.proteum, exposed on cliff above the Fairthorn Farm Stream.	(SK 69160430)
190	Thirklow Farm Stream, H.smithi in shale cliff above Loc. 148 of Holdsworth, 1963.	(SK 68560514)
191	Thirklow Farm Stream, H.smithi and H.cf.undulatum present in weathered yellow mudstone in shale cliff above Loc. 148 of Holdsworth, 1963.	(SK 68560514)
192	Thirklow Farm Stream, thin ankeritic limestone in stream bed Hd.proteum, Loc. 148 of Holdsworth, 1963.	(SK 68560514)
201	Gawsworth Common, northern quarry, deformation structures (Category II) present in a mudstone near the base of the quarry face).	(SJ 92406840)
202	Gawsworth Common, central quarry, turbidite succession.	(SJ 68359248)
203	Gawsworth Common, southern quarry, turbidite succession.	(SJ 68209227)
203a	Deformation structures (Category III) present in bed 18T/199 in the southern quarry, Gawsworth Common.	(SJ 68209227)
203b	Deformation structures (Category III) present in bed 18T/199 in the southern quarry, Gawsworth Common.	(SJ 68209227)
203c	Deformation structures (Category III) present in bed 18T/201 in the southern quarry, Gawsworth Common.	(SJ 68209227)

204 Deformation structure (Category IV) present in a cross-cut on the western side of the southern quarry, Gawsworth Common. (SJ 68209224)

210 Limestone bullion bed, N.nuculum, Ceratoikiscum sp., exposed in the bed of the Swallow Brook. (SK 06626743)

211 Limestone bullion bed, H.subglobosum, exposed in the bed of the Swallow Brook. (SK 06686731)

SECTIONS REFERRED TO IN THE TEXT

1T	Limekiln Stream
2Ta) 2Tb)	Pot Bank Quarry
3T	Fairthorn Farm Stream
4T	Thirklow Farm Stream
5T	Blake Brook
6T	Blake Brook
7T	Gun End Stream
8T	Heath Hay Stream
9T	Thorncliffe Stream
9Ta	Stream to the south of Thorncliffe
11T	Wiggenstall Stream
11Ta	Wiggenstall Stream (tributary)
12T	Endon Rough Wood End (marl pit)
14T	Dingle Brook
15T	Oakenclough Stream
16T	Combes Valley
18T	Gawsworth Common.

APPENDIX III

MICROFOSSIL SPECIMEN NUMBERS

Ceratoikiscum aff. bicancellatum A. present in the Wiggenstall Stream, Section 11T, Loc. 126.

Original No.	Catalogue No.	Original No.	Catalogue No.
1a	207	7b	232
1b	208	7c	233
1c	209	7d	234
2a	210	8a	235
2b	211	8b	236
2c	212	8c	237
2d	213	8d	238
2e	214	9a	239
2f	215	9b	240
3a	216	9c	241
3b	217	10a	242
3c	218	10b	243
4a	219	11a	244
4b	220	11b	245
4c	221	11c	246
5a	222	11d	247
5b	223	12a	248
5c	224	12b	249
5d	225	WS1	250
6a	226	WS2	251
6b	227	WS3	252
6c	228	WS4	253
6d	229	WS6	254
6e	230	WS7	255
7a	231		

Ceratoikiscum aff. tricancellatum A. Present in the Wiggenstall Stream, Section 11T, Loc. 130.

Original No.	Catalogue No.	Original No.	Catalogue No.
1	256	10	265
2	257	11	266
3	258	12	267
4	259	13a	268
5	260	13b	269
6	261	14	270
7	262	15	271
8	263	16	272
9	264	17	273

18	274	31	287
19	275	32	288
20	276	33	289
21	277	34	290
22	278	35	291
23	279	36	292
24	280	37	293
25	281	38	294
26	282	39	295
27	283	40	296
28	284	41	297
29	285	42	298
30	286	43	299

Ceratoikiscum aff. bicancellatum B. (unless where stated) Present in the Swallow Brook at Loc. 210.

Original No.	Catalogue No.	
1	300	
2	301	Albaillella aff. pennata
3	302	Albaillella aff. pennata
4	303	Albaillella sp.
5	304	
6	305	Radiolaria Genus B
7	306	Albaillella sp.
8	307	Albaillella sp.
9	308	
10	309	
11	310	
12	311	Radiolaria Genus B
13	312	" "
14	313	" "
16	314	" "
17	315	" "
18	316	Corythoecia Forman sp.
19	317	Corythoecia Forman sp.
20	318	
21	319	Radiolaria Genus B
22	320	
23	321	
24	322	
25	323	
26	234	
27	325	Radiolaria Genus B
28	326	Radiolaria Genus B
29	327	
30	328	
31	329	
32	330	
33	331	

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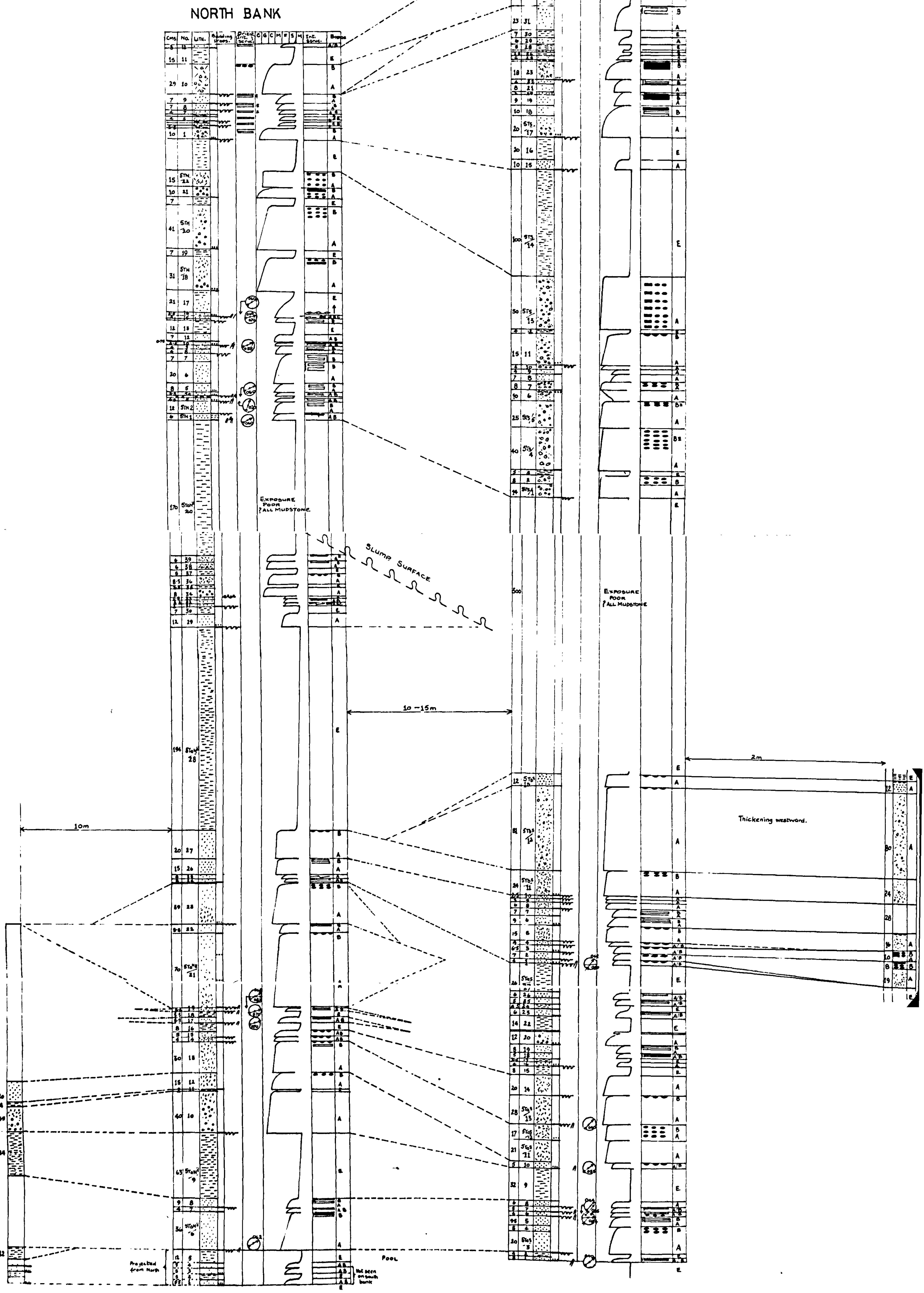
FIG IIA
DETAILS OF THE SUCCESSION AT LOC. 142
IN THE INTERVAL H1A - H1B (INCLUSIVE)



KEY TO SYMBOLS USED IN TEXT DIAGRAMS FIG. VI.A.

LITHOLOGY

- Conglomerate
- Shale
- Conglomerate
- Mudstone (not shaded in Figs. 2.Fa., 2Fb and 2a)
- Grit
- Random mudstone clasts in sandstone
- Sandstone
- Mudstone clasts — on upper bedding plane; internal layer
- Siltstone
- Limestone

EXTERNAL FEATURES

- Armoured base of a bed
- Sharp based bed
- Bioturbated base of a bed
- Sharp base of a graded bed
- Erosive base i.e. channel
- Load cast base
- Lenticular bed
- Irregular base
- Weakly defined bed boundary
- Ripple marked surface
- Fault
- Ripple marked surface
- Impression of Stigmaria on upper bed boundary
- Prod mark cast
- Flute cast
- Abundant prod casts
- Bounce or skip cast
- Groove casts
- Brush cast
- Groove cast
- 020° / ⊙020° Orientation of a directional structure.

INTERNAL STRUCTURES

- Parallel lamination
- Microfaulting of parallel lamination
- Fine
- Microfaulting of distorted lamination
- Coarse
- P P P P — Plant debris random
- Recumbent lamination
- —P—P—P— Plant debris on a parting plane
- Convolute lamination
- Plant debris concentrated in a layer
- Distorted lamination
- Graded bedding (normal)
- Ripple cross-lamination
- Graded bedding (inverted)
- Ripple cross-lamination
- Burrows
- Cross-bedding
- Granularia
- Slump structure
- Granularia

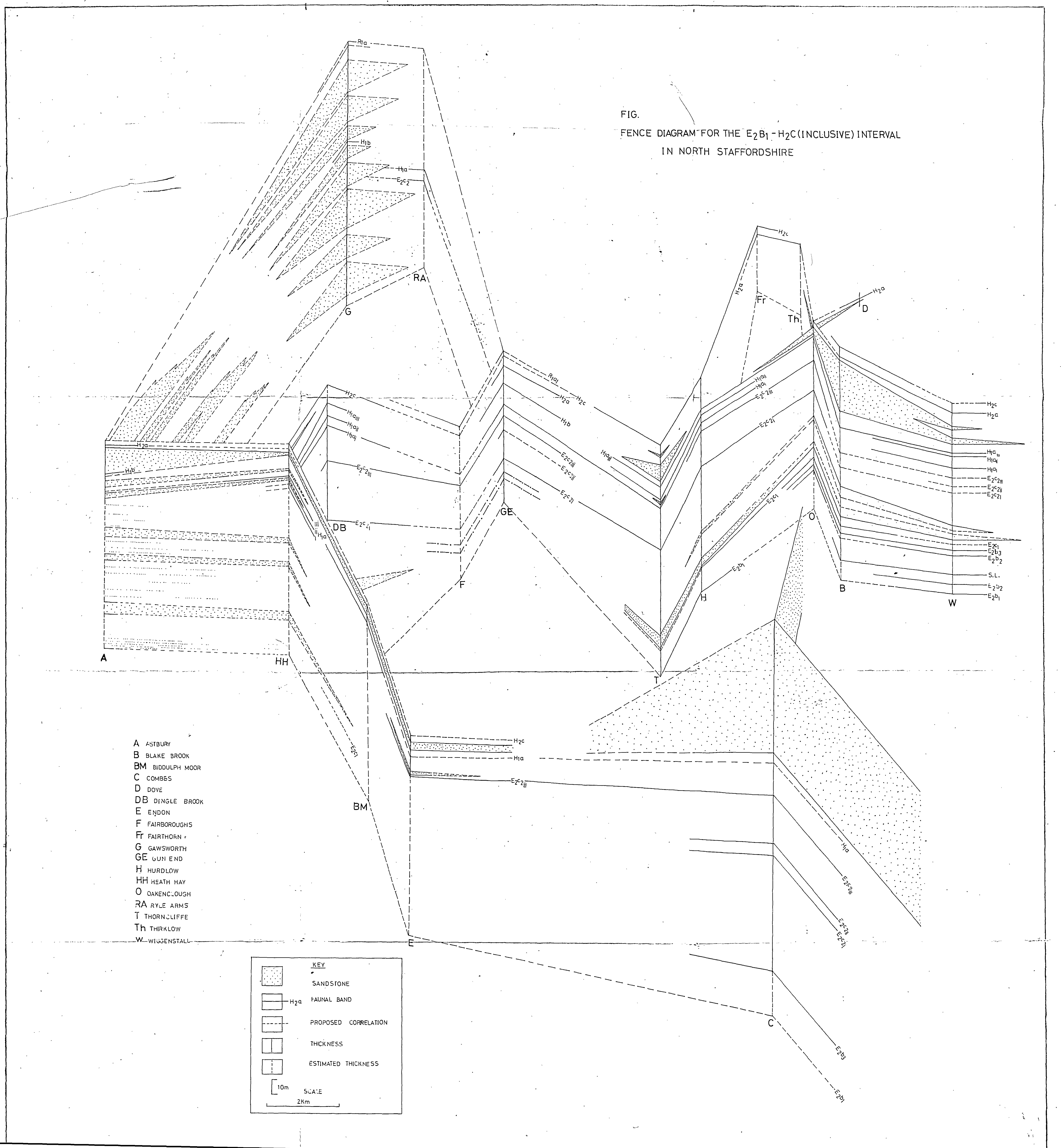


FIG.
FENCE DIAGRAM FOR THE E_2B_1 - H_2C (INCLUSIVE) INTERVAL IN NORTH STAFFORDSHIRE

NAMURIAN SUCCESSIONS IN THE INTERVAL E2a - R1b (inclusive)

Fig: V11A