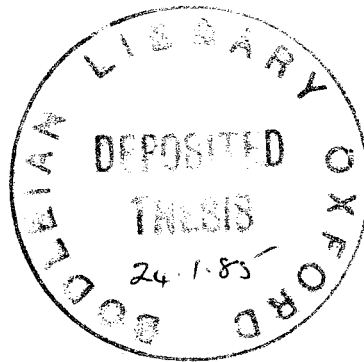


THE ANALYSIS OF QUATERNARY CAVE SEDIMENTS AND ITS BEARING
UPON PALAEOLOGIC ARCHAEOLOGY, WITH SPECIAL REFERENCE
TO SELECTED SITES FROM WESTERN BRITAIN

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22. MENDIP

22.1. The Mendip Region

The Mendip Hills are a series of Variscan periclinal folds, cored by Old Red Sandstone and Lower Limestone Shales and flanked by Lower Carboniferous (Dinantian) Limestone. The modern surface expression is c.40km long (roughly east-west) and c.5-8km wide; the sandstone reaches c.330m O.D. in places but much of the top of the hills is constituted by a slightly lower limestone plateau (c.260-300m O.D.). However, Mendip is in fact an even more impressive feature than these figures suggest, because it is largely a fossil landform that has only been partially exhumed. During Triassic times, Mendip stood at least 150m higher above the surrounding country. Subaerial erosion of this highland led to the formation of the thick Triassic Conglomerates which are now plastered over the Carboniferous Limestone slopes. During the Jurassic and Cretaceous, Mendip was submerged beneath the sea and the hills were entombed in relatively soft marine deposits. Some of these mesozoic rocks were eroded during the Tertiary, but it was not until the Pleistocene that Mendip once again began to emerge as a major landform, still with a topography essentially inherited from the Triassic. During the Pleistocene, the limestone plateau has been lowered by solution (accounting for the present difference in altitude between the limestone and the emerging sandstone core), various flats and benches have been cut

into the flanks of the hills, and most of the Mendip caves have been formed. An introduction to the geology and geomorphology of the area may be had by reference to Green and Welch (1965), Smith and Drew (1975) and Savage (1977).

Mendip is one of the best documented limestone areas in Britain, probably because the impressive massif remains eminently accessible, situated as it is within the 'lowland zone'. The enormous literature on caves, karst and quaternary deposits is similarly accessible, due to the efforts of such workers as Balch (1948), Smith and Drew (1975), Barrington and Stanton (1977), and Hawkins and Tratman (1977). However, it is unlikely that so much information would be available if it were not for the highly professional activities of a large number of local societies, each producing publications, amongst which may be mentioned:

Bristol Exploration Club Caving Report and Belfry Bulletin;
Cerberus Spelaeological Society News; Mendip Caver; Mendip Caving Group Journal; Mendip Nature Research Committee News and Reports;
Proceedings of the Somerset Archaeological and Natural History Society; Proceedings of the University of Bristol Spelaeological Society; Wessex Cave Club Journal and Occasional Publications.

Given this concentrated research, it is ironic that Mendip has not in fact revealed a very detailed picture of the Quaternary. This is due to the actual topography of the hills. The plateau on top of Mendip holds only rather thin superficial deposits because it has been subject to both chemical and physical erosion ever since its exhumation. The flanks of Mendip are generally quite steep and there are very few areas that have been able to act as long term sediment traps. Conversely, at the foot of the slopes and at the mouths of gorges, there is rather too much sediment, disposed as massive talus aprons and fans, deposits which are

extremely difficult to study and which, at least for the first few tens of metres, are usually comparatively recent. The hills were cut off from the pleistocene landscape to the south and north-west by a marine transgression during the Holocene which blanketed the lowland area with shallow water deposits. Even beyond the limits of this transgression, recent alluvium is often quite thick and the water table is very near the surface. Eastern Mendip, which might have provided more continuous links with the surrounding lowlands, has been devastated by modern quarrying (on a scale of tens of square kilometres). Mendip pleistocene sites, including caves, therefore tend to be on a rather small scale and isolated, one from another, so that it is difficult to construct a firm regional stratigraphy. Hope for the future probably lies in the closest possible co-operation between karst geomorphologists and sedimentologists, so that the scattered 'positive records' (deposits) can be tied in with the detailed evolution of the topography. Similarly, we must make full use of remnants or derivatives of any former regional sediment body, such as the loess cover postulated by Findlay (1965). Whether or not Mendip was ever glaciated (cf. Hawkins & Kellaway 1971) is still subject to heated debate, but it is clear that an answer, one way or the other, is a high priority. Finally, it is imperative that more work be done on the western fringes of Mendip, in order to establish how far the more continuous stratigraphic record now recognised along the Bristol Channel (cf. Hawkins 1977; Gilbertson & Hawkins 1978) might be traceable inland.

Despite the difficulties over regional synthesis, Mendip caves are legion and many of them contain interesting pleistocene deposits. Westbury-sub-Mendip Fissure (cf. section 22.4.) has produced abundant faunal evidence for at least two early Middle

Pleistocene temperate periods, and Sun Hole (cf. section 22.2.) and Minor Quarry (Weston-super-Mare; cf. Hawkins & Tratman 1977) contain bone material suggesting later Middle Pleistocene interglacials. Faunal remains thought to date from the last interglacial (with Hippopotamus) have been recovered from Milton Hill Fissure (Wells; cf. Balch 1948), and perhaps from Hutton Bone Cave (Davies 1926). Devensian faunas are too common to mention individually (cf. references in Barrington & Stanton 1977). Uranium-series techniques are helping to date damper periods with speleothem formation (cf. Atkinson et al. 1978) and this approach will prove invaluable in the future, especially if dates can be tied in with the faunal record and the local geomorphology.

Archaeological finds from Mendip are quite common. However, leaving aside the question of the Westbury-sub-Mendip flints (cf. section 22.4.), there is only one recorded find of possible Lower Palaeolithic age (a small ovate found on the surface below Dolebury Camp, near Churchill; D.A. Roe, pers.comm.). Otherwise, Lower Palaeolithic material has only been recovered from open sites in such areas as the Avon Valley, some 15km north of Mendip (eg. Ham Green and Chapel Pill Farm; cf. Roe 1974), or Castle Cary, 10km south of Shepton Mallet (a subtriangular handaxe in Broom Chert; D.A. Roe, pers.comm.). This apparent gap may well be associated more with the present lack of recognised Mendip deposits of the requisite age and geomorphic setting than with true demography. Middle Palaeolithic artefacts are known from the Uphill Quarry caves (Weston-super-Mare; cf. Harrison 1977), from caves in the Wookey Hole Ravine (Hyaena Den and Rhinoceros Hole; cf. Roe 1981), and from Lime Kiln Hill Quarry (Mells; Vranich 1981). The Upper Palaeolithic (cf. Campbell 1977) is well represented, both by material dating from the E.U.P.

(e.g. Uphill Quarry caves; Soldier's Hole, Cheddar; Badger Hole and Hyaena Den, Wookey Hole Ravine) and from the L.U.P. (e.g. Flint Jack's Cave, Soldier's Hole and Sun Hole, Cheddar). Gough's Cave (Cheddar), with over 4500 artefacts in the extant collections, maintains its position as one of the most important L.U.P. sites in Britain.

Naturally, only a very small selection of all the possible topics concerning Mendip can be covered in the present chapter. Section 22.2. deals with the recent stratigraphic interpretation of the Sun Hole deposits. Section 22.3. involves an attempt to evaluate the reliability of the data recovered from the caves of the Wookey Hole Ravine. Finally, section 22.4. contains a discussion of certain diagenetic aspects of the ancient deposits in the Westbury-sub-Mendip Fissure.

22.2. Sun Hole

22.2.1. Sun Hole - Introduction

Sun Hole (ST 467541) is an apparently small fissure cave situated half way up the western cliffs of Cheddar Gorge, Somerset. The cave was excavated by the University of Bristol Spelaeological Society, under the direction of the late Professor E.K. Tratman, during the periods 1927-8 and 1951-3. Further small scale excavation was carried out by J.B. Campbell in 1968. The present author has been working in the site since 1977. Numerous primary publications have already appeared: Tratman and Henderson (1928); Davis (1955); Jackson (1955); Ollier (1955); Tratman (1955); Bramwell (1957); Ollier (1958); Tratman (1963); Campbell (1970, 1977); Collcutt et al. (1981).

In their introduction to the latest report, Collcutt et al. stated their aims as follows:

The present study, again initiated by Professor Tratman, seeks to clarify a number of outstanding problems:

(a) The sedimentary history of the deposits remained uncertain. The particle size analyses of Ollier and Campbell could not be reconciled. A more detailed study of the deposits was called for, using a much wider range of techniques.

(b) During several visits to the cave in the 70's, it became clear that microfauna was present in layers other than those in which it had previously been found. As a pilot project, care was taken to recover such material from sediment samples before any potentially destructive analyses were undertaken.

(c) The chronology and environmental history of the cave as proposed by Campbell were not totally convincing. New biological, geological and chronometric data were needed.

(d) During the early excavations, very coarse stratigraphic subdivisions and a spit recording system were used. The exact provenance of the Later Upper Palaeolithic artefacts, human skeletal remains and associated (?) fauna was therefore uncertain, even after Campbell's attempt to localize them. Consequently, all sampled material down to 0.063mm. was scanned under the microscope in the hope of locating concentrations of flint, bone and charcoal.

(e) The cave had never been bottomed. We have been able to add a further three metres, making a total of eight metres, but, happily, the deposits continue. We hope that excavation will proceed but stringent safety precautions will be necessary. (1981:21-2)

In the present chapter, the results published in 1981 will be set out again, since the Sun Hole project constitutes an integral part of the author's research. However, a slightly more detailed discussion of the sediments will be included here. Also, new and extremely interesting information has been provided since 1981 by various members of the project team. Rather than integrate this new information fully into the earlier (1981) discussion, the opportunity will be taken to juxtapose the data from the two phases of study, in such a way as to highlight our changing conclusions and objectives. The gradual evolution of ideas is a very real, and interesting, part of any research project; it is a pity that the attitude of so many authors to this dynamic aspect seems to involve embarrassment, resulting in either suppression or apology (cf. the present author's hasty dismissal of his first report on Joint Mitnor Cave (p.795, above)!).

22.2.2. Sun Hole - Lithostratigraphy

Two systems of layer notation have already been employed for the site, that of Tratman (1955) and that of Campbell (1977). The former is much too coarse for the present purposes, whilst the latter is a descriptive system which is too subjective and which cannot easily be extended to the newly uncovered, deeper strata. Therefore, a simple numbering from the top has here been used wherever possible. The following table shows the equivalences as far as can be accurately established:

COLLCUTT et al. (1981)	TRATMAN (1955)	CAMPBELL (1977)	
not observed	1-3 "Postglacial"	(D)	
1	?4	?C	
2	}	C/B	
3		C/B	
4		B2-9	
5		B2-9	
6		5'	B2-5 to B2-8
7			B2-4
8			B2-4
9		"Pleistocene deposits"	B2-4
10			B2-4
11			?B2-3, ?B2-2
12			B2-2
13		5"	B2-1
14		6	A2
15	6	A2	
16		A2	
17		?A2, ?B1-3	
18	"boulders"	B1-1, B1-2, ?B1-3	
19		A1	
20		A1	
21-35 recently exposed			
E			
D	noted	noted	
C		A0	
B		A0	
A		A0	

It may be stated immediately that the latest particle size analyses agree well with Ollier's (1955) results. Campbell's results are texturally much too coarse, probably due to dry sieving of whole samples and consequent recording of artificial aggregates as individual particles.

Sediment colours, using Munsell notation, are matrix colours at the time of sampling (dry high summer), since later humidity-standardised determination in the laboratory showed little differentiation between layers, probably due to oxidation effects. Sediment samples are denoted by the label "SNH". The section (fig. 60) is semi-schematic with material over about 5cm being drawn accurately. Sampling locations are shown as black triangles. For safety reasons, the section could not be cut vertically; the top of the section is some 2m further north (distant from the observer) than the base and the drawing has been corrected for this effect. Note that stratum boundaries are only shown where they can be clearly recognised on site. Fig. 60 is essentially of the same exposure as that figured by Tratman (1955) and Campbell (1977); both these publications contain plans of the small cave. The term 'gravel' is used below to denote particle size and nowhere implies form or genetic relationships. The phrase 'dolomitic conglomerate' is descriptive; this material may or may not be Dolomitic Conglomerate (Triassic).

The lithostratigraphic units used here, as in 1981, are Layers, with arabic numerals, and Units with roman numerals. This system was conceived as a preformal classification (cf. p.151), with Layers corresponding as closely as possible to 'beds' and 'lithozones', and Units to 'members'. Note, however, that the exposures discussed here are extremely localised and that we are very far from being able to propose a useful formal scheme. The deposits may be divided into three main Units which will now be described, starting from the base (i.e. the present lower limit of excavation).

SUN HOLE

TRANSVERSE SECTION W-E

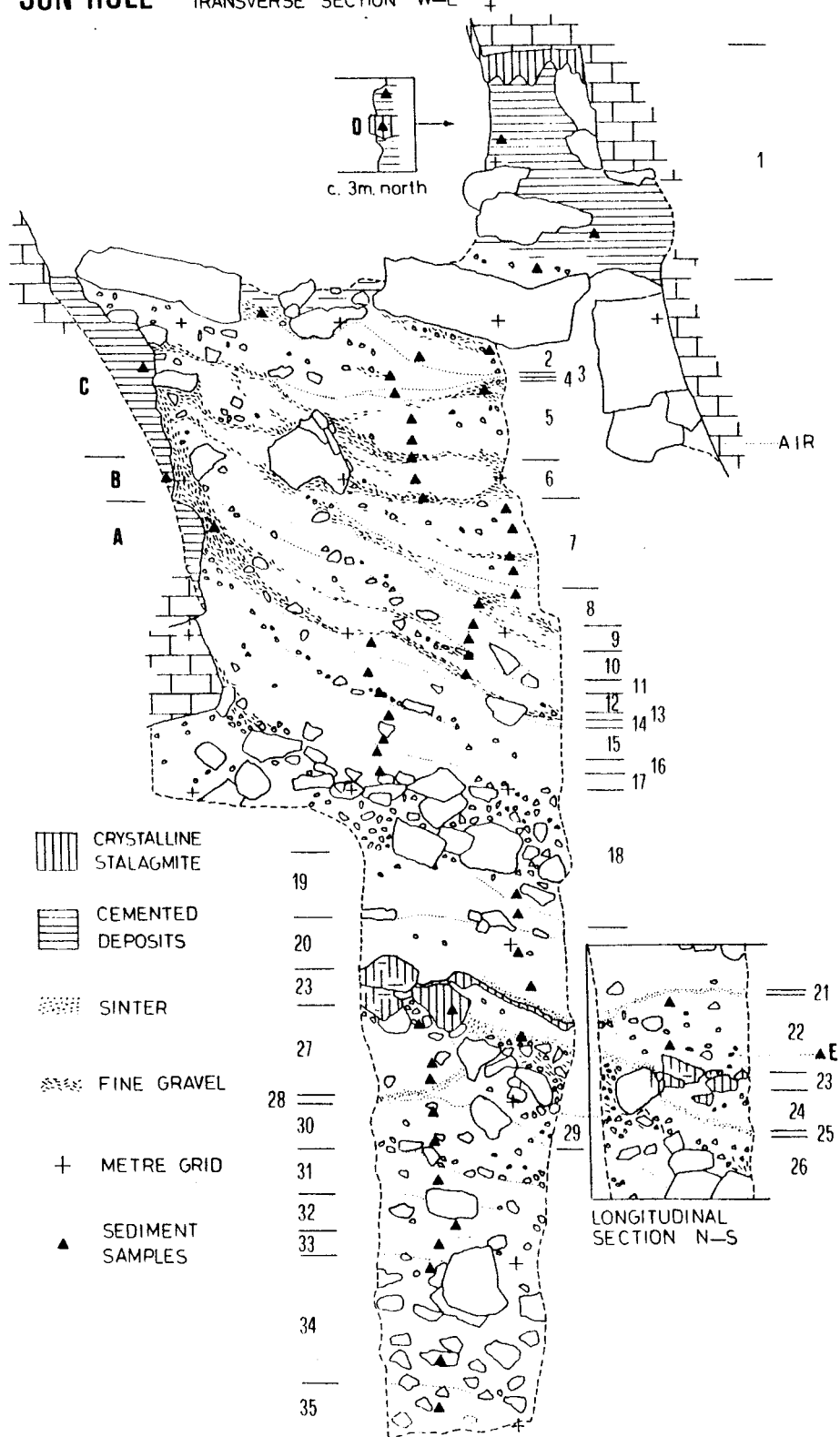


Fig.60 Sun Hole - Main Sections

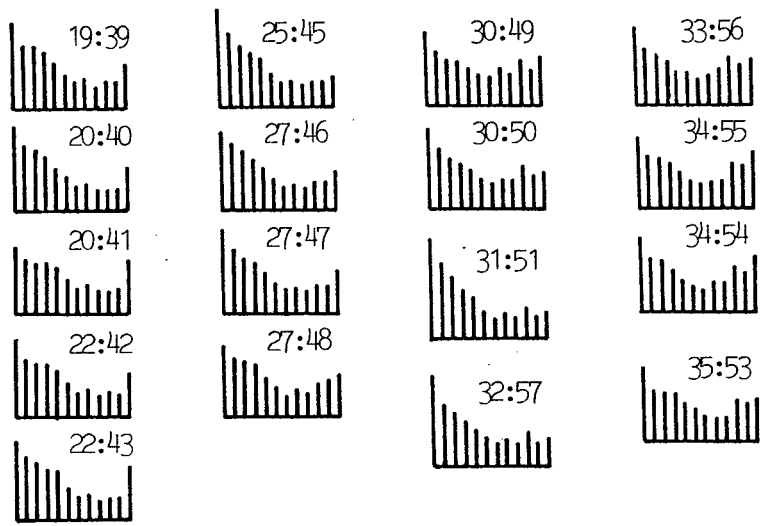
(after Collcutt et al. 1981)

Unit III (Layers 35-19)

These layers have a generally high clay content (25-38% of material <4mm). There is extreme variation in matrix carbonates, ranging from solid stalagmite and sinter (porous carbonate nodules, infra) to clay-rich layers with under 20% total carbonates. There are abundant crystalline concretions, often resembling fragments of 'breccia', and surface growths on stones. The layers have a generally low gravel content with a predominance of coarse gravel, and even small boulders, over the finer grades; this conclusion was reached by visual examination on site supported by extrapolation of a normal curve fitted to the measured grades 1.0-22.62mm. Coarse and medium non-carbonate sands are more important than in higher strata. Dolomitic sand, metallic (hydr)oxide aggregates (some of them dense and with worn surfaces), silicified crinoid ossicles and fragmentary terrestrial mollusca are present, the last in sufficient quantities to be classed as a minor source material for the sediment itself in some layers. There is extensive fissuring (infra), especially of concretions and dolomitic conglomerate, coupled with staining ('red' and 'dark brown'), alteration and blocky disintegration of calcite mudstones, and grainy disintegration of dolomitic limestones. Fractured stalactite and curtain formations are abundant, sometimes altered to a biscuity consistency.

Layer 35 (SNH53) Reddish brown (5YR 4/3) very compact silty clay; very low in matrix carbonates; rare altered coarse gravel and concretions; matrix support; very rare micromammals and mollusca; diffuse upper boundary, lower boundary not observed.

Layer 34 (SNH54, 55) Reddish brown (5YR 5/4 to 4/4 at top) compact clayey loam; increasingly sandy and carbonate-rich



WHOLE SANDS 4.0-0.063mm $\frac{1}{2}\Phi$ units

a

DECALCIFIED SANDS 1.0-0.063mm $\frac{1}{2}\Phi$ units

b

I-bars indicate decalcified sands as percentages of whole sands

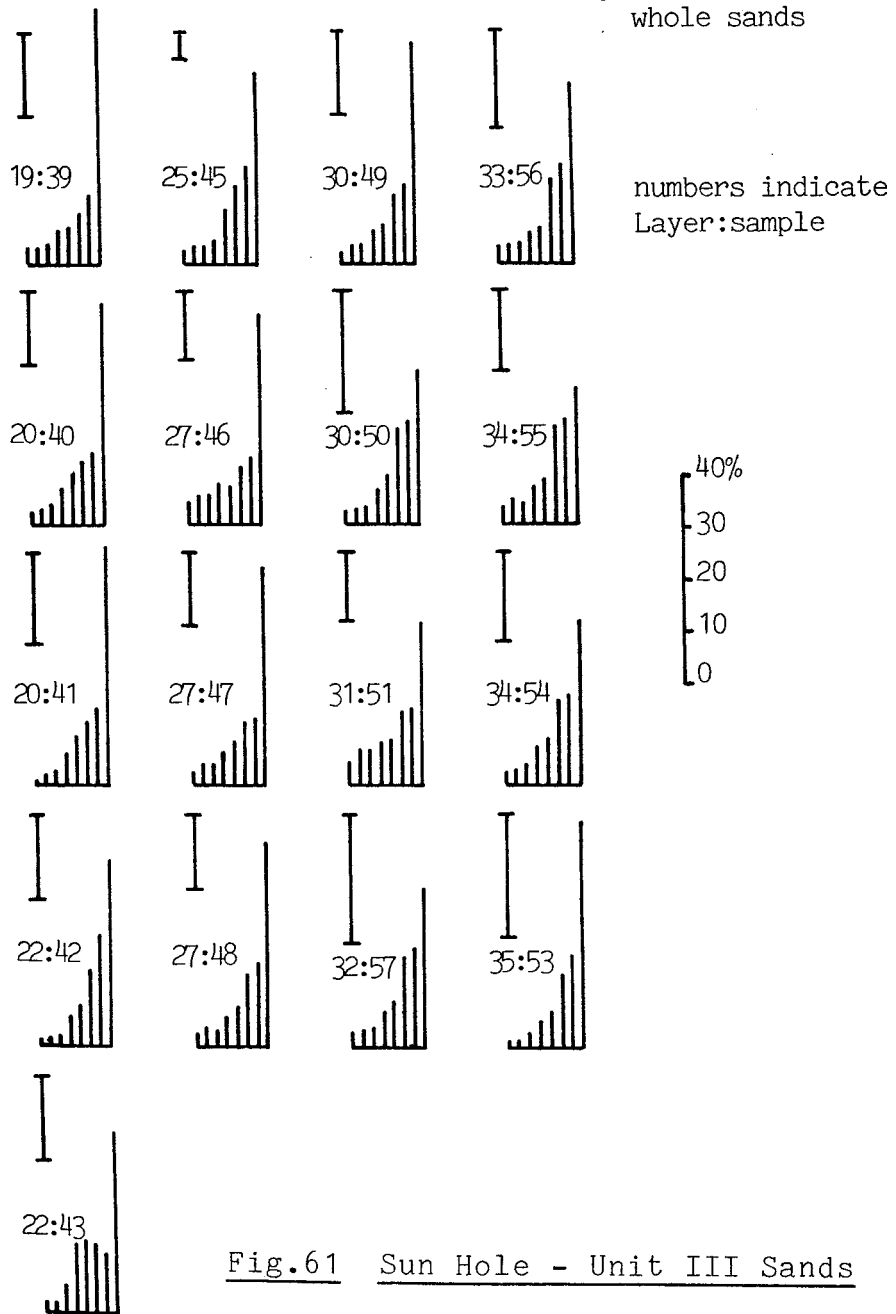


Fig.61 Sun Hole - Unit III Sands

upwards; some altered coarse gravel; common concretions; rare stalactite fragments; common organic and metallic (hydr)oxide aggregates in sand; matrix support; mollusca and micromammals; diffuse upper boundary.

Layer 33 (SNH56) Reddish brown (5YR 5/3) compact sandy clay; some matrix carbonates, especially dolomitic sand; some altered coarse gravel and common limestone ghosts; common concretions; common organic and metallic (hydr)oxide aggregates in sand; partial matrix support; common mollusca and micromammals; very diffuse upper boundary.

Layer 32 (SNH57) Reddish brown (5YR 4/4) compact clayey loam; low in matrix carbonates; some altered medium gravel and concretions; rare unsound shale (?); common organic and metallic (hydr)oxide aggregates in sand; partial matrix support; mollusca; diffuse upper boundary.

Layer 31 (SNH51) Reddish brown (5YR 4/3) compact sandy loam; generally low in matrix carbonates but sands quite rich in limestone clasts; common altered medium gravel; some concretions; partial matrix support; abrupt upper boundary.

Layer 30 (SNH50, 49) Stone line at base including large crystalline concretions. Reddish brown (5YR 4/3) silty clay; very low in matrix carbonates; rare coarse gravel with some concretions near top; stalactite fragments; base quite rich in non-carbonate silt and sand (including quartz, organic material and metallic (hydr)oxides) as well as in dolomitic sand; rather loose at base, becoming well compacted near top; patchy clast support; mollusca; abrupt upper boundary.

Layer 29 Reddish brown (5YR 4/4 with 'cream' specks) loose silty loam; some matrix carbonate, especially sand; common coarse gravel and concretions; affected by suffosion of Layer 26;

clast support; abrupt upper boundary where Layer 28 is present.

Layer 28 Reddish brown (6YR 5/4 with 'cream' specks) discontinuous sinter band; abrupt upper boundary.

Layer 27 (SNH48, 47, 46) Reddish brown (6YR 4/3 to 5YR 4/4 at top, 'cream' specks throughout) clayey loam; more silt towards base but increasing sand, coarse gravel and matrix carbonates upwards; some granular concretions as well as common crystalline concretions; quite loose towards top; clast support; mollusca and micromammals becoming rarer upwards; diffuse upper boundary.

Layer 26 Highly suffused breakdown layer with coarse rubble and some airspace; loose pockets; irregular but quite abrupt upper boundary.

Layer 25 (SNH45) Reddish brown (6YR 4/5 with 'cream' specks) major sinter band with a little non-carbonate sand and silt as well as abundant clay; abrupt upper boundary.

Layer 24 Reddish brown (5YR 4/3 with 'cream' specks) compact silty loam; moderate matrix carbonates; increasing coarse gravel towards top; slightly suffused in places; clast support; diffuse upper boundary.

Layer 23 (SNH44) Reddish yellow (c.6YR 7/6) irregular breccia with flowstone spreads and small stalagmites; some fracturing and minor disruption of these features; abrupt upper boundary.

Layer 22 (SNH43, 42) Reddish brown (5YR 4/3 with 'cream' specks towards top) compact sandy loam; rich in clay at the base; quite rich in matrix carbonates; common coarse gravel; common speleothem (especially stalagmite) fragments; clast support; mollusca and micromammals; abrupt upper boundary.

Layer 21 Reddish brown (6YR 5/4 with 'cream' specks) thin sinter band; rather diffuse upper boundary.

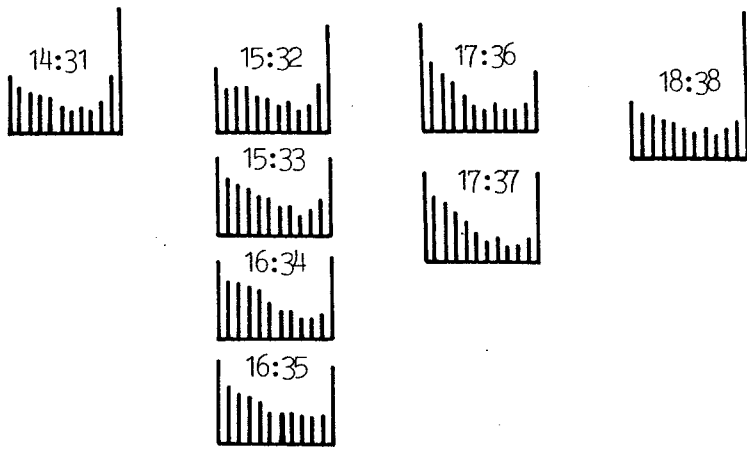
Layer 20 (SNH41, 40) Reddish brown (6YR 5/3 with 'cream' specks towards base) compact sandy loam; rich in clay towards top; moderate matrix carbonates; quite common coarse gravel, slightly altered; granular concretions near base; point-to-point cementation near top; stalagmite and stalactite fragments; clast support; mollusca and micromammals; diffuse upper boundary.

Layer 19 (SNH39) Reddish brown (5YR 4/3) compact clayey loam; moderate matrix carbonates; some slightly altered coarse gravel and concretions; stalagmite fragments; partial matrix support; rare mollusca and micromammals; extremely abrupt upper boundary.

Unit II (Layers 18-14)

These layers have a very high silt content with variable but usually rather minor quantities of clay. There is a dominance of fine sand over other sand grades, especially with respect to non-carbonate, mostly quartzitic sand, where the 0.090-0.063mm grades account for 60-70% of the 1.0-0.063mm material. Calcitic fine sand and silt is also a strong component, accounting for much of the matrix carbonate, although some concretions are present in certain layers. Stalactite fragments are only present in quantity towards the base of the unit. Gravel is still quite coarse and is a little more common than in Unit III. There are very few signs of alteration and even the fragile dolomitic conglomerate is often intact. There is very little dolomitic sand.

Layer 18 Major breakdown layer containing large boulders and much coarse gravel; some stalactite fragments; common airspace. This layer has suffered extreme suffosion, the only



WHOLE SANDS

a

DECALCIFIED SANDS

b

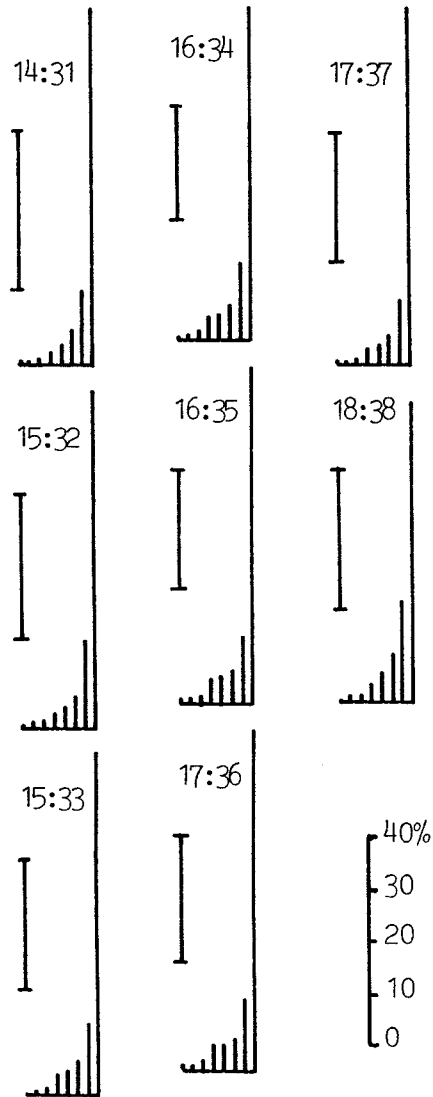


Fig.62 Sun Hole - Unit II Sands

(conventions as in fig.61)

significant matrix material being a thin band of fine sand and silt (reddish brown 6YR 5/3; SNH38) between the boulders at the base of the layer; this probably represents a lag deposit. Layer 18 may contain less disturbed finer strata towards the west wall, material which has not been sampled due to its dangerously loose composition. The whole layer has an irregular diffuse upper boundary.

Layer 17 (SNH37, 36) Brown (7.5YR 5/4) silt and fine sand; some sand sized mica platelets; quite low in matrix carbonates but with a slight rise towards the top accompanied by a little clay; common medium gravel; matrix loss towards base by suffosion and point-to-point cementation throughout; quite loose; patchy clast support; rather diffuse upper boundary.

Layer 16 (SNH35, 34) Brown to reddish brown (7.5YR 5/4 to 6YR 5/4 at top) fine sand and silt; some sand sized mica platelets; increasing carbonates towards top; common coarse gravel; well compacted; clast support; abrupt upper boundary.

Layer 15 (SNH33, 32) Stone line at base. Reddish brown (5YR 4/3 to 4/4 at top) silt and fine sand; some sand sized mica platelets; low in matrix carbonates, decreasing even further towards top; rare, slightly altered coarse gravel, especially near base; a little clay towards top; well compacted; patchy clast support; rather diffuse upper boundary.

Layer 14 (SNH31) Light brown (7YR 6/4) silt; low in matrix carbonates; rare coarse gravel; straw stalactite fragments; well compacted; partial matrix support; extremely abrupt upper boundary.

Unit I (Layers 13-1)

Fine sand and silt continue as major components, although they contain less carbonate than below. Coarse limestone sand

becomes very common. Clay plays a minor but consistent role. Concretions and clast-surface growths are quite common, as are small stalactite fragments. Fine angular gravel, often forming irregular lenses sometimes almost devoid of fine matrix, is a dominant feature throughout (cf. p.310). Alteration, staining, fissuring, blocky and grainy disintegration, and pink chalky coatings on stones are quite common but are very variable from layer to layer. Similarly, crinoids, dolomitic sand and coloured minerals (hematite, dark cherts, etc.) show a patchy distribution. Compaction is very variable within this unit; low compaction is probably primary, since the gravel lenses are not continuous enough to allow much later suffosion.

Layer 13 (SNH30, 29) Brown (7.5YR 5/4) silt with fine sand; moderate matrix carbonates; extremely abundant fine gravel; quite loose in places; clast support; diffuse upper boundary.

Layer 12 (SNH28) Light brown (7YR 6/4) silt with fine sand and a little clay; moderate matrix carbonates; some fine and medium gravel, slightly altered; some concretions; well compacted; clast support; rather diffuse upper boundary.

Layer 11 (SNH27) Light brown (7YR 6/4) silt with fine sand; moderate matrix carbonates; common medium gravel, very slightly altered at top; some concretions; moderately compacted; clast support; quite abrupt upper boundary.

Layer 10 (SNH26) Light brown (7.5YR 6/4) sandy silt; moderate matrix carbonates; some medium and fine gravel, rather altered especially towards base; well compacted; clast support; irregular but rather abrupt upper boundary.

Layer 9 (SNH25) Light brown (7.5YR 6/4) sandy silt; slight increase in matrix carbonates; coarse, medium and fine gravel, rather altered; some concretions; well compacted; clast

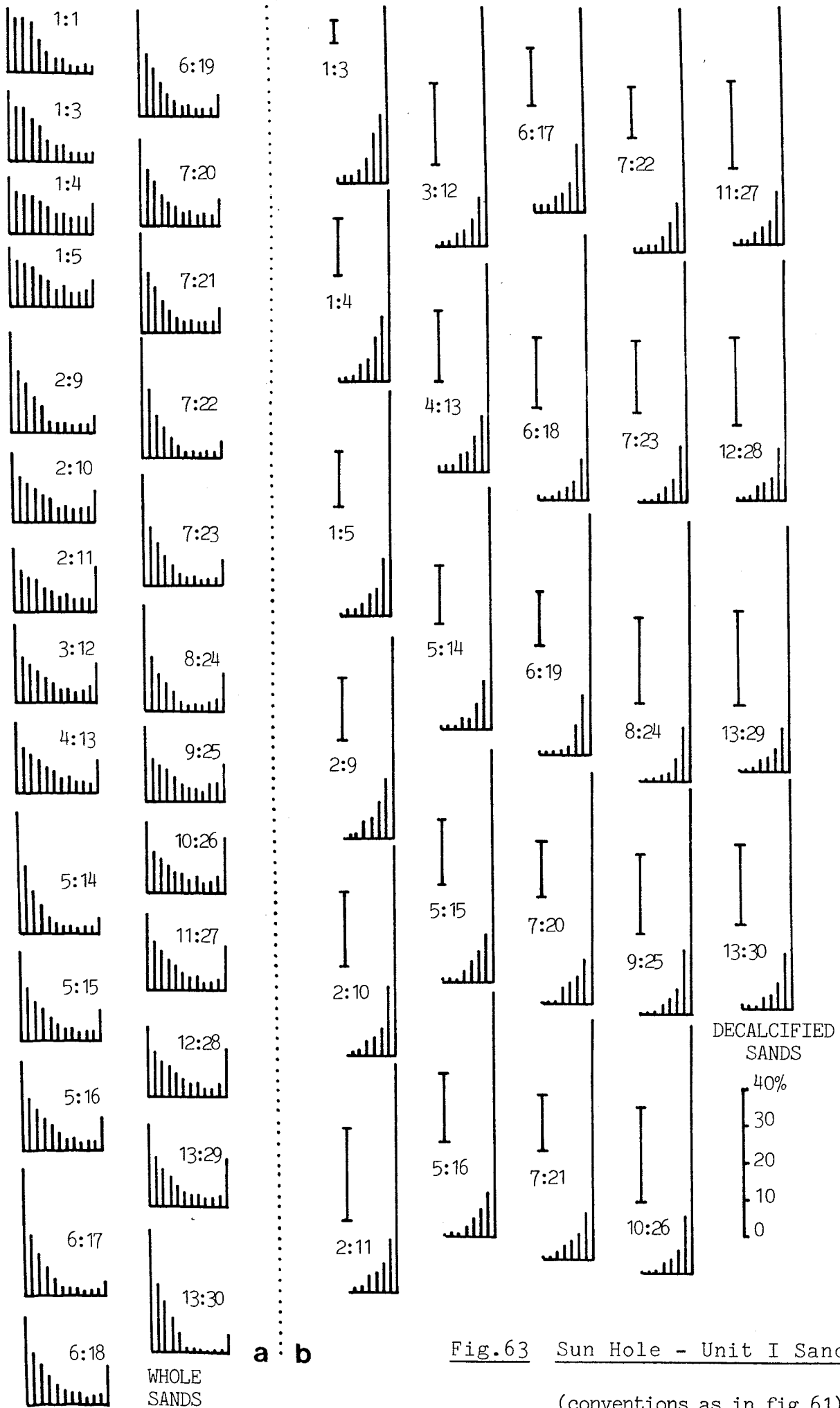


Fig.63 Sun Hole - Unit I Sands
(conventions as in fig.61)

support; rather abrupt upper boundary.

Layer 8 (SNH24) Reddish brown (5YR 4/3) silty loam; quite low in matrix carbonates; some altered fine gravel; some concretions; well compacted; clast support; common micromammals; rather diffuse upper boundary.

Layer 7 (SNH23, 22, 21, 20) Light brown (7.5YR 6/4) sandy silt, with sand and matrix carbonates increasing upwards; fine and medium gravel, usually in the form of discontinuous lenses; a few concretions near the top; well compacted except within gravel spreads; clast support; common micromammals; abrupt upper boundary.

Layer 6 (SNH19, 18, 17) Reddish brown to light brown (6YR 5/3 with 7.5YR 6/4 at base and top) silty loam; slightly altered fine gravel lenses, especially continuous at base and top; moderate matrix carbonates; some concretions; slight rise in clay and non-carbonate medium sand towards the top; some dolomitic sand; quite well compacted in the middle but much less so at base and top where gravel is very loose; clast support; common micromammals; quite abrupt upper boundary.

Layer 5 (SNH16, 15, 14) Reddish brown to light brown (6YR 4/4 to 7.5YR 6/4 at top) silty loam; slightly altered fine gravel lenses; matrix carbonates, alteration and occurrence of concretions increasing towards top; some dolomitic sand; well compacted though a little less so at top; clast support; micromammals and larger bone fragments; abrupt upper boundary.

Layer 4 (SNH13) Brown (7.5YR 5/4) sandy loam; moderate matrix carbonates; some medium gravel, heavily altered; common concretions; some dolomitic sand; well compacted; clast support; abrupt upper boundary.

Layer 3 (SNH12) Reddish brown (6YR 4/3) sandy silt; moderate

matrix carbonate; some medium and fine gravel, heavily altered; common concretions; well compacted; patchy clast support; micromammals; rather abrupt upper boundary.

Layer 2 (SNH11, 10, 9) Brown to light brown (7YR 5/4 with 7.5YR 6/4 at base and top) sandy silt; increasing matrix carbonates towards top as well as increasing quantities of fine gravel; some clay and heavy alteration towards base, together with point-to-point cementation; common concretions; large roof slabs within this layer; quite well compacted except at surface; patchy clast support; modern disturbed surface.

Layer 1 (SNH5, 4, 3, 1) Brown (7.5YR 5/4 with 'cream' flecks) heavily cemented deposits on the east wall, capped by granular stalagmite; increasing quantities of matrix carbonates towards top as well as clay; non-carbonate sands, although decreasing upwards in relative importance, become slightly coarser; partial matrix support, switching upwards to matrix carbonate support; common mollusca and micromammals; upper boundary contiguous with dormant (?) stalactite, lower boundary not clear (loose material between rocks).

In addition to these units, there are five 'layers' which cannot as yet be inserted in the main stratigraphy:

Layer A Light brown (7.5YR 6/4 with 'cream' flecks) highly cemented sandy silt; common medium gravel; clast support; very patchy remains only on west wall.

Layer B (SNH7) Reddish brown (6YR 4/4) slightly cemented silty sand, in structural groove on west wall; moderate matrix carbonates; rare, very fine gravel; matrix support; diffuse upper boundary with Layer C.

Layer C (SNH6) Light brown (7.5YR 6/4 with 'cream' flecks)

highly cemented sandy silt; moderate matrix carbonates; quite common medium gravel; presence of limestone plaques that have been warped to curvilinear or even angled forms; common concretions; matrix support; micromammals; erosion surface at top.

Layer D (SNH2) Crystalline stalagmite blocks embedded within the granular stalagmite capping Layer 1. These are fragments of a floor which was once at least 15cm thick.

Layer E (SNH52) Large broken stalagmitic boss, coarsely crystalline, lying in Layer 22. This could be referable to Layer 23 but it cannot be even vaguely matched with any in situ formation, these being very much smaller, less well crystallised and less pure. The boss might, alternatively, be contemporary with Layer D.

22.2.3. Sun Hole - Sedimentary Processes

Fig. 64 represents the sequence of sedimentary processes which, in 1981, were thought to have given rise to the Sun Hole deposits. Only the more obvious features were noted, since the dangers involved in over-interpretation of very small sections were constantly kept in mind. Certain major aspects of this sequence require some discussion.

The clastic particles, which constitute an important component throughout the deposits, include material from a wide range of carbonate rocks. The dominant type is a dark grey calcite mudstone, mapped by the IGS (Sheet 280) as "chinastone", derived from the Clifton Down Facies of the Lower Carboniferous in which the cave is formed. Exposures in the cave walls and just outside the entrance show the presence of brachiopods, possibly chonetids,

SUN HOLE — SEDIMENTARY PROCESSES

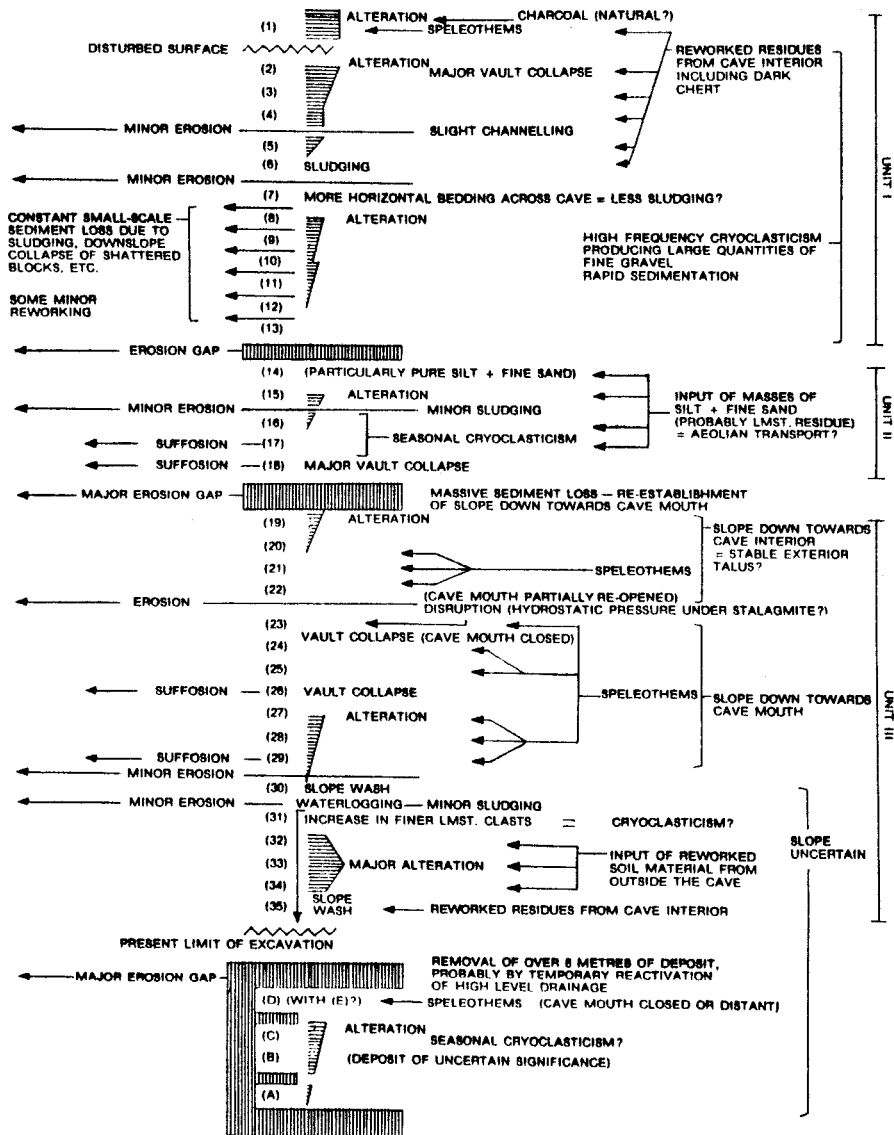


Fig.64 Sun Hole - Sedimentary Events

(after Collcutt et al. 1981)

as well as of oolites that have been somewhat modified by micritisation and, in places, by silica replacement. These features can be seen in many of the calcite mudstone clasts included in the deposits. There are also surprisingly large quantities of dolomitic rock: dolomitic conglomerate, with small, extremely rounded limestone pebbles set in a dolomitised matrix, and a grainy, yellowish dolomitic limestone. Silicified crinoid ossicles are common, especially in the lower layers, although there is no trace of their parent limestone (they are not usually of the same preservation type as the rare crinoids in the dolomitic conglomerate; the latter are altered and 'rough', whilst those in the sediments are dense and rounded). There are rare occurrences of an unidentified, coarse grained, low specific gravity, light grey limestone, which is also present in the modern slope deposits just above and west of the cave entrance. Fragments of a vuggy breccio-conglomerate and of a semi-lithified current-bedded deposit, found in almost all the layers as extremely minor constituents, would seem to represent ancient cave fill.

The presence of dolomitic rocks was first noticed by Ollier (1955, 1958), who suggested that the yellowish type could have come from the Triassic Conglomerates to be found within a kilometre to the west-north-west, for example at Batt's Combe. He also implied that transport would have been through a cave system, not overground, a proposition which seems most reasonable considering the 'impassable' terrain between the outcrops and Sun Hole. If the cave is indeed part of a much larger system, this would help to explain the presence of such diverse rock types, a diversity for which there is no other obvious explanation. These rocks would have been brought to the vicinity of the Sun Hole passage by water transport and later, perhaps very much later,

reworked by collapse and sludging into their present positions, losing all signs of water-rounding in the process. This transport mechanism does not constitute a particularly attractive hypothesis but it was the only one available in 1981.

The 'hanging breccias' (Layers A-C) are cemented sediments, not to be confused with the much older vuggy breccio-conglomerate mentioned above. Campbell (1977) noted fragments of what he called an older breccia in Layers 17-20, which he supposed to have been derived from these hanging deposits. Although some particulate material may well have fallen from the walls into the younger sediments, the 'breccia' to which Campbell refers is due to autochthonous concretionary processes associated with suffosion and waterlogging. There are no large carbonate-cemented aggregates that can be recognised as having come directly from the hanging deposits, barring perhaps the fragments of crystalline stalagmite which could be derived from Layer D (cf. Layer E and the thick slabs of stalagmite recovered by Tratman (1955) from within Unit II). It should be noted that there is no proof as yet that these hanging deposits are older than all the other deposits, nor in fact that they are even internally in the right stratigraphic order. However, this would seem to be the most likely interpretation and it is that which is represented in fig. 64. Nevertheless, these deposits could fit into the gap between Units III and II, or even between Units II and I.

All layers so far examined at Sun Hole contain large quantities of limestone clasts derived from the bedrock. The cave entrance is relatively open to the elements and one would expect frost shattering to have played some role in the development of scree input. When fresh, the calcite mudstone has a very low porosity and permeability. The negligible effect of experimental

freeze-thaw on sound clasts of this rock has already been noted (p.308). It is therefore suggested that, in Sun Hole, the main control of particle size during vault shattering is not the intensity of cryoclasticism but, rather, the structural properties of the limestone. Initially, clasts produced by chemical weathering, various types of stress release and frost shattering will tend to have a distribution with a coarse mean. In general terms, the higher the frequency of temperature oscillations about zero, the more rubble will be produced. A high rate of sedimentation will favour mechanical (percussive) fracture as new material falls onto old, without the benefit of a fine matrix 'cushion'. Perhaps 30% of the gravels from Unit I show good conchoidal fractures with all the stigmata of struck flint; this is a property of the calcite mudstone and conchoidal fractures would not occur in coarser limestones. Secondary cryoclasticism, making use of any remaining weaknesses in the clasts, such as microfissures created during mechanical fracturing or by alteration, will further comminute the material.

In various layers within the sequence, especially those of Unit III, there is widespread deep fissuring of the dolomitic rocks and of crystalline concretions. The calcite mudstone may show a blocky fracture or may even itself be slightly fissured. This fissuring is expressed as a mosaic of curved and stepped cracks which do not penetrate right to the heart of the particle. At Sun Hole, the only British site in which the author has seen this effect, the fissuring is only present in altered layers, the more altered, the more fissuring. Slow hydration and recrystallisation in very damp deposits could account for this phenomenon (cf. p.301). There is no reason to invoke frost shattering, although this process will obviously attack already

fissured limestone. The particularly abundant fine gravels of Layer 6 would seem to have resulted from just such a combination.

Alteration has been estimated mainly by the presence of certain features on larger carbonate particles. The calcite mudstone surfaces show rounding of angles, red and black staining, deep pock marks (differential solution of oolites) and ribbing (high relief of calcite veins). These effects are usually only superficial, although staining may penetrate along structural planes; alteration does not markedly increase microporosity (or even mass porosity) in this limestone. Perfectly rounded limestone pebbles and monocrystalline dolomitic sand are released from the dolomitic rocks. The dolomitic sand can often be seen as a minor mode in the particle size distributions at c.0.17mm (cf. figs. 61a-63a, third bar from the right in each diagram). Ghosts may be present, which represent undisturbed but totally decomposed dolomitic limestone and speleothem fragments; where these are present in quantity, waterlogging is assumed to be the cause (cf. Layer 33 in which even a few calcite mudstone clasts are ghosted). Alteration requires water, a transport medium which would have contributed some of the clays usually found in altered layers and which would be necessary for the growth of concretions within the sediments. A temperature rise would not be necessary, but any rise would certainly accelerate alteration and movement of carbonates in solution.

'Sinter' is a term used here to denote particulate, tufa-like carbonates. It is made up of porous granules which, in section, show complex structure. The core of each granule is mostly white microcrystalline carbonate set in extremely convoluted concentric laminae, separated by slightly darker lines. Some recrystallisation has occurred, with large crystals growing

radially across the laminae. Granules are coated and cemented into larger units by 'orange' crystalline calcite, identical to that which composes the normal concretions (eg. under stones) in the deposits. The internal structure in these granules resembles algal growths. There are also dark dendritic inclusions that recall the stems of some cryptogams. It is thought that the granules were formed on the cave walls and roof around lichens and mosses and that, as growths eventually smothered the plants and became unstable, they fell to the floor to form sinter bands. Such growths would require water and at least some indirect light.

With respect to larger scale carbonate deposition, the growth of crystalline stalagmite as floor formations so near a cave entrance (even allowing for possible cliff retreat), and under such a thin overburden of limestone, would suggest abundant percolation water and the presence of active surface soils with vegetation. When stalagmite is relatively pure, other depositional processes must have ceased and air circulation must have been restricted to allow the growth of good crystals (precipitation due to degassing, rather than evaporation, in a dust-free environment). Layers 19-22 slope up towards the cave entrance, at least within the small area so far examined, suggesting that the cave may indeed have been closed during the deposition of the stalagmite of Layer 23. A stable exterior talus would be difficult to maintain during periods of extensive slope mass movement; rather, a mat of binding vegetation is indicated. Note that a small talus, with reversal of the normal south-trending dip of the deposits, formed during the Holocene (Tratman 1955).

Abundant soil material was washed into the cave during the early part at least of Unit III. This material consists of sand sized and smaller, irregular aggregates containing (hydr)oxides

of iron, aluminium and manganese with colloidal silica, clay minerals and much alkali-soluble organic matter (up to c.1.2% of the fraction under 1mm). Note, in passing, that the small rounded particles of denser iron-rich compounds, seen in many layers at Sun Hole, appear to be ancient weathering residues and are distinct from the aggregates in question here. The lower layers of Unit III also contain unassociated clays and quite large quantities of comminuted terrestrial molluscan shell. The abundance and state of preservation of these shell fragments, coupled with the closed fabric of the sediments, militate against a recent intrusion. No particles showing strong soil fabric are present. These features would suggest derivation from thin residual soils with low pedality, the normal azonal type on limestone slopes. It is of interest that the modern soil outside the cave, apart from having enormous quantities of molluscan remains and organics, is also rich in fragments of partially silicified oolites derived from the local bedrock, fragments which are absent from the cave sediments, save for very rare occurrences in Unit I. Conversely, silicified crinoid ossicles are common in Unit III but absent from the modern soil and the immediately adjacent limestone bedrock. It therefore seems probable that most of the ancient soil material entered the cave from some point further back in the system, not through the Sun Hole entrance. Small amounts of these possibly soil-derived fossils (crinoids) occur throughout Unit III and also towards the top of Unit I (prior to Layer 1).

Silts and fine sands are important right through the sequence but are particularly abundant in the layers of Unit II (cf. fig. 65). The non-carbonate component sometimes resembles the quartzitic residue of the local bedrock; indeed, most of the local Carboniferous Limestone facies contain quartz grains in this

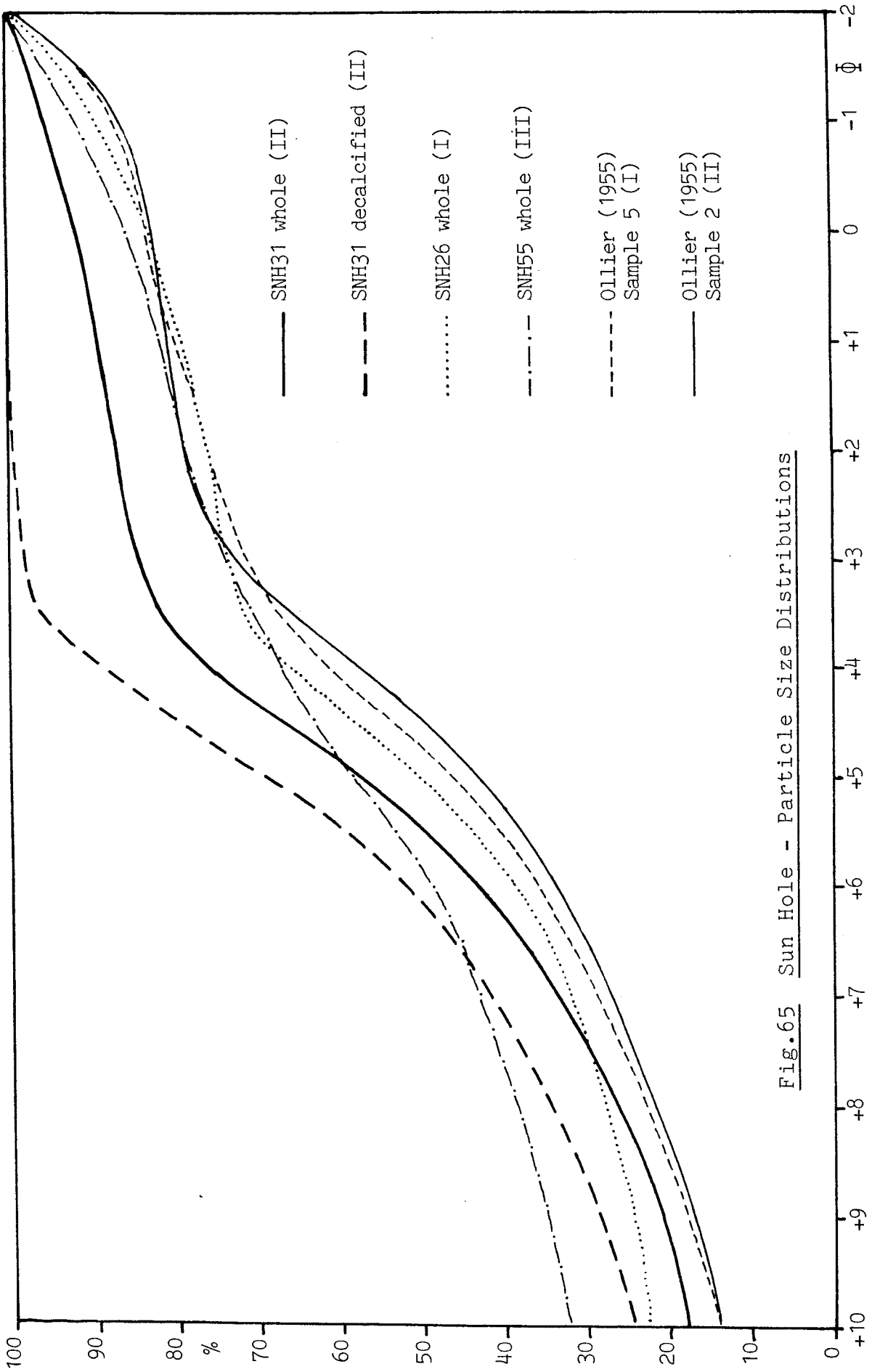


Fig.65 Sun Hole - Particle Size Distributions

size range. However, the fine material in Unit II cannot be the result of in situ weathering since the clays, which are also abundantly present in the limestones, are absent in these layers, as are signs of strong alteration. Similarly, if limestone residues had merely been washed into the cave, the clays would also be present or there would be signs of higher energy water transport (eg. current bedding) and the particle size distribution would not be likely to be negatively skewed. Furthermore, there is a significant mode in the carbonate silts and fine sands which can hardly have been produced by chemical weathering. The only other explanation would seem to be that the material has been wind-sorted. It is hoped to test this hypothesis by scanning electron microscopy of quartz grain surface textures; no significant results have been achieved using optical microscopy (cf. p.476). If this is indeed local aeolian material, conditions must have been rather dry and vegetation cover at best discontinuous. Large quantities of silts would not remain perched on these very steep hillsides for long. It is therefore assumed that Unit II is roughly contemporary with initial wind deposition, although emplacement within the cave itself was probably due to local wash. Judging from the relatively strong easterly (cross-cave) component of dip in these layers, input may have been through the main fissure in the cave roof (which is now largely inactive, probably due to speleothems).

The importance of the entries on the left hand side of fig. 64 must not be overlooked. The arrows represent the minimum number of erosive events present in the sequence. Erosion, being a subtractive process, is very difficult to estimate. Erosion is assumed to have occurred when there is a sharp boundary between layers and at least a slight change in sedimentation pattern.

When there is a radical change in sediment type which cannot be explained by topographic shifts (eg. between Units III and II), a major gap is suggested. In a cave like Sun Hole, with deposits sloping down towards a steep hillside grading into a vertical cliff, we might suspect that the gaps represent greater lengths of time than the extant sediments. The actual mechanism of erosion is not always clear; many of the erosive events in Sun Hole seem to be associated with sludging or merely slope collapse. There is no sign of stream erosion, although it is possible that this process was responsible for flushing the cave and leaving the hanging deposits; this hypothesis requires that the 'hanging breccias' be older than all other sediments yet exposed. It seems likely that stream deposits will eventually be found (as in most caves in highly karstified regions) if excavation can be continued to sufficient depths.

Suffosion, the slow removal of fine matrix from sediment bodies that have a rigid, coarse 'skeleton', has been an important process in many layers, especially those representing vault collapse. The process is still active in Layer 18, where percolating water, having removed large quantities of matrix, is now depositing crystalline calcite in the resulting voids. This layer begins to 'weep' only about an hour after the beginning of rain during the damper months of the year. Those fines which still exist within such a deposit are not necessarily part of the original matrix; they may be reworked material from either above or (stratigraphically) below the suffosed layer.

22.2.4. Sun Hole - The Pleistocene Fauna

Currant (in Collcutt et al. 1981) has re-examined the

pleistocene mammalian fauna in the U.B.S.S. collections from Sun Hole. This material came from the first 8ft (2.4m) of the certainly pleistocene deposits, levels which may be generally equated with all or parts of Layers 2-13 in the present scheme.

Currant records the following taxa:

<u>Talpa europea</u> L.	mole
<u>Homo sapiens</u> L.	man
<u>Canis lupus</u> L.	wolf
<u>Vulpes vulpes</u> (L.)	red fox
<u>Ursus arctos</u> L.	brown bear
<u>Mustela nivalis</u> L.	weasel
<u>Felis sylvestris</u> Schreber	wild cat
<u>Equus ferus</u> Boddaert	wild horse
<u>Rangifer tarandus</u> (L.)	reindeer
<u>Castor fiber</u> L.	beaver
<u>Apodemus sylvaticus</u> (L.)	wood mouse
<u>Dicrostonyx torquatus</u> (Pallas)	collared lemming
<u>Lemmus lemmus</u> (L.)	Norwegian lemming
<u>Clethrionomys glareolus</u> (Schreber)	bank vole
<u>Arvicola terrestris</u> (L.)	water vole
<u>Microtus</u> sp. (usually listed as <u>M. arvalis</u> group but may be a morphological variant of <u>M. gregalis</u>)	microtine
<u>Microtus gregalis</u> (Pallas)	narrow-skulled vole
<u>Microtus oeconomus</u> (Pallas)	northern vole
<u>Ochotona pusilla</u> Pallas	steppe pika
<u>Lepus timidus</u> L.	Arctic hare

The wild boar reported by Tratman (1963) and the hyaena reported by Hawkins and Tratman (1977:203) could not be found in the present U.B.S.S. collection; at least the record of boar seems to be due to misidentification. The sparse fauna recovered by Campbell (1977) from his layer B2-7 (equivalent to Layer 6?) has not been re-examined, but no new species are recorded. Although the verified fauna is of a generally 'cool' type, Currant notes that lightly wooded country would not exclude any of the recorded animals and that such conditions would suit brown bear, wild cat, wood mouse, bank vole and, particularly, beaver. This topographically varied region would obviously present a similar variety of habitats, even during glacial chronozones, a point also made by Bramwell (1957) who suggests that some of the birds from

these levels at Sun Hole would require some bushes and scrubland. However, it is important to remember that we can no longer identify the exact level(s) from which each of these elements came; the finds may represent one or several faunas, concentrated in one layer or disseminated throughout many layers.

All the faunal remains collected during the period 1977-80 were extracted by the present author from sediment samples. Curren's determinations of this material are shown in fig. 66. In addition, collared lemming (Dicrostonyx torquatus) was recovered from Layer C of the 'hanging breccias'. Curren notes that the saiga antelope, an animal reported to avoid uneven ground rigorously, "... may represent a wolf kill on the Somerset Levels during what appears to have been one of the very rare incursions of saiga herds into the British region" (in Collcutt et al. 1981:33). Curren continues:

When considering the new microvertebrate finds, the principal lithostratigraphic boundaries (Unit boundaries) do not necessarily provide a sufficiently detailed framework to express the significant changes seen in the faunal sequence. Unit I is divisible on faunal grounds into three parts, Layer 1 with what may be a very early Holocene fauna wanting in lemmings and including mole and wood mouse, Layers 2 to 8 with abundant Dicrostonyx torquatus, and Layers 9 to 13 in which lemmings are absent and fauna generally scarce. It should be noted that, although the fauna from the old excavations cannot be accurately located within the present stratigraphic framework, the animals preferring at least some woodland (beaver, etc.) were recorded from well within the Pleistocene deposits. It seems very unlikely that these animals were found in the equivalent of our Layer 1, especially since these sediments are easily recognized by their massive carbonate content and were, in fact, clearly described by Tratman as lying well above the spits which produced the woodland types.

Unit II continues downwards through Layers 14 to 18 with a very sparse fauna indeed. The record of Lemmus in [the probably naturally disturbed] Layer 18 is significant in being the lowest evidence so far recovered of any characteristically cold climate forms.

Unit III is by far the most interesting of the newly sampled deposits. Cold forms are entirely absent even though Microtus species are quite well represented. Although no diagnostic forms have been found, there is nothing from the deposits of Unit III that would be inconsistent with an interglacial assemblage. If this preliminary suggestion can be substantiated by additional sampling, it will be the first good evidence of an interglacial fauna in the Cheddar area and one of very few in Mendip as a whole.

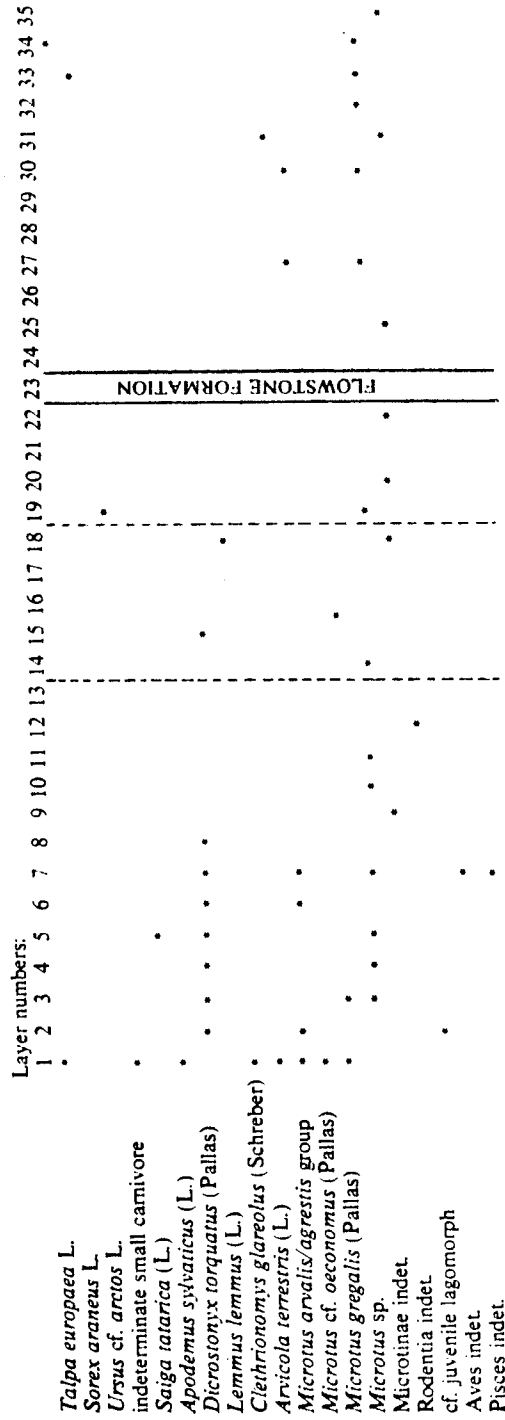


Fig.66 Sun Hole - Fauna from the 1977-1980 Excavations

(after Collicutt et al. 1981)

There is no evidence to suggest that any of the large mammal remains found in Sun Hole are human food debris. Hare, beaver, saiga and reindeer are all part of the known diet of modern wolf packs; horse was also probably in this category but is now virtually unknown in the wild. The microvertebrates are most probably derived from the regurgitated pellets of birds of prey such as the snowy owl. (ibid., p.34)

22.2.5. Sun Hole - Archaeology and Radiocarbon Dating

The Later Upper Palaeolithic artefacts from Sun Hole were found during the early excavations by the U.B.S.S. group; 43 were available to Campbell (1977) for study, of which only 8 were retouched tools. Campbell did not recover any struck flint material or charcoal from his excavation. One of the aims of the present project was to localise the palaeolithic layer(s) by microscopic scanning of all sediment samples; in 1981, it could only be reported that this attempt had failed. One flint blade was found at the very top of Layer 2 in a most probably disturbed position; no other flint, not even sand sized chips, was identified. No significant concentrations of bone debris were recognised. Only the very top of Layer 1 contained charcoal; this was present as abundant sand sized particles and might represent either holocene human occupation (cf. Tratman & Henderson 1928) or natural vegetation fires on the surrounding slopes. Although these results are disappointing, samples from any remaining deposits from nearer the cave entrance will be subjected to the same treatment as soon as they can be cleared of the present cover of tip. The puzzle remains as to why a few human bones were found associated (?) with what was obviously a very minor L.U.P. intrusion into the cave.

Campbell (1977) obtained a date of $12,378 \pm 150$ B.P.

(BM-524) on a radius of Ursus arctos from the B2-7 level of his excavation, apparently the equivalent of part of Layer 6 of Unit I,

providing valuable confirmation of the expected age of the fauna. However, Campbell argued that this bear bone could be situated within the stratigraphic range of the L.U.P. artefacts and that the date applied to the human occupation, indeed, that bear was actually hunted. The present author is not convinced that the rather isolated pocket of sediment in which the bone was found can be accurately placed within the main stratigraphy; this deposit has not been observed during the present study (it lies nearer the front of the cave, in the fragmentary sequence along the east wall) and the argument is based upon Campbell's section drawings alone. Furthermore, there is no evidence that bear, or any other animal, was exploited by man at this site.

Three more bone samples have been radiocarbon dated from the old U.B.S.S. collection. None of these samples can be shown to be archaeological specimens but, with this slight possibility in mind, large herbivore bones were chosen. The samples are referenced with the depths of the excavation spits measured from the top of the pleistocene levels as recognised by Tratman. In order to provide enough material for collagen extraction, each sample contained a number of different bones; these bones were considered by J.W. Jackson to represent single individuals of the species named (Tratman, pers.comm.). The results are as follows:

Birm-819	10,110 \pm 160 B.P.	0.9-1.2m	<u>Rangifer tarandus</u>
Birm-820	10,280 \pm 200 B.P.	1.5-1.8m	<u>Rangifer tarandus</u> and <u>Equus</u> sp.
Birm-821	10,470 \pm 190 B.P.	2.0-2.3m	? <u>Equus</u> sp. (bone and tooth)

The following conclusion was drawn from these dates:

It should be noted that (a) the central dates are in stratigraphic order; (b) the dates suggest relatively rapid sedimentation, a proposition fully

supported by the present study; and that (c) the 2σ bracket covered by the dates (9,790 to 10,830 B.P.) is in keeping with the faunal and sedimentological data. If the archaeological remains fit somewhere within this span of sedimentation, as seems most likely, the younger dating appears more plausible, judging from similar material elsewhere (cf. Jacobi, 1980), than does Campbell's older date. We reiterate that none of the dates are in archaeological association; this question cannot be finally settled until the 'occupation layer(s)' is/are unequivocally recognized. (Collcutt et al. 1981:35)

No new dating evidence concerning Unit I has been forthcoming since 1981. However, in 1984, there is perhaps a general feeling amongst British prehistorians (as yet unvoiced in print) that the L.U.P. may in fact start a little earlier than appeared likely in 1981. Therefore, it should be clearly stated that, although all the factual information given above stands, there is no intrinsic reason why L.U.P. material should not date from the thirteenth millennium B.P.

22.2.6. Sun Hole - Discussion (First Approximation)

The sequence at Sun Hole obviously comprises deposits representing considerable periods and varied environments. Layer 1, and those upper deposits described by Tratman (1955; his layers 1-4) but probably no longer available for study, are holocene in age. The remainder of Unit I (Layers 2-13) represents at least part of Late Devensian time, as indicated by the radiocarbon dates; the faunal remains, and to some extent the sediments as well, suggest significant fluctuation in environment during this period. Unit II is composed of sediments laid down under more rigorous conditions, probably colder and drier. Unit III, with its soil-derived material, phases of carbonate precipitation and lack of cold fauna, would seem to represent an interglacial environment, though here again there are suggestions of climatic fluctuations in the sediments. The dating of the

'hanging breccias' is problematic; these are generally cold climate deposits, with the stalagmite (Layer D), which may perhaps cap them, representing a milder phase.

The possible affinities of the silts of Unit II deserve further discussion. Findlay (1965) noted that certain soil substrates on Mendip have an unusually high silt (20-60 microns) content. The soils involved include brown earths of the Nordrach Series and shallower (slope) soils of the Mendip (Soil) Complex, developed all over the Mendip plateau from approximately Cheddar Gorge eastwards. Findlay was well aware that the insoluble residues from the limestones in this area are rich in silts, but he doubted that the silty soil substrates, averaging c.1m in thickness over very wide areas, could be totally accounted for by in situ limestone weathering. Mineralogical study showed that the limestones generally contain euhedral quartz, rare feldspars (c.1-2%) and rare heavy minerals (mostly zircon, rutile, tourmaline and garnet, that is, the most resistant types). However, Findlay reported that the silty soil substrates contain detrital quartz, appreciable feldspars (5-10%) and more common heavy minerals (very common epidote and chlorite, with hornblende and perhaps micas also more common than in the limestones). Findlay concluded that the silts were most probably of aeolian origin. Certainly, the mineralogy is very similar to that of other 'silty drifts' in south-west England (cf. Harrod et al. 1973; Perrin et al. 1974). Findlay also pointed out that the fine substrates of the related Lulsgate Series Soils become appreciably sandier towards western Mendip and that they pass laterally into the obvious coversands of the Bristol Channel coastal zone.

The present author has checked the particle size distributions in several of the cave sites studied by Campbell

and found that Campbell's reported results for the fine matrices are always too coarse (Campbell's sieves were not at fault and it seems that the most likely explanation is that given above on p.900). Nevertheless, Campbell was still able to make the following suggestion:

In summary, it would appear from the granulometric analyses of the author's samples that Earlier Upper Palaeolithic artifacts at Badger Hole [cf. p.951 in the present text], Long Hole [Gower; cf. Chapter 23 in the present text] and possibly Hyena Den [cf. p.976 in the present text], are associated with layers of silty sand containing variable proportions of thermoclastic scree, the suggested age of which is Middle and possibly early Full Last Glacial, whilst Later Upper Palaeolithic artifacts at Sun Hole, Cathole [Gower; cf. Chapter 23 in the present text], Mother Grundy's Parlour and Robin Hood's Cave [both in Creswell Crags, Derbyshire] are more often associated with higher frequencies of thermoclastic scree, the suggested age of which is Late Last Glacial. (1977:93)

Apparently without knowledge of Findlay's work, Campbell interpreted the fine material associated with E.U.P. artefacts as aeolian sediment and, in the case of Mendip, suggested a link with the coversands further to the west (*ibid.*, p.89). Other instances of possibly Middle Devensian or early Late Devensian siltier deposits on Mendip include Bridged Pot Shelter and Lion Shelter (Ebbor Gorge; McBurney 1959), Soldier's Hole (Cheddar Gorge; with E.U.P. artefacts; Parry 1931) and Picken's Hole (Crook Peak; with possibly E.U.P. or late Middle Palaeolithic artefacts; Tratman 1964; cf. Campbell 1977; Hawkins & Tratman 1977). The last named site has a radiocarbon date of 34,365±2600/-1950 B.P. (Hawkins & Tratman 1977). The mammalian faunas from these silty deposits, unlike faunas from sites younger than c.15,000 B.P., variously include such animals as red-cheeked suslik (Spermophilus cf. major), hyaena (Crocota crocuta), lion (Panthera leo), mammoth (Mammuthus primigenius) and woolly rhinoceros (Coelodonta antiquitatis) (cf. Campbell 1977; Stuart 1977b).

The next step in the study of the Mendip 'silty drift(s)'

must clearly involve attempts to link the cave deposits, including that at Sun Hole, with the almost certainly aeolian soil substrates, using such techniques as scanning electron microscopy of quartz grain surface textures and, more especially, arguments based on silt mineralogy. If such links can be proven, the cave sites can then be investigated for more precise dating evidence concerning this regional sediment body (or bodies). Also, it would be interesting to check whether or not continuity with the coastal coversands, implied by several authors, is a reality, since this would suggest a local wind transport system active from the west or north-west, rather than the easterly derivation usually assumed for all finer aeolian deposits in southern Britain (cf. Perrin et al. 1974).

There remains one further aspect of the data available from Sun Hole which may have important implications for the study of British quaternary cave deposits. Campbell (1977) was able to recover very small quantities of pollen from material split from his sediment samples. The genera represented in Campbell's layer A2, probably the 'coldest' sediment so far exposed, includes traces of Abies (fir), Tilia (lime) and Alnus (alder). There is a large increase in thermophilous tree pollen in Campbell's layer A1, equivalent to the top of Unit III, including Carpinus (hornbeam), but these types of pollen are also present well up into Unit II. It is clear that pollen has migrated both down the sequence and perhaps also stratigraphically upwards, following suffosion paths stepping up the inclined sequence whilst maintaining a generally downward trend. It is fashionable in this country to dismiss cave pollen as meaningless because cave sediments as a whole are, mistakenly, thought to be too open and coarse and therefore always subject to pollution. At first glance, Campbell's results from

Sun Hole would seem to support this conclusion. However, it is difficult to dismiss the presence of Picea (spruce) and Abies in Campbell's samples, neither of which occur naturally in the British Holocene (cf. West 1977); Picea is last recorded in the Chelford Interstadial, Abies in the Ipswichian. Is it mere coincidence that evidence from the most recent study also points to interglacial conditions in Unit III? Some of the layers of Unit III, below the level reached by Campbell, are very rich in contemporary colloids and might function as closed systems for pollen preservation, especially those layers with organic as well as mineral colloids. It is the intention of the research team to build upon Campbell's preliminary work in this field.

In 1981, Collcutt et al. made the following statement:

It would be a simple matter to interpret every minor shift in the faunal and sedimentological parameters and to pigeon-hole all these deposits with the 'classic' labels of British Quaternary stratigraphy. We choose not to do this, since we feel that our information is not sufficiently complete and we have realistic hopes of widening our data base in the near future. For instance, all or part of Unit III might be of Ipswichian age but it could equally well represent various other interglacials. Why be impatient when larger faunal collections and uranium-series dates on stalagmite will surely provide firm evidence one way or another? Similarly, we have restricted our present report to verbal data in order not to seduce the reader with seemingly authoritative tables of numbers and proportions. This is particularly true of the sedimentological study, where we have concentrated upon the range of processes evidenced rather than upon complex shifts through time. We repeat that only one narrow section in the cave has been studied so far. (1981:36)

The priorities for the continuing Sun Hole project were therefore clear.

22.2.7. Sun Hole - Discussion (Second Approximation)

The suggestions made in 1981 were preliminary in as much as it was clear that basic data were lacking at several important points in the arguments. Some new information is now available.

However, this information does not provide 'answers' as such; rather, it serves to raise further questions and thus to orient future research at the site. There has been some additional sampling since 1981 but the restricted study exposures have not yet been extended. The new information will be briefly discussed here and the opportunity will also be taken to clarify certain points raised in the 1981 report.

Before continuing this discussion, it seems important to state, even more explicitly, that our approach to research at Sun Hole involved, and continues to involve, two guiding principles. First, we have endeavoured to integrate information from the various interested disciplines and we have attempted to evaluate the consequences of both concordant and discordant data sets. Second, given the nature of the evidence, we have maintained an extremely cautious attitude towards environmental and chronostratigraphic interpretation. We feel that recent developments have fully vindicated this approach (infra). The present author is therefore greatly disappointed that other researchers have not always seen fit to follow our lead:

The main Unit I fauna, radiocarbon dated to zone III, includes arctic elements - tundra vole, lemmings and reindeer together with the more temperate water vole and probably also field vole. Steppe animals are represented by pika and also saiga antelope. The latter is only the second British record (the first, of Middle Devensian age, is from Twickenham, London). Collcutt et al. noted the more temperate nature of the sparse faunas from Units I and II and suggest that these may be partly of interglacial age. It seems more likely, however, that these beds will prove to date from the Late Devensian Interstadial. (Stuart 1983:31)

Stuart has clearly not acted in accordance with the sort of guiding principles noted above. First, he pays scant attention to data from outside his own particular field, namely palaeontology; this contrasts with the much more broadly based

view of A.P. Curren, for whom very few quaternary disciplines are a 'closed book'. Second, Stuart has not been able to resist the 'pigeon-hole' approach. The "main Unit I fauna" is certainly not radiocarbon dated exclusively to Pollen Zone III, as reference to Collcutt et al. (1981), or to previous sections of the present text, will show. It is not quite clear how our suggestion of interglacial conditions (actually in Unit III) has become superseded by a suggestion of "the Late Devensian Interstadial", presumably equivalent to "the Late Devensian Windermere Interstadial (= Allerød in part), c.14,500-11,000 years B.P." (Stuart 1983:23). No evidence is adduced to support this counter-suggestion and it is most sincerely to be hoped that Stuart has not merely 'counted from the top', since this would be a facile and, in the context of a necessarily brief synthesis, a rather high-handed approach.

Since the 1981 report, several colleagues have expressed surprise that we did not subdivide Unit I further, along the lines suggested by the three, relatively clear faunal groupings noted by Curren. The reason for this is quite simple, namely, both Layers and Units are lithostratigraphic concepts, whilst the faunal groupings are biostratigraphic concepts. There is no obligation, indeed it would be unacceptably restrictive, to merge the two systems. Curren is perfectly free to define his own 'rock intervals'; for the moment, he is satisfied that the minor lithostratigraphic units, Layers, have sufficient palaeontological integrity to justify their use as parallel biostratigraphic units, thus avoiding a currently unnecessary proliferation of terms. Note that we have collectively decided not to employ the term 'biozone' for the faunal groupings at this stage of the project because it is felt that even explicitly informal usage is too

open to misinterpretation and premature 'reification'. This is also the reason for the choice of 'layers' and 'units', rather than the informal use of 'beds' and 'members', in the lithostratigraphic scheme. Even in an informal classification, 'beds' and 'members' should be three-dimensional phenomena; our present appreciation of the Sun Hole sediments is still approximately two-dimensional.

Despite the lack of any need to force the two stratigraphic schemes into rigid correspondence, the present author is willing to discuss the possibility that the faunal changes between groups of layers in Unit I might coincide with shifts in the sedimentary parameters. Additional microfaunal remains have been recovered since 1981 from various layers in Unit I but no new taxa have been recognised (Currant, pers.comm.).

The youngest faunal grouping was obtained from Layer 1. There are strong suggestions that this is an early holocene fauna and the sedimentary evidence is totally concordant with such a date (cf. the massive increase in tufaceous carbonate precipitation compared with lower strata). There are already perfectly good lithologic grounds to expect that Layer 1 will eventually need to be separated from the rest of Unit 1; the reason that this has not yet been done is simply that there is no acceptable exposure of the relevant boundary (cf. fig. 60). A better exposure will become available shortly and the question of lithostratigraphic classification will then be reconsidered.

The other two faunal groupings in Unit I comprise Layers 2-8 and Layers 9-13. There are no presently recognised lithologic criteria that would serve to define major subdivisions within the sequence of Layers 2-13. These sediments are quite variable on a small scale and there are even a few irregular trends

(e.g. a slight decrease in the silt component and a slight increase in the allochthonous sand component upwards), but this material presents the sort of overall homogeneity that the present author would normally associate with roughly 'member' rank. Looking at the Layer 8/9 boundary more closely, there is no marked lithologic shift. Nevertheless, the boundary is quite abrupt and Layer 9 is slightly richer in matrix carbonates than adjacent strata. Perhaps more significantly, there is an apparent change in bedding geometry, the strong easterly component of dip seen in Layers 9-13 (and in Unit II) weakening in Layer 8 and disappearing by the top of Layer 7. Note that we are concerned with cross-cave dips here; a strong southerly dip component, out of the cave mouth, is maintained throughout Layers 2-13. It seems possible that the combination of the easterly dip component with the generally tabular bedding (as opposed to bedding converging to the west) in Layers 9-13 might be due to input via the linear roof fissure (cf. p.923), with minor low energy redistribution due to wash, creep and other generally 'damp' processes. The term 'sludging' was used in 1981 (cf. fig. 64), a word which was deliberately chosen for its vagueness but which, in retrospect, probably conveyed the idea of rather more energetic conditions than those which are in fact likely to have prevailed. It may therefore be said that the faunal change at the Layer 8/9 boundary does not appear to correspond to a high ranking lithostratigraphic boundary. Nevertheless, the change in bedding geometry remains interesting. One wonders whether there is any significance in the fact that Layers 9-17, which show the easterly dip component (open roof fissure?), are all extremely poor in microfauna, whilst Layers 8-2, with little cross-cave dip (relatively closed roof fissure?), are comparatively rich in microfauna. The Layer 8/9

boundary probably marks a general biotic change, but it may also represent a micro-environmental shift towards conditions within the cave that were more attractive to the birds of prey and other small predators responsible for microfaunal accumulations.

Whether or not the (inferred) closing of the roof fissure has any specific environmental significance on a regional scale remains very much a matter for future investigation.

In 1981, it was reported that the attempt to identify archaeological debris in the sediment samples had failed. Examination of much larger splits of all the original sediment samples from Layers 2-13 (SNH 9-30) has since resulted in the recovery of certain material which may possibly be relevant to this topic.

Thirteen fragments of chert (sensu Clayton 1984; i.e. a group of rocks including chalk flint) have been extracted from the 1.0-0.5mm sieve fraction of SNH 28 (Layer 12). These fragments are all highly angular and, although they are very small, they all display the characteristics of brittle fracture unmasked by any later abrasion. Linear incipient fractures are common, especially near points of impact, and a few pieces carry clear points and/or cones of percussion, incipient cones, tiny bulbar scars, edge-lances or arcuate snap terminations; two of the largest pieces (but still under 1.0mm in width) even show undulations. Overall shapes include three true flakes, although most of the pieces are more equidimensional, roughly tetrahedral forms. The fragments are variously 'patinated', an effect which is by no means restricted to surfaces. At one extreme, there are pieces that are moderately transparent in air and strongly so under water. Structural elements within the chert are picked out by 'milky' hydration zones, but some original colour can still be seen, even

in very thin pieces. This colour is difficult to define, since we are dealing with transmitted rather than reflected light. However, it may be visualised as a 'tinge' of very approximately strong brown (c.7.5YR 5/6), which is reasonably close to the Munsell colour when seen through more than c.0.5mm of rock, more 'watery' in thinner pieces and more 'milky' (losing chroma and gaining value) in hydrated zones. More 'patinated' pieces are less transparent and the most highly affected fragments are opaque in air and merely translucent under water. The dominant structure within the chert consists of masses of roughly spherical 'grains', c.15-25 microns in diameter; these would appear to correspond to the lepispheres figured and discussed by Clayton (1984). As has been said, these structural elements are visible (especially under water) because of 'patination' (natural alkaline etching, rather than the artificial acid etching used by Clayton); some highly 'patinated' pieces have actually lost some of these 'grains' from their surfaces, leaving zones with roughened texture. As the chert becomes more 'patinated' and the structural elements are etched to give a truly 'sugary' texture throughout, the rock becomes less isotropic; some incipient fractures are stepped and multiple, and they have clearly been initiated after some structural differentiation. Other structural elements include elongated quartz monocrystals with thin rims/overgrowths, and long curved objects which are probably silicified shell fragments. One chert flake (c.1.72mm long and c.0.97mm wide) contains a foraminiferal test, of the chambered spiral form so common in (but not restricted to) species from the Cretaceous. The relatively large test is c.0.38mm in diameter in the plane of the spiral; there are c.2.5 coils (revolutions), with c.10 chambers to a coil and comparatively straight septa. Although the fossil has

been etched, it is possible that enough detail remains for specialist identification. SNH 28 has also produced five angular chips of a 'white', opaque chert with a slightly hackly fracture, a rock type not seen in other samples.

A single chert flake was recovered from SNH 20 (the top of Layer 7); its maximum dimension is c.2.05mm. It shows various brittle fracture characteristics. The raw material is very similar in overall structure and colour to the transparent type from SNH 28, save that this flake includes a tiny primary vug bordered by irregular quartz crystals (druse).

The present author is not particularly experienced in the identification of cherts. However, it seems unlikely that the transparent type is a Lower Carboniferous chert. It is probably either an Upper Greensand chert or a comparatively shallow-water facies (cf. the detrital and bioclastic component) of chalk flint. Axminster Greensand chert (as observed in Lower Palaeolithic artefacts from Broom, Devon/Dorset) appears to be composed of large, irregular structural elements (c.90-350 microns; bioclasts?) floating separately in a clear chalcedonic matrix. Clayton (1984) implies that Greensand cherts from southern England are typically chalcedonic rather than lepispheric. Most mesozoic cherts (including flint) that occur naturally on Mendip have been subject to very long periods of alteration and fragments are usually totally opaque and very friable. It is therefore surprising to find angular fragments of quite fresh chert at Sun Hole. However, it would seem premature to claim that these tiny chips necessarily represent archaeological debris or even natural debris derived from a manuport. Furthermore, those certain artefacts from the old excavations that the present author has seen are made from a blue/black chert (flint), quite unlike the

new material reported here. On the other hand, a single impact on one larger piece of chert could easily have produced all the tiny chips so far recovered, and Mendip Upper Palaeolithic sites often show a rather broad range of raw materials. The Sun Hole case will obviously require further investigation although, from a theoretical point of view, it is pleasing to be able to demonstrate that tiny chert debris, showing fresh mechanical fractures, can sometimes be identified from alkaline cave sediments of late Upper Pleistocene age. With respect to extraction techniques, it should be noted that etched chert surfaces interfere with the process of wetting in such a way that air bubbles will be trapped when pieces are immersed in most common liquids; small chert fragments often float until the bubbles are removed and care must be taken not to lose the pieces during wet preparation.

No new information is yet available for the silty strata (Layers 14-17) of Unit II. Additional sampling for identifiable microfauna has so far proved fruitless (Currant, pers.comm.), although some fine bone debris continues to come to light. However, the western part of Layer 18, unaffected by the suffosion evidenced further east (cf. p.907), has now been exposed and sampled. This is a rather unusual deposit since, apart from larger limestone clasts (including boulders). it is composed of masses of angular, unaltered but slightly edge-rounded limestone 'grit'. The 'grit' has a particle size distribution with a very strong mode in the 0.5-8.0mm fraction, a badly sorted calcitic sand and coarse silt 'tail', and a minor mode in the colloids; apart from the colloids, it looks remarkably like artificial grit from a mechanical crusher (cf. a Rosin distribution). Given the paucity of finer matrix, the deposit is comparatively well

compacted. There are no internal bedding features and no sign of any other specific structural properties. Although most of the coarser debris is local calcite mudstone, there are also significant quantities of dolomitic conglomerate, a light grey limestone, speleothem fragments and aggregates of limestone (calcite mudstone) debris cemented by crystalline calcite. Despite microscopic scanning of c.30kg of this sediment, not a single bone fragment (mega- or microfaunal) was found in the fraction >0.5mm diameter. These results reinforce the impression that Layer 18 is a major collapse deposit. However, the presence of exotic limestone types is puzzling since they cannot be intrusive in this relatively closed fabric. Some sediment must have collapsed at the same time as material from the roof/walls, although this sediment does not appear to have included faunal remains. Now that an original finer component (as opposed to a derived suffosion lag; cf. SNH38) has been recognised in Layer 18, it will probably become useful to split this deposit off from the other, lithologically distinct layers of Unit II.

New information concerning Unit III indicates an extremely complex situation. Both Carrant and the present author have extracted microfaunal remains from larger samples of a number of the layers in this unit. Carrant (pers.comm.) has been able to recognise two groupings within this new material. The first comes primarily from Layers 19-20. Only unspecified Microtinae had been previously recorded from these layers; to these must now be added the collared lemming (Dicrostonyx torquatus) and the Norwegian lemming (Lemmüs lemmus). The faunal fragments are of a distinctive preservation type, including a dark staining of the bone. A tooth of Dicrostonyx with the same preservation characteristics has also been recovered from Layer 24; since Layer 23 has clearly been

naturally disturbed in this area (cf. fig. 60), it seems possible that the lemming tooth in Layer 24 has worked its way down from a higher level. The second faunal grouping comes from at least Layers 31 and 34; further sampling will be necessary before the complete stratigraphic range of the grouping can be defined. Layers 31-34 had previously provided mole (Talpa europaea), common shrew (Sorex araneus), unspecified voles (Microtinae), and remains of a water vole initially identified as Arvicola terrestris. These last specimens, together with new material, are now thought to be referable to the earlier form, Arvicola cantiana. Curren has identified additional Sorex remains from the new samples and has added the following species: wood mouse (Apodemus sylvaticus), bank vole (Clethrionomys glareolus) and pine vole (Pitymys arvaloides). An important characteristic of this material is that less damaged specimens (including more fragile parts) are restricted to the interior of carbonate-cemented aggregates.

The terrestrial mollusca extracted by the present author from Layers 33-34 have been examined by C. Ellis (Imperial College, London University). Despite the extremely fragmentary nature of the specimens, she has been able to identify Lyrodiscus sp. Additional samples have been taken in order to try to extract more complete material using flotation techniques rather than sieving.

Speleothem fragments from Layers 23, E and D have been subjected to U-series analysis by P. Smart (Bristol University). The samples studied so far are not optimal, there being a certain amount of detrital contamination and perhaps a little recrystallisation. Further sampling will be necessary before any detailed discussion of speleothem chronology can be attempted. Nevertheless, it would appear that all three of the 'layers' date from (possibly) different periods within the first two thirds of

the Upper Pleistocene. Note that only Layer 23 is an in situ formation.

This information may be summarised as follows. First, there is an upper set of strata, certainly including Layers 19-20 but possibly extending down as far as Layer 22, which contains a 'cold' lemming fauna. Second, there is the stalagmitic material of Layer 23 which appears to represent an intra-devensian (pre-'glacial maximum') episode. Third, the high position of the disturbed floor slabs of Layer D seems to suggest that the cave was filled to approximately this level only relatively shortly before the deposition of Layer 23. The disturbed stalagmite of Layer E, embedded within Layer 22, would also indicate that its surrounding context is younger than the beginning of the Upper Pleistocene. Fourth, certain faunal elements (A. cantiana, P. arvaloides, Lyrodiscus sp.) indicate a date for the biotic component of at least Layers 31-34 within the later Middle Pleistocene (Carrant and Ellis, pers.comm.). Furthermore, it may be firmly stated that the faunal assemblage of Layers 31-34 is by no means incompatible with interglacial conditions, whilst (pace Stuart) it is most certainly incompatible with an age within the Windermere Interstadial, or even with an environment similar to that prevailing during this interstadial. Finally, in order to prevent any possible misunderstanding of the 1981 discussion, it should be noted that no sign of an ipswichian fauna has yet been recognised at Sun Hole.

The complexity of Unit III, and of the various 'hanging' and derived elements, will obviously necessitate a much more detailed investigation based upon significantly enlarged exposures. Certain topics will require special attention.

Before any attempt to date speleothems, Smart indicated

(pers.comm.) that he believed in situ stalagmite, in this case Layer 23, to be indicative of a significant change in sedimentation pattern and that he would have recognised a major lithostratigraphic boundary at this level in the sequence. The present author agreed in principle and, had the stalagmite been sandwiched between more banal cave sediments, he might well have placed a 'Unit' boundary at this level. However, the sediments above and below Layer 23 are not only similar but also rather unusual. The well stratified sinter bands (cf. Layers 21, 25 and 28) are particularly suggestive of a certain measure of sedimentary continuity. Naturally, the new faunal information and the preliminary U-series results caused the present author to check the sedimentary data as far as was possible without renewed excavation. There are certainly some differences between the post- and pre-Layer 23 strata in Unit III. For instance, compared with lower strata, Layers 19-22 have slightly more, and coarser whole sand, and the whole silts, on the one hand, and the non-carbonate fine sands and coarse silts, on the other, are a little better sorted. Speleothem fragments, especially stalactites and curtain material, are certainly more common in Layers 19-22. There is very little alkali-soluble organic matter in Layers 19-22, but this is also true of the sediments down to Layer 29. Mollusca are present in similar quantities within Layers 19-29. To the present author's mind, there are grounds for placing a major lithostratigraphic boundary at the Layer 29/30 junction which are at least as good as those supporting such a boundary at or about Layer 23. Given the present data base, the author is still disinclined to split Unit III into several units of roughly 'member' rank, although it seems likely that some preformal equivalent of 'submembers' will shortly become useful.

The whole question of the interpretation of Unit III would appear to revolve around taphonomy. Interesting variations in micromammal taxonomy and preservation type have been recognised. We now need to pursue these lines of evidence so as to identify the exact stratigraphic points at which the parameters change or, alternatively, we need to discover whether or not certain strata contain mixed micromammal assemblages. Molluscan debris occurs in most layers of Unit III; we do not yet know whether or not several distinct inputs are represented. It is imperative that we discover to what degree the faunal elements are contemporary with the sedimentary context in each layer. In this connection, Curren's observation that much of the later Middle Pleistocene micromammal material is associated with concreted aggregates necessitates a re-examination of the present author's earlier suggestion that such aggregates are postdepositional (cf. p.917). The aggregates are certainly not derived from any known 'hanging' deposit, but at least some of the aggregates might nevertheless be in a derived position. Also, the present author has never been totally convinced that he has correctly assessed the process(es) responsible for the emplacement of the dense, matrix-supported and weakly differentiated sediments of Layers 31-35. There is a possibility that these are major mass movement deposits and that the included faunal material is significantly older than the sedimentary context. Relatively long distance transport by mass movement through the karstic system would help to explain the presence of exotic rock types at Sun Hole; stream transport was suggested in 1981 (cf. p.916), but this hypothesis was never very attractive because of the lack of even a minor component of abraded and rounded pebbles (except for those clearly derived from decomposing dolomitic conglomerate). To settle this point,

not only will larger exposures be necessary, but we will also need to discover what lies beneath these dense sediments.

Concerning palynology at Sun Hole, Dr. K. Crabtree (Bristol University) has very kindly expressed an interest. However, it would seem best to postpone work on the pollen until some of the contextual uncertainties can be overcome. The site will definitely not afford the 'luxury' of a sequence of meaningful pollen assemblages, so that we must be certain, before any analysis, that samples come from reasonably discrete contexts of known sedimentary history. There are no such contextual problems associated with the carbonate sinter and work will go ahead shortly to try to extract spores from these suspected eucladioliths.

At the beginning of this section, it was stated that the most recent investigations have raised new and more detailed questions concerning the site. This situation is pleasing, since it would hardly be worthwhile to continue the work if we could only duplicate earlier findings. Sun Hole is logistically a very difficult site to excavate, due to its deep stratigraphy and its location on a precipitous slope/cliff directly above the most heavily frequented road on Mendip. Despite these difficulties, research should continue as long as we are able to frame specific questions in terms of testable hypotheses.

22.3. The Caves of Wookey Hole Ravine

22.3.1. Wookey Hole Ravine - Introduction

Wookey Hole Ravine (ST 532478) is a short, but steep sided valley, running generally southwards from Wookey Great Cave at the valley head, out towards the lower land at the foot of the Mendip

'escarpment'. The Great Cave is still very much active, its large stream receiving water from a catchment on the plateau above that has been estimated at a minimum of some 33km² (Barrington & Stanton 1977); this stream is the source of the River Axe. Water flow is no longer 'natural', the floor of the ravine being occupied by a paper mill, involving canalisation of the water supply since 1852; the Great Cave itself is open for public visits and the interior water levels are therefore controlled.

The geology of the area is quite complex, due to a series of thrust faults around the Variscan periclines, although the sequence is relatively clear. The oldest rocks are the Portishead Beds (Old Red Sandstone), outcropping at over 300m O.D. on North Hill (north of Wookey Hole) and on Pen Hill (east-north-east of Wookey Hole). Passing southwards or west-south-westwards towards the Wookey Ravine, rocks of the Lower Carboniferous are progressively encountered: Lower Limestone Shale, Black Rock Limestone (often massive or crinoidal), Burrington Oolite, Vallis Limestone (bioclastic) and Clifton Down Limestone (calcite mudstone). Younger rocks (Hotwells Limestone, Quartzitic Sandstone Group (Millstone Grit), and Lower Coal Series) are present along the Ebbor Thrust, a kilometre to the west of Wookey Hole, but it does not seem likely that these outcrops were part of the Wookey Ravine catchment, at least during the Upper Pleistocene. The Wookey Hole Ravine itself is cut into Triassic Dolomitic Conglomerate which constitutes the fossil infill of a very much larger, ancient valley. The land surface for at least c.1km around the ravine (west, north and east) is composed of this conglomerate, although Carboniferous Limestone (often calcite mudstone) outcrops underground, within the fourth chamber of the Great Cave (c.160m into the hillside) and periodically from thereon

inwards until the eleventh chamber, where the system passes once and for all into the primary limestones.

The sites discussed in this section are three small 'caves', formed exclusively within the Dolomitic Conglomerate, on the eastern side of the Wookey Hole Ravine. The sites lie very roughly one above the other, with Badger Hole at the top of the slope (its floor being at c.72m O.D.), followed by Rhinoceros Hole (c.66.5m O.D.), and Hyaena Den (c.63.5m O.D.) at the lowest point accessible above the recently disturbed valley bottom deposits (i.e. at least 5m above the 'natural' valley floor). A moderately accurate plan of the ravine and its caves is given in Balch (1914, Plate V); a new survey is in preparation.

It is not the author's intention to try to reconstruct and interpret the exact sequences in these three sites. Indeed, he could not do so even if he wished, since preliminary examination of the documents pertaining to earlier studies/excavations, as well as of the extant sediments, suggests that any such reconstruction, if it is now possible at all, will require the establishment of a major research project. One of the most fascinating points about these three sites is, in fact, their intractability. It is not that the sediments, and their contained faunas and artefacts, are hopelessly mixed; on the contrary, at least a few of the contexts appear to be surprisingly discrete. It is simply that there are several indications of an unusually complex sequence of events, possibly involving the transfer of material from one site to another. The author freely admits that he does not 'understand' these sites, beyond the firm conviction that progress cannot be made by the study of any one of them in isolation. The present section is therefore offered as an introduction, an attempt to pin-point some of the unexplained features, in preparation for

future research. To this end, basic, though selected information concerning each site will be set out in order to establish a sufficient framework for a general discussion.

22.3.2. Badger Hole

Description of this site is best approached by starting with the extant deposits, and then working backwards through time to earlier studies and excavations. A plan of the cave is shown in fig. 67; the deposits marked are extremely fragmentary and quite often very solidly cemented by carbonates. The most open area to the west is referred to as the 'Outer Chamber', whilst the area to the east (beyond the central constriction, which is partially 'real' and partially caused by particularly indurated deposits) is referred to as the 'Inner Chamber'. Traditionally, the 'Entrance' is at the west end of the cave, but there is also a large opening, now mostly choked with deposits, leading up eastwards to 'Hole Ground', the field above the site. Barrington and Stanton state that "the cave is basically a roomy tunnel cutting right through a Dolomitic Conglomerate ridge"(1977:29), a proposition which is most reasonable, although the present author does not agree with the further statements (ibid.) that two "passages" connect the two chambers (these 'passages' are merely presently passable routes, not discrete rock-cut features) and that the eastern opening is necessarily a "chimney". The mass of sediment, the 'Talus', choking the eastern opening has been skirted by old excavations, so that one may speak of the 'Northern and Southern Extensions'.

The deposits in the numbered Areas (cf. fig. 67 and the schematic representations in fig. 68) will be briefly described.

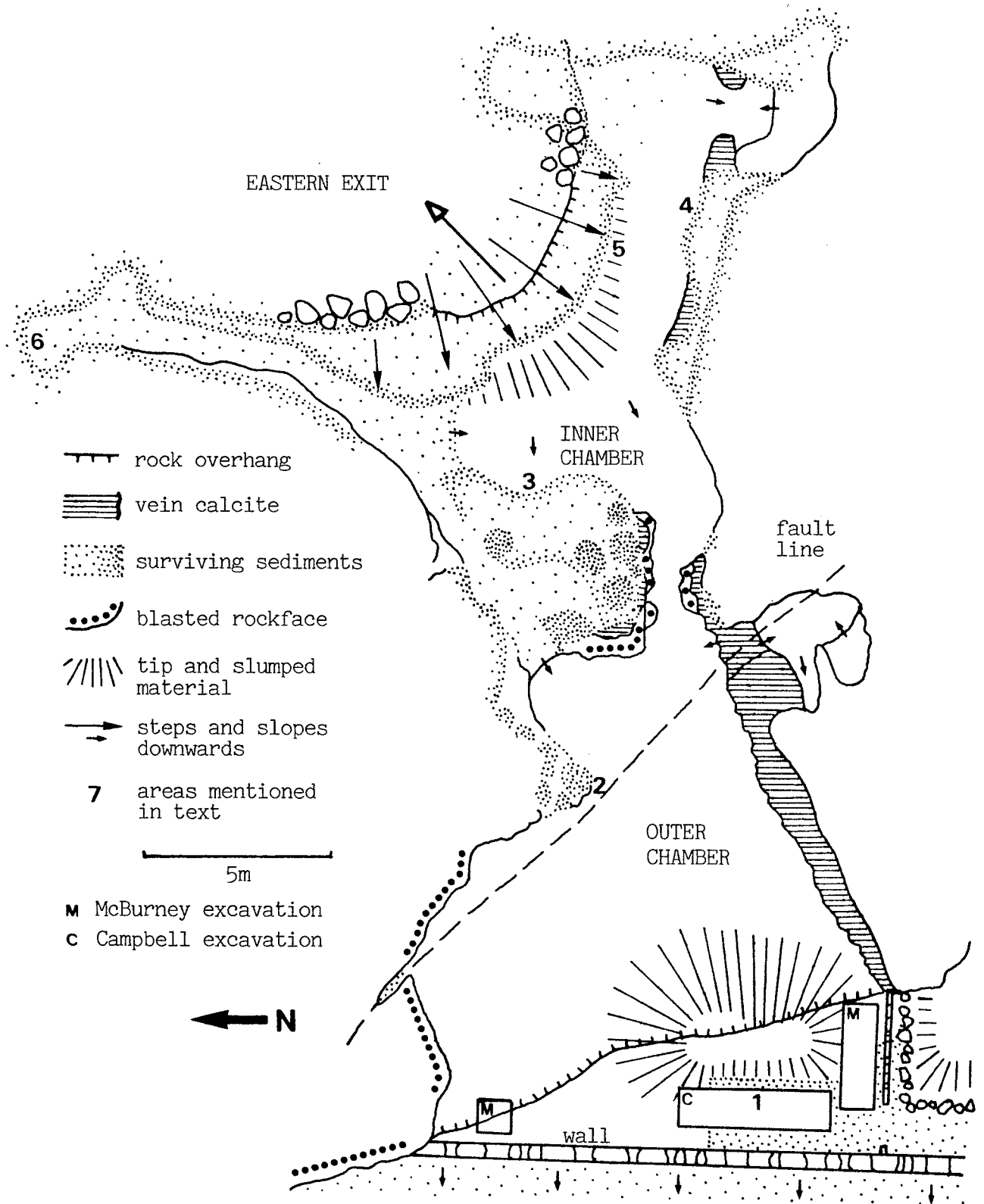


Fig.67 Badger Hole - Plan

Selected sediment samples (with the prefix 'BH') will be noted, so that these may be precisely referenced in section 22.3.5.

Area 1, at the Entrance, is covered by much archaeological tip and other apparently disturbed sediments. However, two deposits are visible above the bedrock (Campbell's designations will be used for these units, infra). The lower, layer "A2" (BH2), is a yellowish red (5YR 4/6), extremely silty deposit, containing relatively large clasts of Dolomitic Conglomerate which are quite heavily rounded and altered (weathering crusts). There is much debris in the coarser sand and fine 'grit' grades (including vein calcite, crinoid ossicles, water-abraded small pebbles and chert); debris of this sort, in the various deposits of the caves of the ravine, will be discussed in greater detail in section 22.3.5. Bone fragments and microfauna are quite common in "A2", and a few small pieces of burnt bone were noted. There is a moderately sharp upper boundary with the next deposit, "B/A3" (BH3). This is a dark reddish to reddish brown (5YR 3-4/4, with 'cream' flecks), badly sorted deposit, much richer in colloids and fine gravel than "A2". The deposit is very weakly cemented throughout by carbonates, and there are large quantities of dispersed, fine sinter particles (cf. p.919; the roof of the Outer Chamber is today covered in tufaceous eucladioliths). This cementation and the sinter component give a misleadingly 'sandy' feel to the sediment as a whole. There is some dolomitic sand, coarse and heavily rounded vein calcite sand and other sand sized debris. Clasts of Dolomitic Conglomerate and vein calcite are present as fine and medium gravel; they show moderate alteration. Bone fragments and microfauna are present. Neither of the units in Area 1 shows any specific structural features, beyond an increasingly loose packing upwards from the bedrock.

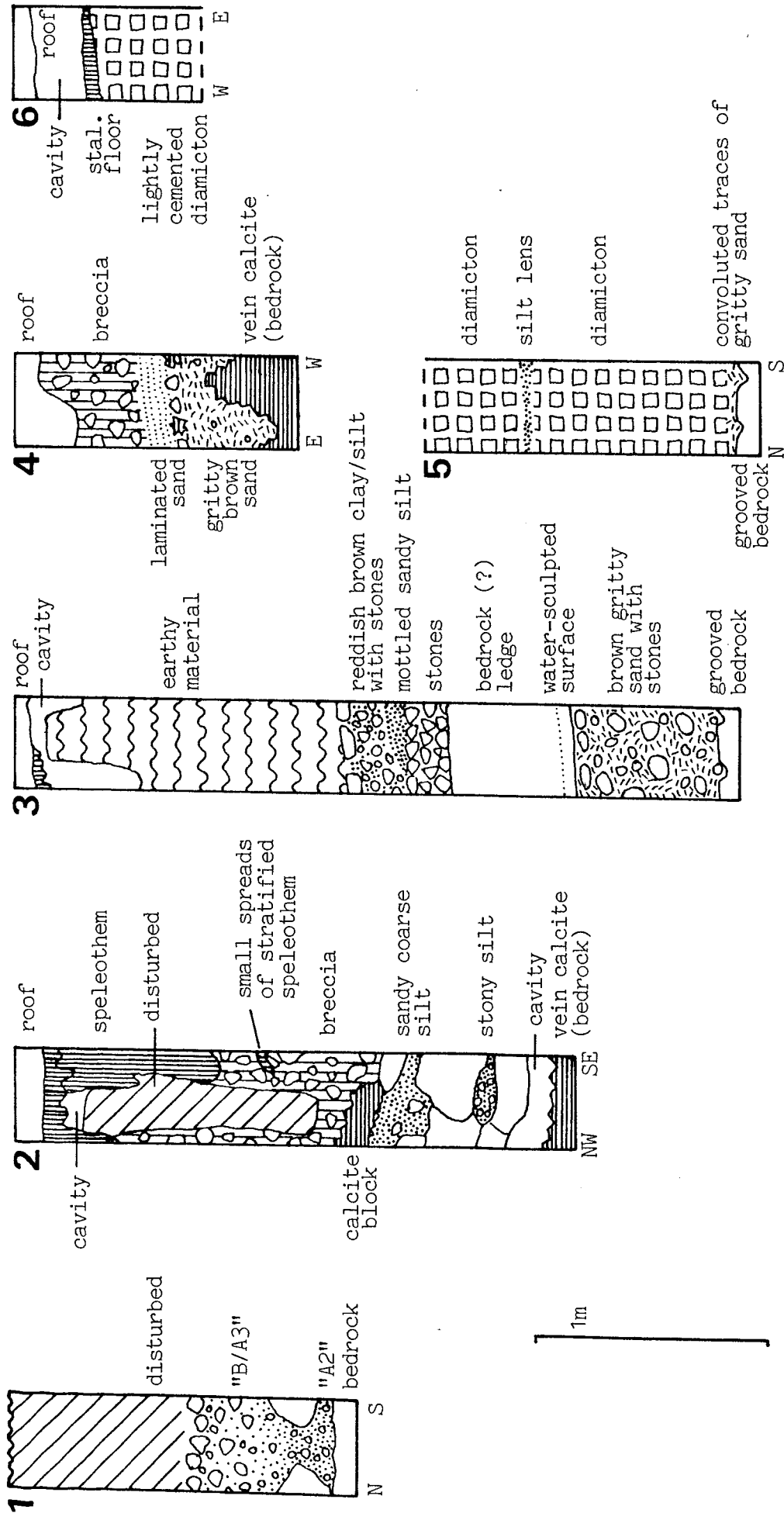


Fig.68 Badger Hole - Schematic Sections (cf. text and fig.67)

(N.B. sections are not tied to a constant height datum)

In Area 2, on the northern side of the Outer Chamber, the deposits are very fragmentary and discontinuous. Pockets of a stony silt, overlain by pockets of structureless sandy coarse silt, are present towards the base. Colours are mottled, with yellowish red (5YR 5/6) and strong brown (7.5YR 5/6) patches, and even some reddish brown (2.5YR 4/4) spots in places. Slightly altered Dolomitic Conglomerate and some vein calcite 'grit' are present, and there are significant colloids associated with redder patches. A fragment of curtain stalagmite was found near the top of the uppermost pocket. There are microfaunal remains. Above these siltier pockets, there is a mass of heavily cemented 'breccia'. The colour is masked by carbonates but seems to be generally 'reddish'. The matrix appears to be a clayey silt with coarse sand and 'grit'. Very common Dolomitic Conglomerate and vein calcite gravel appears to be relatively angular. This deposit is very difficult to observe, but there appear to be a few isolated lenses of in situ stalagmite within the body of the 'breccia'. The deposits are capped by more massive speleothems.

The more southerly access route between the Inner and Outer Chambers seems to have been greatly affected by blasting (assumed to have occurred during Balch's excavations, infra). A structureless 'red' silty clay is present in patches on the floor; it is not clear whether this material is disturbed or whether it is an in situ weathering product of the vein calcite, or perhaps even a true sediment.

In Area 3, roughly central within the Inner Chamber, a more coherent sequence is present. The floor of the Chamber slopes down principally to the west, but also with a minor southerly component. The rock surface shows long, slope oriented grooves, structural fretting and smooth 'potholes', penetrating

up to c.15cm deeper than the general floor level; at least some of these are abrasion rather than corrosion features. Above the floor is a brown (6.25YR 4/4) gritty sand with common medium and coarse gravel. The gravel is mostly strongly altered (rather unsound) Dolomitic Conglomerate; this material is increasingly rounded towards the bedrock but no true stream pebbles are present. The matrix, which gives patchy support, is composed of relatively badly sorted, non-carbonate medium sand, intermixed with dolomitic sand and coarser vein calcite debris. There are a few diffuse siltier patches but there are no internal bedding features. The top of this deposit is contiguous with what appears to be a bedrock ledge, with a clearly water-sculpted lower surface. Above the ledge, there is a zone of relatively loose, angular Dolomitic Conglomerate clasts, followed by a mottled (yellowish red, 5YR 5/6, to strong brown, 7.5YR 5/6) sandy coarse silt. There are a few small Dolomitic Conglomerate clasts in the silt, but most coarser elements are vein calcite. There is some microfauna. At a relatively sharp upper boundary, the silt passes to a reddish brown (5YR 4/4), badly sorted clay/silt with masses of vein calcite coarse sand. The common gravel consists of slightly altered Dolomitic Conglomerate, vein calcite and quite abundant speleothem fragments. This deposit is clast-supported but the matrix is well compacted. There is then a stone line (altered Dolomitic Conglomerate), followed by a thick, reddish brown (5YR 4/4 with 'cream' patches and zones of higher value), earthy deposit. This is a very badly sorted and laterally variable material, although the colloid content is usually quite high. Most of the deposit is composed of 1-2mm aggregates, often very thinly coated with tufaceous carbonate. Vertical fissures and finer cracks are common and the deposit has a low bulk density. Alkali-soluble

organic matter is very patchily present (but no organic structure was noted), representing c.1% of the material <1mm as a general average but sometimes reaching c.12% (i.e. about a third of the value that would be expected in an average peat!) in diffuse zones with bubble vesicular structure. Extremely altered and friable clasts of Dolomitic Conglomerate, vein calcite and speleothem float in the matrix, and there is some dolomitic sand and heavily rounded vein calcite coarse sand. There are fossil and sub-fossil bones, micromammals, terrestrial mollusca, and very common amphibia. There is no clear fabric to this deposit; note that the patchiness seems to be original, since there were no signs of major disturbance by burrowing in the section described (although large burrows were clear elsewhere in this deposit). Westwards, this earthy material is unconformably banked against cemented 'breccia' remnants (resembling those present at the top of the Area 2 sequence) and even against apparently 'recent' speleothems.

Area 4, on the south side of the Inner Chamber, shows a short sequence, sandwiched between a large in situ calcite vein at the base and the southward descending roof. Above the calcite vein is a gritty sand (BH26), brown (6.25YR 4/4) in the body of the unit but with 'black' staining nearer the calcite vein. This material is very similar to that described at the base of the Area 3 sequence, save that coarser elements are much rarer and the dominant component is the non-carbonate medium sand. There are still no obvious internal bedding features. At the top of this sand is a stone line (altered Dolomitic Conglomerate), followed by a well laminated, non-carbonate sand (BH27), with a strong mode in the 0.30-0.15mm range, interbedded with thinner laminae of coarse silt. The overall colour is a strong brown

(7.5YR 5/6). There are clayey silt balls, up to c.1mm in diameter, in many laminae. The very weak matrix carbonate seems to be mostly intrusive, although there is a little dolomitic and vein calcite sand nearer the base and top of the unit. It should be noted that the regular bedding in this unit dips down by c.5° towards the south-east, although this is a very small exposure which may have been affected by settling. Above the laminated sand, after a sharp and slightly convoluted erosive boundary, there is a reddish brown (5YR 4/4) compact clay/silt with very common, relatively angular clasts of Dolomitic Conglomerate and vein calcite. The whole unit is lightly to moderately cemented to give a 'breccia'.

The exposure in Area 5 is of the material constituting the Talus, a massive deposit which has obviously entered via the eastern opening to the exterior slopes. The lowest subdivision is a reddish brown (5YR 4/4), extremely dense deposit (BH22), which is very badly sorted and which may be termed a diamicton. Grit and angular, but moderately altered, clasts of Dolomitic Conglomerate and vein calcite are common, floating in the matrix. There is some non-calcareous sand (cf. the base of the exposures in Areas 3 and 4) mixed into the lowest 10cm. An interesting novelty is the inclusion, at all levels, of common, roughly spherical but nevertheless rather 'knobbly' particles of limestone, in the size range c.0.5-4.0mm. This limestone appears to be a calcite mudstone. There follows a brown (7.5YR 4/4 but 'speckled') clayey silt, which forms a thin but relatively continuous unit across the exposed face of the Talus. There are a few rounded particles of Dolomitic Conglomerate and vein calcite, up to c.5cm, floating in the dominantly non-carbonate silts. However, there is much intrusive matrix carbonate as quite strong in situ concretions; these have a weakly developed 'dendritic' habit and

they may represent rhizoliths, although they are very densely spaced. This deposit is compact and has no visible internal bedding features. Its upper boundary is variably sharp or diffuse and is often slightly convoluted. The highest deposit is another diamicton (BH24), reddish brown (3.75YR 4/4) in colour. This deposit is very similar to that at the base of the sequence (including the calcite mudstone particles), save that it is rather less altered and it contains obvious microfauna. Modern material is being washed down over the top of the Talus from the field above.

In Area 6, the Northern Extension, a diamicton, probably equivalent to the uppermost unit noted in Area 5, is overlain by a relatively thick stalagmitic floor, unlike any other in situ speleothem observed so far in Badger Hole. The Southern Extension is really a tunnel cut into the Talus; the deposits are dense and generally similar to those in Area 5, but the silty unit is absent and there are collapse features, especially at the far end, suggesting comparatively recent disturbance.

The above observations give only a minimal idea of the extant Badger Hole deposits and much greater detail could no doubt be achieved by more exact mapping of these irregular remnants. However, a very generalised sequence can be envisaged. The lowest deposits seem to be non-carbonate sands shifting laterally to a stonier facies (Areas 3 and 4). These appear to be primarily water-concentrated deposits, but their lack of internal bedding and inclusion of local debris suggest a very inefficient mode of final emplacement. They are followed, in Area 4, by water-laid laminated sands, of a kind which is quite typical of medium competence cave streams. The next general unit comprises unstructured silty deposits, with greater or lesser quantities of local coarse material (Areas 1, 2 and 3). Above this are very

stony clays/silts (Areas 1, 2, 3 and 4), sometimes strongly cemented and possibly with internal subdivisions (cf. the stalagmite lenses in Area 2). Within much of the Inner Chamber, the sequence is capped by an earthy deposit (Area 3) which seems to post-date much of the youngest speleothem formation in the cave (cf. Area 2). Closer inspection of this material would probably reveal that it contains quantities of excreta (either animal or human); a late Roman villa is sited in Hole Ground, just beyond and above the eastern opening to Badger Hole. This leaves only the Talus sequence, which has not been observed in clear stratigraphic contact with the deposits further west and south. The inclusion of much non-carbonate sand at the base suggests that the Talus post-dates the lowest, water-concentrated sands in other areas. The calcite mudstone, present throughout the Talus, indicates that these deposits cannot be lithologically correlated with the vaguely similar stony clays/silts (lacking mudstone, except as rare pebbles derived from the Dolomitic Conglomerate) elsewhere in the cave. The geometry of the Talus (with the present exposure of its erosive base a little lower than the unstructured, mottled sandy silt in Area 3 and at about the same level as the laminated sand in Area 4) gives no clue as to its relative stratigraphic position. It is hoped that the microfauna included in the various deposits will eventually help to solve this problem. There is also a chance that excavation just north of Area 3 (at the beginning of the North Extension) might provide some new evidence, although Balch noted in his diaries (infra) that the rock floor rises very steeply in this direction.

Shackley (1972) reported on the analysis of samples from an exposure at an unspecified point within the Inner Chamber. From her description, it seems that this material could only have

been situated in the vicinity of Area 3, although there are still major discrepancies with the present author's observations. Shackley described, but did not figure, a continuous sediment sequence, c.2m deep, showing a division into three units, labelled A, B and C from the base upwards. Unit A, c.1m thick, was a yellowish red (5YR 5/6, 4/8, 5/8, 5/6 - from base to top [the very high chroma values reported by Shackley may indicate that she was using wet material]) crumbly coarse sand, with rounded and surface-etched elements (size?); crinoids and brachiopods were noted. Shackley suggested that this unit contained some water-laid material. Unit B, c.50cm thick, was a yellowish red (5YR 4/8), stony, uncompacted sand, with highly angular coarse debris, interpreted as being "thermoclastic" (cryoclastic) scree. Unit C, c.50cm thick, was a yellowish red (5YR 5/7-8) coarse sand, interpreted as being "redeposited" (an unexplained term) and emplaced by a stream; it contained frog bones. Shackley states that there was no charcoal, alkali-soluble organic matter, archaeological material or bone (larger bone?) in any of the 22 samples taken. There was no attempt to integrate her findings with those of earlier reports. The present author finds Shackley's observations puzzling and her interpretations unsupported by her data (cf. also p.138).

Campbell (1977; Campbell et al. 1970) excavated at the Entrance to Badger Hole (cf. fig. 67) in 1968. Area 1 of the present report is in fact the east face of Campbell's trench and his layers "A2" and "B/A3" are clearly identifiable from his section drawing. Campbell suggested that "A2" was mostly sandy and quite firmly packed, with "thermoclastic" and weathered scree near the base. He interpreted the fine component as aeolian in origin. Rare faunal remains included hyaena (Crocota crocota),

a cat (Felis sp.), otter (Lutra lutra), a fox (Vulpes/Alopex), bear (Ursus cf. arctos), horse ("Equus przewalskii" [E. ferus]), giant deer (Megaloceros giganteus) and perhaps reindeer (Rangifer ?). A radiocarbon date on grouped burnt bone fragments (including an otter scapula) from near the top of the unit produced a date of >18.000 B.P. Campbell argued, from the information in Balch's diaries (infra), that this unit was the source of the E.U.P. artefacts found in previous excavations; the present author would agree that at least the majority of the stone tools do indeed appear to have originated in the generally silty deposits at this site. Campbell interpreted layer "B/A3" as "thermoclastic" scree. A little more fauna was recovered at the "interface" between "A2" and "B/A3", including bear, horse, woolly rhinoceros (Coelodonta antiquitatis), collared lemming (Dicrostonyx torquatus) and northern (root) vole (Microtus ratticeps [M. oeconomus]). Campbell noted common badger holes, especially within the looser material above "B/A3"; this upper material contained bones of badger, a canid, an ovicaprid and a bovine.

McBurney (1961) dug in the Entrance to Badger Hole in 1958 (cf. fig. 67). He located the in situ deposits just south of Area 1 and, in a mostly synthetic paper, he argued that a single "Proto-Solutrean" occupation had occurred at the site at a time of relatively mild climate.

H.E. Balch was responsible for the main excavations at Badger Hole during the period 1938-53, with a few visits up until 1957. Deposits once filled the cave nearly to the roof in most areas, so that the scale of the work can be gauged from the presently sediment-free volume. Unfortunately, very few details were ever published (cf. Balch 1947). The first three feet of deposits were often disturbed by badgers. Modern artefacts as

well as Romano-British pottery were recovered from these levels, together with the bones of sheep and poultry, and oyster shells. Beyond three feet, Balch began to find flint artefacts (now recognised as being of E.U.P. type) and pleistocene animals (listed in Balch (1947:80) as mammoth, woolly rhinoceros, hyaena, bear, two types of horse, red deer, roe deer, reindeer, boar, bison, polecat, voles, mice, pika, hedgehog, "etc."). This faunal material, now in Wells Museum, merits re-examination. Human bones were also found; one jaw was found in cemented breccia, so that at least some of this material might be of pleistocene age (cf. Oakley et al. 1971). W.I. Stanton, who worked at the site as a boy, remembers (pers.comm.) that the child jaw was removed from the breccia before blasting, thus contradicting Balch (1947). Balch reported a continuous stratum of river sand, containing broken stalagmitic pillars, at the base of the sequence, some five to six feet from the original surface.

Further information is available in Balch's six unpublished diaries, also housed in Wells Museum. The present author has briefly examined the first two diaries, covering the period 1938-53. Balch cannot be considered to have been a good stratigrapher by any standards but, in other sites on Mendip, he seems to have been able to recognise at least major stratigraphic units. The scarce and confused details in the Badger Hole diaries might therefore indicate that the stratigraphy was always difficult to understand. Nevertheless, certain interesting points emerge and the diaries would no doubt repay even more detailed analysis.

First, Balch speaks about the highly cemented breccias in the constriction between the Outer and Inner Chambers as if they formed a mass quite discrete from the uncemented deposits piled against them. Using cementation as a stratigraphic criterion is

always risky but, coupled with the frequent references to badger holes, domestic animal bones and pottery, it would seem that the first few feet of deposits in at least the Outer Chamber were composed of completely disturbed and even 'imported' sediment. The cemented pleistocene remnants of the upper part of the sequence seem to have been buried within this material, rather as the remaining 'breccias' would be if modern debris were again dumped in the cave. In the cemented 'nunataks', at levels which were explicitly described as "red", there are records of animal bones (including woolly rhinoceros teeth), human bones and rare flints, at depths of only 1-2 feet from the top surface in any given yard square. This might suggest that the original stratigraphic range of the archaeological material was wider than merely the "yellower" deposits further down. Balch recorded river sands at depth in most squares across the east side of the Outer Chamber. Such sands were particularly deep in a trough or channel, cut into the bedrock, which passed out westwards through the Entrance at a point just north of Campbell's trench. Lying in or on the sands were large fractured stalagmitic pillars and slabs of stalagmitic floor, an observation confirmed by Stanton (pers.comm. to the present author). In some areas, Balch explicitly stated that the sediments became progressively sandier downwards, until true river sand was reached; no sharp boundaries are mentioned. In the Inner Chamber, sand was again present at the base of the sequence, often associated with fretting of the bedrock or deep potholes and linear trenches or channels. Locally (close to Area 3 in the present terminology), a sequence was described, involving black gritty sand at the base with some clay linings to bedrock features, followed by dark brown sand with "pebbles" or "small stones", overlain by stalagmite clasts,

and with "manganese peroxide" marking the base of the fossiliferous strata above. Sand clearly passed beneath the dense deposits of the Talus in the centre of the Inner Chamber. The base of the Talus itself produced large bones; Stanton (pers.comm.) remembers that the tusk of a mammoth was recovered from this level.

Unfortunately, Balch's notes do not clarify the relationship between the 'main' sequence and the Talus. The details of the upper part of the sequence in the Inner Chamber are rather difficult to understand. Balch recognised four feet of earthy deposit, referred to at one point as "hard burned up clay"; he believed this to be comparatively recent material. However, very near the present limit of in situ deposits, just south of Area 3, Balch described a "manganese floor" with flint material at only two feet into the deposits.

In summary, the combined information from the various studies seems to suggest that Badger Hole contains the following material: basal sands, some of them water-laid, associated with large, fractured speleothems; silty deposits containing later Middle Devensian material (artefacts and fauna); stony clays/silts, of unknown age but perhaps in part containing similar archaeological and palaeontological material to that of the underlying silts; a massive tongue of diamicton, younger than the basal sands, but otherwise of uncertain age; masses of holocene material piled unconformably against irregular remnants of older deposits at boundaries which, in some areas, might even be anthropogenic. The Badger Hole deposits will be discussed further in section 22.3.5.

22.3.3. Rhinoceros Hole

Rhinoceros Hole is not really a 'cave' as such, although it might once have been more extensively roofed over. A massive near-vertical calcite vein provides a structural discontinuity, with a very small cavity to the south of the vein at a high level, and a larger cavity to the north at a lower level which links with a small stream resurgence conduit leading away downwards and northwards. This site is thus a relatively minor 'irregularity' in the steep hillside below Badger Hole.

The site was found by Balch (1914), who appears only to have opened the cavity to the south of the calcite vein and perhaps the very top of the more northerly cavity. Balch recorded, in order of abundance, woolly rhinoceros (hence the name of the site), horse and hyaena.

A much more extensive excavation was carried out by members of the U.B.S.S., led by Professor Tratman, during the period 1970-76. Most of the deposits in the site were eventually excavated, leaving only a major section on the south side of the site and material downslope to the west (in the narrow zone before the highest mill canal is reached). Tratman et al. (1971:268) noted a tooth of Dicerorhinus hemitoechus in the "deeper deposits". Hawkins and Tratman (1977:206-7) reported a cold fauna (including mammoth and woolly rhinoceros) with crude bone implements in the "upper levels" of the site, and a warm fauna (Hippopotamus amphibius, Dicerorhinus hemitoechus and Palaeoloxodon antiquus) with Middle Palaeolithic ("Mousterian") implements from the "base levels". ApSimon noted that the U.B.S.S. team had found " a small Mousterian biface on the edge of a stream channel"(1979:101). Sadly, Professor Tratman died before the excavation could be

properly published and the task has now fallen to his collaborator, C.J. Hawkes. Tratman wrote his notes in the expectation of publishing the site himself; synthesising the various documents in his absence has therefore proved a slow process but the report is nevertheless expected shortly (to appear in P.U.B.S.S.).

D.A. Roe (pers.comm.) has examined some of the artefacts and confirms the presence of Middle Palaeolithic material; there is also a unifacial leaf-point on a blade blank, of E.U.P. type. All the stone artefacts appear to have come from very low levels in the sequence. A.P. Carrant (pers.comm.) has examined the faunal material from the U.B.S.S. excavation, together with a few remains provided by the present author from his sediment samples, and reports a moderately coherent cold assemblage, of the Citellus [Spermophilus]/Crocuta/Mammuthus/Coelodonta type, dispersed throughout all but the obviously holocene strata. Warm elements (including Dicerorhinus) are represented only by an extremely small number of specimens, the provenance of which is not yet clear. Both Roe and Carrant will present full reports in the forthcoming synthesis edited by Hawkes.

The present author was only able to observe the main southern section (Main Locus, N/01 section), together with a small section (Lower Locus, N/00 section) a little lower down the slope (westwards), after excavation had been completed (cf. fig. 69). In the following description (a summary of which will also be reproduced in the forthcoming synthesis), Tratman's layer notation will be retained, although subdivisions (numbers in brackets) recognised by the present author have sometimes been added. Sediment samples have the prefix 'RH'.

Main Locus, N/01 section

The bedrock is composed of a major vertical calcite vein,

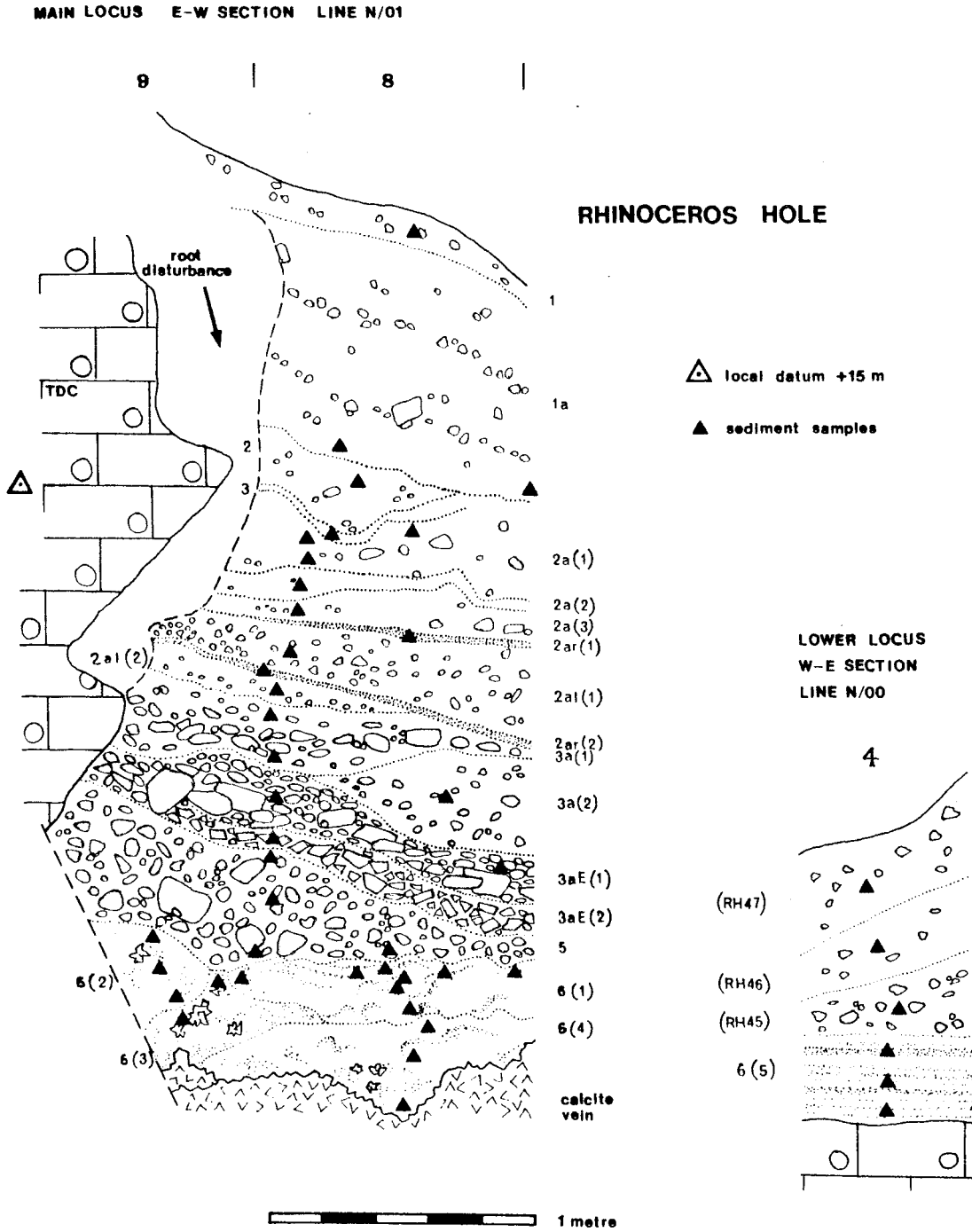


Fig.69 Rhinoceros Hole - Southerly Sections

running approximately ENE-WSW (slightly oblique to the E-W section in fig. 69), set in Triassic Dolomitic Conglomerate.

Layer 6(4) (RH1-3) Dark reddish brown (3.75YR 3/4) clayey silts; extremely compacted; some fine laminations but highly distorted; much decomposing vein calcite, otherwise no carbonates; no bone.

Layer 6(3) (RH4, 8) Mass of vein calcite clasts and grit decomposing in a clayey matrix (various reddish browns, c.5YR 4/4); probably structural (vein) rather than depositional.

Layer 6(2) (RH5-7) Clayey fine sand and silt (various strong browns and yellowish reds, c.6.25YR 4/5); extremely compacted; no apparent bedding; some decomposing vein calcite, otherwise no carbonates; no bone.

Layer 6(1) (RH9-16) Clay and silt lenses (various reddish browns and browns, 7.5 to 5YR 4/4); extremely compacted; signs of compression and plastic distortion (overthrusting) in a direction towards the west; weak prismatic structure especially near base, apparently induced by loading; tongues of material from Layers 6(4-3) injected into base; little sand, but including FeMnAl nodules; rare vein calcite grit, otherwise no carbonates; no bone; upper boundary moderately distinct but highly contorted and rising steeply towards the south.

Layer 5 (RH17-20) Reddish brown (5YR 4/4) at top, darkening to dark reddish brown (5YR 3/4) downwards; very stony, sandier near top, clayier towards base including distinct pockets and 'rafts' under stones; well compacted; no preferential orientation of stones; common Dolomitic Conglomerate gravel, moderately altered and differentially etched; some altered vein calcite gravel; weak surface concretions on stones; sands include vein calcite, FeMnAl aggregates and nodules,

heavily altered crinoids, angular grey chert, irregular shiny quartz grains, carbonate concretions; matrix carbonates moderately rich near top, becoming weaker at depth; common bone, including much sand sized debris; upper boundary moderately abrupt, undulating.

Layer 3aE(2) (RH21) Reddish brown (5YR 4/5 with 'buff' speckles), very stony, silty clay; quite compact; gravel mostly large vein calcite clasts, some conjoinable, with weak alteration and surface concretions; sand fraction includes rare, very altered crinoids, FeMnAl aggregates and nodules, rare carbonate concretions, irregular shiny quartz grains; common vein calcite grit in two quite distinct conditions - unaltered and almost totally decayed; small decayed stalagmite (?) fragments (speckles); carbonate rich; common bone; diffuse upper boundary.

Layer 3aE(1) (RH22-23) Reddish brown (5YR 4/4) very stony and clayey deposit; quite compact; sub-horizontal preferential orientation of stones but with an 'undulating' tendency; rounded Dolomitic Conglomerate blocks, up to 25cm; vein calcite gravel in two distinct conditions - unaltered and moderately altered with varied surface concretions and staining; much vein calcite grit, again in two conditions; rare sand sized FeMnAl aggregates; very weak polyhedral structure in fines near top (stable surface?); carbonate rich; very common bone, including sand sized debris; sharp, undulating upper boundary.

Layer 3a(2) (RH24) Brown (6.25YR 4/4) calcareous silt with randomly oriented large stones; quite compact; mostly vein calcite gravel but some Dolomitic Conglomerate, with moderate surface concretions; vein calcite grit and carbonate concretions; very rare bone; rather diffuse upper boundary.

Layer 3a(1) (RH25-26) Reddish brown (5YR 4/4) clayey silt with large Dolomitic Conglomerate clasts and increasing vein calcite gravel with depth, all slope oriented, especially in the middle where the deposit is rather matrix-poor; rather loose; surface concretions and matrix carbonates, stronger towards base; slightly altered vein calcite grit; rare bone; abrupt upper boundary.

Layer 2a1(2) (RH27) Brown (6.25YR 4/4) silty clay with fine vein calcite gravel, slightly altered with weak surface concretions; rather loose; vein calcite grit and sand sized carbonate concretions; carbonate rich; rare bone; rather diffuse upper boundary.

Layer 2ar(2) (RH28) Yellowish red (5YR 4/6) silt with very common vein calcite grit and sand; rather loose; vein calcite slightly altered with weak surface concretions; very rich in matrix carbonates; rare bone; rather diffuse upper boundary.

Layer 2a1(1) (RH29) Strong brown (6.25YR 4/6) clayey silt with vein calcite sand and some larger altered vein calcite clasts; well compacted; surface concretions including a little alkali-soluble organic matter; carbonate rich; rare bone; rather diffuse upper boundary.

Layer 2ar(1) (RH30) Dark yellowish red (5YR 3/6) clayey silt with very common vein calcite grit and sand; quite compact; varied but not extreme alteration; no bone; upper boundary rather diffuse.

Layer 2a(3) (RH31) Reddish brown (5YR 4/5) clayey silt with vein calcite sand and a few larger clasts; quite compact; varied alteration and surface concretions; common calcite grit; very rich in matrix carbonates; common bone, including much sand sized debris; quite distinct upper boundary.

Layer 2a(2) (RH32) Brown (6.25YR 4/4) clayey silt with only small vein calcite and Dolomitic Conglomerate clasts, moderately altered with strong surface concretions; loose; rich in matrix carbonates and sand sized carbonate concretions; rare bone; rather diffuse upper boundary.

Layer 2a(1) (RH33-35) Reddish brown (5YR 4/5) clayey silt and some vein calcite sand, with coarse vein calcite and Dolomitic Conglomerate gravel; moderate alteration and surface concretions; disturbed (burrows originating from much higher) and loose towards top but quite compact at base; carbonate rich throughout but particularly at base (sand sized concretions); some bone near base only; upper boundary quite distinct.

Layer 3 (RH36) Variable matrix of silty to gritty (vein calcite) clay (reddish brown, 5YR 4/4), with some fine gravel, mostly of Dolomitic Conglomerate; moderate alteration and surface concretions; fine stone line at base; quite loose; some clay balls up to 4mm; moderate carbonates; bone and mollusca; rather diffuse upper boundary.

Layer 2 (RH37) Reddish brown (5YR 4/4 with light specks) clayey silt; altered vein calcite gravel with a little Dolomitic Conglomerate, all with strong surface concretions; extremely loose, no apparent structure; patches of vein calcite sand with carbonate concretions; mollusca, no bone; quite distinct upper boundary.

Layer 1a (RH38-39) Badly sorted matrix (dusky red, 2.5YR 3/2) including silt, clay and vein calcite sand and grit, with Dolomitic Conglomerate gravel and a few larger vein calcite clasts, all heavily altered; some stone lines; very loose especially at base (burrows, modern root-layering) but slightly

compacted upper surface; carbonate and humus rich; weak crumb structure; recent and fossil bone, mollusca; distinct upper boundary.

Layer 1 (RH40) Dark reddish brown (5YR 3/2) deposit, very similar to Layer 1a but a distinct depositional event; modern surface.

Lower Locus, N/00 section

Bedrock of slightly case-hardened Dolomitic Conglomerate.

Layer 6(5) (RH42-44) Strong brown (7.5YR 4/5 with dark flecks), quite clean fine to medium sand with a clay/silt component mainly in aggregates (clay balls); well compacted; horizontal laminated bedding clear and generally undisturbed; sand contains well silicified and polished crinoids, varied dark minerals, spherical highly polished quartz grains, FeMnAl nodules; some heavily altered vein calcite grit and carbonate rhizoliths near top, otherwise no carbonates; rare bone only at top; abrupt upper boundary.

Above Layer 6(5) are three deposits (cf. RH45, 46 and 47) that appear to represent material generally referable to 'units' 5, 3 and 2 respectively. All these layers are finer (less stones and more clay) than any possibly corresponding deposit in the Main Locus.

The deposits from Layer 5 (inclusive) upwards are clearly visible on site as separate strata. However, the distinction between them is often based upon the relative importance of the coarser fraction, especially vein calcite, and upon slight colour changes, usually due to vein calcite alteration, very slight variations in colloids or the development of carbonate concretions. Under analysis, the deposits do not generally show marked differentiation in finer sediment type, all these layers being

generally badly sorted. In fact, the deposits do not represent a particularly logical sequence at all, with well characterised constituents, such as crinoid ossicles or FeMnAl nodules, appearing in adjacent strata in rather haphazard proportions. Couple this with features such as extremely variable compaction (irrespective of gross texture), clay balls, clay 'rafts', distinct alteration conditions within a single layer, or diffuse and irregular boundaries, and the overall impression is that many of these deposits have been radically reworked. Possible sediment sources are the upper cavity at this site (south of the calcite vein and just above the main section in fig. 69), Badger Hole and any other as yet unknown cavities further up the slope, and the steep slope itself (which reaches c.40° just above Rhinoceros Hole). The presence of a major vertical calcite vein has obviously played an important part in this development, both as a sediment source and a structural control. Periodic collapse of the vein, as well as of any fragile conglomerate roof which might once have existed, would certainly have caused instability in the deposits of the upper RH cavity and of the slope above. The present author feels unable to extract environmental information from Layers 2-5. It is not impossible that some of the material reached its present position even as late as the Holocene. Layers 1-1a are certainly postglacial (probably including spoil); modern artefacts are included as well as an assortment of historic and more ancient objects. It should be noted that Tratman (pers.comm.) indicated that the distinction between Layers 3a-5 became very difficult northwards, into the 'central' part of the excavation, in the 'mouth' of the lower cavity. Incidentally, "Layer 4" was merely a localised roof/wall collapse within Layer 5. Layer 3, which is only a minor feature in the section observed by the present author,

appears to have filled a depression, c. 80cm deep, in the underlying deposits in the 'mouth' to the lower cavity, in such a way that the westerly dipping strata down to Layer 3aE were obliquely truncated at an easterly dipping boundary with Layer 3. Since there is nowhere for sediment to go in this direction (into the lower cavity), unless it went right down the resurgence conduit and was later flushed away, how did such a geometry arise? Another interesting point indicated by Tratman was that large broken slabs of laminated stalagmitic floor, sometimes 10cm thick, were found lying at all angles; in a letter to the present author, Tratman stated that "nearly all, if not all" of these slabs came from Layer 3aE but his section drawings show large stalagmite fragments up as far as Layer 3. How did thick crystalline stalagmite form in this tiny 'niche' in the hillside?

The water-laid deposits at the base of the sequence (Layers 6) are of considerable interest. Layers 6(4), 6(2) and 6(1) are the distorted remains of deposits laid down in a pool, behind (south of) the calcite vein. They represent stagnant or very weak flow conditions. Note that the distortion of these deposits, as well as the undulating appearance of strata up to Layer 3aE(1), are probably due to loading and basal rotation; there is no sign of the involvement of ground ice. Layer 6(5) represents a much more active stream. Professor Tratman originally envisaged these sediments as being due to a resurgence, flowing out of the back of the lower cavity at Rhinoceros Hole and joining the main (Great Cave) stream in the valley bottom. He mapped the sediments across the rock platform in front of Rhinoceros Hole, north of the calcite vein, in what he called a stream trench. However, judging from Tratman's section drawings, the sands do not appear to have been restricted to any such channel; most low

areas on the platform have such a deposit. In the Lower Locus, the sands have some microstructural features (eg. lens elongation) that suggest, though not unequivocally, that flow was more nearly north-south, rather than east-west. Finally, the sands themselves are not really the sort of deposit that one would expect to find in transit in a minor resurgence; they are much too coarse. If the sands did come from the Rhinoceros Hole resurgence, then this conduit has been active since that time; the deposits now totally filling the conduit (reached by a tight crawl) are finely laminated silts and clays, with no trace of clean sands or, indeed, of any particle whatsoever above 0.25mm. However, Tratman's sections sometimes show silts above sands. Did silts from the resurgence ever occupy a channel cut into a more extensive sand body?

The Rhinoceros Hole deposits will be discussed further in section 22.3.5.

22.3.4. Hyaena Den

An appallingly inaccurate plan and various sections of Hyaena Den are given by Boyd Dawkins (1874), the main excavator of this site; a modern plan of part of the system may be found in Tratman et al. (1971). The cave consists of a chamber, the "Antrum", which was extensively truncated on its western side by the construction of the highest mill canal in 1852. From the south-eastern corner of the Antrum, known as "Area F", a large opening leads up to the surface. Again from Area F, a passage ("Area B") leads off to the north-east; after about 5m, this passage swings round to the south-east ("Area D") and, after another c.12m, it expands and turns upwards, finally narrowing into a fissure or conduit ("Area E"). There is also a restricted, high

level north-easterly continuation from Area B ("Area C"). This contorted morphology is only important here in as much as the opening above Area F comes out to the surface only just north of the 'entrance' to Rhinoceros Hole, and the upward conduit in Area E (now choked with sediment) is very close to the similarly choked resurgence conduit in the back of Rhinoceros Hole.

Boyd Dawkins dug in Hyaena Den from 1859 to at least 1874. He recognised (1874) only a very coarse stratigraphy, comprising the following main units: Lower Red Earth and Stones, Bone-Bed (sometimes including manganese "floors"), Upper Red Earth and Stones. Artefacts (now known to include both Middle Palaeolithic and E.U.P. types; cf. Tratman et al 1971) and a cold fauna (of the same broadly Middle Devensian type found in the other Wookey Hole Ravine caves) were recovered from levels within the Lower Red Earth and the Bone-Bed. One milk molar of Dicerorhinus hemitoechus, from an unreported context, was identified by Falconer (Boyd Dawkins 1863). This framework does not give us very much to go on, but certain geometric features are of interest. Units seem to have been thicker towards the south-east of the Antrum, indicating that sediments were entering via the roof opening in Area F. Barrington and Stanton (1977) have suggested that the western entrance to the Antrum (severely affected by the canal cutting) may have formed by cliff recession after the cave had been filled with pleistocene deposits; certainly, early finds of Roman coins and tufaceous stalagmite with frog bones on the western side of the sediment-filled chamber suggest that an entrance was present before the canal cutting. The Area F opening was totally choked before Boyd Dawkins started digging upwards through its fill. In an early report (1863), he claimed a large body of barren grey clay with stones quite high in this

choke, overlying red earth and higher than the Bone-Bed in contiguous areas within the cave below. Tratman et al. (1971) dismiss this claim as impossible but the present author is not so sure, since the zone dug by Boyd Dawkins appears to have been significantly further to the north-east than that examined recently (infra). The narrow, gently ascending passage of Area C was reported by Boyd Dawkins (1874) to have contained bones near the surface of the local deposits, as a layer higher than the cave roof just to the south-west; if a normal stratigraphic sequence was present, these bones could only have reached their position from further to the north-east (deeper into the hillside), since all more westerly routes were then blocked by older sediments. The Area D passage descends gently to the south-east; bones were found in a layer against the passage roof, with red earth below. However, at the far end, towards Area E (contra Tratman et al. 1971, who mistakenly indicate Area C), Boyd Dawkins noted that a stiff grey clay rested upon a horizontal layer of sand. He described the situation as follows:

As we approached the further end of the bone-bed [in Area D], the [underlying] red earth became a paler hue and of a greater tenacity; the stones also became larger, and the organic [bone] remains more rare. At its further [south-eastern] edge was a layer of fine sand ..., 4 inches in thickness, underlying grey clay ..., full of large stones, and containing a few large bones. This latter extended completely up to the roof ..., and was 20 inches in thickness. (1863:265)

The accompanying figure (*ibid.*, fig.7) shows an oblique boundary, with the red earth and bone layer overlying the clay and sand; the clay became thicker south-eastwards, rising to fill the whole upward-trending fissure/conduit in Area E itself. However, Boyd Dawkins's later section (1874, fig.91) is most equivocal and one cannot tell whether he believed the fine, water-laid sediments of the ascending fissure (Area E) to be earlier or later than the red earth and bone layer; the junction

between the two sets of deposits is shown as being more nearly vertical than in the 1863 version and this junction has been moved significantly further south-east. If the water-laid sediments were the older, they must once have filled the whole of the Area D passage; how, then, was this material removed, upslope, to make way for the red earth and bone layer? Note that Boyd Dawkins (1863:266) spoke of the grey clays in both Areas E and F as if they were very similar deposits.

Balch conducted some digging in Hyaena Den, the only points of any great interest here being that he apparently found 'hearths', "as low as the present floor of the Den"(1914:168) in Area F, and that thin stalagmitic floor material was present just above the rock floor in an unspecified area of the cave (the stalagmite was mentioned in a sentence following a reference to Area D).

Tratman et al. (1971) have produced a useful synthesis of the available data concerning Hyaena Den. It should be made clear, however, that the faunal material from the old digs was not subjected to expert re-identification, merely to taxonomic modernisation. The undermined choke of the opening in Area F had eventually begun to collapse in 1892 and the resulting 'talus' deposit furnished the U.B.S.S. team with numerous, broadly Middle Devensian faunal remains. Traces of a grey clay, overlain by unconsolidated brown sand (with a sharp boundary between the two), were found apparently in situ on the southerly sloping bedrock below the collapsed material. Some traces of undisturbed strata, apparently part of the original sequence of slope deposits leading down from the surface into the cave in Area F, were also found at a much higher level. A convoluted sediment boundary was noted at one point in this minor sequence. Tratman et al. lend much too much importance to the sediments in this tiny exposure. Their

contention, based upon rare pollen grains in a generally altered matrix, that "layer 3a", perched on rock ledges 2.5m above the floor of the Den itself, belongs "to the final stages of the Eemian or at the latest to the opening stage of the Weichsel glaciation"(ibid., p.256) is particularly unacceptable, even if only on geometric grounds (both Boyd Dawkins and Balch found later material directly below the U.B.S.S. exposure).

Unfortunately, spoil from the U.B.S.S. excavations at Rhinoceros Hole was dumped into Area F of Hyaena Den, thus deeply burying all the exposures before the present author could examine them. However, it has been possible to verify that the clayey silts in the ascending fissure (E) are indeed very similar to the deposits in the Rhinoceros Hole resurgence conduit, although the latter are generally a little coarser and better stratified.

22.3.5. The Caves of Wookey Hole Ravine - Discussion

Had Hyaena Den, Rhinoceros Hole and Badger Hole been strung out along the valley side at approximately the same altitude, one might have been tempted to overlook the occasional anomalies and to recognise a similar and coherent sequence in each site. However, the sites lie approximately one above the other and there are exterior slope and/or interior conduit connections between them. Each site contains water-laid deposits of one sort or another, and at least two of the sites contain ruptured stalagmitic floors. The geometry of the caves and hillside makes it extremely unlikely that mature streams could have been flowing in all three of them at the same time. The author quickly became uneasy about the obvious, but perhaps misleading similarities between the three sequences. To date, the

author has not been able to prove any unusual relationships between these sites. However, two topics will be discussed here which may have some bearing upon the question: the likely sources of some of the sediments, and the possibility of reactivation of previously sediment-choked conduits.

The most obvious (and most accessible) approach to sediment sourcing in these deposits is the microscopic observation of the different types of particle in the size range 0.125-4.0mm. A wide range of particle composition is involved, and any given type of particle may be present in various different 'preservation' states. The author thus began to gather rough estimates of the proportions of different particle types in the various available sedimentary units. The results of these observations are somewhat surprising; the author therefore intends to start all over again, with a more precise and detailed set of particle categories and a statistically controlled counting technique. Nevertheless, some of the preliminary observations will be noted here, in order to show the reader why the author finds these sites increasingly puzzling.

Fig. 70 contains a summary of the relevant data. Note that some particle types only appear in larger size grades, so that their absence in fine, water-laid deposits is of no interest (entries marked 'not applicable'). Many of the particle categories are self-explanatory, although a few require comment. The difference between 'polished' and 'altered' crinoid ossicles (all at least partially silicified) is that the former are dense, rounded and shiny, whilst the latter are stained, fissured, fretted and generally angular and porous. 'FeMnAl nodules' are small rounded sand grains or tiny pebbles of dense metallic (hydr)oxides, usually with a concentric shell structure, which are assumed to

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>F</u>	<u>G</u>	<u>H</u>	<u>I</u>	<u>J</u>	<u>K</u>	<u>L</u>	<u>M</u>	<u>N</u>	<u>O</u>	<u>P</u>
<u>1</u>	X	X	X	X	0	0	0	1	1	0	0	1	X	0	2	2
<u>2</u>	4	0	0	4	0	0	0	1	0	0	1	0	0	0	1	3
<u>3</u>	0	0	0	0	4	0	1	0	2	0	1	2	0	0	2	4
<u>4</u>	0	1	0	0	0	3	2	2	3	2	0	0	0	2	2	3
<u>5</u>	0	2	0	0	1	4	2	2	3	2	2	2	0	1	2	4
<u>6</u>	2	0	4	2	0	2	1	2	3	3	0	2	2	3	3	3
<u>7</u>	2	0	0	0	0	2	0	2	3	3	0	2	2	4	3	3
<u>8</u>	3	X	X	X	X	X	X	0	1	X	X	0	0	0	1	4
<u>9</u>	4	0	0	4	0	1	0	1	1	1	2	2	0	2	3	2
<u>10</u>	4	0	0	3	0	0	0	1	1	0	0	1	0	1	1	4
<u>11</u>	4	0	1	4	0	0	0	1	1	0	0	0	0	0	2	3
<u>12</u>	2	0	0	1	1	0	0	1	2	0	1	1	0	0	4	1
<u>13</u>	2	0	0	0	1	0	0	1	2	0	1	2	2	0	4	1

- 1 DOLOMITIC CONGLOMERATE (natural clasts from Badger Hole)
2 NORTH OF HOLE GROUND FIELD (ST 535482) c.300m NNE of Wookey Hole Ravine; soil sample over Dolomitic Conglomerate
3 NORTH HILL (ST 544510) Portishead Beds (Old Red Sandstone); soil sample
4 SWILDON'S HOLE (ST 531513) Black Rock Limestone; influent stream deposits
5 EASTWATER CAVERN (ST 539506) Black Rock Limestone; influent stream deposit
6 WOOKEY GREAT CAVE (ST 532480) Triassic Dolomitic Conglomerate; effluent stream deposit
7 RHINOCEROS HOLE Layer 6(5) basal stratified sands
8 RHINOCEROS HOLE resurgence conduit silts & HYAENA DEN Area E clayey silts
9 BADGER HOLE layer "A2" silts (BH2)
10 BADGER HOLE layer "B/A3" stony clays/silts (BH3)
11 BADGER HOLE diamicton (BH22 and BH24)
12 BADGER HOLE basal gritty sand (BH26)
13 BADGER HOLE laminated sand (BH27)

A VEIN CALCITE; B MASSIVE LIMESTONE CLASTS; C CALCITE MUDSTONE CLASTS;
D DOLOMITIC CONGLOMERATE CLASTS; E ANGULAR AND SEMI-ANGULAR OLD RED SANDSTONE;
F OLD RED SANDSTONE PEBBLES; G SHALE; H CHERT; I DARK MINERALS;
J POLISHED CRINOIDS; K ALTERED CRINOIDS; L FeMnAl NODULES; M CLAY BALLS;
N SPHERICAL QUARTZ GRAINS; O SEMI-ROUNDED QUARTZ GRAINS; P ANGULAR QUARTZ

X - not applicable; 0 - absent; 1 - trace; 2 - present; 3 - common;
4 - abundant

Fig.70 Wookey Hole Area - Sedimentary Stocks

represent reworked ancient weathering residues of cherts and metal-bearing vein minerals. 'Clay balls' (mud balls, silt balls) are defined on p.417. The three types of quartz grain differ markedly in gross characteristics; 'spherical' grains are exactly that, and they are clear and have very shiny surfaces; 'semi-rounded' grains are comparatively smooth but they are of irregular, 'knobbly' form; 'angular' grains are sharp and fresh and they appear to be due to mechanical fracture; no 'frosted' or 'holohedral' quartz types were noticed in these samples. Quartz grains of 'spherical' type are usually accompanied by very small quantities of similarly sized, spherical or ellipsoidal grains of a shiny 'opaque white' opaline rock.

The most readily available source of sediments in the Ravine is the local bedrock. This is composed of Dolomitic Conglomerate with common massive calcite veins. The conglomerate is a clastic rock made up of debris from the underlying Lower Carboniferous and Upper Devonian strata. However, the catchment of the ancient (Triassic) valley seems to have been largely restricted to generally unsilicified, bioclastic limestones, judging from the sampled exposures in the Wookey Hole Ravine. The conglomerate may contain rounded pebbles and cobbles of limestone and masses of carbonate fossils but, in this area, it appears to be very low in non-carbonate residues above fine sand grade, save for a few altered and weakly silicified crinoid ossicles dispersed at wide intervals along the rock faces. The soil sample (taken at 40cm depth) from just north of Hole Ground contains material which is clearly largely derived from the underlying conglomerate. This also appears to be true of layer "B/A3" (BH3) in the Entrance to Badger Hole. The Badger Hole diamicton (BH22 and BH24) is quite similar as well, except for the

presence of small, moderately rounded and spherical but 'knobbly' calcite mudstone particles. This addition would seem to indicate transport over a relatively longer distance (as compared with the Hole Ground soil sample), a proposition which is entirely consistent with a model of mass movement on pleistocene slopes. The source for the calcite mudstone could have been the outcrops beyond the Dolomitic Conglomerate cover, or a facies of the conglomerate which itself contains mudstone (apparently unlike the more local bedrock).

The other possibly available source is the Wookey Great Cave stream catchment. Samples were taken from soil over Portishead Beds (Old Red Sandstone), from demonstrably very recent stream deposits at the entrances to Swildon's Hole and Eastwater Cavern (both influents of the Wookey Hole system), and at the stream exit of the Great Cave at the head of the ravine. These samples can only serve as a very rough guide to all the possible source material in this catchment, especially since the samples only represent the sediments which are in transit under the present hydrological regime. Nevertheless, a reasonably clear pattern emerges. At the 'input' end of the system, the sediments are still quite varied, there are significant quantities of relatively fragile rock or particle types, and rounding of particles is by no means extreme. At the effluent, fragile particles are rare, and well silicified crinoid ossicles and other 'hard' particles have been highly rounded and polished. The author does not usually set much store by the gross condition of quartz grains but, in this case, it is difficult to deny the possibility that the extreme modification of some grains is due to abrasion within this large cave system. The only other explanation might be that the spherical grains are derived from pockets of residues,

ultimately attributable to mesozoic strata (eg. Greensand), stored somewhere back in the system. Note that the clasts of massive limestone (probably Black Rock Limestone) present at the influent caves have been replaced by local limestone at the effluent. The presence of so much calcite mudstone and Dolomitic Conglomerate (some of which is quite angular) in the Great Cave samples is, in fact, a little surprising; their occurrence may have been inflated by the recent blasting of tunnels to extend the show cave. Clay balls are common in cave streams, especially in those which have a fast response rate to rainfall (i.e. quickly fluctuating flow regimes), as does the Great Cave stream. Finally, note that the effluent sediments still contain a relatively large proportion of 'exotics' apparently derived from further back (north) in the catchment (Old Red Sandstone, shale, chert, dark minerals, polished crinoids, FeMnAl nodules).

When it comes to comparing the Great Cave stream sediments with other strata in the caves of the ravine, it is not at all surprising that there is a very close match with the Rhinoceros Hole stratified sands (Layer 6(5)). Even the particle size analysis is similar, although Layer 6(5) is a little coarser (but note that the water levels within the Great Cave are artificially controlled). It therefore seems highly probable that we are here dealing with a tiny 'terrace' remnant of the Great Cave stream, possibly representing comparatively gentle flow in a back channel of the main stream. This 'terrace' is at least 5m and perhaps as much as 12m above the present 'natural' level of the valley floor. The slopes above this channel appear to have been stable since the regular stream sedimentation was not interrupted. It seems extremely unlikely that Rhinoceros Hole was a much larger cave at this time, since stream water backing up

into such a backwater would have produced differently structured and textured sediments, as would have a stream 'leaking' into the conduit at the back of the site. It seems reasonable to assume that the Rhinoceros Hole stratified sands date from a period prior to the accumulation of archaeological and palaeontological material in Hyaena Den.

The silts and clays of the Rhinoceros Hole resurgence conduit and the Hyaena Den ascending fissure (Area E) contain very different material from the sands discussed above, even when the finer particle size distribution is taken into account. These fine sediments appear to represent comparatively local catchment. Balch (1914) noted an active spring on the east side of the valley bottom, directly below the sites of interest here. The present author has not yet seen this spring or its sediments, nor does he know the source of its water. However, its presence might suggest a persistent minor drainage system, at least partially separate (in sedimentary terms) from the Great Cave system. It would seem reasonable to assume that the Rhinoceros Hole and Hyaena Den conduits were active after the deposition of the 'terrace' sands, but might they also have functioned after the deposition of some of the broadly Middle Devensian material in these sites?

The other deposits so far examined are not so easily interpreted. As has already been said (p.974), the various strata above the water-laid levels at Rhinoceros Hole appear to show a truly anarchic distribution of the particles under consideration; nothing further can be added until more precise results are available. As a general proposition, the author agrees with Campbell that layer "A2" (BH2) at the Entrance to Badger Hole may contain much derived aeolian material, although silts rather than sands are involved. Mineralogical analysis of these silts is

obviously necessary (cf. p.932). Given the general nature of this deposit, the author was rather surprised to find that, in addition to small pebbles of bioclastic limestone clearly derived from the decomposition of the Dolomitic Conglomerate, the coarser grades include quantities of material which is much closer to the Great Cave stream sediments than to the local bedrock debris. The silts of "A2" seem to have been mixed with an input somehow derived from a very wide catchment and, given the rounding characteristics, an efficient stream appears to have been involved at some stage. The obvious answer might appear to be that the basal stream deposits in Badger Hole represent an ancient link with the Great Cave system and that a degree of local mixing has pulled some of this material up into "A2". However, the sands of Area 4 (BH26 and BH27) are quite different; indeed, they may even represent a third type of sediment, distinct from both the local debris and the (modern) Great Cave sediments. These Badger Hole sands certainly contain 'exotics', but not in such large quantities as the Great Cave sediments. Furthermore, the presence of altered unrounded crinoids and relatively angular Old Red Sandstone and chert clasts suggests either a different route or a very different sediment distribution system (different source erosion patterns, flow regimes, transit times, etc.). Are the Badger Hole basal sands a 'cold' climate phenomenon? And where did the efficient stream component in the "A2" silts come from? Note that mixtures of "A2" and the basal sands at Badger Hole, together with a local input from the Dolomitic Conglomerate, would provide theoretical sources for the apparently randomly variable Rhinoceros Hole sediments.

Some of the difficulties over sediment sourcing, the possible association between water-laid deposits and fractured

stalagmitic floors, and the peculiar geometry of certain strata (cf. Areas C, D, E and F in Hyaena Den), justify a theoretical discussion of the possible effects of reactivation of previously sediment-choked cave zones. However, it must be stressed that there is no proof as yet that reactivation has ever occurred at any of these sites. The subject is raised simply because, under the circumstances, it would seem negligent not to consider it. It is a great pity that all the relevant sediments had been excavated from Rhinoceros Hole before the author was able to see them, because this is the simplest case to analyse. However, a rough model may be set up using such little information as is still available. The Rhinoceros Hole conduit rises to the surface, so that, during reactivation, pressure would build up under sediments blocking that exit. If the Rhinoceros Hole stalagmite was not derived from a totally different cave (eg. Badger Hole) via exterior slope movement, it too must once have blocked the resurgence exit. We need to model disruptive conditions but not conditions so violent as to flush the cave. Assuming that sediment filled the conduit no higher at its inner end than at its outer end, and using a generalisation of the sediment type found in the Rhinoceros Hole deposits to represent a choke, it can be calculated that a head of water of between 2 and 6m would be likely to cause quick conditions at the back of Rhinoceros Hole; a greater head would probably flush the cave. Since a cubic metre of water weighs one tonne and the cross-section of the accessible part of the conduit varies between 0.25 and 0.8m², the pressure developed with a 6m head would probably have been enough to rupture a sealing stalagmite, especially since it may have been weakened since its formation. A 6m head, developed more or less locally, does not seem unreasonable. Thus, if the

Rhinoceros Hole conduit had been reactivated by local drainage at a time when some of the broadly Middle Devensian material had already been deposited, a situation might have developed which would have allowed fracturing of a relatively thick stalagmitic floor and creation of quick conditions in the sediments (with sinking of some heavier particles).

Discussion of the Wookey Hole Ravine sites cannot be taken any further without new and more precise data. However, the author feels that enough information is available to suggest that the sedimentary history of these caves is not nearly so straightforward as it might at first sight appear.

22.4. Westbury-sub-Mendip Fissure

22.4.1. Westbury-sub-Mendip Fissure - Introduction

Westbury-sub-Mendip Fissure (also known as 'Bone Fissure', 'Bone Cave', 'Cavern') lies at between 213 and 244m O.D. on the southern edge of the Carboniferous Limestone plateau (ST 507504), above the eponymous Somerset village. The modern geomorphology of the area is not strictly relevant since the deposits date from a period (Lower Middle Pleistocene and possibly earlier) when the land surface would have been significantly higher and the topography very different. The site was discovered in 1969 during limestone quarrying (Heal 1970); continued quarrying cut back through the huge sediment-choked cavity, the present precipitous exposures being c.90m long and c.30m high. The site is in fact part of a major cave system, both phreatic and later vadose features being apparent on the exposed walls. Due to both the quarrying and the sediment choke, it is difficult to visualise

the exact shape of this huge cavity. In the present exposure, the cave runs approximately north-west to south-east, the south-western wall having been largely removed, thus revealing the sediments. At the eastern end of the quarry, there are signs that the cave continues, perhaps swinging slightly more to the south, whilst at the western end of the exposure there may be a continuation to the north-east. A limestone bluff now separates the upper deposits in the sequence (infra) into two distinct areas, as will become clear below. Major cavities, leading down, out of the floor of the main cave, have been noted at various stages during quarrying, both at the western and eastern ends of the accessible site (cf. Barrington & Stanton 1977). A more detailed description of the site, together with excellent photographs, is given by Bishop (1974, 1982). It is important that the reader should appreciate the scale of the Westbury deposits and the extreme difficulty involved in the study of the enormous, constantly eroding exposures (cf. Roe 1981, Plate 25).

Westbury-sub-Mendip Fissure is extremely important for its abundant and diverse faunal remains; the most recent discussion is presented by Bishop (1982), with Stuart (1982) providing additional details and an overview. The possibility that archaeological remains, which would certainly be amongst the oldest in Britain, are present at various levels in at least 6m of deposit has also been raised (cf. Stanton 1973; Bishop 1974, 1975, 1982; Tratman 1977; Stringer et al. 1979; Roe 1981; Wymer 1982). A large collection of well provenanced flint objects from Westbury is now being studied by G. Cook (Oxford University). These objects cannot be discussed here, beyond a note that, as in many ancient cave sites, the flint is very heavily hydrated and friable.

Since 1969, there have been two main phases of study at Westbury. Up until 1976, a programme of surface collection, section cleaning and small scale excavation was carried out by members of the University of Bristol Spelaeological Society; the work of M.J. Bishop was integrated into, and supplemented, this programme. In 1977, the present author was asked to produce a report (unpublished) on the U.B.S.S. surface collection of bear teeth; the findings suggested that the remains resembled those from Mosbach (designated by some authorities as Ursus deningeri deningeri), a conclusion also reached by Bishop (1982) after detailed examination of a much larger collection from Westbury. Preliminary descriptions of the sediments as they appeared at various times during this first phase of study are provided by Stanton (1973) and Bishop (1974, 1982). The second phase of study began in 1976, when a programme of more extensive excavation was set up by the British Museum (Natural History), under the direction of P. Andrews. Work at the site continues but, in order not to pre-empt Bishop's monograph (1982), detailed findings from the second phase of study have not yet been published (although they have been communicated to Bishop); brief references may be found in Andrews (in Aston 1977), Department of Palaeontology, B.M.(N.H.) (1978) and Stringer et al. (1979). M.L. Shackley and J. Boardman have examined some aspects of the sediments, and W.I. Stanton continues to provide helpful discussion not to mention year-round surveillance of the retreating exposures. Comprehensive study of the deposits is now being conducted by D.I. Gordon (Bristol University).

In 1981, the present author was invited to contribute to the B.M.(N.H.) project. A specific brief was suggested, namely the study of certain major sedimentary features that were thought

to be more or less directly connected with diagenesis at the site. It is this aspect of the sediments alone which will be discussed here. However, some stratigraphic and lithologic framework is necessary for this discussion. The published framework supplied by Bishop (1982) will be used wherever possible. More detailed lithostratigraphic classification, based upon the unpublished and unfinished work of the B.M.(N.H.) team, will nevertheless be necessary in some areas.

22.4.2. Westbury-sub-Mendip Fissure - General Description of the Deposits

The following is the lithostratigraphic framework provided by Bishop. It should be noted that Bishop's use of the terms 'Member' and 'Complex' does not correspond to international geological practice, although his meaning is reasonably clear.

Fig. 71 is based upon Bishop's schematic section.

The well-layered sequence of the Central Belt is now almost entirely lost, but the layered cave deposits of the West and East Basins and the waterlaid sands and gravels of Bed 1 are still preserved. For convenience in the present work, beds constituting the East Basin Complex and West Basin Complex are abbreviated to EBC and WBC in places.

Bed 1. This thick sequence comprises over 15m of fine sands, and gravels, of which almost the entire constituents are silica-based rock particles, hence the overall term for this unit, the Siliceous Member. As a whole this sedimentary unit has a pale-yellow appearance while, in detail, layers range from dark brown (n.b. the gravels) to yellow to very pale yellow. The silica-sand constituent is almost entirely within the fine sand grade 3.25-4.25 ϕ (0.10-0.05mm), and a considerable thickness of these fine sands are present exclusive of other sedimentary grades except mica particles which are common throughout.

Bedding in the fine sands is variable, from well-bedded bands of 3-4mm thickness to uniform beds a metre or more thick. Grading and cross bedding are common, indicating deposition by water, and contortions and minor faulting occur indicating slumping and settlement of the deposits. The lighter-coloured layers, usually a few centimetres thick, invariably contain a high silt percentage giving them a clayey feel, so their light-coloured appearance probably relates to the impermeable nature of the sediment where mineral-enriched waters were permeating through the sands elsewhere.

Gravels occur at various levels as lenses or channel fills, predominantly up to 30cm thick and 150cm wide in cross-section, but in places fine

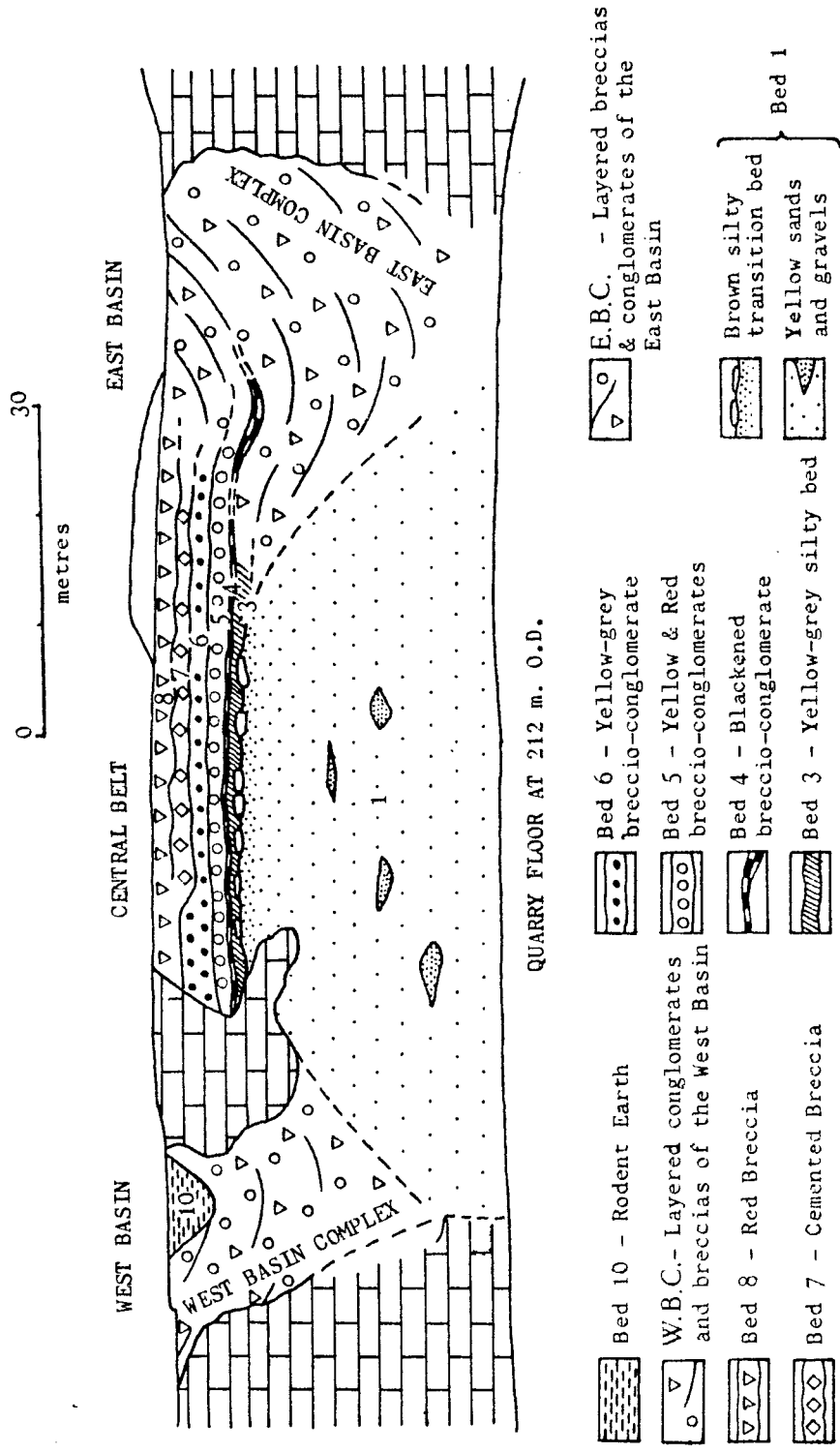


Fig.71 Westbury-sub-Mendip Fissure - Schematic Section

(after Bishop 1982)

gravels also formed thin basal layers under sands where beds were graded. The coarsest gravels of 3-4cm size, occurred at the lowest levels of the Siliceous Member, and tended to be of smaller particle size further up, until the uppermost 4m after which no gravels were encountered, which suggests that the higher-energy water supply that brought in the gravels gradually diminished. Gravels over 0.5cm pebble size are mainly composed of a well-rounded pale yellow-white siliceous rock, which is heavily weathered and extensively bored by a small organism. Occasionally fragmentary macrofossils were seen, such as small ammonite whorls and Rhynchonellids, all of which tended to suggest a Jurassic age, though specific identification was difficult. The gravels also contained subangular pebbles of yellow chert probably also of Jurassic origin, angular pebbles of Carboniferous Limestone chert, vein quartz, and small round pebbles of clear quartz. The only other constituent of the coarse gravels and the finer gravels are the bone fragments and teeth of mammals They are highly mineralized and rolled, so much so that they closely resemble the condition found in similar remains from the Red Crag of Norfolk.

In the finer gravels, below 1.5cm pebble size, limonite is a common constituent, both as small rounded pebbles and as a matrix encrusting the gravels themselves. This encrusting 'pan' is very common in the fine gravels, and often totally infilled voids between the pebbles indicating that the limonitic matrix built up after the deposition of the gravel lenses. This might be expected where iron-rich solution could drain or permeate out of the sand and gravel body most easily through the interstices of the gravels.

At about 1.5m from the top of the Siliceous Member, the sediments contain a higher proportion of silt and clay, and darken to a brown colour. The uppermost part of this deposit is a brown silty clay in which there lies a series of massive limestone boulders, the whole forming a very definite transition before the overlying sediments of the Calcareous Member. Cessation of deposition in Bed 1 apparently coincided or was followed by partial collapse of the limestone roof of the cavern. The transition horizon was only seen in the Central Belt and was here a horizontal feature, whereas the Calcareous Member sediments occupy lower levels in the East and West Basins than the top of Bed 1 The only contact between the sediments of these basins and Bed 1 observed was in the West Basin where there was no evidence of a transitional zone. This strongly suggests that large parts of the west and east extremities of Bed 1 were slumped and remobilized, and their place has been taken by the heavy overburden of the West and East Basin Complexes.

All deposits overlying the Siliceous Member have limestone constituents and some have calcareous matrices, and are thus collectively referred to as the Calcareous Member.

The East Basin Complex. This thick sequence of beds forming the eastern portion of the infill, mainly comprises layers of angular to rounded limestone pebbles set in silty or clayey matrices mostly of red-brown colour. Mammalian remains occur at all levels, but this part of the infill has not been studied in any great detail by the present writer. The base of the sequence has never been seen due to covering scree material [recent collapse]. The beds making up this easterly sequence sag downwards possibly as a result of slumping during and after deposition, which may well have occurred if the East Basin is sited over a drainage cave as suggested earlier [cf. p.990 in the present text]. At the level of the Central Belt of deposits, beds from that Belt run into the East Basin Complex, intertonguing with additional beds. Thus layers such as Bed 4 ... can be traced into this sequence, and characteristically they are thicker and sedimentologically of a different character. All the features of this sequence indicate that it was an area of incoming sediment where cave

sediments sludged in to fill an actively slumping basin, until the height of the top of Bed 1 was reached, when incoming sediments traversed the East Basin depositing a particular portion of the sedimentary load, and swept over the top of Bed 1 depositing the rest of the load as a horizontal bed.

Bed 3. This lies directly over the transitional layer of the Siliceous Member in the Central Belt. Its contact with the brown silty clay below was very marked suggesting discontinuous sedimentation, which would be in keeping with basal sediments of the East Basin partly representing sedimentation between Bed 1 and Bed 3 times. Bed 3 formed a uniform layer 1-1.2m thick, was pale yellow to grey-white in colour, and consisted of small agglomerations of fine sand and silt. Sub-angular limestone fragments of all sizes occurred within this matrix, mostly rather corroded, but less limestone was present in this bed relative to any other in the Calcareous Member except perhaps Bed 10. Mammalian teeth and bones were extremely abundant in this bed, the bones represented by broken splinters to entire long bones and mandibles. This was the only horizon in which articulated bones were recovered, which ranged from finds of bear limb bones to associated mustelid bones to bat bones. Large bones and mandibles were recovered in all attitudes within the matrix, and this and the above features suggest the whole entered the cavern as a water-laden mud or sludge from the cave habitation area.

Nearly 30m of this bed was exposed laterally, but after the destruction of the Central Belt in 1974 no exact equivalent remained. It seems most likely that this bed, like others above it, probably has a facies equivalent within the East Basin, or tongues out into the East Basin. [...]

Bed 4. At the top of Bed 3 well-rounded limestone pebbles become common, and a black deposit coats pebbles and occurs as flecks within the silty matrix. The black appearance of this bed and the high proportion of small, well-rounded pebbles differentiates it from beds above and below. Where matrix occurs, it is similar to the matrix of Bed 3, but has been stained to variable degrees by a black deposit. Analysis of the black-coated pebbles has shown that this stain is iron-manganese based, and can thus be equated with iron and manganese oxides and hydrates coating stream-bed pebbles in caves described by [W.B.] White (1976). The mineral coating is characteristically very thin, and concentrations of it on pebbles mark where beds of streams flow into caves from the surface.

In the Central Belt the bed averages about 0.3m thick, but to the east Bed 4 could be traced into the East Basin Complex, where it is thicker and of different sedimentological character. Here the bed has lost nearly all traces of matrix and the pebbles, while still well rounded, no longer are stained black but are covered by a thin film of brown silt. Bones and teeth are abundant in all parts of Bed 4, and tend to be stained black in both areas where this bed is found. The freshness of the contained bones suggests they have had a short depositional history, so the very rounded pebbles of Bed 4 may have washed in rapidly, though derive from a source area where they were exposed to a high degree of rounding. On deposition of the main sedimentary load the bed appears to have been exposed to active stream flow, encrusting large parts of it with the black iron-manganese deposit.

Bed 5. This bed which averages 1.2-1.5m thick, is characteristically made up of rounded pebbles and cobbles in a substantial matrix of silt of pale-yellow colour. Near the top and bottom of the bed are bands in which the matrix is stained a red-brown colour and the pebbles are stained black. Fragmentary bones and teeth were extremely abundant, the bone remains frequently including many small bone fragments, suggesting much of the material was derived from a cave habitation area where animal debris had accumulated over a period of time. [...]

Bed 5 was commonly indurated by calcareous solution making large portions of the bed hard and well cemented, often to the extent that its entire thickness was affected along a few metres of exposed section.

Bed 5 could be traced across the Central Belt and into the East Basin, and although there is no clear trace of this bed in the West Basin today, Tratman's notes (typescript, University of Bristol) describe a similar bed within the West Basin at about the equivalent level ... in 1969.

Bed 6. This bed, about 1.5m thick, was similar to Bed 5 except that its matrix was more pale in colour and was not cemented to the same degree. The concentration of bone remains was lower than Bed 5, but otherwise the bed was so similar that it could be grouped with Bed 5, though the upper red band of the latter provided a continuous division across the Central Belt.

Bed 7. This bed was easily differentiated from Bed 6 in consisting of angular fragments and blocks of limestone, often cemented together with calcite flowstone. Voids between the limestone were either open, filled with calcite, or were filled with a red-brown silty clay. Bone remains were common, but larger bones were invariably splintered and crushed as a result of the inter-boulder contact due to the lack of matrix sediment. The nature of the limestone debris suggests that much of this material fell directly from cave walls, so unlike beds below this horizon may have largely accumulated in situ. This and the presence of abundant calcite cementing the deposit indicates a profound change in the sedimentary regime and cave morphology, suggesting possibly a deterioration in climate leading to increased cavern breakdown, and an advancing cavern entrance bringing with it conditions sympathetic to flowstone formation.

Tratman's notes (typescript, University of Bristol) indicates that this bed was present in the West Basin in 1969 at about the same level

Bed 8. This bed also contains a high proportion of angular limestone debris, but lacks the calcite cement of Bed 7, and has between the limestone blocks a red-brown silt characteristic of many cave earths. Bone remains were relatively scarce. This bed reached ground level, and with Bed 7 was of irregular thickness, the bed probably being partly in situ cave debris, and partly sludged in debris, forming the terminal depositional phase within the cavern.

The West Basin Complex. This sequence of beds is even more variable than those of the East Basin, but probably accumulated under similar circumstances. In exposed section the beds of this Basin have been physically separated from beds of the Central Belt by a limestone bluff This natural barrier within the cavern is traversed at the base by the sands of Bed 1, and at an early stage in the exposure of the infill beds of the West Basin covered the face of this feature extending to the Central Belt. The series of sediments connecting the West Basin and Central Belt were only seen for the last few months of 1969 before the east face was worked back, and they subsequently fell away from the face to reveal the limestone bluff. Sadly, the short life of this section never allowed close investigation to elucidate correlations between beds of the Central Belt and West Basin. In 1969 beds belonging to the Central Belt sequence certainly extended westwards around the bluff dipping down into the West Basin, but all well-stratified beds on either side of the Basin were interrupted by a massive amorphous earthy infill which stretched down from the surface deep into the Basin. The remnants of this infill are seen in Bed 10 described below. The more extensive sequence originally seen on the east side of the West Basin, and the apparent absence of correlatives of Central Belt beds on the west side of the West Basin, suggests that beds of the Central Belt tongued out into the Basin within a mass of further cave sediments unique to this Basin. The West Basin sequence must, it would seem, have to be accumulated via a different

entrance to the East Basin, and its basinal morphology may, like the East Basin, relate to its being sited over a drainage cave or caves, one of which has in the past been exposed.

Bed 10. This unit termed the 'Rodent Earth' is actually a V-shaped infilling at the top of the West Basin which cuts across the bedding in that Basin. The 'bed' is a large mass of red-brown cave earth containing angular corroded limestone fragments and a concentrated layer of bones and teeth of small mammals. This fossil-rich horizon lies within the mass approximately following the basin contour, though the whole unit inclusive of the small-mammal deposit is designated as Bed 10. As mentioned above, this bed was a part of a much larger infill excavated into the beds of the West Basin, which earlier excavators found to be largely barren of faunal remains. An analogous structure in the Mendips is Nod's Pot doline (see Ford and Stanton 1968) where a vertical clay-filled shaft over 20m deep is excavated through a breccia mass, though the mode of origin of the structure is unexplained. In the case of Westbury, it is possible that the West Basin sequence was exposed to a downcutting stream that excavated a conduit to a drainage cave at the base of the Basin, and the resulting pit was infilled by a mass of cave earth. The exact circumstances of the formation of Bed 10 are very puzzling, and while this unconformable structure is clearly the youngest unit in the infill, the fauna from it belongs, within the limits of Pleistocene faunal discrimination, to the same faunal group as the rest of the Calcareous Member fauna. The interesting feature of its fauna, as discussed later, is the fact that it appears to be derived from an owl-pellet accumulation, and this suggests that the cavern entrance was nearby by Bed 10 times, which probably played an important part in the formation of this unit.
(1982:17-22)

Bishop has abandoned "Bed 2" and "Bed 9" of his earlier report (1974); they were roughly equivalent to the material below Bed 4 in the East Basin and to the upper west part of the West Basin Complex, respectively.

Concerning the lithogenesis of these deposits, Bishop (1982) suggests that Bed 1 is a fluvial unit, including much derived aeolian material, introduced into the cave by meltwaters from snowfields during a glacial chronozone. The large blocks and brown silt at the top of the unit would represent roof material and insoluble limestone residue released as permafrost conditions broke down. Stanton (1973) interprets Bed 1 as fluvial material, derived from a low relief landscape formed under very warm, humid conditions (Late Pliocene). The material near the top of the unit would merely represent dewatering of the cave. Bishop (1982) suggests that Beds 3, 5 and 6 may have entered as flood deposits

under temperate conditions; the sediment would probably have been derived from higher, dry areas of the cave system. Bed 4 would indicate the presence of active cave streams. Stanton states that Beds 3-6 "are clearly not water-laid"(1973:291); he attributes the rounding of the limestone clasts to in situ (diagenetic) solution of clasts in a clayey matrix. Bishop (1982) interprets Bed 7 as in situ thermoclastic (cryoclastic) scree, and Bed 8 as material sludged into place, possibly by means of solifluction (gelifluction?). Stanton (1973) suggests that Beds 7-8 are the result of long term collapse of the cave roof, probably aided by deep frost action penetrating from the land surface during cold periods of the Pleistocene. Bishop (1982) refers to Bed 10 as containing much limestone detritus, but he does not specify any genetic mechanism; the "ravine", cut into the West Basin Complex and in which Bed 10 was later deposited, is thought to have been eroded by a cave stream. Stanton does not mention Bed 10. Some of these points will be taken up in the following sections.

The present author's work has been concentrated in two areas. The first is the upper west part of the East Basin; Bishop's definition of Beds 4-7 will serve as a sufficient stratigraphic framework in this area. The second area is the West Basin and all the deposits there exposed in 1981. Bishop defines only Bed 10 and the heterogeneous West Basin Complex. It will be necessary to propose subdivisions of these units; any possible correlation of the units of the "Calcareous Member", as expressed in the West and East Basins, is irrelevant here and the subject will not be discussed.

The only published section representing the work of the B.M.(N.H.) team at Westbury is included in Stringer et al. (1979). Unfortunately, this section shows only gross lithologic variations,

without a lithostratigraphic classification as such; moreover, the reproduction is so poor that individual beds cannot be distinguished in many cases. Therefore, the following set of units will be recognised here, in ascending order:

- Yellow Silts (YS) [18] (a facies of Bed 1)
- Brown Silty Clay (BSC) [17] (highest facies of Bed 1)
- Crushed Bone Layer (CBL) [16]
- Reddish Brown Silty Breccia (RBSB) [15]
- Yellowish Brown Silty Breccia (YBSB) [14]
- Reddish Brown Clayey Silt (RBCS) [13]
- Yellow Silty Breccia (YSB) [12]
- Yellow Laminated Silt (YLS) [11]
- Yellowish Red Breccia (YRB) [10]
- Pink Breccia (PB) [9]
- Dark Brown Silty Breccia (DBSB) [8]
- Brown Breccia (BB) [7]
- Grey Silty Breccia (GSB) [6]
- Upper Red Breccia (URB) [5]
- Dark Red Breccia (DRB) [4]
- Red Silts (RS) [3]
- Rodent Earth (RE) [2] (the microfauna-rich facies of Bed 10)
- Upper Silt (US) [1] (highest facies of Bed 10)

Note that the numbers in square brackets after each unit are not official bed numbers but merely a device to aid the reader in the present discussion. The set of units listed do not necessarily represent all the beds in the West Basin so far recognised by the B.M.(N.H.) team. Furthermore, the present author has grouped some beds into composite units (eg. RS [3]) for ease of reference. In most cases, the listed unit names are those which were in use on site in 1981; given the relatively advanced stage of study of the West Basin stratigraphy at that time, it is hoped that the (informal) units discussed here will still be identifiable within the lithostratigraphy to be published shortly by the B.M.(N.H.) team. Further lithologic

and lithogenetic details will be given below, where necessary for the accomplishment of the present aim. It should be noted that the set of units listed are represented by exposures covering a vertical interval of c.30m.

22.4.3. Westbury-sub-Mendip Fissure - Aspects of the East Basin Deposits

It will be remembered that Bishop has interpreted Beds 4-6 in the Central Belt and East Basin as due to flood emplacement of reworked sediments, with Bed 4 representing the direct effects of a stream. Stanton, on the other hand, has denied the possibility that these are water-laid sediments and has suggested that the rounding and alteration of the limestone clasts are due to postdepositional processes.

The present author observed three main sedimentary units at this point in the cave: a dark deposit (equivalent to Bed 4), a light grey deposit (equivalent to at least some part of Bed 5) and a unit comprising alternations between yellower and redder bands (equivalent to Bed 6 and perhaps part of Bed 5). The precise boundary between Bishop's Beds 5 and 6 is not important here. The bulk of all these beds comprises relatively large (mode at c.10cm) and spherical limestone cobbles, usually with at least partial matrix support provided by badly sorted silt or clayey silt. Individual depositional units tend to be tabular, with a gentle apparent dip (c.5°) downwards approximately towards the west; the limestone cobbles are stratified and oriented in accordance with this dip and they show good size sorting in individual units. The matrix is usually a moderately compacted silt, which is extremely rich in carbonates and lacking in fine

structural features.

In greater detail, Bed 4 contains cobbles which are slightly more prolate and a little smaller than in higher units. The cobbles have highly altered surfaces, with 'pock marks', exfoliation crusts and globular encrustations rich in iron and manganese; most cobbles are deeply rotted. Bone fragments are very common and are similarly stained with metallic (hydr)oxides. The matrix is also dark and, although it is very rich in carbonate silts, there is a significant component of non-carbonate colloids. There is also a little alkali-soluble organic matter. The next deposit (lower Bed 5) is quite similar but the metallic (hydr)oxides are generally lacking and the colloid component is weaker, resulting in a lighter colour. The limestone cobbles are more spherical and slightly larger than in Bed 4, although there is also some more irregularly shaped fine limestone gravel. The limestone shows deep 'pock marks' and may be slightly rotted even to the core. There is some bone debris but it is not highly stained. The yellower bands of the top unit (Bed 6 and parts of Bed 5) contain material which is very similar to the lower part of Bed 5, save that some limestone clasts show extreme edge rounding rather than more continuous sphericity. However, the redder bands of this top unit contain much larger quantities of non-carbonate colloids, giving a dense, blocky or pelletal fabric; in a few zones, there are fine laminations almost completely lacking in carbonates. Small 'black' limestone ghosts occur within clayier zones of the redder bands and bone fragments are also stained. There is a significant alkali-soluble organic content in these zones. Most redder bands thin, or wedge out, down to the west. At one point within the top unit (fig. 72), there is a clear channel feature, containing comparatively

angular clast-supported coarse material, overlain by well bedded silts and clays.

With respect to the lithogenesis of these deposits, the most important parameters would seem to be: high sphericity and good size sorting of the limestone cobbles; generally very high particulate carbonate content in the fine matrix; partial matrix support; and good macrofabric. As was noted by Stanton, these deposits were certainly not dominantly deposited by running water, because totally different fabric and composition would then have resulted. However, the present author cannot agree that the cobbles are merely the result of in situ alteration of originally more angular clasts. Strong solution of limestone clasts may sometimes increase rounding but not sphericity as such. Limestone in the lower horizons of the modern soils in the vicinity of the cave, and also in some of the cave deposits in the West Basin where solution can be demonstrated (infra), is present as highly irregular, 'bulbous' particles, often with solution preferentially affected by the internal limestone structure. Furthermore, any solutinal effect strong enough to produce such extreme modification of large clast form would necessarily have removed or redistributed the masses of carbonate silt in the matrix. Finally, in situ alteration would not explain the size sorting of cobbles.

The present author envisages a starting point with deposits higher up in the cave system (to the east), including much deeply altered limestone. These deposits would have been periodically moved into their present positions by a variety of low energy slope processes: creep, slumping or even wetter sludging. The unsound outer layers of the limestone particles would have been ground away, leaving spherical cobbles and large quantities of

calcareous silt. Movement of this sort would have provided a weak sorting mechanism, reinforced by more or less extreme destruction of any smaller, rotted particles. This one mechanism provides an economical explanation for cobble sphericity, sorting and macrofabric, as well as for the presence of the silt. Given deeply altered source material, movement would have had to be neither particularly fast nor over any great distance (cf. p.359).

Having said this, it is also clear that the deposits have indeed suffered some diffuse, postpedositional alteration. The superficial 'pock marking' of limestone is a common effect in silty matrices, with tiny differences in carbonate phase (associated with structural features and fossils) providing scope for differential solution. The dark metallic (hydr)oxides of Bed 4 would indeed appear to indicate extreme dampness. Bishop implies that linear concentrations of strong staining occurred in areas of sediment now destroyed, but no such features are apparent in the present exposures of Bed 4. If the (hydr)oxide mobilisation was caused by the proximity of running water, then any true stream sediments must have been lost in an unconformity at the top of the present exposures of this unit. The present author feels that streams would not be a prerequisite for this dark staining. The redder bands which tongue into the deposits of the top unit (Bed 6 and parts of Bed 5) of this sequence are clearly wash deposits, some of them displaying the laminated structure characteristic of organised sheet flow, and others, the fabric characteristic of the movement of coherent aggregates. Within these bands, limestone clasts may be heavily ghosted, but the effect is localised (matrix-dependent), siltier subunits immediately below showing no such alteration. The true channel noted at this level certainly contains water-laid fine sediments

in its upper part, but the coarser sediments at its base may represent fluid mass movement. There has been very little alteration or mobilisation of metallic (hydr)oxides in the sediments contiguous to the channel, suggesting that water flow in the channel was of very limited duration (perhaps only as afterflow of a mass movement event).

Bishop has interpreted Beds 4-6 in more or less syndepositional terms, whilst Stanton has preferred a single diagenetic explanation for the most striking features of these sediments. The present author feels that a more complex history is in fact indicated: (1) formation of a generally autochthonous sediment body at some point higher in the cave system; (2) alteration of these sediments, either under contemporary conditions or during long periods of diagenesis; (3) reworking and comparatively slow transport of these sediments to their present position, with (4) penecontemporaneous metallic (hydr)oxide mobilisation due to extreme dampness at lower levels, and (5) interspersed wash input and perhaps fluid mass movement input at higher levels; (6) comparatively minor diagenetic modification of the deposits since their final emplacement, save for ghosting of limestone in more corrosive matrices.

Taking up point (6) above, it seems rather surprising that Beds 4-6 do not in general appear to have suffered much diagenetic modification in the hundreds of thousands of years since their final deposition. In fact, some reorganisation of original carbonates and infiltration of external carbonates have indeed occurred nearer the cave walls, resulting in moderate to strong cementation. However, one would expect some preferential drainage routes through these sediments to have evolved in order to cope with the ground water which must have reached this area,

at least in the later part of its history when the cave had been totally unroofed by generalised surface lowering of the Mendip Plateau.

This brings us to a feature informally known as "Brighton Beach", for reasons which will be apparent if the reader refers to figs. 72 - 73. The feature occurs at roughly the point where the Central Belt meets the East Basin. It is a large, apparently discrete body of sediment with a morphology reminiscent of a parabolic channel infill in cross-section (c.3m thick by c.6m wide). It is developed at the same level as Bed 4 and the lower part of Bed 5, with which it has quite sharp but totally clast-defined boundaries ("Brighton Beach" is very poor in fine matrix). However, this feature is not a channel infill but a major diagenetic structure resulting from preferential subsurface drainage. The Bed 4/5 boundary can be traced right across the feature, because the limestone clasts of these two beds are diagnostic even in the absence of the fine matrix (i.e. deep rotting, weathering crusts, metallic (hydr)oxide encrustations and 'pock marks' in Bed 4, as compared with weaker rotting and deeper 'pock marks' in Bed 5). Similarly, dark stained bone is common in the lower part of "Brighton Beach", with less common lighter coloured bone in the upper part. The boundary is clear enough to be drawn as a continuous line, which 'sags' slightly in the centre of the feature.

The fine matrix of Beds 4-5 is predominantly carbonate material. In the "Beach", this vulnerable carbonate has been segregated into much denser concentrations (calcite films and granules), thus removing the physical support once given to the larger particles by the matrix. This has resulted in widespread cataclasis (crush brecciation), with the spherical and unsound



true channel

Brighton Beach



detail of true channel

Fig.72 Westbury-sub-Mendip - Brighton Beach



┌──────────┐ c.25cm



Fig.73 Westbury-sub-Mendip - Brighton Beach

limestone clasts being shattered into angular fragments by the point pressures developed within the settling deposits. Note, in passing, that carbonate segregation and cataclasis are less developed in the lower part of the "Beach", a situation which is predictable since the source Bed 4 has more insoluble residue. No great vertical displacement would be required to produce the cataclastic effect; only a few centimetres of compaction would bring the larger particles into contact, since Beds 4-5 are only just matrix-supported. Once stress had shifted from approximately isotropic conditions to highly oriented pressure at points of contact, cataclasis would ensue. Some cemented groups of clasts show repeated alternations between rupturing and re-cementation. There has therefore been only minor downward dislocation of the Bed 4/5 boundary within the "Beach" as compared with the level in the immediately adjacent, unaffected deposits. Nevertheless, the boundary between the "Beach" itself and the source deposits is sharp, not only because of the contrast in fine matrix, but also because even the minor compaction that has occurred within the "Beach" has been sufficient to cause a strong shear zone to form, in which nearly all the original cobbles have been so reduced to fine, angular debris that they are hardly recognisable. The exposed part of "Brighton Beach" is now very unstable and it is probable that the shear zone at its boundaries has become more intensely active since the south-western cave wall and supporting sediments were recently removed. The "Beach" had evolved in response to dominantly vertical stresses; now its exposed part must readjust to more lateral stresses.

The formation of "Brighton Beach" probably started due to a minor accident of drainage. Once begun, the processes would have been self-perpetuating and a greater and greater proportion

of ground water in transit would have been concentrated along this route. It appears that there was once a small passage in the south-west wall of the cave at about the level of the "Beach" (Stanton, pers.comm.); such a cavity might have encouraged preferential drainage at this level. Even though the matrix of Beds 4-5 has little insoluble residue, one would expect to find major lag deposits and intrusive bedded sediments in the lower part of the "Beach" if water had used this route as a regular and comparatively high energy drain; such deposits do not exist. Only minor inversely graded lags, with little or no intrusive material, are present, usually under larger rocks near the base of the feature. "Brighton Beach" represents only a relatively modest phenomenon in terms of sediment translocation (solute mobility and suffosion); the characteristics observed are probably indicative of an overall loss of mass of well under 10%. The visually striking effects of this diagenetic system are therefore all the more impressive.

Finally, it must be stressed that "Brighton Beach" is not a 'stratified' feature and there is no reason why it should be expected to have developed in the same host sediments throughout its extent. A zone of 'fine gravel', in the lowest redder band (possibly at the top of Bed 5), but above and just to the east of "Brighton Beach", is of interest in this connection. This 'gravel' in fact comprises many spheres, or bunches of coalesced spheres, composed of segregated calcite which has built up around small 'seeds' of limestone or other materials. An incipient stage of this process is also visible in some exposed sediments in the West Basin.

22.4.4. Westbury-sub-Mendip Fissure - Aspects of the West

Basin Deposits

The deposits of the West Basin show the effects of what may be called a 'major diagenetic axis', a persistent near-vertical zone of convergence for stresses, water movement and sediment translocation. A highly schematic representation of the deposit geometry is shown in fig. 74. The exposures upon which this schematic section is based are discontinuous and often difficult of access, either because they are precipitous or because they must be repeatedly exhumed from under masses of constantly collapsing sediment. The author believes the idealised relationships indicated to be accurate, but a measure of uncertainty is introduced by the fact that the base of the sequence is nearer the observer than the top (i.e. the exposures are not in a vertical line).

The original morphology of the bedrock cavity in this area is difficult to reconstruct. It was suggested above that the cave may continue towards the north-east (away from the observer in fig. 74) but this may only be true at the level of the higher part of the fill. The bedding of the limestone in which the whole cave is formed dips southwards by at least 50°; to the west of the extant sediments, and in patches between the remaining deposits of the lower part of the fill, the limestone is exposed at a sloping bedding plane. There is at least one major fault, visible near and below the base of the fill, and also to the east of the highest deposits. At the very bottom of the 'diagenetic axis', a phreatic passage leads out through the floor of the West Basin, although this is now deeply buried under quarry rubble. The south-western wall of the West Basin (destroyed by quarrying)

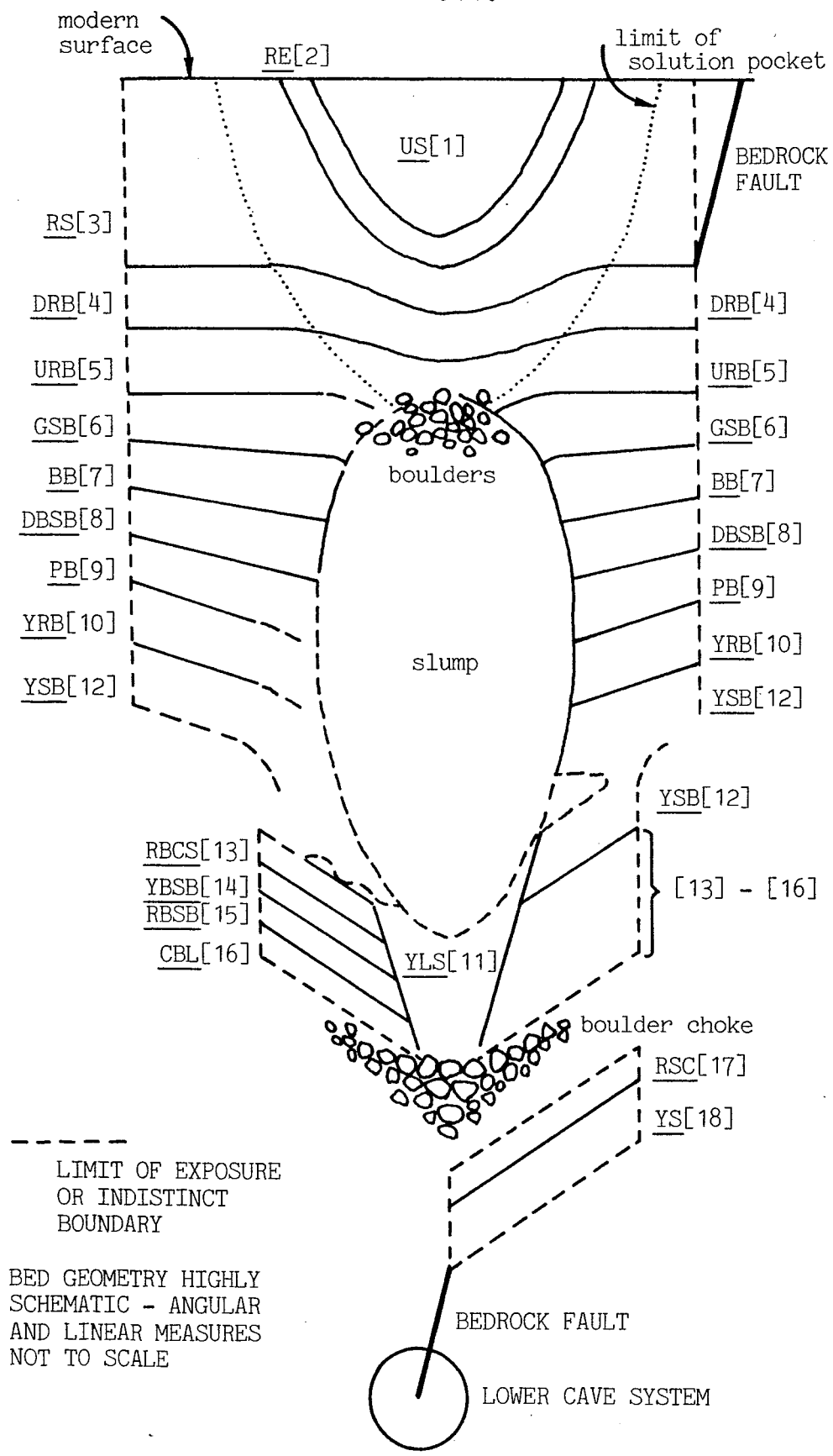


Fig.74 Westbury-sub-Mendip - West Basin

also appears to have followed a bedding plane, so that it would have sloped up northwards, overhanging the Basin.

The lowest deposits in the West Basin sequence are subunits of Bishop's Bed 1, the only unit of his scheme which is still demonstrably continuous between the West Basin and the areas further east. The top of Bed 1 is some 16m lower in the West Basin than it is in the Central Belt. YS [18] is a silty facies, typical of the higher parts of Bed 1 elsewhere; RSC [17] is very much clayier and it contains a little carbonate. Bishop has stated (supra) that the topmost "transition zone" of Bed 1 was not visible in the West Basin during his examinations, but it seems to the present author that RSC [17] may be a remnant of this "zone". Thus, Bed 1 does not appear to have been merely dissected, and some other explanation must be found for the massive vertical displacement. In the Central Belt, Bed 1 shows very clear subhorizontal current bedding at all levels. True bedding features are still present in the exposures in the West Basin, but these features dip irregularly downwards towards the 'diagenetic axis'; there has been considerable deformation, both plastic and brittle, and, in places, minor injection of the clayier material into the silts. The violent dip and deformation are particularly apparent in exposures slightly to the east of the central line of the basin.

The Bed 1 exposures in the West Basin are plastered against the sloping bedrock. The boulder choke at the base of the next group of deposits (above and to the north-east) also lies against the bedrock bedding plane. In addition, it fills the top of a narrow vertical fissure which may well have developed along the main fault in this area. The boulder choke is composed exclusively of limestone particles of various sizes, usually cemented together

by calcite. The calcite is often badly altered (friable) but, in better crystallised zones (away from the top of the underlying fissure), it sometimes shows 'healed' fractures. Uranium series determinations on this material give an ancient infinite 'date'. The limestone of both the larger boulders and the fissure walls is vertically fretted and rilled; most particles in the choke are extremely edge-rounded (but not spherical) and there is no sign of recent cataclasis. The clasts nearest the top of the underlying fissure are coated in black metallic (hydr)oxides. Between and perched upon larger boulders, there are totally undisturbed pockets of horizontally laminated silt, but most spaces between rocks are air-filled. At various points along the exposures of this choke, there was a significant out-draught of cool air and, just east of the main 'diagenetic axis', the draught was sufficient to extinguish a lighted match as soon as it was placed in the airflow (i.e. a flow of c.15-20km/h). This observation was made on a hot summer's afternoon when the whole of the West Basin had been in sunlight for several hours.

The deposits CBL [16], RBSB [15], YBSB [14] and RBCS [13] all slope down radically towards the 'diagenetic axis'. To the west of the 'axis', these units variously show such features as ferruginous aggregates, common clay/silt pellets, clay skins over sand sized particles and aggregates, very patchy concentrations of friable carbonate, crushed or (alternatively) rounded and polished bone fragments, near vertical orientation of some elongated particles, minor near-vertical faults with 'slicken-siding', distorted lenses of laminated silty clay, and small recumbent or detached folds oriented towards the south-east (towards the 'diagenetic axis'). On the east side of the 'axis', the individual units are still generally recognisable, but

deformation has been even more extreme (cf. fig. 75). There are signs of alteration (rotting and dark staining of limestone clasts, staining of bone debris, lack of carbonates in the finer matrix fraction, etc.) throughout these deposits.

The thick deposit YSB [12] is problematical, since it is not uniform throughout its thickness and the transition from a lower to an upper facies occurs at a level where the exposures are particularly poor. The lower facies is a weakly to moderately calcareous laminated silt, with a few continuous sand partings and more common, localised clay partings. The laminations dip down violently towards the south-west (out of the section), with a less marked component of dip towards the centre line of the 'diagenetic axis'. Plastic deformation has not been extreme but there are common high angle faults (converging downwards on the 'diagenetic axis') and more localised low angle faults. The upper facies of YSB [12] has a similar matrix to the lower facies but it lacks the laminated structure and faulting; relatively angular limestone clasts become common upwards. It is not clear whether the upper facies of YSB [12] pre-dates or post-dates YLS [11].

YLS [11] is a 'cone' of sediment which cuts through units [13] to [16] and at least the lower facies of YSB [12]. The contact between YLS [11] and the surrounding sediments is sharp but sometimes convoluted. Where later deformation has not been so extreme as to obscure them, low angle faults in such units as RBCS [13] and YSB [12] stop abruptly at the contact with YLS [11]. However, another set of almost vertical faults pass right through YLS [11] and sometimes a little way into underlying deposits. YLS [11] is composed of badly sorted clayey silt, with vertical variations in fabric, from massive to laminated, and a small component of fine gravel (altered limestone and chert). The



Fig.75 Westbury-sub-Mendip - Deformation Structures

Lower calcareous deposits in the West Basin.

faulting has not greatly disturbed the bedding and there is little deformation, except around large limestone slabs which seem to have fallen into the deposit when it was still plastic; some faults pass straight across plastic deformation structures. Unlike all other units in the lower part of the West Basin fill, the overall bedding angles in YLS [11] are nearly horizontal in the NW-SE plane, and there is only a slight dip to the south-west.

In the units from the upper facies of YSB [12], YRB [10] and upwards towards the top of the sequence, general bedding angles slowly lose the dip converging upon the 'diagenetic axis' and approximate to more nearly horizontal configurations. Similarly, clear traces of more violent disruption (faults, deformation structures, etc.) are generally absent. Conversely, diagenetic features such as small scale suffosion pockets and carbonate segregations become moderately common. Nevertheless, there are still two major diagenetic phenomena that are worthy of discussion. The feature at the top of the sequence, marked on fig. 74 as the 'solution pocket', will be treated first, leaving the 'slump', mid-way up the sequence, until last.

The 'solution pocket' is a deep, basin shaped zone of sediment from which the carbonates of the original beds have been more or less completely removed. The borders of the 'pocket' are gradational and there is no concentration of redeposited carbonates. However major bed boundaries within the outer zones of the 'pocket' are often picked out by weak accumulations of secondary carbonate. Units URB [5], DRB [4] and RS [3] are generally rich in limestone clasts and finer carbonates. As one moves towards the 'solution pocket', the fine carbonates are mostly lost and the limestone becomes more and more altered, with deep rotting and increasingly convoluted surface morphologies. A few black limestone ghosts

survive around the periphery of the 'pocket', and especially near the bottom; some large clasts are now represented by black silhouettes alone, showing that they degraded by rotting rather than by progressive size reduction around a sound core. Elsewhere, only a badly sorted, non-calcareous clay/silt/fine sand remains, together with residual chert fragments, themselves often highly corroded. However, the local Clifton Down Limestone also contains abundant fossil corals and columnar stromatolites (as a bioclastic rather than a growth-position component) which are neither silicified nor dolomitised, but which have nevertheless survived the generalised carbonate solution. These fossils occur as frequent discrete particles even in the centre of the 'solution pocket'; at the borders of the 'pocket', the fossils stand out sharply from the surfaces of the decomposing source limestone. This situation may be compared with the occurrence of fossil brachiopods, which are quite common in the limestone and which stand out from corroded surfaces, but which are totally absent within the 'solution pocket'. Well mineralised bone is also present in these beds, and it does not appear to have suffered any significantly increased alteration within the 'solution pocket', save perhaps at the very bottom of the 'pocket' where the bone is a little friable. RE [2] is exceptionally rich in microfauna, sometimes localised in small groups suggesting relatively undisturbed 'owl' pellets (Currant, pers.comm.). Despite the loss of most of the carbonate component, it is still relatively easy to trace individual bed boundaries across the 'solution pocket'. Such a study reveals major downwarping of the beds, increasing in degree upwards towards the modern surface. There is a loss in bed thickness of most of the lower affected units, a loss which is most extreme along the central axis (units [1] and [2] are not

present outside the 'pocket' at all). This downwarping has occurred without any significant disorganisation of the bedding, although beds often become rather 'wavy' or 'stepped'. The present author cannot agree with Bishop's suggestion (supra) that that part of Bed 10 containing the "Rodent Earth" is unconformable with the flanking units. Fig. 74 shows that the 'solution pocket' does not occupy the full width of the West Basin. However, a soil has developed from the modern surface (or thereabouts) right across the Basin; soil horizons are displaced only slightly downwards as they cross the 'solution pocket'.

The 'slump' is a large body of heterogeneous, unstratified sediment, now present only in the middle section of the West Basin sequence. However, earlier observations (C.J. Hawkes and W.I. Stanton, pers.comm.; cf. also Bishop 1982) suggest that this feature (or something like it) originally continued further up the sequence, perhaps even as far as the modern surface. The feature once appeared to have a sandier vertical 'core', of which there is now no trace. The 'slump' is a very difficult phenomenon to observe accurately, since the distinction between it and material which has collapsed very recently is not always clear. The continuous line in fig. 74 indicates those areas in which the author was able to find a convincing boundary between the flanking deposits and the 'slump'. This boundary consistently passed almost straight into the exposures (i.e. towards the north-east); digging into the exposures laterally for more than c.2m proved too dangerous and it was impossible to get 'behind' the feature. One cannot therefore be certain at present whether the 'slump' is a generally cylindrical deposit, plastered onto the 'outside' of the main sequence, or whether, at least within middle levels of the sequence, it is an extensive dyke, passing significantly

north-eastwards through the main sequence, although circumstantial evidence (infra) would suggest that the former configuration is more likely.

The top of the 'slump' cannot be convincingly demonstrated to be overlain by any in situ deposits; this area is covered by masses of loose debris which probably collapsed very recently. It is therefore possible that the 'slump' did indeed continue to a higher level, as suggested by early observers. Digging down through the recent material, one comes to a zone where the sediments are still very loose and rich in large limestone clasts and boulders. There are many airholes in this material and, at the time of observation (cf. p.1013), there was a moderate and very consistent in-draught. Indeed, an in-draught was noted at small openings all over the top third of the 'slump'. Lower down the exposures, the sediment of the 'slump' becomes better compacted and even quite dense. Large elongated limestone slabs, lying parallel to the 'slump' boundaries (i.e. almost vertically), are quite common. In general, it is clear that the 'slump' is a mixture of the surrounding bedded deposits and there is no trace of any significantly different input. Indeed, near its boundaries, the 'slump' often contains recognisable 'blocks' of sediment (up to c.40cm across) reworked from the main sequence. The highest unit so far recognised as having certainly contributed sediment is GSB [6], although the top of the 'slump' contains dispersed material quite like that of the 'solution pocket' (including discrete limestone fossils). At the 'slump' boundaries themselves, tongues of some of the contiguous deposits (eg. YSB [12], PB [9] and DBSB [8]) may be drawn out and down, and they may even be severed from their source by minor faulting. No convincing boundary could be found at the bottom of the 'slump' and it is

therefore not clear whether it once passed over or now passes behind YLS [11].

Despite many uncertainties over details, the general aspects of the diagenetic system in the West Basin are reasonably clear. The Siliceous Group is dominantly composed of stream sediments which would have been laid down more or less horizontally throughout the cave. After the deposition of these sediments, an exit at the bottom of the West Basin (probably including the phreatic passage noted during quarrying) became active, either by collapse into a lower system or by unblocking of a previously choked conduit. This drain continued to function throughout the later development of the West Basin sequence. The Siliceous Group was slowly but steadily sapped from below, causing the loss of huge quantities of sediment without the total disruption of bedding in the remainder. Probably when this process was well under way, the first major units of the "Calcareous Group" were laid down. These deposits were soon caught up in the continuing downward trend. The actual emplacement of units [16] to [13] may well have been due to reworking of other cave deposits (cf. rolled bones, pellets of fine sediment, and structures indicating lateral as well as vertical distortion). By this time, exposures of the Siliceous Group were probably available significantly above and to the east of the subsiding West Basin deposits. The thick unit YSB [12] may have derived much of its sediment from this source, at first by running water and later by less efficient processes (slumping, sludging, etc.). The angular limestone clasts in the upper facies of YSB [12] may represent breakdown from the walls after the removal of sediment support. Deformation continued, pulling the bedding planes of YSB [12] down towards the axis of subsidence and causing the bedded silts to rupture. At least

after the formation and subsidence of the lower facies of YSB [12], probably quite localised superficial drainage took advantage of the marked depression caused by the downwarping. The laminated silts of YLS [11] were laid down in this depression.

The sapping of sediments from below seems to have continued far up into the "Calcareous Group". However, continued subsidence was not nearly fast enough to keep up with sedimentation. The increasing overburden would have increased general compaction and it would probably have retarded subsurface through-flow of water, or at least directed flow along preferential routes. The overall diagenetic effects probably drifted away from bulk sediment removal towards more selective processes, especially those involving chemical mobilisation.

The 'owl' pellets in RE [2] suggest that an entrance was relatively close at this time. At some later date, this entrance approached near enough to allow aggressive water to reach the area and begin to form the 'solution pocket'. The differential preservation of carbonate fossils, the lack of major disruption of the stratigraphy, and the absence of deep zones of secondary carbonate accumulation, argue for comparatively weak solution over a long period. The originally carbonate-rich deposits suffered appreciable loss of volume, resulting in localised downwarping. Water would have drained down the former axis of subsidence and out of the bottom of the cave. This ancient route would have been favoured because of inherent weakness (cf. faulting) and also because downwarping had caused bedding planes to converge on this axis. Note that the modern soil affects sediments both to the east and west of the 'solution pocket'. Indeed, the geometry of the soil horizons is not 'conformable' with that of the 'solution pocket'. It is therefore clear that the 'solution

pocket' is not merely a recent pedogenic side effect.

The interpretation of the 'slump' must necessarily remain somewhat conjectural. First, it seems highly unlikely that this is a very recent feature produced by collapse at a free face (i.e. during or after removal of the south-western rock wall by quarrying). Had unconfined sediment at such a high angle once started moving, it is probable that a major slide would have developed, bringing the debris into a stable configuration right down near the foot of the exposure. On the other hand, the author would suggest that this presently unstable material is a prime candidate for a future slide, perhaps to be triggered by a heavy summer rain storm like that which occurred on Mendip in 1968. The only reasonably certain point concerning the 'slump' is therefore that it probably occurred within a relatively confined space. The dating of the phenomenon depends upon whether or not it once continued up to the modern surface. The exact mechanisms involved would be different, subject to whether the 'slump' is a dyke or a cylinder. Bishop's implicit suggestion (supra) that the whole 'slump' is the infill of a deep stream channel seems highly unlikely, if not impossible, in such an unstable substrate. Similarly, Bishop's analogy with the situation at Nod's Pot (ST 476549) would not appear to be valid. Ford and Stanton (1968) describe Nod's Pot as having a shaft (over 24m deep and c.2m wide) penetrating through well consolidated breccias; the shaft is filled with "mud", mostly derived from superficial clayey deposits within the closed depression above the site. Thus, the combination of a competent substrate and a demonstrably intrusive secondary fill, not to mention a source of water in an overlying lake, is quite different from the situation observed at Westbury. Nevertheless, it is possible to construct a plausible hypothesis for the

Westbury phenomenon, granted that this is seen as an idea in need of testing rather than a definitive explanation.

Consider the probable situation in the cave before the 'slump' occurred. We know that an axis of weakness, brought about by long term downwarping, faulting and preferential drainage, passed from top to bottom of the sequence. This weakness would have been greatest away from the cave walls, since the walls would have provided both physical support and a potential source of carbonates for cementation of the nearest sediments. Because of the apparent morphology of the cave, it seems probable that this axis of weakness was not strictly vertical but, rather, slightly sloping, with its top further to the north-east than its base. We know for certain that the south-western wall of the cave overhung the West Basin deposits. Some loss of volume would have occurred along the axis of weakness but it is not necessarily true that the deposits would have adjusted at the same rate. It is even possible that a suffosion feature, rather like "Brighton Beach" but with a much greater vertical component, would have developed along the axis. The strong draughts, noted near the top of the 'slump' and within the lowest boulder choke, must represent convection through relatively deep airways. It is very tempting to assume a link between the two areas (a hypothesis which could be tested by winter smoke tracing) and to suggest that the route represents the remnants of an original suffosion 'pipe'. The undisturbed bedded silts perched within the lowest boulder choke are consistent with this choke being part of a major subsurface drain. Eventually, the increasingly weakened sedimentary 'skeleton' along the axis would no longer be able to resist the overburden pressures. The sediments nearer the south-western wall might then have collapsed into the weakened zone but, because of the relative confinement

and the already 'leaning' configuration of these sediments, the hinging component of movement would have favoured the survival of a relatively coherent column of sediment rather than the development of a totally chaotic collapse. Some downward movement would of course have occurred, a movement which would have caused the 'slump' to bite into the surrounding deposits. However, the occurrence within the 'slump' of organised blocks of sediment from these surrounding deposits and the drag folds and tongues at the 'slump' boundaries suggest that this component of movement was very slow, involving no great vertical displacement. It is even possible that the collapse of the south-westerly sediments left a deep cavity which would have accelerated local drainage; the sandy 'core', observed during the early stages of quarrying, might have represented the resulting fill.

22.4.5. Westbury-sub-Mendip Fissure - Postscript

The huge and ancient cave infill at Westbury affords a superb opportunity for the study of diagenetic effects. These effects are of theoretical interest in their own right, but it is also obvious that they must be taken into account during any attempt at reconstruction of the original depositional environments at this particular site. It seems especially important that in situ diagenetic effects should be differentiated from inherited properties of reworked sediments. It is to be hoped that the study of bone taphonomy, currently being undertaken by other members of the team, will complement some of the observations made here. The present author has concentrated upon some of the more obvious and large scale diagenetic features at Westbury. However, detailed examination of more subtle effects,

especially those involving chemical alteration (eg. within the phosphate system), would certainly be rewarding. D.I. Gordon has indicated (pers.comm.) that it is indeed his intention to explore such possibilities.

22.5. Mendip - Conclusion

The sites and problems discussed in this chapter are reasonably representative of the current situation concerning pleistocene cave deposits on Mendip. The dynamic, even disruptive, effects of the topography of the southern flanks of the hills is well illustrated by the Wookey Hole Ravine sites and by the fact that, at Sun Hole, any elation over finding a later Middle Pleistocene fauna must be tempered with the recognition that it is possibly in a derived context. On the more positive side, the suggestion of using derived loessic material as a regional 'marker' has at least been taken one step further. At Westbury, the author concentrated upon diagenetic effects, a subject which is particularly important if we are to understand such ancient sites. However, Westbury raises another important question, namely, why have the deposits survived at all. The reason may well be that the Fissure is perched on the very top of the southern flank of Mendip and has thus been by-passed by most later drainage systems. It is interesting that a similar antiquity has been suggested for the deposits in fissures at Batscombe (Batts Combe, Batt's Coombe) Quarry (Cheddar; Hawkins & Tratman 1977), a site which is in an identical topographic position to the Westbury Fissure. Conscious analysis of the landscape would doubtless permit the recognition of many, more complex distribution patterns for sites of various ages. Finally, both Westbury and Batscombe illustrate the

equivocal relationship between quaternary studies and the gigantic scale of limestone quarrying on Mendip (cf. Barrington & Stanton 1977). The chances of finding new, and especially more ancient, sites are definitely increased by the quarrying, but destruction nearly always follows close on discovery. Even granted the high level of surveillance provided by members of the local societies, it must be admitted that Mendip quarrying far outstrips our ability to respond to new sites. Mendip can certainly boast the longest list of defunct cave sites from any comparable area in Britain.

23. GOWER

23.1. Introduction

The Gower Peninsula (West Glamorgan) is an area only c.25 km long (east-west) and c.13 km broad (north-south). The sites of interest here are in the southern part of Gower, especially along the south coast itself.

The geology of the area may be summarised as follows. Two anticlinal systems, oriented WNW-ESE, govern both the outcrop lithology and the relief. The northern axis, from Burry Holms (west) to Pwll-Du Bay (east) and passing along the Cefn Bryn (reaching 185m O.D. in places), is cored by shales (Silurian) and quartz conglomerates (Old Red Sandstone, Devonian); shales and limestones (Dinantian, Lower Carboniferous) overlie the flanks of the anticline. The limestones of the southern limb of this anticline outcrop along the coast from Nicholaston (west) to Pwll-Du Head (east), and those of the northern limb outcrop on the coast eastwards to the Mumbles. The southern axis, from Worm's Head (west) to Oxwich Point (east), which reaches a height of 110m O.D. in places, shows only limestone (Dinantian) outcrops, with these rocks forming the coast between the points mentioned. In the minor syncline between the two anticlines (eg. around Penrice), there are shales of the Millstone Grit Series (Carboniferous). Much of the interior of Gower (to within 1.5km or less of the south coast) is covered with in situ or derived

till, referable to at least two pleistocene glaciations; these materials, recognisable especially by their exotic rock contents, may sometimes constitute important sources for later deposits on the south coast.

The limestone of south Gower comprises a number of different types (eg. Penmaen Burrows Limestone, Caswell Bay Oolite, High Tor Limestone, Hunts Bay Oolite, Oxwich Head Limestone, etc.), most of which contain caves of one kind or another. Cave formation along the coast has been favoured by two particular features. First, the coastal limestone is highly faulted, dominantly at right angles to the anticlinal axes but with a component more perpendicular to the local irregularities of the coastline in places. These faults usually run for at least 1-2km inland, defining many fault blocks, normally with down-throw to the west. Second, most of the limestone types show more or less linear dolomitised zones, developed along faults, joints and bedding planes. Even though the coastal limestones have not been heavily karstified, these two types of structural weakness, acted upon by local subsurface drainage and oscillating pleistocene sea levels, have produced a highly serrated coastline, containing innumerable gullies, fissures and shallow, but sometimes quite roomy caves. Many of these 'irregularities', from tiny clefts and ledges to vast caves such as Bacon Hole (infra), contain pleistocene deposits, often held in place due to carbonate cementation.

Rather than begin this chapter with a general discussion of the Pleistocene in Gower, we will start with a single cave site and then work 'outwards', thus approximating the way in which the author came to be interested in the area.

23.2. Bacon Hole

23.2.1. Bacon Hole - Morphology

Bacon Hole (SS 559868) is a complex morphological unit owing its position to a near-vertical fault, which intersects the coastal cliffs and passes inland slightly east of north (fig. 76). It should be noted that all figures relating to this site are schematic, pending a forthcoming major publication under the direction of C.B. Stringer (British Museum (Natural History)). In fig. 76, the extant cave mouth may be visualised as being a little over 30m across. The limestone shows good tabular bedding, dipping down by c.15-20° to the south-east. The whole form of the site has been controlled by the interaction between the main fault and the bedding, the latter sometimes being picked out by dolomitised zones. The landward part of the site is still roofed over to form a cave. Indeed, there is much limestone directly above the site, standing as a massive bluff to over 50m O.D. The cavity has been formed by the breakdown of huge tabular slabs, some of which survive in the deposits. This cavity has a general east-west cross-section which is approximately horizontal, so that the cave roof has widely spaced 'steps' on the eastern side of the fault and closely spaced 'steps' to the west, reflecting the dip of the rock strata. Similarly, the rock floor of the site, best seen on the exposed platform to the south, is stepped in a series of ledges. On the eastern side of the platform, the ledges have their scarp faces (risers) pointing generally westwards and their treads sloping gently away to the south-east. Thus, despite the dip of the rock strata, the platform as a whole rises slightly eastwards. There is good evidence to suggest that much more of

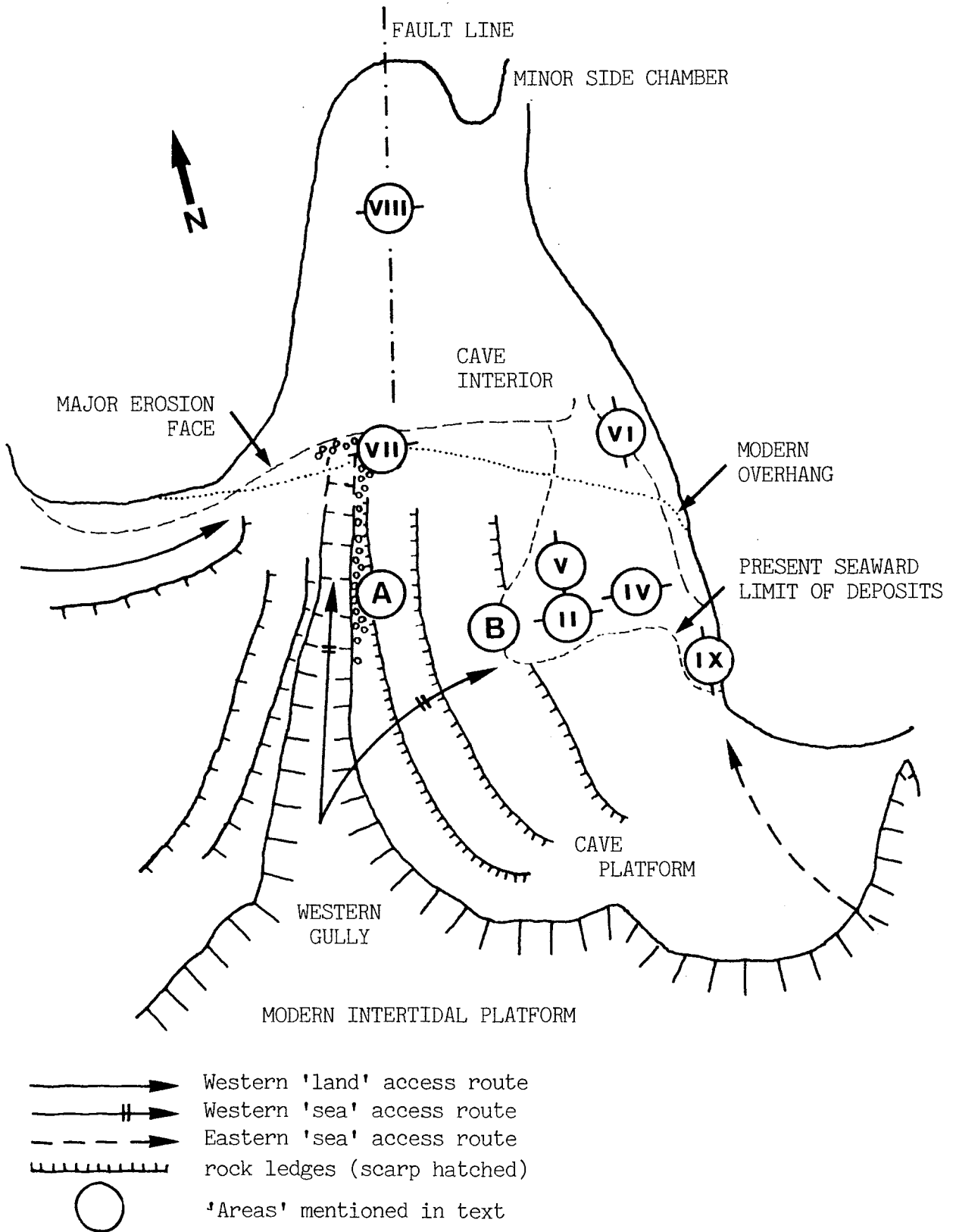


Fig.76 Bacon Hole - Highly Schematic Plan

(not to scale)

the platform was formerly roofed over, probably even up to the Late Devensian (cf. section 23.2.4.). Beyond the cave platform, the rock falls away, in a series of major east-west steps, to the modern intertidal rock platform below. The western gully, which runs right into the site and under the extant deposits, was also developed along the main fault.

Bacon Hole, therefore, shows very clear evidence of structural guidance in its formation. There are signs of minor vadose modification, especially where the fault meets the cave roof, but it is extremely unlikely that the site was ever part of a really significant subsurface drainage system. Signs of direct marine modification are also absent. No etched, sculpted and bored limestone surfaces, such as those which are so obvious on the modern intertidal platform, have been observed at any point on the cave platform or inside the cave. Nor are there any obvious wave-cut notches at the level of the cave or marine (subaqueous) deposits within it. It would therefore seem unlikely that the site has been within the intertidal zone at any time during the Upper Pleistocene and Holocene, if indeed it was ever within this zone. The majority of the extant deposits lie higher than 11.5m O.D. The only clear marine modification can be seen in the western gully, and also in the eastern gully just beyond the site, features which have been sculpted by holocene (and most probably more ancient) high tides. Bacon Hole doubtless owes much to the general erosive forces developed along this coastline but it does not appear to be, strictly speaking, a 'sea cave'.

It has been said that much of the cave platform was roofed over up until a late date in the Pleistocene. It is also clear that the cave deposits were formerly much more extensive. Today,

a major erosional face, c.10m high in places, crosses the cave mouth, cutting right down through the sequence to bedrock in the centre. However, on the eastern side of the platform, the lower (and most interesting) part of the sequence still survives, largely because of the dip of the underlying rock ledges, away from the most recent erosional system acting dominantly along the western gully.

When considering sedimentation in this site, three major transport routes must be taken into account (cf. fig. 76). The only major 'land' access route connects with the steep landward slopes above and to the west of the site, from which sediments could be transported into the cave. This route only became available when the roof of the cave had been significantly breached. The highest energy 'sea' access route has long been along the western gully, a route by which sediments have been both added to and subtracted from the cave deposits. The eastern 'sea' access route is not nearly so direct, but neither is it so steep or irregular because of the dip of the rock strata. This route was probably taken by much of the wind-blown sand present in the deposits. The sediments on the eastern side of the site would also have drained along this route, so that minor erosion and some subsidence have occurred in a seaward direction, especially in the most south-easterly of the extant deposits. In addition to the fact that no cavity is now visible, there is no sign in the deposits that major quantities of sediment have ever been added or eroded along a route leading from/into the limestone towards the back of the cave. Considerable amounts of sediment have reached Bacon Hole from the exterior but, overall, the most consistent source has still been the collapse and decomposition of the surrounding rock.

A clearer picture of the site may be had by reference to the photographs in Stringer (1975, 1977).

23.2.2. Bacon Hole - Previous Excavations

The first recorded excavations in Bacon Hole were carried out by Wood and Benson (Benson 1852; Falconer 1860, 1868) in the cave interior (Area VIII in the present terminology; cf. fig. 76). The stratigraphy is summarised by Falconer:

1. At the bottom, and lying immediately above the rocky floor, patches of yellow sand, a few inches thick, abounding with shells
2. A thin layer of stalagmite
3. Upon this stalagmite, a bed of blackish or dark-coloured sand varying in thickness ... from 18 inches to 2 feet, and containing a mass of bones These bones when first exposed were quite soft and friable, crumbling under the fingers when handled; but after a few days' exposure to dry air they became hard and susceptible to repair. [...]
4. Immediately above the black sand, and at places almost intermixing with it, a deposit of 'red soil' or ochreous cave loam, containing [faunal] remains [...] This stratum varied from 1 to 2 feet in thickness, from the intermixture, in some places of loose limestone breccia, and in others of sand free from bone. The breccia is represented in Mr. Benson's [1852] section as a separate bed. The blackish sand and cave-earth beds may be regarded as different conditions of the same deposit. [...]
5. Above the stratum of red-earth and breccia a bed of stalagmite of very irregular thickness, [...]
6. Above this bed of stalagmite, another bed of breccia, in most places cemented throughout by stalagmite, It varied from 1 to 2 feet in thickness.
7. The uppermost bed of stalagmite, forming a very regular deposit, which ranged generally from 9 inches to 1 foot in thickness, but in some places extended to upwards of 2 feet. [...]
8. A superficial deposit of dark-coloured alluvial earth, about a foot thick, (1868:503-4)

Fig. 78 shows the schematic configuration of these deposits as reported by Benson (1852). The numbering used by Falconer has been added and the texturing reflects the suggested correlation with the stratigraphy recognised during the most recent excavations (infra).

Two important points were noted during this early work.

First, bed 1, the shelly sand, was interpreted as a marine deposit. J. Prestwich had already recognised traces of raised beach, in Mewslade Bay and underlying terrestrial deposits in various Gower coastal caves, and Falconer (1860, 1868) equated bed 1 with this high sea level. In fact, bed 1 is most unlikely to have been a true marine deposit, judging from recent observations, but it must certainly have shown very strong marine influence and the general hypothesis is still valid. The second point is that the fauna recovered from the immediately overlying beds, and especially from bed 4, the red-earth and breccia, was recognised as being of temperate type, including straight-tusked elephant (Palaeoloxodon antiquus) and narrow-nosed rhinoceros (Dicerorhinus hemitoechus). Because of the crude chronostratigraphic framework of the time, involving only a single 'glacial age', these observations puzzled Falconer. The 'beach' deposits contained a fully modern marine molluscan assemblage, yet the overlying mammals appeared to be archaic. This caused Falconer to assume, although with obvious reservations, that the whole sequence was 'post-glacial'. Only later was the Bacon Hole fauna referred to an interglacial; indeed, this fauna, and similar finds from other Gower caves, came to be included in the general definition of the mammal assemblage now considered to be typical of the Ipswichian (cf. Sutcliffe 1960). The molluscan material from the 'beach' deposits in the various sites is also ipswichian, its 'modern' appearance merely reflecting the slower evolution and more stable biogeography of this group in the later Pleistocene when compared with the mammals.

Allen and Rutter (1946) carried out restricted excavations in Bacon Hole and recorded similar findings to those of the earlier workers. Griffiths (1972) recognised that significant deposits were still present on the eastern side of the platform,

outside the modern cave. He also recovered a piece of ivory which appeared to have been worked by man (cf. section 23.2.5.).

Griffiths's work provided the extra interest which contributed to the decision to undertake major new excavations at the site. It should be remembered that, at that time (and even today), there was no unequivocal proof of the presence of man in Britain during the Ipswichian (sensu stricto).

23.2.3. Bacon Hole - Recent Excavations

The recent excavations at Bacon Hole were begun in 1974 by a team from the British Museum (Natural History) and the Institute of Archaeology (London), under the direction of C.B. Stringer. Work has continued at the site, with the emphasis shifting more towards palaeontological aspects as it became clear that at least no major archaeological assemblage was present. In addition to the large number of palaeontologists who have been involved at various stages (listed in Stringer 1975, 1977; Currant et al. 1984; see also section 23.2.4.), a number of workers have studied aspects of the sediments: J.A. Catt (granulometry and mineralogy), P.A. Bull (SEM study of sand grains), M. Fielding (granulometry) and A. Henry (general sedimentology). The present author became involved from 1980 onwards, concentrating upon synthetic factors (lithostratigraphy, sediment body geometry and structure, depositional and postdepositional environments, etc.) observable on site. These field observations will constitute the major part of the following discussion. However, the author has taken a comprehensive set of sediment samples and it is hoped that these can be analysed in detail in the near future.

The non-hierarchical lithostratigraphic classification

devised by C.B. Stringer and A.P. Carrant is very well suited to the present task and it will therefore be used here. The most coherent sequence, containing the least altered sediments, occurs towards the southern end of the platform deposits (including Areas II, IV and V in fig. 76 ; cf. the transverse section in fig. 77). The units present in these Areas are as follows:

Basal Pebbles (BPB) This material is composed of nearly spherical cobbles (up to c.10cm) and smaller (rarely down to c.5mm), often flatter pebbles, all of which are extremely well rounded. BPB has been observed only in Area IV as a thin spread over limestone bedrock or as thicker pockets in irregularities in the bedrock, but the unit as a whole appears to be thickening towards the east (unexcavated). A few pebbles and shell fragments had also been observed at the base of the deposits further west, prior to 1980. The lithology of the particles is spatially variable, with some zones composed almost entirely of limestone cobbles and pebbles, and others with much higher proportions of exotic rocks, including various sandstones; the petrography of these rocks is being studied by A. Henry. There is no preferential fabric in this unit and it is usually clast-supported; the matrix is identical to the Coarse Grey Sands (infra) above. However, in one pocket, the sand provides matrix support and also separates the coarse elements from the bedrock. Note that there is a very marked gap in the particle size distribution between the cobbles/pebbles and the sandy matrix of this unit; there is practically no fine shingle in the 0.5-5.0mm range.

Coarse Grey Sands (CGS) This unit is best developed (c.40cm thick) in Area II but it is also clearly present in Area IV. The matrix is a well sorted, fine to medium, dominantly quartzitic sand, with a 'base' colour of pinkish grey (7.5YR 6/2). However,

BACON HOLE, WEST GLAMORGAN

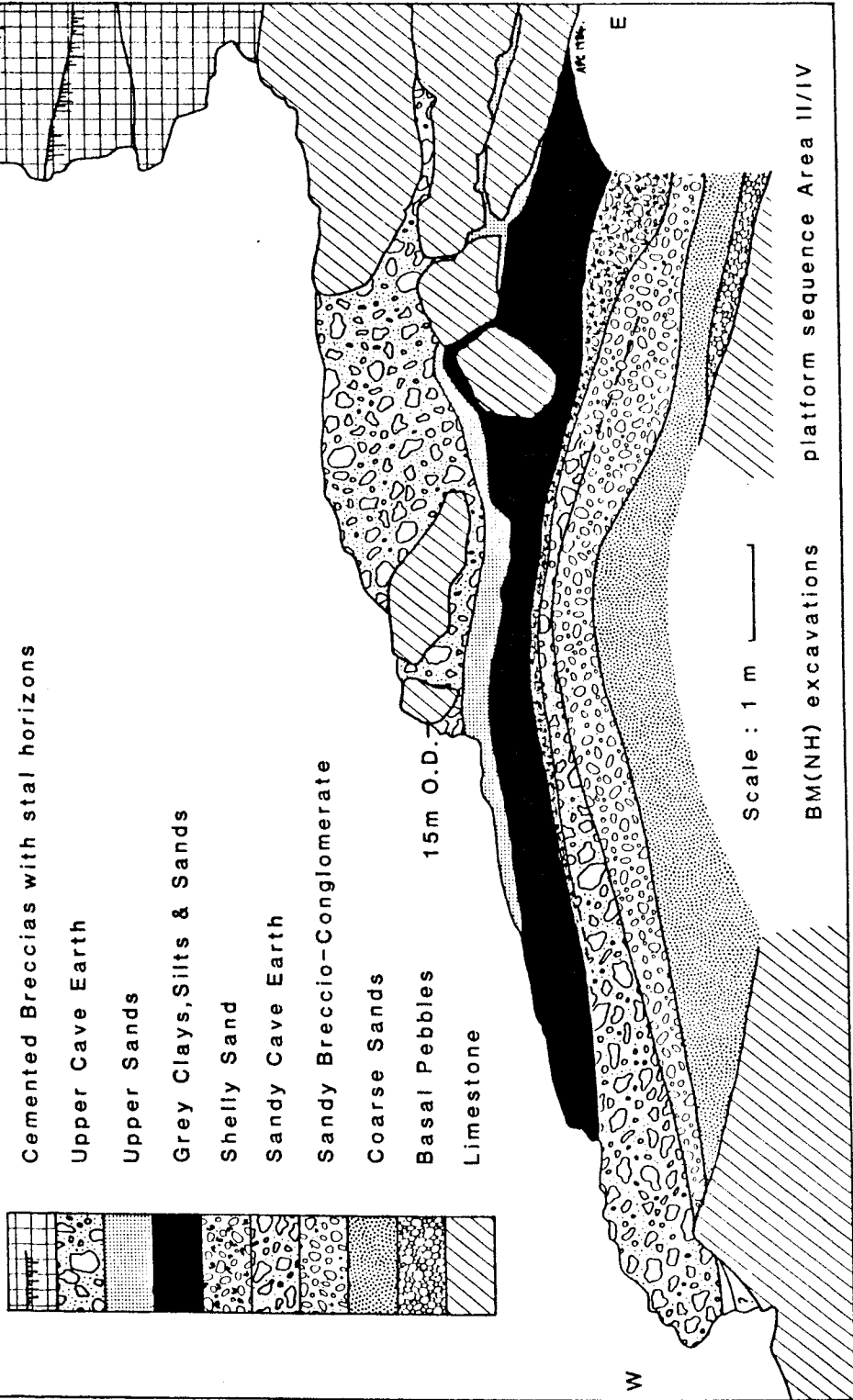


Fig.77 Bacon Hole - Platform Section (after Currant et al. 1984)

in Area II, at the bedrock contact and just above, there are a few large limestone clasts and the matrix has taken on a strong brown colour (7.5YR 5/6); the clast and bedrock surfaces may show even more 'orange' colours. There are scattered 'brown-orange' flecks throughout the deposit. Away from the bedrock, the unit also contains matrix-supported limestone clasts, comparatively small and rare in Area II but larger and more common in Area IV. Two types of limestone are present. The first is a fine grained, 'dark grey' calcitic rock, identical to the dominant type in most of the Bacon Hole deposits and in the bedrock of the site. Clasts of this material are angular and unaltered, except for superficial modification of those at the very base of the unit, as noted above. The second, much rarer type is a coarse, 'saccharoidal' limestone, rich in dolomite rhombs, with a variable but generally dark reddish grey colour (c.5YR 4/2). Clasts of this material are slightly rounded and have rather friable, 'sandy' surfaces, but they are relatively sound, resisting even light hammer blows. In addition to the dominant quartzitic sand, the matrix also contains coarser sand sized calcitic limestone and a few shell particles, as well as mineral grains of vein calcite and monocrystalline dolomite. Except at the very base, where there is a slightly denser zone with patches of very weak carbonate cementation, the matrix is only loosely compacted with minimal contact between grains. The fabric of the matrix appears uniform in all exposures and there are no bedding features.

Coarse Orange Sands (COS) In Areas II and IV, CGS grades upwards, with a relatively thin (c.5-10cm) but conformable boundary zone, into COS, although there are a few areas in which the boundary appears a little sharper over c.10-20cm laterally. COS is also present, to a depth of at least 30cm, at the bottom of the

sequence so far exposed in Area V. The matrix of COS is very similar to that of CGS except that it has a more uniform strong brown colour (7.5YR 5/6). Superficially altered ('orange' stained), but angular, calcitic limestone clasts are present in quantity throughout, sometimes giving patches of clast support. Clast size may reach c.15cm near the top of the unit. Rare clasts of the dolomitic limestone are still sound but a little more friable, and there is more dolomitic sand in the matrix. In general, the unit is still badly compacted and lacking in bedding features. However, towards the top of the unit in all Areas, the silt and colloid content increases and compaction is a little higher. Residual (detrital) pyrite crystals are present in this uppermost zone. In Area V, the top of the unit is quite dense and clayey, but this may be due to slight postdepositional enrichment through an airhole scree immediately above (infra).

Sandy Breccio-Conglomerate (SBC) This material, in the 'type' exposures in Areas II and IV, is composed of fine limestone clasts and limestone residues with an admixture of another sediment type, the second type quickly becoming more important, and even dominant, towards the west and south in a very regular manner. This second type comprises small (rarely larger than 5cm) rounded pebbles, shell debris (often quite coarse fragments or almost complete shells), fine shingle and quartzitic medium sand. The pebbles are mostly of calcitic limestone but there are some exotics. An interesting feature is the presence of some small limestone particles which carry rough, planar or concave surfaces, but which show extreme rounding of all salient points; these may be referred to as 'proto-pebbles'. The facies change is apparent even across the c.2m south-north extent of the Area IV trench, with shingle and sand to the south passing into limestone debris, with only a

few discrete and very thin sand lenses, to the north. No sign at all of SBC was observed in Area V. In Area II, the emplacement of SBC seems to have disturbed slightly the top of COS, since there is a c.5cm thick zone in which limestone clasts are set at angles nearer the vertical than is normal in either COS or SBC. In SBC as a whole, the abundant coarser particles give clast support and the deposit is rather loose, even within sand lenses. Calcitic limestone clasts (as distinct from pebbles and 'proto-pebbles') are angular but they are moderately altered; they may be internally stained along structural features and some have actually split along these planes to produce pockets of angular limestone 'grit'. Clast sizes are mostly below c.5cm, rising to c.10cm at the top of the unit. Dolomitic limestone clasts were extremely rare in the observed exposures and were very friable. Matrix colour is very variable in this deposit but it is generally a yellowish red (5YR 5-4/6-8), with 'white' shell fragments, 'dark grey' or 'red stained' limestone grit and 'buff' sand lenses. Except in the better organised sand lenses which are dominantly quartzitic, there is much dolomite and vein calcite sand. SBC shows weak subhorizontal bedding of larger particles (but without preferential orientation of long axes), stratification which is also shown by the thin and areally restricted lenses of shingle and sand.

Sandy Cave Earth (SCE) This deposit is generally similar to the 'limestone facies' of SBC, the distinction between the two units becoming obscure towards the east of Area IV where even the upper, limestone-rich sediments have very common shell fragments. There is always a diffuse and undulating boundary zone between the two units when they are both present, giving a strong impression of a conformable sequence. SCE is generally dominated by calcitic limestone clasts (commonly 0.5-200mm), although the size of the

clasts and proportion of matrix varies radically over very short distances. At the base of this unit in Area V there is a zone of coarse airhole scree (above COS, SBC being absent in this Area), up to 70cm thick and with practically no matrix. Elsewhere, there are strongly undulating and discontinuous bands of coarser or finer clasts, with more or less matrix, but the deposits are nearly always loose, with some airholes. Nevertheless, there are common but spatially restricted zones with matrix support. Clasts of calcitic limestone are still markedly angular but they are moderately to strongly altered, with staining and splitting; a few particles even show thin alteration crusts. Only a few, very rounded clasts of dolomitic limestone remain and these usually disintegrate under slight pressure between the fingers. There is a continuum from these unsound clasts, to sandy ghosts with no coherence once disturbed, to the coarse dolomitic sand in the matrix. Other small to medium clasts in SCE include fragile roof speleothems (thin plaques with irregular 'mushroom-shaped' protuberances on one side), vein calcite, vein hematite (with a botryoidal tendency) and fragments of limonitic geodes. Shell debris is common. The matrix is rather badly sorted and laterally variable, although there are often modes in the coarse sands, fine to medium sands, medium silts, and colloids (the variable nature of the particle size distribution shows up well in the analyses by Catt and Fielding). In most Areas, there is a tendency for the lowest part of this unit to be more silty and there may even be a few ill-defined silty lenses. Colour is a moderately uniform yellowish red (5YR 4/6). In Areas II and V, the top 5-10cm of SCE are slightly richer in colloids and fine carbonates, and there are patches of weak cementation, strengthening southwards in Area II.

Shelly Sand (SS) This unit is composed of large quantities of badly sorted shell debris and a little carbonate sand; there is very little HCl-insoluble residue (fine sand with some silt and colloids). Some small calcitic limestone clasts, which are altered (red-stained and pitted surfaces) and rather unsound, float in the matrix; there are rare large clasts. The matrix colour is strong brown (7.5YR 5/6), markedly speckled with 'white' (shell). Shell fragments often show point-to-point cementation and the basal 1-2cm are usually quite heavily cemented; there is no sign of significant quantities of intrusive carbonate. The unit has no preferential fabric or internal bedding features, although limestone clasts tend to lie horizontally in most zones. SS is not present in Area II. In Area V it is c.8cm thick and on the western side of Area IV it is c.12cm thick. However, on the eastern side of Area IV, SS thickens to c.65cm. Here, the unit dips down slightly eastwards and very strongly southwards, with even more heavily altered (and even ghosted) calcitic limestone clasts bedded at up to 50° from the horizontal; the lower boundary at this point obliquely truncates the SBC/SCE material below. In all exposures, the lower boundary of SS is sharp.

Grey Clays, Silts and Sands (GCSS) This deposit comprises four main subunits:

The lowest subunit, the "dark pan", is a thin (c.0.5-1.5cm) band of almost black colloidal and non-particulate material, with a few small, altered limestone clasts. Metallic (hydr)oxides and phosphates are present, as are large quantities of organic matter (fragments of the band often ignite in a flame). The band has a finely foliated structure; it is very well compacted and coherent, yet it is of quite low bulk density (although fragments do not float in water). There are a few restricted and extremely thin

(<1mm) lenses of lighter grey mineral colloids. The band is continuously present in Areas II, IV and V. The sediment above the band (infra) peels cleanly off the band at a knife-sharp contact; the lower boundary of the band, although quite sharp, is welded to the underlying deposits. Larger objects (limestone clasts, bones, etc.), enveloped in the overlying sediment, may indent the surface of the band but they are never draped with dark material. The "dark pan" phenomenon is best represented by this major basal band; there are traces of similar, but much thinner and less continuous, bands in the first c.10cm of the overlying subunit (infra) towards the south of Areas II and IV. There are also discrete clasts (up to c.3cm across) of thin "dark pan" throughout GCSS in Area IV.

The second subunit is a dense clayey silt with some quartzitic medium sand. Calcitic limestone clasts are rare, usually quite large and often extremely unsound or even ghosted, especially to the south where the deposit becomes increasingly sticky. There are also some light 'pink' carbonate ghosts which could represent either limestone or speleothem fragments; small phosphatic aggregates (coprolite fragments) are moderately common. Catt (pers.comm. to Stringer) has identified the amorphous mineral, collophane, from this and other levels of CGSS. The matrix has a low but consistent carbonate content. There are sometimes traces of fine, convoluted bedding and "dark pan" lenses (supra), but it is extremely difficult to follow any feature for more than a few decimetres. Matrix colour is variable but generally pale or greyish brown (10YR 5-6/2-3). This subunit may be traced in most Areas but it is clearest in Area V where it is c.20cm thick.

The third subunit is generally richer in sands, a significant proportion of which are dolomitic. Colours are a

variety of browns (in the range 5YR 4/2 to 7.5YR 5/4). Moderately sound but heavily altered calcitic limestone clasts, up to c.25cm in diameter, are more common; they have a gentle dip towards the north whilst the subunit itself slopes gently southwards. There is a moderate carbonate content in the fine matrix. The deposit is dense and there are practically no traces of internal fine bedding. The subunit is of variable thickness due to a strongly undulating upper boundary. In Area II, the modern surface truncates this subunit, younger deposits having been removed by natural erosion.

The fourth (highest) subunit shows more pronounced development of thin, discrete clayey, silty and sandy lenses and laminations. There are common small and localised channel and spillway features. Colours reflect the texture, the clays and silts being 'greyer' and the sands 'brownier'. Small to medium, altered calcitic limestone clasts are moderately common and there is some shell debris of medium to coarse sand size, debris which becomes increasingly common towards the south. There is a variable carbonate content, from weak to moderate, in the fine matrix. Very rare detrital grains of pyrite occur at some levels.

These four subunits seem to be present in most Areas although it is often difficult to recognise precise boundaries between the upper three. This difficulty becomes extreme towards the south of Area IV where the unit as a whole thickens (the base descending) to c.1.5m. Here, most of the deposit consists of finely laminated silty clays, with a slightly 'green' tinge; bedding is often at over 50° from the horizontal (down generally southwards). There are also minor channels with various different orientations. Limestone clasts are very rare but some quite large ghosts may still be seen. Note that the "dark pan" is still

present at the base even in this Area.

The sequence within GCSS as a whole is further complicated by the presence of colour banding, often accompanied by weak induration. These colour bands may be either generally red (as extreme as 2.5YR 4/8 in places) and associated with iron (hydr)oxides (especially goethite; Catt, pers. comm. to Stringer), or grey/brown (as extreme as 5YR 3/1 in places), with the inclusion of manganese oxides and slightly enriched matrix carbonates. Individual colour bands are from c.1 to 20mm thick and they often cut across bedding features. Towards the south of Area II, the thinner red bands may be locally quite hard and very rich in iron compounds. In general, the banding undulates gently but usually with a lower frequency than the irregularities in the substrate bedding features. Banding is best developed in sandier zones and may almost disappear in the clayiest zones. A variable number of colour bands (up to c.25 clear bands) may appear in any given vertical exposure and they sometimes coalesce or bifurcate; bands of the two types ('Fe' and 'MnCa') never cross one another. Towards the south of Area IV, some colour bands are obliquely and sharply truncated by erosion features (channels) within the local sequence of the GCSS unit.

Upper Sands (US) This unit is dominantly composed of compact, well sorted, fine to medium quartzitic sand. Bedding is very well developed and most clear in Area IV, where it may be seen as continuous, wavy laminations. The waves are in phase throughout the unit thickness and their crests are generally oriented across the gentle slope (i.e. the crests are east-west and the slope is down to the south), although there is also some waviness at right angles to the main trend. Subunit thickness does not vary in response to the wave forms but there is a

tendency for laminations to be slightly thicker to the north of particles larger than c.5cm. A few individual laminations show internal, weakly developed inverse size grading of the sand particles. There are appreciable quantities of sand sized shell debris, dispersed uniformly throughout the deposit. Towards the base, there are still a few very thin clay lenses, and the colour banding seen in GCSS also continues into this lowest zone of US. Colour is variable and some of the banding may be as dark as 5YR 3/2, although at least the middle part of the unit is generally brown (7.5YR 5/4). For lithostratigraphic purposes, the lower boundary of US may be defined as sharp (a bedding surface), although in most Areas there is in fact a conformable gradational boundary with GCSS, sand laminae quickly becoming more common upwards until only sand is present. Small angular calcitic limestone clasts, showing little if any alteration, are a minor component in some zones of US and are often present in thin gritty lenses. However, towards the east of Area IV, and to a lesser extent towards the north of Area V, there are much larger quantities of limestone, especially nearer the base of the unit. In Area IV, the source can be seen to be the in situ breakdown of large fallen roof slabs. This material was originally designated as a separate unit (the Coarse Brown Sands; Stringer 1977). From a lithogenetic point of view, it would seem that this is just a scree-rich facies. However, there are sufficient grounds for lithologic subdivision if this should eventually prove useful for biostratigraphic purposes. In Area IV, the base of the next unit (Upper Cave Earth, infra) is slightly irregular and it locally truncates the bedding features of US. However, in the north-south exposure in Area V and slightly southwards towards Area IV, the very sharp boundary between US and the overlying deposit is parallel to the bedding in

US, even where larger limestone clasts in the overlying deposit have indented both the boundary and the bedding features below. In this zone, the first few centimetres of US are very well compacted and contain a higher proportion of colloids than elsewhere in this unit; the bedding may be picked out by darker staining. In this uppermost zone, there is slight alteration of calcitic limestone clasts but dolomitic clasts are usually very unsound.

Upper Cave Earth (UCE) The base of UCE is sometimes expressed as a zone of dense, reddish brown clay/silt/sand, with roughly horizontal fissility; the zone may contain variable amounts of edge-rounded limestone debris. This feature is particularly apparent in Area IV, where the zone has a thickness of c.5cm before grading smoothly into the more open material above. The body of this unit is a scree-rich deposit with a matrix of reddish brown (6.25YR 4/4), badly sorted sandy silt. Limestone clasts, mostly of the calcitic type, are present in sizes from coarse sand to boulders. There are signs of only the weakest alteration. Clasts are organised into a weak fabric showing a tendency towards slope bedding (gently down to the south), although there is no preferential orientation of long axes. The deposit is usually clast supported and, although it is still quite loose in places (and even unstable in east-west sections such as in Area IV), there are generally less and smaller airholes than, for example, in SCE. The matrix is rich in carbonates of all sizes and there are no signs of alteration or significant carbonate mobility. Compaction of the matrix is normal to loose with no specific microfabric features. Unlike most underlying deposits, no marine shell was observed in this unit. Seen over all the exposures in Areas IV and V, UCE appears to be relatively homogeneous, lacking the

lateral fluctuations in texture, composition and fabric seen in SCE. The modern surface truncates UCE in Areas IV and V. Only above and to the east of Area IV do younger deposits (Cemented Breccia with Stalagmite, infra) survive against the cave wall; here, any matrix boundary between UCE and the higher deposits has been lost through heavy suffosion, although there is no sign of a radically angular unconformity.

Before continuing the description of the main sequence, certain other deposits on the cave platform should be mentioned.

In Area IX (fig. 76), a huge fallen roof slab protects sediments against the east wall of the cave. These sediments are heavily altered (suffosion, mobilisation of carbonates, etc.) because they are lying in the main drainage route out of the cave to the south-east. Also, a bedding plane in the limestone has been opened up by solution as a continuation of the platform surface behind the sediments (undercutting the east wall) further increasing through-drainage. Nevertheless, lateral equivalents of GCSS (almost certain), and of US and UCE (probable), occur in this Area as a stratified sequence. These deposits all slope down to the south, following the bedrock slope, but they also dip by as much as 40° down to the east, towards the open bedding plane; fine bedding features are absent in all three deposits but larger particles show strong preferential orientation in accordance with the overall dip. Below the GCSS equivalent in 1980-1 another deposit was observed, consisting entirely of relatively large (c.8-15cm) calcitic limestone clasts, resting on the bedrock and extending down the platform to reach an absolute height of c.9.7m O.D. This material could only be penetrated for a few decimetres for fear of disturbing the huge roof slab which appeared to be chocked against it. Clasts were very heavily rounded, with strong

alteration crusts, but, although some of the clasts were roughly spherical, most showed large, re-entrant (concave) forms. There was very strong point-to-point carbonate cementation. There were no exotic rock types, no oriented fabric and no particulate matrix. This deposit has not yet received an official name but it will be referred to as the "Cemented Limestone Cobbles" (CLC) in the discussion in the next section. By 1984, CLC had been totally destroyed and all traces of it removed; it seems likely that this destruction was caused by an exceptional storm event since many huge, already disturbed blocks of cemented sediment had also moved significantly down the platform in this vulnerable area.

At the point marked B in fig. 76, the platform deposits terminate as a 'mound' of material draped against and over a major step in the bedrock (with a riser c.1m high). These deposits have been heavily cemented by apparently intrusive carbonates as well as by mobilisation of internal carbonates, without significant disruption of the fine matrix of the original sediment. The lower part of these deposits, abutting the riser of the step, consists of a well structured pebble bed, more than 40cm thick. The pebbles are nearly always very well rounded and they are often slightly or moderately flattened. The lithology of these pebbles is being studied by A. Henry, but it is clear that many exotic types are present. A few pebbles carry the borings of marine organisms. In a roughly north-south plane, the pebble axes are dominantly horizontal, but each pebble dips by 20-25° down to the east, with common imbricated contacts (nose-on-tail). The pebbles are all comparatively small (<8cm) and there is a slight fining-upwards trend, superimposed over minor fining-upwards cycles. Most of this deposit is either pebble-supported or very locally shingle-supported. Thin sandy lenses may be present but it is

difficult to observe such features in this highly cemented unit; there are certainly no major beds of such material. Samples of the matrix have not yet been disaggregated for detailed study but it would appear that quartzitic medium sand and fine shingle, with shell fragments, are the main components. In 1980, a narrow trench was cut in the north side of this deposit in an attempt to link it with the stratigraphy observed further east. Large limestone slabs were soon encountered which rendered this project very difficult. However, a thin sand body, generally quite similar to CGS, was seen to tongue into the upper levels of the pebble bed, and to drape the rock step (riser) behind the pebbles. This tongue of sand was followed back eastwards, but it could not be physically connected (i.e. there was a gap of c.30cm) with the CGS unit lying immediately upon the (higher) tread of the bedrock step against which the pebble bed is banked. Thus, assuming that the sand tongue is referable to CGS, alternative readings of the stratigraphy are possible: either the pebble bed pre-dates, or mostly pre-dates, CGS so that we are observing a normal younging-upwards sequence; or (older) material from CGS has slumped off the rock step into the (younger) pebble bed. A further possibility is that the sand associated with the pebbles is not derived from CGS but is, instead, a lithofacies which is broadly contemporary with the pebbles. The pebble bed has not yet been given an official name but it will be referred to as the "Cemented Imbricated Pebbles" (CIP) in the discussion in the next section.

Above CIP and its sandy zones, there is a thick cemented deposit which may be equated with absolute certainty with SCE (there is a continuous exposure back towards Areas II and V). Note that CIP nowhere contains derived clasts from this cemented zone of SCE, thus ruling out the possibility that CIP is a

significantly more recent deposit, plastered onto the outside of the mound underneath an overhanging ledge of SCE. It is clear that further excavation will be necessary to provide more conclusive data on the stratigraphic position of CIP. For the moment, the author takes the minimal view that all available information is consistent with, even if not firmly evidential of, a correlation between CIP and SBC. Although this attitude departs from strict lithostratigraphic practice, it would seem preferable to any alternative reading which might force the premature assertion of several high sea levels (cf. section 23.2.4.).

The sediments on the 'lip' of the western gully, at point A and against the base of the sequence in Area VII (fig. 76), clearly represent recent deposition (as indicated by the nature of the sediments and the demonstrably holocene faunal content). They are described here both because they represent useful comparative material and also because their presence may explain an otherwise puzzling statement in the literature (discussed on p.1066 below). At point A, the sediments represent a classic high level storm beach, developed at the limit of the ballistic effect of waves but beyond the sorting effect of significant quantities of water. As observed in 1980-1, the deposit comprised small, mostly flattened pebbles, lying on the first bedrock step. A few pebbles carried the borings of marine organisms and there were rare limestone 'proto-pebbles'. The pebbles were imbricated, with the dip away from the gully towards the east. Pebble support was normal but there were a few zones of shingle support. There was much fine shingle and shell debris, especially towards the base of the c.15cm thick deposit; the surface of the deposit was composed of openwork pebbles. There was thus a clear vertically developed sieve structure. More sand was present towards the back (east) of

the step (against the bedrock, between the pebbles), and just south of the main pebble zone there were small areas of laminated sand representing minor reorganisation by water draining out of the sediments. Passing northwards towards Area VII, the deposit progressively lost its structure as more and more, angular limestone clasts were included. At the base of the major erosion face in Area VII, the sediment was a loose, unstructured, openwork mixture of pebbles, shingle, shell debris, limestone clasts and discrete carbonate cemented aggregates ('breccia' clasts). This facies represents a syndepositional blend of storm beach material and sediment falling from the major erosion face. In 1984, the storm beach was observed to have undergone a major change. The features mentioned above were still generally visible, and the lateral trends were still clear, but there had been a massive input of large (up to c.10cm) edge-rounded limestone clasts (some of them sufficiently modified to be termed 'proto-pebbles') and even a few similarly sized pebbles. It is inferred that a block of ancient breccia fell into the northern end of the gully, that the block was reduced to its component rock elements and that these were thrown back up during a violent storm (cf. the destruction of CLC, supra).

The major erosion face which cuts right through the pleistocene cave deposits in Area VII (including the whole east-west section across the modern cave mouth) exposes strata that appear to be the lateral equivalents of two of the units already described from further down the platform. The whole of this erosion face is very heavily suffused and altered, and there has been much carbonate mobilisation and secondary cementation (cf. p.446). Nevertheless, GCSS is certainly present as a continuous tabular unit, c.85cm thick. The individual subdivisions

defined above cannot here be recognised with certainty, except for the basal "dark pan" which is still clear. The base of this unit lies at c.16m O.D., that is, c.2m higher than in Area IV, implying a general slope of c.5° at the most, up into the cave. There is also an extremely gentle dip component down to the east in the cave mouth exposure. Above the GCSS equivalent, there is no obvious sign of US (except for a slightly sandier zone) but there is a deposit, c.40cm thick, which closely resembles UCE, save that there is a much larger colloid component and the rare dolomitic limestone clasts are all ghosted. The upper boundary of this material is reasonably sharp but the matrix is here altered, recemented and probably disturbed/replaced due to suffosion; this exposure will not serve as a boundary stratotype for the transition between UCE and the overlying deposits (infra). Below the GCSS equivalent, there is a heavily suffosed scree-rich deposit which is too altered for recognition. At the top of this deposit, immediately below the "dark pan" of the GCSS equivalent, there are small pockets of shelly material which may represent SS. The present exposures in the cave mouth show no pebbly units, although cemented pebbles may be seen if one climbs down into the gully and back up under the deposits. Just above the sloping bedrock on the western side of the main gully, and sandwiched between indeterminate scree-rich material, there are quite extensive occurrences of a very badly altered, relatively thick (>5cm) stalagmitic floor. This floor cannot yet be traced north, right into the erosion face, but it does come to within c.2m of the face at a level which suggests that it is stratigraphically lower than at least the GCSS equivalent.

Despite the difficulty with the precise definition of an upper boundary for UCE in all the Areas so far described, it is

clear that the next set of deposits overlies UCE with no obvious intervening units. These upper deposits have not yet been studied in detail but they are collectively referred to in Currant et al. (1984) as the "Cemented Breccias with Stalagmite horizons" (cf. fig. 77 in the present text). The present author would prefer to replace the term "horizons" with "lithozones". The abbreviation CMBS will be used here in order to avoid confusion with the Coarse Brown Sands. In the major erosion face above Area VII, CMBS is present as a series of deposits with a maximum thickness of c.7m. This material is continuous with sediments cemented to the rock wall along the western 'land' access route to the site. Exposures up to c.3.5m thick are also available against the east wall, from Area VI southwards to a point above and just to the east of Area IV (fig. 76).

The base of CMBS is usually composed of masses of angular limestone scree. Especially in the main cave mouth section, it can be clearly seen that much of this scree represents the in situ breakdown of huge fallen slabs. The limestone clasts may often have an average size of only c.10-25cm but careful examination shows that they refit to produce slabs sometimes 3m or more across. Zones of conjoinable clasts usually show strong preferred orientation, reflecting disintegration of the original slabs along bedding planes with only minor lateral displacement of elements. The zones between former slabs show chaotic macrofabric. No certainly original fine matrix can be recognised in this material.

Above this basal 'slab' subdivision, the rest of CMBS is composed of a complex series of fining-upwards cyclothems. Most subunits are highly lenticular in form so that it is very difficult to follow a given stratigraphic horizon (sensu stricto) for any great distance laterally (i.e. for more than 2-3m). This material

has not been logged accurately, because it is usually difficult (and dangerous) to reach, but it seems likely that at least fifty cycles are represented in a vertical line through the greatest development of this unit (i.e. above Area VII). The details of each cycle are different but the general pattern is clear. At one extreme, a cycle may start with coarse (up to c.20cm) limestone clasts and fine upwards to badly sorted, carbonate-rich sand. At the other extreme, a cycle may start with fine limestone gravel or grit and fine upwards to carbonate-rich silt. Overall, siltier end-members appear to be most common. Generally finer grained lenses tend to be thinner than generally coarser lenses; maximum lens thickness varies from 5-30cm with only a few lenses beyond these values. Many cycles are followed by a phase of carbonate precipitation, although later secondary cementation has reinforced this effect. Towards the top of the unit, the penecontemporaneous carbonate deposition may take the form of thin spreads of purer speleothem. On two occasions, at the very top of the sequence and at a level c.1.5m down into the sequence (in the centre of the cave mouth), calcite is present as true stalagmitic floors, both of which are continuous across the cave mouth (but not westwards into the material on the 'land' access slopes) and also right down to the southern limit of this unit above Area IV. The upper stalagmitic floor is very thick (formerly including major stalagmites and columns) directly below the fault line in the roof of the present cave, and it thins southwards, being c.8cm thick (with some additional stalagmites and much phytogenic tufaceous carbonate) above Area IV. The lower stalagmitic floor is always thinner, thinning to only 1-2cm above Area IV, but it has a more consistently dense crystalline structure.

The geometry of the component subunits of CMBS also shows

a clear pattern. In the material on the 'land' access slopes to the west, beds are much more continuous and the bedding dips down uniformly eastwards towards the cave by c.15°. Crossing the cave mouth eastwards, subunits become increasingly lenticular and there are fewer subunits in a vertical sequence at any one point. In the main body of the unit (i.e. below the lower true stalagmitic floor), the apparent east-west bedding angle is c.10° down to the east, decreasing to c.5° at the east side of the present cave mouth. A similar tendency is seen in the north-south exposure along the east wall, with both the whole unit and individual subunits thinning southwards, subunits wedging out and an overall seaward dip of c.5°. Returning to the centre of the present cave mouth, the subunits approximately half way up the sequence can be seen to start to dip very slightly into the cave (northwards). This inward dip increases upwards through the remaining sequence to reach a general value of c.12°. Locally, at the very top of the sequence below the fault line, the uppermost subunits, including the capping stalagmite, form a sort of high 'corniche', with subunits dipping by as much as 20° into the cave as well as by c.5-10° both east and west away from this high point.

The only material that has yet been examined closely in the CMBS sequence is a bone-bearing lens, just beneath the upper stalagmitic floor, in Area VI. Later erosion has not been so extreme here, nor is the erosion face so nearly vertical as it is in most other exposures. Accordingly, the sediments have suffered much less suffosion and alteration, although bulk cementation is still quite strong. The bone-bearing lens is composed of fine, angular limestone gravel, fining upwards to badly sorted, carbonate-rich silt with limestone grit. There are no obvious fine bedding features.

Fig. 78 shows the sequence of deposits observed in Area VIII after the southerly side of the excavation by Wood and Benson had been emptied of back-fill. The deposits in Area VIII have still been very heavily altered and suffused, even though they are some 20m north of the major erosion face at the present cave mouth. Moderate suffusion is generalised but there are also some even more open preferential drainage routes (cf. p.447). This disruption of the sediments means that internal fine structures, indicative of depositional processes, can no longer be observed. The deposits present are nevertheless sufficiently well characterised to allow a highly probable correlation with the units already recognised on the platform outside the present cave. Faunal correlation supports the same links as suggested here. Because of the postdepositional alteration, usually resulting in very varied and blotchy colours, Munsell designations will not be given.

The lowest unit is very heavily altered, as is the irregular bedrock surface upon which it lies. This is a variegated deposit, with a generally 'reddish' to 'buff' colour, becoming 'greyer' upwards. The matrix is very clayey/silty but it has a significant medium to coarse sand component. Calcitic limestone clasts are common, being larger near the base. The clasts are always altered, but their condition ranges randomly from relatively sound to ghosts stained 'black' and 'bright red'. There are a few altered stalactite fragments. Because of its altered condition, this deposit represents the weakest link in the correlation scheme; its relative stratigraphic position together with what little can be seen of its original composition suggest that this may be an equivalent of SCE.

The next deposit is certainly equivalent to SS. The unit

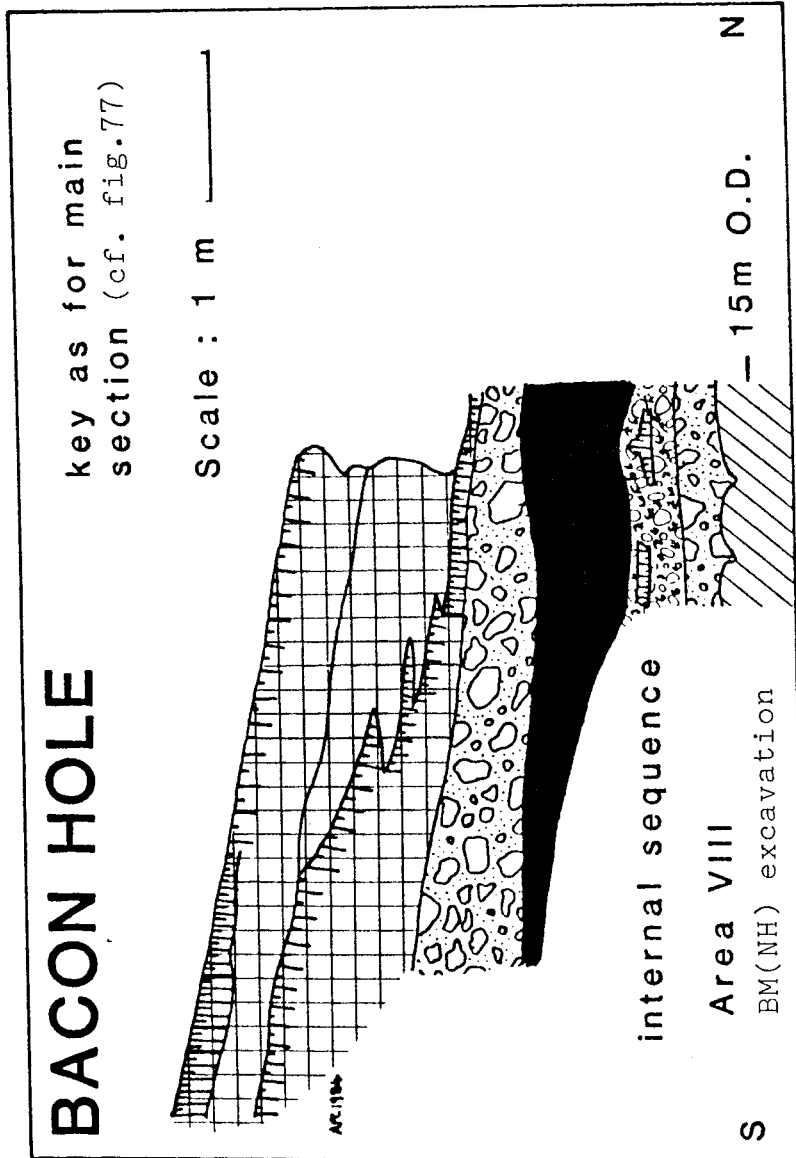
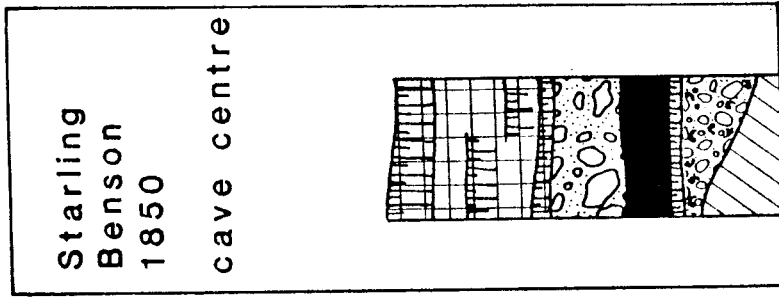


Fig. 78 Bacon Hole - Interior Sections (after Currant et al. 1984)

is still very rich in shell debris at this point and there are slightly fewer limestone clasts. One new component has been added, namely quite common small fragments of curtain speleothems and stalactites, including true straws. This shelly sand is c.40cm thick towards the western side of the exposure but it wedges out eastwards.

Especially towards the top of the SS equivalent, but also in places penetrating deep down into this unit, there are large slabs of a major stalagmitic floor, some of them up to c.20cm thick. The stalagmite is internally stratified, with 6-7cm crystalline sequences separated by thin dirty bands. Some clasts show at least one major internal unconformity. Traces of a 'reddish' breccia adhere to the undersides of some stalagmite clasts (the SS equivalent in general does not contain aggregates of any such breccia). Stalagmite slabs lie horizontally, or at angles up to the vertical, and one of them was clearly upside-down with its small bosses underneath.

The next deposit is the equivalent of GCSS. Here, the sediment is very similar to GCSS on the outer platform but the subdivisions cannot be recognised, save that the basal "dark pan" is still present. The absolute height of the base of this deposit (c.15.8m O.D.) is very close to that recorded for the GCSS equivalent in the main erosion face at the present cave mouth.

In 1980, a large fragment of stalagmitic floor was recovered on the east side of the Area VIII exposure (where the SS equivalent is missing), at the boundary between the GCSS equivalent and an underlying heavily altered sediment. This lower sediment is generally similar to the possible SCE equivalent (on the west side of the exposure) described above, but the two occurrences were not continuous and it is perhaps unwise to assume

that they necessarily represent the same unit. The author did not see the easterly stalagmite fragment before it was removed. In general, it is quite similar to the slabs noted in the SS equivalent on the west side of the exposure.

Note that there is no possible equivalent for either of these disturbed stalagmite occurrences in the sequence on the southern part of the platform, although the presently isolated and heavily altered floor to the west of the main gully might be a correlate.

Above the GCSS equivalent in Area VIII there is a 'reddish', silty, scree-rich deposit. The limestone clasts are altered and the matrix has been heavily suffused in places, with carbonate segregated to form dirty calcite crusts over clayey pellets. This deposit is generally similar to UCE, a proposition supported by faunal correlation.

Immediately above the UCE equivalent there is a very thin (c.1cm) in situ stalagmitic floor. This material can only be traced for a metre or so before it 'wanders off' southwards, upwards into the overlying lenticular deposits at a most probably time-transgressive contact (cf. fig. 78). The stalagmite has been heavily reinforced from above by later subsurface accumulation of calcite. It is not clear from the present exposures whether this stalagmite (where it directly overlies the UCE equivalent) is unrepresented in the exterior deposits or whether it might be correlative, or even time-correlative, with the lower true stalagmite in the CMBS sequence.

The highest deposits in Area VIII are clearly equivalent to some part of CMBS. The capping stalagmitic floor is also present.

Throughout the present cave interior, there is a

discontinuous and sometimes demonstrably disturbed layer of sticky dark 'mud', overlying the upper stalagmite. Because of the disturbance, it is difficult to estimate the maximum thickness but it is unlikely that it is in excess of 15-20cm. This layer contains holocene fauna and archaeological remains from the Iron Age onwards. The cave interior is presently very damp and small pools and puddles form under the most persistent drips. Modern crystalline speleothem formation is very slow and restricted to areas which cannot be polluted by other sediments; the pools do not contain speleothems. Thin and restricted lenses of laminated sediment may form in deeper puddles. Some puddles contain small masses of bacteria, like wet cottonwool, and some algae. Small worms (probably either nematodes or annelids) were also observed in the wet 'mud' but not in the puddles which are probably depleted in oxygen. The limestone clasts in the organic-rich 'mud' are moderately altered and some of them can be at least partially crushed between the fingers. Bird guano, feathers and nesting material seem to represent a major source of organics and a few fungal fruiting bodies were observed in association with such material. There is a constant 'rain' of small tufaceous concretions from the roof, where colonies of algae, lichens and bryophytes grow until they are entombed in calcite; once fallen, these weak concretions break up to add both organics and carbonates to the muddy sediment. On low topographic rises that are slightly less damp than the surrounding sediment, sometimes quite concentrated carbonates have been precipitated in the first centimetre or two of deposit to form weakly indurated crusts. Limestone clasts in these zones may have irregular concretions on their undersides. Fine networks of desiccation cracks may also occur on such rises, especially in organic-rich zones. Except

near the puddles with the most active drips, the 'mud' is usually very slightly salty.

The modern surface outside the cave in Area II, and also in small patches further north, has remained sufficiently stable to allow the formation of a closed 'turf' cover. The small plants all have fleshy leaves which are usually laid flat on the ground, thus showing specialisation to maximise light catchment and minimise desiccation. The plants have a strong tap-root which separates into a multitude of fine rootlets after the first 20cm or so; these rootlets may penetrate to bedrock right through the pleistocene deposits. The roots have never been observed to be associated with rhizoliths or even macroscopic etching of carbonate particles. There is no horizon development, save for a very thin zone of slight enrichment in organic matter at the top. Had such vegetated surfaces ever existed within the pleistocene sequence, at Bacon Hole or in other similar situations, it would seem extremely unlikely that they could now be identified.

23.2.4. Bacon Hole - Interpretation of the Sequence

Very detailed faunal information (mammals, birds, fish, amphibians, terrestrial and marine mollusca, foraminifera, ostracods) is available from Bacon Hole (cf. Stringer 1975, 1977; Carrant et al. 1984). Reference to this material will be made in this section only in order to support or clarify inferences concerning environmental factors. In passing, it should be noted that the Bacon Hole deposits constitute the most impressive set of discrete palaeontological contexts known to the present author from any British cave. This proposition is not only supported by the taxonomy and condition of the faunal material itself, but also

by the nature of the deposits, which generally provide a superb stratigraphic record composed of comparatively low energy sediments expressed in continuous and regular geometries.

Before discussing the detailed implications of the Bacon Hole deposits, it will be necessary to reconstruct the form of the cave at various periods in the past. The relevant factors are as follows:

(1) The succession from BPB to UCE comprises a series of roughly tabular units, or of units wedging out generally northwards. Overall bedding angles are low, varying from roughly horizontal to c.5° down generally southwards or south-eastwards. Nowhere are there significant cones of material or major sets with high bedding angles. There are quite common roof slabs in most areas and bedded in most sedimentary units.

(2) This pattern changes radically in CMBS. In the main part of the CMBS succession (between the lowest 'roof slab' subdivision and the lower true stalagmitic floor), the bedding angles and sediment body geometry clearly indicate dominant input along the western 'land' access route. Towards the top of CMBS, the zone of maximum input drifts eastwards towards a point roughly half way across the present cave mouth. However, at no point in the CMBS succession are there signs of significant input from the massive eastern rockfaces now present above the site; there are not even any minor beds banked up against the foot of the east wall. Furthermore, pure crystalline stalagmite has formed towards the top of the CMBS succession, even as far south as Area IV.

These observations clearly suggest that the cave was formerly roofed over to a much greater extent than it is today. In the lower series, from UCE downwards, all information points to derivation of exterior sediments only from a seaward direction,

although input of minor amounts of fine material through restricted roof fissures is not ruled out. At this time, the cave roof must have covered all the exposures of sediment described in the last section. The 'slab' subunit of CMBS seems to represent a major degradation of the cave roof, leading to the opening of a 'land' access route from the west, and only from the west. As time passed, the opening in the roof was enlarged but, because it was progressively blocked by incoming sediment, the effective route migrated eastwards, allowing more direct input to the CMBS 'corniche' in the centre of the cave. However, the eastern part of the cave was still adequately roofed over, otherwise scree would have entered from the east and the stalagmitic floors would not have formed so far down the platform. It seems probable that, at least towards the end of the deposition of CMBS, all 'entrances' to Bacon Hole were very restricted and it is even possible that sediment reached the roof in some southerly areas. Perhaps the roof towards the south was already fractured and unsound, and partially supported by sediments. In the Holocene, the sea rose again, first destroying the massive slope deposits that must have been present on the modern intertidal platform and near, or even over, the 'mouth' of the cave, and then cutting back, especially along the most vulnerable line up the western gully, into the body of the cave sediments. As the sediments were undermined, they collapsed and were evacuated seawards. The southern part of the roof, with any sediment support removed, also collapsed. The last fragments of this roof, which fell after the main phase of marine erosion, litter the present sediment and rock surface on the platform. Truly enormous amounts of sediment and rock must have been removed in a comparatively short period during the maximum holocene transgression. It is salutary to note that, apart from

the impressive erosion faces cut into older deposits, the only material trace of the holocene sea (so far) is a thin spread of pebbles and shingle, itself demonstrably transitory, along the lip of the western gully. Indeed, holocene sedimentation as a whole has been minimal. Only when the sea level drops significantly will major deposits begin to accumulate again at Bacon Hole.

The oldest deposit so far observed at Bacon Hole is represented by BPB. These pebbles and cobbles are clearly of marine origin but the present sediment body in no way constitutes any sort of 'beach', since it lacks all the characteristic structural features. This is merely a lag deposit, containing reworked material from one or more old 'beaches'. The matrix appears to be at least dominantly intrusive (cf. CGS); note that the small areas with matrix support indicate reworking after fines had begun to infiltrate the coarse lag. The absolute height of this material is of no great interest, although it does probably give a rough indication of the minimum extent of former marine activity.

It will be convenient to discuss CLC (in Area IX) at this point, not because it was likely to have been in any way correlative with BPB, but because it might also have been mistaken for a 'beach'. Again, CLC had none of the structural features of a 'beach' and, in addition, it was totally devoid of exotic rock types. The form of the cobbles is most efficiently explained by chemical solution and there is no need to invoke marine abrasion of free-moving particles. If this deposit could have been examined away from the erosion/alteration front, it is likely that much less spherical forms would have been found. Although the fact that CLC was lying at the base of the main south-easterly drainage route out of the site is sufficient explanation for the condition

of the cobbles, solution would also have been accelerated by the corrosive effect of spray at times of high storm seas during the Holocene.

Another reference to presumably marine (littoral) material at Bacon Hole has been made by Bowen:

At the entrance to the cave, separate from the above succession [that described by Stringer (1975) and including units from CGS to CMBS], is (i) marine sand, (ii) head or scree, with (iii) shingle beach lying unconformably across (i) and (ii) (1977:23)

It is not clear what Bowen means by "at the entrance". It is possible that he is indicating the material at point B, in which case both the lithogenetic inference and the geometry are incorrect (the sediments at point B are discussed below). Alternatively, the reference is to the sediments banked against the base of the major erosion face in Area VII. As has been said above, this is all demonstrably holocene material and, in any case, the discrete units defined by Bowen do not (now) exist in this Area. At no point in the site has the present author observed a sequence comparable to that described by Bowen.

CGS overlies BPB, or bedrock where BPB is absent, in the main platform sequence. This quartzitic sand is remarkable for the combination of good sorting, on the one hand, and lack of both compaction and fine bedding structures, on the other. These characteristics could not result from deposition by either water or by efficient wind action. The sand must represent wind 'dumping' as the organised exterior air currents were disrupted and radically slowed upon entering the cave. This could have happened with a generally southerly wind blowing into the entrance, with any wind tipping sand into the cave through roof fissures, or with a generally northerly wind tipping sand over the contemporary overhang at the cave mouth. It is likely that the

first of these mechanisms was at least partly responsible, because not even low cones of sand are present (any reworking would have increased compaction) and the sand contains a few littoral shell fragments. Bull has not recognised aeolian surface textures on the sand grains, suggesting that we are dealing with a localised sediment transport system, but he does note (pers. comm. in Carrant et al. 1984) an increasing amount of marine surface modification upwards through this unit and on into COS, SBC and SCE above. The evidence of sand mobility, the lack of compaction during deposition and the lack of significant alteration of the angular limestone clasts in CGS suggest a generally cool and dry environment.

The input of sand continued during the deposition of COS but a much more important contribution was provided by the breakdown of the cave roof and walls. It is not clear which of the many possible environmental and contextual parameters (cf. p.284) might have been responsible for this increase in scree production. The limestone clasts must represent truly localised rockfall, since lateral derivation of any sort would necessarily have induced relatively clear bedding features and greater compaction of the matrix. The weak alteration of the limestone clasts and the increase in colloids suggest a shift to a slightly warmer and moister environment. The survival of pyrite crystals in the matrix-rich yet well aerated deposit shows that any amelioration was limited; the pyrite would have been oxidised under moist, warm conditions.

CGS and COS together appear to represent a conformable sequence. Although there is a true temporal change in sediment characteristics, there is also a clear lateral change, with the purer sands better developed to the south and wedging out into the

cave, whilst scree input is more pronounced towards the interior. Thus, it seems likely that the CGS/COS boundary may be slightly time-transgressive, with more scree-rich material being deposited progressively further south as the balance between scree production and sand input changed. By the time the present cave mouth is reached, there is no longer any sign of significant sand input; the coarse surface texture of a scree body would have trapped saltating sand further south. If the scree facies alone were present at the base of this northerly sequence, or further into the cave, there would be no obvious lithologic criterion that would enable easy differentiation from any other scree-rich unit, especially given the high degree of postdepositional alteration in the relevant areas. However, CGS and COS have a characteristic fauna which, hopefully, would serve to identify a time correlate under such circumstances; no such fauna has yet been recovered from areas north of the lithologically characteristic exposures already described.

The two "coarse sand" units contain land mollusca indicative of open conditions and bare rock faces or scree slopes (J.G. Evans, pers.comm. in Currant et al. 1984). Horse is present, as is a large form of the northern vole (Microtus oeconomicus), believed by Stuart (1982:188) to indicate a relatively cold environment. Thus, the faunal data complement the environmental inference drawn from the sediments.

SBC overlies COS in the main platform sequence. Towards the south, the surface of COS is slightly disrupted, which is not surprising given the nature of the SBC sediments at this point (infra). Elsewhere, there is a relatively abrupt decrease in (but not a complete cessation of) sand input, which, together with the fact that there is a major faunal change, might suggest that

an unrepresented period intervenes between the two units. The most southwesterly expression of SBC in Areas II and IV is sufficiently well structured to allow firm identification of the extreme 'landward' edge of a true storm beach. The present author believes that CIP is likely to be part of the same sediment body (cf. the discussion of stratigraphy on p.1050), but the interpretation of SBC as a storm beach is not dependent upon this correlation. CIP is a 'classic' storm beach (with the penecontemporaneous or postdepositional addition of fines and carbonates); it has an almost perfect analogue in the material observed in 1980-1 on the lip of the western gully at point A.

It is worthwhile discussing the information which may be safely deduced from the presence of such beach material, especially with respect to contemporary sea level (see also p.450). The shingle and pebbles owe their positions to the ballistic capabilities developed by waves, and especially storm waves; the sediment was not deposited under water but was literally thrown up onto the platform. The consistent fabric of both the holocene and pleistocene material is indicative of such a process, as are some of the individual components. For instance, the limestone 'proto-pebbles' clearly represent angular clasts which fell into the gully, were violently edge-rounded and were then thrown up onto the storm beach, probably all within a comparatively short time (cf. p.1052). Similarly, the low proportion of pebbles with the borings (dwelling and anchor structures) of marine organisms is of interest. Even small pebbles of the great majority of softer rock types in the modern intertidal zone carry frequent borings, but these pebbles are located in protected sites (rock pools and fissures) and they are not disturbed by the tides. The marine organisms will not bore into pebbles which are constantly subject

to violent movement up and down the coastal gullies. Thus, only rarely do bored pebbles become available to be incorporated into storm beaches at significantly stepped and incised points along the coast (see also p.1096). Obviously, the sea must be 'geographically' very close in order that a storm beach may form, but variations in mean sea level of a few metres, without significant lateral shifts, may be swamped by the effects of the energy parameters and the geometry of the coast. These factors may be of generalised types: the form of the whole coastal platform, effective storm wind direction, amplitude and frequency of storms, etc. However, extremely localised factors are also very important, especially the precise geometry of the last few metres of the wave access route and that of the available 'catchment'. Today, waves penetrate along the western gully, right under the cemented deposits towards the north end. A series of steps and basins in the gully floor create enough resistance to storm waves to cause small pebbles to be thrown up onto the rock 'lip' above; the pebbles remain there because little water actually breaks over them (except during exceptional storms, cf. p.1049) and also because the platform slopes down slightly away from the gully. However, what would happen if we filled the northern end of the gully with coarse sediments or even large boulders, so that, at least for a time, the waves were abruptly checked further south? A situation of this general type seems to have occurred between 1981 and 1984; not only was the sediment on the edge of the gully increased by at least a factor of four, but some clasts were thrown at least as far east as the base of the mound at point B. We cannot assume that such a situation has never before occurred during the Holocene, so that we may deduce that some storm events are erosive and that the condition of these

beaches is in constant flux. Similarly, since we may reasonably assume that the western gully has been slightly deepened during the Holocene, what would the resulting storm beach look like if the gully floor were, say, half a metre or a metre higher? The width of the gully (which will have increased during the Holocene) also has an effect upon the trajectory of pebbles. The ancient deposits, CIP and SBC, lie up to c.2m higher than the modern storm beach and also much further east onto the platform. Nevertheless, the author can see absolutely no justification for making a more specific statement than 'sea level at this time was probably similar to that of the present day, with an unquantifiable possibility that it may have been a metre or two higher'.

Moving northwards within SBC, the storm beach material quickly gives way to more terrestrial sediments, with the occasional inclusion of lenses of wind-blown sand. This terrestrial material is generally similar to SCE, so that the two may be discussed together. The really interesting point about SCE is that, apart from a minor but consistent input of wind-blown material, it represents local sedimentation, in the strictest possible sense. This is indicated by the rapid fluctuation in sediment characteristics, both vertically and laterally, with the establishment of no overall pattern save the heterogeneity itself. Most of this material represents the breakdown of the cave roof immediately above any given point; the lack of structural indicators shows that, once coarser material had fallen, it then remained in that position and was not significantly reorganised by any form of slope movement. Extremely fragile components, such as roof speleothem fragments and vein minerals from the limestone (clasts of which are quite often up to c.5cm across, but only c.2-5mm thick), could not possibly have survived even minor

reworking in these coarse deposits. The occasional groups of bones found in articular association in SCE point to the same conclusion. Because many zones of SBC and SCE are openwork deposits, with relatively large communicating voids, there is obviously a potential for the downward movement of smaller particles. However, there is no well compacted or even more continuous zone of fine sediment between the clast framework at the base of these deposits, and sandy material, perched precariously on top of larger clasts, is common at all levels. Even small bird bones sometimes occur in articular association. In Area V, the base of SCE is clearly marked by a discrete limestone collapse deposit which, of course, could not have contained any bones at the time of its deposition; the lack of major translocation of fines is shown by the fact that this collapse deposit is still almost devoid of microfauna (Stringer, pers.comm.). SCE therefore represents a tabular sediment body which built up over the whole floor of the cave, in a reasonably gentle manner, due to the patchy breakdown of what was probably a less competent set of strata outcropping in the cave roof (cf. the relatively more common traces of dolomitic limestone). The accreting surface of these sediments would probably have been rather irregular, a feature indicated by the localised occurrence of coarse lenses with relatively high dip and random orientation. Because of the undoubted proximity of the sea at this time, we may perhaps invoke the involvement of such processes as salt crystal wedging, hydration and the increased solutional effects of salty water (the salt being supplied from the air, not directly from sea water), but there is absolutely no reason to suggest a major cryoclastic phase, especially since the firm environmental indicators (infra) point to markedly temperate conditions.

Returning to the detailed characteristics of the more terrestrial facies of SBC, we can already see the operation of the processes described above. However, the tendency towards horizontal bedding of clasts suggests that build-up was at first comparatively slow. The boundary with SCE appears conformable. Thus, as input of limestone debris increased slightly, the more terrestrial facies (SCE) quickly encroached seawards, over the top of the more littoral facies. The boundary between SBC and SCE may well be time-transgressive, the base of SCE in landward areas (where SBC is not present) perhaps being time-correlative with SBC in the southerly areas. The accumulation of SCE above SBC necessarily involved a raising of the contemporary surface, a factor which could have been sufficient to prevent the penetration of littoral-derived material (both storm beach sediments and sands moved by wind saltation) as far into the cave as had previously been the case; this is minor progradation in the sense defined by Curray (1964). Thus, the presence of SCE to the south does not necessarily indicate a significant lowering of sea level in the later part of the SBC/SCE chronozone.

Apart from the direct evidence of high sea level, the climatic implications of SBC and SCE are mainly seen in the alteration of these deposits in the main platform sequence. Postdepositional alteration, during the accumulation of higher units, can be ruled out as the main cause, both because there are no vertical alteration gradients in SCE, and also because SS, with its vulnerable shell debris, is not radically altered. Long term diagenesis within SBC and SCE can also be ruled out because there is no trace of carbonate mobility or suffosion. The calcitic, and especially the dolomitic, limestones in SBC and SCE were penecontemporaneously altered to a moderate degree. This

observation alone would not be enough to support a suggestion of a temperate climate. However, these units do not contain a fine matrix which would keep the limestone clasts anything like permanently damp. Furthermore, there is no sign that significantly large quantities of water ever trickled through these units; the total lack of subsurface concretions on the undersides of clasts is particularly telling in this respect. Yet alteration requires water, and the degree of alteration observed can only be explained if such water as was present contained 'corrosive' substances (salt, organic acids, etc.) in some quantity. It is this aspect which implies a generally temperate climate (compare the condition of SBC and SCE with that of UCE, infra).

The faunal information from SBC and SCE allows an even more secure identification of a warm temperate climate, with mammals and land mollusca typical of the 'Ipswichian' (i.e. as faunally defined). There are even adult and juvenile specimens of Cory's shearwater (Calonectris diomedea), suggesting that the limit of the nesting range of this bird was at least 10° of latitude further north than it is today (C. Harrison, pers.comm. in Curren et al. 1984). The 'marine' elements include a range of littoral mollusca (P. Palmer, pers.comm. in Stringer 1975, 1977; Curren et al. 1984) and generally near-shore fish (A. Wheeler, pers.comm. in Stringer 1977) which is similar to the modern fauna near the Gower coast. The extinct foraminifera, Rosalina sp., is known from the Ipswichian and earlier interglacials (J. Whittaker and R. Hodgkinson, pers.comm. in Stringer 1977).

Inside the present cave, in Area VIII, the SS equivalent contains large fragments of stalagmitic floor which must pre-date this enclosing sediment. There is no sign that a major sequence of hanging deposits was contributing old sediment at this time;

the nature of the SS equivalent would make it particularly easy to spot such pollution had it occurred. The stalagmite sometimes has traces of red 'breccia' adhering to its underside which might be referable to SCE, although this is only conjecture at present.

H.P. Schwarcz (pers.comm. in Currant et al. 1984) has produced a number of U-series dates on this material, with central values in the range 129-116ka (associated with error brackets in the order of 20ka or less). The stalagmitic floor fragment below the GCSS equivalent towards the east of Area VIII (cf. p.1059) appears to be significantly older, although it was associated with derived vein calcite (Schwarcz, loc.cit.).

The upper boundary of SCE is sharp in all areas of the cave. The weak cementation zone is probably referable to later phases, but the slight increase in colloids and matrix compaction at the top of this unit in Area V (the overlying SS having no such matrix to contribute) might suggest a minor non-depositional event. However, there is no obvious faunal discontinuity between SCE and SS when due allowance has been made for the change in sedimentation pattern. True erosion of SBC/SCE occurred to the south of Area IV before the emplacement of SS but this effect is not widespread (infra).

SS includes land mollusca, rodents, limestone clasts and small quantities of mineral fines, but the dominant component is littoral shell debris. There is absolutely no trace of the sort of bedding features which would certainly have resulted from subaqueous deposition. Also, sea water could not have penetrated so far without radically disturbing the underlying deposits. Note that there are no marine-abraded pebbles, rock shingle or even significant quantities of quartzitic sand. The base of the unit shows a slight, but consistent, slope up into the cave. Some

of the shell debris might have been contributed by such agencies as birds or wind-blown seaweed, although the sheer scale of the unit makes it extremely unlikely that such processes would suffice to explain the whole phenomenon. SS must therefore be the direct result of wind transport of individual grains. The paucity of the mineral component shows that the source must have been extensive subaerial exposures of littoral shell beds, probably on a rocky substrate. Such exposures are not likely to have occurred under normal circumstances; even a few major storms could not have thrown up enough shell to provide a temporary source for wind redistribution leading to such a substantial unit as SS. It seems probable that SS represents at least the onset of a true regressive phase in the marine record, although the lack of intercalated mineral sediment lenses and the homogeneity of the deposit would suggest that a relatively short time span is physically represented. There would seem to have been a little more or less contemporary alteration, with the basal cementation representing authigenic reorganisation of shell carbonate, but there is no clear indicator of climate beyond the continued presence of an interglacial fauna.

It seems unlikely that SS would not once have been present in most parts of the site, so that its absence in the observed exposures in Area II probably indicates erosion. It is possible that a diastem separates SS and GCSS in all parts of the cave, especially since there would appear to be a significant faunal discontinuity (infra).

The succession represented by the deposits of GCSS is rather difficult to interpret in detailed terms because the present condition of the deposits is usually due to a complex blend of depositional, penecontemporaneous and slightly postdepositional

processes. It will be recalled that four general subunits have been defined, with the best exposure in Area V.

The first subunit, the "dark pan", is both the most widespread and the most discrete; the "pan" is present at this level in every exposure in the cave, without exception. Indeed, it is clear that the top of this material once formed a stable, subaerial surface which was most probably synchronous in all areas of the site. During its deposition, the organic-rich mud was no doubt quite sticky, but it was never extremely plastic or fluid or it would have penetrated further into the voids in the underlying units. Relatively slow deposition of predominantly fine sediment, with contemporary alteration in a damp micro-environment, is indicated; tiny clayey lenses represent puddles. As the top surface stabilised, the deposit must have compacted (probably with quite pronounced decrease in thickness) and hardened in most areas, since large objects laid down on this surface have not penetrated deeply into it and there are no deformation structures beyond gentle warping of the foliation in the sediments. Similarly, the subunit could not have withstood so consistently the emplacement of higher deposits if it had not been generally well consolidated. Curreant was the first to point out that a true palaeosurface, rather than a subsurface postdepositional effect, was involved here. The present author then carefully examined all exposures in section and stripped almost a square metre of this horizon (sic) on the west side of Area V. The nature of the evidence leaves no possible doubt that Curreant's suggestion is correct. There has not even been any significant postdepositional reinforcement of this surface, because overlying deposits peel cleanly away. The presence of this surface is rather frustrating since, although it has been slightly etched by the

layering of modern roots (which are still present), it seems likely that paw prints of hyaenas (whose bones, prey refuse and coprolites often lie on the surface) would eventually be found if a large enough area could be stripped so as to reveal slight depressions that would have been damper and full of more plastic sediment. However, such stripping simply cannot be justified at present because it would entail the excavation of too much of the overlying deposits, material which is of such great importance to the understanding of the earlier Upper Pleistocene in this region. Note that a few localised and thin spreads of similar material, also with upper boundaries representing fragments of younger palaeosurfaces, occur within the lower part of the next subunit, as do disturbed fragments probably derived from these levels.

The three upper subunits of GCSS consist of generally homogeneous silty clays with altered limestone, followed by limestone clasts in a more sandy matrix (including much dolomitic sand), followed by a return to finer sediments with more discrete textural laminations and an increase in quartzitic sandy lenses upwards. A number of processes are evidenced in these sediments. Calcitic limestone often shows extreme alteration and ghosting, and the dolomitic type has nearly always been reduced to unstructured sand grains. There is an irregular decrease in this effect up through the GCSS succession. However, a very few littoral shell fragments have survived in all but the most radically altered zones, and bones do not usually show marked alteration (but cf. p.1092). Carbonate is always present in the fine matrix but there are no concentrations (concretions, cemented bands, etc.). Thus, processes of alteration were active which did not result in significant leaching or restructuring of the carbonate system. The effects of deposition and minor erosion

by water are seen in the lenses and laminations of fine sediment, and in the small channel-like features, suggesting accreting surfaces with puddles, small pools, spillways and rills. In Area IV, a larger pool formed, with a thicker sequence of decantation deposits. Some sort of depression already existed in this Area at the time of the deposition of SS. It seems likely that a preferential drainage route, operative either from the surface or as a sump, was active here. This proposition is supported by the increasingly extreme dip of laminations in GCSS down through the sequence, a geometry which is indicative of progressive subsidence. The extreme dip and alteration of the residual sediments in Area IX is also probably referable to the same broadly diagenetic system. The middle subunit of the three upper divisions of GCSS contains limestone clasts with up-slope dips, suggesting very slow creep; high pore water content, a gentle slope and a generally plastic matrix are all that would have been required in this context, and ground ice was definitely not involved (cf. survival of fine bedding structures and lack of convolutions and injections). The colour banding, associated with iron and manganese (hydr)oxides, is clearly a feature resulting from alteration linked with fluctuating ground water. Redder and browner/greyer bands tend to alternate, suggesting that pairs represent differential dislocation of iron and manganese (with a little carbonate) compounds respectively during a single alteration phase. Catt has identified goethite in the redder bands, a mineral which tends to form at the top of the water table, so that the redder bands are perhaps the upper elements of each theoretical couplet. Note that the banding generally becomes more diffuse up through the sequence. The greenish colour towards the south of Area IV (a colour which fades slowly upon exposure to air) suggests

that iron compounds are present in a reduced form at that point. It is obvious that the banding is postdepositional with respect to the substrate in which it has formed, but the presence of small channel features which cut through banded sediments shows that the process of banding was active actually during the deposition of the GCSS unit as a whole.

Bringing these observations together, it may be said that the sedimentation rate in GCSS seems to have been low, but to have increased very slowly, and probably irregularly, up through the succession. Organic matter and local sediments, perhaps with an airborne dust component, were probably augmented by fines arriving through small roof fissures, and there was an increasing input of saltating quartzitic sand grains towards the top of the unit. There are clear indications of quite extreme dampness at most levels, although this is slightly less marked towards the top. Water not only produced small scale physical reorganisation of the finer sediments at the accreting surface, but it also affected the deposits at depth. Alteration of carbonates was quite extreme but there was no efficient removal of solutes, suggesting relatively stagnant pore water. The disintegration of all types of limestone continuously contributed to the fine matrix. Water content fluctuated, encouraging the metallic (hydr)oxide banding, but the sediments never, or rarely, dried out completely because no desiccation cracks, carbonate concretions or columnar iron concretions are present. Note also the survival of rare detrital pyrite crystals. The holocene sediment in the present cave interior was described on p.1061. This material does not constitute a close analogy for any of the GCSS sediments, but a vaguely similar set of processes seem to have operated in both units. The present author believes that it is very likely that bacteria

and algae helped to produce the alteration effects in GCSS, because such agencies efficiently break down chemical structures without necessarily encouraging leaching of the products. Detailed geochemical analysis of these deposits, as well as identification of surviving organic compounds (especially the lipids and hydrocarbon pigments), would certainly produce more environmental information.

It must now be decided whether the GCSS deposits represent a special micro-environment, dependent upon unusual site-specific parameters, or whether the above environmental inferences can be at least partially extended to include the regional environment (climate). It will be helpful here to reconsider the very rough analogy between GCSS and the interior holocene sediments. The Holocene may be broadly characterised as a generally warm and not excessively humid period (this is a very coarse generalisation but it seems reasonable in the present context). However, the holocene sediments slope into the present cave and they are underlain by an impermeable stalagmitic floor. This is not the case in GCSS. There is no obvious way that large amounts of holocene sediments could have been evacuated from the cave interior; thus, the whole period is represented by c.20cm of deposit at the most. GCSS probably represents a shorter period than the Holocene (an inference based upon general considerations of probable chronology at Bacon Hole); it is up to a metre thick and yet alteration is much more extreme than in the holocene deposits. At present, the sea is very close to the cave and is indirectly contributing large amounts of salt which radically increase carbonate solution. GCSS contains only very minor amounts of marine-derived material (even allowing for the effects of shell solution), suggesting that the sea was significantly further away at that time. GCSS is

present throughout the cave and is not associated with any peculiarly concentrated drainage route. At least mildly oxidising conditions must have prevailed, since some structured organic matter (eg. plant or insect detritus) and secondary sulphide concentrations would otherwise have survived. Thus, there is no reason to suspect that the present state of the deposits is merely the result of totally restricted drainage. Naturally, a cave always represents a special micro-environment but there is no reason to believe that Bacon Hole would have been markedly different from any other large cave in the region, and the author would expect to see similar effects in other Gower caves in deposits dating from the GCSS chronozone. Overall climatic humidity would appear to be indicated, with the absence of a marked dry season. Furthermore, it may be tentatively suggested that such humidity conditions, coupled with the lack of evidence for efficient leaching, would not appear to be compatible with a truly warm temperate climate.

The faunal evidence from GCSS also suggests a deterioration in climate. The typically interglacial assemblage, present in the underlying units, becomes more restricted, with the disappearance of such animals as fallow deer (Dama dama). New elements include a mammoth (Mammuthus sp.) and the presently boreal bean goose (Anser fabalis), together with the northern vole (Microtus oeconomus) which had previously disappeared after the deposition of COS. However, enough warmer climate indicators remain to show that the climate did not deteriorate so far as to be characterised as 'cold' (cf. Stringer 1977; Currant et al. 1984).

The boundary between GCSS and US (including CBS) is conformable and gradational. Note that weak colour banding

persists near the base of US, indicating that stagnant pore water content was still high during episodes within the earlier part of this period; there are even a few, very minor water-laid lenses. However, the bulk of US consists of wind deposited sand. The bedding is laminar, although the rare inverse grading indicates the occurrence of transitory ripple systems. There is a tendency for laminations to be slightly thicker to the north (in the lee) of larger obstacles, although the author has not yet had the opportunity to quantify this feature in detail. Note that, like other dominantly mineral aeolian sediments in Bacon Hole (cf. GCS, COS, quartzitic sand lenses in SBC/SCE), US does not penetrate very far into the cave, although minor traces might have been merged with the GCSS equivalent in Area VIII due to diagenesis. Bull (pers.comm. in Stringer 1977) has indicated that, unlike GCS and COS, US contains a minor component of wind-modified quartz grains, a factor which suggests a slightly larger scale sedimentary system. Marine-derived material is still evident (fine shell debris, relatively abundant foraminifera, etc.) and it seems likely that the sands are referable to a generally littoral source. The shell content of this unit was discussed in section 14.3. and it was noted that the debris was dynamically compatible with the quartzitic sand, suggesting a unitary source for the two components. However, Carrant (pers.comm.) has indicated that much of this shell debris is from terrestrial mollusca. This point would seem to be particularly important, since land snails would not be expected to occur in any great quantity on beach sands or sand flats. On the other hand, sand dunes, even with only very sparse vegetation, may carry remarkably large molluscan populations (cf. the modern dunes around Oxwich Bay, some 5km west of Bacon Hole). A dune field could not possibly have formed near Bacon

Hole if sea level had not been appreciably lower than it is at present, thus making a significant area of the main rock platform (which is now in the intertidal zone) available for sand accumulation. Furthermore, such dunes, and material derived from them (such as US), would be expected to occur as a fragmented but nevertheless regional sediment body (cf. section 23.3.). Given that large quantities of coastal sand were available and that at least some of the sand had a marine source, one might also predict that a sandy shore (which might have pre-dated or been contemporary with US) would have provided an additional habitat for littoral mollusca (eg. sediment filter-feeders), of a different type from the normal rocky habitat evidenced by all the other Bacon Hole marine mollusca (ancient and modern). Hopefully, the very rare identifiable fragments of littoral shell in US and the very top of GCSS will eventually provide a test for this hypothesis.

One last aspect of US is of interest, namely the dominantly cross-slope wavy bedding. Wavy bedding is often characteristic of niveo-aeolian sediments (cf. p.483), but there are good reasons to suppose that this is not the case at Bacon Hole. Larger objects show no preferential orientation of long axes with the slope; the thickness of individual laminations does not vary as a function of wave form; waves are usually in phase through appreciable thicknesses of deposit; individual subunits are quite continuous and lenticular beds are rare; there are very few laminations with dense, very fine grained sediment; and there are no deformation structures indicative of truly plastic behaviour. The wavy bedding in US seems to be a postdepositional effect, associated with very gentle creep of the whole unit due to the incompetence and plasticity of the underlying GCSS. Some of the waviness also seems to be due to additional loading produced by limestone

boulders in the overlying UCE. If larger exposures were to become available, one would expect to see microfaulting, especially near local increases in slope.

From the point of view of the sediments, the climatic implications of US are obscure. Decreasing evidence of pore water and increasing sand mobility would suggest that the climate had become significantly drier than during the deposition of GCSS, although pore water and sand mobility are always inversely coupled, with positive feedback as the sands build up. The limestone clasts in US (and CBS) do not show appreciable signs of alteration. There is no information to assess the probable temperatures at this time. So far, the faunal information is similarly rather poor. We may note the persistence of northern vole, but also the presence of typical temperate foraminifera, including the last occurrence of Rosalina sp. at Bacon Hole (cf. Stringer 1977; Currant et al. 1984).

US was truncated before or by the emplacement of UCE in at least the more southerly exposures but, in one zone just south of Area V, there is a clear diastem, representing a non-depositional episode. It may be inferred that any dune field beyond the cave had also been stabilised or removed by this time. There are signs of a certain measure of dampness during this episode (colloid input, compaction, minor manganese mobilisation) but these effects cannot be translated into even rough climatic terms because there is no indication of how long deposition might have been suspended. The effects noted would have eventually occurred at a stable sandy surface even in a dominantly dry environment.

In general terms, UCE is quite similar to SCE, and very broadly similar conditions are indicated. However, certain characteristics of UCE are significantly different. Limestone

clasts show a tendency towards more planar slope bedding, although energy levels were not high enough to orient the long axes. The matrix is much more continuous although compaction is still low and there are many minor voids. There is a strong shift to more 'terrestrial' finer material (especially the carbonate-rich silts) and the poorly sorted matrix shows much less lateral variation. There is an almost total absence of littoral shell and other 'marine' indicators. Thus, UCE is more organised than SCE, indicating a slightly more unified, and possibly more energetic, depositional system. However, this tendency has not progressed to the point where specific depositional processes may be unequivocally recognised. There was probably a greater wash input, although this must have remained very diffuse since there are no fine bedding features and matrix compaction is low. Generally slow deposition would certainly help to explain the greater homogeneity. The only exception to this overall impression is provided by the denser fine material near the base of the unit which is almost certainly referable to more continuous wash. The most striking difference between UCE and SCE is that the former shows signs of only very weak alteration, and this despite the fact that its matrix would theoretically be much more competent to hold pore water.

UCE is an environmentally neutral deposit; there are no signs of extremes of either humidity or temperature. Relying, therefore, upon the negative evidence alone, one might suggest a generally 'mild' climate. The fauna, on the other hand, is striking, although it too may suggest mild conditions. Classic 'interglacial' indicators, such as straight-tusked elephant (Palaeoloxodon antiquus), narrow-nosed rhinoceros (Dicerorhinus hemitoechus) and a number of terrestrial molluscan taxa (Discus,

Oxychilus, Clausilia; with a caveat from Evans, pers.comm., that there is still some difficulty in eliminating recent intrusions into this exposed deposit), are present, but so is a small variant of the northern vole (Microtus oeconomus). It should be noted that most of the 'interglacial' faunal remains from the nineteenth century excavations were recovered from the UCE equivalent inside the present cave (cf. Stringer 1977; Carrant et al. 1984).

It is rather difficult to take discrete samples of the stalagmite immediately above the UCE equivalent in Area VIII, because of the later reinforcement. Nevertheless, a hopefully pure sample has allowed Schwarcz (pers.comm. in Carrant et al. 1984) to suggest a date of 81 ± 18 ka as a minimum age for the youngest 'interglacial' fauna at Bacon Hole.

The change in sediment pattern at the beginning of the CMBS chronozone was noted above on p.1063. It is at present impossible to assess the probable time lapse between UCE and CMBS, or the conditions prevailing during this episode, because of the degraded exposures of the relevant boundary. The stalagmite mentioned above might suggest a significant break in clastic sedimentation, at least further into the cave. The lack of a good boundary stratotype also presents classification problems, since one might eventually wish to make a differentiation at this level of at least 'member' status.

CMBS has not yet been studied in detail and little further can be added beyond the points made at the beginning of this section and at the end of section 8.3. The two high level stalagmitic floors indicate at least appreciable moisture at those points in time. The fact that they are so extensive and relatively pure might well indicate that all 'entrances' to the cave were

restricted or even completely closed. This is consistent with a model of constantly accreting exterior slope deposits during the Devensian. The top stalagmite has been dated (Schwarcz, pers.comm. in Curren et al. 1984) in Area VIII to 13 ± 3 ka, in Area VI to 12 ± 10 ka and above Area IV to 4.6 ± 2.9 ka; this last determination, on calcite covering a mandible of Ovis, appears to be accurate and to indicate localised growth or even a certain measure of time-transgressiveness for the whole unit, as well as the presence of some sort of access at this time. The lower stalagmite has been dated to $62 \pm 42 / -37$ ka. CMBS does not appear to be rich in fauna, but access also appears to have been possible at the time of deposition of the silty scree immediately below the top stalagmite (in Area VI) and the sparse faunal material includes reindeer (Rangifer tarandus), brown bear (Ursus arctos) and glutton (Gulo gulo) (cf. Curren et al. 1984).

In summary, it may be said that Bacon Hole introduces a slightly different set of problems and, above all, possibilities from those encountered in most of the other sites discussed in the present text. The interplay between three major sources (littoral material, strictly local limestone breakdown and exterior terrestrial slope deposits), each acted upon by processes which lost transport competence relatively quickly, laterally away from the point of 'entry/formation', has resulted in deposits which are particularly interesting in terms of the persistence or progression of lateral lithofacies. Given these well characterised sources, it is comparatively easy to recognise and interpret the facies changes. However, it should not be forgotten that, in theory, all cave sediments that have accumulated under the influence of geometrically (geographically) heterogeneous 'entry' routes will display some form of facies progression. Often, it is

the recognition of such changes which is the difficult stage, either because of only minor source differentiation or because of a lack of sufficiently extensive exposures. Interpretation, on the other hand, is usually a matter of common-sense arguments, the very banality of which constitutes overwhelmingly powerful confirmation. At Bacon Hole, for example, the differential penetration of storm beach and aeolian material is entirely predictable and thus provides more conclusive proof for the genetic hypotheses than could ever be derived from the study of a single vertical section. It is imperative that lateral facies changes be consciously sought out in all cave situations so that similar, self-evident arguments may be applied.

23.2.5. Bacon Hole - Archaeological Considerations

Brief mention must be made here of suggestions that palaeolithic archaeological material is present in Bacon Hole.

In 1912, H. Breuil and W.J. Sollas pronounced that certain red ochre 'painted bars', on stalagmite adhering to the cave walls within the north-east side chamber (cf. fig. 76), were of human origin and possibly referable to the "Aurignacian period". These findings were never properly published, the references only appearing in newspaper articles (The Times, October 1912) and lectures (cf. the "Editorial Note" appended to the article by Morgan 1913). Morgan (1913), however, supplied a very detailed description of the phenomena (together with a photograph) and came to the following conclusions: natural red iron compounds were common in this area of the cave and were present on the walls and floor; the two sets of roughly parallel bars (one vertical and the other horizontal, with strokes up to 14 inches long and often over

an inch thick) were composed of this same material, and not of any industrial paint (as had been suggested by some critics); despite the frequent occurrence of irregular patches of (natural) colour all over the walls, at least the majority of the bars themselves could only be explained as human activity (an argument based mainly upon the geometry of the phenomena); thin (1/100 inch) films of calcite over a few of the bars suggested that they were not of very recent origin. Garrod (1926) reiterated the claims for a palaeolithic origin; the claims have been largely ignored by recent researchers (but see Wilcock 1981).

The present author attempted to match Morgan's very exact descriptions (bar by bar) with the red staining observable in 1980. Iron compounds were indeed present as blotches and linear features, but there was absolutely no possible match with Morgan's descriptions. Thus, the original phenomena have been destroyed, covered by stalagmite or otherwise modified beyond recognition. It seems most unlikely that the original bars, 'painted' on top of curtain stalagmite, could date from the Palaeolithic, since we have very good general evidence for extensive speleothem formation in the later Devensian and early Holocene. The bars might have been painted at a later period and there is always the possibility that ochre miners were trying the quality of the pigment. The present author does not consider that the thin calcite films covering certain features would constitute evidence of antiquity beyond a few decades; this part of the cave wall is still weakly active. There remains the possibility that the bars and their disappearance were entirely natural. Morgan cited the following features as evidence of brush strokes: a sharp boundary at the top of each bar, but a diffuse or 'trickle-marked' lower boundary; pigment only on high points and not in the intervening

hollows; bars thickening southwards, both generally and rhythmically within each high-point element; pigment penetrating deeply into the underlying calcite (thought to indicate an original binding agent, such as animal fat). The present author suggests that these features are also consistent with the fixing activities of micro-organisms (bacteria, and their symbiotes and predators), reacting to gravity, water trickle and the fact that what little light reaches the area is incident from the south-west. Certainly, colonies of micro-organisms ('organic slime') were living on the pigmented surfaces in 1980 and the properties of individual patches as described by Morgan were sometimes in evidence. Furthermore, in the interval between 1980 and 1981, the author observed that some red patches changed, albeit only just enough to allow certain recognition, in both colour intensity (brightening as well as paling) and shape/position. There remains only the question of whether or not linear colonies of micro-organisms might sometimes be expected to develop approximately parallel sets, a question best left to ecologists.

Two other possibilities of ancient archaeological material have recently been recognised within the deposits at Bacon Hole but, since they are still under study, they can only be described very briefly here. Griffiths (1972) recovered one object from a sandy deposit with limestone clasts in the vicinity of Area IV; this object was once thought to have come from the CBS facies of US but Stringer (pers.comm.) now believes that it was more likely to have been found in a sandy zone within GCSS. This is a 'tablet' (c.8x3x0.5cm) of ivory with surface markings and overall shape that appear rather unusual (cf. Stringer 1977, plate 3). G. Cook has examined this object using SEM techniques and concludes that its origin is still unclear (pers.comm. in Curren et al. 1984).

A further set of objects has been described by Stringer as follows:

[The] grey clays and sands [GCSS in the current terminology] contain a number of mammalian bones with a high degree of polish restricted to their ends only. It is extremely difficult to account for this polishing, and only the absence of good flint tools [of any flint at all] or human remains from the site urges caution about their interpretation as humanly produced artefacts. (1975:34)

The pre-1977 sample of this material was submitted to Dr. G. Diamond [an archaeologist] for microscopic examination under polarised light and he concluded (Diamond, pers.comm. 1977) that the majority showed a polish which was probably caused by adsorbed grease, consistent with their use for a purpose such as dressing animal skins. Furthermore there were series of non-random scratches on the ends of the bones which were unlikely to have been caused by natural processes or the activities of other animals, and which indicate the probable direction of rubbing during use. (1977:41)

It should be noted that this polish is often truly extensive and very obvious to the naked eye. Nevertheless, G. Cook (pers.comm. in Currant et al. 1984) is of the opinion that the polish is not artefactual, an opinion shared by the present author. The overall condition of GCSS must not be forgotten in this connection and it seems possible that the bone 'polishing' is due to a combination of geochemical, biochemical and perhaps minor physical factors in this damp environment. Further work is in progress to try to identify the most probable causes. The present author would not be at all surprised if a careful search of the holocene 'mud' within the cave were to produce bones with at least weakly 'polished' ends.

Bacon Hole has indeed produced unequivocal archaeological material dating from the Iron Age onwards. It is therefore of interest to note an object, found by J.G. Rutter in an unstratified context, that might easily be taken for an artefact if considered in isolation. This was a limestone cobble with a very regular, shallow depression set into one major surface in a manner reminiscent of a simple quern. However, after a brief search of the intertidal zone, the present author was able to find several

examples of very similar objects which always lay on sandy material with the depression downwards. If abrasive sand grains trapped under a cobble of relatively soft stone are nevertheless able to move slightly in any original irregularity in the lower cobble surface, the quern-like form will be a common result after the passage of a sufficient number of tides, granted only that the cobble itself is heavy, or well wedged enough to prevent significant reorientation. This last point would suggest the possibility of multiple depressions on one cobble, rather like the multiple facets on periodically disturbed ventifacts.

23.3. Beyond Bacon Hole: A Brief Survey of the Quaternary of the South Gower Coast

In terms of palaeontology and U-series dating, the Bacon Hole sequence, between at least SBC and UCE inclusive, is representative of the last interglacial (loosely, the Ipswichian) and of some part or parts of Oxygen Isotope Stage 5 of the deep-sea record. There has already been considerable debate concerning the exact significance and correlation of individual sedimentary units and their contained faunas at Bacon Hole, many of the arguments being framed in supraregional terms (cf. Stringer 1975, 1977; Bowen 1977a; Stringer & Currant 1981; Sutcliffe 1981; Turner 1981a, 1981b; Stuart 1982, 1983; Currant et al. 1984). The present author does not intend to enter into all the details of this debate. Rather, it would seem more profitable to draw the reader's attention to the enormous potential of the south Gower coast (cf. fig. 79), a regional potential which, if realised, should largely obviate the difficulties to be expected at any single site or contextual group of sites.

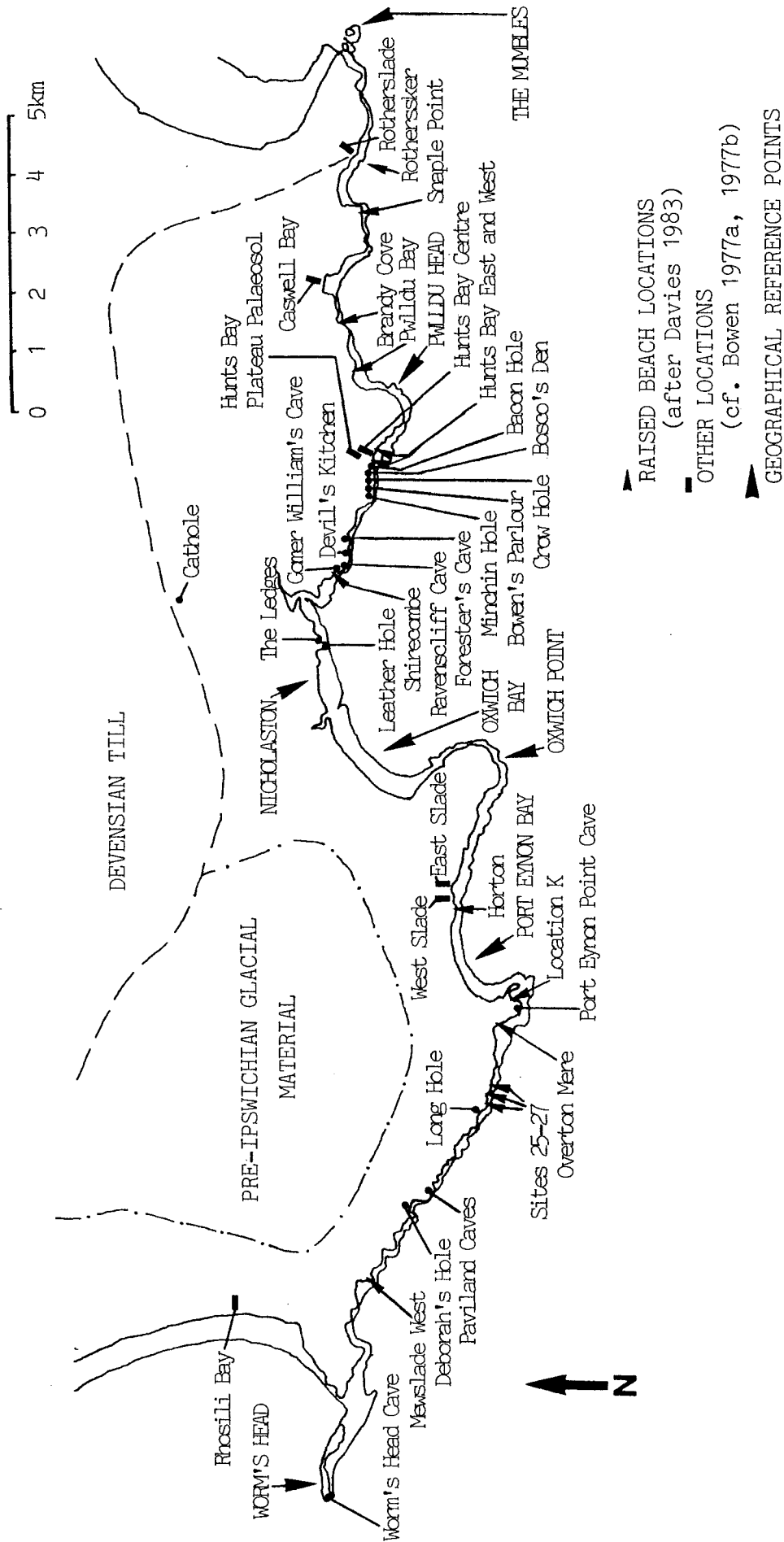


Fig. 79 The South Gower Coast

The main lithostratigraphic 'marker' on the Gower coast is a raised beach unit, which had already been noted in the nineteenth century (cf. Falconer 1868; Prestwich 1892; Tiddeman 1901) but which was most systematically examined by George (1932), who named it the Patella Beach. The unit appears to survive at literally hundreds of points along the rocky coast, only those areas extensively obscured by holocene sediments (eg. Oxwich Bay) lacking modern exposures. The unit is present at altitudes between 0 and 15m O.D. depending upon the coastal topography (generally lower in bays, higher along promontories). George chose the exposure of the Patella Beach in Minchin Hole (also known as the "Outer Beach" in this site) as being both representative and also placed in a useful stratigraphic relationship with fossiliferous terrestrial deposits. Sutcliffe (1981; cf. also Sutcliffe & Bowen 1973) has argued for the acceptance of this exposure as the formal stratotype, but the present author would argue that the Minchin Hole exposure has not yet been properly described.

George (1932) noted that the Patella Beach is expressed either as a storm beach facies (pebbles and cobbles) or, more rarely, as a shingle facies, and that a very variable proportion of exotic rock types are included at individual exposures. This variation in exotics has led Mitchell (1972, 1977) to recognise two beaches, one "Hoxnian" and the other "Ipswichian", at roughly the same altitude along the coast. Bowen (1973b, 1977b) has supported George's original view that this difference is not chronostratigraphically significant and that only one raised beach is present at the exposures in question. However, it has been suggested, on good stratigraphic grounds, that an older beach (or, more exactly, a true intertidal deposit) is indeed present in Minchin Hole, the "Inner Beach" at this site (cf. Sutcliffe 1981).

The status of George's "Neritoides Beach", recognised immediately above the Patella Beach in a few sites, is still unclear; at least some of the exposures cited by George (1932) do not appear to be true 'beaches' in any sense of the word (eg. at Minchin Hole).

To the present author's mind, the Patella Beach would appear to be such an important lithologic unit that it deserves more detailed study and better definition. All authorities are agreed that there is considerable variation in composition and expression, but even gross texture, petrology and geomorphology have rarely been quantified and accurately mapped. There are many minor, but interesting, details of individual exposures that have not yet been discussed in print. For instance, the exposure on the extreme western side of Hunts Bay contains cobbles of softer rocks (limestones, sandstones, siltstones), many of which have been extensively bored by marine organisms before the cementation of the deposit by carbonates; this suggests that the deposit may have been actually included within the tidal zone (cf. p.1069) at some time prior to the Holocene. Similarly, George (1932) noted interesting taphonomic variation in the shell content of beach material, with only thicker-shelled taxa occurring in higher energy sediments; it would be most informative to quantify such trends.

Amino acid racemisation determinations have recently become available from littoral shells included in the Gower beaches (cf. Andrews et al. 1979; Davies 1983). Contributions in Bowen and Henry (1984) suggest that the results are already firm enough to allow the establishment of formal "aminozones" correlated with the Oxygen Isotope Stages of the marine record. The present author believes this uncritical reliance on AAR to be premature. There has been no discussion of possible thermal anomalies which

might be caused by different depths and micro-environments of burial. The D-alloisoleucine/L-isoleucine ratio is known to be subject to interference from leaching (polymer fractionation with preferential removal of D, especially because of its more vulnerable concentration in free amino acids and terminal sites in more complex organic compounds; cf. Wehmiller 1982). It is imperative that detailed geochemical and biochemical data be made available to support the integrity of the AAR determinations at specific sampling sites; so far, the only information made available is the enantiometric ratio of total amino acids. Despite the fact that the points mentioned here are a real cause for concern, it should be noted that the majority of sampled beach deposits in Gower show good AAR grouping, suggesting that they are of similar age, and that the one deposit which can be demonstrated on stratigraphic grounds to be older (the "Inner Beach" at Minchin Hole) appears to have a significantly higher D/L ratio than the main Patella Beach group. It is interesting that the uncemented beach material at Horton appears to be AAR-correlative with the Minchin Hole "Inner Beach" (Davies 1983); the Horton beach had previously been equated with the Patella Beach by most authorities. It seems clear that error will often occur if any one stratigraphic method is allowed to dominate; more plausible results will only be achieved by comparison of the widest possible range of criteria.

Palaeontology, lithostratigraphy, U-series dating and AAR determinations (littoral shell) suggest that both SBC at Bacon Hole and the "Outer Beach" at Minchin Hole may be taken as equivalent to the Patella Beach and referable to Oxygen Isotope Stage 5 (cf. contributions in Bowen & Henry 1984). Nevertheless, the relatively coarse time definition presently available would not allow more precise chronocorrelation if only intraregional

data were considered. However, the gross altitudinal properties of the Patella Beach in general would suggest that Oxygen Isotope Substage 5e is the period involved, since the world-wide sea levels during later 'temperate' substages of Stage 5 are thought by most authorities to have been at least 10m lower than the modern level (but cf. Stearns 1976).

There are very few known occurrences of deposits significantly older than the Patella Beach. Bowen (1973b, 1977a, 1977b) infers a glacial episode from the inclusion within the Patella Beach of derived exotic rock types; presumably, the same argument could be applied to the exotics in the older "Inner Beach". Indeed, it has been suggested (Bowen & Henry 1984), apparently on grounds of AAR determinations, that Gower was not glaciated during the interval between the two beaches. Traces of pre-devensian glacial material, some of which are probably in situ fluvio-glacial deposits and possibly even some undisturbed till, are still present inland on the western Gower 'plateau'. Nearer the seaward entrance to Minchin Hole, the "Outer Beach" directly overlies the "Inner Beach". However, a wedge of terrestrial material eventually appears between the two 'beaches' and thickens slowly inwards. The first unit encountered, the "Lower Red Cave Earth" (Sutcliffe 1981; Sutcliffe & Currant 1984) lies "disconformably" (the nature of the discontinuity not being described) upon the "Inner Beach"; it is a scree-rich deposit with a fauna similar to that of CGS/COS at Bacon Hole. Further into the cave, other units, including a stalagmitic floor, appear above the "Lower Red Cave Earth" and below the landward equivalent of the "Outer Beach". It is to be hoped that an increasingly complex 'pre-Patella Beach' sequence will be discovered as excavation continues.

Returning to the Ipswichian (sensu lato), there are a

number of sites which contain deposits that post-date the Patella Beach but which pre-date units that can be certainly referred to the Devensian on either lithogenetic or faunal grounds.

It was suggested above that US at Bacon Hole ought to be part of a regional sediment body. Minchin Hole contains a similar deposit, called "sandrock" because it is cemented by carbonates. George (1932) and Bowen (1977a, 1977b) correlate the "sandrock" with massive aeolian sand exposures at Caswell Bay and Shirecombe, sand which is overlain by head deposits; the Caswell Bay sand is said to contain comparatively complete specimens of temperate land mollusca (A.S. Kennard, in George 1932) in its cemented upper part and comminuted shell throughout. Bedded aeolian sand is in fact present in a great number of sites along the coast, often in approximately the right stratigraphic position to suggest (and only suggest, at this stage of our knowledge) correlation with the Bacon Hole and Minchin Hole units. In particular, many of the cliff sites (caves, shelters or simply slopes) west of Minchin Hole contain such material (eg. Gomer William's Cave and the Ledges). At Ravenscliff Cave, a sequence was recorded (cf. Falconer 1868) with hard dark grey gritty sand (base), cemented breccia with stalagmite slabs and ferruginous sand, and lighter coloured sand and stalagmite (top). The only published record of Hippopotamus (cf. the faunal definition of the Ipswichian) from Gower refers to a few specimens found at some unspecified low level in this sequence. The site of Devil's Kitchen, a large unroofed cave, contains an extremely thick (up to c.7m) cemented series of aeolian sands, interbedded with thin spreads of fine angular limestone scree. The stratification of the sand at this site is not of the usual planar form but comprises well developed, low-angle cross-bedding, showing that the cave was already

unroofed and that airflow was still coherent enough to create structures indicative of more dynamic conditions. This bedding would require detailed analysis before palaeo-wind directions could be inferred, although George (1932) has already suggested derivation from the east and south-east at Shirecombe, a location only just to the west of Devil's Kitchen. These coastal sand exposures are most interesting but, as with the Patella Beach, it would be dangerous to assume that all broadly similar deposits are necessarily time-correlative. George (1932) has pointed out that sand bodies strictly contemporary with the Patella Beach itself should be present somewhere in the area. Little work has yet been done to characterise the various exposures. The following criteria from US at Bacon Hole might afford at least a starting point for wider recognition: dominantly quartzitic sand with a very strong mode at c.0.2mm; mature mineralogy with few accessory and heavy minerals (Catt, pers.comm. to Stringer); some aeolian modification of quartz grains as seen under SEM; frequently well bedded; the last occurrence of Rosalina sp.; uniform distribution of comminuted mollusca, including much terrestrial material; and very sparse occurrence of mammalian remains, with some broadly 'temperate' types.

If the Patella Beach and a unitary aeolian sand body (cf. US at Bacon Hole) can be recognised extensively along the Gower coast, they will provide a very useful stratigraphic 'sandwich' for intervening deposits. At Bacon Hole, SS might possibly have regional significance. The problem with this material is that it is largely composed of littoral shell fragments from species which are present at least in certain older units (eg. SBC and SCE). Thus, the seaward shell-rich expression of the "Neritoides Beach" at Minchin Hole (Sutcliffe 1981) is roughly

in the right stratigraphic position but there is no obvious way of proving strict correlation.

The other unit within the 'Patella Beach - aeolian sand' interval at Bacon Hole that ought to have regional significance is GCSS, which, it will be remembered, appears to have a conformable boundary with US. However, in this case, it is not the specific lithology which might be traced laterally but the fact that a significant level of humidity has been inferred; one would therefore expect very different sedimentary effects to have occurred in different kinds of site. Only in larger caves might deposits which are lithologically similar to GCSS be expected to form. No certain correlate has yet been described in print from any other Gower site. However, early reports concerning Minchin Hole are rather suggestive:

At the [seaward] Entrance [...] (3) one foot of sand [the "sandrock" of recent reports]; (4) next, a deposit of blackish or dark-coloured loamy sand, resembling in mineral character the corresponding ossiferous deposit of 'Bacon Hole' [GCSS of recent reports], and attaining a depth of 2½ foot:- abundant remains of Rhinoceros, Elephas, and Bos were yielded by this bed, and shells of Helix hispida were found attached to the matrix which encrusted some of the bones; (5) at the bottom, and resting upon the rock-floor, lay a bed of greyish-yellow, coarse, and gritty marine sand [possibly the "Inner Beach" of recent reports?], ranging from one to four feet in thickness (Falconer 1868:507)

The mammals noted by Falconer may be compared with the Dicerorhinus, Palaeoloxodon, Mammuthus, Bos and (sic) Bison recovered from GCSS at Bacon Hole. Further into Minchin Hole, Falconer recorded a "black unctuous sandy loam, 1 foot" (ibid., p.508), which was presumably the lateral equivalent of "bed 4", although the description is not absolutely clear. George (1932) did not mention any 'dark' deposit between the "Neritoides Beach" and the overlying "wind-blown sand" (sandrock). Sutcliffe (1981) records an "Earthy Breccia Series" above the "Neritoides Beach" but he does not describe the lithology of the unit or its

relationship with the stratigraphically higher "sandrock". Sutcliffe and Currant note that, in addition to quite typical interglacial fauna in the lower parts of the "Earthy Breccia Series", there is a small form of Microtus oeconomus in the higher parts of "the interglacial sequence, as at Bacon Hole" (1984:35). One assumes that the "sandrock" is not counted as part of the interglacial deposits. It is imperative that a proper stratigraphic and sedimentological study be made of the entire Minchin Hole sequence as soon as possible.

Difficulties over the definition of interglacial/glacial, and more particularly over formal Ipswichian/Devensian, boundaries are already apparent in the above discussion and some mention of the 'state of play' in Gower must be made here. It will be recalled that the national chronostratigraphic units are defined at type sites, Bobbitshole (Ipswich, Suffolk) for the Ipswichian and Four Ashes (Wolverhampton, Staffordshire) for the Devensian (Mitchell et al. 1973). Despite the fact that there is no dating evidence nor even a plausible set of other correlation criteria at either type site, the dominant school of quaternary studies in this country has pre-empted empirical solutions to the problem by equating the Ipswichian with Oxygen Isotope Substage 5e and by placing the Ipswichian/Devensian boundary at c.110ka (cf. Birks & Birks 1980:276; Stuart 1982:6); no boundary stratotype has been proposed. In Gower, we may plausibly relate the Patella Beach to Substage 5e, and therefore to the currently arbitrary definition of the Ipswichian. However, this still does not allow us to recognise the Ipswichian/Devensian boundary, because neither sufficiently precise dating nor direct oxygen isotope data (eg. on speleothems) are yet available. The most sensible step would therefore be to define local 'interglacial' and 'glacial'

chronozones, without worrying for the moment whether or not we can relate them exactly to the national units. There are no agreed guidelines for the setting-up of regional chronozones in the British Quaternary, but general stratigraphic principles (cf. Hedberg 1976) must obviously be used.

At present, there are only two sets of criteria which could be used in Gower to define an 'interglacial/glacial' boundary: lithologic criteria, with a climatically oriented lithogenetic rationale, and faunal criteria, again with a climatic rationale. It is also possible that climatic constraints could be relaxed so that ease of boundary recognition could play a more important role. The first coherent definition of British 'Eemian' (loosely, Ipswichian) mammalian faunas was proposed by Sutcliffe (1960); he included the early finds from Bacon Hole (mostly from the UCE equivalent inside the cave). We might therefore attempt to use the upper limit of UCE, together with any faunal change across the boundary, as the stratotype for an 'interglacial/glacial' boundary. However, Bacon Hole has not provided (and seems unlikely ever to provide) a good exposure of the UCE/CMBS boundary. This is generally the case for all known exposures of broadly contemporary material in Gower caves (because the boundary is not exposed at all, because it is exposed but heavily degraded as at Bacon Hole, or because it may have been well exposed but was not properly described at the time of study), although a concious search might remedy the situation. Even allowing that the base of the Patella Beach provides an acceptable starting point, there is still a lack of sufficient physical (rock) criteria to define the end of a local interglacial chronozone using cave deposits; this difficulty cannot be solved with palaeontological criteria alone, since a physical stratotype is still necessary. However,

Bowen has proposed an interglacial chronozone, the "Pennardian", based on the Gower deposits:

This interglacial is provisionally named from the deposits along the coast, and in sea caves, at Pennard, Gower. They consist of intertidal and storm wave marine deposits and cave earths which contain a temperate fauna. (1977a:7)

This is not, of course, meant to constitute a formal proposal - unfortunately, since it would then be easy to dismiss the idea as procedurally invalid. In fact, Bowen (1980) now accepts that the suggestion was premature but he still cites Minchin Hole as the most likely future stratotype for an eventual interglacial chronozone of early Upper Pleistocene age in Gower. Minchin Hole may well turn out to be the right site, but it is no good just waiting for a stratotype to 'appear' - it must be carefully 'constructed' through accurate recording of relevant data especially obtained for the purpose.

No explicit attempt has yet been made to define a regional last glacial chronozone, although equivocal usage of the term "Devensian" (hereafter indicated by 'Gower-Devensian') hides a de facto definition. Bowen (1977a) suggests that, in open-air localities (eg. Hunts Bay), the 'Gower-Devensian' begins with reddish colluvial silts, representing the stripping of interglacial soils (cf. the definition of a palaeo-argillic brown earth on the Hunts Bay Plateau; Clayden 1977). Although this seems generally reasonable, it does not guarantee that the 'prospective Pennardian' (assuming a defined upper limit in a cave deposit) and the 'Gower-Devensian' would share a unique time boundary, a situation which would seem highly undesirable and likely to lead to confusion.

The main problem with the definition of a Gower 'interglacial/glacial' boundary is that definitions have too often

been proposed based upon existing information and that no-one yet appears to have gone out to look for the best boundary. The best boundary would obviously incorporate lithologic and palaeontological criteria (and ultimately quantified chronological criteria) and it would be traceable over wide areas. This means that at least some criteria must be recognisable both in caves and in the open. Returning to the reddish colluvial silts noted above, if only they could be recognised within a fossiliferous cave sequence, then some progress might be made. Henry (cf. Bowen & Henry 1984) has recently defined the Hunts Bay Formation (broadly co-terminous with the 'Gower-Devensian'); the colluvial silts, present at its base along major stretches of the Gower coastal exposures, are defined as the Pwll-Du Red Beds (Member). Work on heavy minerals, clay minerals and thin-section fabric by Case, Davies and Andrews (in Bowen & Henry 1984:32) confirms that the Pwll-Du Red Beds are an accumulation of pedogenic aggregates; one assumes that final publication will provide a powerful set of criteria with which to recognise this unit elsewhere. Now, merely for the sake of argument, let us formulate the hypothesis that the reddish silts at the base of UCE in Bacon Hole are correlative with the Pwll-Du Red Beds. The fact that there is absolutely no positive evidence to support such a correlation at present is irrelevant; the important point is that we have a testable hypothesis. When eventually we are able to correlate cave and exterior deposits (whether or not the Pwll-Du Red Beds or UCE are actually involved), we can then decide, collectively, whether or not a chronohorizon has been discovered and whether or not this chronohorizon will serve as an 'interglacial/glacial' boundary.

Henry's definition of the Hunts Bay Formation, combining the work of many previous researchers with careful field and

laboratory checking, now serves as a useful framework within which to discuss the broader aspects of the 'Gower-Devensian'. These open-air deposits are quite complex and laterally variable, but there is a generalised sequence of colluvium (base), coarser head, finer head (sometimes replaced by diamicton partially derived from old glacial material), and silt (top). The in situ Welsh Till of the Langland Bay area (thought to date from the glacial maximum at c.18ka) tongues into the Hunts Bay Formation below the capping silts. These silts have long been recognised as being of aeolian origin (cf. George 1933) and they represent one of the most areally continuous sediment bodies in the last glacial sequence; they are currently defined as the Port Eynon Silt (Member) of the Hunts Bay Formation. Case (1984) has provided useful criteria for the recognition and subdivision of this silt unit.

Very little recent work has been carried out in the last glacial deposits of Gower caves. Many caves in the area produced 'cold' faunas during early excavations (cf. Allen & Rutter 1946) but it is very difficult to relate these finds to specific stratigraphic intervals. Similarly, Gower is important for its palaeolithic cave sites (eg. Goat's Hole at Paviland, Long Hole, Cat Hole, Deborah's Hole, Bosco's Den, etc.) but again the stratigraphic context is usually unclear. The work of Campbell (1977) is tantalising, since he noted a fine sand and silt unit (his Layer A3c) at Long Hole, lying above deposits containing Earlier Upper Palaeolithic artefacts, and a silty sand (his Layer A3) at Cat Hole (also known as Cathole), lying below deposits containing Later Upper Palaeolithic artefacts. It is clear that Gower has considerable potential for archaeological research. Paviland, for instance, is one of only three British Upper

Palaeolithic sites to have produced over 5000 artefacts. However, it is also clear that caves, with all their possibilities for fine stratigraphic subdivision, preservation of faunal remains and recovery of directly dateable material, are a finite resource. It is particularly important that any 'mainstream' archaeologist working in Gower should involve other specialists (on site), both because the stratigraphic record appears to be intrinsically detailed and because quaternary studies have gathered a considerable momentum in the area thus making collaboration that much more rewarding for all involved.

24. NORTH WALES

24.1. Introduction

This chapter centres around the recent, and continuing, excavations at Pontnewydd Cave (Clwyd). The region of interest includes the coastal 'plain' of North Wales, from Llandudno in the west to Prestatyn in the east. From these two points on the coast, curvilinear outcrops of Carboniferous Limestone penetrate inland, swinging south and east in quite narrow arcs to the Cynrŷ-Brain and beyond. The region is topographically bounded to the west and south by the highlands of the Cambrian Mountains, and to the east, with an ill defined and hilly contact zone, by the Cheshire Plain.

The main interest of this region lies in the fact that it occupies the 'sparring ground' between the Welsh and Irish Sea Glacial Provinces. One could not wish for a more inhospitable situation with respect to the preservation of long sequences of pleistocene deposits and, not surprisingly, no such sequences are known, although till bodies nearly 100m thick are present in some places. Bowen (1973, 1977) summarises what little data has been recovered from this region. Generally, both Welsh and Irish Sea tills are known and, although there is a possibility of a Late Devensian readvance, most of this glacial material is lumped into one unit, for want of any good criteria for regional subdivision, and the unit is simply referred to the Devensian. It has been

suggested, in addition, that traces of older material may perhaps be present as isolated remnants on higher ground (cf. Rowlands 1971).

With respect to the major details of chronostratigraphy in North Wales, this is all that can be said - until one considers the odd bits of tantalising information from caves in the region.

First, there are two caves in the Ffynnon Beuno Valley (SJ 085725), Ffynnon Beuno Cave itself and Cae Gwyn Cave. Excavations at these sites were published by Hicks in a number of journals, the following list representing the apparent chronological order (with respect to the continuing excavations) of the contained information, rather than the mere order of publication: 1887, 1885, 1886a, 1886b, 1889 and 1888. Both caves contained fauna and artefacts, the latter being referable to the Earlier Upper Palaeolithic in Ffynnon Beuno but, in the present author's opinion, only to the Upper Palaeolithic in general in Cae Gwyn (cf. Campbell 1977). Hicks described the 'best' section in Cae Gwyn Cave as follows:

The section in this chamber showed, 1, a fine red loam from 1 to 2 feet in thickness, burrowed by rabbits and containing a few recent bones; 2, a band of laminated clay from 6 to 8 inches in thickness, containing ferruginous and stalagmitic layers; 3, a reddish clayey earth in some parts sandy, and with pebbles of felsite, granite, gneiss, quartz, quartzites, sandstones, and of local rocks. Angular fragments of stalagmite were also found in this deposit. The animal remains in it belonged to Lion, Hyaena, Bear, Red Deer, Reindeer, Horse, and Rhinoceros [a longer list is appended to Hicks's article]. The largest number of the remains obtained from this cavern were found in this chamber; but they did not occur here in horizontal layers, but in inclined and evidently disturbed position. It is perfectly clear that they had not been disturbed by man but by water-action, and probably at different times, as bones containing clean sand in their hollows had been encased afterwards in a clayey deposit. The conditions so clearly seen in this chamber prevailed throughout the whole of the cavern, and the evidences of water-action were recognizable at all points. (1886a:12)

An Upper Palaeolithic end-scraper was also found in this layer 3. The stratigraphy and nature of the deposits in Ffynnon Beuno Cave are comparable; in this second site, at least some of

the fauna and artefacts lay in an equally derived context. The reader's attention is drawn to the similarity between these deposits and those of Pontnewydd Cave (infra). The "water-action" described is, to the present author's mind, almost certainly to be equated with debris flow. However, no chronological correlation is implied; the similarity is noted merely to underline the regional 'flavour' of all these cave deposits.

Hicks suggested that the fauna and artefacts from Ffynnon Beuno and Cae Gwyn pre-dated the local glaciation. Up to the 1886 season, he had no proof for this suggestion; it was based merely upon exposures of apparently in situ boulder clay, underlain by bedded sands and gravels (thought to be of marine origin), at various points in the valley, including some exposures at higher altitudes than the caves. The then known entrances to the caves had all been cleared, and the deposits heavily disturbed, before the first recorded examination by Hicks or any other informed individual. Of course, it was obvious that glacially derived material was actually contained in the cave deposits, although this was soon forgotten in the ensuing debate. The fact that Hicks believed the cave entrances to have been sealed by till after the emplacement of the faunal and artefactual material drew immediate and vehement criticism from his contemporaries and the argument took on national, and even international, importance. In 1886 (Hicks 1886b), a buried, north-west entrance to Cae Gwyn Cave was discovered, with the cave deposits (co-extensive with layers 2 and 3, supra), containing bones and another artefact, clearly stratified under some six metres of well bedded sands, gravels and 'boulder clay'. Hicks repeatedly cited this evidence as unequivocal support for his original suggestion (1886b, 1888, 1889). However, McKenny Hughes (1887,

1888), who had actually taken part in the investigation of the sites as a member of the committee set up by the British Association for the Advancement of Science, expressed the opinion that the sand, gravel and 'boulder clay', although well stratified, did not constitute in situ evidence of glaciation after the emplacement of the cave deposits; he believed these exterior deposits to be slope debris derived from glacial material. It is of interest that the section drawings supplied by Hicks do indeed show the bedding to be parallel to the slope and, in one drawing (Hicks 1888, Fig.3), the bedding is shown to be markedly wavy downslope.

Garrod (1926) reiterated Hicks's claims for Cae Gwyn and, in the process, let the reasoning flow over to Ffynnon Beuno and its "Middle Aurignacian" and "Proto-Solutean" (E.U.P.) artefacts. McBurney moved the end-scraper from its true position, deep within Cae Gwyn, to a new situation, "stratified between two layers of true bolder clay"(1965:27).

Rowlands (1971) renewed interest in these sites by dating a bone (probably of mammoth) in the old collections from Cae Gwyn to 18,000 ^{+ 1400} - 1200 B.P. (Birm-146). Rowlands suggested that both caves had been sealed by till (the 'readvance' event in the later Devensian) after the deposition of fauna and artefacts. He based this proposition on a publication by Hicks, said to date from "1885"; the journal, volume number and page numbers in fact refer to Hicks (1887), where only the findings up to 1884 are reported, findings that did not include the exposure at the 'buried' entrance of Cae Gwyn. Any reader who accepts Rowlands's views will therefore assume that the derived glacial material within the cave(s) is in situ till. Rowlands also cited Boswell, who merely had this to say:

Although for a time some difference of opinion was held as to whether or not the undisturbed boulder clay of the Vale of Clwyd actually sealed up the caves, the consensus of opinion was finally in favour of that view. (1932:77)

Boswell presented no new evidence and he did not even cite the relevant literature. His suggestion of a "consensus" can only refer to the fact that Hicks appears to have been the last to have published an eye-witness account of these excavations.

The present author believes this question to be still open. It must never be forgotten that the original accounts and discussion were all heavily biased by various dogmatic viewpoints concerning the nature of glaciation, marine transgression and stratigraphy. When the author visited the sites in 1977, it appeared that the caves themselves had been more or less totally emptied. However, the north-west entrance to Cae Gwyn was still buried, presumably because the deep shaft cut through the sands, gravels and 'boulder clay' had collapsed or had been deliberately refilled. Hicks clearly stated in all his later publications that the cave deposits continued on into the open, under the 'glacial' deposits. There is every chance that this whole controversy could be resolved by new excavations; indeed, it is hardly credible that this has not already been done.

In all this discussion of glacial stratigraphy, the fauna and artefacts from these caves have had to take something of a subsidiary place. Rowlands (1971) noted that, judging from continental parallels, the radiocarbon date appeared to be rather too young for the archaeology, and he therefore suggested that the collections as a whole represented quite a temporal spread. Surprisingly, he did not bring forward the existing evidence that all this material was in a derived context. Because of this oversight, Oakley (1971) immediately responded by pointing out

that the 'Red Lady' of Paviland Cave (Gower) had been dated to a similarly 'young' age. Oakley's objection to Rowlands's argument is of doubtful value, considering the geographical differences, but, given full knowledge of the problem, it can be seen that Oakley's article is totally irrelevant because there is absolutely no useful association between the flints, most of which are from Ffynnon Beuno, and the dated bone from Cae Gwyn. Fortunately, although both Campbell (1977) and Morrison (1980) accept that at least Cae Gwyn was sealed by till, they do not make any claims for association between the radiocarbon date and the artefacts. On the other hand, they both interpret the Ffynnon Beuno fauna and artefacts as a single, temporally discrete archaeological assemblage, despite the facts that the Ffynnon Beuno and Cae Gwyn faunas were never documented separately and that some of the Ffynnon Beuno artefacts (including the single 'leaf-point'; cf. Hicks 1886a:8) and the majority of the fauna came from contexts affected by "water-action" (i.e. probably by debris flow). Jacobi (1980) proposes two hypotheses concerning the Ffynnon Beuno artefacts: either one industry or two industries may be represented. Campbell (1980) is now happy to see two industries at Ffynnon Beuno, one "Aurignacian" and the other "Lincombian", thus harking back to the unacceptable theories of Garrod (1926), and this despite his earlier statement:

The apparent association of the two tool forms [a busked burin and a leaf-point] at Ffynnon Beuno Cave reinforces my view of the "mixed" [typologically, not physically] nature of the British Earlier Palaeolithic, a view which discounts the a priori attempts of previous workers such as Garrod (1926) to divide the relevant material into separate "cultures" such as "Aurignacian" and "Proto-Solutrean" on purely typological grounds. (1977:147)

Note that both Jacobi and Campbell are basing their arguments on the presence, not of two artefact types, but of two artefacts. Most commentators have suggested, more or less

explicitly, that the single scraper on an 'aurignacian' blade from Cae Gwyn represents an aurignacian industry. However, Campbell (1980) now refers this scraper to yet another industry, the "Maisierian".

All in all, a century's work in, and discussion of, the Ffynnon Beuno Valley cave sites provide a very good example of how not to deal with material in such contexts.

The next site of interest is Cefn Cave, which is only some 700m down the Elwy Valley (southwards) from Pontnewydd Cave. From Cefn, Boyd Dawkins reported both 'cold' (e.g. reindeer) and 'warm' (e.g. hippopotamus) faunal elements, but no palaeolithic material (but cf. Campbell 1977), apparently from a single layer:

Pebbles derived from the boulder clay, and rounded waterworn fragments of bone, showed that the contents had been introduced into this cave by a stream. Some of the remains, which were marked with teeth, may have been introduced by the hyaenas. (1874:286)

This description is again reminiscent of debris flow. Some doubt remains concerning the 'warm' fauna, since Boyd Dawkins seems to have used the name "Cefn Caves" rather loosely. Nevertheless, there appears to be no reason to doubt that interglacial fauna (probably from the Ipswichian) was present in one of the Elwy Valley caves. Since no such fauna has been found during the recent excavations in Pontnewydd Cave, Cefn Cave itself appears to be the most likely source. A team, led by H.S. Green (pers.comm.), is now investigating this site and some original deposits have been located.

The last major site in this region is Pontnewydd Cave. This cave was first excavated by Boyd Dawkins (cf. 1874, 1880) but, again because of uncertainty as to which site is indicated, the scanty information in these publications is of little use. The report by McKenny Hughes and Thomas (1874) is much more

informative. Whether or not any excavation, as opposed to section cleaning, was involved is unclear, but these authors provide a description of the stratigraphy, as well as of fauna (including a human tooth) and artefacts recovered from Boyd Dawkins's tip. Till-derived sediments were again recognised (cf. also McKenny Hughes 1887) and the artefacts were said to be of "Le Moustier" or "St Acheul" type, no clear distinction being made between the two possibilities at the time. Presumably because vaguely 'cordiform' handaxes are present (cf. Mellars 1974), it has usually been assumed, up until recently, that the artefacts are mousterian (cf. McBurney 1965; Morrison 1980). Indeed, Oakley et al. (1971) and Molleson (1976) have suggested "Mousterian of Acheulean Tradition", presumably on the grounds of the presence of any sort of handaxe at all. Oakley et al. also state: "The cave deposits are sealed by St. Asaph Drift which would now be classified as Weichselian." (1971:36). Luckily, we will not have to argue this point, since there was absolutely no suggestion at the time of the nineteenth century excavations that the cave was ever observed to be sealed by till of any age.

In 1977, the present author was engaged, by H.S. Green of the National Museum of Wales, to undertake a brief field survey of the known palaeolithic cave sites, and of some palaeontological sites, in this area, in order to assess their suitability for further excavation. On the evidence of undisturbed deposits, which seemed to correspond to the uppermost unit described by McKenny Hughes and Thomas, the author advised that Pontnewydd appeared to be the most promising site. Several seasons of excavation have now been completed and work continues. However, the author was asked by Green (in litt.) to leave the project in early 1982 and his own part in the research is thus unfinished. The reader should refer to Green (1981a, 1981b, 1981c), Green et al.

(1981), Green and Carrant (1982) and Green et al. (in press)* for full details concerning the recent excavations. The careless publication by de Lumley (1981:125-6) should be ignored. The information given by Cook et al. (1982) is only in summary form but it is essentially accurate up to that date. The article by Stuart (1983:17-8) is significantly inaccurate and it is best to consult the primary sources.

There are many problems associated with Pontnewydd, but the recent investigations have nevertheless demonstrated, beyond reasonable doubt, the following general points. First, an artefact assemblage (of whatever precise cultural or temporal significance) is present which dates, or which in part dates, from a period prior to 150ka. Pontnewydd is therefore over 250km to the north and west of the nearest known Lower Palaeolithic sites with comparable artefact totals (but not necessarily types) (cf. Roe 1981). Second, the cave can claim to be one of only two known Middle Pleistocene hominid sites in this country (cf. Swanscombe, Kent). Third, the Pontnewydd sequence demonstrates glacial activity in the region during, at the very least, one period prior to the Ipswichian. Since the lithology of this early till-derived material is quite similar to some certainly devensian tills, a complete reappraisal of the evidence for glaciation in the region is called for. The fourth point concerns theory and methodology. Due to both natural processes and earlier excavations, Pontnewydd presents one of the most complex problems of stratigraphy, in all its aspects, that the author has ever come across. Yet, the recent work has shown that highly significant information can be extracted from such apparently irredeemable contexts. On the other hand, the recent work has also shown that, even though we have the technical expertise, we

* cf. postscript, p.1218.

are not yet equipped, mentally, either to accept such contexts for exactly what they are, or to make the co-operative effort to extract all the relevant information that is actually present in such contexts. Basically, the Pontnewydd project represents something rather new and exciting in British cave research, but it will fall (is falling) far short of its potential because we have not been able to adapt outworn, but comfortable, mental attitudes to the challenge of the new situation. The Pontnewydd project has gone a considerable way in the right direction but, sadly, it cannot yet claim the standing of truly interdisciplinary research (pace Roe 1982).

In the following sections, the present author's final contribution to the Pontnewydd project is presented in substantially the same form as it will appear in Green et al. (in press). Only the discussion (section 24.7.) has been adapted and enlarged slightly in order to give more coverage of the contextual problems at this site. The reader should remember that the author's work represents only a small part of the whole project. Explanatory details, supplied by colleagues, have been added where necessary, but a full appreciation of the site can only be gained by reference to the various publications. Particular aspects of the study of this cave have also been noted at several points in Part I of the present text (see especially Chapter 14). The examination of Pontnewydd presented here should be seen as an attempt to answer the following general question: how does one go about studying cave deposits which were mostly emplaced by relatively violent processes, which were repeatedly disturbed and eroded during later events, and which were further fragmented by nineteenth century excavators and twentieth century soldiers and cavers? The approach adopted by the author has been

the strictest possible adherence to stratigraphic principles and procedure, an approach which, although unpopular with some members of the project team, seems nevertheless to have provided a moderate amount of plausible information. The author has also tried to make his approach as explicit as possible, so that the reader may follow, step by step, the exact lines of reasoning which underpin the higher levels of inference.

24.2. Pontnewydd Cave - Summary

The remainder of this chapter deals with the following major topics at Pontnewydd Cave:

24.3. Detailed description of each deposit in each exposure;

24.4. Correlation of the various exposures and justification of a composite stratigraphy for the site as a whole;

24.5. General considerations concerning the major sediment sources and processes which have resulted in the observed sequence of deposits;

24.6. Detailed examination of the development of the Pontnewydd sequence;

24.7. Discussion.

The following is a summary of the sequence of sedimentary events which appear most likely to have given rise to the Pontnewydd deposits. It should be noted that periods of non-deposition and periods of sedimentation, the results of which have later been totally destroyed, probably represent by far the greater part of the total time span of this sequence.

Lower Sands and Gravel submember (LSGs) - A series of gravelly deposits, derived largely from glacial sediments, was

brought into the cave by repeated debris flows and irregular stream action. Towards the top of LSGs, input of clastic sediments slowed and probably stopped altogether for a time. Calcite cement began to form within existing deposits.

Upper Sands and Gravel submember (USGs) - Debris flows brought further material, very like that of LSGs, into the cave.

Intermediate complex (Ic) - The history of the cave and its surroundings now becomes unclear. The surviving sediments have been violently dissected and disrupted, again apparently by debris flow. However, the period between the deposition of the last sediments of USGs and the final disruption(s) of the Ic sediments seems to have included a temperate stage, perhaps of interglacial status, when soils could provide organic matter and there could be significant growth of stalagmite. These patchy sediments also contain the first occurrence of limestone debris and animal bones, together with the remains and tools of man.

Lower Breccia bed (LBb) - A major debris flow entered the cave, causing additional disruption of existing deposits and incorporating some older material into its own mass. Local limestone debris had become more important at the expense of glacially derived material from further afield.

Stalagmite lithozone (Sl) - When sediment input ceased, stalagmites started to grow on the older deposits.

Silt beds (Sb) - Water began to reach the study area and a pool was formed in which silts collected. At first, stalagmite was still formed, interstratified with the pool deposits, but later the silts built up without interruption.

Upper Breccia bed (UBb) - Another massive debris flow reached the area, channelling into and incorporating older sediments. Local limestone debris had become dominant.

Red Cave Earth bed (RCEb) - Traces of one final debris flow, by then almost exclusively composed of limestone debris, survive in one area of the cave.

Upper Clay and Sand beds (UCSb) - A stream flowed westwards out of the cave, depositing clays and sands. Water was probably running at this high level because the lower cave passages were still choked by masses of sediment.

Laminated Travertine lithozone (LTl) - As water found its way deeper, stalagmite began to grow, eventually building up a thick floor.

Earthy lithozone (El) - Traces of organic-rich, earthy material probably represent input during the Holocene.

24.3. Pontnewydd Cave - Lithostratigraphy

Those deposits rendered accessible by the end of the 1981 season, when the author last visited the cave, survive as extremely fragmented bodies of sediment. Intra-site correlation is often taken for granted in sites where sediments can be followed as more or less continuous units. This is not generally the case at Pontnewydd. Furthermore, no Area in which the whole stratigraphic sequence is present has yet been discovered, so that no master section is available. Consequently, correlation between the various Areas within the site must be clearly demonstrated. The validity of the suggested stratigraphic sequence, and of the geological, environmental and chronological interpretation put forward later in this chapter, will be largely dependent upon the accuracy of the correlation so far achieved.

To this end, the sequence in each Area will be described separately. This entails frequent repetition and a monotonous,

dense presentation, resulting in a text which is, admittedly, totally indigestible. It is suggested that the following section be regarded as optional; the main argument may be resumed on p.1151.

The following lithologic description of the Pontnewydd sediments, as observed up until October 1981, is based upon the framework set out in the International Stratigraphic Guide (Hedberg 1976).

Each 'Area' within the site is denoted by a capitalised alphabetic label (cf. fig.80). Areas may be subdivided if necessary by adding to the Area label the terms (N), (E), (S), (W) or (C), the last referring to 'central'. The Area label is terminated by a colon.

Each Area sequence is divided into lithostratigraphic units, informally referred to as 'lithozones', numbered continuously from 1 downwards.

Sediment samples collected by the author appear, with the prefix 'PN', in brackets after the unit label. Munsell colours are given throughout, except in the cases where the verbal description is not accompanied by a colour code; the colours apply to fresh, damp sediment on site. 'Pebble' is here used to denote a siliceous rock fragment, of more than 2mm diameter, that displays extreme rounding. When the word 'gravel' is preceded by the adjective 'siliceous', the deposit contains numerous pebbles. When the word 'gravel' appears without the adjective 'siliceous', it refers to particles of more than 2mm diameter, irrespective of lithology and shape characteristics; these may or may not be indicated by additional qualification. Information derived from laboratory analyses is included at a qualitative level only when it is felt that such detail could be recognised on site with

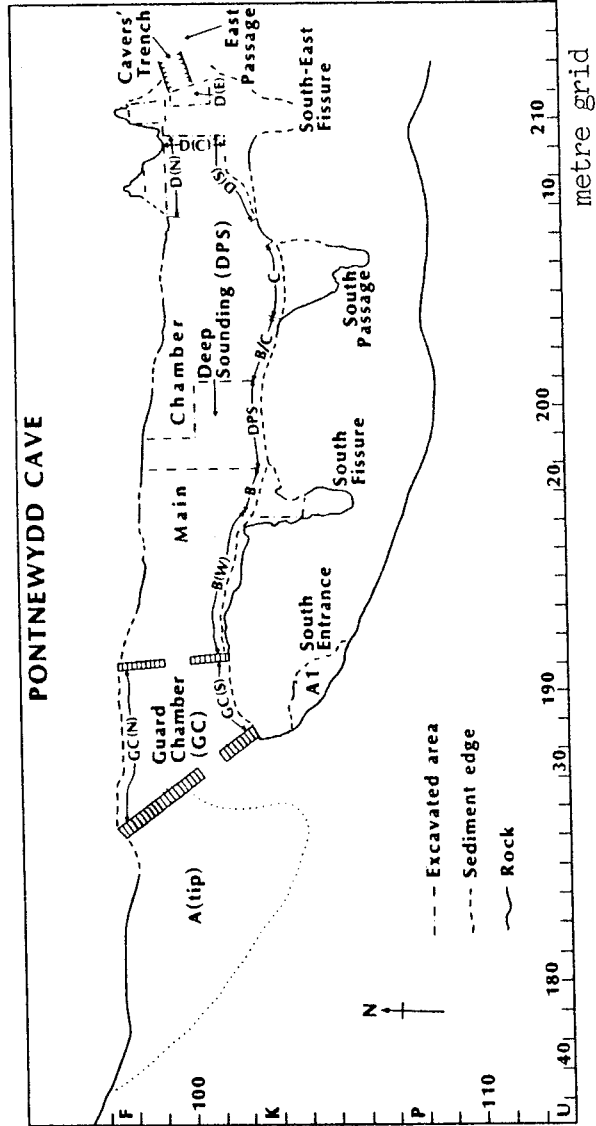


Fig.80 Pontnewydd Cave - Plan

relatively little difficulty.

No claim is made that the following descriptions are in any way exhaustive.

Description of the Deposits (cf. figs.81-83)

CAVE EXTERIOR (Area A)

A:2 - Angular limestone rubble with fine sand matrix; grades smoothly downwards from loose deposit, to well packed material with clasts aligned in continuation of bedrock jointing, to sound bedrock; matrix colour reddish brown (5YR 5/3); thickness variable but not usually over 20cm.

A:1 - (PN 13) Pockets of cemented pebbles and sand; no limestone. These deposits occur as a thin veneer on the rock wall north of the entrance, as the fill of a shallow depression in A:2 just south of the outer door, and as the fill of a small fissure c.5m south-east of the main entrance (this fissure, the 'South Entrance', runs parallel to the main cave chamber); nowhere do these deposits survive beyond the modern drip-line. The small fissure, developed on a near-vertical joint, is triangular in section with a base of c.75cm. The floor has a series of parallel flutes set at right angles to the fissure; there is a gentle dip inwards and a marked asymmetry of the flutes, with the steeper flank east of each ridge. The pebbles of the highly carbonate cemented deposit in this fissure (sampled; matrix colour light brownish grey (10YR 6/2)) are randomly oriented and usually unfractured; the top 2-3cm consists of fine sand and silt completely filling the fissure; the whole deposit is vuggy and penetrated by modern roots; there is no apparent bedding, save in the top, finer sediments. The texture of this deposit is discordant with the sculpting of the bedrock.

A(tip) - Compound tip (demonstrable) overlying A:1-2 right across the cave mouth but especially thick towards the north-west, where it is present as a mound. There are buried turf-lines but there is no extensive differentiation of deposits within the tip, although the lithologic range is identical to that of the undisturbed sediments within the cave. There is no turf-line at the base.

GUARD CHAMBER (Area GC)

The Guard Chamber, constructed during the last war, has an intact concrete floor. There are restricted deposits cemented to both the north and south rock walls.

GC(N) - Cemented pebbles in a coarse sandy matrix; matrix colour light brownish grey (10YR 6/2); extending from the concrete floor upwards for a maximum of c.65cm, reaching Site Datum 99.50; unconformably overlain in places by dormant and active flowstone; rock wall highly fissured and dangerous.

GC(S):5 - Pebbles in a coarse sandy matrix with finer gravel and sand lenses; rich in colloids; well compacted but only slightly cemented; some imbrication visible at various levels, nose-up into cave; sets of graded bedding quite well developed; matrix colour brown (10YR 5/3); from concrete floor up to Site Datum 99.35.

GC(S):4 - Thin (c.1-2cm) band of yellow (10YR 8/6) colloids, mostly carbonates; not plastic; no structure; sharp lower boundary.

GC(S):3 - Thin lens of heavily cemented gravelly coarse sand; matrix colour brown (10YR 5/3); max. thickness c.5cm; sharp lower boundary.

GC(S):2 - Patches of heavily cemented sandy silt with limestone clasts and a few pebbles; some small (5-15cm) blocks of corroded

stalagmite; matrix colour yellowish brown (10YR 5/4); max. thickness c.14cm; sharp lower boundary.

GC(S):1 - Cemented limestone clasts, with some fractured pebbles, in a matrix of sandy silt and clay; matrix colour brown (8.75YR 5/4); sharp lower boundary; highest point reaching Site Datum 100.05.

CAVE INTERIOR

The floor of the main cave chamber was levelled by the army and a coarse limestone grit was laid down, usually c.5-10cm thick. Wherever this grit has been removed during the present excavation, the deposits below have been found intact. The deposits remaining against the walls and in various side passages will be described generally from west to east (fig.80).

AREA B (WEST)

From the inner brick wall of the GC to the South Fissure; shallow and discontinuous deposits adhering to the rock wall; in places overlain unconformably by quite extensive flowstone.

B(W):4 - Pebbles in a coarse sandy matrix; rich in colloids; apparently bedded but difficult to observe due to massive carbonate cementation; matrix colour brown (10YR 5/3); max. thickness c.55cm to grit floor.

B(W):3 - Highly cemented sandy silt with limestone clasts and a few, mostly fractured pebbles; bone present; matrix colour yellowish brown (10YR 5/4); extremely patchy survival but max. thickness c.80cm; sharp lower boundary.

B(W):2 - (PN 240) Laminated (with laminae less than 1mm thick) crystalline stalagmite, in places slightly corroded and friable, containing small blocks of more massive stalagmite and fragments of stalactite; cemented into its lower part, large limestone

particles and artefacts; the lithozone lies unconformably on B(W):3 and dips down southwards behind the lower deposits to fill, partially, a cavity between them and the rock; max. thickness of purer speleothemic portion c.4cm; max.height Site Datum c.99.97.

B(W):1 - Clayey deposit partly filling small cavities between B(W):2 and rock wall.

The stratigraphic links between Areas B(W) and B are obscure; it may be possible in the future to demonstrate that some lithozones in one Area are co-extensive with lithozones, or parts of lithozones, in the other.

AREA B (South Fissure) (cf. fig.82)

Deposits largely intact and present in some quantity.

B:9 - Sandy siliceous gravel; just showing above modern grit floor at Site Datum 98.90.

B:8 - (PN 21, 202, 203) Informal name: "Intermediate". Cemented coarse deposit with over 90% of the gravel being pebbles, often fractured, and the remainder, highly corroded (granular) limestone particles and carbonate concretions; matrix of badly sorted sand and silt with a high carbonate content; non-carbonate sand fraction positively skewed; bone present, matrix colour brown (10YR 5/3); c.35cm thick; lower boundary quite sharp but becoming more diffuse into Fissure.

B:7 - (PN 25) Blocks (5-25cm) of crystalline stalagmite, slightly altered and partially recemented into a discontinuous lithozone; individual pieces not more than c.8cm thick; defines a sharp boundary between the deposits above and below but disappears as a lithozone very quickly towards the east and deeper into the Fissure; no longer extant.

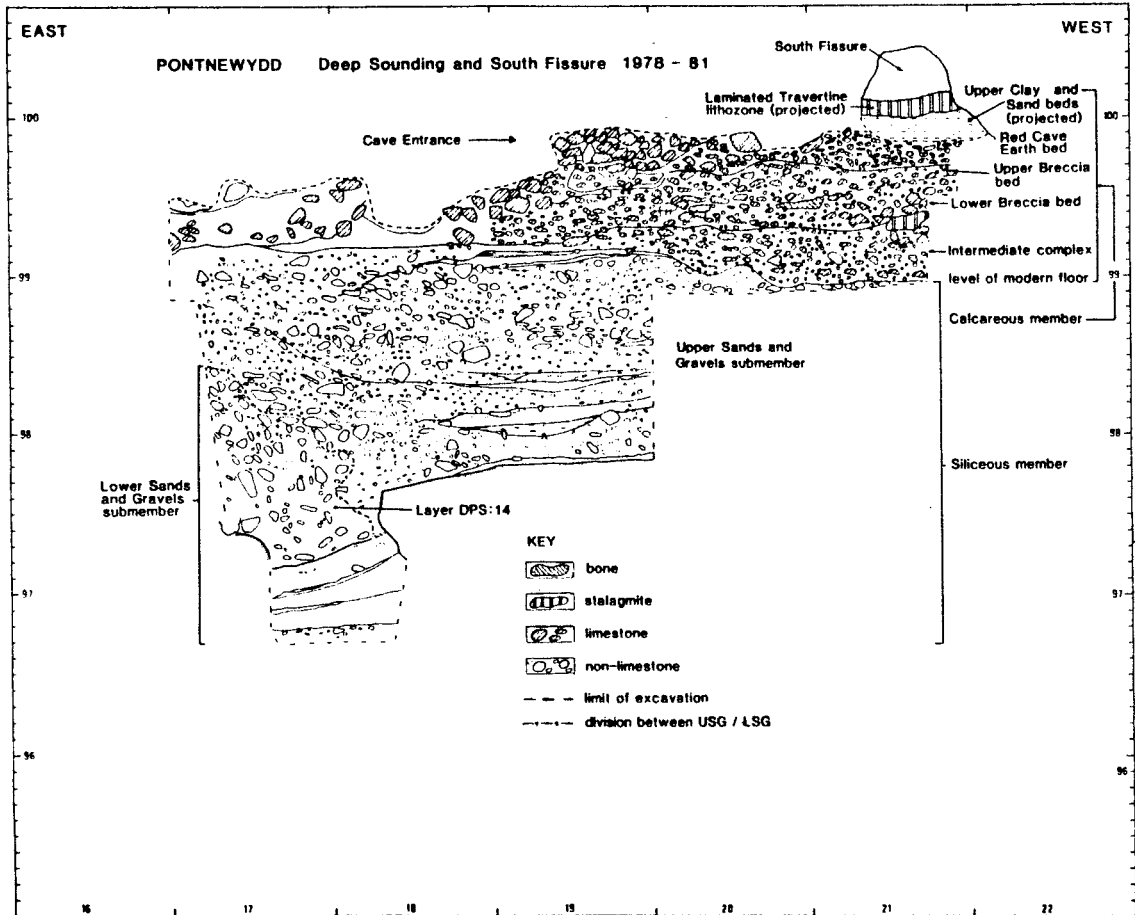


Fig.82 Pontnewydd Cave - Deep Sounding and South Fissure

B:6 - (PN 20, 204, 205, 206) Informal name: "Lower Breccia".

Heavily cemented coarse deposit with fractured pebbles and superficially altered limestone particles in roughly equal proportions; matrix of badly sorted sandy silt with a high carbonate content; non-carbonate sand fraction positively skewed; some small rounded stalagmite blocks especially near base; moderate organic content towards top; bone present; matrix colour yellowish brown (10YR 5/4); c.25cm thick, thinning to minimum 8cm into Fissure; lower boundary with B:8, where B:7 is absent, rather diffuse.

BOUNDARY B:6/5 - Due to the masking effect of the carbonate cementation, this boundary cannot be seen within the metre band K. However, the sediments of the two deposits, once disaggregated in the laboratory, are perfectly distinct. Two sediment samples (PN 19, 207) were collected from as near the top of B:6 as possible but it is likely that they just overlap the true boundary. The B:6/B:5 distinction was proposed before excavation of Area D (infra) and before excavation had proceeded beyond line K/L into the South Fissure. The boundary becomes progressively clearer into the Fissure and is perfectly visible by the time line L/M is reached.

B:5 - (PN 18, 208) Informal name: "Upper Breccia". Heavily cemented coarse deposit with nearly 75% of gravel being slightly altered limestone clasts and the remainder, fractured pebbles and carbonate concretions in roughly equal proportions; matrix of silt with badly sorted sand and a high carbonate content; non-carbonate sand fraction negatively skewed; some stalactite and stalagmite fragments, including a disturbed stalagmitic boss at the junction with B:4; bone present; matrix colour yellowish brown (10YR 5/4); c.10-15cm thick. thickening

to max. 40cm into Fissure.

B:4 - (PN 17, 209, 210) Informal name: "Red Cave Earth". Coarse deposit containing angular limestone clasts and small amorphous concretions with extremely rare small pebbles; silty matrix with a high carbonate content but the deposit is not cemented, although it is highly compacted; abundant crystalline dendritic concretions and a few stalagmite fragments; bone present; matrix colour reddish brown (5YR 5/4); c.30 cm thick at greatest development but wedging out southwards into the Fissure and destroyed by earlier excavation eastwards; sharp lower boundary; no longer extant.

B:3 - Indurated lithozone; limestone badly corroded or present only as ghosts; matrix highly cemented by carbonates and FeMnAl oxides; variegated colour (informally - buffs, blacks, rusts, etc.); basin-shaped cross-section; developed above B:4 in the entrance to the Fissure but, as B:4 wedges out into the Fissure, developed above B:5; dipping and thickening southwards; max. thickness yet observed c.20cm; moderately distinct lower boundary.

B:2 - Clayey deposits not yet accessible for detailed study since they have been destroyed in the first 2 metres or so of the Fissure (cavers' trench); probably susceptible to subdivision at a later stage; approx. colour reddish brown (5YR 4/4); greater than 20cm thick; penetrating down laterally for at least 50cm in a thin (1-3cm) fill between the Fissure walls and B:4-6; lower boundary not yet observed in detail away from the walls.

B:1 - Travertine overlying B:2 deep within the Fissure; so corroded that it can be penetrated with the hand; lower boundary not yet closely observed; c.15cm thick at its surviving northern

edge but becoming thicker towards the south where it is augmented by roof columns (after 3-4m the South Fissure widens out to an unknown extent); highest point yet observed Site Datum 100.15.

AREA DPS (Deep Sounding) (cf. fig.82)

The deposits of the Deep Sounding lie in two channels cut into the rock floor of the cave. The lower channel appears to run approx. north-south; its floor has not yet been reached at Site Datum c.96.65. The tops of its east and west walls have been exposed and form lips, c.80cm apart, which are both deeply undercut. The upper channel, with its floor at Site Datum 97.80, appears to run approx. east-west. Its south wall has not yet been exposed and must therefore lie south of the visible south wall of the (higher) main chamber (i.e. this channel undercuts the the south wall of the main chamber). Part of the north wall of this channel has been exposed approximately two thirds of the way across the main chamber (cf. fig.80). This wall displays large (on average c.15cm long) scallops which are not markedly asymmetrical. The floor of this channel, where it is not interrupted by the lower channel, is approx. horizontal and has solutional boxwork. The deposits in the lower channel remain well organised right up to the rock walls (where these are visible), whilst the deposits in the upper channel lose all signs of bedding before reaching the north wall. None of these deposits contains recognisable bone or limestone particles, save for two instances of large heavily corroded limestone blocks in the upper deposits near the north wall. The deposits will be described primarily as seen in the south section of the Sounding.

DPS:22 - (PN 229) Medium siliceous gravel and badly classed sand; rich in colloids; only exposed to a thickness of c.10cm; matrix

colour yellowish brown (10YR 5/4).

DPS:21 - (PN 228) Fine siliceous gravel and moderately well classed fine sand; rich in colloids; bedding apparent; matrix colour yellowish brown (10YR 5/4); c.8cm thick; sharp lower boundary.

DPS:20 - (PN 216, 227, 215) Moderately well classed medium to fine sand, fining upwards, but with some small pebbles near the top; rich in colloids; matrix colour brown (10YR 5/3); c.12cm thick, thinning eastwards to c.7cm; lower boundary sharp.

DPS:19 - (PN 226) Strong carbonate and FeMnAl concretion developed on sands identical to DPS:20; rather vuggy; matrix colour dark brown (10YR 3-4/3); c.2-5cm thick, disappearing towards west wall; lower boundary moderately sharp.

DPS:18 - (PN 225, 214) Laminated (less than 1mm) silty fine sand and clay; matrix colour dark yellowish brown (10YR 4/4); c.17cm thick, thinning to c.7cm eastwards; lower boundary sharp.

DPS:17 - Coarse sand; rich in colloids; matrix colour dark brown (10YR 4/3); c.2-3cm thick, wedging out towards west wall; lower boundary moderately sharp.

DPS:16 - (PN 224) Strong carbonate and FeMnAl concretion developed mostly on sands identical to DPS:17; rather vuggy; matrix colour dark brown (10YR 3-4/3); discontinuous, present in patches not thicker than 3cm and absent towards west wall; rather diffuse lower boundary.

DPS:15 - (PN 223) Fine siliceous gravel and badly classed sand; rich in colloids; bedding apparent; matrix colour dark brown (10YR 4/3); c.18cm thick; lower boundary sharp.

The boundaries and bedding of DPS:22-15 are not horizontal but, in section, dip gently to the east, with the greatest dip at the top of this sequence (cf. fig.82). These surfaces are not planar but are slightly concave-up.

DPS:14 - (PN 222) Massive carbonate and FeMnAl concretion in which fine particles are almost totally absorbed into the ground mass and large (up to 5mm) pure calcite crystals (dog-tooth spar) are common; rather vuggy; some coarse and medium siliceous gravel with long axes often almost vertical; the base of this mass lies within the lower channel but its summit stands (at Site Datum c.98.40) well above the floor of the upper channel; matrix colour yellowish brown (10YR 5/4) with blotches of brownish yellow (10YR 6/6); max. vertical extent c.120cm; sharp boundaries on all sides.

The deposits DPS:22-14 have been informally named: "Lower Sands and Gravels".

The deposits in the upper channel will be described, from the channel floor upwards, in the area immediately to the west of the lower channel. The coarser units of these deposits swing over the protruding summit of DPS:14, losing thickness and stratigraphic definition; the finer units wedge out before reaching DPS:14. The mass of DPS:14 does not reach the western lip of the lower channel and there is a gap of 15-20cm (cf. fig.82). This gap is filled with a chaotic deposit which, at its upper end, seems to be co-extensive with the lowest unit of the upper fill (DPS:13) but, at its lower end, seems to disturb DPS:15. The floor of the upper channel has a variable thickness (0-2cm) of black sticky sand, especially within solutional features.

DPS:13 - (PN 1) Very coarse siliceous gravel and cobbles with badly classed sand; rich in colloids; no apparent bedding; matrix colour light yellowish brown (10YR 6/4); 10-35cm thick.

DPS:12 - (PN 220, 2, 221) Fine siliceous gravel, present in the west section of the Sounding, but not in the south section; fines upward into laminated (less than 1mm) sand, present in

both sections; laminations undulate whilst retaining their relative thickness; matrix colour various olive browns (2.5Y var.); c.12cm thick, wedging out towards east and north (i.e. the lithozone occupies a trough oblique to the excavation grid); lower boundary sharp.

DPS:11 - (PN 3, 213) Moderately well classed medium sand with some fine siliceous gravel; rich in colloids; no obvious bedding; matrix colour greyish brown (2.5Y 5/2); c.10cm thick, thinning to the west and wedging out to the east; lower boundary sharp.

DPS:10 - (PN 4) Medium siliceous gravel with badly classed coarse sand; rich in colloids; graded bedding; matrix colour yellowish brown (10YR 5/4); c.5-10cm thick, thickening to c.25cm eastwards before thinning out over DPS:14; lower boundary sharp.

DPS:9 - (PN 5) Badly classed medium sand with some siliceous gravel; rich in colloids; weak bedding; matrix colour greyish brown (2.5Y 5/2); c.8cm thick, thinning westwards and wedging out eastwards; lower boundary sharp.

DPS:8 - (PN 218) Fine sand lens; matrix colour light grey (2.5Y 7/2); c.4cm thick, wedging out rapidly east and west; sharp boundary with DPS:9 and DPS:7 (infra).

DPS:7 - (PN 219) Fine siliceous gravel and badly classed sand; rich in colloids; no apparent bedding; matrix colour yellowish brown (10YR 5/4); c.17cm thick; lower boundary sharp.

[Having cleaned this section back some 15cm further south, it was noted that in reality DPS:8 lies stratigraphically within DPS:7. However, the boundary which would separate DPS:7 into two units cannot be followed beyond the restricted occurrence of DPS:8 and the nomenclature was therefore left unchanged.]

DPS:6 - Fine sand lens; matrix colour light grey (2.5Y 7/2); c.2cm thick, wedging out rapidly eastwards; lower boundary

sharp.

DPS:5 - (PN 6, 201, 7) Coarse siliceous gravel and cobbles, becoming finer from approx. mid-way up the unit, with badly classed sand; rich in colloids; bedding apparent as preferential orientation of clasts; matrix colour greyish brown (10YR 5/2); c.50cm thick, thinning slightly eastwards; boundary with DPS:7 rather diffuse.

DPS:4 - (PN 8) Laminated (less than 1mm) silt and fine sand with a little fine siliceous gravel; very small colloidal carbonate content; matrix colour pale red (2.5YR 6/2); c.2cm thick, wedging out rapidly east and west; lower boundary sharp.

DPS:3 - (PN 9) Medium and coarse sand with a little fine siliceous gravel; no apparent bedding; tiny red (2.5YR high chroma) flecks (oxides) giving a matrix colour of yellowish red (5YR 4/6); c.2cm thick, wedging out rapidly east and west; lower boundary sharp.

DPS:2 - (PN 10, 212) Silt with some colloidal carbonate; no apparent bedding; matrix colour pale red (2.5YR 6/2); c.8cm thick, wedging out rapidly east and west; lower boundary sharp.

DPS:1 - Laminated (c.1mm) sand; matrix colour various pale reds (2.5YR var.); 2-3cm thick, wedging out rapidly east and west; lower boundary sharp.

The deposits DPS:13-1 have been informally named: "Upper Sands and Gravels".

The relationships of the higher DPS deposits with those of Area B to the west and Area B/C to the east (infra) are not always clear. DPS:5 is almost certainly co-extensive with B:9. DPS:5 also appears to be co-extensive with parts of B/C:4-3, but other parts of these latter deposits must lie stratigraphically above DPS:1; the single boundary theoretically formed when the lithozones

DPS:4-1 have finally all wedged out to the east cannot be followed into the much coarser sediments of DPS:5 and/or B/C:4-3.

Furthermore, there is a band, c.5cm thick, of fine gravel and sand (unlabelled, but sampled: PN 11) which lies directly above DPS:1 and below traces of a deposit with limestone particles; the band appears to be co-extensive with both B:8 and B/C:3. Since the sediment of this band is quite coarse, shows no bedding and is masked by carbonates, any internal boundary would be very difficult to observe; a stratigraphic link between B:8 and B/C:3 makes very little lithologic sense. Further work on this problem is obviously required, although the most likely solution would seem to be that B:8 in fact cuts into (PN 11), with a boundary somewhere to the west of the main DPS section, and is thus stratigraphically higher than (PN 11).

AREA B/C (cf. fig.83)

From the east side of the Deep Sounding to the South Passage.

B/C:4 - Coarse siliceous gravel and badly classed sand; matrix colour dark brown (7.5YR 4/4); max. thickness to grit floor c.8cm.

B/C:3 - (PN 14) Medium siliceous gravel and badly classed sand; rich in colloids; imbrication in places, nose-up into cave; matrix colour dark brown (7.5YR 4/4); max. thickness to grit floor c.35cm; very diffuse lower boundary with B/C:4; distinction between B/C:4 and B/C:3 fading rapidly westwards.

B/C:2 - (PN 26) Fine siliceous gravel and badly classed sand; rich in colloids; moderate carbonate content including some coarse sand sized particles (corroded); no apparent bedding; traces of bone; flecks of FeMnAl and high organic content giving matrix colour of yellowish brown (10YR 5/6); max. thickness

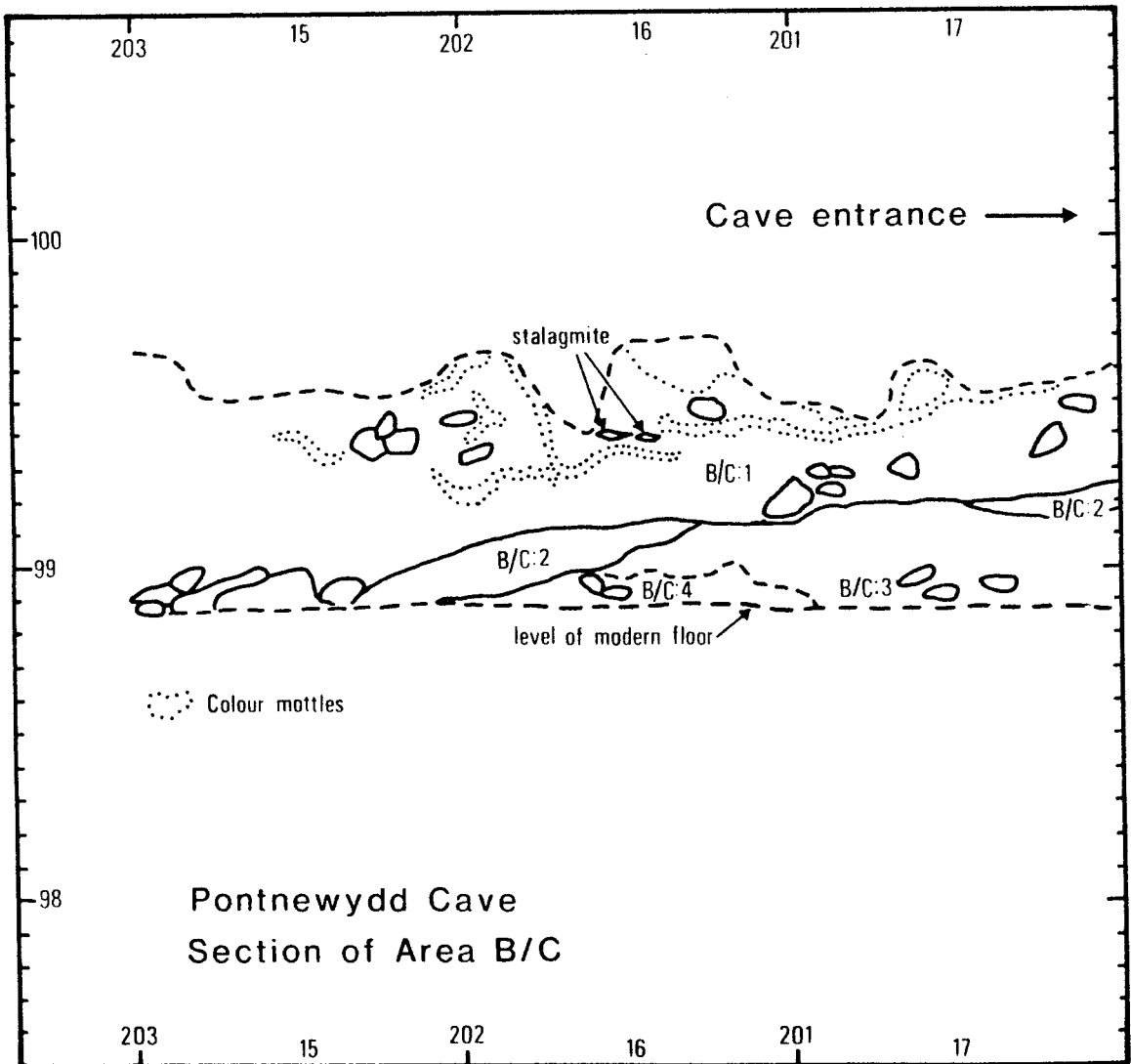


Fig.83 Pontnewydd Cave - Area B/C

c.18cm but present in two separate, lithologically identical lenses (cf. fig.83); lower boundaries quite sharp.

B/C:1 - (PN 211, 217) Weakly cemented veneer of sandy silt and clay, with some large limestone fragments and some traces of corroded stalagmite of uncertain status; large mottles, reddish yellow (7.5YR 6/6) and red (2.5YR 5/6); bone present; thickness extremely variable; reaches Site Datum 99.70 in places; lower boundary usually sharp but more diffuse where the veneer is very thin.

Between Areas B/C and C there is clean rock down to the grit floor, separating the deposits in the two Areas by a minimum of 40cm.

AREA C (South Passage)

This 'passage' was named in the belief that a larger cavity than the South Fissure lay behind the sediments. In fact, this embayment in the rock, which is developed on a major joint, narrows down rapidly to little more than a crevice, blocked by flowstone. It is possible that the cavity may be larger at a lower level.

C:8 - Coarse and medium siliceous gravel with badly classed sand; rich in colloids; organic matter present at top; matrix colour yellowish brown (10YR 5/6); exposed above grit floor for 10cm.

C:7 - Small lens of sandy silt towards eastern side of embayment; matrix colour pale brown (10YR 6/3); max. thickness c.7cm; sharp boundaries.

C:6 - Irregular band of large limestone fragments (up to 30cm but mostly nearer 15cm in length); highly altered and stained red (2.5YR high chroma) in their lower parts (organic matter present), quite sound on top; variable thickness but not over c.15cm; irregular lower boundary, some fragments penetrating up to 10cm down into C:8 (cf. stained areas).

C:5 - (PN 23, 232) Cemented coarse deposit with highly altered limestone particles and fractured pebbles in roughly equal proportions, though the pebbles are mostly smaller and the limestone larger; cemented matrix of sandy silt with a high carbonate content; non-carbonate sand fraction markedly polymodal; moderate organic content; matrix colour yellowish brown (10YR 5/4); bone present; c.35cm thick; sharp boundary between finer elements of C:5 and C:8 in between the blocks of C:6.

C:4 - (PN 24) Badly corroded stalagmitic boss; the apron and root are still crystalline; the boss was found lying at a slight angle from the vertical (leaning eastwards); the material cemented into the root is identical to C:5; there is a prominent rock pendant almost immediately above the boss; crystalline calcite, similar to that forming the root of the boss, penetrates C:5 immediately below the rock pendant; width of the vertical component near its base greater than 10cm; no longer extant.

C:3 - (PN 22) Coarse deposit with over 60% moderately altered limestone, c.10% large carbonate concretions, and the remainder, fractured pebbles; cemented matrix of silt with some fine sand; non-carbonate sand fraction extremely negatively skewed; small fragments of stalactite and stalagmite; matrix colour yellowish brown (10YR 5/4); bone present; c.50cm thick; lower boundary rather diffuse but nevertheless visible on site.

C:2 - (PN 15) Informal name: "Pan". Indurated lithozone; limestone present only as ghosts; matrix highly cemented by carbonates and FeMnAl oxides; variegated colour (informally - buffs, blacks, rusts, etc.); traces of bone; basin-shaped cross-section; max. thickness in centre of section c.35cm; moderately sharp lower

boundary.

C:1 - (PN 16) Small pocket of silty clay with a few small pebbles; fissile in the horizontal plane but bedding not obvious; matrix colour reddish brown (5YR 4/4); the pocket, which has a max. thickness of 10cm, lies between C:2 and the eastern wall of the embayment; lower boundary sharp.

These deposits have been truncated by recent disturbance; their highest point (C:2-1) lies at Site Datum c.100.00. Between Areas C and D(S) there is clean rock down to the siliceous gravels, separating the majority of the deposits in the two Areas by a minimum of 150cm.

AREA D (Threshold of the East Passage)

This Area may be considered to have three subdivisions. D(S) consists of deposits, running east-west, adhering to the south wall of the main chamber. D(C) consists of deposits, running north-south, across the main chamber at the threshold to the East Passage. D(N) consists of deposits, running east-west, adhering to the north wall of the main chamber. The eastern extremity of D(S) is contiguous with the southern extremity of D(C), and the northern extremity of D(C) is contiguous with the eastern extremity of D(N); the form of these exposures is therefore approximately a right square bracket (cf. fig.80). The stratigraphy is clear in this Area; the subdivisions will only be used to give more precise locational information and, with one exception, lithozones will be defined that are valid for the whole of Area D. Although separated from Area D by sediments rather than a physical hiatus, the deposits of Area D(E) must be described independently until such time as they are linked to the main Area by excavation. Towards the eastern end of D(N) there is another embayment, similar

to but apparently smaller than the South Passage. As this embayment is also developed upon the same structural feature as the South Passage, for consistency it may be referred to as the North Passage (cf. fig.80)

D:10 - Coarse to medium siliceous gravel and badly classed sand; rich in colloids; organic matter and FeMnAl oxides near top; matrix colour yellowish brown (10YR 5/6-8). This sediment has only been exposed for a few tens of centimetres all along the base of the exposures. If the bedding of these gravels is oblique to the unconformity at their upper boundary, the material subsumed under 'D:10' may in fact be referable to more than one similar lithozone. With this same caveat, co-extensive with C:8.

D:9 - Small discontinuous lenses of sandy silt and sandy clay in D(N) and northern end of D(C) only; matrix colour olive brown (2.5Y 4/4) with 'ginger' specks (high chroma); max. thickness c.3cm; sharp but slightly convoluted upper and lower boundaries.

D:8 - (PN 12, 244, 309) Informal name: "Orange Intermediate" - junior homonym which must not pre-empt the demonstration of the correlation of the various "intermediate" deposits (cf. section 24.4.). Medium to fine pebbles, fining upwards, with badly classed clayey sand; in general, low to moderate carbonate content; more carbonate in D(S) where it is localised in tiny calcite growths, the size and shape of fish scales, lying horizontally in the sediment; flecks of FeMnAl oxides and rich organics, within the fine matrix and associated with the calcite growths, give a varied matrix colour of red (2.5YR 4/8) to brown (7.5YR 4/4) with flecks of higher chroma; no obvious bedding; a few corroded particles that are cold dilute HCl-soluble and which are not speleothems or concretions;

thickening eastwards from 4 to 15cm in D(N), max. 20cm in D(C) and thinning again (lower boundary rising) in D(S) to nothing more than a stain at the western extremity; lower boundary variable, from sharp to diffuse, extremely diffuse in the centre of D(C).

D:7 - (PN 308) Informal name: "Buff Intermediate" - junior homonym which must not pre-empt the demonstration of the correlation of the various "intermediate" deposits (cf. section 24.4.). Medium coarse deposit containing mostly medium to fine pebbles, often fractured, with a few extremely corroded (granular) limestone particles; matrix of very weakly cemented, badly classed silt and sand with a moderately low carbonate content; non-carbonate sand fraction positively skewed; rich in colloids; FeMnAl aggregates in sands; much organic matter in aggregates and as coatings to sand grains; bone present; matrix colour dark brown (10YR 4/3), drying very rapidly to a lighter 'buff' colour; present in D(C) only; wedging out before reaching northern and southern extremities of D(C); thickening eastwards, max. observed thickness 15cm; sharp lower boundary.

D:6 - (PN 242, 241, 307) Medium coarse deposit with medium and fine pebbles, often fractured, and some altered limestone, so altered in D(C) as to be 'granular'; more and larger limestone clasts as the main chamber walls are approached, especially limestone-rich in the mouth of the North Passage; matrix of sandy silt; non-carbonate sand fraction positively skewed; carbonates, moderate and giving weak cementation in D(C), become much richer towards the walls of the main chamber where the deposit is strongly cemented, especially near the North Passage; moderate organic matter and some FeMnAl aggregates, the latter more common in D(C) and more localised in quite discrete pockets

(c.1-10cm across, redder colour); small corroded stalagmite fragments; bone present; matrix colour yellowish brown (10YR 5/4); channels through D:7 and slightly into D:8 in the centre of D(C); c.30-40cm thick; lower boundary progressively sharper eastwards.

D:5 - (PN 306) Medium coarse deposit containing mostly medium and fine fractured pebbles with some carbonate concretions but very little (corroded) limestone; in all other parameters, almost identical to D:6 in D(C); present only in D(C); c.15-20cm thick, with a distinct lower boundary in the present exposure in D(C), but the whole deposit becoming indistinguishable from D:6 by c.100cm further west.

D:4 - Discontinuous stalagmite occurrences which must be separately referenced with the Area subdivision code:

D(S):4 - Stalagmitic boss lying on D:6 and below a rock pendant; may be approximately in situ but not convincingly cemented into D:6; no longer extant.

D(C):4 - Very thin spreads of calcite with a biscuity texture associated with the base of D:3 (infra) and interstratified with the lower part of D:3.

D(N):4 - A stalagmite (dated sample D534); its apron, which is only c.2-3cm thick and is finely laminated, extends all round the base for c.50cm; its root penetrates and further cements D:6; it is vertical and lies directly below a rock pendant; it is c.25cm high, its undamaged apex being in D:2 (infra); quite constant width reduction upwards, culminating in a close approximation to the minimum diameter given by Curl's Theory (cf. p.556); no longer extant, although parts of the apron remain.

D:3 - (PN 302', 302") Informal name: "Pond" - not acceptable as a lithostratigraphic designation. Laminated (less than 1mm)

silts with some clay partings and very little coarse material; a few very fine pebbles, small corroded limestone particles and FeMnAl aggregates; very low organic content present only as coatings to larger sand grains; dendritic concretions and bone present; intimately associated with D(C):4 and also containing at least one floating limestone block with dripstone on its upper surface; matrix colour brownish yellow (10YR 6/6); present only on north side of D:2 channel (infra) in D(C), and in D(N); c.8cm thick, thickening eastwards to c.15cm in D(C); in general terms, the base of D:3 approximates to a horizontal plane, with a range of only c.6cm in absolute height over its entire exposure but, in detail, the lower boundary is either gradational with D(C):4 or sharp but irregular, with infiltration between larger elements of D:6 in D(N) where the two lithozones are not sharply separated by the apron of D(N):4.

D:2 - (PN 239, 238, 237, 305, 304, 303) Medium coarse deposit containing mostly slightly altered limestone particles but with some medium and fine fractured pebbles; limestone particles are smaller and more compact (equidimensional) away from cave walls, larger and more elongate or platy near the walls and especially in the North Passage; limestone has a blocky fracture near the top of the deposit in D(C); matrix of silt with some sand, weakly cemented by carbonates away from the cave walls but very strongly cemented near walls, especially in the North Passage; non-carbonate sand fraction negatively skewed; small fragments of stalagmite and stalactite, the latter quite common; bone present; only traces of organic matter, associated with larger sand grains; modern roots in places; matrix colour light yellowish to yellowish brown (10YR 5-6/4); in places in D(N) only 5-8cm thick before disturbance; in D(S) c.25cm thick before

disturbance; in D(C) undisturbed, c.30cm thick but up to 80cm thick in an east-west trending channel in the centre of the chamber which cuts through the underlying D:3, D:5 and D:6; lower boundary sharp and often marked by larger particles aligned flat along the boundary.

D:1 - Clayey deposit which may be slightly disturbed; matrix colour reddish brown (5YR 4/4); up to 15cm thick before certain disturbance; present only in D(C); lower boundary patchy, rather diffuse to quite sharp, with some minor infiltration between larger particles of D:2.

AREA D(E)

A cavers' trench (c.50cm wide) has been dug into the upper deposits of Area D(C) and on, c.15 metres, into the East Passage. A small section has been cleaned on the north side of this trench. Another section has been cut north-south across the trench, slightly into a small side passage (the South-East Fissure), also partly disturbed by cavers (cf. fig.80). This is Area D(E), starting 2 metres east of the section described above in D(C).

D(E):9 - Coarse deposit with limestone and pebbles; only upper surface as yet exposed, at Site Datum 99.40-50.

D(E):8 - Thin band of silty clay; very high carbonate content including calcite 'wafers'; matrix colour various pinks (5YR var. high value); c.1-2cm thick; lower boundary sharp.

D(E):7 - Laminated (less than 1mm) silts with some clay laminations; very little coarse material; bone present; matrix colour brownish yellow (10YR 6/6); c.10-20cm thick, but up to 35cm thick (upper boundary rising) in the mouth of the South-East Fissure; sharp lower boundary.

D(E):6 - Medium coarse deposit, the upper half of which can be

traced west along the cavers' trench and is co-extensive with D:2; apparently lithologically identical to D:2; up to 50cm thick towards the north of this Area, but only c.15cm thick (boundaries converging) in the mouth of the South-East Fissure; lower boundary sharp.

D(E):5 - (PN 236) Badly consolidated lithozone; limestone altered with a blocky fracture; FeMnAl oxides and carbon (no structure) present giving a black colour to the matrix; not cemented; developed to a thickness of c.5cm in D(E) but thinning westwards along the cavers' trench and wedging out or disturbed before D(C); diffuse lower boundary.

D(E):4 - (PN 235, 243) Laminated (less than 1mm) clays and silts with very little coarse material; irregular silt lenses at or near base in places; some clay pellets (mud clasts of fine to medium sand size); moderate carbonate content mostly localised in dendritic concretions; modern roots; traces of bone; matrix colour reddish brown (5YR 4/4); c.30cm thick; becoming disturbed westwards towards D(C) but may possibly be intact at base and co-extensive with D:1; lower boundary sharp and gently undulating.

D(E):3 - (PN 234) Laminated (c.1mm and less) sand with some clay; very little coarse material; a few small only superficially altered limestone particles (angular), fine pebbles and FeMnAl aggregates; some clay pellets up to coarse sand size; very few modern roots; moderate carbonate content, mostly particulate; bone, mollusca and other faunal remains present; matrix colour dark brown (10YR 4/3); c.25cm thick; lower boundary sharp and irregular with minor convolutions; in addition to the main body of sediment which occupies the total width of the East Passage (if correlation across the cavers' trench is allowed), there is

an east-west channel, at least 25cm wide and reaching D(E):5, filled with this deposit and also with some pockets of sediment resembling D(E):2 (infra), against the south wall; the bedding within this channel is highly convoluted.

D(E):2 - (PN 233) Clayey sand with very few coarse particles; some modern roots; no apparent bedding in lower part, upper part vide infra; moderate organic and carbonate contents; bone, mollusca and other faunal remains present; matrix colour brown to dark brown (7.5YR 4-5/4); c.10cm thick, thickening slightly in south channel (if correlation allowed); rather diffuse lower boundary with minor convolutions.

The deposits D(E):4-2 have been informally named: "Upper Clay(s) and Sands". D(E):4 has also been called: "Red Clay".

D(E):1 - Informal name: "Laminated Stalagmitic Floor". Laminated (c.1mm and less) crystalline to biscuity travertine; c.30cm thick; gradational lower boundary with D(E):2, with alternating clay and calcite laminations, the former thinning and the latter thickening up into the true travertine; co-extensive with flowstone on the walls.

EAST PASSAGE

Still further into the East Passage (at Site Grid Reference c.214.00 and beyond), between deposits that are co-extensive with D(E):6 and D(E):4, disturbed slabs of crystalline travertine begin to appear in some quantity. These slabs include minor bosses and are generally the right way up. In places, there are two or more conjoinable slabs. Until this area can be examined in detail, this travertine will be referred to as STAL.X(EP).

RF (DEPOSITS ADHERING TO THE ROOF OF THE CAVE)

Nearly all the way around the cave, on the roof or high on the

walls, there is a dark stain, which is sharpest at its top surface but which gradually fades downwards and is lost after c.15cm. The top of this stain has been surveyed for ten metres on the north wall of the main chamber and nine metres on the south wall, starting approximately at the line of the section in D(C) and working westwards. Variations in height amount to no more than 60cm, the gently undulating line always falling between Site Datum 100.35 and 100.95. If the cave were to be filled with deposits to this level, there would only be an air gap of at most 50cm between the sediment and the highest point of the roof in any area (high points usually being slightly north of the centre line in the main chamber). In several places around the cave, in crevices and irregularities in the rock, there are pockets of sediment (coded RF), which never lie above the top of the stain and which often end abruptly exactly against the top of the stain. The sediment has a plastic, earthy texture; rich in organics; bone present; matrix colour dark reddish brown (5YR 3/2-3); the pockets are not usually cemented or even well consolidated.

MAIN CHAMBER (NORTH)

There are various small patches of highly cemented sediment along the north wall of the main chamber, between the inner wall of the GC and Area D(N). There are no obvious major fissures or passages. These patches of sediment have not yet been studied.

NOTE: Reference Sediment Samples from the Pontnewydd Area.

Five samples (marked CGR 1-5) from the sequence of deposits at Cae Gronw Cave (above and to the north of Pontnewydd Cave); in the keeping of the National Museum of Wales.

PN 230 - modern soil c.30 metres south of Pontnewydd Cave, on the hill slope (quite steep), well away from any possible disturbance

associated with digging at the cave.

PN 231 - modern gravel from a spit (just above high water - summer) in the Elwy, approximately below the cave.

PN 301 - decomposed limestone (hardly any coherence) from a block of bedrock lying in a backwater (west bank) of the Elwy, c.5m north of the eponymous bridge at Bont Newydd.

NOTE: Local Bedrock.

No detailed geological survey of this area is yet available. The rock was mapped (Geological Map 79SW, 1850) as undifferentiated "(Lower) Carboniferous Limestone", and the dip was shown as c.20° N.E. The 1973 edition (IGS sheet 107, Denbigh, solid, 1:50,000) contains no significant revision or subdivision of the Carboniferous; the limestone as a whole is now referred to as "(Dinantian) Dyserth Limestone Group". The cliff exposures in the vicinity of the cave are heavily weathered and difficult to approach. There are major bedding planes at about 40cm intervals and only minor, widely spaced joints. Locally, the dip would seem to be a little less than suggested above and there is a greater northerly component. The main chamber and East Passage of Pontnewydd are developed on a bedding plane but the north-south cavities are developed on joints, probably opening in response to the presence of the valley to the west. The main east-west feature may well have had a phreatic origin, but important vadose modification has caused a 'drift' in morphology down towards the south, so that the slight northerly dip is no longer apparent as a morphological control.

Clasts, contained in the sediments, and bedrock, where it could be examined closely, seem to be of a very similar nature. The rock is a calcite mudstone with some patchy coarse recrystallisation,

giving a slightly massive texture and only poor conchoidal fracture. On a fresh break, it is grey in colour (c.10YR 5/1, with tints of a higher chroma). Brachiopods have been noted. Porosity of the unaltered rock is estimated to be very low.

A sample of the rock from the cave wall contained 96.4% carbonates. The dark residue contained euhedral quartz crystals (often set in radial clusters), fossil hydrocarbons and complex sesquioxides. The residue was composed of only c.10% quartzitic sand (fine), the yet finer grades being too rich in non-particulate matter to give a meaningful size distribution.

From observation on site, chemical weathering of the limestone can be seen to proceed by intense alteration of the surface, with periodic exfoliation of the 'chalky' weathering crust, thus revealing a more or less fresh surface. Under the microscope, a series of distinct bands like onion skins can be seen, each less altered than its outer neighbour. Only if weathering is extremely severe does the effect penetrate macroscopically more deeply than c.1mm. The limestone may then become unsound with a highly blocky fracture (common in proximity to running water), reduced to a 'chalky' ghost (common in proximity to standing water) or extremely porous and granular (common in deposits not dominated by carbonate material). Drips that are not releasing carbonate attack the limestone, leaving a dark clayey deposit, very similar to the residue under analysis noted above. Minor but apparently distinct variants have been noted amongst the limestone clasts in the cave sediments themselves; it is not yet clear whether these are separate rock facies or merely the result of alteration governed by different processes.

24.4. Pontnewydd Cave - Correlation

It can be seen from the deposit description that very similar lithologic trends are evidenced in each Area sequence. The lowest deposits comprise siliceous sands, often rather coarse, and gravels, the pebbles of which are only moderately fractured. At progressively higher levels in each sequence, there is generally an increasing limestone component, the non-carbonate sands become finer, and pebbles become rarer and more severely fractured. The presence of such trends in each Area suggests that the deposits may be to some extent correlative.

However, before any attempt at correlation is made, it should be recognised that the mode of emplacement of many of the deposits could render purely lithologic correlation either difficult or, conversely, spuriously easy. The bulk of the deposits throughout the cave are demonstrably the result of mass movement at various velocities but always significantly faster than creep. In the context of Pontnewydd, such movement will be referred to as 'debris flow'. This term is now preferred in place of "solifluction" (Green 1981a) and "mud-flow" or "mudflow" (Green et al. 1981; Green 1981a), since the characteristics of these sediments are thus accurately and unequivocally described. It must be demonstrated that, for any proposed correlation involving such material, the processes involved in debris flow (cf. p.371) are not likely to have resulted in the creation of lithologically very similar, yet non-correlative sediment bodies. The temporal implications of any proposed correlation will be discussed towards the end of this section and in later sections.

Analysis for certain major characteristics has been carried out on sediment samples from the better exposed sequences in the

cave: Areas B, DPS, B/C, C, D and D(E). These samples are not random for many of the characteristics, since spatial trends within the sediments are obvious. Such trends should make correlation more difficult but, if achieved, more reliable, as inter-unit variability will thus be shown to outweigh intra-unit variability. However, the spatial trends and the sampling plan, necessitated by the configuration of the extant deposits, disallow the calculation of the statistical significance of any observed association. Statistical methods will be used to suggest clustering but the resulting coefficients of similarity/correlation are best considered as being on an ordinal rather than a ratio scale, except in the case of more extreme values. The methods chosen are non-parametric, with grouping achieved by agglomerative hierarchical procedures or by total linkage to selected levels of association (infra). It should be noted that the choice of sediment characteristics to be used in the statistical analyses will inevitably affect the outcome of those analyses. An effort has been made not to allow preconceived opinions concerning correlation to influence the initial choice of sediment characteristics. Once a characteristic has been included, it has never been removed whatever its observed effect upon the calculations.

Data, reflecting ten major sediment characteristics, were first organised into a matrix using either a three or four state code (fig. 84). Some of the information was derived from observation (e.g. bedding) but most was extracted from numerical results on continuous scales (cf. figs.95-100). Continuous variables were subdivided to give the discrete coding either at roughly equal intervals or at obvious discontinuities, depending upon the distribution of the values of a variable over all samples

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
PN1-DPS:13	111	111	111	111	111	222	111	211	XXX	111
PN2-DPS:12	111	211	111	111	111	221	XXX	111	XXX	221
PN3-DPS:11	111	211	111	111	111	221	XXX	111	XXX	111
PN4-DPS:10	111	111	111	111	111	222	111	211	XXX	221
PN5-DPS:9	111	211	111	111	111	221	XXX	111	XXX	211
PN6-DPS:5	111	111	111	111	111	222	111	221	XXX	211
PN7-DPS:5	111	111	111	111	111	222	111	221	XXX	211
PN11	111	211	111	111	111	221	111	211	XXX	111
PN12-D:8	211	111	211	222	222	211	211	211	XXX	111
PN14-B/C:3	111	221	111	111	111	221	111	221	XXX	211
PN15-C:2	211	221	211	211	XXX	XXX	XXX	XXX	221	111
PN17-B:4	211	221	222	211	222	211	XXX	222	111	111
PN18-B:5	221	221	221	211	222	221	221	222	111	111
PN19-?B:6	221	111	221	221	221	221	221	221	XXX	111
PN20-B:6	221	111	221	211	221	221	221	221	211	111
PN21-B:8	211	111	211	211	211	221	211	221	221	111
PN22-C:3	221	221	211	211	222	111	221	222	211	111
PN23-C:5	221	211	211	221	221	211	221	222	221	111
PN26-B/C:2	211	211	211	222	211	221	111	221	221	111
PN222-DPS:14	111	111	XXX	111	111	222	111	XXX	XXX	111
PN226-DPS:19	111	111	XXX	111	111	221	XXX	XXX	XXX	221
PN229-DPS:22	111	111	111	111	111	222	111	211	XXX	111
PN234-D(E):3	221	221	211	211	221	111	XXX	221	111	221
PN235-D(E):4	211	221	211	211	221	111	XXX	222	XXX	221
PN242-D:6	221	111	221	221	211	221	XXX	221	211	111
PN244-D:8	211	111	XXX	222	111	221	111	221	XXX	111
PN302"-D:3	221	222	211	211	221	111	XXX	222	211	221
PN303-D:2	221	221	221	211	222	221	221	222	111	111
PN304-D:2	221	221	221	211	222	221	221	222	111	111
PN305-D:2	221	221	221	211	222	221	221	222	111	111
PN306-D:5	221	111	221	221	211	211	221	221	211	111
PN307-D:6	221	111	221	221	211	221	221	221	211	111
PN308-D:7	221	111	221	222	211	221	211	211	221	111

	(111)	(211)	(221)	(222)
(1) Bone	absent	trace	common	-
(2) Skewness, non-carb. 2.0-0.09mm	+ve	neutral	-ve	-
(3) % Carb., 1.0-0.063mm	0	1-40	41-60	61-100
(4) % Soluble organics, <1mm	<0.2	0.2-0.75	0.76-1.5	>1.5
(5) % Carb., 1.0-22.6mm	0	1-10	11-60	61-100
(6) % 1.0-22.6mm in <22.6mm	<25	25-50	51-70	71-100
(7) % Pebble fracturing	<50	50-80	81-100	-
(8) % <0.063mm in <1.0mm	<25	25-50	51-75	76-100
(9) Limestone alteration	weak	moderate	extreme	-
(10) Bedding (macroscopic)	none	weak	strong	-

XXX not available / not applicable

Fig.84 Pontnewydd Cave - Coded Sediment Characteristics

(cf. figs.95-100)

analysed. Note that, in five cases, only a three state code could be justified; these variables are thus weighted so that they potentially contribute more to the overall association than do four state coded variables. The coefficient of similarity of Sokal and Sneath (1963) was then calculated for every pair of samples. This coefficient was used to construct the dendrogram in fig.86 by means of unrestricted single linkage. The tighter groupings (S_{SS} greater than 0.900 - arbitrary) are shaded for ease of reference.

It was felt that the particle size distribution of non-carbonate material in the range 0.09 to 2.00mm might also afford information on correlation if considered in more detail. This material is fine enough not to produce difficulties over sample size, yet, owing to its relative coarseness and stability (both mechanical and chemical), it represents the sediment component that is most likely to resist major diagenetic modification or dislocation. The percentage results of this size analysis (cf. fig.97), with nine half phi classes, were converted to ranks (fig. 85). It was argued that similar sediments should display statistical correlation between ranks for a given size class. In essence, the location and relative importance of size modes in one sample are compared with the same characteristics of modes in another sample. The rank correlation coefficient of Kendall (1948) was calculated for every pair of samples, using the correction for tied ranks. However, the correction had no effect upon the resulting clustering and was therefore abandoned. Fig.87 is a dendrogram produced using unrestricted single linkage of S-values, derivatives (without correction for tied ranks) of Kendall's tau which are easier to plot and tabulate (cf. fig.87 for the relationship between S and tau). The tighter groupings

(+3.5) (+3.0) (+2.5) (+2.0) (+1.5) (+1.0) (+0.5) (0) (-0.5)

PN1-DPS:13	9	8	7	6	5	4	1	2	3
PN2-DPS:12	6	4	2	1	3	5	7	8	9
PN3-DPS:11	9	8	6	3	1	2	4	5	7
PN4-DPS:10	9	8	6.5	4	5	6.5	3	2	1
PN5-DPS:9	9	8	7	4	2	1	3	5	6
PN6-DPS:5	9	8	7	4	5	6	3	2	1
PN7-DPS:5	9	8	7	5	3	6	2	4	1
PN11	9	8	5	1	2	4	6	7	3
PN12-D:8	9	7.5	2.5	2.5	6	5	7.5	4	1
PN14-B/C:3	6	3	2	1	4	9	7	8	5
PN15-C:2	3	1	2	4	5	6	7	8	9
PN17-B:4	3	2	1	4	5	6	7	8.5	8.5
PN18-B:5	3	2	1	4	5	7	6	9	8
PN19-?B:6	6	7	4	5	9	8	2	3	1
PN20-B:6	6	5	4	7	9	8	2	3	1
PN21-B:8	9	8	7	6	5	4	2	3	1
PN22-C:3	1	2	3	4	9	7	5	8	6
PN23-C:5	4	3	5	6	8	9	2	7	1
PN26-B/C:2	9	7	4	3	5	8	2	6	1
PN222-DPS:14	9	8	7	6	5	4	3	1	2
PN226-DPS:19	7	6	4	2	1	3	5	8	9
PN229-DPS:22	9	8	7	6	5	4	1	2	3
PN234-D(E):3	2	1	3	4	6	5	7	8	9
PN235-D(E):4	1.5	1.5	3	4	5	6	7.5	7.5	9
PN242-D:6	8.5	4	6	3	8.5	7	5	2	1
PN244-D:8	9	8	7	2	5.5	5.5	4	3	1
PN302"-D:3	1	2	3	4	5.5	7.5	9	7.5	5.5
PN303-D:2	1	2	3	4	6	7.5	9	7.5	5
PN304-D:2	1	2	3.5	3.5	7	8	9	6	5
PN305-D:2	1	2	3	4	6	7.5	9	7.5	5
PN306-D:5	5	3	6	4	9	8	7	2	1
PN307-D:6	6	5	7	4	9	8	3	2	1
PN308-D:7	8	5	7	3	9	6	4	2	1
I.L.R.	3	1	2	4	5	6	7	8.5	8.5

(insoluble limestone residue)

The lower limit of each $\frac{1}{2}\Phi$ grade heads each column

Fig.85 Pontnewydd Cave - Ranked Non-Carbonate Sand Grades

(cf. fig.97)

(S greater than +24 - arbitrary) are shaded for ease of reference.

Certain major groupings appear to be reasonably constant under the procedures reported above. In fig.86, the grouping on the left contains all the samples derived from the siliceous sands and gravels which always occupy the lowest position in every Area sequence. These sediments will be considered to be correlative at a high (less specific) level in the hierarchy. In fig.87, based upon non-carbonate sand data alone, this grouping is not so clear. Most of the coarser siliceous deposits still cluster on the left, but better classed medium sands (e.g. PN3-DPS:11 and PN5-DPS:9) have dissociated from the main group. In that these sands are all stratified within the main siliceous grouping, it may be safely assumed that their location in fig.87 represents facies similarity rather than stratigraphic affiliation of any kind.

Two other groupings are constant in both figs.86-87:

(i) PN19-?B:6 + PN20-B:6 + PN306,307,242-D:5-6

(ii) PN18-B:5 + PN303,304,305-D:2

The correct stratigraphic order is maintained in these groupings, each of which comprises lithozones from both Areas B and D.

Further linkages in figs.86-87 are more obscure, but they are in many cases informative and the reader is invited to return to them at the end of this section, when a full correlation scheme has been suggested.

Using the same coefficients and sediment characteristics as above, it will be interesting to observe how linkages are located between different Areas, with the deposits of each Area in stratigraphic sequence. This will avoid the chaining that may obscure relationships in the dendrograms. However, in order that

Sokal & Sneath Coefficient of Similarity S_{ss}

Agglomerative hierarchical
 Unrestricted single linkage
 Mixed 4 and 3 state code
 Constituents = 10
 Sample = 33

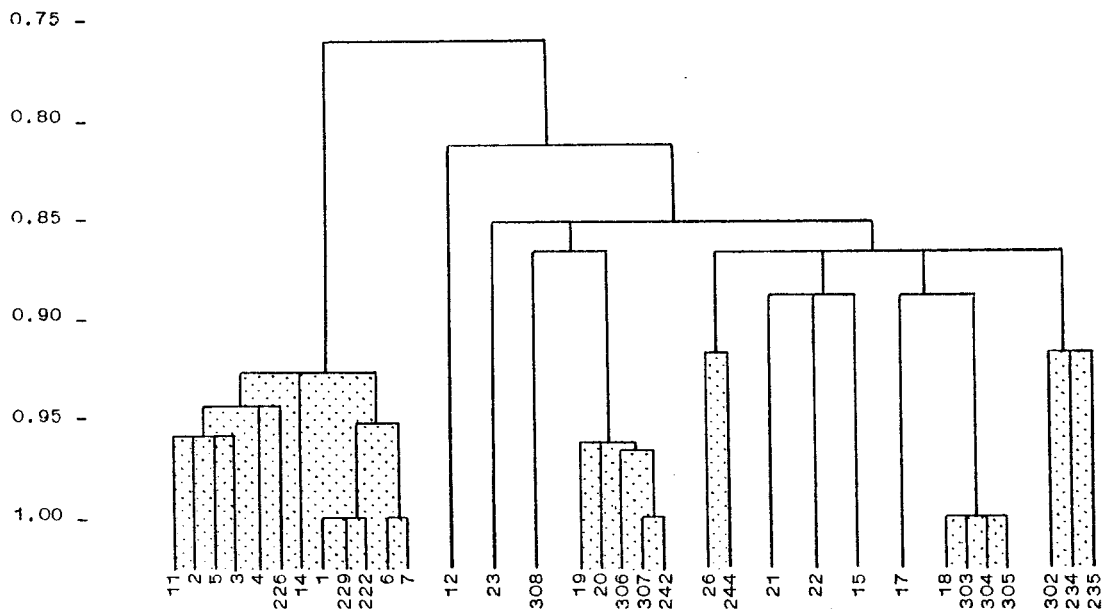


Fig.86 Pontnewydd Cave - Lithologic Correlation
Similarity Coefficients (cf. fig.84)

S-Derivative of Kendall's Rank Correlation Coefficient

$$\tau = \frac{2S}{m(m-1)}$$

Non-carbonate sands 2.00-0.09 mm.
 Agglomerative hierarchical
 Unrestricted single linkage
 Constituents $m = 9$
 Sample $n = 34$

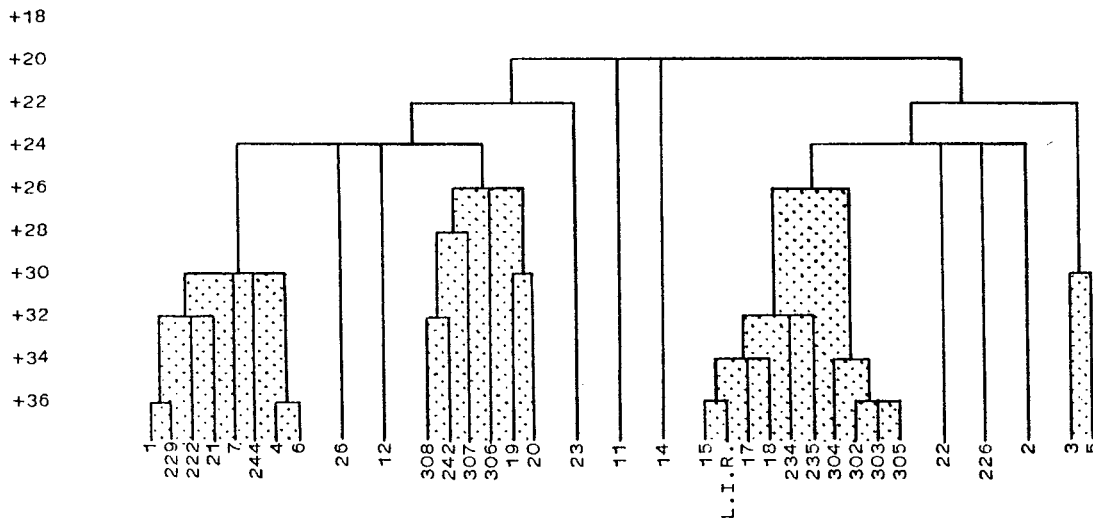
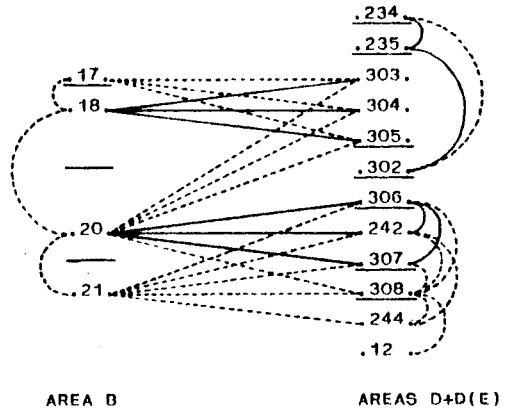
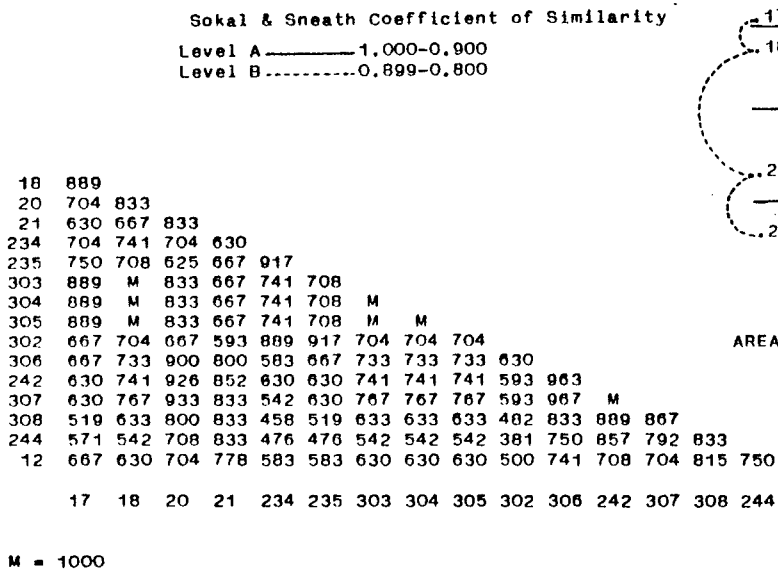


Fig.87 Pontnewydd Cave - Lithologic Correlation
Rank Correlation (cf. fig.85)

the diagrams be readable, some choice must be made as to the range of values of the coefficients to be plotted. Therefore, the assumption (supra) is made that values of S_{SS} greater than 0.899 and of S greater than +24 are significantly higher than $S_{SS} = 0.899$ to 0.800 and $S = +24$ to +18 respectively, and that values of S_{SS} greater than 0.799 and of S greater than +16 are significantly higher than S_{SS} less than 0.800 and S less than +18 respectively. Should any reader find the assumption unwarranted, the exact values of the coefficients are also tabulated alongside each diagram.

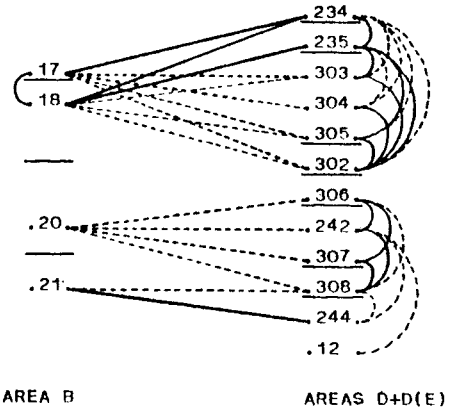
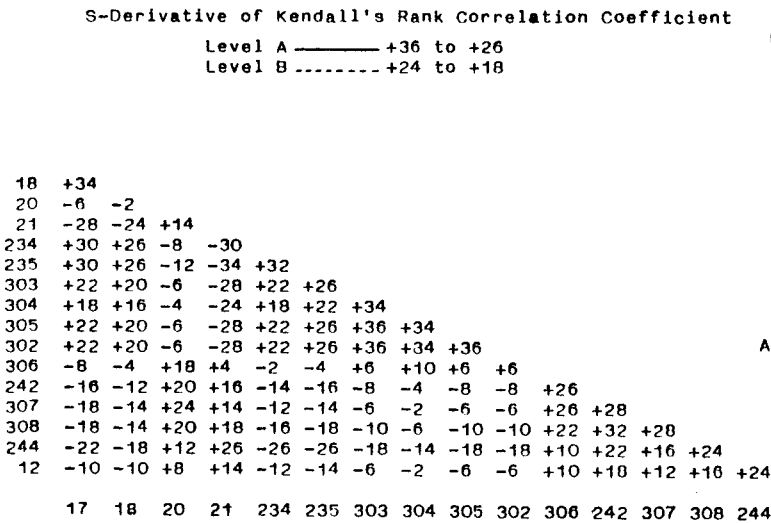
Figs.88(S_{SS}) and 89(S) represent the relationships between Areas B and D+D(E), the stratigraphic order being demonstrable since D:2 is co-extensive with D(E):6. PN19, which probably slightly overlaps the B:5/6 boundary, has here been eliminated but, on both diagrams, it plots exactly as PN20. In fig.88, note that the similarity between B:6 and D:2 is no greater than that between B:6 and B:5. If one goes to Level A inter-sequence links, exactly the same groupings as in the dendrograms can be seen, namely B:5+D:2 and B:6+D;5-6. In fig.89, no Level A or B links cross the 'boundary' B:5/6-D:3/5, again confirming the groupings. Note that, in fig.89, inter-sequence Level A links with Area D(E) (PN 234 and 235) are not markedly greater than intra-sequence links, even if overall lithology allowed such a correlation.

Figs.90(S_{SS}) and 91(S) show the relationships between the Areas already examined and Areas B/C and C. Note that PN26-B/C:2 has been allowed to find its own position since there is no stratigraphic contact with Area C. This position was subsequently found to be concordant with all other available evidence. From the dendrograms, it was to be expected that Areas B/C and C would not group very closely with other Areas. However, the dichotomy



Graphic Plot of Inter-lithozone Similarity; lithozone boundaries marked, samples in stratigraphic order.

Fig.88 Pontnewydd Cave - Lithologic Correlation
Similarity Coefficients (cf. fig.84)



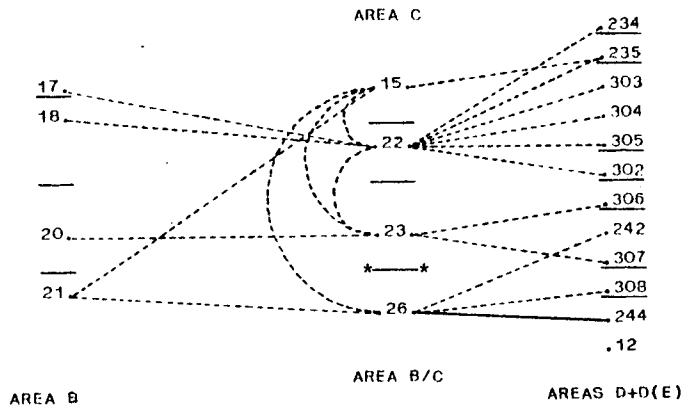
Graphic Plot of Inter-lithozone Correlation; lithozone boundaries marked, samples in stratigraphic order.

Fig.89 Pontnewydd Cave - Lithologic Correlation
Rank Correlation (cf. fig.85)

Sokal & Sneath Coefficient of Similarity

Level A ——— 1.000-0.900
 Level B - - - - - 0.899-0.800

17	778	815	704	593				
18	778	867	767	600				
20	722	767	800	700				
21	889	667	767	867				
234	722	815	704	593				
235	867	833	750	625				
303	778	867	767	600				
304	778	867	767	600				
305	778	867	767	600				
302	722	852	741	556				
306	667	733	833	733				
242	667	667	778	815				
307	667	700	800	767				
308	667	567	733	833	22	889		
244	667	458	625	917	23	833	833	
12	733	667	741	770	26	833	600	767
	15	22	23	26	15	22	23	



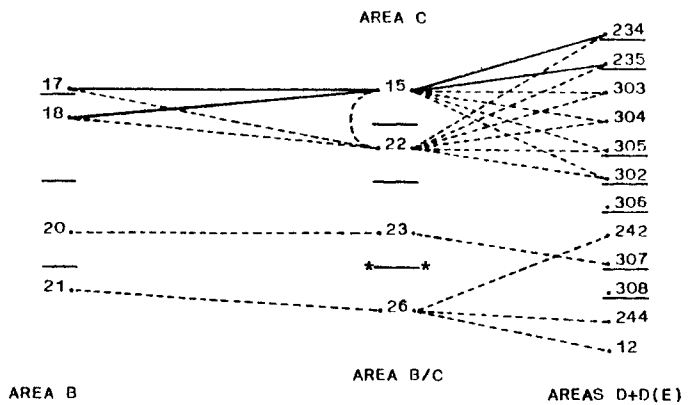
Graphic Plot of Inter-lithozone Similarity; lithozone boundaries marked, samples in stratigraphic order - but *—* indicates stratigraphic hiatus between Areas B/C and C.

Fig.90 Pontnewydd Cave - Lithologic Correlation
Similarity Coefficients (cf. fig.84)

S-Derivative Of Kendall's Rank Correlation Coefficient

Level A ——— +36 to +26
 Level B - - - - - +24 to +18

17	+34	+18	+2	-10				
18	+30	+20	+4	-6				
20	-8	+2	+22	+16				
21	-30	-20	0	+18				
234	+32	+22	+2	-16				
235	+32	+20	+2	-16				
303	+22	+24	+10	-10				
304	+18	+24	+12	-10				
305	+22	+24	+10	-10				
302	+22	+22	+10	-10				
306	-6	+8	+12	+6				
242	-14	-4	+10	+18				
307	-16	-2	+18	+16				
308	-16	-6	+10	+16	22	+18		
244	-24	-16	+4	+22	23	+2	+12	
12	-12	-10	+2	+20	26	-12	-10	+14
	15	22	23	26	15	22	23	



Graphic Plot of Inter-lithozone Correlation; lithozone boundaries marked, samples in stratigraphic order - but *—* indicates stratigraphic hiatus between Areas B/C and C.

Fig.91 Pontnewydd Cave - Lithologic Correlation
Rank Correlation (cf. fig.85)

already observed is clearly maintained at the 'boundary' B:5/6-C:3/5-D:3/5. Fortuitous links in fig.90, such as B:8-C:2 and B/C:2-C:2, are the result of vaguely similar sediments being assessed on only six characteristics, including four three-state codings (cf. fig.84).

It must now be decided whether the observed similarities between B:5, C:3 and D:2 on the one hand, and between B:6, C:5 and D:5-6 on the other, all of which represent debris flows, are likely to reflect some reality other than that they are parts of the same two, formerly continuous sediment units. Note that these groupings have long been recognised on site; the present numerical treatment, although totally independent of any previous assumptions, only serves to formalise the pattern. It is the author's firm opinion that the chances of erroneous correlation are minimal with respect to these deposits. Sediment geometry and lithogenetic considerations support this view (infra). This is the only reasonable conclusion - a conclusion that does not involve special pleading and untestable hypotheses - that can be reached from the present lithologic data. If this correlation is indeed proven, beyond doubt, to be incorrect by some means other than sedimentological, the only course available is to abandon any attempt at lithologic correlation within the debris flows, on the grounds that their gross composition is subject to aleatory variation. Note that the weakest component in the suggested correlation is Area C; the relevant deposits in Areas B and D are remarkably similar. If the correlation between Areas B and D is disproved, there is no way the correlation between Areas C and D can be salvaged using lithologic data.

Using the B:5-C:3-D:2 and B:6-C:5-D:5-6 links as markers, the following overall correlation may be suggested. At the same

time, the opportunity will be taken to organise the deposits into an informal (preformal, cf. p.151) lithostratigraphic framework, following as closely as possible the guidelines set out in Hedberg (1976). Since Pontnewydd Cave is likely to be of some importance to quaternary geology in North Wales, it is hoped that this framework, with any necessary modification, will be raised to formal status at some point in the future. The matter of unit-stratotypes is not discussed here; the lithozones from which some units derive their names are indicated in the preceding section. The term 'breccia', although not totally appropriate, is retained from Hughes and Thomas (1874), in recognition of the fact that they understood these deposits quite well. The framework is summarised in fig.92 and the resulting deposit geometry is schematically represented in fig.93. This same correlation was used as the basis for the Stratigraphy in Green (1981a) and Green et al. (1981).

The Pontnewydd Cave formation is evidenced entirely within the confines of the eponymous limestone cave site (SJ 01527103, 89.5m O.D.). The formation does not extend beyond the known entrance. Present exposures are described in section 24.3. of the present text. cursory examination suggests that the components of the formation may be present up to a minimum of 35m from the entrance. If the main cave passage continues in the same direction (eastwards), there is c.1km of rock available for further horizontal development. However, if the cave changes altitude or direction, or takes on a branching form, there is considerably more rock available, especially to the north-west. The cave lies 50m above the present surface drainage (the Elwy) and has 26m of immediate limestone overburden, increasing slowly to the north-west. Other cave entrances with quaternary sediments

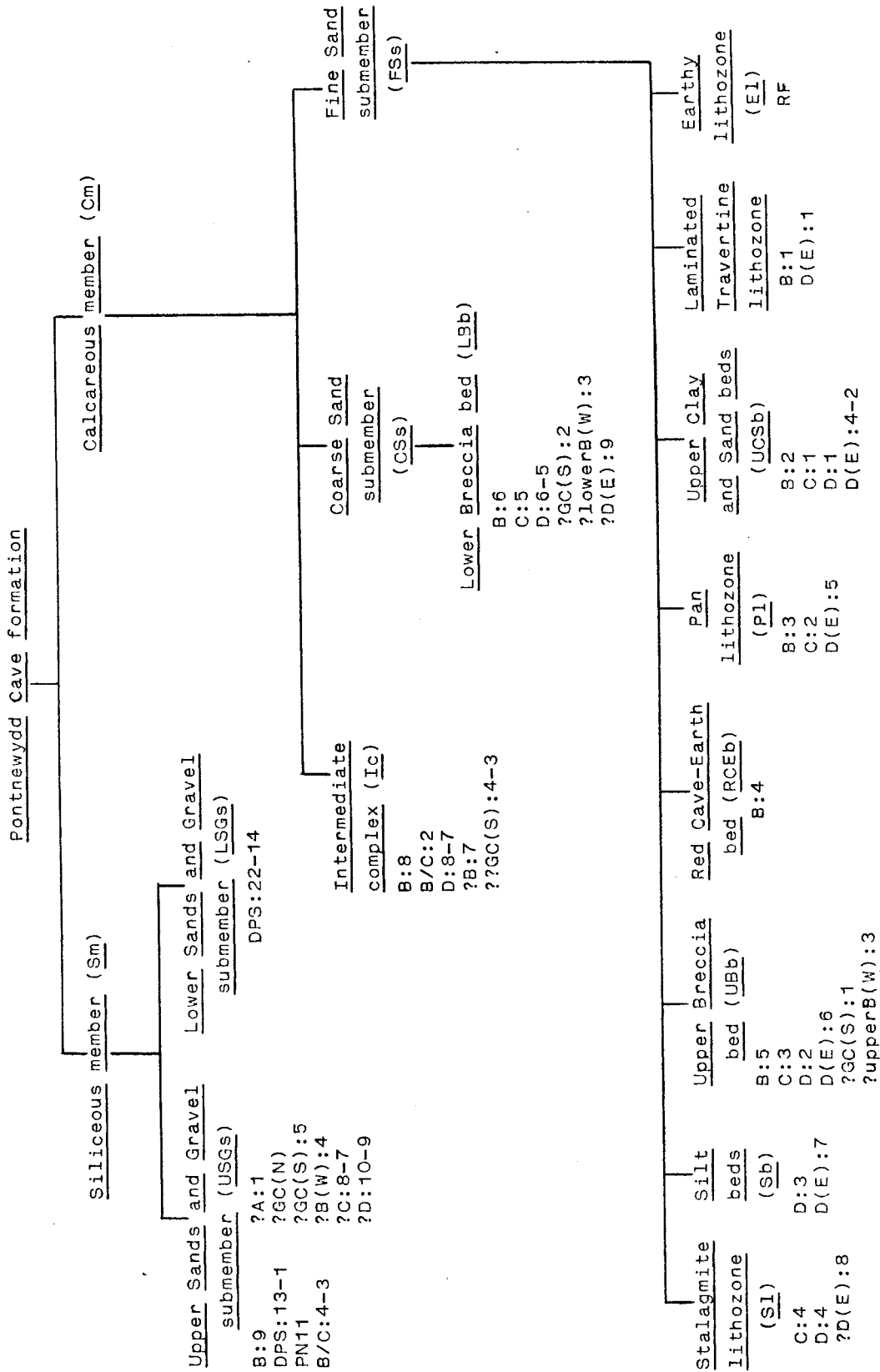


Fig.92 Pontnewydd Cave - Lithostratigraphic Classification

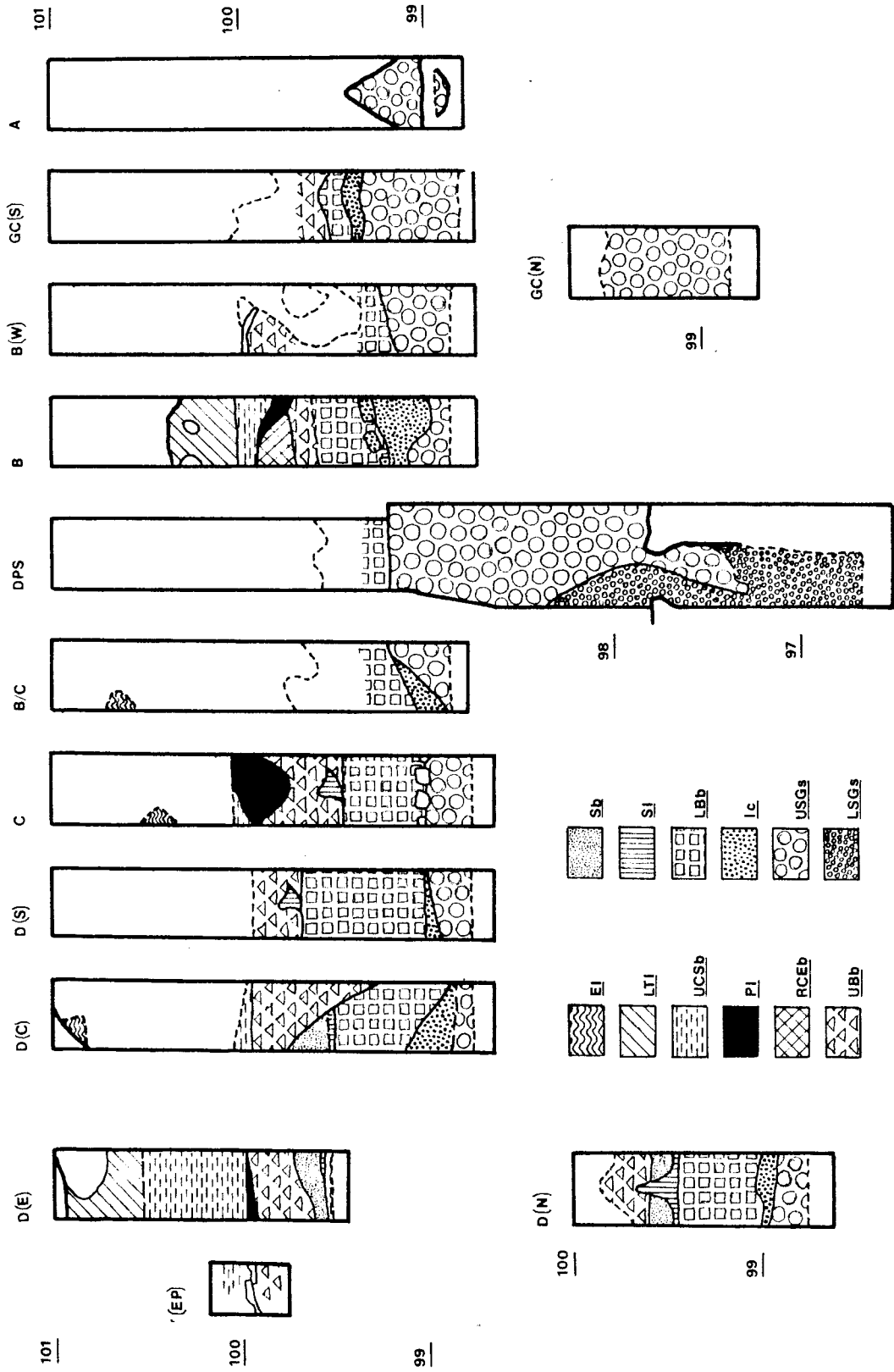


Fig.93 Pontnewydd Cave - Schematic Lithostratigraphy

are present in the vicinity. The formation may only be extended by lithostratigraphic observation of deposits inward from the Pontnewydd entrance and not merely by proof of passage links within the karstic system.

The formation is composed of a heterogeneous sequence of deposits, with varying texture and varying proportions of material derived from the local basement (Carboniferous Limestone) or from demonstrably exotic sources (quartzitic medium to coarse sand and diverse siliceous rock fragments, in bulk mostly with mudstone or siltstone textures). The formation is unified in four ways: (1) sorting of the various deposits is usually rather poor; (2) many of the deposits show matrix-support for included coarser clasts; (3) bedding is usually sub-horizontal; (4) each deposit usually shows clear lithologic similarities with the deposit immediately above and below, although the complete sequence shows a marked lithologic drift, away from exotics towards more local material upwards. The formation demonstrably (cf. biostratigraphic and chronostratigraphic data in Green et al., in press) contains major diastems at various levels, a proposition which accords with the inferred lithogenesis of the deposits (cf. sections 24.5. and 24.6. of the present text). The definition of several formations, based upon these diastems, would obscure the unifying features noted above and would serve no useful lithostratigraphic purpose. Only in the unlikely event that a diastem may be traced significantly beyond the formation might this judgement be reappraised. However, if major sets of new deposits are discovered that do not share the diagnostic unifying features of the formation, they should not be included in the formation. The following would be examples of such divergent material: major sets of well bedded and sorted sands, silts, clays and/or clast-supported

gravels; major sets of material bedded at high angles and showing some angular contacts with known units of the formation; major sets of quartzitic or chert gravels; major sets of lenticular bedding; major sets (not just a single thick unit) of clast-supported material with little or variable orientation of the clasts in component units. All these examples of lithologic divergence would have major contextual implications. The lateral penetration of a minor unit (bed or lithozone) of the formation into such divergent material would not suffice to allow the divergent material to be included in the formation. The occurrence of divergent material intertonguing with, or even completely immersed in, the formation, even at a level within the formation previously defined as a diastem, would not necessarily require the formation itself to be split into new formations; clear lithostratigraphic advantage must be demonstrated before such a step.

The Pontnewydd Cave chronozone is unequivocally defined by the formation. However, the age range of the chronozone is not yet clear. No material that is certainly older than the Middle Pleistocene has been recognised; at the other limit, the chronozone runs up to the present.

The Pontnewydd Cave formation may be divided into two members:

Siliceous member (Sm), with a dominant siliceous component;
Calcareous member (Cm), with common matrix carbonate, speleothems, limestone clasts and bone.

Sm may be divided into two submembers:

Lower Sands and Gravel submember (LSGs). This unit, exposed only in the Deep Sounding, contains lithozones DPS:22-14. It comprises a series of generally well stratified sands and

siliceous gravel, some lithozones being heavily cemented, mostly by carbonates. Note that the massively indurated lithozone DPS:14 may be in the right (youngest) stratigraphic position or it may be considerably older than some or all of the other deposits of this unit.

Upper Sands and Gravel submember (USGs). This unit is best exposed in the Deep Sounding where it contains lithozones DPS:13-1. Elsewhere, deposits of similar lithology underlie lithozones clearly belonging to higher units; these include GC(N), GC(S):5, B(W):4, B:9, (PN 11), B/C:4-3, C:8-7 and D:10-9. Lithozone A:1, although isolated, is also probably part of this unit. The deposits comprise moderately well to badly stratified siliceous gravels with occasional beds of finer material. These gravels may be cemented near the cave walls but there are no discrete horizontal zones of carbonate cementation as in LSGs.

Cm may be divided into three subunits:

Intermediate complex (Ic). This unit is termed 'intermediate' since its deposits have lithologic characters in common with both the units below (USGs) and above (CSs; infra). It is a 'complex' as its component lithozones, each rather different, are often present only as lenses or pockets and, even when more continuous, show rapid lateral facies changes. In some cases, it is not yet possible to identify the relative stratigraphic order of the lithozones. The complex is polythetic in the sense that not all the component lithozones show all the identifying characteristics: coarse sand and siliceous gravel (usually quite fine); high organic and sesquioxide contents; small quantities of highly corroded limestone; moderate to high matrix carbonate, sometimes crystalline; traces of bone. The

lithozones involved are B:8, B/C:2 and D:8-7. The disturbed speleothem fragments of B:7 are probably best included in this complex, as is the colloidal carbonate of GC(S):4. The status of the cemented sands GC(S):3 is uncertain since this very restricted deposit is of unique lithology at this depth in the sequence; it will be included here until its affinities can be clarified. Note that the complex is as much defined by the more easily recognisable units which lie above and below it as it is by internal homogeneity.

Coarse Sand submember (CSs), which at present contains only the Lower Breccia bed (LBb). This unit includes B:6, C:5 and D:6-5. D(E):9, although not yet penetrated to any great depth, almost certainly belongs to this unit. Remnants of the unit are probably represented in GC(S):2 and in the lower parts of B(W):3; a polluted remnant may even be present near the base of B/C:1. The deposits comprise coarse, badly classed siliceous sand, with common fractured pebbles and a little corroded limestone. There is some matrix carbonate and the deposits are usually cemented, becoming strongly cemented near the cave walls. Bone and organic matter are quite common. Lithozones included in this unit are considered to be the result of a single 'event'.

Fine Sand submember (FSs). This unit is differentiated from other units by the fact that its component deposits contain non-carbonate sand that is predominantly fine; major speleothems and limestone clasts are also common. It is possible that it may prove useful in the future to abandon this unit and to replace it with three new submembers which would contain S1 + Sb, UBb + RCEb + P1 and UCSb + LT1 + E1 respectively, as defined below.

At present, FSS may be divided into the following eight subunits:

Stalagmite lithozone (S1). The unit contains C:4, the various occurrences of D:4 and possibly D(E):8. The unit comprises several isolated stalagmites and bosses, together with thin, more or less corroded spreads of speleothem, intimately associated or interstratified with Sb (infra). Correlation, apart from the recognition of the lithologic similarity of speleothems in general, depends upon the grouping of units which lie above and below. There is no implication that the chronozones of the individual components overlap or even represent the majority of time included in the S1 chronozone itself. Should it become necessary to draw a more precise boundary between S1 and Sb (infra), that boundary should be placed at the first (lowest) occurrence of bedded silts.

Silt beds (Sb). The unit includes D:3 and most probably D(E):7. These deposits are laminated silts, with very little coarse material. Their relationship with S1 has been noted above.

Upper Breccia bed (UBb). The unit includes B:5, C:3, D:2 and D(E):6. Remnants of the unit are probably represented in GC(S):1 and in the upper part of B(W):3. The deposit includes abundant, slightly altered limestone clasts with a few fractured pebbles. The matrix contains high proportions of silt and fine sand, much of which is carbonate. The deposit is usually cemented, highly cemented near the cave walls. Bone is quite common but organic matter is rather rare. Lithozones included in this unit are considered to be the result of a single 'event'.

In addition to confusing similarities in overall texture, UBb is often of a very similar colour (wet or dry) to LBb.

However, if a sample of material from UBb of less than 1mm particles is ignited in an oxidising flame, the resulting colour is almost always at least one point of hue redder than similarly treated material of LBb in the same Area. Typical figures in Area D(C) are UBb 5-6YR, LBb 7YR. (The difference is due to the nature of the colloids and to the proportion of carbonates.)

Red Cave Earth bed (RCEb). This unit is only represented by lithozone B:4. The unit is no longer extant; the present author retains loose samples which, although most unsatisfactory, are the only available 'stratotype'. The unit contains many, quite angular limestone clasts, set in a carbonate-rich silt. It is not cemented. There is a little bone present.

Pan lithozone (Pl). This unit is represented by B:3, C:2 and D(E):5. Although the unit is easily defined on lithologic grounds alone, it will be more informative to point out here that it is a zone of alteration rather than a depositional unit. It has always been observed associated with the base of UCSb (infra); it may be developed on the material of RCEb or UBb which it radically modifies, producing a dark, often indurated lithozone.

Upper Clay and Sand beds (UCSb). This unit includes B:2, C:1, D:1 and D(E):4-2. The deposits comprise laminated silty clays, passing upwards into well bedded clayey sands, and finally becoming increasingly clayey again near the top. There is much small bone present, and some organics, especially in the upper part of the unit. Near the cave walls, material from this unit has usually penetrated down between the walls and the lower units, so that young bones and fines have been mixed with older coarse elements. This situation is particularly well evidenced in the thin veneers of GC(S):1 and B/C:1.

Laminated Travertine lithozone (LT1). This unit includes B:1 and D(E):1. There are small corroded remnants of travertine adhering to the cave walls at similar heights in various parts of the cave. Given the survival potential of such material, further study will be required before they are assumed to be correlative. Lithozone B(W):2 appears to be in the right stratigraphic position for inclusion in this unit but, unlike undoubted components of LT1, it contains extremely varied speleothem fragments and cement; its geometric expression is also atypical. LT1 forms thick, horizontally bedded shelves which probably were once part of a more or less continuous 'floor'. It has a gradational boundary with UCSb below it; if an exact boundary is required, it should be placed at the first (lowest) occurrence of a reasonably continuous calcite lamination.

Earthy lithozone (E1). Isolated remnants of this unit adhere to the roof and walls (RF) in many areas of the cave. No stratigraphic contact with any other unit has yet been observed. It is a dark, plastic deposit, rich in organics and small bone.

Four remaining lithozones cannot as yet be allocated their proper place in the above framework. B(W):1 may be only an extremely localised deposit of no great significance. It has already been noted above that B(W):2 is anomalous with respect to other defined units. C:6, composed entirely of limestone blocks, probably represents localised collapse of wall or roof; however, it is not entirely impossible that this is a sorting phenomenon associated with LBb, which is a debris flow. STAL.X(EP) has not yet been observed closely. If it does in fact represent approximately in situ travertine, it must be allocated separate

unit status and be placed in the stratigraphy between UBb and UCSb. Whether it could be proven to lie stratigraphically above or below RCEb depends upon the recognition of the latter deposit in another exposure, preferably in the East Passage.

The suggested framework represents a lithologic correlation. Further information, bearing upon general correlation of the deposits and their contents, may be found in the following sections and in other chapters in Green et al. (in press) in which geological, biostratigraphic and chronostratigraphic data are presented.

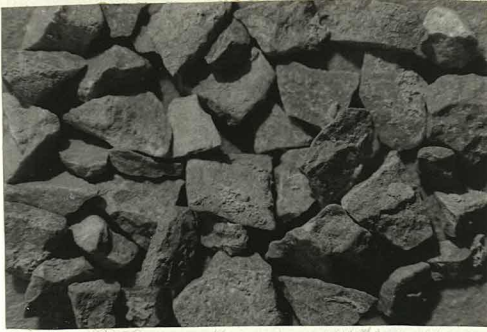
24.5. Pontnewydd Cave - Lithogenesis: General Considerations

24.5.1. Sediment Sources

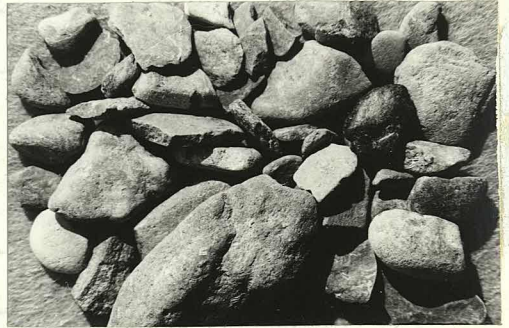
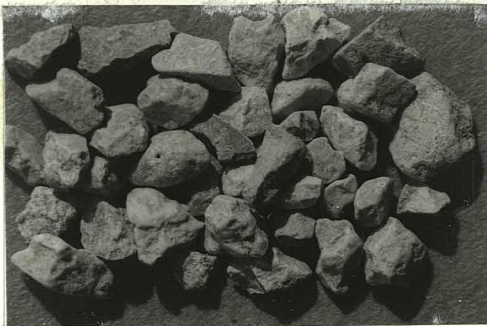
The areas of the cave now under investigation must have formed a relatively passive recipient for coarse sediments derived from nearer the contemporary entrance(s) or from outside the cave. Similarly, the fine sediments are mostly allochthonous and some of them have demonstrably arrived from deeper within the system as well as from areas of the cave to the west of the excavations.

It is not necessarily valid to assume that a sediment was formed only shortly before its emplacement in the study areas. Both surface terrain and cave systems are capable of storing large quantities of sediment and of releasing them, millennia later, under very different environmental conditions from those during which the sediment was formed. Since so little is known about the geomorphological system of which Pontnewydd was a part, it is not even apparent to what extent sediments from originally discrete sources may have been mixed, perhaps long before they

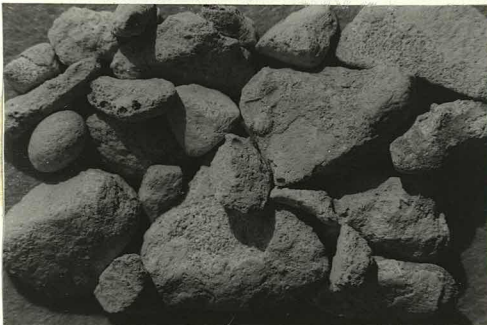
RCEb 17



UBb 305



LBb 307



Ic 308

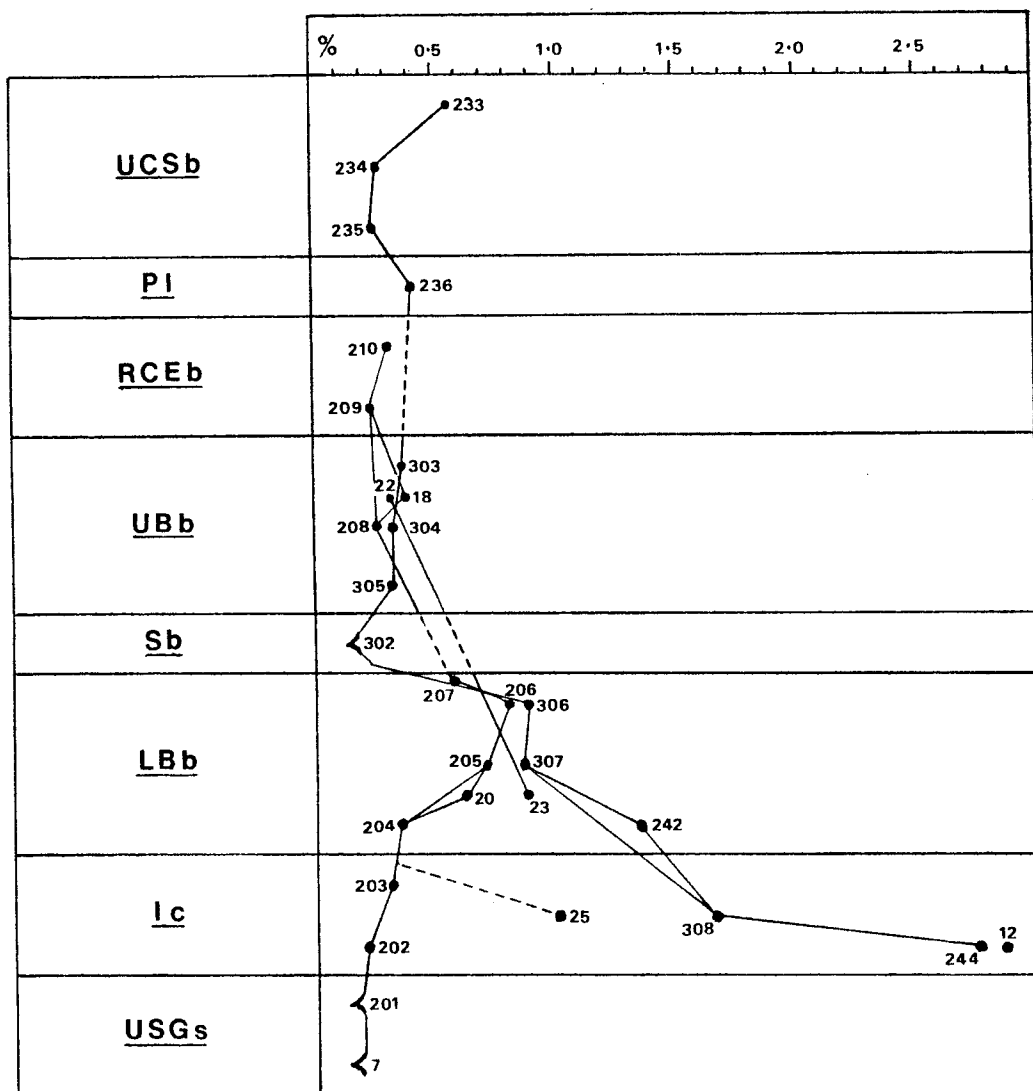


USGs 7



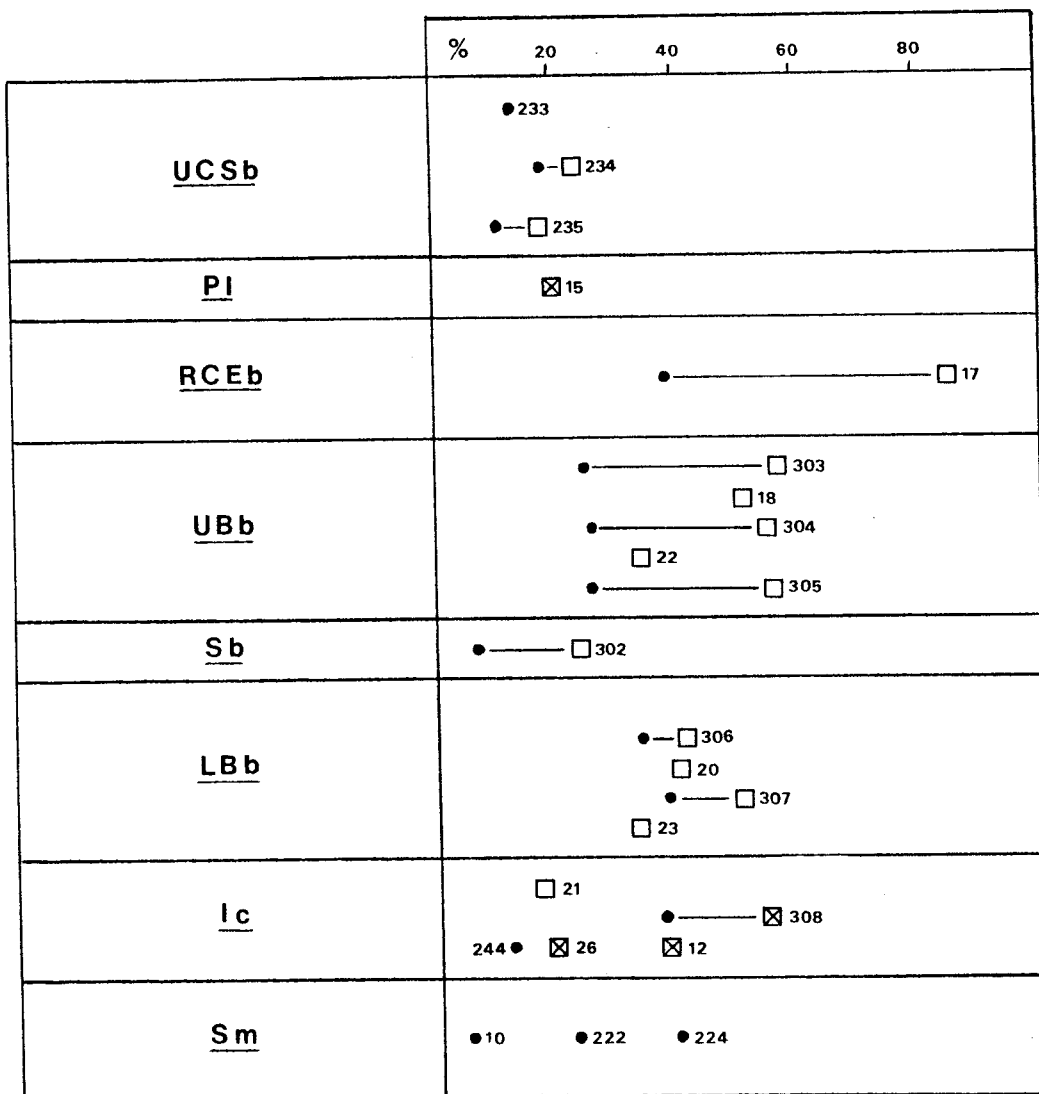
Fig.94 Pontnewydd Cave - Representative Limestone Clasts and Pebbles

Condition of limestone (left) and of mudstone and siltstone (right). Particle sizes shown centre upon the fine gravel class.



Percentage organic matter in the fraction under 1mm. Points are PN sediment samples linked in stratigraphic sequences. NaOH extraction; colorimetric results; calibration by ignition of peat extract.

Fig.95 . Pontnewydd Cave - Organic Matter



● % less than 1 mm.

□ % 1.000-0.063 mm.

☒ approximate value due to masking by organics + FeMnAl

Points are PN sediment samples.

Weight loss after cold 20% HCl treatment.

Fig.96. Pontnewydd Cave - Carbonate Content

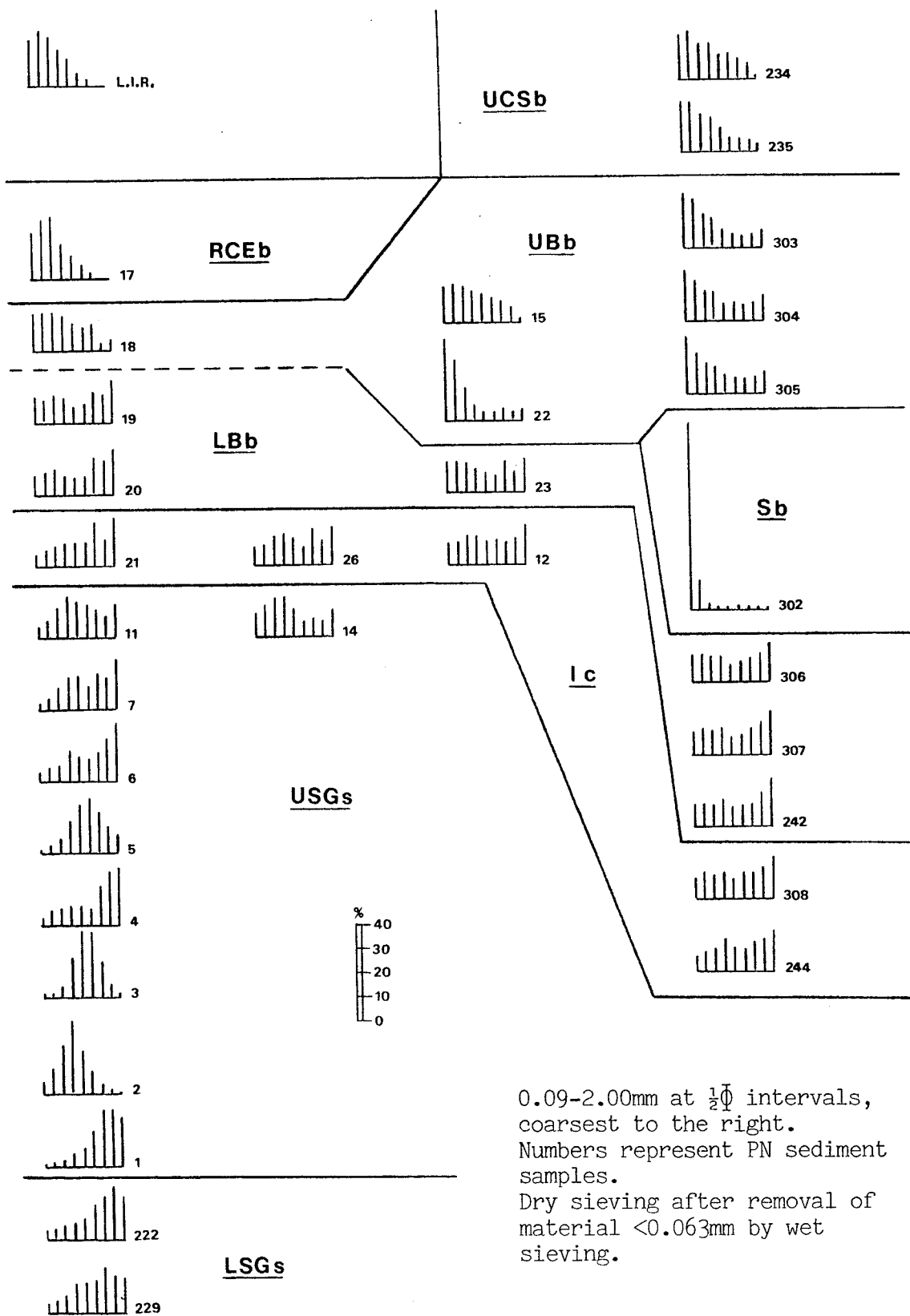


Fig.97 Pontnewydd Cave - Size Distribution of Non-Carbonate Sands

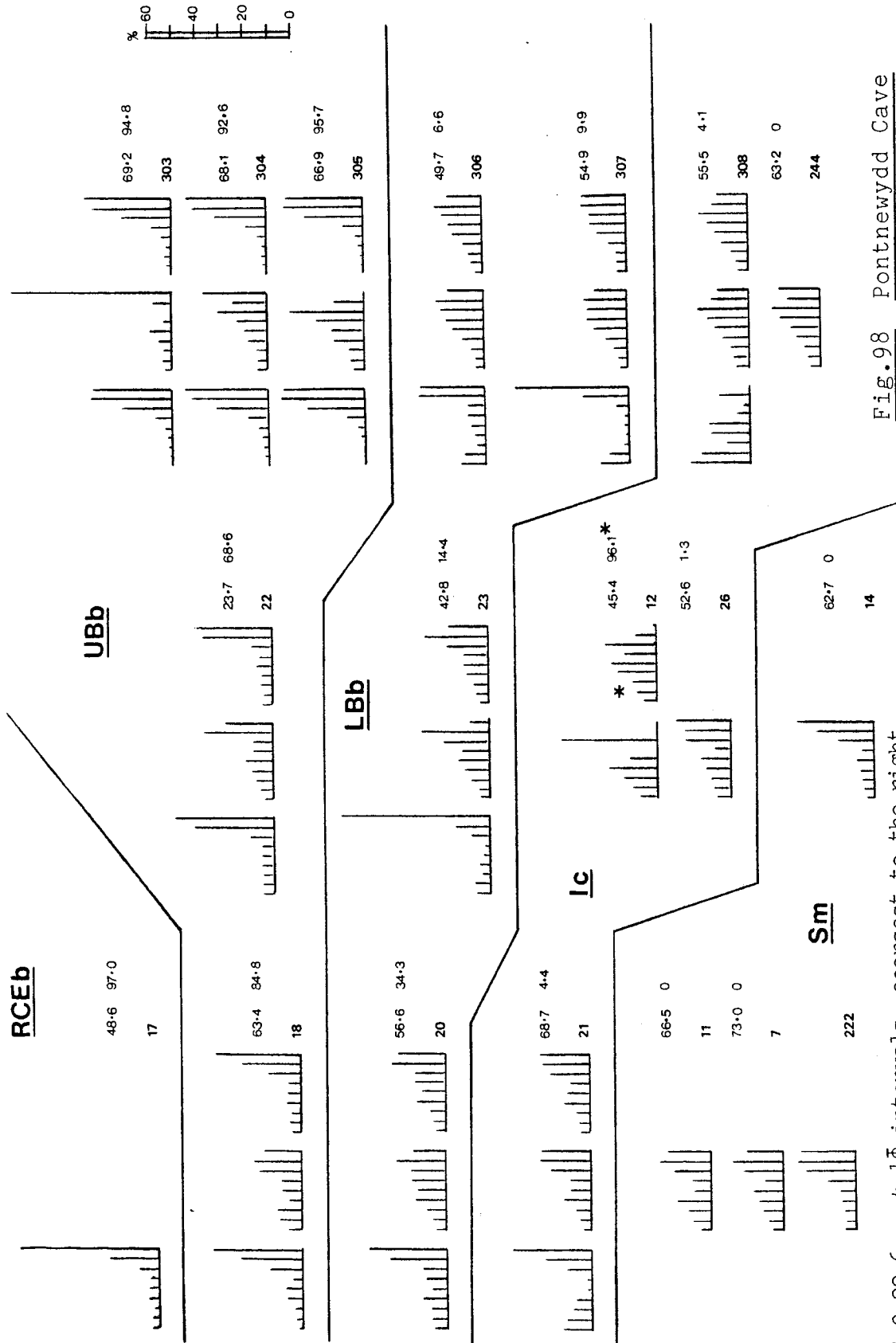
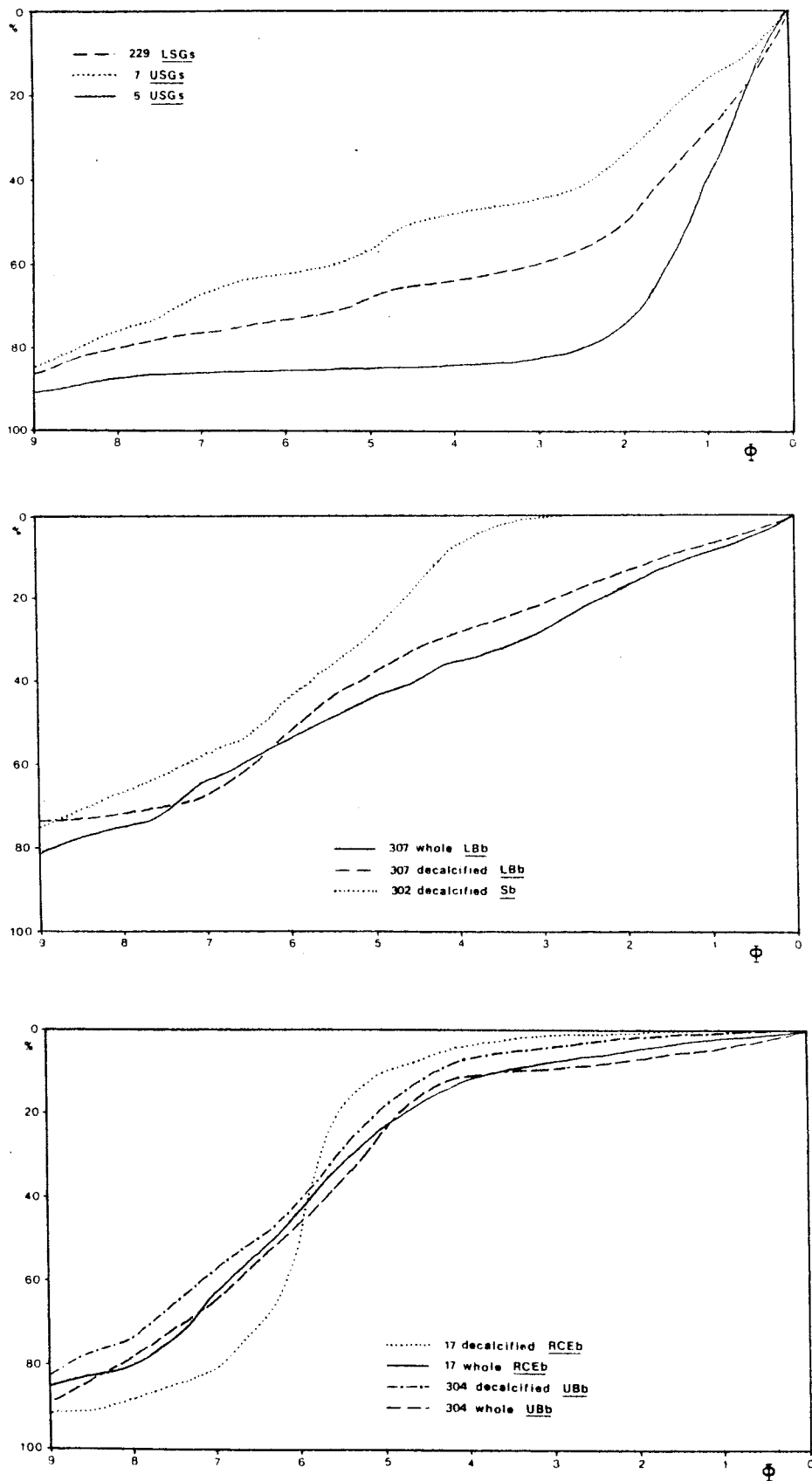


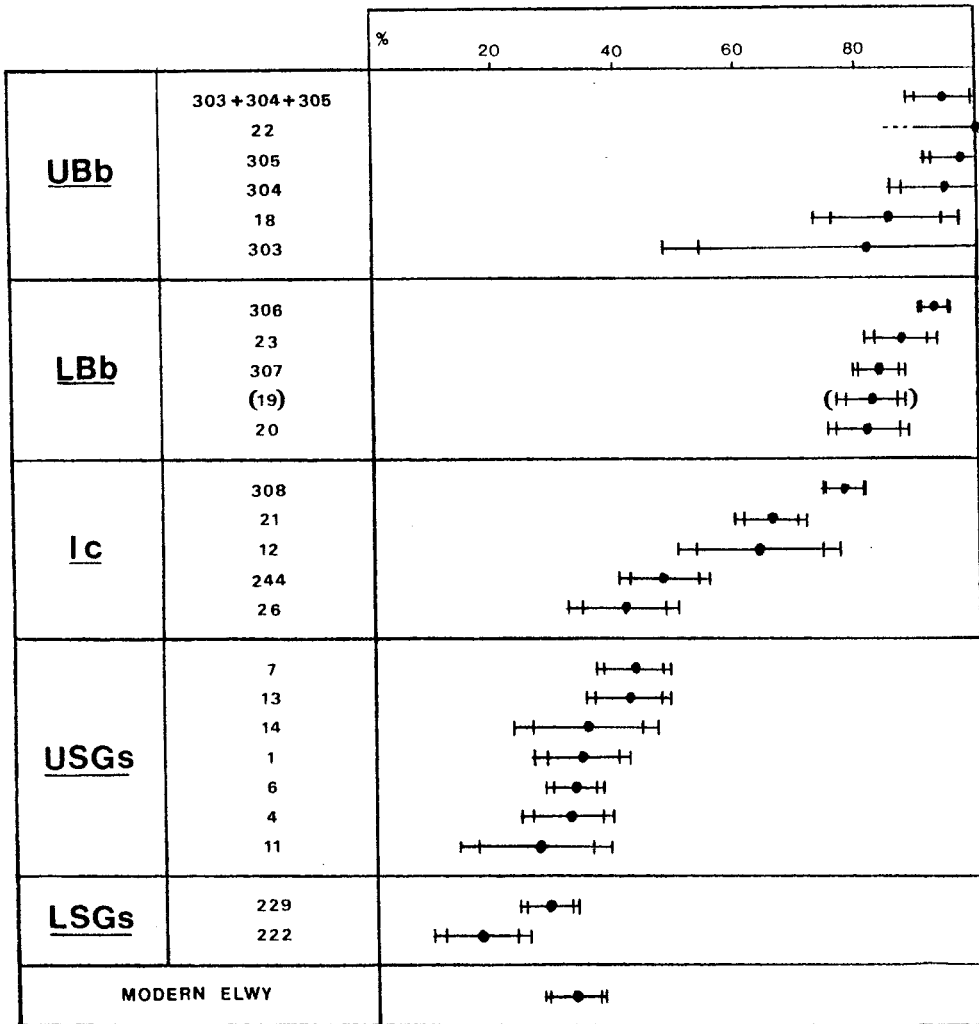
Fig. 98 Pontnewydd Cave
Coarser Particles

1.0-22.6mm at 1/2 intervals, coarsest to the right.
Carbonate particles (left), pebbles (middle), combined (right).
Percentage figures: 1.0-22.6 in <22.6 (left), carbonate in 1.0-22.6 (right). *carbonate-rich aggregates only.



PN sediment samples. Wet separation at 0.063mm; dry sieving of sands; hydrometer method for silts and colloids.

Fig.99 Pontnewydd Cave - Particle Size
Distributions



Percentages of fractured siltstone and mudstone pebbles (8-16mm) by number counts. PN sediment samples.

Bars represent confidence intervals:

$$p \pm (z\sqrt{[pq/n]} + 50/n) ; z(95\%) = 1.96. z(99\%) = 2.576$$

Fig.100 Pontnewydd Cave - Pebble Fracturing

reached the study areas and by processes which had long since ceased to operate.

Consequently, there is as yet poor resolution, only allowing the recognition of very generalised sources, such as 'till' or 'cave entrance facies'. In the following sections, it should not be assumed that the term 'source' refers to temporally, or even geographically, discrete material. Furthermore, all 'sources' are at present hypothetical in that they have been inferred from mixed cave sediments. Although in the future it may be possible to identify actual sources in situ, it seems likely that much of this material would have been destroyed long ago. Hopefully, regional sediment bodies will prove an exception (cf. Embleton in Green et al., in press).

24.5.2. Speleothems

Major speleothems in growth position are comparatively rare at Pontnewydd and most of these have been dated by radiometric methods (cf. various contributions in Green et al., in press). D(E):1 was clearly in place (dates D188:226a1). The heterogeneous speleothem B(W):2 (date B274) was in place and contained material referred to UBb cemented into its base, although there was clear disturbance of the UBb surface and there may well be a diastem at this point. The stalagmite D(N):4 (dates D534) was also convincingly in situ (cf. p.1143). The stalagmitic boss C:4 (dates C0:78852 and C133) was disturbed but appeared to be approximately in situ from a stratigraphic point of view (cf. p.1139). The boss D(S):4 (date D604) was at a unit boundary but was not cemented into the underlying LBb (cf. p.1143). Thin spreads of stalagmite and an occurrence of dripstone, D(C):4, were in situ but have not been dated. Other dated speleothems recorded

as having been in situ, or possibly in situ, were not observed by the author.

A large number of radiometric dates have been produced from speleothem fragments contained within the deposits. No lithologic data is available concerning the possible number of generations of speleothems thus represented. The clasts of STAL.X(EP) almost certainly represent a single formation, as do those of B:7, the latter being the only material that the author has been able to examine in detail.

The environmental implications of major speleothems are discussed in Chapter 13 of the present text.

24.5.3. Debris Flow

The mechanisms of debris flow have been discussed in section 9.4. (p.371) of the present text. The implications of this discussion for the study of the Pontnewydd sediments are many. First, it is clear that nowhere in the deposits are slopes sufficiently high to initiate debris flow. Although it is difficult to assess overall slope in these fragmented exposures, most bedding angles seem to lie between 2° and 5°, dipping into the cave. It is therefore necessary to suggest source areas for all the flows that lay at relatively high altitudes, most probably equal to or greater than the height of the cave roof at the present entrance, and this at a very conservative estimate. Source areas might have been provided by steep surface slopes, by some near vertical cavity in the cave system itself which has since been destroyed, or by some sort of piping or failure of major valley fill (e.g. till, with or without overlying ice) which had previously buried the cave mouth.

Once a flow had penetrated the extant areas of the cave, it is difficult to see why it should stop until it was forced to do so by cave topography. Note that debris flow possesses not only momentum but also limited cohesive strength, allowing it to override minor obstacles (cf. the effect of DPS:14 on later flows). In that a flow would tend to lose water to well below the critical level only when it had already reached stability within the local topography, it follows that it could never later be remobilised as a flow without massive erosion to re-establish high gradients. We might therefore expect flows to be represented as generally tabular bodies of sediment. Making due allowance for any later removal, this is exactly what is observed in LBB and UBB as they are defined above. Any other correlation scheme requires flows to change thickness radically with no apparent external influence: the physics of such a situation are difficult to visualise. Furthermore, had a flow in fact been arrested for any reason within the excavated areas, we would expect to find a well characterised armoured snout; such features would appear to be absent.

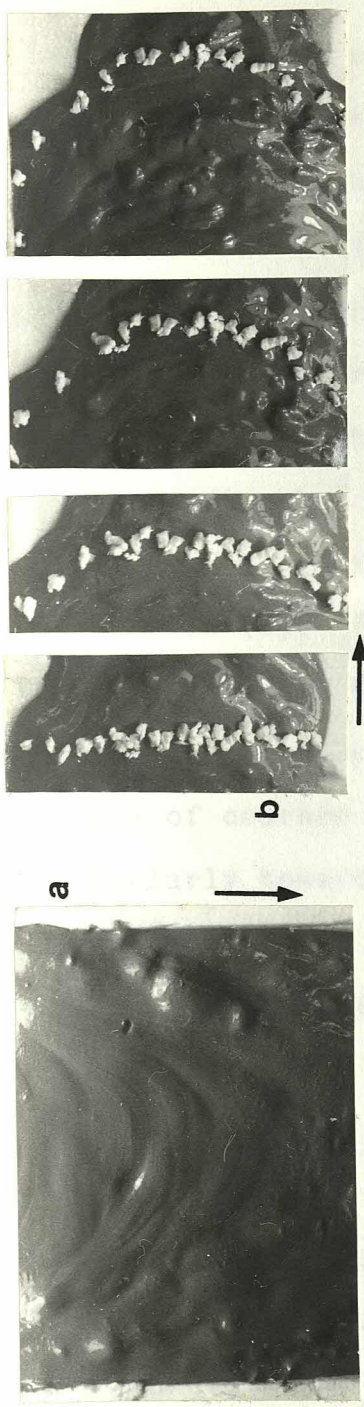
It was noted in section 9.4. that channelled debris flow is often erosive. That this is also true of the Pontnewydd material is indicated by several different observations. First, debris flow deposits, though generally tabular, may also be seen to occupy localised channels in underlying sediments; this is particularly clear in Area D(C). That these channels are not wholly the result of earlier erosion by running water is suggested by the lack of sediments and alteration phenomena characteristic of fluvial processes immediately below debris flow material within the Cm sequence, and also by the survival of 'vulnerable' deposits, such as Sb, perched on top of the channel banks. Several

units interpreted as debris flows, such as some of the components of Ic, are only 10-20cm thick. Although precise quantification would be necessary to prove the point, it would seem highly likely that such thicknesses are well below the critical thickness for flow in such coarse deposits at these low angles of slope. Much sediment must therefore have been eroded even when channelling is not obvious. There is a series of quite continuous lithologic gradients, starting with the highest lithozones of Sm and passing upwards through the Cm sequence: (a) limestone particles become increasingly common upwards; (b) siliceous pebbles become decreasingly common upwards; (c) siltstone and mudstone pebbles become increasingly fractured upwards; (d) non-carbonate sand becomes increasingly finer upwards; (e) silt and carbonate fine sand become increasingly common upwards; (f) organic matter, usually very rich in Ic, becomes increasingly rarer in the deposits above (cf. figs. 94 - 100). Although these trends are undoubtedly reinforced by changes in primary sediment source through time, operating to the west of the excavated areas, the smooth persistence of the trends is most efficiently explained by reworking of material from old debris flows by each new one. Indeed, LBB in Area D(C) contains small discrete pockets of the underlying Ic sediments. The fact that flame structures, plications or push features have not been recorded in the present exposures may indicate that sediments underlying each new flow did not themselves become fluidised, thus underlining the importance of an initial steep slope. Should such 'plastic' features be found in the future, they would probably indicate that the deformed flow was still fluid and that it had occurred only very shortly before the overlying flow. Note that it would seem unlikely that much coarse debris was contributed from the walls

and roof of the cave in the immediate vicinity of the excavations. There are no major rubble cones or large blocks of limestone and no obvious feeder chimneys. The placement of ancient stalagmites under extant prominent rock pendants argues for long term stability of the roof.

Apart from the observation that debris flows may transport fragile objects without damage, there has been little consideration of how included coarser particles could be modified. Pebble fracturing (cf. fig.100) is here considered to be the result of point loading, torsion or even impact, situations which might be expected to arise quite regularly in debris flows of this type (cf. Currant in Green et al., in press, where the condition of larger bones is discussed; also p.577 of the present text). Mechanical rounding should be restricted to vulnerable edges. At this site, highly rounded and spherical stalagmite fragments and limestone particles are primarily the result of postdepositional alteration (infra). Transport of already altered material by debris flow should result in differential preservation, with most smaller particles being crushed to fine sediment and only larger spherical cobbles surviving (cf. p.356); no trace of any such deposit has been observed at Pontnewydd.

There has been little opportunity for the author to study the internal organisation of each debris flow. However, sorting of the type recognised in open sites has obviously been in operation. It is most probable that future quantification of spatial trends in shape, size, orientation and damage of sediment particles, bones and artefacts could be related to local details of flow regime and cave morphology. The general sorting trend already explains why the apparently unpromising remnants of sediment, left by earlier excavators against the walls and in



(a) Flow in motion seen from above. (b) Progressive distortion of a line of polystyrene chips floating on the flow surface. (c) Long sections of arrested flow. (d) Cross-sections of arrested flow. Arrows indicate direction of flow; flow towards observer in d (left), away in d (right).

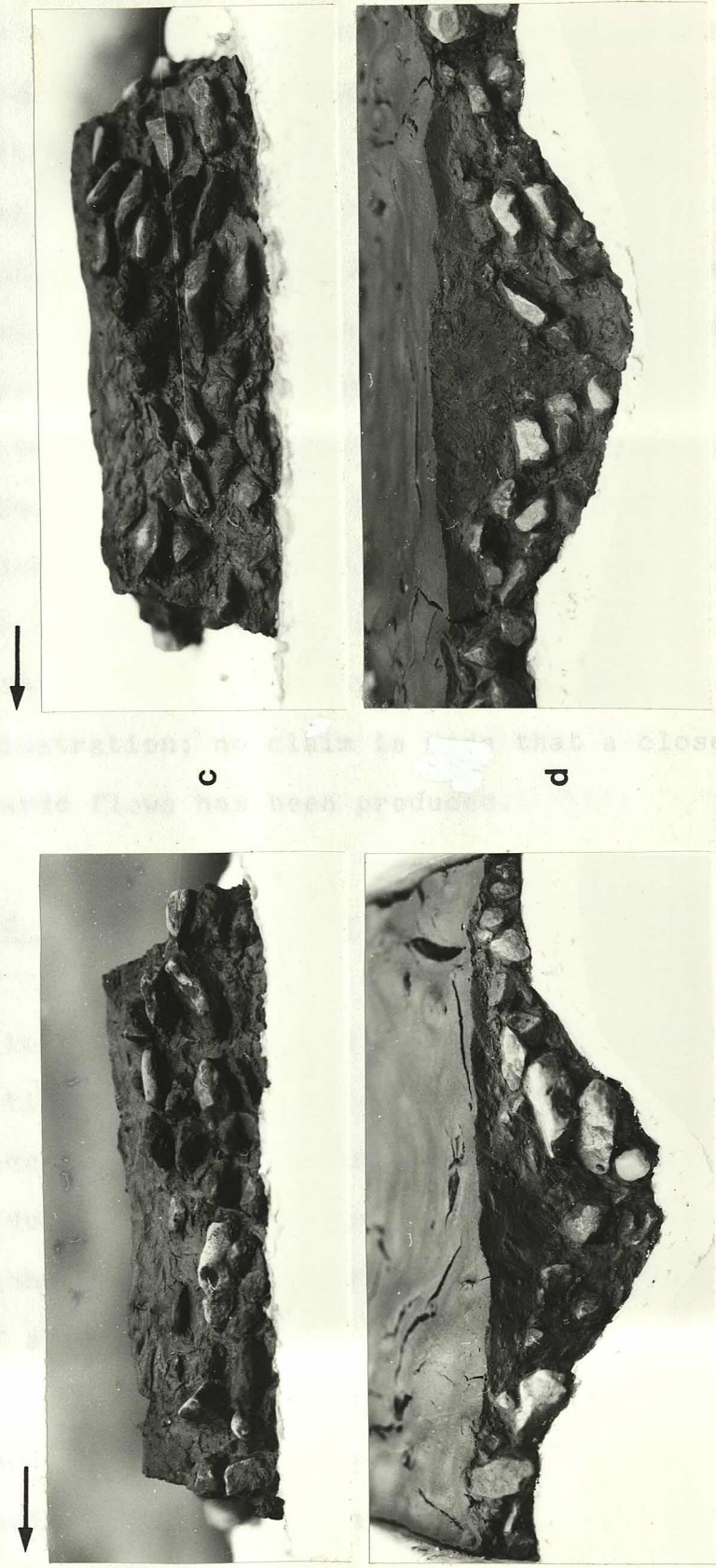


Fig. 101 Pontnewydd Cave - Experimental Debris Flow

small side passages, have proved to be so rich in large artefacts. The scope for an integrated taphonomic approach is substantial. Indeed, unless such an approach is implemented, the understanding of the Pontnewydd sediments, fauna and especially artefacts will remain on a very primitive level.

Fig.101 represents 'experimental' debris flow produced in the laboratory with material of UBb from Area D(C). Particles of over 15mm diameter have been removed in order to scale down the flow. The velocity profile and lateral sorting are already apparent in (a). The velocity profile is more clearly shown in (b). The tendency towards bedding parallel to the basal surface is seen in the long sections of (c). The cross-sections of (d) show sorting of coarser particles towards the flow boundaries and particularly towards the outer edges. This material merely provides a graphic illustration; no claim is made that a close analogy to the Pontnewydd flows has been produced.

24.5.4. Diagenesis and Carbonate Mobility

The presence in caves of deposits cemented by carbonates is commonplace; traditionally, though often rather inaccurately, such deposits have been called 'cave breccias'. They are usually interpreted as being due to postdepositional changes under warm, damp climatic conditions (cf. Chapter 12), a proposition which is readily defensible if a vertical gradient has developed, suggesting strong leaching and/or input of carbonate-rich water. However, some cave deposits show lateral gradients in cementation, or no significant gradient at all, and may be well beyond the reach of large quantities of aggressive water, as at Pontnewydd. Furthermore, there is a marked tendency in Europe for older

deposits to be more highly cemented than younger ones under similar topographic conditions. This would suggest that more complex processes may sometimes be involved rather than a single phase of postdepositional cementation under climatic control.

First, it should be noted that the Pontnewydd sediments do in fact show one type of sub-surface carbonate deposition which is definitely under direct climatic control. The deposits of both UCSb and RCEb contain quite abundant crystalline dendritic concretions that are obviously rhizoliths (both mould and cast types). Indeed, roots, sometimes still alive, have been observed in association with these concretions even in the East Passage. Modern roots were common in the disturbed material and tip which covered the sections of in situ deposits before the present excavations. However, rhizoliths have never led to even partial consolidation of the deposits. The presence of rhizoliths naturally implies the growth of plants on the immediately overlying land surface. The present author would further suggest that rhizoliths so far into a system imply trees in the surrounding landscape; this suggestion could be checked either by following the root systems (which would normally be very difficult) or by applying a substance to living roots which would have a physiological effect (preferably a temporary one) on the source plants. There are no zones with rhizoliths that can be referred to periods of formation significantly older than the Holocene at Pontnewydd.

When considering cemented sediments within a limestone cave, it is always necessary to take into account the possibility of both external and internal sources for the carbonate cement. The former involves the penetration of carbonate-rich water, whilst the latter involves the penetration, or development within

the deposit, of aggressive water which will mobilise existing carbonates. In practice, the same water may fluctuate between an aggressive and a non-aggressive state very rapidly and over very short distances (cf. Chapter 12). Since it may be argued that DPS:14 is unlikely to have had a significant original limestone content (cf. p.1194), it will be best to start the discussion with that deposit, although the accuracy of this assumption makes little difference to the argument presented here.

DPS:14 consists of pebbles that are supported in a matrix of coarse siliceous sand and clay, the whole being massively cemented, mostly by carbonates. Such a deposit would not be expected to have contained large primary voids, yet DPS:14 now has irregular and abundant vugs up to 5mm across, indicating that fines have been removed. The vugs are lined with drusy calcite crystals that may either show good euhedral development of the free faces or, in other zones, smooth hummocky surfaces. Sand grains, small pebbles and etched calcite crystals often float in younger clear calcite. Some vugs are partially filled with uncemented fine sand and silt. There are even tortuous vugs developed along the contacts between large calcite crystals. In some zones there are scalenohedral crystals up to 5mm long, whilst elsewhere there are patches of white, friable calcite. No hypothesis that does not involve major and recurrent remobilisation of carbonates can account for all these features.

Carbonate particles in Ic are heavily altered, whilst those in overlying units are progressively less so. Limestone clasts may be reduced to a fragile cryptocrystalline skeleton with very high porosity. Fragments of stalagmite may be vuggy, but more commonly regular porosity, at right angles to the bedding, has developed along contacts between the original prismatic

crystals. Voids are usually still open but there are varying amounts of more or less crystalline cement with common impurities. There are also frequent patches of coarse crystalline mosaic, which could be truly neomorphic but which are beyond doubt primarily authigenic. Some fragments of speleothem have been completely reduced to a fragile, biscuity consistency.

Mass cementation at Pontnewydd is usually most highly developed near the cave walls, reflecting the control over drainage exercised by the bedrock morphology. Note especially the smoothly vaulted roof which favours sheet flow rather than drip. Much external carbonate could be introduced into the deposits with this water. However, even ignoring the alteration of carbonate particles noted above, the fact that most units of Ic, with very low carbonate content, are much more weakly cemented than LBb, with a higher but often only slightly less altered limestone content, indicates that internal carbonates have contributed significantly to the cement. Note that the unusually high level of alteration seen in all the Area C deposits is probably due to the fact that they are blocking what may be an important drainage channel.

The question now arises as to how water may become aggressive in such an environment. Only when water penetrates very rapidly from the land surface in the form of stream flow might some significant corrosive potential be maintained (cf. Pan lithozone). Otherwise, it is necessary to invoke those processes mentioned in Chapter 12, all operating on the scale of individual pores and over very considerable lengths of time. This is diagenesis rather than 'weathering'. The overall process may accelerate, slow or change emphasis according to prevailing climate, but it is essentially a continuous modification of the

geochemistry of the cave deposits. As a general statement, it may be said that only the silicates approximate to closed systems under such conditions.

The reader might like to consider the implications that such diagenesis might have in connection with the radiometric dating of speleothems. The fact that the author has so frequently observed unequivocal proof of carbonate remobilisation at all levels within the Pontnewydd sequence is the reason why he is so insistent upon the need for double-checking using parameters that would not be similarly affected by alteration (cf. p.1212).

24.6. Development of the Pontnewydd Sequence

24.6.1. The Siliceous member

The gravels and coarser sands of these deposits consist of various siliceous rocks which are foreign to the hard-rock basement of the Pontnewydd area. Texturally, the majority of these larger particles are siltstones and mudstones, with similar mechanical properties, but other types, including some crystalline rocks, also occur. Rocks of this general character are still common in the modern Elwy and are also present in the sediments of the valley slopes. Their petrology and ultimate source are discussed by Bevins (in Green et al., in press) but it is clear that a powerful transport medium would have been necessary to bring them to the vicinity of the cave. It seems most likely that glacial transport was involved (cf. Bull, Embleton and Bevins in Green et al., in press), though it is uncertain how much fluvial modification occurred before emplacement in the cave. These are quite soft rocks but none of the stigmata (striae, edge-snubbing,

etc.) usually associated with glacial action have been observed on material from the cave. It would be interesting to see whether a good sample of the rarer but harder rock types show such stigmata. Overall pebble shape is wholly controlled by the bedding planes in the siltstone and mudstone; in these deposits, and also higher in the sequence, discoidal and ellipsoidal forms, with their main development parallel to the bedding, are always dominant. That some fluvial modification has indeed taken place is indicated by the relatively common wear cupules (not observed in associated pairs) which are probably the result of trapped, but not totally immobilised pebbles rubbing against each other in a fluid medium.

The mode of emplacement of these deposits appears quite variable. Many of the finer beds are indicative of flowing water, although they are never as well sorted as the deposits of average surface streams. The apparent lack of current-induced structures, such as cross-bedding and cut-and-fill structures, would seem to indicate that efficient and persistent flow, involving delicate equilibria, was not achieved. The relatively high colloid content of these beds is of interest (cf. fig. 99) since the colloids are not present as discrete laminae but are distributed throughout the sediment. The finest beds, such as DPS:2, are silty and very badly sorted, suggesting settling in still water.

The coarse gravel beds, which make up the bulk of this member, are obviously not the product of an efficient stream. Sorting in these beds is extremely poor and irregular. However, they are not purely dry collapse deposits, since they are often bedded and may show imbrication. There is again a high colloid content, with colloids most apparent on the undersides of pebbles. Bull (pers.comm.) has pointed out that this feature is referable

to clay rafting, often seen in debris flows. However, there are also lesser amounts of colloids all over the pebbles, sometimes forming a very thin but continuous 'skin'. Given the probable antiquity of the deposits and the texture of the component rocks, liberation of fines from the rocks themselves cannot be ruled out as a source for at least part of the colloid content, both of the gravels and, indeed, of the finer beds. On the other hand, many beds show a degree of matrix support for the coarser elements that most certainly cannot be accounted for by such alteration products.

Whatever the exact mechanisms responsible for the emplacement of this material, they do not appear to have been particularly violent or disruptive. Samples of siltstone and mudstone pebbles (8-16mm) have been extracted from several beds in this member and compared with very similar material from the modern Elwy (PN 231). Particular attention was paid to pebbles fractured across bedding planes. These were counted, care being taken to eliminate the rare fresh breaks which may have occurred during sampling. Figures for LSGs and USGs are not significantly higher than those for the Elwy (cf. fig.100), suggesting that emplacement was still a fluid process with little confined rotation and crushing. Note that fracturing due to alteration and compaction, observed in some pebbles at the base of DPS:13 against the bedrock, is quite different, producing splitting along bedding planes, crazing and very blocky break surfaces.

From the above discussion, it would appear that inefficient stream flow and ponding played some part in the development of Sm. However, the bulk of the deposits are referable to debris flows of relatively low viscosity. It was suggested in Chapter 9 (p.376) that imbricate structures might

reflect the 'muddy water' phase often associated with such flows; the structures also indicate that flow, in USGs, was towards the east into the cave. Note that the structures mentioned here are clear trains of similarly sized pebbles, the nose of one lying upon (touching) the tail of another; the term 'imbrication' is not used to cover a general oblique trend in the orientation of clasts, a fabric which, unlike the true imbricate structures, the author would not consider to be necessarily current-induced. It is even possible that sediments showing good graded bedding may indicate subaqueous debris flows that have briefly attained sufficient velocity to act as miniature 'turbidity currents'. The restricted exposures of the Sm sediments exclude discussion of deposit geometry and the erosive power of the flows.

When comparing LSGs and USGs, it can be seen that the beds of the former are slightly more organised, although the extremely small exposure calls for caution. It is possible that LSGs represents more efficient stream action with fewer debris flow events. The character which served to establish the unit (submember) differentiation is the presence of several horizons of strong carbonate deposition in LSGs, whilst carbonates are usually totally absent in USGs away from the cave walls. It is clear that sedimentation in LSGs was interrupted by at least two periods of quiescence, during which carbonates and associated metallic oxides and hydroxides could be precipitated. If DPS:14 is indeed in stratigraphic order, and is not a much older deposit (there are no obvious lithologic characters which set it apart from the other beds of LSGs), then the last event evidenced in this unit is another, more massive cementation phase which would probably have taken a relatively long time. Note, in passing, that this deposit shows strong near-vertical orientation of pebbles,

probably indicating extremely viscous flow or even wet collapse. The outer form of the deposit is almost certainly due to later erosion. The total lack of limestone particles or ghosts, coupled with the coarseness of the quartzitic sands (the limestone insoluble residue contains mostly fine sand and silt; cf. fig.97), indicate that this cementation is unlikely to have been merely an authigenic effect. In any case, DPS:14 must have been already cemented in order to resist the influx of USGs. Finer beds of UGSs fill channels around the mass of DPS:14 and several of the coarser beds override it. It is interesting that the only bed in USGs which contains carbonates, not apparently derived from the deposits above or from the walls, is DPS:2. This is a deposit that formed by settling under quiet conditions when some carbonates could be trapped. The obvious overall inference is that USGs represents a more continuous and probably a more rapid accumulation than LSGs.

The available evidence is not sufficient to determine whether there is any climatic significance in the change of sedimentation pattern between LSGs and USGs. The difference could be due to very localised topographic mechanisms. However, the low organic content of Sm as a whole (less than 0.2% in the fraction below 1mm) would indicate that a closed vegetation cover was not present in the vicinity of the cave at any time during the deposition of these beds.

One further point is worthy of discussion. The absence of limestone particles in these deposits as a whole is rather puzzling. Not only are clasts absent but so too are the dark, sticky ghosts that usually survive in ancient gravelly deposits in caves (e.g. the lower levels of Joint Mitnor Cave, p.805). Total removal of all traces of limestone would seem highly

unlikely, especially since those units which show good bedding have never been observed to display the sort of disruption one would expect to see after patchy loss of volume. Note that two limestone blocks, c.15cm thick, were in fact found well into Sm towards the north side of the Deep Sounding. They appeared to have fallen from the nearby channel walls; one of them had a sculpted surface. They were corroded but by no means totally unsound, requiring a lump hammer to break them. It would seem that this member never contained limestone. Yet there is a major rockface above the cave. The sediments of Sm cannot therefore have been derived from any surface deposit (till, terrace material, etc.) that lay exposed for long with its upper surface near the level of the cave entrance. There would seem to be three possible explanations: (a) more or less pure exotic sediment was introduced into some part of the cave system west of the study areas very shortly after it arrived in the vicinity and before it could be polluted with limestone from the cliffs and slopes above; (b) exotic sediment was introduced via vertical cavities directly from the plateau above, where there were no cliffs in a position to supply limestone; (c) the sediments were derived from within a thick exotic sediment body that choked the valley to well above the level of the cave. These suggestions are similar to those put forward during the discussion of initial slope requirements for debris flows (p.1181). If major fluvial deposits are envisaged as the immediate source of the Sm sediments under (a) above, it should be remembered that even the modern Elwy, in the present period of comparatively low scree production, contains significant quantities of limestone. Therefore, for this hypothesis to be tenable, it must be supported by an explanation for the lack of limestone in the cave deposits. The author is unable to suggest

such an explanation, except perhaps in a glacial context, involving subglacial or englacial streams, or possibly supraglacial or proximal proglacial streams (given that only very fresh rock surfaces, with little or no regolith, were available due to immediately subsequent glacial scouring).

24.6.2. The Intermediate complex

It has already been stated that the sediments grouped into this complex are extremely heterogeneous and fragmented. If the information base improves in the future, it is possible that some units may be reallocated, or that more coherent subsequences may be recognised in some Areas. Nevertheless, the complex is justifiable on lithogenetic grounds, both because the components contain the first traces of sediment derived from a strictly local source and because it is desirable to maintain the integrity of the overlying LBB as a single sedimentary event.

B/C:2 and D:8 represent modified sediments which, at least in their pebble and sand components, generally resemble some beds of USGs (such as B/C:3), beds from which they were probably in part derived. Sorting is even worse than in USGs, large pebbles (over 32mm) are rare or absent and there is a general increase in pebble fracturing. The major difference between these deposits and USGs lies in the important organic and carbonate contents of the former. The organic matter is present as dark, amorphous coatings on mineral particles, often associated with considerable quantities of sesquioxides. The term 'sesquioxide' is used here, as elsewhere in this chapter, to refer to material in which at least iron and manganese have been detected; the exact structure of these minerals has not yet been

studied and it is likely that complicated oxides and hydrates are in fact involved. (The same is true of the term 'FeMnAl oxides'.) In B/C:2, the high carbonate content is distributed throughout the sediment with little structure; there are some highly altered carbonate sand grains which may be particulate in nature rather than precipitational. In D:8, much of the carbonate is highly organised into 'fish scales' lying horizontally in the sediments; these forms grade into a few larger plaques of carbonate, up to 10mm long and 2mm thick. All these carbonates are heavily corroded. Organic matter and sesquioxides are associated with the carbonates, but they are always richest at the top surface and decrease down into the body of the carbonate particle, suggesting that the association is at least partly due to infiltration. Just how these 'fish scales' formed is not yet clear. They are generally too bulky to represent calcite rafts originating on a still water surface. They could possibly be the reworked remains of thin rimstone, but their good horizontal development, within a deposit that almost certainly represents minor debris flow and which itself is not particularly well bedded, favours a postdepositional origin. It is possible that they were precipitated from fluctuating carbonate-rich waters, which periodically saturated the sediments but never actually overlaid them as a free body (cf. the absence of cap sediments deposited in water, but note the possible erosive power of overlying debris flows). In these two Areas, organic matter and carbonates have often penetrated the top of the underlying USGs deposits, so that it may be difficult to define an exact boundary (cf. D(C) in particular). Note also the staining in Area C.

In Area D(C), the deposits of D:7 directly overlie the sediments described above. Much material has been reworked from

D:8 but there is also a small, though significant, content of highly corroded limestone particles, some of them quite large (c.5cm). Note also the important bone component and the fact that this appears to be the oldest unit containing artefacts and human remains. The unit occupies a wide and very shallow trough which is probably erosional, but there is no true channelling of the underlying sediments. Again, this is a minor debris flow which is, in its own right, lithologically intermediate between D:8 and LBb in this Area.

In Area B, the situation is rather different. B:8 contains a few altered limestone particles, moderate quantities of finer carbonates and some bone material. The sand and gravel contents resemble those of USGs in this Area, although the pebbles are significantly more fractured. However, for some reason, either locational or temporal, there was no input of organic matter or sesquioxides. From what little can be seen of its geometry, it is possible that this bed represents a lateral debris flow, associated with the South Fissure and channelling the underlying USGs (a possibility which would explain the difficulty with PN 11, noted on p.1136). Fabric studies will be necessary to confirm this suggestion. The blocks of stalagmite, which constitute B:7, were almost certainly derived from a major travertine floor, but all that can be deduced from their present stratigraphic position is that they must have been formed prior to the emplacement of LBb. It is interesting that this stalagmite contains significant quantities of organic matter, on average c.1.0%. Although the stalagmite is badly corroded, showing orthogonal development of secondary porosity with respect to the bedding, the organics are not located in the pores but are stratified in very thin spreads between laminae of calcite. This

organic matter is certainly syndepositional with the calcite. The organic content of other major speleothems in the cave has not yet been measured, although a sample recently analysed by the author, said to be derived from an in situ floor remnant stratified above LBb in Area D(E) (pers.comm. Green; unseen by the present author), contained no measurable organics. Note that, in all Areas other than B, LBb contains small fragments of stalagmite but never anything like the concentration seen in B:7.

Lithozones 4 and 3 of Area GC(S) have not yet been studied in detail. GC(S):4 probably represents a decomposed speleothem. It is not clear how these two deposits may relate to the other units of Ic.

Attempting to interpret this complex may be somewhat premature. However, merely as a working hypothesis, it is suggested that the influence of an interglacial, or at least a major interstadial, is present. The inference is drawn solely on the association of organic matter and carbonate precipitation, an association which implies the presence of soils and vegetation in the vicinity of the cave. Such high levels of organics in non-fluvial sediments have only been observed by the author in certainly, or most probably, interglacial cave sites in this country, for instance, in the Hyaena Stratum at Tornewton Cave (p.714), in the talus cone (K lithozone) at Joint Mitnor Cave (p.101) and in Unit III at Sun Hole (p.921). As at Pontnewydd, the organics are always present as amorphous coatings on sand grains or in association with calcite or phosphates. The absolute levels of organics at Pontnewydd are similar to the maxima reported by Jefferson (1976) from modern cave sediments in South Wales. Jenkins (in Green et al., in press) has indicated the presence of weathered minerals in the Intermediate complex, although Bull

(ibid.) has not recognised any strong pedogenic features on the quartz grains (SEM analysis).

Beyond this hypothesis, it may be said that the sediments of Ic show signs of a complicated series of events, including debris flows. Unfortunately, the present restricted and fragmented exposures are not sufficient to clarify the matter further.

24.6.3. The Lower Breccia bed

That some local material was already reaching the study areas from the direction of the cave entrance during some part of the deposition of Ic is evidenced by the inclusion of small quantities of limestone. The major debris flow of LBb continues this trend, the deposit having a higher and more evenly distributed limestone content. Other trends are also continued, such as increased pebble fracturing. A particularly pebbly facies of this unit, D:5, could possibly represent a separate (younger) flow, but it would appear more likely that it is the result of the collapse of a coarse remnant of Ic or USGs onto the surface of the main flow while the latter was in motion. Partial integrity would be maintained by differential shear as long as flow remained more or less laminar (cf. p.377). The fine matrix of D:5 is almost identical to that of D:6. In Area D(C), LBb occupies a wide trough, as does Ic below it, but the trough is deeper, showing a tendency towards true channelling. Although not particularly marked, there is also a suggestion that some large particles have been displaced towards the cave walls.

The environmental implications of LBb are obscure. The scale of the debris flow is quite impressive. The portion removed by the various excavations alone totals some 55m³ at a conservative

estimate, and the whole flow may have originally been an order of magnitude or more larger. The drop in the organic content of this unit compared with Ic is quite marked. There is no evidence for a fresh influx of organic matter and the moderately rich organics that do exist could easily have been derived from sediments reworked from Ic or from the main source of Ic. These two factors might imply conditions cooler than full interglacial but, without exact knowledge concerning the morphology of the cave entrance and of the source sediment bodies, such factors could be misleading.

24.6.4. The Stalagmite lithozone and Silt beds

At some time after the emplacement of LBB, stalagmites began to grow on its surface wherever the roof morphology was favourable. Radiometric dating of speleothems suggests that this process took place over tens of thousands of years, though not necessarily continuously. The shape of the stalagmite D(N):4 suggests that speleothem formation was waning at that point, although this may have happened at some time within this lengthy chronozone rather than at its end. That so little sedimentation occurred over such a long period can only be explained by assuming that this part of the cave was almost totally sealed off from more active areas, and especially from the land surface. Indeed, the stalagmites themselves suggest a relatively isolated cave environment. Schwarcz (in Green et al., in press) has produced some oxygen isotope data on one occurrence of this material.

Certainly towards the back of the cave, but probably rather further west than the extant exposures, a large pool formed in which badly sorted fine sand and silt settled. These sediments are rhythmites but further study will be necessary to ascertain

whether there is likely to be any regular periodicity. Carbonate precipitation continued, at least during the earlier stages of pool sedimentation, and is represented by thin stalagmite laminae interstratified with Sb.

The sediments of Sb need have no climatic implications. From the point of view of overall particle size, the material could easily have been derived from existing deposits by elutriation. However, Carrant (Green & Carrant 1982) has recorded a new fauna, Bull (in Green et al., in press) a new quartz grain suite and Jenkins (ibid.) a degree of mineral freshness from these beds, all of which would indicate 'cold' conditions. If these authors are satisfied that the new material represents a direct link with the contemporary surface environment, and not just reworking of older sediments stored somewhere in the system, the fact that Sb has a low organic content may be significant. It will obviously be informative to examine stratified subsamples of Sb in order to identify any temporal trends. Such an examination would have guaranteed interesting results, since it should be possible to prove one of the following hypotheses: (a) the 'cold' elements represent an older, reworked component; (b) the 'cold' elements represent a contemporary element but the unit as a whole represents a (very rare) example of the transition from 'warm' to 'cold' conditions; (c) the 'cold' elements represent a contemporary element and the basal stalagmite also formed under 'cold' conditions. Horizontal variation in particle size or composition, or in the thickness of laminations, might indicate the direction of the source(s). At present, there is no evidence to reconstruct the direction of water flow.

24.6.5. The Upper Breccia bed

This unit represents the best preserved debris flow yet examined. It also shows the most developed structure, including many of the features noted in the survey of the literature on this subject in Chapter 9. There is marked lateral sorting of both coarser elements and platy or elongate elements. The latter types would not present any great obstacle to coherent movement in a laminar flow but, as has already been noted (p.375), larger particles in a debris flow tend to rotate about an axis at right angles to the flow direction; flatter particles would therefore produce considerable resistance, and would be sorted to the sides. The central region (in D(C)) is composed almost exclusively of small, compact limestone clasts floating in the fine matrix. In Area D(C), the flow occupies a channel, c.50cm deeper than the normal tabular occurrences and c.175cm across, situated roughly in the middle of the chamber along the same vertical axis as the troughs occupied by LBb and Ic. The nature of the substratum seems to have had little effect upon the erosive power of the flow; in places the uncemented silts of Sb are intact, whilst in others UBb has cut deeply into the coarser material of LBb. Channelling has occurred beneath the centre of the flow simply because the flow velocity was greatest along this axis. In Area B, the flow has eroded underlying deposits right across the Fissure, and at a relatively steep angle, suggesting not only that the constriction caused the flow to 'bite' deeper, but also that there was a significant increase in gradient towards the south. It seems possible that UBb, with its greater organisation, may have been a more fluid and plastic event than LBb or the components of Ic. Given the relatively fine nature of the matrix in the centre of UBb, the

author would expect fluid escape structures to be present, structures that would be difficult to recognise unless horizontal sections were carefully cleaned with this possibility in mind.

This deposit contains a much higher proportion of limestone fragments than the units beneath it. C:3 and the base of D:2 have very high fine sand and silt contents, material clearly derived from reworking of Sb. However, the matrix of UBb is generally very much finer than that of LBb, even in Area B which may have been 'upstream' of the pool. Limestone clasts in a matrix of such fine material would form a typical cold climate entrance facies.

24.6.6. The Red Cave Earth bed

Sadly, this unit is only present as an extremely restricted deposit in Area B (cf. p.580). It is exactly the sort of entrance facies sediment referred to above. That its present position is again due to debris flow, or perhaps to slightly slower mass movement, is shown by the rare fractured siliceous pebbles and by the rounded edges of the otherwise unaltered and angular limestone clasts. The deposit is also very dense despite its lack of cementation. The matrix is so rich in silt (cf. fig. 99) that there is a good possibility of an aeolian source. The insoluble residue of the local limestone has a similar particle size distribution and many of the extant slope deposits in the Pontnewydd area have high silt contents. The silts in RCEb are probably extremely local wind sorted material rather than sediments of any regional importance.

The lack of cementation and alteration in RCEb is of interest, especially since the exposure is very close to the cave

wall. It seems highly unlikely that the cave could have remained generally dry after the emplacement of RCEb if this unit is of any great antiquity. Bull (pers.comm.) has remarked upon the apparent absence of desiccation cracks throughout the deposits. When organised samples of any of the deposits are removed from the cave, they crack within hours. Some shrinkage may have helped to open up the gaps between the stratified deposits and the walls, gaps which are now full of younger sediments, but preferential drainage is much more likely to have been responsible for the main development of these features. It is therefore inferred that RCEb is significantly younger than UBb and, furthermore, that it is a relatively recent deposit.

24.6.7. The Upper Deposits

The Pan lithozone, Upper Clay and Sand beds, Laminated Travertine lithozone and the Earthy lithozone form a sequence that is extremely common in British caves. Even the nearby Cae Gwynn Cave seems to have contained a similar sequence (cf. p.1109). The basic mechanisms of reactivation have been discussed at several points in the present text (cf. section 1.4. and Chapter 10). The general model is as follows.

During a glaciation, permafrost, or even actual ice-sheets and their associated basement till, seal off the influent sections of a cave system. Water, which would normally be quickly absorbed into fissures and sink-holes, flows overland. Major influent systems are rapidly blocked by mass movement of various types. What little water that still penetrates the cave can only carry the finest material, sediment which is quickly deposited, clogging the formerly active drainage system. When the permafrost breaks

down, for example near the end of a glaciation, masses of water are released, pushing sediment chokes deeper into the system. In order to re-establish the old drainage pattern and equilibrium with the local geomorphology, streams must excavate down through the choked conduits, much as surface streams must clear their choked valleys. This will be quite a lengthy process. In the mean time, streams will flow out to the surface through high, previously long abandoned sections of the system. Even if deep conduits are in fact open, the vadose zone may remain 'perched' if valleys are still buried under relatively impermeable sediments.

This is clearly what has happened at Pontnewydd. At the onset of stream flow (in this particular section of the cave), the immediately subjacent deposits were violently altered (Pl), a process which was quickly inhibited by the deposition of clays by the stream itself (cf. D(E):4). The presence of clay pellets shows that the stream was eroding existing clayey deposits and that it was probably rather more energetic than the particle size distribution would at first suggest. That this phase of sedimentation was quite rapid is shown by the later contortion of these clays, which probably resulted through loading of originally badly compacted material. Had the majority of the older deposits not been cemented, much more considerable erosion might have occurred. It is not clear whether the stream flowed right out of the present entrance, but it certainly flowed at some time into the South Fissure, removing all but the threshold occurrence of the uncemented RCEb. The thin veneer of GC(S):1 appears to have been affected by infiltration of fines from above (cf. p.1170); the possibility of outflow through the present entrance should be checked by a search for pollution of GC(S):1 by the rich and characteristic fauna of UCSb. No fine stream deposits or

water-worn rock surfaces have been encountered on the rock platform outside the cave. As stream flow became more efficient, and perhaps as new source sediments were reached, sand sized and larger material began to arrive in the study areas (cf. D(E):3). The presence of only superficially altered, angular limestone particles, both as sand and fine gravel, indicates that the stream was downcutting through immature sediments somewhere further back in the system. When some of the water began to find an outlet at a lower level, stream flow in the study areas became sporadic, with the deposition of more clay as flow waned (cf. D(E):2). Between flows, thin stalagmite laminae were precipitated, formations which became thicker as water flow became rarer. Eventually, flow ceased altogether and a thick travertine was formed (LT1). The presence of E1 in the cave probably indicates that, by that time, a nearby entrance was open, allowing the accumulation of organics and earthy material, washed and blown in or brought in by animals.

The general lack of diagenesis in these deposits would indicate that the period covered was the end of the last glaciation and the present interglacial. However, Currant (in Green et al., in press) has noted that at least the upper, sandier portion of the UCSb contains a holocene fauna, allowing a more precise dating of these events. In the present author's opinion, this fauna is in no way at odds with the general model set out above. The study areas represent only a tiny part of the local karstic system. The rock massif in which Pontnewydd Cave is developed is not particularly broad in terms of rainfall catchment so that, if the karst was not sufficiently well flushed by the initial general thaw at the end of the glaciation, little water would be available to continue the process. Alternatively, the specific reactivation of the study areas might have been the

result of a local collapse of older material, that had previously been bypassed by flushing, a collapse that did not occur until the beginning of the Holocene. The general model is valid but the faunal details show, once again, that one must not overinterpret water-laid sediments in restricted exposures. In this case, the sediments themselves do not give precise data pertaining to the dating of the reactivation event.

24.7. Pontnewydd Cave - Discussion

The following discussion concerns certain stratigraphic and contextual aspects of the sequence at Pontnewydd that are best seen in the light of a combination of data provided by the various specialists who have worked at this site.

The case for the present lithologic correlation of the deposits has been argued in detail above. Inference concerning the lithogenesis of each deposit supports this correlation. If the discussion is widened to include all information provided in the (final) drafts of the first interim report (Green et al., in press) seen by the present author, the majority of the suggested links would appear to hold in those cases where relevant data are available. However, some measure of uncertainty, which the present author believes to be slight but which should properly be assessed by the team as a whole, remains in the case of Area B (South Fissure).

Several dates on fragments of speleothem from Area B do not fit the proposed correlation. The most extreme case is sample B396, which has given both U-series and TL dates (Debenham, Aitken, Walton and Winter in Green et al., in press) that would suggest that lithozone B:8 may be the approximate chronological equivalent

of lithozones C:3, D:2 and D(E):6. Thus, the deposit which first received the name 'intermediate' would appear to date from some period within the Devensian, as do other deposits which, after lithologic correlation, have been grouped with lithozone B:5 as the Upper Breccia bed.

Schwarcz (ibid.) has indicated that one sample from Area B may have been subject to such processes as recrystallisation (sample B0b, from lithozone B:7 not the base of lithozone B:6 as suggested by Schwarcz, which has produced two dates, 139 ± 7 ka and 204 ± 20 ka) but this does not automatically imply that all these samples are suspect. As for the sediment bodies, it should not be forgotten that Area B presents considerable difficulties with respect to stratigraphic definition. However, these difficulties were very quickly recognised and the present author then took extreme care to ensure accurate sampling of both sediments and those stalagmite fragments for which he is responsible (including B0b). The author does not believe that the apparent chronological problem is the result of sampling error.

The South Fissure does not contain large quantities of fossiliferous deposits and, as has been said, the stratigraphy is difficult to follow. Normally, one might be justified in leaving such a problem in order to concentrate upon the much more promising sequence in Area D. However, there are reasons why such a step might be unwise in this case.

First, many of the lithostratigraphic units were originally defined (informally) in Area B, the first Area to be examined during the present excavations. The author is totally in agreement with the proposition, generally accepted by the project team, that the Area D sequence will eventually provide the most suitable stratotype for the Pontnewydd Cave formation.

Nevertheless, to abandon Area B on the grounds that there are problems with its correlation with Area D would seem to be contrary to the spirit, if not the letter, of the International Stratigraphic Guide. Let the correlation problem be solved, or at least let some serious attempt be made towards a solution, before Area B is superseded by Area D.

Second, if the problem is not resolved, there will always be the possibility that the present lithologic correlation is in fact wrong. If it were wrong, there would be irrefutable evidence that such correlation cannot avoid homotaxial error in the context of the site as a whole (cf. p.1161).

Third, if the correlation were wrong, doubt would be cast upon the very concept of debris flows at Pontnewydd. At present, the main flows of the Lower and Upper Breccia beds are seen as regular, generally tabular bodies, a concept supported by all the available literature on such phenomena. Any other correlation would suggest much more tortuous sediment bodies and would necessitate a radical rethinking of the processes involved. Green has indicated (ibid., introduction to Chapter III) that his observation of the Area B deposits shows that the Upper Breccia bed cuts down into the Lower Breccia bed and the Intermediate complex, as one proceeds into the South Fissure (cf. p.1130 and p.1203 of the present text). He uses this as an argument to cast doubt upon the provenance of finds and dated stalagmite fragments. However, the present author cannot see how this directly affects the problem, since some of the dated stalagmite fragments were collected by him (the present author) from deposits which, by definition, are indeed the lithostratigraphic units indicated. Green (loc.cit.) has also suggested that old finds can now be stratigraphically reallocated, thus producing a more consistent

picture. This suggestion does not even merit comment. Far from casting doubt upon the general concept of tabular sediment bodies, the observation of the behaviour of the Upper Breccia bed actually supports the proposed model. The South Fissure represents a considerable constriction compared with the main chamber; there is therefore a concrete reason why debris flows should become more erosive. Indeed, we do not as yet know whether or not there was a general increase in slope into the South Fissure (note that the stream responsible for the Upper Clay and Sand beds took this route).

Finally, any alternative correlation could only be inferentially geochronologic, not chronostratigraphic; there is no conceivable way that a lithozone such as B:8 could be part of, or even strictly contemporary with, the same sediment body as evidenced by lithozones C:3, D:2 and D(E):6. Consequently, the taphonomic situation, with regard to all types of 'object', would become infinitely more complex in all Areas of the site. One might be able to ignore Area B in any stratigraphic scheme, but one cannot ignore these deposits as potential sources for the Area D material.

There is another case where combined data have a bearing upon the overall stratigraphy of the site, this time with a rather more positive, but nevertheless slightly disturbing, result. It has been suggested that much of the total time span of the Pontnewydd sequence is not represented by extant clastic sediments. One of the major gaps appears to follow the emplacement of the Lower Breccia bed. The only material deposited over an extremely long period, perhaps as long as 200ka (cf. Green in Green et al., in press), was stalagmite; the various occurrences are grouped here as the Stalagmite lithozone. However, the dating evidence

has shown that useful chronostratigraphic subdivision can probably be made of this unit. The dates fall into two main groups, c.225-160ka and c.95-80ka (Green, *ibid.*). Comparison of this information with the faunal data shows that at least one more subdivision must be present. The Silt beds contain a Late Devensian fauna (Currant, *ibid.*), yet these beds are clearly interstratified towards the base with stalagmite (D(C):4; the definition of an exact lithostratigraphic boundary does not change the fact that this boundary is lithogenetically gradational. This material is usually very heavily corroded, but it is to be hoped that samples good enough for dating will eventually be found, perhaps towards the cave walls. The disturbing factor is that there are no direct stratigraphic or lithologic criteria that can as yet be used to differentiate between these three subdivisions. Nowhere has one set of speleothems been observed in stratigraphic contact with another. Pleas by the present author that these speleothems, indeed all speleothems in the cave, whether in situ or as clasts, be examined with respect to micropalaeontology, heavy minerals, trace elements, internal microstratigraphy, etc., have to date been consistently ignored. All the present author has been able to do with the samples and resources available to him is to show that a sample, presumably from the Stalagmite lithozone, does not have the massive organic content of the constituent blocks of lithozone B:7 (cf. p.1198).

The context of the archaeological material is discussed in some detail by Green in all the reports that have so far appeared and also in his contributions to the forthcoming interim report. The present author is in complete agreement with Green's proposition that the occupation site must have been in or near the original cave entrance (wherever that might have been).

Similarly, again in agreement with Green, the information available from the sediments would lend no support whatsoever to a suggestion that the archaeological material represents a mixture with a range of any great temporal significance, although the sedimentological evidence cannot, of course, rule out such a possibility.

The sedimentary and topographic context of the site is of interest in any discussion of the exact nature of the archaeological occupation. It is quite clear that the area of the cave now under investigation was not the precise site of occupation. Apart from the fact that this area must have been most inhospitable (dark, cold and very damp), the recovery of archaeological material from debris flows (from the Intermediate complex to the Upper Breccia bed) entails the assumption that it came from elsewhere. We have good reason to believe that the occupation site was close by. For one thing, the sheer density of finds militates against significantly long distance transport. However, this does not mean that we can necessarily characterise the physical limits acting to restrict the size of the occupation; the exact site has been totally destroyed by a combination of processes, including glaciation.

A clue to the nature of the cave occupation is provided by the living-space available in the cave entrance area. The potential settlement area within the drip-line covers no more than about 30 sq.m. and, taking into consideration a range of ethnographic data on the living-space requirements of human beings, would accommodate no more than half-a-dozen persons Such a site, unless a larger entrance chamber has been destroyed by natural processes of erosion, could scarcely qualify as other than a transit site of some kind (Green 1981a:192)

The probable living-area in the cave entrance covers no more than 30 square metres and would hardly have accommodated more than half a dozen persons for any length of time. (Green 1981c:36)

Such estimates of the potential living area within the present cavity, estimates that are resubmitted by Green (in Green et al., in press), would seem to be of doubtful relevance.

T. Ford (pers.comm. quoted by Green, *ibid.*) has indicated most reasonably that there is no evidence to suggest that the ancient cave entrance was any more extensive than the present one. However, it would also seem difficult to rule out the possibility that the entrance was in fact as large as the "Archway" (a huge natural arch with a complex of avens, passages and rockshelters, lying near the present Elwy below Cefn Rocks) or, conversely, that it was a restricted vertical shaft unsuitable for any sort of occupation, possibilities which Ford happily accepts (pers.comm. to the present author). Indeed, there is no reason to reject the further possibility of a site on open ground just outside the cave entrance, an entrance which might even have been buried and thus completely unsuspected by the ancient people.

The fact that the raw materials from which many of the artefacts were made are also naturally present in the earlier cave deposits (Bevins, *ibid.*) might appear to strengthen the association between cave and occupation (although no member of the project team has actually suggested such a link). However, allowing that the cave was indeed accessible to man, the presence of nodules in sufficient numbers and of sufficient size has yet to be demonstrated. Of course, no 'grub-pits' have been identified within the cave. Since these rock types must also have been present in surface deposits throughout the valley, stream beds would have provided exposures at least as attractive as the cave deposits.

The artefacts recovered include handaxes; Levallois flakes, blades and points; scrapers and a small number of other implement types. Such an assemblage would be typical of an 'activity' rather than an 'industrial' site and the writer would argue (Green, 1981[a]) for the site to be regarded as a temporary hunting encampment which controlled the passage of game through the Elwy Valley and at which butchery of animals, principally horse, took place for skins, meat or both. (Green 1981c:36)

First, it should be noted that Green presents no data

whatsoever to support a link between the horse remains (or the remains of any animal) and the archaeological occupation. Curreant (in Green et al., in press) presents detailed data concerning the fauna, with no mention of the possibility of anthropic effects; several large den carnivores are, however, noted in the faunal lists. Concerning the artefacts, Green (ibid.) reiterates the suggestion noted above, and adds that there is a low proportion of waste flakes. Newcomer (ibid.) has convincingly demonstrated, by replication, the difficulty of recognising human manufacture with waste from some of these raw materials (there is only a small flint component amongst this assemblage, the remainder being of a wide variety of less familiar rock types; cf. Bevins, ibid.). Newcomer also notes the chemical vulnerability of this fine waste (cf. p.1192), to which must be added the possibility of mechanical comminution during transport in debris flows. Even if fine waste has survived - and no such material has been recognised by the present author, despite microscopic scanning of all sediment samples for this very purpose -, the deposits should contain natural chips totally indistinguishable from true retouch and preparation debris, since it is accepted that pseudo-retouch is present on some artefacts (Green 1981a; Green in Green et al., in press). However, it is hoped that the reader will not conclude that the present author believes this theoretical argument to be sufficient reason for curtailing the search for knapping debris. On the contrary, the author would like to see efforts redoubled to extract such material so that the discussion can be based upon hard fact (e.g. by wet seiving on site).

Discussion of the sedimentary context may be taken further. An archaeological 'living floor' is an areal entity with little significant thickness (at least as such entities are usually

defined by archaeologists; cf. Chapter 20), whilst a debris flow is very much a volumetric entity. The incorporation of the former into the latter involves not only the obvious dilution factor but also complex relationships between debris discharge rate and rate of mobilisation of the archaeological material. For instance, if the debris flow were actually initiated in the sediments which contained the artefacts, the immediate dilution factor would simply be the depth of failure in the deposit. However, if the initiation occurred up-flow of the occupation material, dilution would also depend upon the velocity of the flow and how quickly artefacts in its path were eroded. Once the occupation material had been incorporated, further overall dilution might occur, both by additional input of archaeologically sterile sediment and also due to the sorting capabilities of debris flows, with respect to both shape and size of particles (artefacts). Of course, these same sorting phenomena, coupled with varying flow parameters and cave morphology, could also lead to localised concentrations of particles, which would be dimensionally non-random. Artefacts are present in at least three discrete debris flow deposits. How far is the present collection representative of the original industry? How many artefacts remain to be excavated from deposits of unknown extent, and how much of the original occupation material was incorporated into the debris flows in the first place? The fact that only some 22 kilos of stone artefacts had been recovered by the end of the 1981 season may have little bearing upon the duration of the occupation (contra Green, *ibid.*). Indeed, the present author would go as far as to say that, until proper examination of the context is undertaken, the typology of the artefacts may have little bearing upon the typology of the original industry. Certainly, comparison with other Lower

Palaeolithic industries, in this country and abroad, is totally premature. In any case, one wonders why Green insists upon comparing the Pontnewydd material with other demonstrably biased collections (Green 1981a; Green in Green et al., in press). The sad fact that more reliable comparative material is not apparently available is surely no justification. If nothing useful can be learnt, why compare the Pontnewydd material with anything?

The temporary and small scale occupation of this site (sensu lato) would certainly seem to be a most reasonable proposition on the general grounds of what is currently known about the archaeology of Britain during this period. Nevertheless, the present author remains to be convinced that Pontnewydd Cave has yet provided any strong internal evidence to support this view.

In the present author's opinion, the study of the Pontnewydd deposits has only just started. We have only just begun to recognise the main factors which have influenced the formation of the sequence. Unless the general strategy is changed so as to approach the site along more 'taphonomic' lines, as the palaeobiologists in the team are already trying to do, we will learn little more. At present, Pontnewydd represents a footprint in a desert, a clue as to what might be possible in this improbable region of Britain. It would seem highly unlikely that many uncomplicated sites (archaeological, palaeontological, geological, etc.) will ever be found in this region. It is therefore imperative that as much reliable information as possible be extracted from Pontnewydd. From a chronostratigraphic point of view, none of the Pontnewydd deposits seen by the author could ever function as holostratotypes for regional units but, if the stratigraphic approach initiated by the author is properly

maintained, the Pontnewydd Cave formation could one day provide an invaluable parastratotype (cf. Hedberg 1976). As things stand at the moment, the present author would not attempt to correlate Pontnewydd with another site, even one in relative proximity. The commitment of the project team to the stratigraphic approach may be gauged from the fact that, in the forthcoming interim report, only two of its members have made correct use of the lithostratigraphic framework that the present author has so painstakingly constructed. Not even the Area lithozones have met with general approval.

This chapter began with the 'tale' of the Ffynnon Beuno Caves. Sadly, uncritical and simplistic use of data is already beginning to establish a 'Pontnewydd folklore' in the general literature:

Ultimately, a reliable chronological framework for the Middle Pleistocene will emerge only when terrestrial sequences are firmly dated, and tied to the oceanic record.

Some sites have already been correlated in this manner, although with varying success. Two of the best examples are the sites of Bilzingsleben in East Germany ... and Pontnewydd in North Wales (Green et al., 1981)... [reference to a location map]. In each case, archaeological evidence has been dated, correlated with independently dated climatic stages shown in marine cores, and the correlations then checked by palaeoclimatic evidence. (Dennell 1983:41)

Those involved at Pontnewydd must now decide whether they wish to pursue accuracy or whether they will let the folklore grow.

Postscript

Since this chapter was written, the First Interim Report on Pontnewydd, referenced above as "Green et al., in press", has indeed appeared (1984). Sadly, the publication of the report necessitates no changes, with respect to either fact or opinion, in the present chapter.

25. SUMMARY AND CONCLUSION

Geo-archaeology implies archaeological research using the methods and concepts of the earth sciences. [...]

A fundamental distinction must be drawn between technique and goal. Earth-science methodologies contribute critical empirical information and conceptual approaches to an understanding of prehistorical context. [...]

Inevitably, no one individual can master more than a few of the more useful techniques. But a competent geo-archaeologist should be able to evaluate diverse sources of empirical data, as generated within the archaeological project and as available from external sources, in order to apply the information to construct an integrated model of a geo-environmental system. Ideally, this model eventually will be linked with information on biota, demography, and material culture to generate a higher-order model of prehistorical settlement and subsistence patterning.

(Butzer 1982:35)

In the Introduction to this thesis (Chapter 1), the historical importance of caves to quaternary research and the development of cave sedimentology are set against the presently growing persuasion that cave sites lack sufficient contextual control and quality for modern research. The author, as a palaeolithic archaeologist, states his conviction that caves constitute an irreplaceable source of archaeological information; if a dominantly geological approach is what is needed to re-establish confidence in the cave context, then so be it - hence, the present 'geoarchaeological' thesis. From the outset, the author affirms his intention to examine the sedimentary processes active within caves and the relationship between the latter and the quaternary landscape.

Part I of the thesis is devoted to the theory of

sedimentology as applicable to cave sites. In most cases, caves as a whole, let alone archaeological caves, will not furnish all, or even most, of the requisite information, given the primitive level of study which has so far been the norm. Thus, any type of site will be discussed provided that it can be reasonably argued that the findings will be relevant to the cave context.

Chapter 2 deals with the cave environment, with a particularly detailed and technical discussion of cave meteorology. This chapter serves two purposes. First, it is demonstrated that caves are complex environmental entities and that, at present, we are very far from a complete understanding. Second, by drawing the reader's attention to the physical mechanisms behind meteorology, the author hopes to dispense with any simplistic climatic preconceptions which might hinder the whole purpose of this thesis.

Since the author wishes to communicate with as wide a readership as possible, including non-geological specialists, Chapter 3 summarises the basic properties of sediments and sets up the vocabulary necessary for their description. The opportunity is also taken to place the study of structure (fabric, patterning, geometry, facies) in its rightful place as the most powerful tool for the diagnosis of sedimentary environments. The textural and compositional parameters, studied by most cave sedimentologists, are relegated to a subsidiary position.

Chapter 4 is a simple statement reflecting the author's belief that most sedimentological expertise is gained in the field.

Chapter 5 contains a discussion of boundary features and stratigraphy, aspects of sedimentology (and of most other quaternary sciences) which, amongst other things, permit the

recognition of 'entities' worthy of study. The International Stratigraphic Guide is proposed as a document which not only facilitates communication but which also provides a strong and flexible framework within which a researcher can test his own ideas.

Chapters 6 (Quantification) and 7 (Analytical Techniques) are allied in that the author argues against the mechanistic application of procedures which the 'user' does not understand. At present, cave sedimentology is drowning in inappropriate mathematical and analytical techniques, largely because of indiscriminate borrowing from other disciplines. Logical statement of the problem, involving explicit definition of the parameters involved and the hypotheses to be tested, must precede the choice of demonstrably appropriate evaluation techniques.

The next block of chapters deals with the main sedimentary processes to be expected in caves. Chapter 8 firmly challenges one of the two 'foundation stones' of climatic determinism by examining the various effects of ice and demonstrating that, although ice is undoubtedly a most important sedimentary agency in this context, real proof of its involvement cannot be supplied by simple observation of such parameters as the proportion and size characteristics of limestone scree. A set of more diagnostic ice-induced structures are proposed for future research. Chapter 9 contains a detailed discussion of mass movement phenomena; many different types of mass movement, each with different contextual implications, are listed, in place of the single 'solifluction/gelifluction' category in which all such phenomena are usually placed. Chapters 10 (wash processes, fluvial processes, sub-surface drainage processes and marine processes) and 11 (aeolian processes) cover the dynamic effects of water and

wind, with particular attention to the special dimension of the cave context. Chapter 12 challenges the second 'foundation stone' of climatic determinism by showing that there is very much more to the processes of alteration (chemical weathering) than a simple rise in temperature. Simplistic definitions of palaeosols, in caves and rockshelters, are rejected and are replaced with a more realistic discussion of 'alteration systems'. The subject of carbonate mobility, already broached in Chapter 12, is pursued in Chapter 13 which deals with major speleothems. Speleothems are not uniform lumps of calcite but complex sedimentary sequences worthy of detailed investigation in their own right.

In Chapter 14, the author reviews the topic of biological material in caves. Various diffuse and amorphous substances are noted, as well as more structured faunal remains; there is a whole section on the difficult subject of cave palynology. A discussion of biological material might seem out of place here but, apart from the fact that such material may often constitute a significant sedimentary component, the palaeontological concept of taphonomy is so close to the geological and archaeological ideas expressed elsewhere in the present text that the analogy cannot be ignored.

The last block of chapters in Part I deals with more complex interpretative matters. Provenance and palaeogeography are briefly discussed in Chapter 15, although these are subjects which have had to take second place in the present thesis with its strong bias towards the identification of depositional processes. Diagenesis, particularly with respect to carbonate systems, is treated in Chapter 16. Chapter 17 contains a discussion of correlation, with a special plea for the explicit definition of the type of correlation involved, whether it be based on physical parameters (eg. lithocorrelation), inferred parameters

(eg. correlation by 'climatozones') or temporal parameters (chronocorrelation). The author expresses his belief that correlation should not be a passive, synthetic exercise but, rather, an active programme of fieldwork with the specific aim of studying the relationships between strata in different exposures or sites. Dating methods, applicable to materials found in caves, are discussed in Chapter 18. There is a worrying tendency for the results of complex physical dating techniques to be taken on face value even when they are not supported by valid stratigraphic criteria; sometimes, the 'event' which has been dated is obscure or even totally illusory (i.e. the 'event' is in fact a meaningless 'average' of many separate events). Chapter 20 contains a discussion of contextual archaeological concepts. Many archaeological examples are presented throughout the thesis; in Chapter 20, such subjects as archaeostratigraphy, site formation processes, living floors and anthropogenic structures are presented in a manner designed to stress the accelerating and highly desirable convergence between the contextual theories of the geological, biological and archaeological sciences.

Part II contains a number of case studies drawn from the author's own practical research. None of these sections or chapters constitutes a site report. Rather, certain aspects of particular sites are discussed in greater or lesser detail in order to provide site-oriented examples of some of the theoretical issues which have been raised in Part I.

Four areas of Western Britain are represented, each of which contains sites with a certain regional 'flavour'. The caves of South Devon all lie at comparatively low altitudes and they have received large quantities of exotic sediments derived from the varied rocks which surround the small limestone outcrops.

Chapter 21 includes discussion of the Torbryan Valley caves (specifically Tornewton Cave and Three Holes Cave), which are characterised by certain disruptive processes including fluid mass movement; of Joint Mitnor Cave and the concept of a 'pitfall trap'; and of Pixie's Hole and the identification of an archaeological 'living floor'. The caves of Mendip are very much more isolated from the surrounding landscapes because of the relatively high relief of this region. Chapter 22 includes discussion of Sun Hole with its long but minimally exposed sequence; of the Wookey Hole Ravine caves (Badger Hole, Rhinoceros Hole and Hyaena Den) with their perplexing variation in apparent sediment sources; and of the Westbury-sub-Mendip Fissure, an ancient site which affords a superb opportunity for the study of diagenesis. The caves of the south coast of Gower variously derive their sediments from either marine or terrestrial sources, depending upon the prevailing sediment transport systems, sea levels and, ultimately, climates. Chapter 23 centres upon the site of Bacon Hole, but a final section stresses the potential for correlation between the cave and open sites of this region which, although quite small, possesses an excellent stratigraphic record covering at least the later Middle and Upper Pleistocene. The caves of North Wales constitute an unexpected source of information in this region with its history of repeated glaciation; these caves are usually 'residual' sites, containing complex mixtures of material which must be interpreted with great care. Chapter 24, which includes a detailed discussion of Pontnewydd Cave, illustrates both this 'residual' character and also the difficulties, many of them associated with our present inability to sustain co-operative interdisciplinary research, presented by such sites.

Certain themes run strongly through the pages of this thesis and it is appropriate to bring them together here by way of a conclusion.

Historically, cave sedimentology, as applied to archaeological sites, has been primarily concerned with the reconstruction of regional environments or climate. A set of empirical and extremely generalised models was derived during the formative stage of the discipline's development. New techniques have been added, usually by borrowing from other disciplines, but each new addition has brought with it a 'foreign' interpretative framework. In the terms of Clarke (1968:59), the situation may be likened to a Black Box; the input is provided by a few measurable parameters and the output emerges as quantified climate. Admittedly, things go on inside the Box, and we must always bear in mind that individual sites lend an individual flavour to the contained sediments. However, we seem to have become so sure that the (apparent) deterministic relationships between measurable parameter and climate represent some sort of natural law, that the actual workings of the Black Box are now considered to be all but irrelevant. We are even prepared to dismiss patently reliable evidence which conflicts with our rigid models, a dismissal speciously justified by the conflict itself, certain proof of the idiosyncrasies of individual sites. In short, cave sediments are no longer studied, they are merely classified by assumed climatic type.

The author categorically rejects this approach, both because it is appallingly inaccurate and because it ignores most of the contextual objectives which he believes to be of such great importance to archaeology and other quaternary sciences. The Black Box approach is in fact no more than an intellectual trap,

encouraging the legitimisation of facile and sometimes downright ridiculous ideas, simply because mechanisms, and thus proofs, are, by chosen definition, unobservable. Tear down the shrine of the Black Box and one finds that there are indeed many areas which, at present, are 'unknowable' but, without a single exception, none of these areas lies within the domain of mechanisms and processes. Contrary to received wisdom, we either know, or can expect to be able to find out, exactly what goes on inside the arbitrary but convenient Black Box. The only reason why we cannot complete a deterministic chain of deduction, from observation of an ancient sediment to reconstruction of such topics as climate, is that, in the vast majority of real cases, the physical evidence is lacking. It is not the workings of the Black Box that are unknowable so much as the input. Recognition of this truth is consistently avoided by many cave sedimentologists, who merely feed their Black Box the values of some small set of parameters which are always knowable (eg. particle size or composition), whether or not these values are relevant to the system under study. The truly saddening thing is that such researchers appear to believe that their approach is infallible since they never fail to derive an 'answer' to their climatic questions.

In the present thesis, the author has stressed the importance of the concept of sedimentary process. The models used are firmly based upon the Principle of Uniformitarianism, in its modern 'methodological' as opposed to 'substantive' form. This involves the simple assumption that natural laws are constant in time and space, and that all relevant natural laws may be made explicit through scientific procedure. We may demonstrate, for example, both physically and by explicit theory, that a gentle stream does not move boulders, that clean sand will not accumulate

above its intrinsic angle of rest, or that a given material will rupture if subjected to a defined amount of stress. From these basic consequences of natural laws, we have come to understand the constellations of effects which we call sedimentary processes. We know how a stream or the wind erodes, modifies and deposits sediment, or if we do not, we can find out. By observation of the modern world, we have recognised geographic, and thus temporal, patterns which we call sedimentary facies, patterns which we can satisfactorily explain by the operation of natural laws. Many relationships are dauntingly complex but this does not mean that, given a valid reason for wishing to do so, we could not eventually reduce the system to predictable components. However, in the modern world, we can, theoretically, measure every single input to the system, every stress and strain and raw material.

When it comes to observing ancient deposits, it is immediately apparent that, at least within the limits set by available study resources in particular real cases, we cannot analyse a given sediment in such minute detail as to reconstruct precisely the very physics of its formation. Yet if we make do with slightly less detailed analysis, we will quickly find that the perceived properties of a sediment are not necessarily determinate with respect to process. Many different processes, or sequences of processes, may produce the 'same' result. Theoretically, one might be able to extend the limits of perception until a determinate level was achieved but, in most real cases, the resources simply will not be available. It could be argued that the same problem will be encountered with modern sediments but, in this case, we are not interested in particular real cases so much as in the extraction of general theory; if need be, we can usually afford to search for a situation in which we can

actually watch the sediment forming. The difficulty with ancient deposits is compounded by the absence from the physical record of certain data vital to the understanding of an ancient sedimentary system. A deposit may have become isolated from its contemporary landscape by erosion or it may have suffered radical modification since its deposition. Moreover, our feeble ability to quantify time is severely crippling, because it removes the only absolute yardstick applicable to all sediments. In an ancient sediment, we can say that a stony sand is becoming stonier upwards only because it is also becoming less sandy. In a modern context, we could be much more precise by quantifying the changing sedimentation rates of the two components independently. Thus, the actualistic approach to ancient sediments is rational and appropriate, beyond any glimmer of a doubt, but the approach is never infallible with respect to the interpretations resulting from its application. The probability that an interpretation is close to the truth is always dependent upon the quality of the preserved data, the available study resources and, above all, upon the ability of the researcher to locate the area of overlap between what he wishes to know and what, under the particular circumstances, the sediments can actually reveal.

The experience of mainstream sedimentologists over the last century and more has shown unequivocally that the most rewarding properties of sediments, with respect to diagnosis of sedimentary environments, are those synthetic attributes expressed as structure, geometry and facies progression. To date, this aspect of sediments has been almost totally ignored in archaeological caves. In the present thesis, the author has tried to assemble as much information as possible that might have a bearing upon the types of structure to be expected in cave

sediments, even though this has often meant ranging far beyond the cave context in search of relevant examples. No doubt, the list of structures is as yet very far from complete. The author is by no means satisfied with the level of documentation, especially of graphic documentation, of actual cave sediments which he has so far achieved. This is largely the result of the very real constraints of time and money under which this research was carried out. Nevertheless, any detailed shortcomings of the present thesis are unimportant if the author has succeeded in his principal aim of replacing the ludicrous situation, in which existing tenets of climatic determinism were thought to be more or less infallible whilst the actual mechanisms were held to be either irrelevant or simply unknowable, with a situation in which, although much remains unknown, realistic and powerful methods of increasing our knowledge, almost without limit, are clear. As opposed to climatic determinism with its weak empirical generalisations and cocksure pronouncements, the author's more plodding approach may be termed lithogenetic reductionism, the doctrine that tenacious observation of even the most complex sediment will eventually serve to identify that specific set of attributes or attribute states which is demonstrably the result of comparatively simple natural laws and which is thus truly diagnostic of that particular sedimentary environment, whether ancient or modern.

If sedimentary environments (environments of deposition, postdepositional modification and erosion) can be identified in cave sequences, then a firm contextual framework can be set up for interdisciplinary research. The author's opportunities in this direction, as described in the present text, have so far been few, but he is convinced that co-operative research with such flexible and perceptive individuals as C.B. Stringer and

A.P. Carrant has already resulted in an understanding of certain sites which simply could not have been achieved by a mere 'multidisciplinary' approach.

Finally, we may return to palaeolithic archaeology - the essential, if at times inconspicuous, motivation for the present thesis. It was the enormous gap between archaeological cave sedimentology and mainstream sedimentology which prompted the author to undertake this research. Again, lack of specific opportunities has meant that impressive demonstrations of (positive) archaeological applications are few and far between in the present text. Nevertheless, it will require no great effort of imagination for the reader who has followed the arguments set out in this thesis to visualise the immense contextual possibilities inherent in the mainstream sedimentological approach advocated here. Now that the author is satisfied that a coherent methodology is available, he is no longer prepared to wait for better opportunities; such opportunities must be made.

APPENDIX: SIMULATION OF PARTICLE SIZE DISTRIBUTIONS

M.J. COLLCUTT & S.N. COLLCUTT

(a) Background

This appendix concerns the theoretical link between number distribution and normal volume distribution, with particles idealised as perfect spheres.

The diameters of perfect spheres are transformed, such that:

$$\Phi = -\log_2 D \quad (i)$$

(where D represents the various diameters)

A volume frequency distribution is constructed with a normal p.d.f.:

$$f(V) = \frac{1}{\sigma_V \sqrt{2\pi}} e^{-\frac{(\Phi - \mu_V)^2}{2\sigma_V^2}} \quad (ii)$$

(where μ_V and σ_V are the mean and standard deviation of the volume frequency distribution)

Numerical simulation of specified populations (specified μ_V and σ_V) allows the calculation of the corresponding number frequency distribution. For any specified case, it is seen that the number frequency distribution is normal, with a p.d.f.:

$$f(N) = \frac{1}{\sigma_N \sqrt{2\pi}} e^{-\frac{(\Phi - \mu_N)^2}{2\sigma_N^2}}$$

(where μ_N and σ_N are the mean and standard deviation of the number frequency distribution)

It is also seen that $\sigma_N = \sigma_V$, that is, the shape of the number frequency distribution is identical to the shape of the volume frequency distribution. However, μ_N (and the whole number frequency distribution) is displaced to higher Φ values with respect to μ_V . Simulations with varying σ show that $(\mu_N - \mu_V)$ is proportional to σ . Initial algebraic framing of the problem resulted in a situation in which a complex expression could have been simplified by completing the square. It was intuitively recognised that the missing factor was of the right form to express the relationship between μ_V and μ_N . Repeated simulation showed that this factor, $3\sigma_V^2 \ln 2$, accurately predicted the value of μ_N .

Thus, in order to rule out the possibility of any special cases, mathematical proof is required for the proposition that the number frequency distribution is normal, such that:

$$\mu_N = \mu_V + 3\sigma_V^2 \ln 2 \quad \text{and} \quad \sigma_N = \sigma_V \quad (\text{A})$$

(b) Mathematical Proof

Let us assume a perfect sample of total volume, one. Let us also assume that the sample may be divided into discrete " Φ " classes, so that in any class of mean diameter Φ , the volume (V_Φ) of the particles in that class may be written:

$$V_{\bar{\Phi}} = \frac{1}{\sigma_V \sqrt{2\pi}} e^{-\frac{(\bar{\Phi} - \mu_V)^2}{2\sigma_V^2}} \quad (\text{iii})$$

(from equation (ii) since $\int_{-\infty}^{+\infty} f(V) d\bar{\Phi} = 1$)

Now the mean volume (V_{mean}) of the particles in each class is:

$$V_{\text{mean}} = \frac{4}{3}\pi(D/2)^3$$

From equation (i), $D = e^{-\bar{\Phi} \ln 2}$

$$\text{So, } V_{\text{mean}} = \frac{4}{3}\pi(e^{-\bar{\Phi} \ln 2}/2)^3$$

$$\text{or, } V_{\text{mean}} = \frac{\pi}{6} e^{-3\bar{\Phi} \ln 2} \quad (\text{iv})$$

Also, the number ($N_{\bar{\Phi}}$) of particles in each class is:

$$N_{\bar{\Phi}} = V_{\bar{\Phi}}/V_{\text{mean}}$$

That is (from equations (iii) and (iv)):

$$N_{\bar{\Phi}} = \frac{6}{\sigma_V \sqrt{2\pi^3}} e^{3\bar{\Phi} \ln 2 - \frac{(\bar{\Phi} - \mu_V)^2}{2\sigma_V^2}} \quad (\text{v})$$

The total number (N_{tot}) of particles in the sample is therefore given by:

$$N_{\text{tot}} = \int_{-\infty}^{+\infty} N_{\bar{\Phi}} d\bar{\Phi} \quad (\text{vi})$$

To obtain the p.d.f. $f(N)$, we therefore have (from equations (v) and (vi)):

$$f(N) = \frac{N_{\bar{\Phi}}}{\int_{-\infty}^{+\infty} N_{\bar{\Phi}} d\bar{\Phi}} \quad (\text{vii})$$

The following deals with the determination of:

$$\int_{-\infty}^{+\infty} N_{\bar{\Phi}} d\bar{\Phi}$$

Let us first of all determine the mean (μ_N) of the number frequency distribution.

We would expect that if the distribution of $N_{\bar{\Phi}}$ is symmetrical, the mean of the distribution would be equal to the value ($\bar{\Phi}_{\max}$) of $\bar{\Phi}$ where $N_{\bar{\Phi}}$ is a maximum.

Now $\bar{\Phi}_{\max}$ is a value of $\bar{\Phi}$ for which:

$$\frac{dN_{\bar{\Phi}}}{d\bar{\Phi}} = 0$$

From equation (v):

$$\begin{aligned} \frac{dN_{\bar{\Phi}}}{d\bar{\Phi}} &= \frac{d}{d\bar{\Phi}} \left[\frac{6}{\sigma_V \sqrt{2\pi^3}} e^{3\bar{\Phi} \ln 2 - (\bar{\Phi} - \mu_V)^2 / 2\sigma_V^2} \right] \\ &= \frac{d}{d\bar{\Phi}} \left[\frac{6}{\sigma_V \sqrt{2\pi^3}} e^{[\bar{\Phi}(6\sigma_V^2 \ln 2 + 2\mu_V) - \bar{\Phi}^2 + \mu_V^2] / 2\sigma_V^2} \right] \\ &= \frac{6}{\sigma_V \sqrt{2\pi^3}} \frac{(6\sigma_V^2 \ln 2 + 2\mu_V - 2\bar{\Phi})}{2\sigma_V^2} e^{3\bar{\Phi} \ln 2 - (\bar{\Phi} - \mu_V)^2 / 2\sigma_V^2} \end{aligned}$$

Thus the condition that $dN_{\bar{\Phi}}/d\bar{\Phi} = 0$ is:

$$(a) \quad \bar{\Phi} = 3\sigma_V^2 \ln 2 + \mu_V$$

$$\text{or (b) } e^{3\bar{\Phi} \ln 2 - (\bar{\Phi} - \mu_V)^2 / 2\sigma_V^2} = 0$$

It could be shown by a second differentiation (here omitted) that condition (a) occurs when $N_{\bar{\Phi}}$ is a maximum:

$$\text{i.e. } \bar{\Phi}_{\max} = 3\sigma_V^2 \ln 2 + \mu_V$$

It can be seen by observation that the left hand part of condition (b) approaches zero as $\bar{\Phi}$ approaches $+\infty$ or $-\infty$, so we might assume that condition (b) occurs when $N_{\bar{\Phi}}$ is a minimum.

We must now prove that the distribution of $N_{\bar{\Phi}}$ is

symmetrical in order to write $\mu_N = \bar{\Phi}_{\max}$.

Therefore, let us examine $N_{\bar{\Phi}}$ for values of $\bar{\Phi}$ equal to $\bar{\Phi}_{\max} \pm K$, where K is any constant.

$$(1) \bar{\Phi} = \bar{\Phi}_{\max} + K$$

From equation (v):

$$N(\bar{\Phi}_{\max} + K) = \frac{6}{\sigma_V \sqrt{2\pi^3}} e^{3\ln 2(3\sigma_V^2 \ln 2 + \mu_V + K) - (3\sigma_V^2 \ln 2 + K)^2 / 2\sigma_V^2}$$

Examining the exponent, we note that:

$$3\ln 2(3\sigma_V^2 \ln 2 + \mu_V + K) - (3\sigma_V^2 \ln 2 + K)^2 / 2\sigma_V^2 =$$

$$\frac{1}{2\sigma_V^2} \left[18(\sigma_V^2 \ln 2)^2 + 6\sigma_V^2 \mu_V \ln 2 + (6\sigma_V^2 K \ln 2 - 6\sigma_V^2 K \ln 2) - (3\sigma_V^2 \ln 2)^2 - K^2 \right]$$

$$(2) \bar{\Phi} = \bar{\Phi}_{\max} - K$$

From equation (v):

$$N(\bar{\Phi}_{\max} - K) = \frac{6}{\sigma_V \sqrt{2\pi^3}} e^{3\ln 2(3\sigma_V^2 \ln 2 + \mu_V - K) - (3\sigma_V^2 \ln 2 - K)^2 / 2\sigma_V^2}$$

Examining the exponent, we note that:

$$3\ln 2(3\sigma_V^2 \ln 2 + \mu_V - K) - (3\sigma_V^2 \ln 2 - K)^2 / 2\sigma_V^2 =$$

$$\frac{1}{2\sigma_V^2} \left[18(\sigma_V^2 \ln 2)^2 + 6\sigma_V^2 \mu_V \ln 2 + (-6\sigma_V^2 K \ln 2 + 6\sigma_V^2 K \ln 2) - (3\sigma_V^2 \ln 2)^2 - K^2 \right]$$

Since this exponent equals that in case (1), we have shown that:

$$N(\bar{\Phi}_{\max} + K) = N(\bar{\Phi}_{\max} - K) \quad \text{for any } K,$$

and that the distribution of $N_{\bar{\Phi}}$ is symmetrical about $\bar{\Phi}_{\max}$.

Thus, since $\bar{\Phi}_{\max} = 3\sigma_V^2 \ln 2 + \mu_V$, the mean (μ_N) of the distribution of $N_{\bar{\Phi}}$ is:

$$\mu_N = \mu_V + 3\sigma_V^2 \ln 2$$

(viii>A)

Let us now examine the integral $\int_{-\infty}^{+\infty} N_{\Phi} d\Phi$.

From equation (v):

$$\int_{-\infty}^{+\infty} N_{\Phi} d\Phi = \int_{-\infty}^{+\infty} \frac{6}{\sigma_V \sqrt{2\pi^3}} e^{3\Phi \ln 2 - (\Phi - \mu_V)^2 / 2\sigma_V^2} d\Phi$$

Having determined that $\mu_N = \mu_V + 3\sigma_V^2 \ln 2$, we would like to transform the exponent to the form:

$$-(\Phi - \mu_V)^2 / 2\sigma_V^2$$

$$\text{or } -(\Phi - \mu_V - 3\sigma_V^2 \ln 2)^2 / 2\sigma_V^2$$

This can be done by the method of completing the square.

First:

$$-(\Phi - \mu_V - 3\sigma_V^2 \ln 2)^2 / 2\sigma_V^2 =$$

$$\frac{1}{2\sigma_V^2} \left[-\Phi^2 + 6\sigma_V^2 \Phi \ln 2 + 2\mu_V \Phi - 6\sigma_V^2 \mu_V \ln 2 - (3\sigma_V^2 \ln 2)^2 - \mu_V^2 \right]$$

Our exponent is equal to:

$$3\Phi \ln 2 - (\Phi - \mu_V)^2 / 2\sigma_V^2 =$$

$$\frac{1}{2\sigma_V^2} \left[-\Phi^2 + 6\sigma_V^2 \Phi \ln 2 + 2\Phi \mu_V - \mu_V^2 \right]$$

Thus, to complete the square, we must add the following to the exponent:

$$\frac{1}{2\sigma_V^2} \left[-6\sigma_V^2 \mu_V \ln 2 - (3\sigma_V^2 \ln 2)^2 \right]$$

Simplifying this expression, we have, to complete the square:

$$\frac{3 \ln 2}{2} \left[3\sigma_V^2 \ln 2 + 2\mu_V \right]$$

Because this expression does not contain Φ , it is now valid to write our integral as: (ix)

$$\int_{-\infty}^{+\infty} N_{\Phi} d\Phi = \frac{6}{\sigma_V \sqrt{2\pi^3}} e^{\frac{3\ln 2}{2}(3\sigma_V^2 \ln 2 + 2\mu_V)} \int_{-\infty}^{+\infty} e^{-\frac{(\Phi - \mu_V - 3\sigma_V^2 \ln 2)^2}{2\sigma_V^2}} d\Phi$$

Let us now examine this right hand integral. If we were to attempt to find an expression for the indefinite integral of this function, by parts, we would end up with a diverging infinite series. It is therefore necessary to make a further transformation.

$$\text{Let } (\Phi - \mu_V - 3\sigma_V^2 \ln 2) / \sigma_V = Z$$

$$\text{Then } \frac{dZ}{d\Phi} = \frac{1}{\sigma_V}, \text{ or } d\Phi = \sigma_V dZ$$

So we may say that:

$$\int_{-\infty}^{+\infty} e^{-\frac{(\Phi - \mu_V - 3\sigma_V^2 \ln 2)^2}{2\sigma_V^2}} d\Phi = \sigma_V \int_{-\infty}^{+\infty} e^{-Z^2/2} dZ$$

Let us therefore examine the integral:

$$I = \int_{-\infty}^{+\infty} e^{-Z^2/2} dZ$$

We may square this integral as follows:

$$I^2 = \left[\int_{-\infty}^{+\infty} e^{-y^2/2} dy \right] \left[\int_{-\infty}^{+\infty} e^{-Z^2/2} dZ \right]$$

Clearly, changing all the variables does not alter the value of the indefinite integral I.

Hence,

$$I^2 = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} e^{-(y^2+Z^2)/2} dy dZ$$

Yet another transformation must now be made.

Let $y = r \cos\theta$ and $Z = r \sin\theta$

This is a standard rectangular-to-polar transformation and has the effect of changing the limits of y and Z , from $+\infty$ to $-\infty$, to those of r , from 0 to $+\infty$, and θ , from 0 to 2π .

Thus:

$$\begin{aligned} I^2 &= \int_0^{2\pi} \int_0^{+\infty} e^{-r^2/2} r \, dr \, d\theta \\ &= \int_0^{2\pi} [-e^{-r^2/2}]_0^{+\infty} d\theta \\ &= \int_0^{2\pi} [0 - (-1)] d\theta \\ &= 2\pi \end{aligned}$$

Then, since for this application I is positive,

$$I = \sqrt{2\pi}$$

Thus, equation (ix) now becomes:

$$\int_{-\infty}^{+\infty} N_{\Phi} d\Phi = \frac{6}{\sigma_V \sqrt{2\pi^3}} e^{\frac{3\ln 2}{2}(3\sigma_V^2 \ln 2 + 2\mu_V)} \cdot \sigma_V \sqrt{2\pi}$$

$$\text{or: } \int_{-\infty}^{+\infty} N_{\Phi} d\Phi = \frac{6}{\pi} e^{\frac{3\ln 2}{2}(3\sigma_V^2 \ln 2 + 2\mu_V)} \quad (x)$$

Returning to equation (vii), the required p.d.f. $f(N)$ is:

$$f(N) = \frac{N_{\Phi}}{\int_{-\infty}^{+\infty} N_{\Phi} d\Phi}$$

so,

$$f(N) = \left[\frac{6}{\sigma_V \sqrt{2\pi^3}} e^{3\Phi \ln 2 - (\Phi - \mu_V)^2 / 2\sigma_V^2} \right] / \left[\frac{6}{\pi} e^{\frac{3\ln 2}{2}(3\sigma_V^2 \ln 2 + 2\mu_V)} \right]$$

$$f(N) = \frac{1}{\sigma_V \sqrt{2\pi}} e^{-\frac{3\bar{\Phi} \ln 2 - (\bar{\Phi} - \mu_V)^2 / 2\sigma_V^2 - \frac{3 \ln 2}{2} (3\sigma_V^2 \ln 2 + 2\mu_V)}{2\sigma_V^2}}$$

We note that the exponent in this expression is equal to:

$$\begin{aligned} & \frac{1}{2\sigma_V^2} [6\sigma_V^2 \bar{\Phi} \ln 2 - \bar{\Phi}^2 + 2\bar{\Phi} \mu_V - \mu_V^2 - (3 \ln 2 \sigma_V^2)^2 - 6\sigma_V^2 \mu_V \ln 2] \\ & = -(\bar{\Phi} - \mu_V - 3\sigma_V^2 \ln 2)^2 / 2\sigma_V^2 \end{aligned}$$

So our p.d.f. becomes:

$$f(N) = \frac{1}{\sigma_V \sqrt{2\pi}} e^{-\frac{(\bar{\Phi} - \mu_V - 3\sigma_V^2 \ln 2)^2 / 2\sigma_V^2}{2\sigma_V^2}}$$

Substituting $\mu_N = \mu_V + 3\sigma_V^2 \ln 2$ and $\sigma_N = \sigma_V$, we have:

$$f(N) = \frac{1}{\sigma_N \sqrt{2\pi}} e^{-\frac{(\bar{\Phi} - \mu_N)^2 / 2\sigma_N^2}{2\sigma_N^2}}$$

- which is a normal p.d.f., with mean (μ_N) and standard deviation (σ_N). (>A)

(c) Statistical Proof

The following proof was most kindly supplied by Professor D.E. Barton (Queen Mary College, University of London). Note that terms are redefined and not necessarily identical to those used in section (b) above.

The general PPS problem is where one has a distribution of individuals with different values of some variable x . The proportion of individuals in the population with a given value of x will be denoted by $p(x)$; the mean and variance of this population will be denoted by μ and σ^2 . Suppose a mode of sampling so that the proportion in the sample has expected value $g(x)$, where $g(x) \propto b(x)p(x)$, the function $b(x)$ being a measure of

"size". Since $g(x)$ is a proportion, the constant of proportionality is determinate. Writing β for the average value of $b(x)$ in the actual population (as opposed to the apparent one), we have $g(x) = b(x)p(x)/\beta$.

In the particular case examined here, x is minus the \log_2 diameter and $b(x)$ is the volume of a sphere with this diameter, which may be written Ke^{-cx} , where $K = \pi/6$ and $c = 3\ln 2$. We also have the property that x is normally distributed.

In these terms:

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2} \left[\frac{x-\mu}{\sigma} \right]^2}$$

$$\beta = Ke^{-\mu c + \frac{1}{2}c^2\sigma^2} \quad \dots\dots\dots \text{[from theory]}$$

$$\frac{Ke^{-cx}}{\beta} = e^{-c(x-\mu) - \frac{1}{2}c^2\sigma^2}$$

So that:

$$g(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}Q}$$

$$\begin{aligned} \text{where } Q &= \left[\frac{x-\mu}{\sigma} \right]^2 + 2c(x-\mu) + c^2\sigma^2 \\ &= (x-\mu+c\sigma^2)^2/\sigma^2 \end{aligned}$$

Thus the observed (apparent) distribution is normal, with mean $\mu - c\sigma^2$ and variance σ^2 .

This result corresponds exactly with the mathematical result of section (b).

PARTICLE SIZE DISTRIBUTION - NUMERICAL EXAMPLE

PROGRAM "PARTCALC" - SNC 1980.

NORMAL DISTRIBUTION OF VOLUME, MEAN(V) = 6.5, STAND.DEV.(V) = 1.31

CLASS MEAN	DIST(V)	NUMBERS	DIST(N)
2.25	7.88976E-4	0.162187	2.80474E-9
2.75	2.5305E-3	1.47131	2.54255E-8
3.25	7.01584E-3	11.5378	1.99383E-7
3.75	0.0168145	78.212	1.35157E-6
4.25	0.0348356	458.307	7.91994E-6
4.75	0.062387	2321.52	4.01179E-5
5.25	0.0965822	10165.3	1.75665E-4
5.75	0.129251	38476.9	6.64915E-4
6.25	0.14952	125896	2.1756E-3
6.75	0.14952	356089	6.15352E-3
7.25	0.129251	870633	0.0150453
7.75	0.0965822	1.84012E+6	0.0317988
8.25	0.062387	3.36192E+6	0.0580969
8.75	0.0348356	5.30958E+6	0.0917542
9.25	0.0168145	7.24882E+6	0.125266
9.75	7.01584E-3	8.55472E+6	0.147833
10.25	2.5305E-3	8.72725E+6	0.150814
10.75	7.88976E-4	7.69627E+6	0.132998
11.25	2.12645E-4	5.86702E+6	0.101387
11.75	4.95426E-5	3.86622E+6	0.0668116
12.25	9.97776E-6	2.20234E+6	0.0380584
12.75	1.73709E-6	1.08447E+6	0.0187407
13.25	2.61422E-7	461619	7.97719E-3
13.75	3.40091E-8	169857	2.93527E-3
14.25	3.82454E-9	54027	9.33633E-4
14.75	3.7179E-10	14855.1	2.56709E-4
15.25	3.14224E-11	3530.74	6.10142E-5
15.75	2.26953E-12	725.438	1.25362E-5

THEORETICAL PARAMETERS FOR N-DISTRIBUTION:

MEAN(N) = 10.0685

STAND.DEV.(N) = 1.31

SKEWNESS(N) = 0

KURTOSIS(N) = 3

NUMERICALLY DERIVED PARAMETERS FOR N-DISTRIBUTION:

MEAN(N) = 10.0685

STAND.DEV.(N) = 1.30996

SKEWNESS(N) = -2.52989E-4

KURTOSIS(N) = 2.99896

Comment: Discrepancy due entirely to rounding errors.

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SITE INDEX

The following is a site index of the locations referenced in the present text, rather than a gazetteer. However, in some cases, a little more geographical information is included here than in the main text, and some alternative or supplementary names are also indicated. Entries are listed alphabetically, according to the most familiar element of the site name; elements such as "GROTTE" or "ABRI" are usually placed after the specific name, although less familiar, but non-specific, foreign language elements (e.g. "BAUME") may sometimes be placed alphabetically, depending upon the most common usage in the texts consulted by the present author. In addition to particular sites, general regions and regional sediment bodies have been indexed; sites or other geographic units which are not in some way associated with caves, rockshelters or limestone slopes are included within square brackets.

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- TABUN (Mount Carmel, Israel) - 7, 453, 611
 TARKÓ SHELTER (Hungary) - 357-359
 [TASMANIAN GRÈZES-LITÉES - 416]
 TAUNG (Cape Province, South Africa) - 6
 TEYJAT, LES GISEMENTS DE (Dordogne, France) - 8
 THREE HOLES CAVE (UPPER CAVE) (Torbryan, Devon) - 325, 386, 542, 678, 689, 692, 729, 739-787, 788, 789
 TORBRYAN general (Devon) - 417, 601, 691-692, 726, 728-730, 787-789, 851
 [TORBRYAN SERIES SOIL SUBSTRATES (Devon) - 729]
 TORCOURT (TOR COURT) CAVE (Torbryan, Devon) - 689, 697, 729, 788
 TORNEWTON CAVE (Torbryan, Devon) - 485, 486, 516, 596, 680, 689, 691-739, 749, 756, 774, 787, 788, 789, 851, 888, 890, 1199
 TOURTOIRAC, LA GROTTÉ-ABRI DE (Dordogne, France) - 625-626
 TRAMP'S CAVE (SHELTER) (Chudleigh, Devon) - 689, 820, 889, 890-892
 TROU-MAGRITÉ (Prov. de Namur, Belgium) - 7
 [TWICKENHAM GRAVELS (London) - 935]
- UPHILL QUARRY CAVES (Weston-super-Mare, Somerset) - 897, 898
- VACHONS, LES ABRIS DES (Charente, France) - 8
 VALLONNET, LA GROTTÉ DU (Alpes-Maritimes, France) - 453, 571
 VAUFREY, LA GROTTÉ DE (Dordogne, France) - 529, 588
 [VELVET BOTTOM (West Mendip, Somerset) - 412-413]
 VERLAINE, LA GROTTÉ DE (Prov. de Luxembourg, Belgium) - 316-317, 489
 VÉRTESZÖLLÖS (Hungary) - 637
 VICTORIA CAVE (North Yorkshire) - 592
 VILLÁNY FISSURE (Hungary) - 4
- [WADDON SERIES SOIL SUBSTRATES (Devon) - 891]
 WELLINGTON VALLEY CAVES (Western Australia) - 3
 WESTBURY-SUB-MENDIP FISSURE (BONE FISSURE, BONE CAVE, CAVERN) (Central Mendip Somerset) - 517, 610, 896, 897, 898, 989-1025, 1025
 [WEST RUNTON (Norfolk) - 583]
 WILDKIRCHLI (Switzerland) - 7
 WILTON (South Africa) - 7
 WINDMILL, WINDMILL HILL CAVE see BRIXHAM CAVE
 WOKEY HOLE GREAT CAVE (Wokey Hole, Somerset) - 1, 948-949, 982, 984-986, 987
 WYE VALLEY CAVES (Gloucestershire/Herefordshire) - 302

YABROUD (Syria) - 7

YEALM BRIDGE CAVE (Yealmpton, Devon) - 689

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