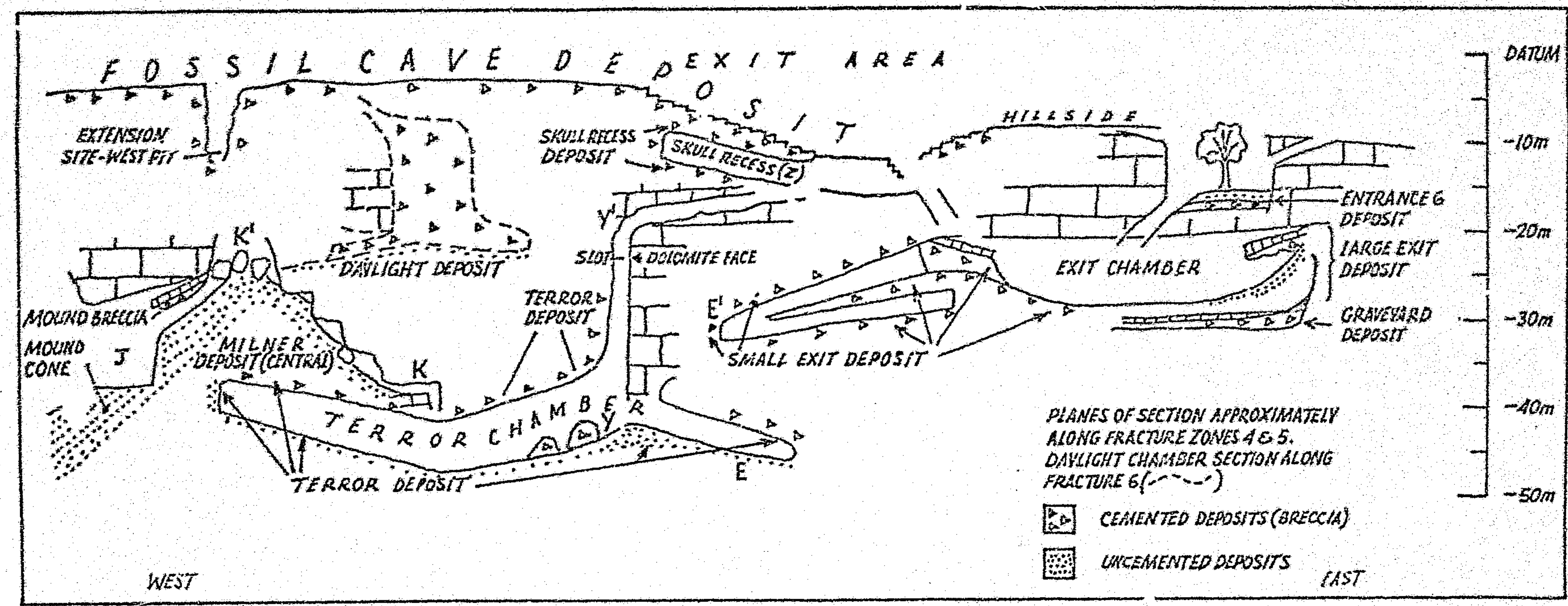

Fig. 8.3 Superimposed east-west sections through the Sterkfontein hill showing the altitudinal relationship of various deposit masses (see text for explanation)

many seem to be related, and thus to make some proposals about the relative ages of the deposits and their effect on the morphology of the cave system. All the main deposits will be discussed except Elephant Deposit and the Fault Cave Deposit since these lie distant from all the other debris bodies.

8.2.1 Fossil Deposit and the Daylight Deposit

The Daylight Chamber lies directly beneath the Extension Site of the Fossil Cave. The south wall of this Chamber, discussed earlier, was regarded by Robinson (1962) as the south wall of the original Fossil Cave. However, Robinson did not suggest that the Daylight Deposit might be connected with the Fossil Deposit, even though the floor, and the north and east sides of the Daylight Chamber consist of breccia.

This connection seems very likely however, since Fossil Deposit overlies the east end of the Daylight Chamber (Fig. 8.2). Also the Extension Site pit has been sunk into the breccias to a depth of 10m below datum, with no sign of the breccia terminating; and since the Daylight breccia rises up to 7m below datum (Fig. 8.3) it seems certain that the two breccia masses are in fact one. Since the Daylight breccia can be traced to a depth of 30m below datum, the Fossil Deposit would descend to this depth (Fig. 8.3).

8.2.2 Fossil Deposit and Milner Deposit

Robinson (1962) calculated that the apex of the 'Mound' debris cone (the large cone at the east end of Milner Hall) should lie directly beneath the Extension Site section of the Fossil Deposit. Hearing the sound of the excavators hammers above him he concluded that the apex of the Mound was not very far beneath the hillside. Robinson was correct about the position (point K', Fig. 8.2), and the apex is known to rise to within 11m of the pit in the Extension Site (Fig. 8.3).

Finding artefacts at the apex of the Mound, Robinson (1962) assumed that he had located the underside of the bone rich breccia (point A, Fig. 8.7e) of the surface Fossil Deposit.

However, several specimens of bone material have been encountered at a lower level in the Mound breccia (pink breccia attached to the wall above the younger Mound material), which Robinson regards as recemented bone-free breccia (point B, Fig. 8.7e). For this and other reasons (8.4.3 below) Robinson's interpretation seems incorrect. The debris mass of the Mound has presumably infiltrated down the avens aligned along the various fracture zones; it seems reasonable to suppose that the Fossil Deposit is thus connected directly to the Mound Deposit, as well as to the Daylight Deposit. As such, the Fossil Deposit would extend downwards as far as 42m below datum, to the floor of Milner Hall (Fig. 8.3).

8.2.3 Fossil Deposit and the Terror Deposit

It will be recalled that Terror Chamber is formed entirely as a collapse void within a cemented deposit. The west end of this chamber lies directly beneath the Mound apex (point K', Fig. 8.2) and at exactly the same level as the tourist pathway cut into the Mound (33m below datum - Fig. 8.3). It seems definite therefore, that the west end of the Terror Chamber has formed within the Mound debris cone.

The Terror Deposit furthermore, stretches to the east in a continuous body forming the roof and walls of almost the entire chamber except for the extreme eastern end. It will be noticed that this deposit lies directly beneath the Fossil Deposit over this distance, both deposits being aligned along fracture zones 4 and 5 (Fig. 8.2).

The east end of the Terror Chamber itself suggests that this connection exists: a vertical dolomite wall, discussed earlier (6.2.2(3)), stretches upwards continuously for at least 22m, which indicates that for most of the vertical distance to the surface there is a sheersided slot, or narrow vertical chamber with no impediments to incoming debris, (points Y' and Y, Fig. 8.3, and point Y, Fig. 8.2).

Furthermore, the breccia deposit in the Skull Recess (point Z, Fig. 8.3) is only 6m above, and south of the dolomite wall (point Y). Since the Skull Recess deposit is connected to the Fossil Deposit, it seems probable that a connection exists at both the eastern end of the elongated Terror Chamber and at the western end.

It hard to resist the suggestion that the Fossil Deposit descends continuously to the Terror Deposit, forming perhaps the largest mass of breccia in the cave system.

8.2.4 Fossil Deposit and the Exit Deposit

The Skull Recess deposit, which is visibly connected to the Fossil Deposit, lies directly above the small Exit Deposit on fracture zone No. 5 (Fig. 8.2). The shortest distance between the two is about 7m, and thus the connection seems to be fairly certainly established. In turn there may be a connection between the small Exit Deposit and the easternmost part of the Terror Deposit (E - E', Fig. 8.3), in that one lies only 10m vertically above the other on fracture zone No. 4.

8.2.5 Entrance 6 Deposit and Graveyard Deposit

Entrance 6 and its deposit lie directly above and only 10m from the Graveyard Deposit on fracture zone No. 4 (Fig. 8.2). It seems likely that the debris of the latter deposit entered via Entrance 6, although it may also have been supplied from the large Exit Deposit underneath a hanging dolomite wall (point W, Fig. 8.2).

8.3 I cations of the Characteristics of the Deposits

The deposits discussed above have all affected the internal morphology of the cave system profoundly, and it seems, furthermore, that certain features are characteristic of all deposits. These may be summarised as follows:

(i) The deposits all occupy fracture-zone cavities in the system;

(ii) They all consist of surface debris;

(iii) All appear to be connected directly, along the fracture zone, with surface breccias, (Fossil-Daylight connection, Fossil-Mound-Western Terror connection, Fossil-Skull Recess-Small Exit-eastern Terror connection, and Entrance 6-Graveyard and/or large Exit connection) and all descend to the lowest known levels of the cave system.

With this pattern of characteristics now discerned, it is possible to hypothesise with more assurance about the nature of other important deposits in the system, namely the Elephant, large Exit and Fault Cave Deposits, all of which have affected the morphology of the system to the degree of truncating and entirely blocking several sections of the sys. It seems likely, for instance, that the low-level Elephant Deposit, which straddles several fractures, extends up to the surface of the hill, and that the original Elephant Chamber void extended southwards many metres at least. Similarly the low-lying Milner breccia (point G, Fig. 8.2), which occupies fracture zone No. 4, may extend upwards to Lincoln's Cave, which also occupies this fracture zone (points S and T, Fig. 8.2). Two mud-filled sumps, at points S and T, at present collect modern soil in Lincoln's Cave, and these sumps may have been source-points the Milner Deposit. The very large, low-level (+31m below hill surface) Fault Cave Deposit (points D and E, Fig. 8.2) may also adhere to the pattern discerned for the Fossil and related deposits: the fact that it lies so deep underground, consists of externally derived material (as far as can be seen), is large in volume and occupies an approximately linear passage, suggests that it is in reality a fracture-zone slot-filling which therefore extends, in all probability, to the surface. The thick talus cover on the lower slopes of the Sterkfontein hillock masks the dolomite fractures in the vicinity, however.

In contrast, the highlying (18-27m below datum) large Exit

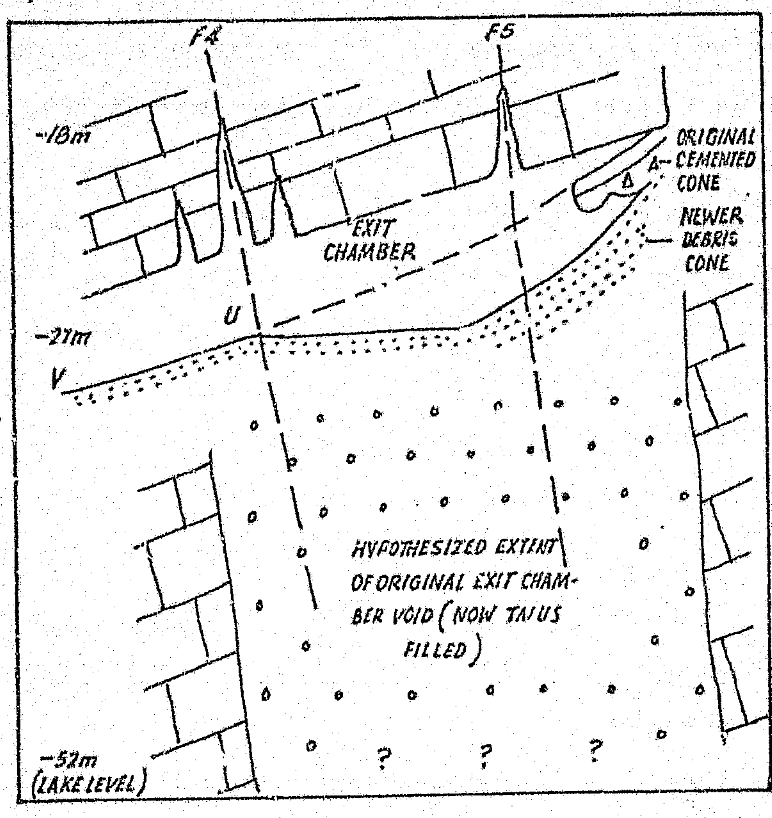

Fig. 8.4 North-south section through Exit Chamber showing possible development of original void and subsequent fillings

Deposit is probably only the topmost visible section of a very large deposit which extends downwards to the lowest levels of the system (45m below datum). (The visible part of the Exit Chamber void is determined by two fracture zones (Nos. 4 and 5, Fig. 8.2), and also occupies the area between these two fracture zones. It is likely therefore that it descends as far as other fracture zone voids in the system). The sloping floor of passage U-V leading off northwards from the Exit Chamber, is probably a modified debris cone slope (Fig. 8.4).

Future research will determine whether or not these hypotheses are correct.

Besides morphological implications, this study of cave deposits also has archaeological implications, especially with respect to dating. As argued above, it is expected that the Fossil Deposit extends continuously downwards in the cave system almost to the level of standing water, a distance of almost 50m. It is therefore reasonable to expect that lowest parts of the deposit are older than the highest parts. Excavation has reached a depth of 7m (Extension Site), a thickness which Robinson (1962) very roughly gauged might represent a time span of up to 10 000 years. Brain (1958) attributed the 11m thickness of the Limework's deposit (Makapan Caves, N. Transvaal) to the dry peak of the first Interpluvial of the Pleistocene. It seems, therefore, that the lowest parts of the large Sterkfontein deposits may contain significantly older archaeological material than has yet been found, especially since it is known that all the cemented deposits contain bone material and that the Mound breccia contains artefacts (Robinson, 1962).

No bone or artefact material has as yet been encountered in the unconsolidated portions of the various deposits, whether these unconsolidated deposits are simply collapsed and subsided parts of the breccia bodies, as Robinson (1962) suggests, or whether they are newer deposits incorporating reworked material altogether, as has been argued below (8.4.3).

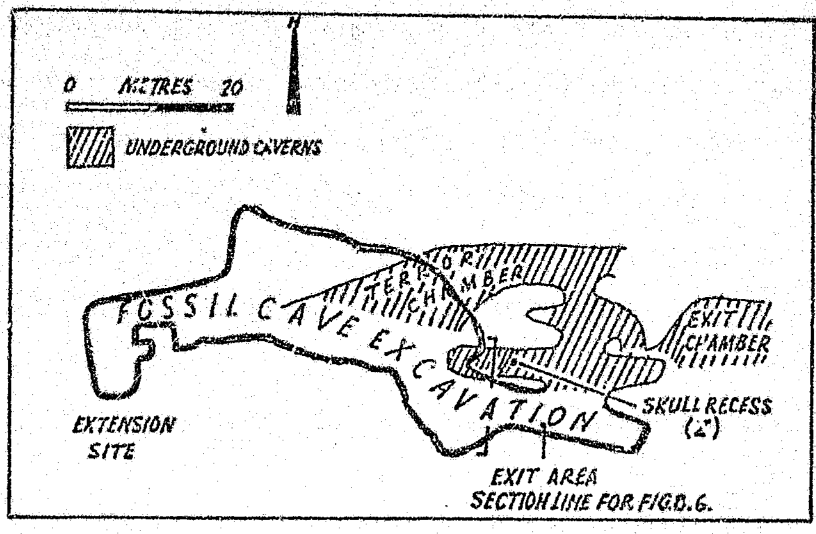

Fig. 8.5 Plan of Fossil Cave excavation and part of the underground caverns

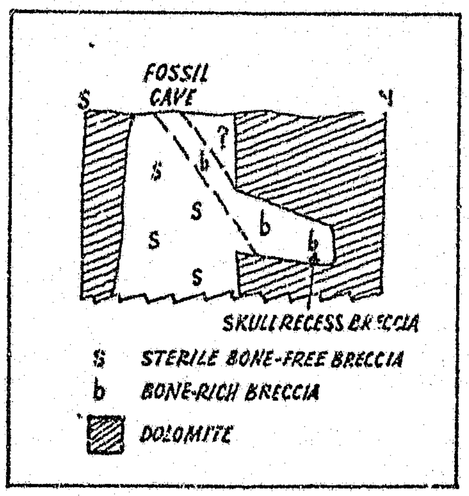

Fig. 8.6 Relationship of Skull Recess Deposit to bone-rich and bone-free breccias of the Fossil Cave (after Brain, 1958)

The implications of an understanding of the large Sterkfontein deposits, both for cave morphology and for archaeology, should stimulate further study of these deposits, in the same way that the Fossil Cave deposits have been closely analysed.

8.4 Examination of the Theories of the Fossil Deposit Development

Several workers in the past have examined the Fossil Cave deposits, and various interpretations have ensued. Because archaeological and especially climatic discussion is based on the stratigraphy of the deposit, an attempt is made here to reconcile the main interpretations which have arisen, (especially those of Brain, 1958; Robinson, 1962 and Brink and Partridge, 1970), in the light of new information.

Brain (1958) interpreted the deposit as one conformable mass of breccia with different properties at different levels. Robinson (1962) however, regarded them as three unconformable deposits, which allowed him to reinterpret climatic and archaeological evidence quite differently (see Chapter 2). Brink and Partridge (1970) reinterpreted the bone-poor breccia and identified a new breccia lying along the north wall of the Fossil Cave. Only Brain has mentioned the Skull Recess breccia (Fig. 8.5), a breccia lying just inside the mouth of the Tourist Cave, off the Exit Area (point Z, Fig. 8.2). By means of breccia matrix analysis, Brain found that this breccia was 'comparable' to the bone-rich breccia of the Fossil Deposit; he therefore concluded that it was connected to this breccia, overlying conformably the bone-free breccia (Fig. 8.6, after Brain, 1958). The present writer finds no such connection, and hence regards the Skull Recess breccia as another separate body of breccia within the Fossil Deposit. Its relationship to the other breccias is discussed below.

8.4.1 Origin of the Bone-Poor Breccia (Robinson's (1962) Lower Breccia; Brink and Partridge's (1970) 'Class II' Breccia)

Brink and Partridge (1970) regard the bone-poor breccia as a collapse deposit, because of the sharp-edged, unweathered appearance of the constituent dolomite blocks, the abundance of these blocks, the proximity of the blocks to one another, the existence of air filled interstices in parts, and the lack of a sandy matrix in many places, the blocks being cemented purely by travertine.

This interpretation conflicts with that of the earlier workers who considered the bone-free breccia to be a gradual accumulation. The solution to this problem seems particularly difficult since the breccia matrix particles show definite changes from one level to another, changes which have been interpreted as indicating a climatic fluctuation (Brain, 1958); i.e. matrix accumulation lasted long enough to overlap changes in climate. It is difficult therefore, to see how the deposit could have accumulated suddently as evisaged by Brink and Partridge.

The solution to this problem has been indicated by Brink and Partridge (1970). They point out that the bone-poor breccia contains pockets of sand within it which have probably 'subsided' from the sandy overlying bone-rich breccia (Brink and Partridge suggested that the entire mass was cemented after the sand had subsided, but this is unlikely since Brain has shown that it everywhere contains more than 60% calcium carbonate cement by weight, indicating simultaneous cementing, not subsequent cementing - Brain, 1958).

The mode of accumulation of the sandy pockets envisaged by the present writer is less one of subsidence prior to cementing and more one of infiltration into the interstices of the collapse blocks, simultaneously and perhaps with the aid of percolating water.

It is felt that this mode of accumulation, if correct, has implications which may invalidate Brain's climatic inferences, though there can be no doubt that he has ascertained conclusively that the breccia matrix has a differing character from level to level.

8.4.2 Implications of the Collapse Theory of Origin of the Bone-Poor Breccia

The main implication of the finding that the bone-poor breccia is a collapse deposit, is that Brain's (1958) matrix analysis (of this breccia) does not necessarily have climatic significance: it seems likely that the infiltration process referred to above, to explain the presence of sand pockets in the rapidly accumulated collapse deposit, is an extremely complex one, if not a chaotic one.

(i) The infiltration process may involve preferred pathways of infiltration which would lead sand to lower levels. Interstices set apart from such pathways would only be filled after the pathway cavities had been - i.e. sand pockets would not have accumulated chronologically with height, as Brain assumed they had, an assumption basic to his and to Robinson's climatic interpretations (Brain, 1958; Robinson, 1962). Percolating water is likely to have aided the process substantially since it is improbable that it flowed through the collapse deposit uniformly. Sand penetration thus relates most probably to preferred pathways leading through the deposit, pathways determined locally by larger voids in the deposit and/or by the routes of percolating water.

(ii) There may also have been sand particle sorting during the infiltration process: the rounded particles and the quartz grains (the concentrations of which are Brain's (1958) evidence for climatic fluctuation) may be transported differently to the angular and the chert grains. Brain (1958) himself shows that the particle size increases on average from the top to the bottom of the breccia matrix, but he offers no explanation for this (Brain, 1958, p.49). Coarser particles may in fact penetrate further the interstices of a collapse-block mound. And this size sorting with depth may affect angularity and quartz ratio measurements if there are varying proportions of these particles in different size

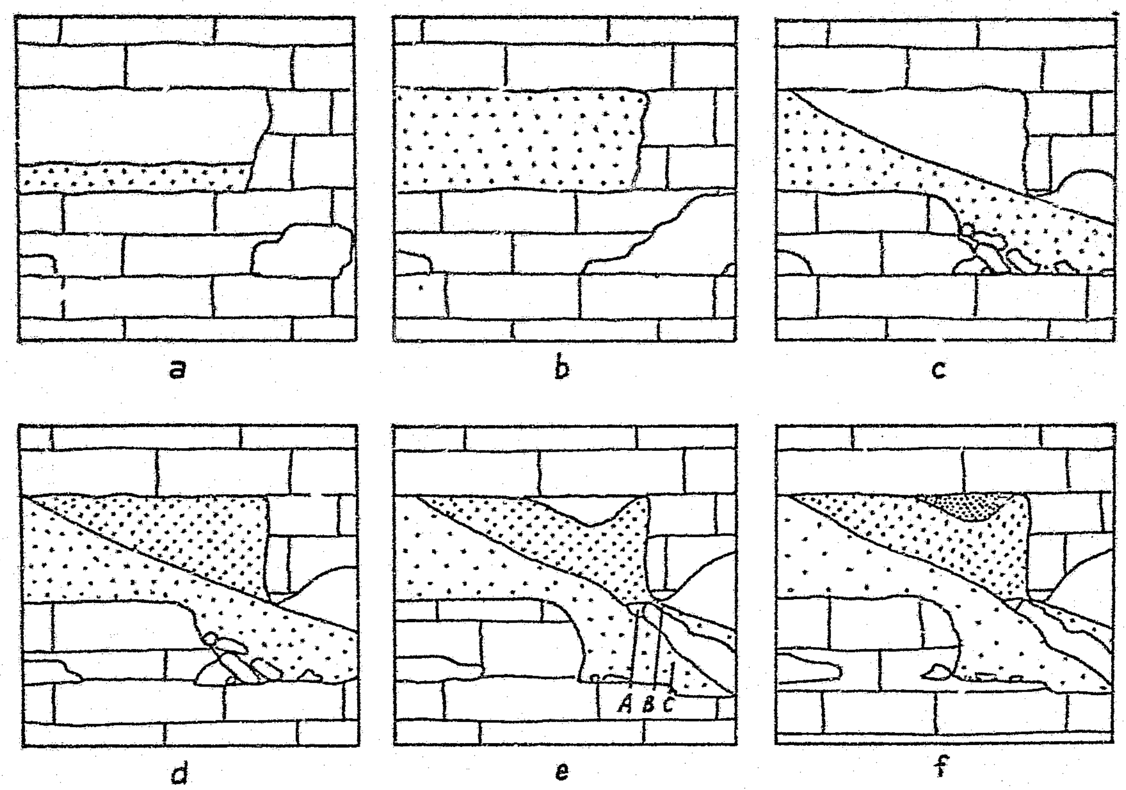

Fig. 8.7 Stages in the development of three unconformable breccias in the Fossil Cave (after Robinson, 1962) Diagrams a and d illustrate additional sections at right angles to the others. a and b show the accumulation of lower breccia and the growth of a lower cavern system. Some time after the fossil cavern filled to the roof, the floor collapsed at the western end (c) opening a new cavity. This filled up (d) wich middle breccia. Then a smaller-scale collapse occurred again (e) opening a smaller cavern, which filled with upper breccia (f).

fractions (Brain only examines the 35-60 mesh particles) in dolomite soils.

For these reasons it does not seem valid to ascribe climatic interpretations to variations which undoubtedly do exist in the breccia matrix, because of all the complex influences which can reasonably be expected to have controlled the infiltration of earth into a collapse deposit of dolomite blocks.

Brain's subsequent analysis of the uppermost chocolate breccia (Robinson's 'Upper Breccia') however, certainly seems to have meaning especially when compared with the analysis of the bone-rich breccia, since both of these deposits are gradual accumulations (see Chapter 9, Climatic Evidence).

8.4.3 Robinson's Theory of Origin of the Fossil Deposit

Because Robinson (1962) regarded the bone-poor breccia as a 'gradual' accumulation, there had to be a reason for the change to a bone-rich breccia overlying this. Robinson proposed that the bone-poor breccia had filled the original Fossil Cave to its roof, (Fig. 8.7b) and that the subsequent bone-rich breccia was deposited only once a void had been created again within the cave. The mechanism he advocated for this was collapse of the Fossil Cave 'floor' with consequent subsidence of the bone-poor breccia into the underground caverns (Fig. 8.7c). The bone-rich breccia then accumulated in the space previously occupied by the bone-poor breccia (Fig. 8.7d).

To explain the abrupt change in deposits from the bone-rich breccia to the small overlying chocolate brown breccia, Robinson used the same argument - namely, subsidence of the bone-rich breccia creates a space which can be filled by the chocolate brown breccia (Figs. 8.7e and f). In this way it was possible to explain the existence of three separate, unconformable breccias in the Fossil Cave. However, there are various objections in this formulation:

(i) There is no need to advocate large-scale subsidence of the bone-free breccia into the underground caverns to explain the existence of the overlying bone-rich breccia, if the former is regarded as a collapse deposit: a collapse deposit necessarily cannot fill the original cave to the roof, and hence there must be space above it in which the bone-rich breccia might collect.

It seems unnecessary to advocate a second slumping of the bone-free breccia to explain the existence of the chocolate brown breccia. The chocolate brown breccia is at present a small body, and there is no evidence of it having been large or widespread. Minor slumping and compaction of the very large bone-rich breccia seems a far more likely explanation of the way the chocolate breccia void was formed. Since Robinson regarded the bone-rich breccia as 'a maximum of 20 feet thick', compaction would not have been considered. However, it has been argued at length that this breccia descends even now 33m below the surface, a mass in which compaction very probably did occur.

It seems more likely that the bone-rich breccia grew upwards from the Milner floor, until at the level of the Skull Recess, accumulation was interrupted by the collapse of the bone-poor deposit, and then continued, sandwiching the latter. This explanation accounts for the fact that the Skull breccia accumulated under climatic circumstances similar to those of the lower bone-bearing breccia in the Fossil Cave (Brain, 1958).

(ii) Robinson claims to have found blocks of bone-poor breccia cemented in the Milner breccia (B, Fig. 8.7e), and quotes these as evidence of the initial collapse of the former into Milner Hall. The present writer has encountered no such blocks of the distinctive bone-free breccia either in the Milner breccia or anywhere else in the cave system.

(iii) Robinson interprets the Mound (Milner Deposit) as the subsided portion of the bone-free breccia (point C, Fig. 8.7e). This seems unlikely for various reasons: firstly, it contains no cemented breccia blocks; it is entirely unconsolidated, as far as can be seen from the 3m excavation i' the side of the deposit, and from the other parts. It seems impossible that this supposed collapse section of a deposit should be so completely and uniformly decalcified that there would be no trace of the original cemented mass. Secondly, this unconsolidated deposit contains no dolomite blocks even of a small size, the largest material being a coarse gravel. Both the bone-free breccia and the bone-rich breccia contain dolomite blocks, especially the former, and one would therefore expect to find such blocks in a deposit derived from either of these. Thirdly, it seems improbable that a collapsed deposit would retain any semblance of layering. Yet the unconsolidated Mound cone is distinctly layered with no evidence of disturbance due to collapse or subsidence (Fig. 6.6).

In short, this unconsolidated mass appears not to be derived as a subsidence feature of an earlier breccia cone, but to be a younger, as yet uncemented deposit, altogether different from the breccia material.

The alternative to Robinson's model may be summ ed as the following:

A bone-rich material enters the cave system, along well-developed vertical avens, and comes to rest in the lowest parts It becomes cemented by percolating $CaCO_3$-rich water. As it is filling a cavity in the upper levels (present Fossil Cave), a roof collapse occurs depositing a heap of closely packed dolomite blocks. The bone-rich material continues to accumulate slowly (now on top of the collapse cone), as some matrix-forming soil penetrates the collapse deposit beneath. The dolomite collapse blocks and pockets of sand, by means of percolating water are cemented into a hard bone-free breccia. The lower parts of the bone-rich material, also cemented by this stage, are attacked by rising phreatic water, undermined, and removed, allowing the influx of new hillslope debris. The roof of the upper cavity (Fossil Cave) is slowly removed, exposing the fillings to attack and decalcification by meteoric water. The effect of attack becomes very pronounced in parts, such as the Exit area (8.5 below).

8.5 Decalcification of the Fossil Deposit Breccias

One of the final stages in the evolution of the Fossil Cave breccias involves the major modifications of the breccias by decalcification and erosion, and the corresponding recent underground deposition. Brain (1958), Robinson (1962) and Brink and Partridge (1970) all refer to the pockets of earth which occupy hollows in the surface breccias, and attribute them to decalcified bone-bearing breccia because of the rich accumulations of bone and artefact material in them. Brink and Partridge (1970) also refer to solution pockets which have pierced the cave system in various places. Decalcification thus appears to be commonplace in the Fossil Cave breccias. However, previous writers have not invoked this process to explain any large features: it seems to the present writer that the development of the entire Exit Area, and the Daylight Chamber, can only be attributed to decalcification. It was postulated earlier that the Exit Area fissure was probably ultimately completely filled with breccia at least to the level of the present hill surface. It is now postulated further, that once this breccia body was exposed directly to aggressive meteoric water, that large-scale decalcification ensued, the water percolating into the voids beneath, transporting the loosened breccia material with it once routeways had been established.

It seems quite possible that given sufficient time, an aperture as large as the present Exit Area (Fig. 8.5) could have been fashioned, an aperture leading not only into the shallow-lying Exit Chamber, but also into the lowest part of the Cave (eastern Terror Chamber, Fig. 8.5).

The same decalcification and erosion process is believed to have

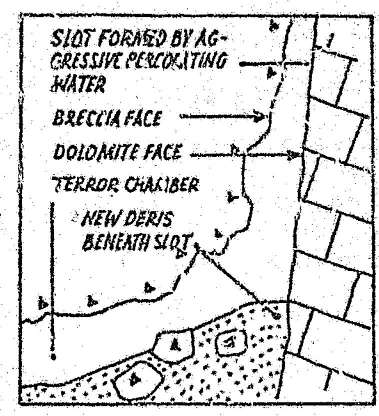

Fig. 8.8 High vertical slot, Terror Chamber, showing opposing breccia and dolomite faces

eroded the aperture in the Daylight Chamber roof, and thereafter to have removed those parts of the Daylight Deposit breccia which lay against the dolomite south wall of the chamber.

This theory seems the only tenable one in that there is no evidence that the apertures and shafts originated by collapse into the underground caves. Also it seems to be the only theory which can explain the existence of bare, vertical dolomite walls in close proximity to walls of breccia, a situation which occurs in both Daylight and Terror Chambers. It appears that the breccia bodies in both cases once lay up against the dolomite walls which contained the early uncemented debris. However, once the debris mass had hardened, the cave above was deroofed, aggressive water percolated downwards, and the breccias were removed from these walls, which are situated beneath the source of the percolating water. The main breccia mass was rigid enough not to collapse once the support of a containing wall had been removed (Fig. 8.8).

If the above process has indeed operated, then the large volumes of breccia removed have been deposited in the caves. The Terror Chamber, lying at the bottom of the re-established shaft, contains a cone of fine material directly beneath this shaft. Daylight Chamber, however, is purely an erosional feature, and the breccia removed during its formation probably contributes to the rise in floor level in Elephant Chamber beneath Entrance 1 (point 7, Fig. 8.2). Unconsolidated floor material in other parts of the cave system may also contain decalcified surface breccia material.

Except for small breccia solution pockets on the hill surface (Robinson, 1962; Brink and Partridge, 1970), features in the cave system arising from the erosion of the cave fillings and deposition of the eroded material - by the agency of percolating water - have not been mentioned before for Sterkfontein.

8.6 Assessment

Externally derived debris bodies have modified all the largest caverns markedly, usually forming the floor, certain walls and even the ceiling (the small northern deepset caverns have only been affected by internal collapse of minor proportions); because of the vast size of these deposits, and the fact that climatic and archaeological interpretations are inferred from them, they have been closely scrutinised.

The debris cone model was presented firstly to elucidate the apparent stages in the development of the debris cones in the cave system, and secondly to amplify Bretz's (1942) discussion of cave deposits which treats the 'clay-fill' deposits almost exclusively. No 'clay-fill' deposits such as those described by Bretz have been encountered at Sterkfontein. Sterkfontein appears to be unique even in the Transvaal on this particular score. The reason appears to be that phreatically widened fracture zones allowed coarse debris in large quantities to enter the cave system, as opposed to the fine clay particles which filtered into the American Caves (Bretz, 1942).

The importance of the fracture zones on deposit accumulation was stressed since fracture zone control explains the depth of debris penetration, the connection of surface and underground debris bodies as continuous masses, and the fact that these bodies appear entirely to consist of externally derived material.

Three partially concealed deposits (Elephant, large Exit and Fault Cave Deposits) have been discussed in the light of the proposed pattern of debris mass development. Fossil Deposit was also examined on this basis: Robinson's argument that the deposit contains three unconformable breccias (Robinson, 1962) was contested, and Brain's earlier view of a conformable breccia mass (Brain, 1958) supported. However, it was concluded that Brain's (1958) climatic interpretations are untenable in the light of Brink and Partridge's (1970) reinterpretation of the bone-free breccia. Large-scale decalcification and erosion of the Fossil Deposit was postulated to explain the present configuration of this exposed deposit (excluding small features like solution pockets). Corresponding deposition of the decalcified deposit material was recognised at two points in the Cave system.

CHAPTER 9 - CLIMATIC EVIDENCE

9.0 The evidence for large scale water level fluctuations underground has been presented. This consists of variable thicknesses of flowstone on the south wall of Milner Hall, different degrees of re-solution on this flowstone, and phreatic attack on the underside of hardened breccia masses in Milner Hall, Elephant Chamber, Terror Chamber, Exit Chamber and Fault Cave.

In addition there is evidence that the rate and type of calcium carbonate deposition has been variable in the past and is now virtually nil.

These phenomena will be discussed with particular reference to a climatic oscillation explanation.

9.1 Water Level Fluctuations

Re-solution features on the Milner Hall wall flowstones, and also on breccias at different levels within the cave system have been described. Various explanations are considered.

9.1.1 Climatic Change

It has been postulated that longterm climatic oscillations cause water-level changes in a cave: Marker and Brook (1970) made tentative climatic interpretations from the abundant evidence for water level fluctuations in Echo Cave, 320km east of Sterkfontein, since theoretically it is reasonable to suppose that a wet climatic phase would raise the level of the surface of the saturated zone in a rockmass. It has been shown that the water bodies in Sterkfontein are probably connected, and that the connections must be poorly developed in order to preserve water body levels at different heights (-40m to -60m).

An increase in the supply of water during a wet climatic phase might thus be expected to cause a rise in water levels. Similarly there is undoubtedly a direct relationship between dry climatic phases and low water levels in cave systems.

9.1.2 Weather

Short-term, large magnitude water level changes can result from long return floods. Such high water levels are of short duration and appear to cause minimal, if any re-solution. The chance of such random events raising cave waters to the same level on more than one occasion is remote and visible stillstand levels would not therefore be imprinted on wall travertines. Furthermore seasonal and long return underground water level fluctuations are of small vertical magnitude in areas of low relief amplitude. They reach major proportions only in areas of great dissection and high seasonal rainfall.

9.1.3 Blocking of Primitive Water Routes

Another factor which may come into play is the effect of blocking. The narrow, primitively developed connecting passages between the water bodies (and between the water bodies and the resurgence) may become blocked by insoluble residues. Such blockage would be random and independent of climatic oscillations, but would nevertheless affect water levels within the cave.

9.1.4 Cut and Fill

It is generally accepted that episodes of cut and fill in river valley alluvia are causally related to climatic oscillations. Such episodes may influence the resurgence levels for ground water. The precise relationship of cut and fill phases to changing climatic conditions is not yet fully elucidated, although it is generally believed that cutting results from arid phase flash floods. Nevertheless, it remains difficult to equate episodes of cut and fill in the drainage line with water level

FEATURES	RE-SOLUTION LEVELS (METRES ABOVE THE LAKE)	FIRST INTERPRETATION	SECOND INTERPRETATION
THICK FLOWSTONE WITH TERTIARY GROWTHS	±8m	2	3
THICK REDISSOLVED FLOWSTONE WITH TERTIARY GROWTHS	5m	3	1
THIN REDISSOLVED FLOWSTONE WITH TERTIARY GROWTHS	2,3m	4	4
THIN REDISSOLVED FLOWSTONE	1,5m	5	2
BARE DOLOMITE WALL		1	
	0	6	5

Fig. 9.1 Re-solution levels on Milner Hall flowstone indicating past lake levels

changes underground caused by changes in rainfall.

9.1.5 The Amplitude of Water Level Fluctuation

The evidence for large amplitude water level changes underground in Sterkfontein is established. The causes of these changes are more difficult to ascertain. However, it seems as though climatic oscillations, whether directly or indirectly, must have caused at least some of the underground water level changes.

9.1.6 Climatic Interpretations

The climatic interpretations which can be made from the Milner Hall flowstone, and other localities where water level fluctuations have occurred, are discussed below. It is assumed that the levels of still-stand identified earlier (6.1) for the Milner Hall flowstone, are climatically determined.

(1) Milner Hall Flowstone

Two interpretations of the sequence of travertine deposition and re-solution are possible, one implying a single climatic oscillation, the other a multiple climatic oscillation.

Single Oscillation. The sequence of water levels is most simply interpreted as follows: firstly, an original high water level during the phreatic excavation of Milner Hall; thereafter a low water level, (level 1, Fig. 9.1)[1], allowing the deposition of flowstone over the entire south wall of Milner Hall down to the lowest existing level of travertine, (level 5). Then the water rises more than 6,5m (level 2), to dissolve the flowstone. The next four levels (3-6) occur at successively lower positions on the wall, as is evident by progressively more eroded flow-

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[1]Ensuing water level numbers refer to Fig. 9.1

stone, until between levels 5 and 6 the flowstone is entirely removed (if it ever developed at this level).

The tertiary growths developed on the travertine above the dropping water level, and apparently have not had time to develop below level No. 4. These tertiary growths may indicate a change in cave environment ending active flowstone deposition.

This interpretation raises certain questions: for example, it is not clear why there should have been a sudden large rise in water level (of 6,5m) and then several small lowerings. This appears inconsistent and suggests that the water may have risen in stages as well, the evidence of which has been destroyed or rendered unrecognisable.

Another possibility is that the small lowering stages represent fewer periods of actual still stand: the present-day lake fluctuations are as large as 1,5m, and therefore the distance between levels 4 and 5 may also represent the fluctuations during one stillstand rather than two. This argument may also apply to the fluctuations between levels 3 and 4, and 5 and 6 although fluctuations of 2,7m and 2,25m[2] seem somewhat extreme during one climatic regime; it seems possible that the phase of dropping water levels in this sequence represents as few as two still stands, not four, a conclusion which fits better with the initial single large rise of water level. The degree of speculation in this interpretation, and the next render these conclusions very tentative as yet.

Multiple Oscillation. This interpretation arises because the upper, thick portion of the travertine can be regarded as the older Deposit, and the lower, thinner portion as the younger, with a time-gap separating the two. Level 3 divides the two, and if it is regarded as the first

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[2] Present-day lake level as indicated on Fig. 9.1 is a mean lake level: the 1,5m distance between levels No. 5 and 6 increases to 2,25m during very dry seasons.

level of this sequence, then the chronological order of the levels is 3 - 5 - 2 - 4 - 6:- when the water level drops from the first position (level 3) to level 5, the thinner travertine is deposited, with the thick travertine all the while becoming thicker. Then the water rises to level 2 dissolving both thick and thin travertines. The water thereafter drops to level 4 and then to level 6.

If the first level (3) is taken as a high level, the sequence indicates two wet climatic phases (levels 3 and 2) and two dry phases (4 and 5). The high water level which seems required in a regular sequence such as this between level 5 and 6, may indeed have occurred without leaving any recognisable trace on the travertines. If this is accepted then the sequence represents three high levels alternating with three low levels - i.e. three wetter climatic phases separated by three drier. This interpretation is in marked contrast with the first which involves only one climatic fluctuation.

In this interpretation it seems unlikely that fluctuations during one climatic phase could explain any two of the observed water levels, as was possible above. However, the effect of river bed incision is likely to be more pronounced during the period of 3 oscillations. Marker and Brook (1970) argue conclusively that the water level fluctuations in Echo Cave are best explained by relatively small changes (due to climatic oscillation) superimposed or a general lowering of ground water (due to river incision). The levels in Sterkfontein suggest an opposite trend however: the second high-low fluctuation (levels 3 and 4) is at a higher level than the first (levels 1 and 2). This may indicate that the second oscillation was far more intense than the first (intense enough to offset the lowering due to incision); or it may indicate that the effective resurgence level in the Blaauwbank River alluvium had risen slightly, as it seems possible that during a wet phase the lower levels of the alluvium

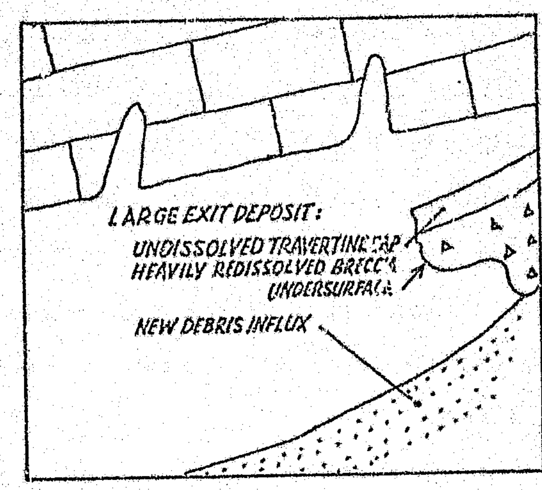

Fig. 9.2 Re-solution of the Large Exit Deposit breccia

would become saturated, thereby raising the effective level of the underflow from the alluvium/bedrock contact to some slightly higher position.[3]

(2) Mound Breccia

It has been argued that the Mound breccia was deposited and cemented simultaneously in an air filled chamber, and that the resolution of this breccia must therefore indicate a rise in water level. This rise is best explained as a response to a wetter climatic phase. The magnitude of the rise, as far as can be ascertained, was approximately the same as that on the wall flowstone (9m).

(3) Exit Chamber

There is evidence of a re-solution phase in the Exit Chamber on the underside of the large Exit Deposit breccia. This breccia hangs from the cave wall, its base removed by re-solution. Its evolution is similar to that of the Mound breccia in that it is a hard breccia which must have accumulated in an air-filled chamber. The ground water then rose and attacked the base of the breccia cone, removing and dispensing the material, and leaving the upper part of the cone suspended from the wall (Fig. 9.2). The water subsided (it now lies 26m below the large Exit breccia) thereafter.

The implication is that a wetter climatic phase caused a long-term rise in water level.

9.2 Changes in Travertine Deposition

9.2.1 Calcite Straws

Vogel and Partridge dated an inner and an outer wall of a calcite straw 4,5m above the water level in Ravjee Cavern. These walls

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[3] It has been argued above (7.2.3(2)) that since water levels in the caves are generally lower than the riverbed, the cave water resurgence is probably at the dolomite/alluvium contact 12m lower than the riverbed.

appear to have been deposited at different times, the earlier at some date before 47 000 years before present, and the older at some date before 50 000 years before present (Vogel, 1970). It is presumed that a change in cave environment must account for the cessation in calcite deposition represented by the unconformity between the inner and outer walls of the straws.

A dry climatic phase could explain the cessation and a wetter phase the resumption of calcite deposition. However, both immersion during a period of high water levels, and also the possible blocking of the percolation routes, could account for the break in $CaCO_3$ deposition on the straw. The last explanation is unlikely, however, since several of the straws in Ravjee Cavern are composed of two separate layers of deposited calcite. Immersion in cave water seems unlikely as no obvious re-solution evidence can be detected on the .traws, although it is possible that the period of immersion, and consequent hiatus in calcium carbonate deposition, was short, neither destroying the calcite straws nor re-dissolving them noticeably. Changes in the supply of $CaCO_3$-charged percolating water thus seems the most plausible explanation. And this factor is best attributed to climatic oscillation.

9.2.2 Thick and Thin Travertines

Ravjee Cavern contains a great thickness of travertine near the present water level. The travertine has been severely attacked by re-solution.

The small calcite straws mentioned above are clearly younger than the phase of thick travertine deposition, since they occur at the same level, but display no trace of re-solution. The difference in quantity of $CaCo_3$ deposited before and after re-solution is so marked that it is pertinent to ask why this has come about. The two walls of the calcite straw dated by Vogel (1970) yielded ages of greater than 47 000 years before present and greater than 50 000 years before present, which suggest that enough time has elapsed for the deposition of large speleothems if conditions suitable for such deposition have existed. Two explanations arise for this marked change in speleothem development, before and after the period of re-solution: firstly that the percolation routes have been blocked in some way, limiting the supply of charged ground water into Ravjee Cavern; and secondly that the concentration and supply of charged ground water has been climatically controlled, such that a thick mass of travertine developed, succeeded by a period of calcite straw formation. Both explanations appear plausible in the setting of Ravjee Cavern.

9.2.3 Aragonite Crystals

These crystals develop on various surfaces within the cave system, and appear to grow best on travertine deposits, in badly ventilated, humid recesses. These younger crystals protruding from travertine surfaces are relevant to this discussion because they indicate a change in the conditions of $CaCO_3$ deposition. They are younger than the underlying travertine and far smaller in dimension.

Aragonite crystals are preferentially precipitated in the presence of a foreign ion (magnesium in the case of the Transvaal system dolomites). Marker (1973) has shown that the magnesium/calcium ratio increases when the rate of solution decreases, and that crystal formation can therefore be attributed to a period of diminishing karst solution.

9.3 Dating the Water Level Fluctuations and $CaCO_3$ Changes in Deposition

Since evidence of climatic change becomes more meaningful once it is dated, dating information will be discussed.

9.3.1 Dating the Ravjee and Milner Deposits

It has been mentioned that the inner and outer walls of a calcite straw in the Ravjee cavern have been dated as greater than 47 000 years before present, and greater than 50 000 years before present, which gives a partial indication of the age of the straw. The thick travertine in Ravjee Cavern, the Milner Hall flowstone and re-solution features imprinted on them can only be dated relative to the straw. Both deposits must be older than the straw because both have been heavily redisolved whereas the straw has not, even though they lie at similar levels.[4]

Another approximate indication of the age of the Ravjee Cavern and Milner Hall speleothems, and their associated phases of re-solution, exists in the relation of these speleothems to the Mound breccia. Above the highest re-solution level (level 2, Fig. 9.1), the Milner Hall flowstone has not been attacked by phreatic water, whereas the Mound breccia has suffered phreatic attack. Since the Mound breccia is 13m higher than level 2 it becomes apparent that the travertine and the flowstone were deposited and redissolved after deposition and re-solution of the breccia had occurred. It has been suggested that the bone-rich breccia in the Fossil Cave may be as old as 1,75 - 2,50 million years old (Cooke, 1970). It was postulated earlier that the Mound breccia is connected to the bone-rich breccia. If this is true, the Mound breccia would be of similar age, i.e. 1,75 - 2,50 million years old. The phases of re-solution which have affected the Ravjee Cavern travertine, the Milner Hall flowstone and the Mound breccia would therefore have occurred after the deposition of the Mound breccia.

9.3.2 Aragonite Crystal Growth

Dating of the phase of aragonite crystal growth may be possible by the C^{14} method since it appears to be among the youngest phases of

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[4]It is assumed that the relationship between water levels and fluctuations of the water bodies have remained approximately the same.

deposition. In relative terms, however, the crystal growth has occurred since the re-solution of the Milner Hall flowstone: crystals have developed on all the redissolved surfaces except at the lowest levels (between levels 4 and 5, Fig. 9.1), where presumably re-solution has been more recent than the phase of crystal growth.

9.3.3 Exit Deposit

Dating of the Exit Deposit sequence of deposition and re-solution is also very approximate. It relies on Brain's finding that the hardest breccias are those which have been cemented during the process of accumulation (Brain, 1958). From this it is apparent that the Mound breccia was deposited and cemented simultaneously: it could not, for example, have been deposited in water and then been cemented once the cave water had subsided to lower levels.

Since the Exit Deposit re-solution features lie 20-24m below datum, it is apparent that the Mound breccia, at 30m below datum, was deposited after the phase of high water levels which attacked the Exit Deposit. Therefore the water and fluctuations which caused the re-solution of the Exit Deposit are older than the postulated dates for the deposition of the Mound breccia, namely 1,75 - 2,5 million years before present.

9.4 Assessment

It was argued that water level fluctuations and changes in $CaCO_3$ deposition in Sterkfontein may well be evidence for climatic change, especially the larger fluctuations and $CaCo_3$ deposition changes. All the evidence quoted suggests two climatic oscillations (from arid to humid, and back to arid) except for the Milner Hall flowstone which was susceptible to two interpretations, one suggesting two and the other suggesting more than two climatic oscillations.

The dating of the fluctuations is at present far sketchier than