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On the Geomorphic History of G.B. Cave, Charterhouse-on-Mendip, Somerset*

(O.S. 6 in. to 1 mile, ST 45 NE., N.G.R. ST 477562)

By

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CONTENTS

INTRODUCTION

This paper is based upon a chapter of the author's thesis "Aspects of the Geomorphology of the Mendip Hills" submitted to the Faculty of Anthropology and Geography, Oxford University, for the Doctorate of Philosophy. Much detail contained in the original has been omitted from the present account because of lack of space. The thesis may be consulted in the Bodleian Library, Oxford.

Between Wells in the east and the Winscombe valley in the west, the Mendip Hills are at their most massive. They present steep flanks to the valleys on the north and south sides which are at or close to sea level. The greater part of the upland is a dissected plateau on limestones, with an average elevation of 820–860 ft. Five major swallet caves have been discovered beneath it. They take surface streams from narrow exposures of impermeable strata down into the limestone and discharge them through great springs at the foot of the south flank. G.B. Cave is the most westerly of the five (*Fig.* 28, A). Its passages have an aggregate length of approximately 4,600 ft. on the plan and the deepest place (the terminus of present exploration down the course of the principal underground stream) is 430 ft. below the elevation of the entrance. The stream is discharged at the principal risings at Cheddar. These are a further 320 ft. below the elevation of the known terminus and 2,900 yd. south-south-west of it, measured on a straight line on the map.

The environs of the cave are shown in *Fig.* 28. It will be seen that the general organization of the structural geology is very simple although, within the cave, the local detail is rather complex (below). Strata strike east-south-east–west-north-west and, south of the crest of Blackdown, dip

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to the south at 25°–34°*. Blackdown itself is a whaleback eminence rising 200 ft. above the local plateau and composed of resistant quartzitic sandstones of Devonian age. The sandstones are the core of a pericline.

They are flanked by a narrow band of Limestone Shales, which are the base of the Avonian (Lower Carboniferous) rocks of the Mendip Hills. The Lower Limestone Shales are mechanically weaker than the strata above and below them, but are generally impermeable. Thus, their surface contact with

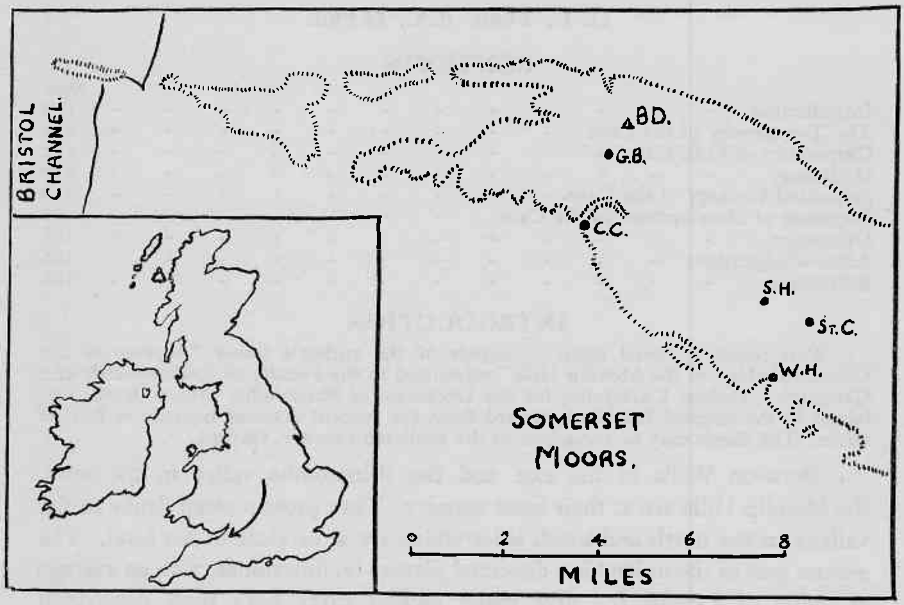

Fig. 28, A.—The western Mendip Hills, showing location of caves referred to in this paper. B.D.—Blackdown. G.B.—G.B. Cave. C.C.—Cheddar Caves and springs. S.H.—Swildon's Hole. St. C.—St. Cuthbert's Swallet. W.H.—Wookey Hole and spring.

the sandstones is marked by a line of springs and lesser seepages. Derived surface streams cross the shales and sink at the contact with overlying limestones. G.B. Cave is developed in the basal member of the Avonian limestones proper, the Black Rock Limestone (Kellaway and Welch, 1955). This is the purest of the Mendip limestones, dolomitization being minimal, described by Green (1958) as "dark grey and black, crinoidal, rather fine grained". It is 750–1,000 ft. thick. The only published analyses of composition refer to the type section at the Bristol Avon Gorge, 17 miles to the

* This is the range of local values measured by G. W. Green of the Geological Survey of Great Britain and plotted upon his 6-in. field maps of the locality. These maps were inspected by kind permission of Dr. F. B. A. Welch. *See also* Dr. Welch's papers (1929, 1932) upon the geological structure of the central and western Mendip areas.

north (Chapman, 1912). These are probably characteristic. CaO and CO_2 content ranges from 82·64 per cent to 97·85 per cent; MgO content from 1·73 per cent to 2·17 per cent, Fe_2O_3/Al_2O_3 from 0·29 per cent to 0·61 per cent and insolubles from 0·43 per cent to 14·51 per cent. Impurities were greater toward the base, in which G.B. is developed, but it will be seen that they are never very large in amount. Individual limestone beds are thin toward the

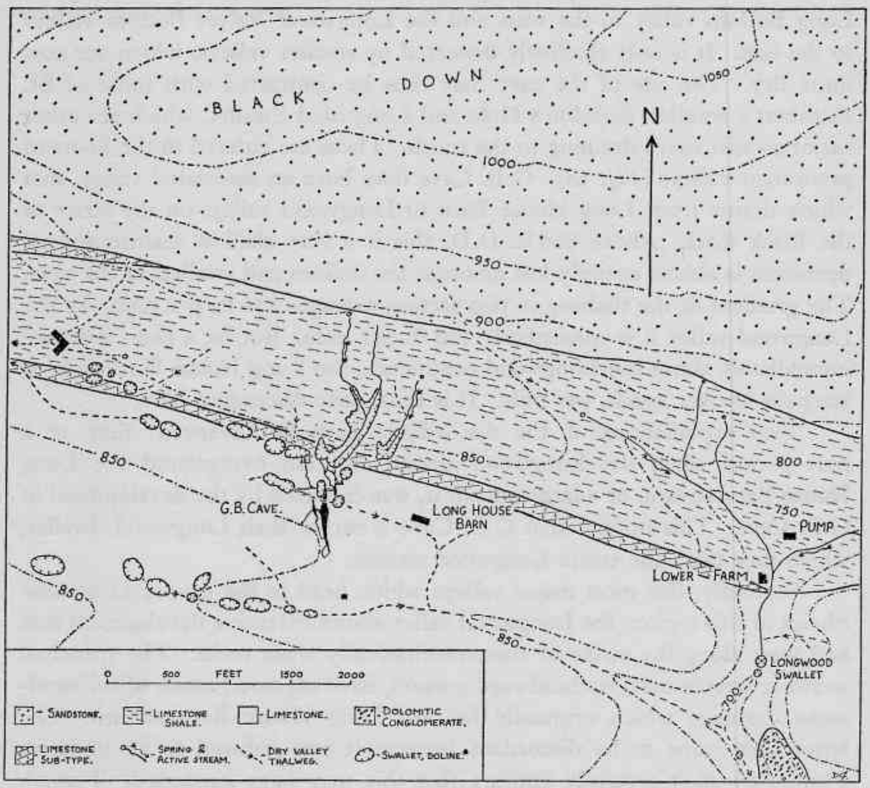

Fig. 28.—The environs of G.B. Cave. The swallets and dolines are drawn a little larger than true scale in this figure and their outlines are conventional. The terms are defined in the text, p. 153.

base (a matter of a few inches thick or less), and there is much thin shale and some chert interlamination. The karst groundwater, however, tends to penetrate particular bedding planes that are 2–8 ft. apart vertically so that the rock is quite massive in its geomorphic function. Shale or cherty planes are generally favoured for penetration.

In the G.B. locale the Lower Limestone Shales/Black Rock contact is marked by a limestone subtype of "coarse, crinoidal limestone with chert nodules and seams. Fossils are silicified."* This is some 60 ft. in thickness. It is prominent throughout the cave, which is also developed in some 100 ft. of the main Black Rock above it and penetrates 20–40 ft. into the passage beds of the Lower Limestone Shales beneath.†

The entrance to G.B. Cave stands at the centre of the northern edge of a broad platform on the Limestones, which extends to Cheddar Gorge and the southern flank of the Mendip Hills. The platform is bounded by the Long Bottom valley to the west and the Longwood–Velvet Bottom valleys to the east. It is only shallowly dissected by smaller valleys, which are now quite dry. The site of the cave may thus be contrasted with those of St. Cuthbert's Swallet, Swildon's Hole and Longwood Swallet, which are other major swallet caves draining to the south. These are entered in the floors of prominent valleys (*Fig.* 28). G.B. Cave does have an associated valley, that which drains from Long House Barn to Longwood valley, on the strike of the Black Rock. Above 800 ft. O.D. this is a very shallow feature and its definition is almost entirely lost amongst the dolines and swallets at the cave. The gradient of the thalweg in this section averages 170 ft. per mile. In the Longwood valley it is consistently 120 ft. per mile. But for a short distance immediately above the Longwood confluence, the Long House Barn thalweg steepens to over 400 ft. per mile. It is thus quite discordant here.

Two explanations of the discordance may be advanced: first, at a past period when the Longwood stream still ran overground the Long House Barn stream, or a large part of it, was captured by the development of G.B. Cave. This implies that G.B. Cave is earlier than Longwood Swallet, which now takes the entire Longwood stream.

Secondly, like most major valleys which head in the Lower Limestone Shales of this region, the Longwood valley shows extensive development east and west along the strike of these mechanically weak rocks. The principal westerly stream may, by headward erosion, have captured much of the sandstone drainage which originally fed the Long House Barn stream. The latter thus came to be discordant because it was reduced to an underfit. From *Fig.* 28 it certainly appears that this may have happened. Though lacking a detailed chronology of Longwood Swallet, which could be compared with that given below for G.B., it is not possible to eliminate the first alternative. From a preliminary inspection the writer suspects that Longwood Swallet is a little younger than G.B.; it is not sufficiently so to explain the full measure of the discordance of the Long House Barn valley. Headward capture at the surface is preferred as the principal explanation.

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* From the 6-in. field map by G. W. Green.

† Penetration of these strata in G.B. Cave is by mechanical processes of gravitational stream cutting only. At St. Cuthbert's Swallet, a large cave of similar depth five miles to the east, artesian phreatic cave development (*see* Stanton, 1954; Glennie, 1954) can be seen at points 120 ft. below the apparent top of the Limestone Shales.

The site of G.B. Cave is exceptional also because of the number of swallets and dolines which dot its surface.* At Longwood Swallet there are only two or three small and ill-formed depressions. At Swildon's Hole there is only one. There are at least nine substantial natural depressions close to or over parts of G.B. Cave. They may be divided into two groups:

First, depressions at the Limestone Shales/Black Rock contact. The greatest of these is that which takes the modern stream in one place and through which the cave is entered in another. As defined by Cvijic (1960), it is an *uvala*, or compound, form. At the contact it turns east–west along the strike for a distance of nearly 100 yd. This anomalous course has been an important factor in the development of the complex of passages in the Entrance area of the cave (below). The stream first sank in the extreme west, where the explorer now enters, but leakage upstream from its surface channel into the limestone led to the development of new, alternative, underground routes. The original sink is now isolated from the principal, wet weather, sink by a col. The wet weather sink is the second in a series of headward captures from the original position. In dry weather all of the water sinks yet higher upstream and is in the process of developing a sizeable new route which will, in time, absorb all the flow.

To the east is another large swallet with a short cave, Read's Grotto, and a lesser stream. Both stream and cave appear to be independent of the known parts of G.B. Cave.

Further depressions on the contact and to the west of the main swallet are associated with the "West Extension" inlet passage in the cave. These depressions are dry and much smaller. They are considered to be residuals of much greater swallets which once took a stream from the Limestone Shales that was independent of those feeding the modern main sink. The East Extension passage heads in a boulder-jammed shaft that is only 40 ft. beneath the surface. But there is no swallet or other depression to mark it. It has been completely erased.

Secondly, depressions to the south of the contact. These are dry. Most notable is the Great Swallet, which is 25 ft. deep and has sides that are nearly vertical.† It appears to be an obvious collapse feature, but neither it nor any of the other depressions in this group are related to the collapse upwards of any part of the known cave. They are attributed to infall at the head of rotted limestone pipes which fed tiny, local rivulets in as tributaries to the main flow sinking in the principal swallet. Great Swallet water is

* In this paper, the term *swallet* is applied to a closed surface depression which takes a permanent or semi-permanent stream. A depression which is dry, save in very wet weather, is a *doline*. *See* Coleman and Balchin (1960) for a discussion of the terminology of closed karst depressions.

† *See* plan in Bendall and Crickmay (1951).

probably represented by a drip that enters a small, fault-located, slot high in the roof of the main passage at the bend above the "Bridge" (below).

From surface configuration, the catchment area of the main swallet and of defunct streams which once developed the Extension and Rhumba Alley inlets is 196 acres (0·305 square miles). This yields an estimated flow of 0·425 c.f.s.* In wet years in the present climatic régime (e.g., the year April, 1960–March, 1961, inclusive) the mean rises to about 0·75 c.f.s. This appears to be a very small flow to open a cave that has some of the greatest underground passages to be found in the Mendip Hills. It is thought, however, that the catchment area, and hence the formative streams, was probably greater in the past.† Working along the strike of the Limestone Shales, the headwaters of the Longwood stream have probably captured about 50 per cent of the catchment fed to the G.B.–Read's Grotto streams. This greater past catchment would have yielded a G.B. stream roughly as large as the present-day one at Swildon's Hole, which is one of the greatest in a Mendip swallet cave.

An additional problem is created by the fact that more than half of the G.B. catchment is on the sandstones. Groundwater basins on these rocks need not conform to the size and shape of surface basins. Because the Limestone Shales' barrier rises higher to the west, it is possible that the G.B. stream includes water from an area west of the surface divide. Conversely, water is likely to be lost, particularly in dry weather, as a result of draw-down by Waterworks pumps placed at lower elevation to the east, at Lower Farm (*Fig.* 28).

THE TOPOGRAPHY OF THE CAVE

(*Figs.* 29 and 30)

This summary is intended to provide a background to the interpretation of form which follows. For its purposes, the cave may be divided into three areas.

1. *The Inlet Passages.* These are Entrance Passage, Ooze Passage, Mud Passage, Stream Passage, Double Passage, which together constitute the Entrance complex, Extension Passage and Rhumba Alley.

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* Mean stream flow, or run-off, was calculated in two steps: (a), mean monthly and annual precipitation figures were extracted from Hannell's equipluve map of the Bristol district (1955), which was modified by a study of short-term (up to 29 years) rain-gauge records on the Mendip Hills; (b), mean monthly and annual run-off was then calculated using the Thornthwaite method (1948, 1955, 1957) and Penman's southern English factors (1956). Mean monthly temperature was obtained by applying standard reductions to the figures for Long Ashton meteorological station (Hannell, 1955). All values quoted are likely to be a little conservative.

† And, of course, it must not be assumed that climate has remained constant.

Entrance–Ooze Passage, Mud Passage and Stream Passage are three semi-independent inlet passages which drop the cave 180 ft. from the main swallet to the Gorge. Double Passage is a loop which interlinks them at a higher level. Entrance–Ooze Passage is large and irregular in form in its upper parts, where it is partially choked with a fill of collapse and stream-laid materials. Below 700 ft. O.D. its gradient and size are greatly reduced and it becomes the Ooze, a constricted, well-formed phreatic tube which opens abruptly into the wall of the Gorge passage, 20 ft. above the floor. Mud Passage is more characteristic of G.B. It is a tall, narrowing rift passage with rough walls and a measure of basal expansion. There are very few traces of smooth solutional action. The gradient is steep and irregular: a few ill-formed potholes demonstrate the predominance of vadose conditions. Like Ooze Passage, it is without a significant stream.

Stream Passage is essentially similar. It heads in a very much collapsed Boulder Chamber that is almost directly beneath the wet weather sink in the main swallet. It channels the sinking water and there is very active erosion in some parts. But traces of an earlier stream fill remain. Double Passage is a phreatic form which climbs 25 ft. upwards from a junction with Entrance–Ooze Passage and then descends to a high-level, much choked, vadose passage that is parallel with Stream Passage and close to the roof of The Gorge. There are complex deposits of stream-laid materials and stalagmite, which indicate a long and varied history.

The Extension inlets have a simpler form. The passages are tall, narrow, joint-guided rifts. These have smooth surfaces for the topmost 2–3 ft. Below, the walls are straight and rough, suggesting 12–20 ft. of vadose cutting. There is basal expansion along a nearly uniform gradient and much collapse at points of structural intersection or tributary confluence. Small quantities of stream fill are banked against the piles of collapse. They are being cleared by intermittent trickles. Rhumba Alley is smaller, with a rounded, smooth-walled phreatic form modified by minor gravitational entrenchment.

2. *The Gorge*. This is one of the major features of Mendips' caverns, a great stream passage which forms the western boundary of most of the cave. It drops steeply from 730 to 420 ft. O.D., a remarkable range for a single passage. Followed from the head, where it closes in very unstable collapse material, its dimensions increase fairly steadily to the westward trending Bridge Limb. The walls are either straight and vertical, or hanging collapse features. There are no traces of any large, solutional faceting, but a few remnants of roof tubes may be seen 20–30 ft. overhead. A solid rock floor is seen for a few feet at a marked constriction south of the Ooze Passage junction. Elsewhere it is quite lost under fallen rock and stream deposits.

The Main Chamber is merely the greatest expansion of The Gorge. At its maximum it is 100 ft. high and 70 ft. wide. There is a steep drop in the floor, the 40-ft. Pitch, where bedrock is again exposed, the second and last instance in the whole of The Gorge.

Below the Pitch, dimensions reduce steadily. The form is still one of straight, rough walls and squared-off roof. Tributaries or distributaries may be seen hanging 12–25 ft. up the west wall, and there are a few residuals of a solutional passage visible in the main roof. Below Upper Sand Dig the gradient of the floor eases abruptly and The Gorge ends in a grid of constricted, choked, distributaries; a disappointing termination to a very impressive feature. Two decades of exploratory digging here by the University of Bristol Spelæological Society have met with no success.

Ladder Dig Extension is a distributary from the roof level of The Gorge. Its form is phreatic. The floor is masked by flowstone burying a coarse stream fill.

Throughout its length, The Gorge shows copious evidence of a past major fill. The present stream channel is deeply incised in it, leaving terraces against the walls. At The Bridge, stalagmite has supported the fill, which spans the stream course entirely.

3. *The Western Oxbows and Distributaries*. It is difficult to characterize the remaining parts of the cave save by the clumsy title used above. White Passage, Rift Passage, the Loop and the Oxbow have cross-sectional forms similar to those of the Extension inlet or parts of The Gorge. At the entries and re-entries to The Gorge, floors are exceptionally steep or hanging so that the Loop and Oxbow might be described as a potential Gorge which did not develop because of stream capture.

The Art Gallery and approach passage to Bertie's pot are distinctive. The former hangs at both ends: it is a small phreatic rift, clearly earlier than the bulk of the

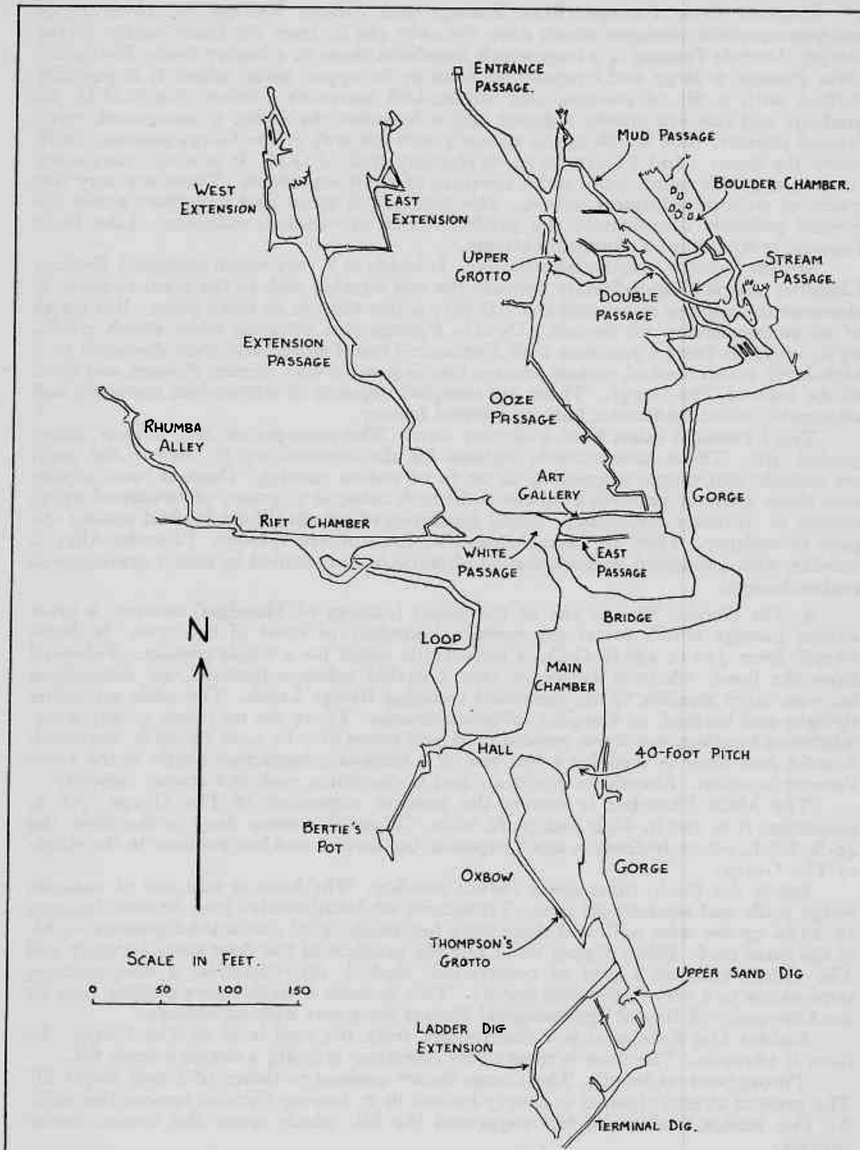

Fig. 29.—Plan of G.B. Cave with topographic names.

Errata.—For "Thompson's Grotto" read "Thomson's Grotto". The Ooze Passage should be shown as entering the west side of The Gorge.

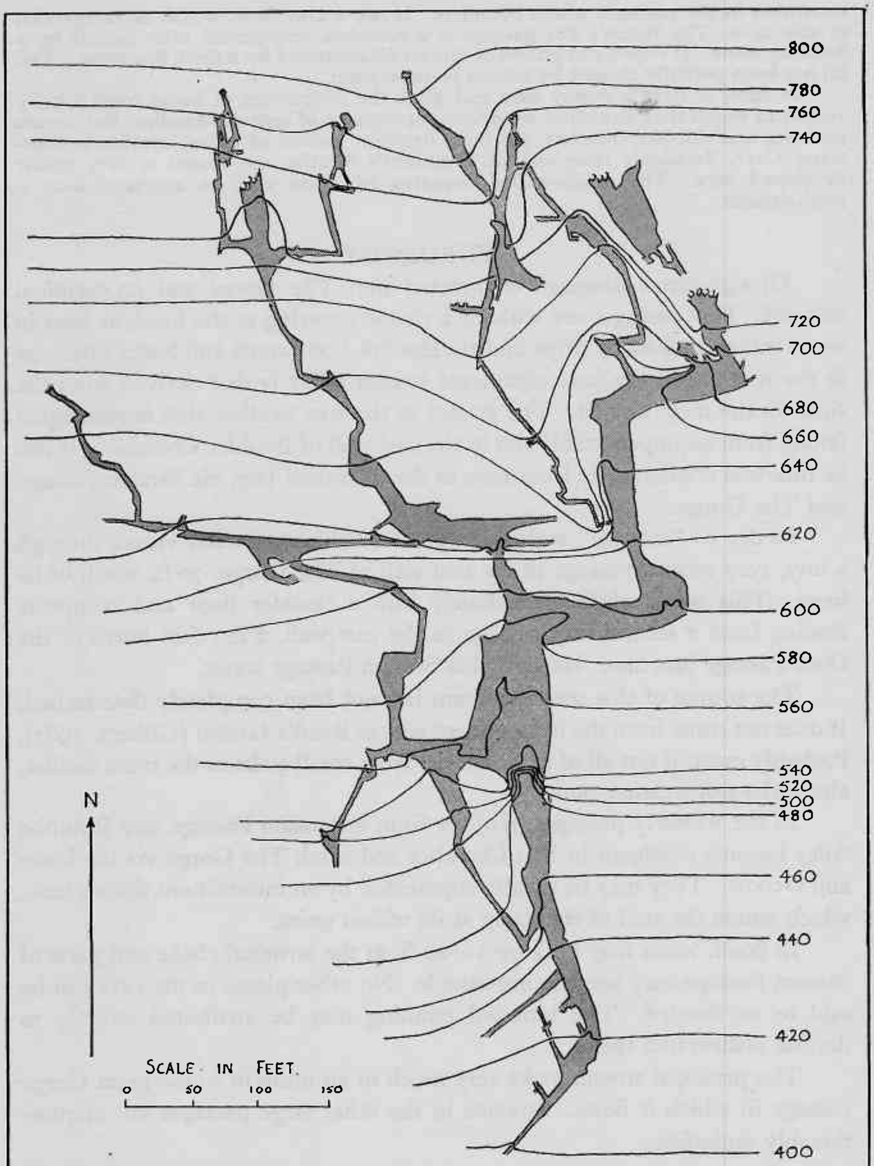

Fig. 30.—Floor contour plan of G.B. Cave. Heights are in feet above Ordnance Datum. The contours are extended between passages and to the margins of the figure in order to stress local topographic relationships and overall descending trends within the cave. They do not indicate any significant characteristic of the rock that encloses the passages.

expansion in the passages which bound it. It has a clay floor, which is exceptional in this cave. The Bertie's Pot passage is a rounded, entrenched tube guided by a bedding plane. It shows two phases of stream fill separated by a thick flowstone. The fill has been partially cleared by stream re-excavation.

In sum, G.B. is a roomy cave and gives the impression of being more wholly vadose in origin than the other major swallet systems of central Mendip. But stream potholes and slot-like trenches, the most frequent indices of vadose erosion in Eastwater Cave, Swildon's Hole and St. Cuthbert's Swallet, are absent or very poorly developed here. The rough-walled, tapering rift form with an aggraded floor is predominant.

HYDROLOGY

All significant drainage is directed into The Gorge and its terminal network. Few passages are without a rivulet entering at the head, at least in wet weather, and many drips and trickles fall from avens and lesser openings in the roofs. But the only significant stream today is that derived from the sinks in the main swallet. The stream at the wet weather sink is seen again falling from an impenetrable slot in the east wall of Boulder Chamber. It can be followed continuously from here to the Terminal Dig, via Stream Passage and The Gorge.

In dry or "average" weather, a greater volume of water enters through a tiny, very recent, passage in the east wall of The Gorge, 70 ft. south of its head. This water sinks immediately into a boulder floor and reappears flowing from a second tiny passage in the east wall, a few feet north of the Ooze Passage junction. Here it joins Stream Passage water.

The source of this second stream has not been completely determined. It does not come from the independent sink at Read's Grotto (Gilbert, 1963). Probably most, if not all of it, is derived from small sinks in the main swallet, above the wet weather point.

In the westerly passages, rivulets from Extension Passage and Rhumba Alley become confluent in Rift Chamber and reach The Gorge via the Loop and Oxbow. They may be greatly augmented by an intermittent showerbath, which enters the roof of the Loop at its widest point.

In flood, water may back up 10–20 ft. at the terminal choke and parts of Stream Passage may become impassable. No other places in the cave can be said to be flooded. The terminal ponding may be attributed entirely to detrital obstruction there.

The principal stream looks very much of an underfit to the great Gorge passage in which it flows. Streams in the other large passages are unquestionably underfits.

STRUCTURAL GEOLOGY OF THE CAVE

Donovan and Wallis (1944) have written that "the cave follows the dip of the rocks". Inasmuch as the cave descends along a course close to the impermeable substratum, this statement is correct, but it conveys a wrong

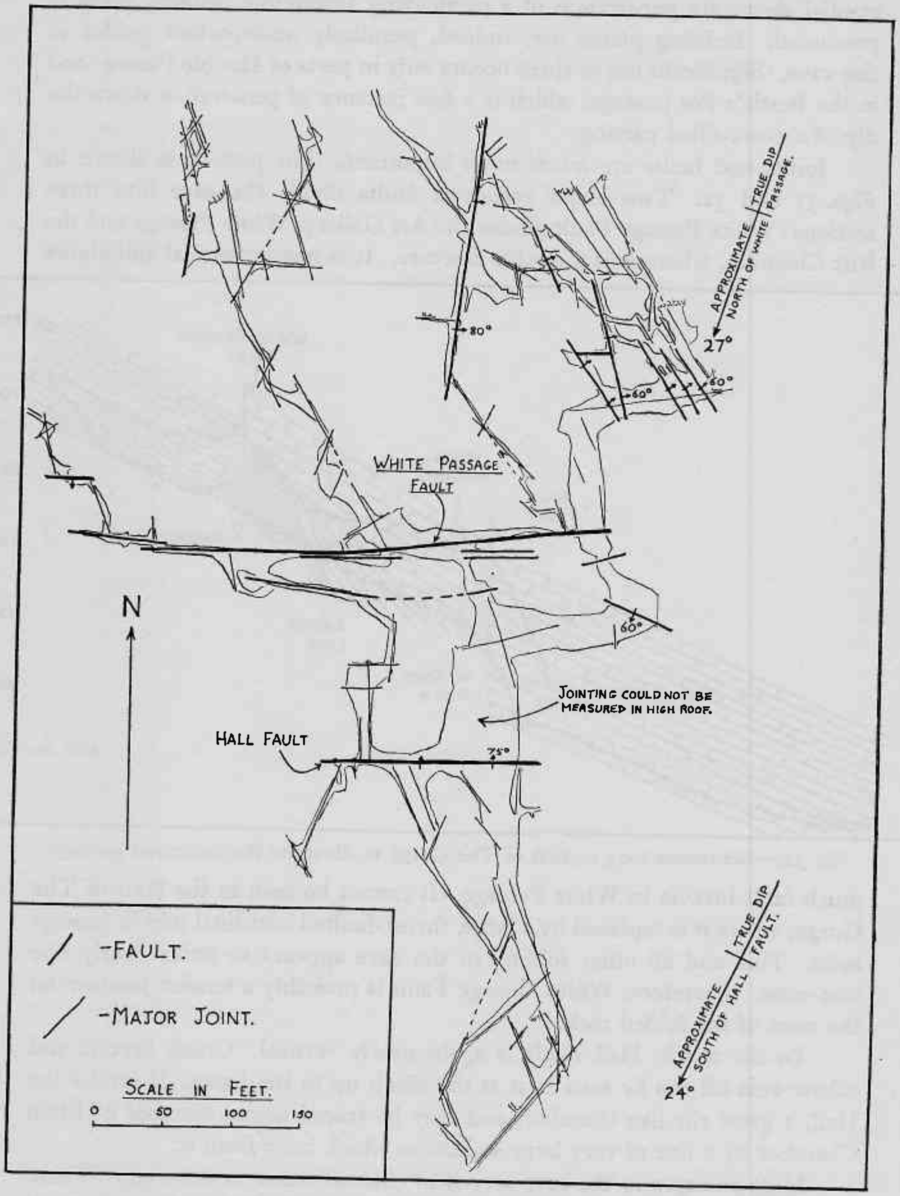

Fig. 31.—Plan of the structural geology of G.B. Cave. Lesser joints and some low-angle thrust faults are omitted.

emphasis. The strata are much dislocated by faulting, so that any substantial down-dip penetration of a particularly favourable bedding plane is precluded. Bedding planes are, indeed, peculiarly unimportant guides in this cave. Significant use of them occurs only in parts of Double Passage and in the Bertie's Pot passage, which is a fine instance of penetration down the dip of a chert-filled parting.

Joints and faults are much more important. The pattern is shown in *Figs.* 31 and 32. Two major east–west faults divide the cave into three sections: White Passage Fault guides the Art Gallery, White Passage and the Rift Chamber, where it is a double fracture. It is nearly vertical and shows

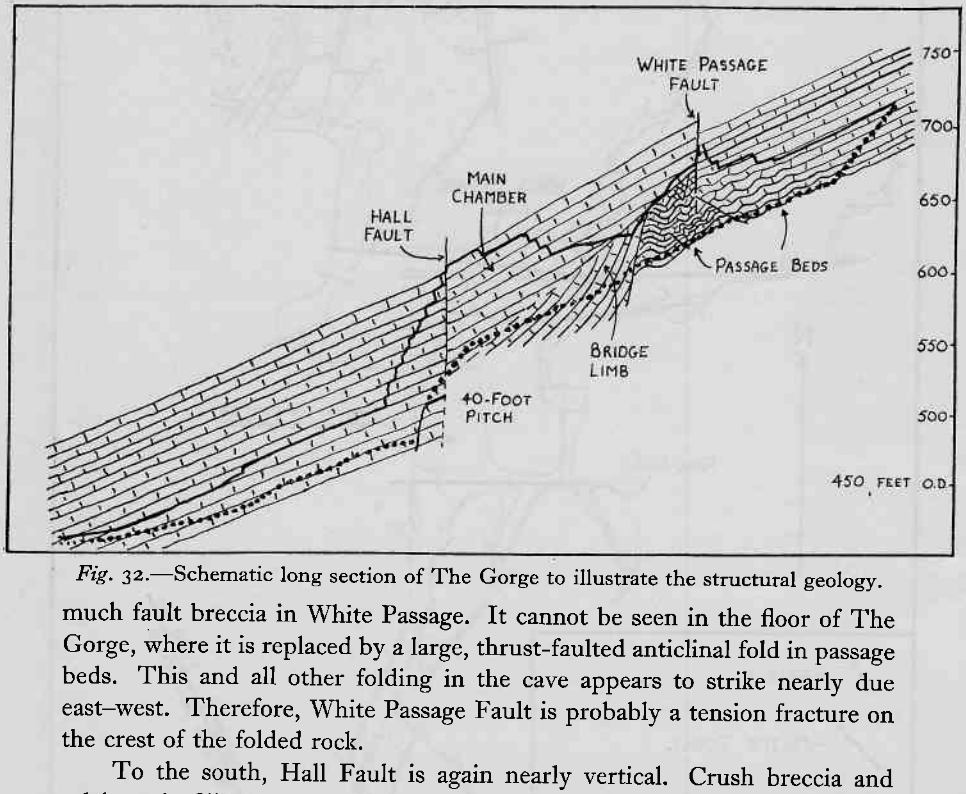

Fig. 32.—Schematic long section of The Gorge to illustrate the structural geology.

much fault breccia in White Passage. It cannot be seen in the floor of The Gorge, where it is replaced by a large, thrust-faulted anticlinal fold in passage beds. This and all other folding in the cave appears to strike nearly due east–west. Therefore, White Passage Fault is probably a tension fracture on the crest of the folded rock.

To the south, Hall Fault is again nearly vertical. Crush breccia and calcite vein fill can be seen in it at the climb up to the Loop. It guides the Hall, a great rift-like chamber, and may be traced across the roof of Main Chamber by a line of very large stalactites which hang from it.

Most passages in the cave served to channel water to the south. These two east–west faults acted as important intercepts. White Passage Fault integrated the three separate inlets, Entrance complex, Extension Passage and Rhumba Alley: Hall Fault dispersed them again.

Between the two faults, large folds in the Black Rock subtype have been faulted and overthrust. Many rock beds have slipped differentially, offering weaknesses along the strike that are exploited in the Bridge limb of The Gorge. There is much tension jointing, which has probably favoured the great collapse that created the Main Chamber. The principal overthrust guided earliest passage development between the Art Gallery and Gorge. The structure offers many potentially unstable situations; for example, along the Bridge limb beds are dipping from the roof and north wall at angles of 40°–70°. Individual blocks have slipped out and fallen readily.

North and south of the central, faulted, area the structure is simpler. Two principal fracture systems occur: the "Terminal" system is composed of joints striking 40°–220° and 340°–160°. It is exemplified in the network of terminal passages and also guides most development in the Extension inlet. The Oxbow system strikes 323°–143° and 23°–203° in the mean.* It is responsible for the orientation of the Oxbow and most passage segments in the Entrance complex.

Thus, all sets of both fracture systems channel flow in a general southerly direction from the swallets. All of the fractures are very large: they extend over the full height and length of passage segments orientated along them. Many were evidently open or very easily penetrated during the early stages of cavern genesis. This open quality of the structure may be attributed to the localized disruption caused by folding and thrusting along the Black Rock/Limestone Shales contact. Cave development has been concentrated along that open zone.

SEQUENCE OF DEVELOPMENT OF THE CAVE

The sequence of development is summarized in *Table I* and a series of diagrams, *Fig.* 33, A–E. The term "phase" is used to denote a particular period of erosion, stalagmite deposition, etc., that was synchronous throughout the cave. A whole-number change of phase, e.g., from Phase 2 to Phase 3, indicates a major change in the sequence, as from phreatic erosion to vadose erosion, or from any kind of erosion to any kind of deposition on to the eroded surfaces. Phase changes indicated by lower-case letters are of a lesser order, e.g., Phases 3a–3b mark a change from the deposition of stream-borne clastic materials to the deposition of stalagmite. The balance of forces has clearly altered during this change, but the predominant activity remains depositional. There is a time overlap between Phases 1 and 2, i.e., higher parts of the cave were already vadose (in Phase 2), whilst the lower parts remained phreatic (Phase 1). But by the close of Phase 2, the whole cave was vadose above 450 ft.

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* The angle of intersection of the two sets of fractures composing each system is always close to 60°. This suggests that the fractures are shear joints, rather than tension joints (*see* Hills, 1953).

Table I.—SEQUENCE OF GEOMORPHIC PHASES IN G.B. CAVE

Phase			
1.		Phreatic erosion	First Erosion
2.	a.	Major vadose erosion	First Erosion
	b.	Diminished vadose erosion	First Erosion
3.	a.	Rock fall and stream aggradation	First Fill
	b.	Stalagmite deposition	First Fill
4.		Major vadose erosion	Second Erosion
5.	a.	Rock fall	Second Fill
	b.	Limited stream clearance	Second Fill
	c.	Stream aggradation	Second Fill
	d.	Limited stream clearance	Second Fill
	e.	Stalagmite deposition	Second Fill
6.		Stream clearance and stalagmite re-solution	Modern Phase

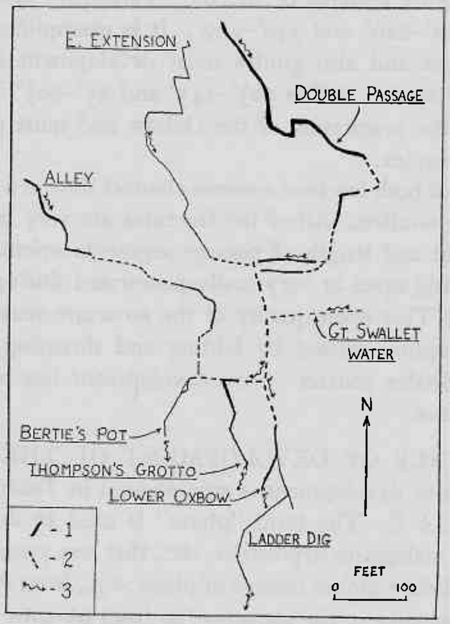
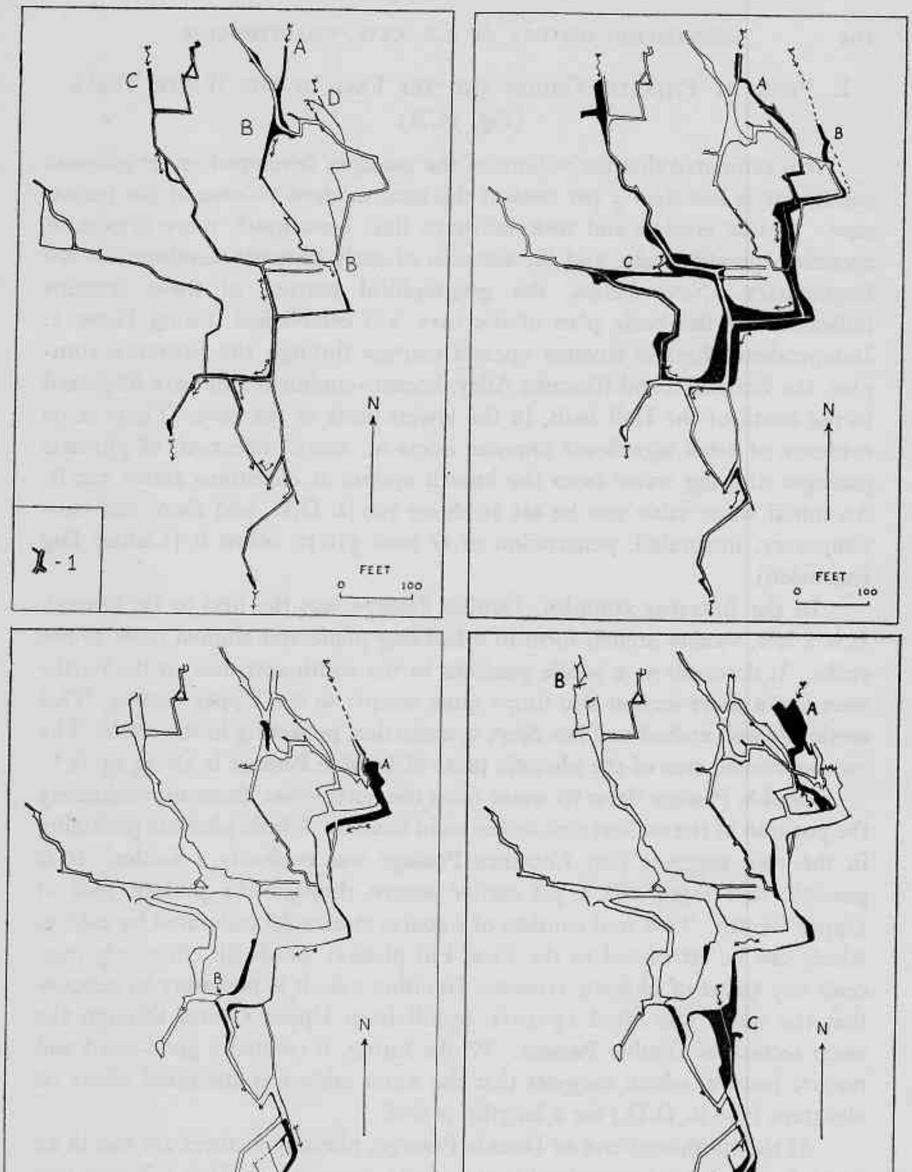


Fig. 33, A–E.—The sequence of development of G.B. Cave.

A. *During Phase* 1. 1, New passages; 2, Conjectural courses of passages; 3, Significant streams during the phase(s) shown in the figure. *Erratum.*—For "Thompson's Grotto" read "Thomson's Grotto".

B. *Early in Phase* 2. 1, Black areas indicate additions to the cave since the situation shown in *Fig.* 33, A: A, The first eastward shift of the principal stream sink; B, Ooze Passage capture of Double Passage water; C, Central Extension capture; D, Initiation of Mud Passage by rivulets spilled off from the new sink.

C. *Towards the close of Phase* 2. A, Mud Passage capture; B, Shift of the principal stream sink to the modern wet weather position and development of a high-level vadose passage connecting with the Double Passage course; C, Rift Passage capture of the Extension stream. (The stream had ceased to flow before the end of the phase.)



D. *Early in Phase* 4. A, The main stream diverted into the head of the modern Gorge; B, The Loop left hanging by main stream entrenchment in the Hall; C, Development of the modern terminal passages leaving Ladder Dig hanging.

E. *At the close of Phase* 4. A, The Ten-Feet Pot and Boulder Chamber captures of the main stream, developing Stream Passage; B, Initiation of the West Extension(?) (this may be a later development); C, The Lower Gorge capture of the main stream, developing the 40-Feet Pitch knickpoint.

I. Phase 1. Phreatic Origin and the Fall of the Water Table (*Fig.* 33, A)

It is estimated that the volume of the passages developed under phreatic conditions is less than 5 per cent of the total modern volume of the known cave. Vadose erosion and rock fall have thus been much more important agencies, quantitatively, and the remains of early phreatic development are fragmentary. Nevertheless, the geographical pattern of these remains indicates that the basic plan of the cave was established during Phase 1. Independent phreatic streams opened courses through the Entrance complex, the Extension and Rhumba Alley, became confluent and were dispersed to the south of the Hall fault, in the lowest parts of the cave. There is no evidence of other significant phreatic inlets or, more important, of phreatic passages drawing water from the known system at elevations above 520 ft. An initial water table can be set at above 760 ft. O.D. and there was contemporary, integrated, penetration to at least 310 ft. below it (Ladder Dig Extension).

In the Entrance complex, Double Passage was the first to be formed. It is a low, weakly arched form in a bedding plane and aligned close to the strike. It descends at a gentle gradient to the south-east, but, at the north-west end a short section also drops quite steeply to the Upper Grotto. This section is well arched and has deep, symmetrical pocketing in the walls. The cross-sectional area of the phreatic parts of Double Passage is 18–25 sq. ft.*

Double Passage drew its water from the north-west, from approximately the position of the earliest sink in the main swallet. A little phreatic pocketing in the roof suggests that Entrance Passage was probably a feeder. It is possible that there was a yet earlier source through the present roof of Upper Grotto. This roof consists of a coarse stream fill indurated by calcite, which can be attributed to the First Fill phases; which fill effectively conceals any traces of phreatic erosion. In either case it is necessary to suppose that the water was lifted 15–20 ft. uphill from Upper Grotto through the steep section of Double Passage. Whilst lifting, it created a good-sized and mature feature, which suggests that the water table was stabilized above its elevation (760 ft. O.D.) for a lengthy period.

At the south-east end of Double Passage, phreatic features are lost in an area of collapse and considerable stalagmite deposition.† It is believed that the water turned SSE. on major joints of the Oxbow system to enter The Gorge passage at roof level by the uppermost bend. There are no phreatic remains in the most northerly limb of The Gorge, but they appear immediately

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* There is minor vadose enlargement, the vadose water coming from a later inlet 50 ft. east of Upper Grotto.

† "Letter box" area of the first explorers.

below the bend in question, thus supporting this contention. They are located on a major vertical joint which has also guided the later vadose development. The phreatic form here is a passage, which is rather tall and narrow with straight walls and squared-off roof. Surfaces are smooth, with shallow pocketing. This form, lacking the roundness associated with much phreatic development in the Mendip region, is characteristic where the controlling joint or fault is large in G.B.

These fragments are aligned to make a concordant junction with Whitsun Folly, which in its turn descends gently southwards until it ends at a point of major roof fall in The Gorge. Here the elevation is accordant to the east end of Art Gallery and, probably, the East Passage.* Art Gallery and East Passage are both well-formed phreatic features. The aggregate cross-sectional area is 20–30 sq. ft., giving a good dynamic fit to the value obtained at Double Passage, their feeder.† It appears that the phreatic flow made a simple bifurcation.

Both passages descend gently to the west. At the western end, a little pocketing in an overthrust that roofs the southern end of White Passage indicates that the phreatic flow turned south down the line of Main Chamber, where collapse has destroyed all traces. The only alternative course is a westward movement along White Passage Fault into Rift Chamber, but this can be eliminated because the links between the Passage and the Chamber are wholly vadose and, therefore, later.

Ooze Passage was the first of the stream captures which have created the Entrance Complex. It developed whilst the water table still stood high in the cave. It will be seen that the line of phreatic flow, Entrance Passage–Double Passage–Upper Gorge, makes a lengthy loop to the east in the course of bringing water to the upstream ends of Art Gallery and East Passage. This loop crosses the SSW. dip of the strata and a number of southerly oriented joints of the Oxbow system. It was thus very liable to a capture underground which would shorten the line of flow. Ooze Passage is that capture. Above 700 ft. it is a large, rough-walled, characteristically vadose rift with a steep gradient (1 : 2·5). Below this level the overall gradient is 1 : 6, which is locally much lower because the overall figure incorporates a vertical drop of 8 ft. at a joint intersection. The passage is constricted and elliptical in cross-section although it follows joints of the Oxbow system, which elsewhere guide large, steep, vadose passages. It appears that the

* See Gilbert (1963) for an interpretation of the eastward termination of East Passage, which is blocked by fill at present.

† In researches in St. Cuthbert's Swallet and Swildon's Hole, where phreatic forms are much better developed, the writer has found that the cross-sectional dimensions of a phreatic conduit fed from a single source tend to remain fairly constant over long distances unless there is extreme distortion of form attributable to a particularly open or complex structural control.

Ooze capture occurred when the water table was temporarily stabilized at or a little below 700 ft.

The only alternative explanation of the abrupt change of form and gradient at this level is that water was held back in a local pond by structural blocking. Because the jointing is the same as in Mud Passage, the only apparent obstructing feature is an anticline across which Ooze Passage discharges into The Gorge. Shale bands here may have provided the barrier. But Rhumba Alley is another constricted inlet where phreatic erosion can be observed to have cut through folded shales. A structural cause is therefore held to be unlikely.

At the outlet into The Gorge, Ooze Passage water would have had to lift abruptly through a height of 20 ft. to reach the Art Gallery. Such a lift belies the "water table" profile of the Passage. It is unlikely that it ever occurred. Immediately to the south is the notable constriction in The Gorge (p. 155), where the roof is exceptionally low. Solid rock appears in the floor for the first time and there is no major fracture guiding the alignment. South of this again, at the bend at the east end of the Bridge limb, is a fault which is thought to have channelled in a small stream from the Great Swallet. This stream was probably very early, joining the main phreatic course at the head of Main Chamber via fractures along the Bridge limb. Ooze Passage water forced a connexion to this Great Swallet line through minute fractures. The absence of larger ones accounts for the modern constriction. This new route involved abandonment of Art Gallery and East Passage.

The Extension inlet descends from 790 ft. O.D. to the Art Gallery. In the East Extension and the main passage south of it, the topmost 2–4 ft. of the rift have a much smoother surface than the vadose wall below, and round into the final ceiling slot. There is no pocketing. In this cave the smoothness suggests a phreatic environment and as the phreatic element is of very small size and immature (lacking pocketing) it is unlikely that it is earlier than Double Passage. But this initial penetration by the Extension stream cannot be as late as the 700 ft. water table suggested by Ooze Passage, for this would require a gradient on the piezometric surface as steep as 1 : 1·7 across well-fractured rocks to support water-filled conduits at 790 ft. O.D. No such gradient has been measured in the Mendip Hills.

The Extension inlet is probably, therefore, only a little later than Double Passage. The phreatic Extension stream joined the main system at some point close to the west end of the Art Gallery.

Rhumba Alley is a well-rounded phreatic inlet, 9 sq. ft. in cross-sectional area. It is clearly scalloped for flow to the SE. There is only shallow vadose entrenchment. The inlet swallets probably lay some distance south of the Limestone Shale contact and the passage appears to have been largely inactive since the water table fell below it.

All early form is lost in collapse at Rift Chamber, the outlet of Rhumba Alley. The Chamber follows the White Passage fault but there has been no phreatic expansion of this prominent weakness westwards of the Alley confluence. The earliest flow, and erosion, was thus confined to a direct, efficient and steeply descending path. In the Loop, phreatic features, comparable to those of the Extension in form and dimension, trace the lower course of the Rhumba Alley water, down to the Hall Fault at 580 ft. O.D.

Two independent phreatic streams, Entrance/Extension and Rhumba Alley, reached the Hall Fault at different points. The water appears to have been dispersed along it and distributed in four separate courses to the south. Highest of these was Bertie's Pot and its approach passage. It terminates in a short drop that is well pocketed and choked at the base (515 ft. O.D.).

Other water passed down the Oxbow to Thomson's Grotto. This is a constricted anastomatic distributary 40 ft. above the vadose floor. Immediately to the south of it, the roof drops vertically for 10 ft., indicating that phreatic flow came from the north.

The principal residual is traced through The Gorge below the Main Chamber. The form is as in the higher parts of The Gorge (p. 155). The solid rock floor of the phreatic passage is preserved above the greater vadose passage at one point. Immediately north of the junction with the Oxbow, bifurcation occurs. A larger element turns into the NE.-trending segment of the Oxbow, which is well pocketed. It terminates there in two tiny circular tubes climbing steeply upwards.

A smaller element guides the main Gorge passage down to a further bifurcation, where the bulk of the remaining flow turned into the Ladder Dig. Only a tiny squared tube continues south towards the present active terminus, where it is lost as a result of later roof fall. Ladder Dig has an arched, pocketed roof which maintains a steady elevation of 450 ft. O.D. across dipping strata. This is the first instance of a truly flat phreatic passage to be seen in the cave. From models in Swildon's Hole it suggests a water table finally stabilized at its level.

The principal features of the phreatic system in G.B. Cave are its steeply descending gradient with very few places where the water lifted back to higher elevation;* its simple, integrated pattern,† which was apparently

* This may be contrasted with phreatic conditions at Swildon's Hole, St. Cuthbert's Swallet, Wookey Hole and the Gough's–Great Oone's System at Cheddar —all within 6 miles of G.B. Cave. In each of these caves water can be shown to have lifted steeply through heights greater than 100 ft.

† The "integration" here should be read as a contrast to the network type of phreatic system where erosional energy is expended along a multitude of alternative routes in the course of the flow of a volume of water from inlet to outlet (see Davis, 1930, for examples). Introduction of vadose conditions will usually lead to the preferential expansion of one of the alternatives at the expense of all the others. In G.B. such preferential expansion can be said to have begun at the beginning of Phase 1, rather than at its close, as might be expected.

established at the onset of cavern genesis; the predominance of a smooth, as opposed to a deeply pocketed, rock surface.

All of these features imply a fast and efficient flow. Taken with the small scale of the phreatic expansion, compared with that of the vadose expansion, the following simple dynamic sequence is suggested: (1) Cavern genesis began when static interstitial water was integrated to the Cheddar outlet* and drained there. (2) The three inlet streams were drawn down from the surface via whichever system of linked interstices they first encountered when leaving the Limestone Shales. Phreatic erosion commenced along these systems. (3) As erosion increased the volume of the underground passages and improved the efficiency of the whole system, including its unknown outlet to Cheddar, the water table fell. This occurred slowly at first, primarily because of inefficiency in the system, permitting local, temporary standstills of a water table such as that in Ooze Passage—but with increasing rapidity—for no further stands can be detected below the Ooze elevation. (4) The drawdown became stabilized at about 450 ft. O.D. The headfall between a water table surface lying against the impermeable Limestone Shales at that elevation and the elevation of the effluent at Cheddar was the minimum required to move water through the remaining phreatic parts.†

It is not necessary to suppose that the fall of the water table from 760 ft. or higher occurred as the result of some fall in the base level of discharge at the effluent that was later than the mature development of Double Passage. A fall to, and stabilization at or about, 450 ft. was inherent in the system when it first commenced to discharge water at Cheddar.

II. Phases 2 and 4—Major Vadose Erosion

Phase 2 began for any particular passage when the water table fell below the passage elevation. It ended, after the water table had stabilized at 450 ft., with a period of deposition (Phase 3). In Phase 4 erosion began again, to be terminated in the same fashion. The erosion phases are considered together in order to show an uninterrupted sequence of events. The term "major" is applied so as to contrast them with the modern phase of erosion. This is also one of predominant gravitational erosion but it is in its infancy, for little fresh work has been done upon country rock. In Phases 2 and 4 most of the expansion of the cave occurred.

It is convenient to subdivide the cave again when considering the sequence:

(*a*) *The Series of Captures in the Entrance Area.* The first capture, Ooze Passage, properly belongs to the transition from Phase 1 to Phase 2.

* Fluorescein tests made in 1961 have established that the G.B. stream is discharged at the principal Cheddar risings (E. K. Tratman, *in litt.*).

† The Cheddar effluent is entirely phreatic in its dynamics and has been throughout a long history.

Some while after it occurred, to judge from dimensional contrasts, the surface sink in the main swallet made a first shift to the east, abandoning the Entrance Passage. The new sink developed the inlet, "A" (*Fig.* 33, B). This fed water to Ooze Passage but spilt off a little into other joints, where it initiated Mud Passage. This passage then took all the water from the Ooze,

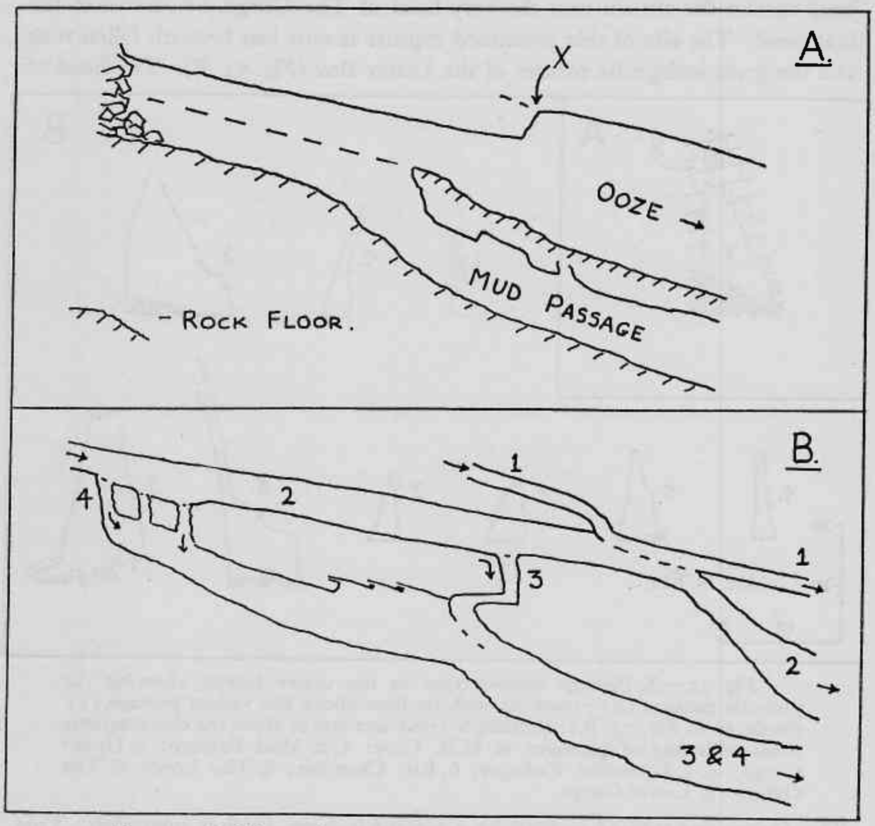

Fig. 34.—A, Schematic long-section of discordant vadose floors, indicating a Mud Passage capture of the Ooze Passage stream; X, The junction with the Entrance Passage. (The discordance of roofs here is characteristic where two passages, which are of different ages, meet.) B, Schematic long-section to show sequence of vadose capture between the modern wet weather sink and The Gorge: 1, The original phreatic route (Double Passage); 2, First vadose route and first capture which developed the head of the modern Gorge; 3, The Ten-Feet Pot capture, initiating Stream Passage; 4, The Boulder Chamber capture.

the elbow of capture being indicated by a sharp knick in the rock floor (*Fig.* 34, A). The new route shortened and steepened the course of the main stream from the surface to The Gorge. Mud Passage was an important conduit, and shows an average of 18 ft. of vadose entrenchment. The stream sink then shifted east again, to the present wet weather site (*Fig.* 33, C). A straight, steep passage was opened in the joint which guides the east wall of the Boulder Chamber, but at higher elevation.* It intercepted the original phreatic connexion between the extant Double Passage and the first bend of The Gorge. This was hardly enlarged before leakage through the guiding joint turned the stream into the very head of The Gorge, i.e., north of the first bend. The site of this presumed capture is now lost beneath fallen rock and the great stalagmite masses of the Letter Box (*Fig.* 34, B). The head of

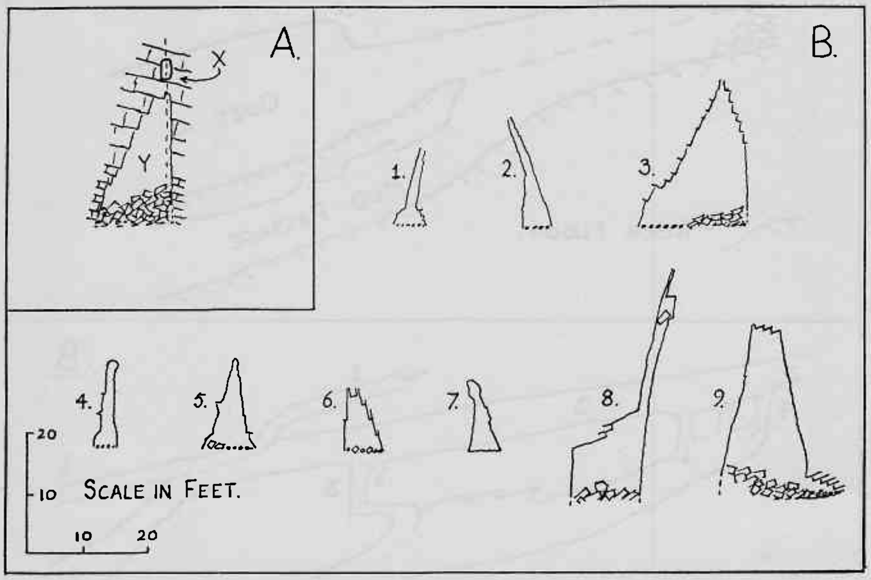

Fig. 35.—A, Passage cross-section in the upper Gorge, showing the phreatic passage (X) preserved with its floor above the vadose passage (Y). (Scale as in *Fig.* 35, B.) B, Sample cross-sections to show the characteristic basal widening of passages in G.B. Cave: 1, 2, Mud Passage; 3, Upper Gorge; 4, 5, Extension Passages; 6, Rift Chamber; 7, The Loop; 8, The Oxbow; 9, Lower Gorge.

The Gorge was robbed in turn by a second leakage, further upstream. This opened the 10-Feet Pot and Stream Passage. A final capture turned the water down into the Boulder Chamber, adding this to the head of Stream Passage in the manner that the first leakage had added a unit to the head of The Gorge. Entrenchment by the Boulder Chamber stream has left the 10 Feet Pot route hanging 15 ft. above the active channel at their junction. The present stream route from wet weather sink to The Gorge has an overall gradient of 1 : 1, the steepest in the cave. But, as noted, it is being robbed by a further headward shift of the surface sink.

* The explorer enters this passage when he climbs out of the 10-Feet Pot above the Devil's Elbow.

In each of these capture passages there is evidence of only one major phase of vadose erosion. Depositional evidence indicates that the 10-Feet Pot and Boulder Chamber captures belong to Phase 4, the others to Phase 2.

A part of this complex sequence is independently suggested by a feature in the Upper Gorge. Between the Mud Passage junction and the northernmost bend of The Gorge the phreatic roof-passage has a solid floor. This is preserved directly over the vadose passage which follows a common joint (*Fig.* 35, A). If a stream had continued to enter the head of The Gorge directly after the water table fell, the phreatic floor must have been entrenched. It escaped because, it has been suggested, flow was diverted first to Ooze Passage then to Mud Passage. At the outlet of the latter, a trench was cut to a depth of at least 20 ft. below the elevation of the adjacent abandoned floor. Thus, when the main stream was finally returned to the head of The Gorge, it neglected the floor for a steeper, more direct route beneath it and through the same controlling joint. The latter was evidently easily penetrated.

(*b*) *The Extension Passages and the Loop.* In the Extension Passages there is evidence of only a single phase of entrenchment, extending from the phreatic element in the roof down to modern floor level. Basal expansion of the trench, so that one or both walls are undertrimmed, is characteristic. This cannot be attributed to any effect of lithological blocking because the gradient of the expanded floor is lower than the actual dip of strata down its course. Nor can it be supposed that it is due to a sudden tightening of the entrenched joints because the floor profile passes accordantly across many changes of controlling joints. The basal expansion appears to be a result of the establishment of an equilibrium profile.

The phreatic channel through the East Extension was entrenched 8–10 ft., then the location of the stream sink shifted westwards along the Limestone-Shale contact, diverting the water to form the central boulder chamber inlet and then the West Extension. The latter is particularly constricted and may be almost entirely a product of the underfit stream of the modern phase. East Extension now hangs 12 ft. above an aggraded floor at its outlet, giving a particularly fine example of the common result of stream capture in this cave.

The vadose Extension stream first discharged into The Gorge via White Passage. Its entrenchment here left the Art Gallery and East Passage hanging 20–30 ft. at their western ends. Then lateral erosion permitted water to leak into the lower-lying Rift Chamber. Two small passages have developed along the line of leakage and turned all Extension waters into the Rift Chamber and the Loop. The bulk of vadose erosion in the Loop can be attributed to the captured waters. There is a minimum of 10 ft. of entrenchment. The bedrock floor can be seen at certain points: it is well scalloped but there is no stream pothole formation. Basal expansion is characteristic and an equilibrium gradient is sustained through a variety of guiding joints and one limb that is in the strike of the bedding.

(*c*) *The Gorge and Distributary Passages.* In The Gorge, lateral erosion over steep gradients has been particularly important. On limbs with a southerly alignment both walls have usually been equally trimmed up to the vertical and roof rock has fallen to attain equilibrium with the increasing width of the passage. Form is less regular where the bearing is closer to strike. The Bridge limb is particularly interesting. As *Fig.* 36, A indicates, it is widest at approximately 10–15 ft. above the solid floor. Above that level,

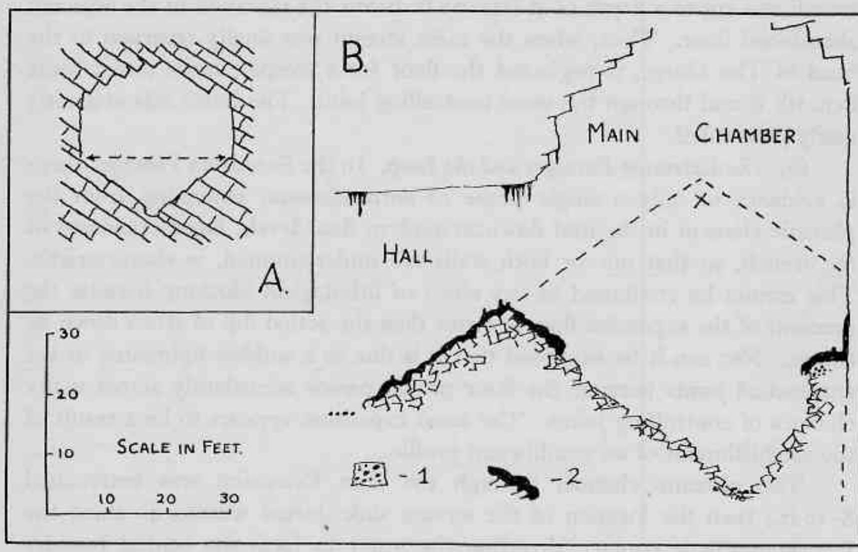

Fig. 36.—A, Cross-section of the Bridge limb of The Gorge illustrating entrenchment below a level of maximum widening. (Scale as in *Fig.* 35, B.) B, Section to show the Hall dejection cone and its conjectural extension to an apex in the Main Chamber (X).

which is the same on both the north and the south sides, the walls are trimmed to the vertical for some distance. Below it, they converge in a shallow V-form trench. It is difficult to explain the position of maximum widening and the straight walls above except in terms of a stream able to maintain a wall-to-wall flow which was then diminished so that only a narrowed channel could be cut. This, and a lesser instance just to the south of the "narrows" in The Gorge, are the basis for the differentiation of Phases 2a and 2b (*Table I*); major stream erosion succeeded by diminished stream erosion. Evidence for this kind of sequence is much better seen in Swildon's Hole and St. Cuthbert's Swallet, where there is no major vadose phase that is without an ensuing diminished, but still eroding, vadose phase.*

Four particular features indicate the sequence of events in Main Chamber and the Hall:

(i) Between the southern end of Main Chamber and junction of the Gorge and the Oxbow below it, is a second fragment of a phreatic passage which has retained its floor above a tall, vadose passage, although both share common joints. When this part of the cave was drained at the end of Phase 1, therefore, the main stream cannot have taken the direct southerly route out of the Main Chamber. The only alternative course is a turn westwards on the Hall Fault into the Hall. From here the water forced a linking route from Thomson's Grotto back into the Lower Gorge (*Fig.* 33, B) and commenced an entrenchment which measures 40 ft. directly beneath the Grotto. Later the main stream *did* return to the direct route out of the south end of Main Chamber, but was able to follow the joints beneath the phreatic floor because the Oxbow entrenchment created an excessively steep hydraulic gradient through a rather open structure. In this example the Oxbow plays the role attributed to Mud Passage at the other end of The Gorge.

(ii) The lower half of the 40-Feet Pitch is in bedrock with a vertical face. This appears to be a knick point which has regressed from the point where the main stream, following its modern course, first poured into the deep trench cut by the earlier Oxbow waters.

(iii) At its junction with the Hall, the Loop Passage is discordant, hanging 15 ft. This has two implications. First, because vadose erosion in the Loop is the work of the Extension stream this stream must have been eliminated or diverted at some time after its first diversion into the Rift Chamber. There is no evidence of a second diversion underground so it is probable that it was eliminated by capture at the Sandstone spring line. Secondly, a powerful stream was able to entrench the floor of the Hall after this elimination. The stream can only have come from the Main Chamber, upholding the interpretation given in (i) and (ii) above.

(iv) The Oxbow in its turn has been left hanging at The Gorge outlet indicating the final return of the main stream to its original, phreatic, course.

The exceptional size of the Main Chamber is thus a product of structure and the sequence of development. The White Passage Fault determined that the Extension stream should enter at its head for a while, to reinforce the erosive power of the main stream. The Hall Fault created distributaries at its southern end: in switching from one of these, the Oxbow, to another, the

* There is no evidence of such a sequence in the Extension, Loop or Oxbow passages because these lost, effectively, all of their water during phases of major, as opposed to diminished, stream flow as a result of surface or subsurface capture. Particularly frequent capture and diversion in the Entrance passages is probably responsible for the lack of evidence there also.

direct course, the stream turned its lateral attack from the west to the east, developing a very wide chamber. It is also the highest chamber, presumably because its great width demanded equivalent collapse to maintain stability.

Bertie's Pot and Ladder Dig, the highest and lowest of the significant distributaries during the phreatic phase, have been entrenched to depths of 3–6 ft. The Oxbow distributaries were abandoned when the water table first fell. From the evidence of deposits, Ladder Dig was abandoned early in Phase 4. The water table fell 50 ft. or more, to or a little below the elevation of the modern terminal passages. Entrenchment to the new level left the Ladder Dig hanging. At the terminus, the passages are flat, constricted and of paraphreatic origin.* All of the vadose water which created the great Gorge passage passed into them, or the comparably restricted Ladder Dig and Bertie's Pot. The contrast in the magnitude of development is remarkable.

III. Phases 5a–5e—The Second Fill

This is much the greater of the two fill deposits in volume. It has three components, which are alike everywhere throughout the cave.

(i) A recent stalagmite at the top (Phase 5e). This is of greatly varying thickness. It is not a continuous deposit, as it is derived from many small seepage sources in roof and wall rather than from waters running through from the principal surface sinks. However, there is sufficient stalagmite present in all passages possessing a Second Fill to indicate that its stratigraphical position is invariably the same. Further, the spread of the recent stalagmite across stream-laid fills (below, (ii)) is everywhere great enough to show that *when most of it was deposited, there can have been no significant streams entering the cave from the Limestone Shales.* The only moving waters were the many tiny seepages responsible for the deposition of calcite. There was no contemporary stream erosion.

(ii) A stream-laid fill. This comprises 20–80 per cent of the observed bulk of deposits at various sites. It is without structure and composed of materials generally in the fine sand–large cobble range,† with the occasional small boulder. All degrees of rounding occur. There is much Devonian Sandstone in all size ranges. A matrix of fine sand constitutes 30–60 per cent of the volume. The fill is not indurated.

(iii) A basal deposit of fallen boulders (Phase 5a). This is plugged with the stream-laid fill but, as the latter is often built high above it, it is evident that the rock had all fallen before much of the stream material was deposited. An estimation at the Bridge limb showed that about 40 per cent of the total

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* This term, advanced by Dr. Tratman in 1957, is used here to denote cave initiation and development under conditions where there is very frequent oscillation between the vadose and the fully phreatic.

† On the Wentworth scale of grain sizes (*see* Wentworth, 1932, Chap. V).

volume of rock removed to create the modern passage was present as fallen blocks on the floor.

Deposits of the Second Fill are being entrenched and cleared in the modern phase, but sufficient are preserved for it to be readily apparent that they were laid in an accordant manner in most of the passages of the cave (*Fig.* 37). Deposition was greatest down the line of the main stream. Stream-laid fill in Stream Passage attains depths of 4–15 ft. It diverted water back into Mud Passage, where depths of 8 ft. are attained. There is no Second Fill in Entrance Passage, Double Passage or Ooze Passage. The Entrance was plugged with a cone of collapse and colluvial material which appears to be contemporary with the Second Fill.

In The Gorge, thicknesses as great as 30 ft. of fill occur. In the Main Chamber it is possible to walk along a gallery floor on the deposit, 20 ft. above the active stream, which has not yet exhumed the underlying solid rock. The Second Fill chokes the active terminal passages, where it is at least 14 ft. in depth.

Down the course of the Extension stream, including the Loop and the Oxbow, the thickness of stream-laid Second Fill is much less, rarely being as great as 6 ft. This implies a weaker stream. But it was able to seal off the capture passages at Rift Chamber and so spill material down its original course past the Art Gallery. There is only 2–4 ft. of material in Rhumba Alley. In the approach passage to Bertie's Pot, the Second Fill is represented only by a sand burying an earlier (Phase 3b) stalagmite. The sand suggests deposition by a little water spilled off from the larger stream flowing from the Loop to the Hall. The hanging entrances of the Art Gallery, East Passage and Ladder Dig lay too high above the local levels of filling for even spill to reach and deposit in them.

The profiles of the deposits in the Main Chamber and the Hall suggest that a little stream erosion intervened between the cessation of rock fall and deposition of the stream-laid fill and, later, between the stream fill and recent stalagmite. These minor phases are numbered 5b and 5d in *Table I*, but they are not supported by the nature of deposition elsewhere. Evidence for Phase 5b is given in *Fig.* 36, B. At floor level the actual line of juncture of the Hall and the Main Chamber is the apex of a cone of large blocks. They are too many to have come from the local roof, which is close at hand. They must have run in from the Main Chamber, and thus be the remains of a much larger cone which had its apex under the highest parts of the roof there, 30–40 ft. to the east. Distribution of the stream-laid fill indicates that, when it was deposited, there was no central cone in the Main Chamber. This must have been sapped and cleared first.

In the Bridge limb and the Main Chamber the stalagmite was laid upon a surface of stream-laid fill that sloped down across the long axes of the

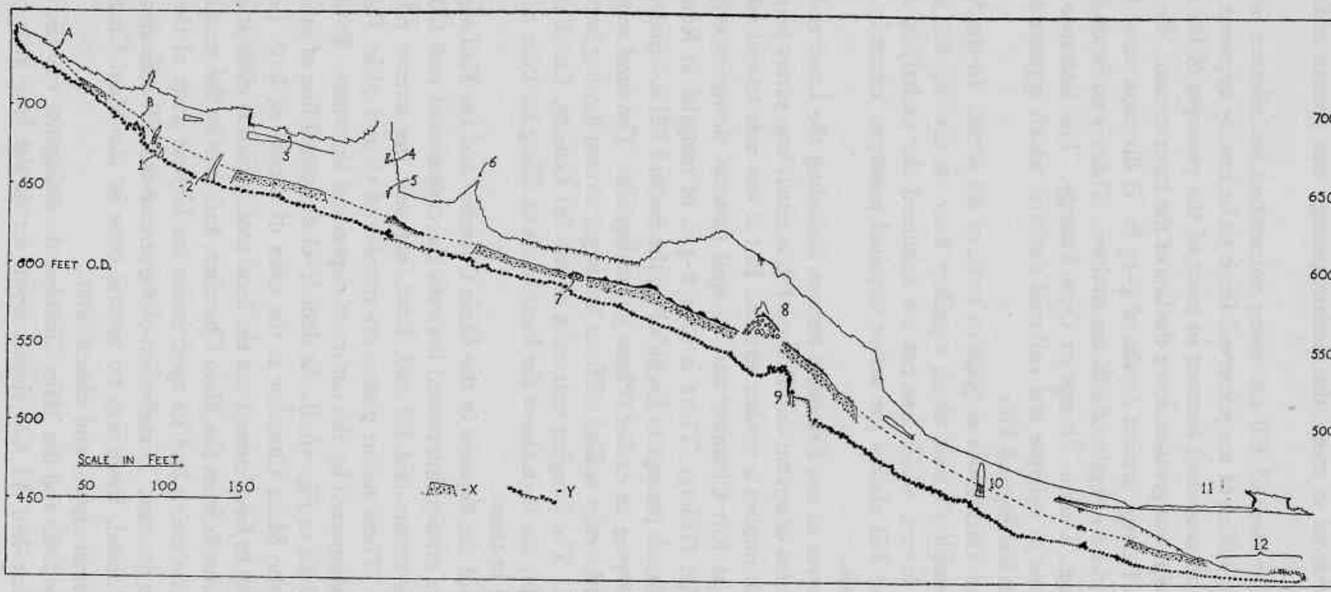

Fig. 37.—Long section of The Gorge, showing the accordance of preserved remains of the Second Stream-laid Fill. A, B, Sand and pebbles jammed in cracks in the cave walls and roof indicate past minimum levels of the Second Fill. X, Second Stream-laid Fill with local occurrence of Second Stalagmite. Y, The modern stream floor (boulders and smaller fill with two exposures of the solid rock base indicated by a hachured line). 1, Stream Passage entry. 2, Mud Passage entry. 3, Whitsun Folly. 4, Art Gallery. 5, Ooze Passage entry. 6, Water from Great Swallet ? 7, The Bridge. 8, Hall entry and dejection cone. 9, 40-Feet Pitch. 10, Oxbow entry. 11, Ladder Dig. 12, Terminal Passages excavated by U.B.S.S.

passages towards the southern and eastern walls respectively. The vertical amplitude of the slope is as much as 10 ft. This is unlikely to be the product of shoaling in an aggrading stream, for the volume of such a stream would have to be enormous. It is probably the result of a limited period of combing down and sapping by a small stream capable of some clearance (Phase 5d).

The Second Fill is the result of a change in the climatic environment at the surface. The alternative explanation, that stream capture above or below ground so reduced the volume of flow that streams which had previously eroded their channels could now merely deposit in them, can be rejected on several grounds. A subsurface capture is out of the question because all accessible passages show the Fill; there is thus no channel available for the diverted, non-aggrading, water during the phase. Capture of certain Sandstone springs by the Longwood valley has been shown to have occurred and would reduce the total volume of surface water reaching G.B. Cave. But this cannot explain the aggradation, for the Longwood capture persists in the modern phase, yet all streams are eroding the fill. In addition, there had been no streams entering the Rhumba Alley and Extension inlets for a long period before the Second Fill. Yet aggrading streams were reintroduced to deposit it there. Reintroduction can hardly have been the result of a capture which depleted the entire catchment of the cave. The climate of the stream-laid fill phase thus appears to have been one which provided a great deal of water at the surface, at least for certain periods of the year, and also furnished an abundance of sand and larger fragments from the Sandstone, where today there is very little exposed.

IV. Phases 3a–3b—The First Fill

There are comparatively few exposures of this Fill. The best example is to be seen in the Bridge Limb (*Fig.* 38). It indicates that a stalagmite floor of 12 in. or more in thickness was built across the full width of the passage and descended into Main Chamber. It was laid on to a mixture of fallen rock and stream-laid materials identical to those of the Second Fill in composition, but smaller in volume. The First stalagmite is substantially thicker than local Second stalagmite deposits. This is a feature of all correlated exposures of First Fill.

The First stalagmite floor was entrenched and most of its southern half removed from the Bridge limb before the Second Fill was laid. Sufficient is preserved to indicate that it was later than the trench attributed to a diminished eroding stream (p. 172). The phase of diminished erosion is therefore placed after the first major vadose phase (2a) rather than the second.

First stream-laid fill is found in the approach passage to Bertie's Pot. It is a typical sand–large cobble mixture, 2–3 ft. in thickness. On top of it is 6–15 in. of stalagmite. The upper surface of this was lightly eroded, then the sand of the Second Fill (p. 175) was laid on top. There is only a little thin stalagmite on top of the sand.

Ladder Dig was largely filled with a flat-surfaced deposit of sand–cobble range, then a stalagmite floor 6–12 in. was laid upon it. Subsequent erosion removed most of this stalagmite and lowered the surface of the stream fill by 18 in. A second stalagmite, 2–6 in. thick, has been deposited upon the lowered floor. It has not been eroded and can evidently be attributed to Phase 5e of the Second Fill.

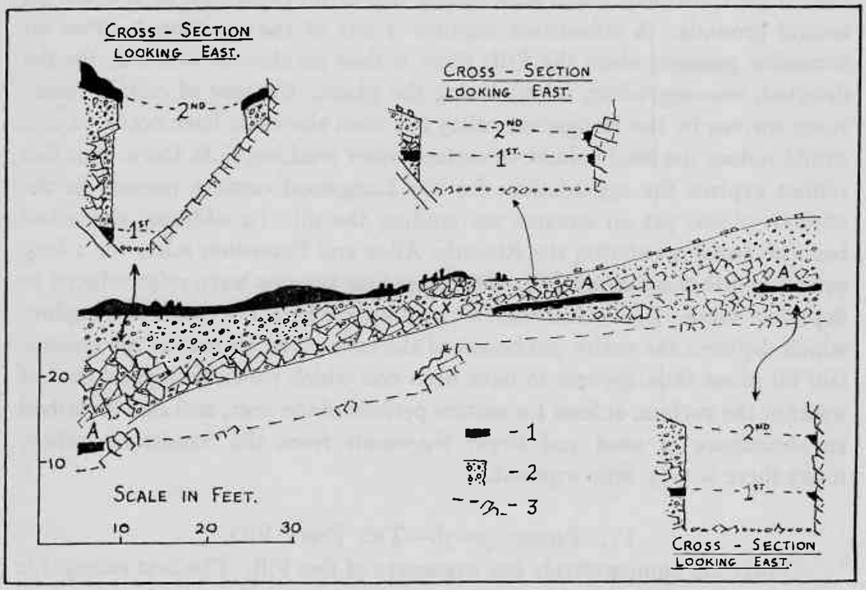

Fig. 38.—Long-section and cross-sections showing First and Second Fill deposits of the Bridge limb of The Gorge. The long-section is of the deposits on the North side of the passage. 1, Stalagmite layer. 2, Stream-laid fill. 3, The modern stream floor. A, Stalagmite of the First Fill. X, The Bridge.

There are no traces of a First stream-laid fill along the independent courses of the Extension and Rhumba Alley streams. These streams must have been eliminated earlier (Phase 2a or 2b) and did not return as they did in the Second period of aggradation. The First stream-laid fill at Bertie's Pot must, therefore, have been introduced by the main (Gorge) stream, flowing through the Hall. As the approach passage to the Pot is entered above the hanging terminus of the Loop passage, the entrenchment which created that discordance must be attributed to a period of major vadose erosion that succeeded the First Fill. This is one piece of evidence for the distinction of two major vadose phases of erosion. Entrenchment of the First Stalagmite at the Bridge is another.

At Ladder Dig, deposition of the stream fill must similarly precede the 30 ft. of entrenchment, which has left that passage hanging. The Second Fill deposits rise only 12–15 ft. up the walls of the 30-ft. trench. They cannot have spilled into Ladder Dig (*Fig.* 37). Many other pieces of evidence attest to the position of the Ladder Dig stream deposits in the sequence.

Deposits of the First Fill in the entrance passages are rather complex. It suffices to say that the stream material entered the cave via the Entrance Passage and Mud Passage sinks. The roofs of First and Upper Grotto are composed of it and local collapse material, indurated by calcite during the First and Second stalagmite phases. The emplacement of massive flowstone of the First Fill directly above the 10-Feet Pot indicates that the Pot, Stream Passage and Boulder Chamber are later developments (Phase 4).

Because the First Fill can be traced to the entrances of the cave and because it was succeeded by a major phase of erosion, neither surface nor underground stream capture can explain its deposition. Like the Second Fill, it appears that it must be attributed to changes in the external climatic environment. It differs from the Second phase in that there was no reintroduction of aggrading streams to the abandoned inlets of the Extension and Rhumba Alley. This, and the comparatively small volume of the stream-borne component, may suggest that the climatic conditions responsible for the change from erosion to aggradation were not as strongly developed in First Fill times as they were in the Second, or that they were not sustained for so long a period.

V. Phase 6—Modern Phase

In the modern phase, erosion again predominates. All streams, including the wet-weather rivulets that flow in the Extension passages and Rhumba Alley, are clearing the Second clastic fills and eroding stalagmite wherever they touch it. Samples of stream water, as opposed to seepage waters entering the roof and walls, are chemically aggressive, although only weakly so at the bottom of the cave.* Most of the limestone material is removed in solution. As the clearance is far from complete, there has been very little fresh attack upon solid rock surfaces. This makes it most difficult to determine whether the volume of the present erosive stream is comparable to those of the two major phases of the past. The writer suspects that it is probably smaller, the Longwood Valley headwaters having reduced the area of the G.B. catchment during Second Fill times.

* This observation is based on seventy-three analyses of stream water in G.B., collected from twelve different sites along the main stream and the Extension and Rhumba Alley tributaries. Samples were collected in wet and dry, summer and winter conditions. Measurements were made of air and water temperature, *p*H, calcium and total hardness for each sample. Titration was by the Schwarzenbach method, using a standard preparation by British Drug Houses (Schwarzenbach *et al.*, 1946).

Above a level of approximately 600 ft. O.D. many calcite formations which are out of reach of the principal streams are being eroded by drips and seepages coming from the interstices which conveyed the original, calcite-depositing, waters.* This indicates that the recent stalagmite phase is not merely at an end along the courses of the streams; it has been terminated by a fundamental change in the relevant chemical composition of all groundwater in rock. This must reflect a change in climate or vegetation cover, probably both. The same point is illustrated by the distribution of stalagmite thicknesses in mud about stream channel courses. Davis (1930) and others have supposed that stalagmite deposition tends to commence beneath drip sources as soon as a cave becomes air-filled. It will only be prevented where there is vigorous stream erosion. If this were so, and the streams failed for comparatively short periods in the vadose history of the cave, as they have in G.B., then stalagmite flows and bosses away from the channels should, in general, be more massive than those in the channels, for they have the benefit of uninterrupted formation. This relationship can nowhere be seen in this cave.† Within and without the stream channels the First and Second phases of stalagmite deposition were discrete in time.‡

There are few instances of re-solution by the formative drip to be found below 600 ft. O.D.§ At its simplest, this may reflect the greater length of the interstitial path from the open air, as depth underground increases. The recent stalagmite phase may thus be persisting here, away from the active stream channels. G.B. Cave differs from St. Cuthbert's Swallet and Swildon's Hole in this respect. Both of the latter show a modern predominance of re-solution, down to their deepest parts. These are 400–450 ft. beneath the plateau, as in G.B.

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* The most spectacular instance of this re-solution from the formative source is to be seen in an aven immediately north of the entrance to the constricted parts of Ooze Passage.

† It does not hold in St. Cuthbert's Swallet or Swildon's Hole either. These two caves show several examples where the stalagmite is much thicker within channels that convey eroding streams today than it is on the channel sides, although the formative drip first passed across the latter. This is because the channels are foci for the gravitationally controlled depositing solutions and because rate of flow was reduced in them. Gour Passage, on the Pulpit Route of St. Cuthbert's Swallet, offers the best instance that the writer has seen.

‡ This should be treated as a general statement. From observations, the writer believes that it is probable that small stalactites, straws and helictites may be in continuous formation at favoured sites. A modern example is the roof of Upper Grotto. As noted, this is of fill, which is exceptionally fine-grained. Although it is indurated with calcite it is still widely permeable. With such a composition, conditions are particularly favourable for the rapid assimilation of solute carbonates in groundwater. As a result, the roof is a forest of straw stalactites. Most of these have been broken off by vandals.

§ The data in Smith and Mead (1962) supports this observation.—*Editor.*

CHRONOLOGY OF G.B. CAVE

No material which might yield a definite date, such as an artefact, or fossil wood in a stream-laid deposit, has been found in the cave. Correlation with the chronological record is obtained indirectly by matching negative shifts of the water table with external base level controls and comparing the sequence of phases in G.B. with sequences obtained in other swallet and effluent caves of the central Mendip region. Rhythm is characteristic: successive phases of erosion, clastic deposition, stalagmite formation then erosion again, etc., are found in each sequence. Erosion (re-excavation) and calcite re-solution mark the modern phase in every example, and there is always a penultimate stalagmite phase.

At G.B. the rhythmic changes of phase were evidently caused by changes in the external environment. This appears to be true in the other caves also. The pattern of general, frequent, environmental change suggests the climatic variations of the Pleistocene. Phases of erosion underground may be attributed to interglacial/interstadial conditions, from the example of the modern phase. The environmental requirements for clastic deposition (p. 161) suggest cold periods, with frost-riving to provide the coarse sandstone detritus, and permafrost obstruction to reduce the volume of water sinking underground.*

Because G.B. Cave rapidly developed as a vadose system down to 450 ft. O.D., it may be presumed that it is later than the erosion surface at 820–860 ft. beneath which it lies. If there is any external base level control this must be at lower elevation and affect the effluent, the Gough's group of caves at Cheddar.† At Gough's, three past levels of the water table may be defined above the modern position, which is at 80 ft. O.D. The penultimate position, which was of prolonged duration to judge from the volume of erosion, stood 50–70 ft. higher (130–150 ft. O.D.). It is here supposed that the penultimate level in G.B. (Ladder Dig at 450 ft. O.D.) was accordant to this. The 50–70 ft. fall to the modern level at Cheddar caused the abandonment of the Ladder Dig and the formation of a new water table system, some 50 ft. below it.

This correlation is supported by cross-reference to Swildon's Hole. In that cave, there are also three abandoned water table levels above the modern one, separated by vertical intervals closely comparable to those at Gough's. There appears to be a complete dynamic correlation between the two systems. The rhythm of erosional and depositional phases is the same as that

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* It will be appreciated that this is a considerable generalization, dictated by the need for brevity. Circumstantial evidence of the occurrence of permafrost in the Mendip Hills during the Pleistocene is given by Reynolds (1927), Corbel (1957), Clayden and Findlay (1960), Tratman (1963).

† The group comprises Gough's Cave, Cooper's Hole, Great Oone's Hole, Long Hole, the Old Cave and Saye's Hole. All are parts of a single effluent system.

of G.B., but there is a greater number of phases (i.e., the origin of Swildon's Hole is older). When the sequences of the two caves are matched, phase by phase, back from the present, Phase 2 in G.B. (Ladder Dig water table) is found to correlate with that in Swildon's which saw the establishment of the penultimate water table, accordant to the 130–150 ft. water table at Cheddar.

The elevation of the 130–150-ft. water table at Gough's was determined by a marine platform, cut at 100–120 ft. O.D., a short distance to the south. West of the village of Easton, there are many remains of this bench on the south flank of the Mendip Hills. It appears to be well preserved elsewhere in the Bristol Channel area.* It may be identified with the "Tyrrhenian" (Mindel-Riss interglacial) eustatic platform of Zeuner (1958, 1959).† Phases 1 and 2 in G.B. Cave are therefore unlikely to be earlier.

They are probably much later because at the Gough's effluent the modern water table is controlled by base levelling to the Main Monastirian platform (Riss-Würm interglacial). There has thus been a considerable time lag between the establishment of the marine level and the adjustment of cave water tables to it. Basal deposits of water-laid sand in the main passage of Gough's Cave belong to the period of this adjustment. Stratigraphically, they are close to a cave earth that is assigned to the Younger Dryas (Donovan, 1955). There is, therefore, little doubt that the modern water table at Cheddar was established at some time during the Würm. The adjustment of the G.B. system to the new water table (Phase 4) must also be assigned to the same period before the close of the Würm, for it was followed by deposits attributed to a cold climate (Phase 5c). When volumes of work accomplished during the erosion phases in the cave are compared to available time in the late Pleistocene chronology, it appears that Phases 1 and 2 are likely to belong to the Riss-Würm interglacial and Phase 4 to the prolonged Gottweig Interstadial (Gross, 1957). Deposits of the First Fill are therefore placed in the Early Würm cold period; the deposits and limited clearances of the Second Fill are attributed to the cold periods and brief interstadials or ameliorations of the Main Würm. Deposits of soft stalagmite in the mouths of Gough's Cave and the Old Cave have been assigned to the Mesolithic.‡ Hard stalagmite deeper within these caves appears to be contemporary and, from the phase position, the equivalent of the recent stalagmite (Phase 5e) at G.B.

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* See North (1929) on the general area, Trueman (1938) on North Somerset, Wills (1938) on the Severn estuary, Driscoll (1958) on the Glamorgan shore and Arber (1960) on North Devon.

† Zeuner's terms for the eustatic levels and the Alpine terminology for the Pleistocene are used in this paper, following the lead given by ApSimon, Donovan and Taylor (1961) in their account of the nearby deposits at Brean Down, Somerset. Tyrrhenian ascription for the 100–120 ft. bench is supported by the local occurrence of other benches immediately below it at the Main and Late Monastirian levels.

‡ Broadly, the Boreal and Atlantic climatic phases of the post-Glacial. See Donovan (1955), Tratman (1960).

DISCUSSION

A distinctive feature of the large swallet caves of the central Mendip area is that no two are much alike in geomorphic form although all are entered from sinks at the Limestone-Shale contact, are contained within the lower part of the Black Rock Limestone and descend to closely comparable depths beneath the same erosion surface. This discussion is concerned with some of the peculiar characteristics of G.B. Cave.

Outstanding is the quantitative predominance of vadose erosional forms, over the whole height of the cave. It appears to be a fine example for the vadose theory of cavern genesis (see Warwick, 1955). In contrast, Swildon's Hole evokes the water table theory (Swinnerton, 1932; Davies, 1960) and St. Cuthbert's Swallet the hypotheses of deep phreatic development (Davis, 1930; Bretz, 1942). The reason why G.B. is the "most vadose" of the great swallet caves is that it was one of the last to develop. Base levels at the effluent were hundreds of feet lower than they were at the time of cavern genesis in the other caves noted. In all of them, the water table fell rapidly from the plateau surface during the first phase of development, in response to the increase in volume of the underground reservoir, the cave. Within each known cave, which is merely the head of a much lengthier underground channel, the table then stabilized at an elevation that was determined by whatever hydraulic gradient, or headfall, was then required to drive phreatic water through the rest of the system. In G.B. Cave this first stabilization occurred at 450 ft. O.D. Vadose processes thus came to be predominant in all higher parts early in the history of the cavern. In Swildon's Hole, the first stabilization was above 600 ft. O.D., and in St. Cuthbert's Swallet above 660 ft. O.D. The zones of early predominance of vadose processes are therefore much more restricted. With subsequent lowering of the respective water tables, these processes have been introduced to greater depths. But there they have had to work upon much larger phreatic passage forms than those of G.B., because the time available for phreatic erosion was much greater. The comparative magnitude of the vadose forms is diminished accordingly.

A second, and rather disheartening, characteristic of the cave is the great and sudden reduction of passage dimensions at the terminal parts.* Similar constriction occurs at the bottom of Longwood Swallet, which is close by. It does not appear in Swildon's Hole, Eastwater Cavern and St. Cuthbert's Swallet, which are farther away.† In part, the reduction at G.B.

* Dr. G. T. Warwick, in private correspondence, has referred to those parts as "miserable rabbit holes at the water table".

† In the remote parts of Swildon's Hole, exploration is halted by clastic fill or water traps in large passages. To the caver, the lowest places in St. Cuthbert's Swallet and Eastwater Cavern *are* constricted—but it is unlikely that these channelled the bulk of the formative water flow, as they did in G.B.

may be attributed to a flattening of passage gradient and the (imminent) change from the historical predominance of a vadose flow to that of a phreatic flow. Kaye (1957) and Weyl (1958) have shown experimentally that rate of calcium carbonate solution increases with rate of water flow. Local rates of flow tend to be higher in the vadose zone.

Another contributory factor is suggested by the pattern of increment of solutes in the cave. This is shown in *Fig.* 39, which compares the major streams of three swallet systems. At the entrance to each, values for total hardness ($CaCO_3+MgCO_3$ in parts per million) are reduced to zero. The

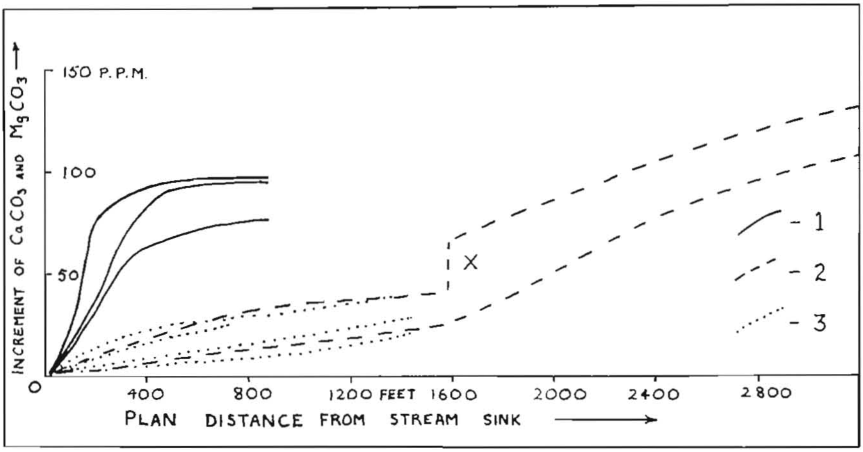

Fig. 39.—The increment of $CaCO_3$ and $MgCO_3$ in the main streams of some central Mendip swallet caves. 1, G.B. Cave. 2, Swildon's Hole. 3, St. Cuthbert's Swallet. (The abrupt increment, at point X, in one of the curves for Swildon's Hole is caused by the entry of a large tributary, Priddy Pool stream, under dry weather conditions. In wet weather (other curve), this phenomenon does not occur.)

rates of increment in the underground courses are thus made directly comparable. Curves are somewhat smoothed and generalized. Each represents a collection of samples made on one particular day. The represented collections range across wet, "average" and dry conditions in each cave.

In St. Cuthbert's Swallet and Swildon's Hole the rate of increment of the solutes is very steady and closely comparable. In the case of G.B. it is initially much more rapid and then falls off to the lowest values recorded, in the lower Gorge. There was very little solvent capability left in samples collected at the terminus.* It appears therefore that the ability of the G.B. waters to dissolve rock is nearly exhausted after a comparatively short

* As determined on the graphs for $CaCO_3$ saturation prepared by F. Trombes (see Corbel, 1959).

journey underground. The dimensions of passages become reduced accordingly. As the pattern of passage dimensions in Longwood Swallet is comparable, the behaviour of the increment curves may be also. No explanation can be offered for the contrasted pattern in St. Cuthbert's Swallet and Swildon's Hole. The likeliest suggestion would seem to be that there is a significant variation in the chemical composition of the Black Rock Limestone (or the interlaminated shales). The G.B.–Longwood and Swildon's–St. Cuthbert's groups of caves lie four miles apart so that this is quite possible. No relevant analyses of the regional composition of the rock have been published.*

Finally, there is the distinctive form of the vadose passage in G.B. This is the tall rift, with lateral expansion at the base that has triggered some collapse higher up the wall. The long profile of the solid floor is smooth and it has a regular gradient which is maintained through many changes of controlling joints. In Swildon's Hole and St. Cuthbert's Swallet lateral expansion is not very common at the base of a vadose rift. There is comparatively little collapse from the walls. There are many potholes of varying size in the solid floor so that it is never smooth and gradients are very irregular.

The explanation is thought to lie in the initial differences in the structure. In G.B. Cave, the tall joints were comparatively open. Vadose streams were quickly able to incise their channels down them and to establish profiles, or gradients, of equilibrium between force available and resistivity to erosion (Hack, 1957). These gradients are strikingly uniform: in the main Extension passage, 1:4–1:4·5; the Loop, 1:4·7; the Oxbow, 1:4·5; The Gorge,† 1:4. The lateral force exerted by an eroding stream is frequently increased once an equilibrium gradient is established (Davis, 1908; Thornbury, 1954; etc.), thus accounting for the widening at the base of the typical passage in G.B.

* For the above reasons, the writer cannot share the confidence of Gilbert (1963), who has expressed the belief that digging in the active terminal passages of G.B. Cave will shortly lead to a larger way on down the main stream course. In this context, a further comparison may be made with the Swildon's and St. Cuthbert's systems. Between the known terminus of G.B. and the effluent, the mean minimum gradient is 1:19. At St. Cuthbert's the equivalent is 1:40; at Swildon's, 1:84. This variation can be interpreted in one of two ways. Optimistically, the steep gradient at G.B. means that there is a good depth of well-drained passages to be found beyond the terminal choke. Mean minimum gradient will flatten at the end of it, to approach the St. Cuthbert's or Swildon's values, and the explorer will encounter the kind of water trap that hampers discovery in those systems. Alternatively, the high gradient at G.B. indicates that passages in the unknown downstream section are very constricted or ill-integrated (a mesh rather than a single channel as in Swildon's), or both, requiring a great hydrostatic head to drive water against high values of containing friction. As a caver, the writer would like to take the optimistic view, but the known terminal passages are a constricted mesh, flattening to the 1:19 gradient. Steeper hydraulic gradients occurred during Phase 1 of the cave's history, in association with very small passages.

† The Gorge profile was measured between "the narrows" and the 40-Feet Pitch.

At Swildon's Hole and St. Cuthbert's Swallet fractures were evidently much tighter. There are no instances of a hanging phreatic passage being preserved with its floor intact because later vadose water could leak through lower parts of the controlling joint. Small irregularities in the resistant channel floor led to the drilling of stream potholes. Once established, these created great imbalance in the distribution of forces, militating against the establishment of equilibrium gradients in the solid rock.

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REFERENCES

Proc. = Proceedings, University of Bristol, Spelæological Society

ApSimon, A. M., Donovan, D. T., and Taylor, H., 1961, "The Stratigraphy and Archæology of the Late-Glacial and Post-Glacial deposits at Brean Down, Somerset", *Proc.*, Vol. 9, 67–136.

Arber, M. A., 1960, "Pleistocene Sea Levels in N. Devon", *Proc. Geol. Assoc.*, Vol. 71 (2), 169.

Bendall, J. H., and Crickmay, R. A., 1951, "A Survey of G.B. Cave, Charterhouse-upon-Mendip", *Proc.*, Vol. 6, 174–186.

Bretz, J. H., 1942, "Vadose and Phreatic Features of Limestone Caves," *Journal of Geology*, Vol. 50, 675–811.

Chapman, M. B., 1912, "The Chemical Examination of the Carboniferous Limestones of the Avon Gorge", *Geol. Mag.* n.s., Vol. 9, 498–503.

Clayden, B., and Findlay, D. C., 1960, Abstracts of *Proceedings of 3rd Conference of Geologists Working in S.W. England.* "Mendip, Derived Gravels and their Relationship to Combes", p. 24. Royal Geological Society of Cornwall.

Coleman, A. M., and Balchin, W. G. V., 1960, "The Origin and Development of Surface Depressions in the Mendip Hills", *Proc. Geol. Assoc.*, Vol. 70, 291–309.

Corbel, J., 1957, "Les Karsts du Nord-Ouest de l'Europe", *Mem. Institut des Études Rhodaniennes de l'Université de Lyon,* No. 12, 544.

— — 1959, "Érosion en Terrain Calcaire", *Annales de Géographie*, No. 366, 97.

Cvijic, J., 1960, *La Géographie de Terrains Calcaires.* Acad. Serbe des Sciences et des Arts, Beograd.

Davies, W. E., 1960, "Origin of Caves in Folded Limestone", *Bull. National Speleological Society of America,* Vol. 13 (1), 36–42.

Davis, W. M., 1908, "The Geographical Cycle", *Geographical Essays.* Dover.

— — 1930, "Origin of Limestone Caverns", *Bull. Geological Society of America,* Vol. XLI, 475–628.

DONOVAN, D. T., 1955, "The Pleistocene Deposits at Gough's Cave, Cheddar, including an Account of Recent Excavations", *Proc.*, Vol. 7 (2), 76–105.

— — and WALLIS, F. S., 1944, "G.B. Cave, Black Down, Mendip Hills: Geological Report", *Proc.*, Vol. 5 (2), 114–118.

DRISCOLL, E. M., 1958, "The Denudation Chronology of the Vale of Glamorgan", *Trans. Institute of British Geographers*, No. 29.

GILBERT, E. V., 1963, "An Account of Recent Developments in G.B. Cave, Charterhouse-on-Mendip, Somerset", *Proc.*, Vol. 10 (1), 58–64.

GLENNIE, E. A., 1954, "Artesian Flow and Cave Formation", *Trans. Cave Research Group of Great Britain*, Vol. III (1), 55–71.

GREEN, G. W., 1958, "The Central Mendip Lead-Zinc Orefield", *Bull. Geological Survey, G.B.*, No. 14, 70–90.

GROSS, H., 1957, "Die geologische Gliederung und Chronologie des Jungpleistozans in Mitteleuropa und den angrenzenden Gebieten", *Quartar*, Vol. 9, 3–40.

HACK, J. T., 1957, "Studies of Longitudinal Stream Profiles in Virginia and Maryland", *United States Geological Survey Professional Paper No.* 294.

HANNELL, F. G., 1955, "Climate" *in* "Bristol and its Adjoining Counties", *Brit. Assoc. Regional Handbook.* p. 3.

HILLS, E. S., 1953, *Outlines of Structural Geology.* London.

KAYE, C. A., 1957, "The Effect of Solvent Motion on Limestone Solution", *Journal of Geology*, Vol. 55, 37–46.

KELLAWAY, G. W., and WELCH, F. B. A., 1955, "The Upper Old Red Sandstone and Lower Carboniferous Rocks of Bristol and the Mendips compared with those of Chepstow and the Forest of Dean", *Bulletin, Geological Survey of G.B.*, No. 9, 1–21.

NORTH, F. J., 1929, *The Evolution of the Bristol Channel.* Cardiff: National Museum of Wales.

PENMAN, H. L., 1956, "Estimating Evaporation", *Trans. American Geophysical Union*, Vol. 37 (1), 43–50.

REYNOLDS, S. H., 1927, "The Mendips", *Geography*, Vol. 14, 187–193.

SCHWARZENBACH, G., BIEDERMANN, W., and BANGERTER, F., 1946, "Neue einfache Titriermethoden zur Bestimmung der Wasserharte", *Helvetica Chimica Acta*, Vol. 29, 811.

SMITH, D. INGLE, and MEAD, D. G., 1962, "The Solution of Limestone", *Proc.*, Vol. 9, 188–211.

STANTON, W. I., 1954, "Joints, Shale Bands and Cave Formation; a Special Case", *Trans. Cave Research Group of Great Britain*, Vol. III, 41–53.

SWINNERTON, A. C., 1932, "Origin of Limestone Caverns", *Bull. Geological Society of America*, Vol. XLIII, 662–693.

THORNBURY, W. D., 1954, *Principles of Geomorphology.* New York: Wiley.

THORNTHWAITE, C. W., 1948, "An Approach towards a Rational Classification of Climate", *Geographical Review*, Vol. XXXVIII (1), 55–94.

— — 1957, "Instructions and Tables for Computing Evapotranspiration and Water Balance", *Drexel Institute, Publications in Climatology*, Vol. X (3).

— — and MATHER, J. R., 1955, "The Water Balance", *Drexel Institute, Publications in Climatology*, Vol. VIII (1).

TRATMAN, E. K., 1955, "Second Report on the Excavations at Sun Hole, Cheddar. The Pleistocene Levels", *Proc.*, Vol. 7 (2), 61–73.

— — 1957, "A Nameless Stream: Suggested New Term", *Cave Research Grp. N/L*, 6, 68–69.

— — 1960, "Gough's Old Cave, Cheddar, Somerset", *Proc.*, Vol. 9 (1), 7–22.

— — 1963, "The Hydrology of the Burrington Area, Somerset", *Proc.*, Vol. 10 (1), 22–57.

TRUEMAN, A. E., 1938, "Erosion Levels in the Bristol District and their Relation to the Development of the Scenery", *Proc. Bristol Naturalists' Society*, Vol. 8 (4th Ser.), 402–428.

WARWICK, G. T., 1955, "The Origin of Limestone Caves", Chapter 3 in *British Caving* (Ed. by C. H. D. CULLINGFORD). London: Routledge, Kegan Paul.

WELCH, F. B. A., 1929, "The Geological Structure of the Central Mendips", *Q.J.G.S.*, Vol. 85, 45–76.

— — 1932, "The Geological Structure of the Blackdown Pericline", *Proc. Bristol Naturalists' Society*, Vol. 7, 388–396.

WENTWORTH, C. K., 1932, "The Coarser Grained Clastic Sedimentary Products", Chapter V in Twenhofel, *Treatise on Sedimentation*, Vol. 1. New York: Dover.
WEYL, P. K., 1958, "Solution Kinetics of Calcite", *Journal of Geology*, Vol. 66, 163–176.
WILLS, L. J., 1938, "The Pleistocene Development of the Severn from Bridgnorth to the Sea", *Q.J.G.S.*, Vol. 94, 161–242.
ZEUNER, F. E., 1958, *Dating the Past*, 4th ed. London: Methuen.
— — 1959, *The Pleistocene Period*. London: Hutchinson.