Boyd

TRANSACTIONS

BCRA

BRITISH CAVE RESEARCH ASSOCIATION

Volume 1 Number 3 September 1974

Instant Hydrology in Dentdale

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A very short summary of the principal conclusions should accompany every contribution.

References to other published work should be cited in the text thus . . . (Bloggs, 1999, p.66) . . . and the full reference with date, publishers, journal, volume number and page numbers, given in alphabetical order of authors at the end, thus . . .
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BRITISH CAVE RESEARCH ASSOCIATION

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Photo by T. D. Ford.

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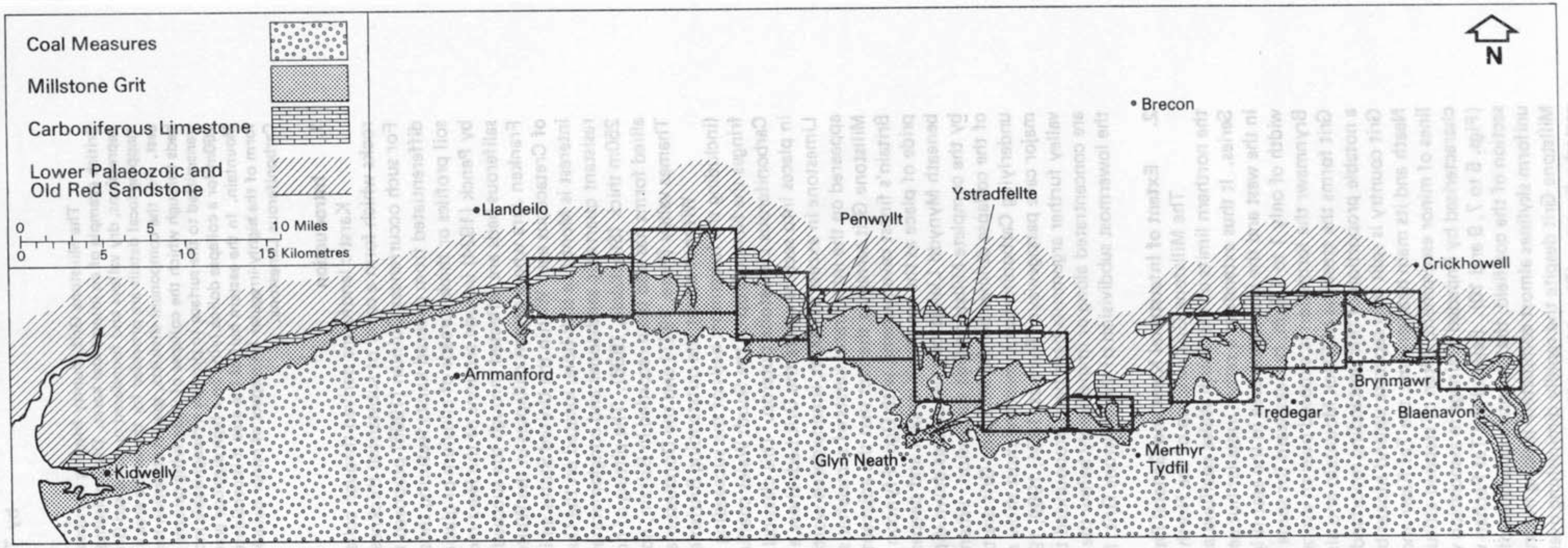

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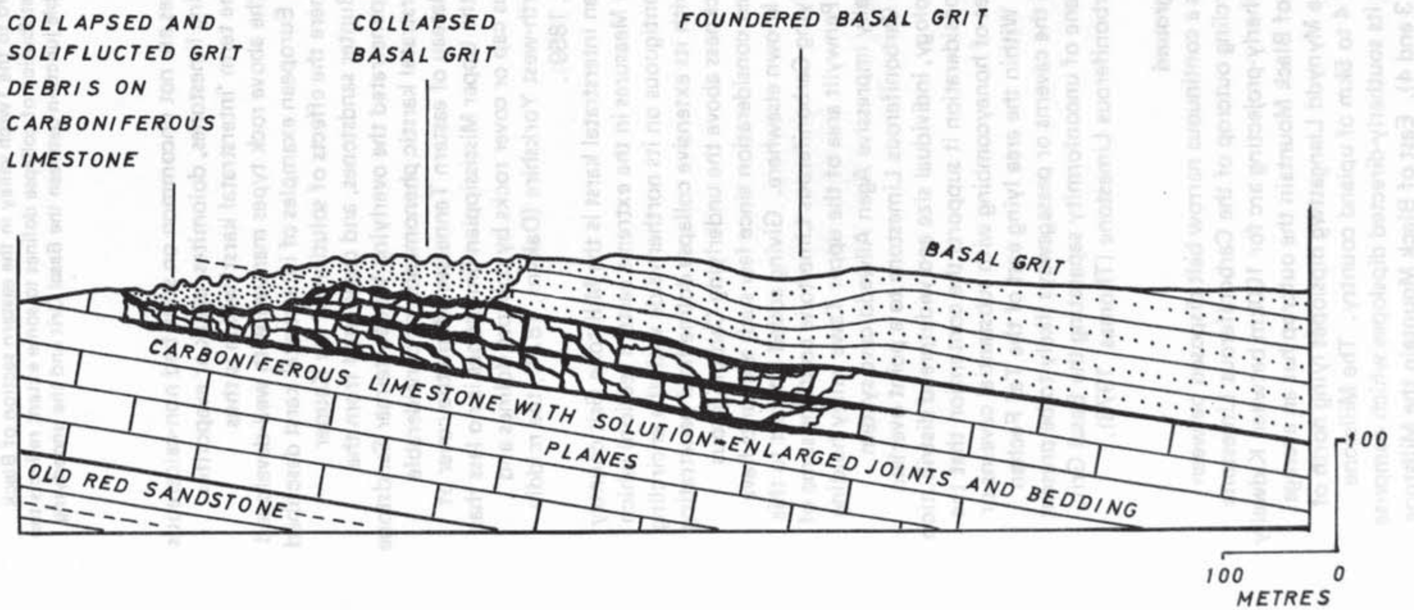

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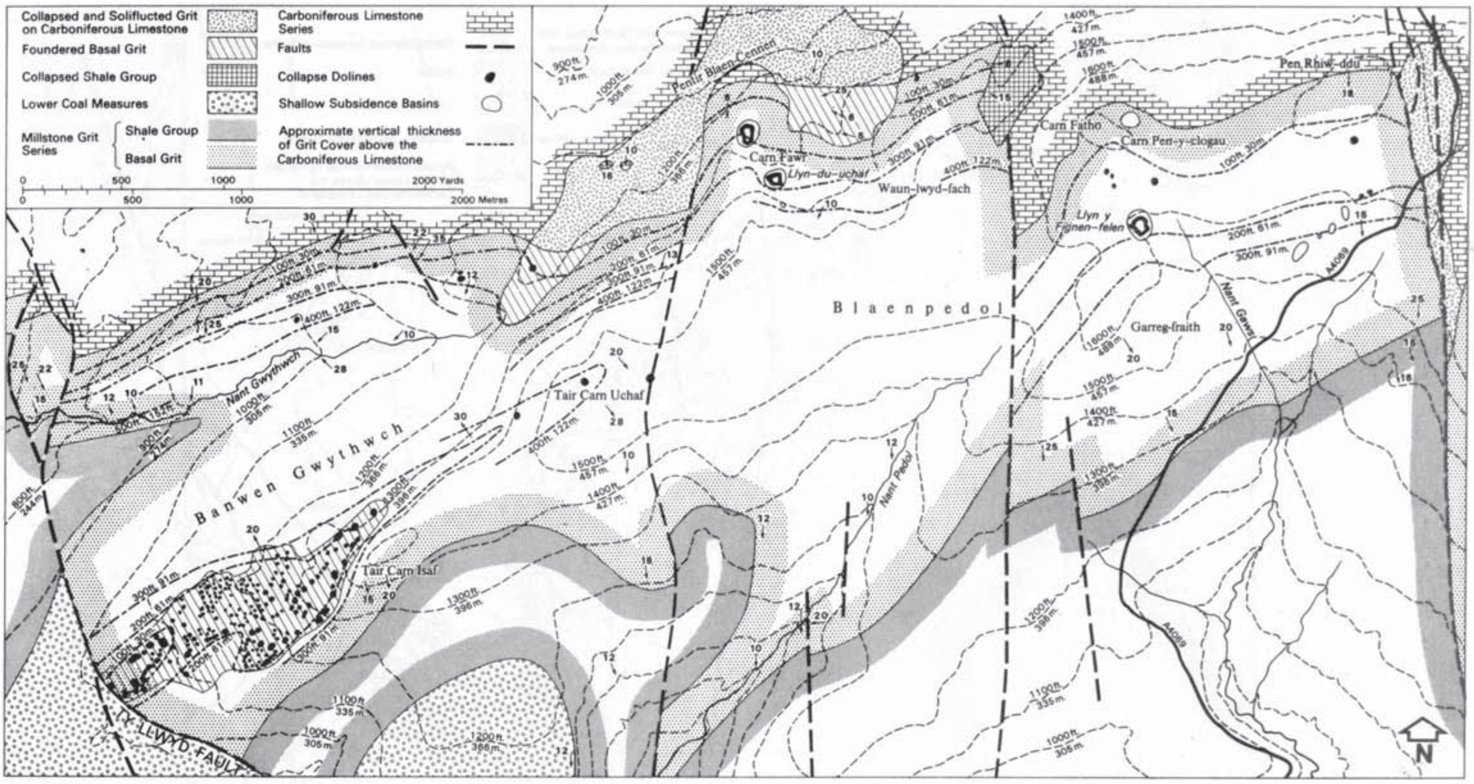

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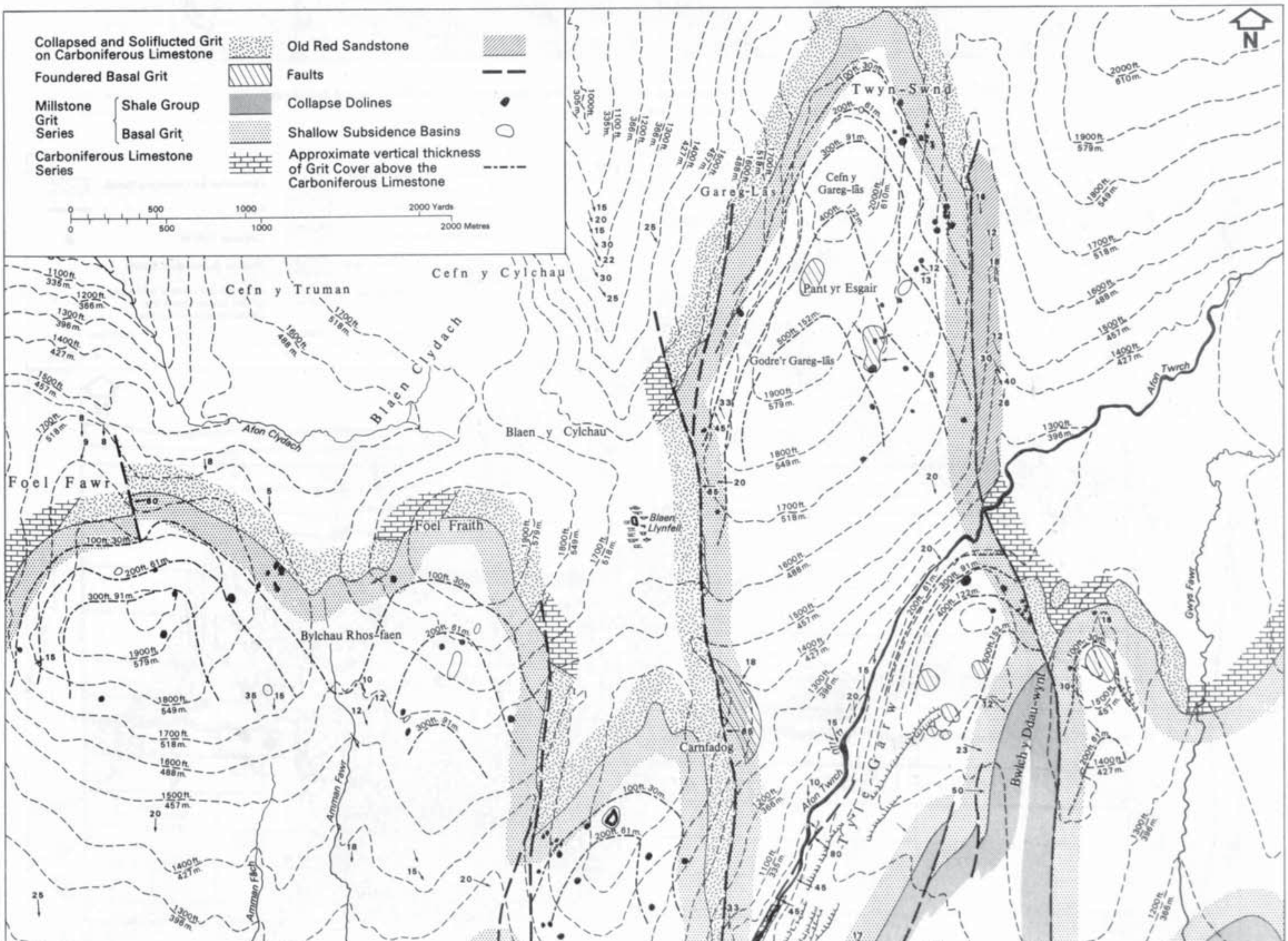

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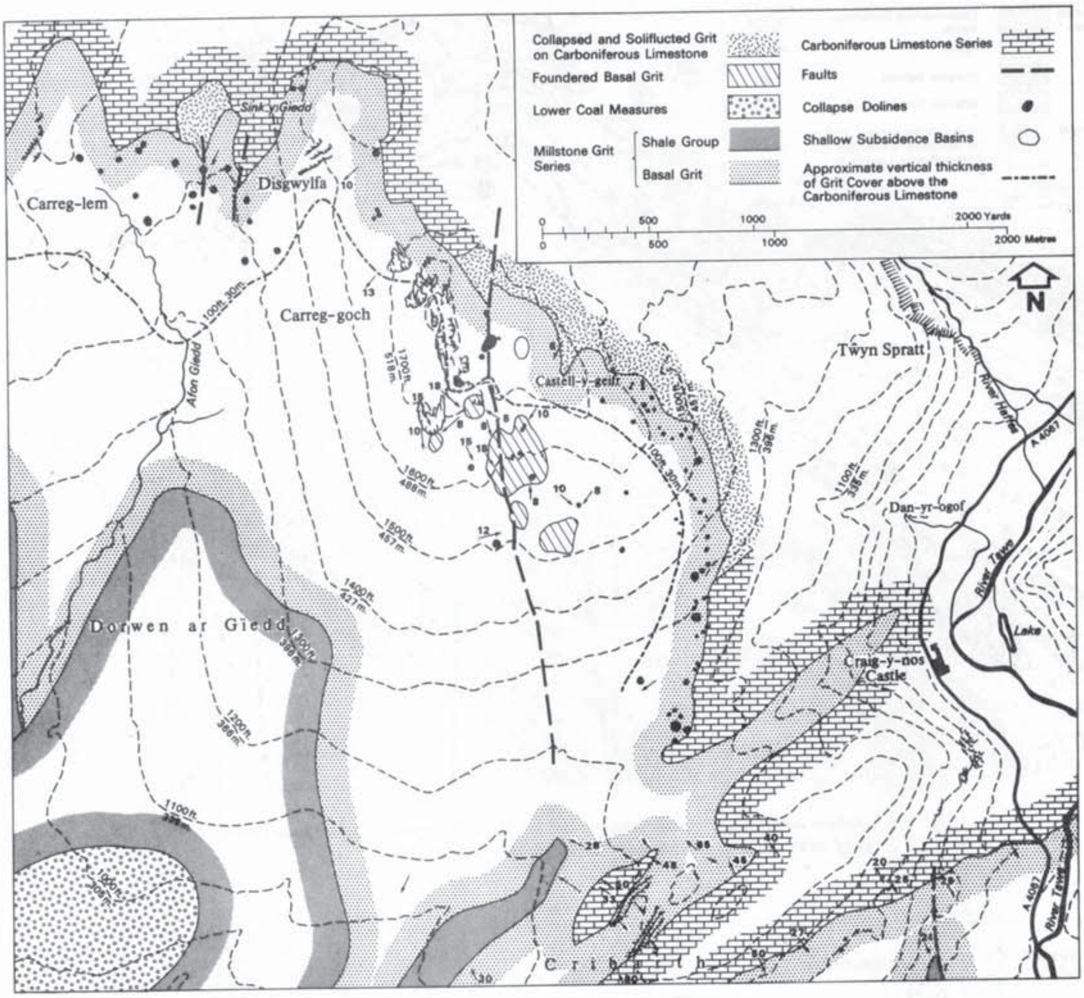

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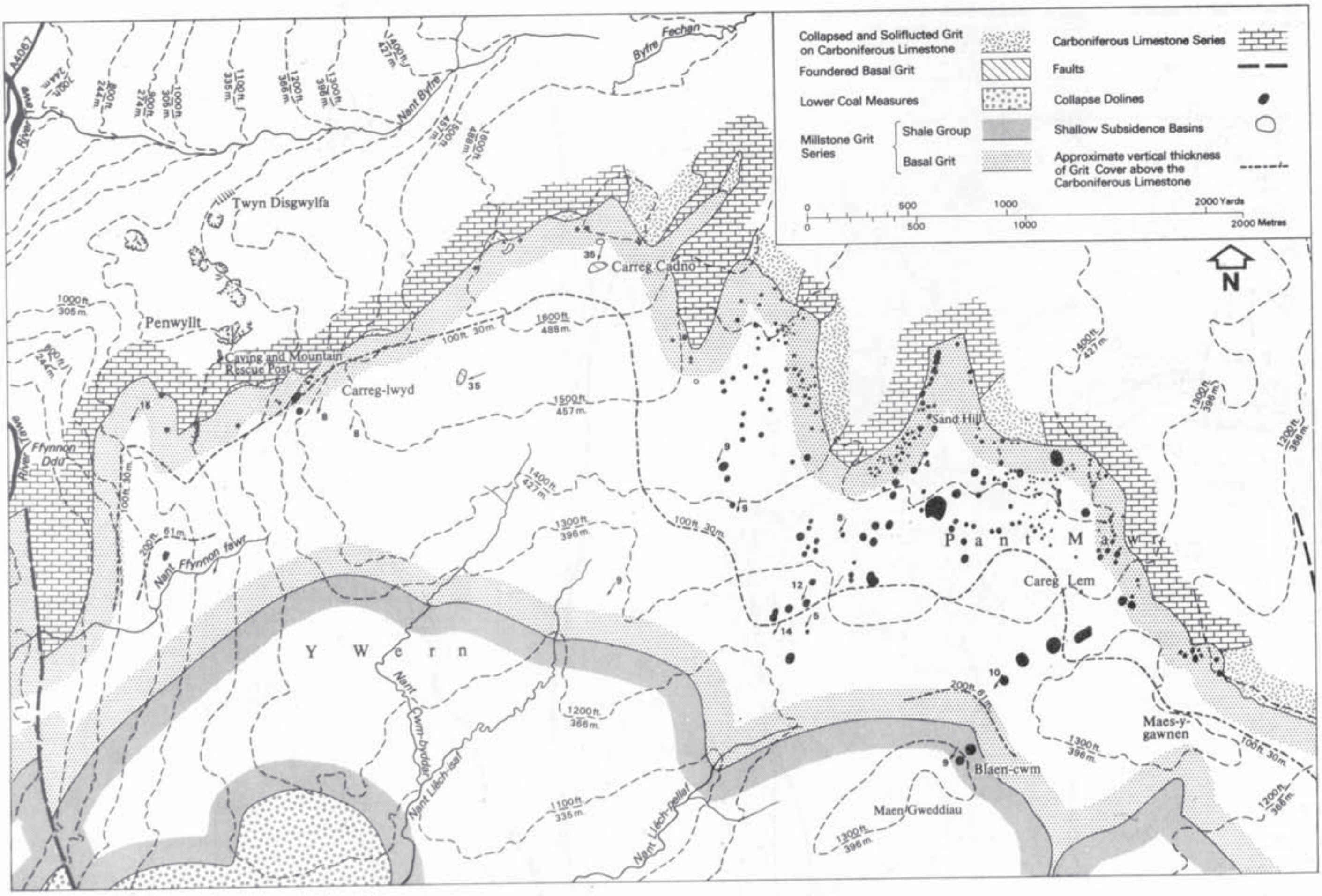

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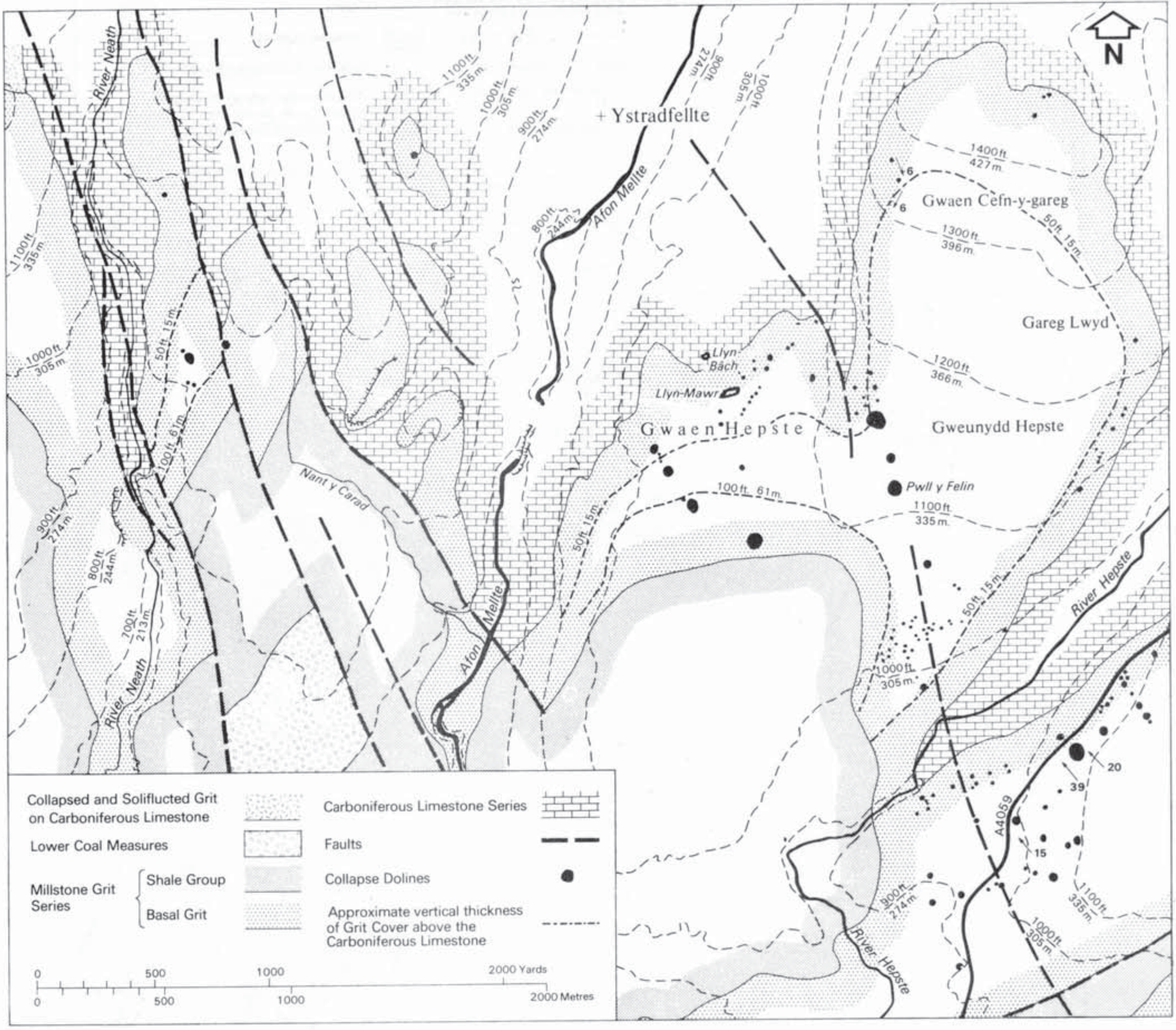

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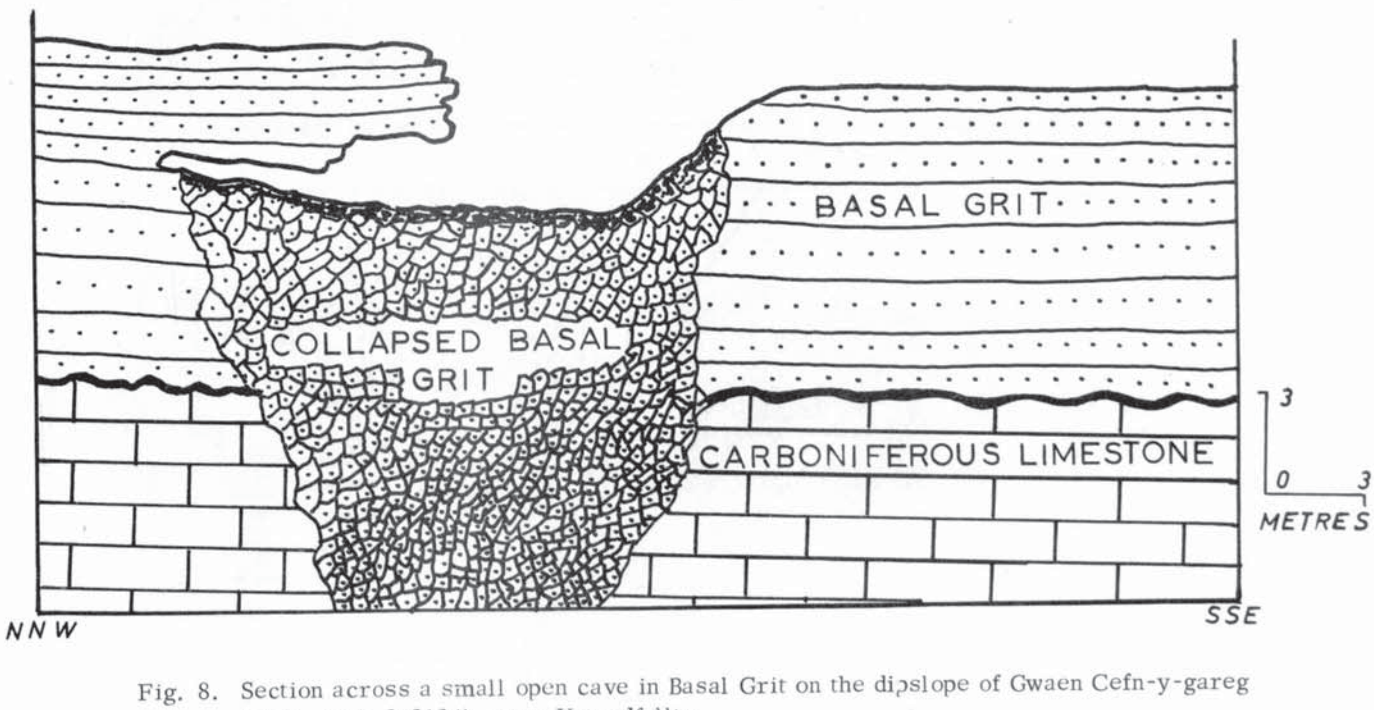

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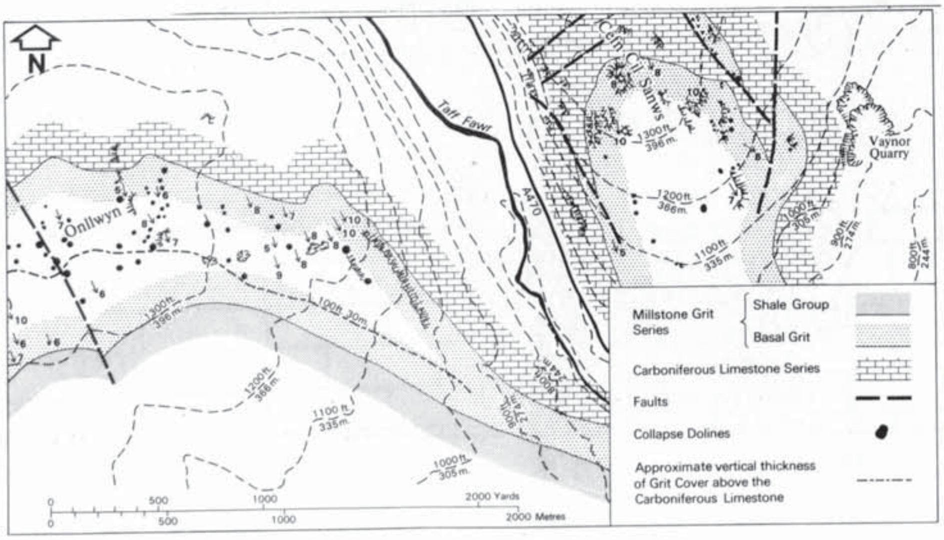

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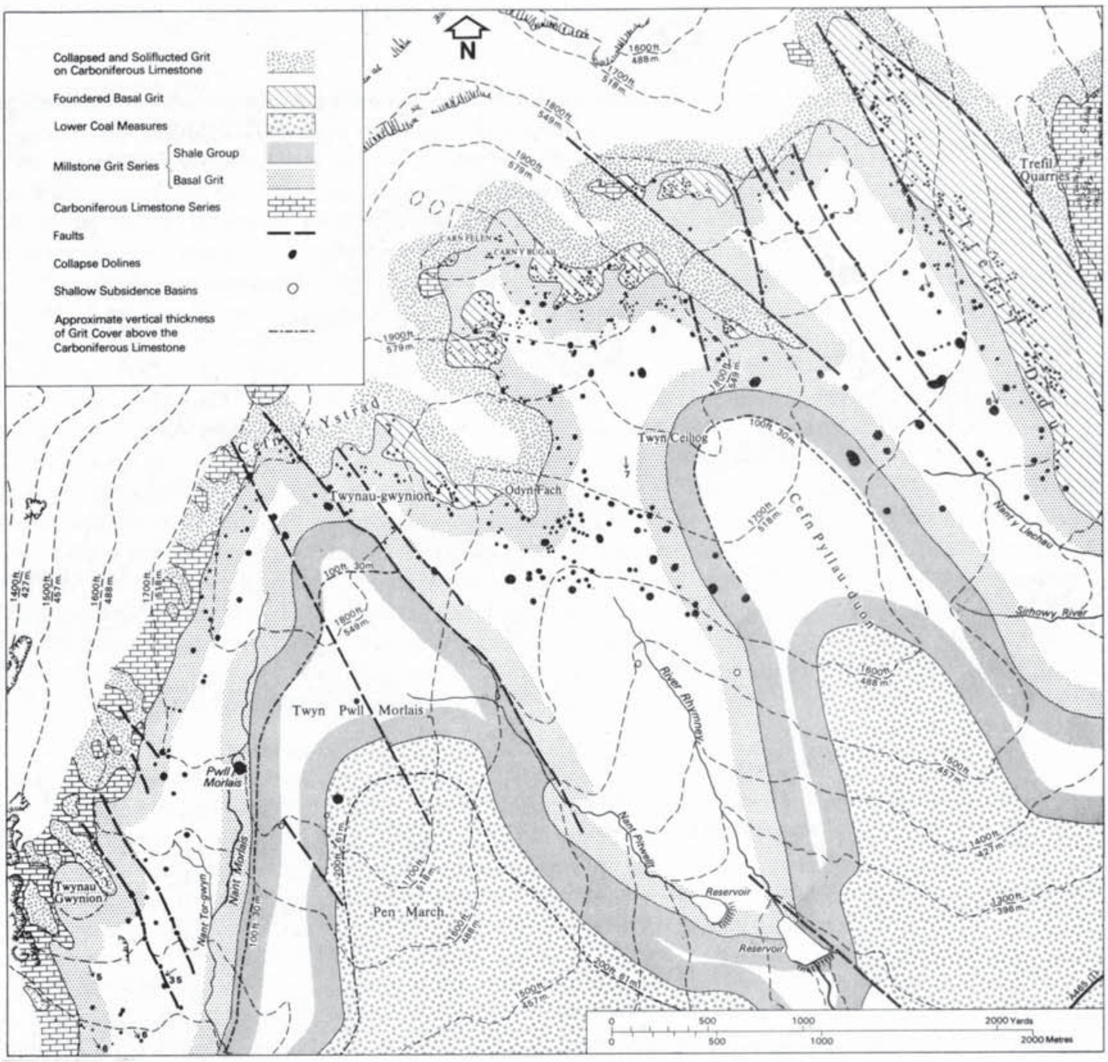

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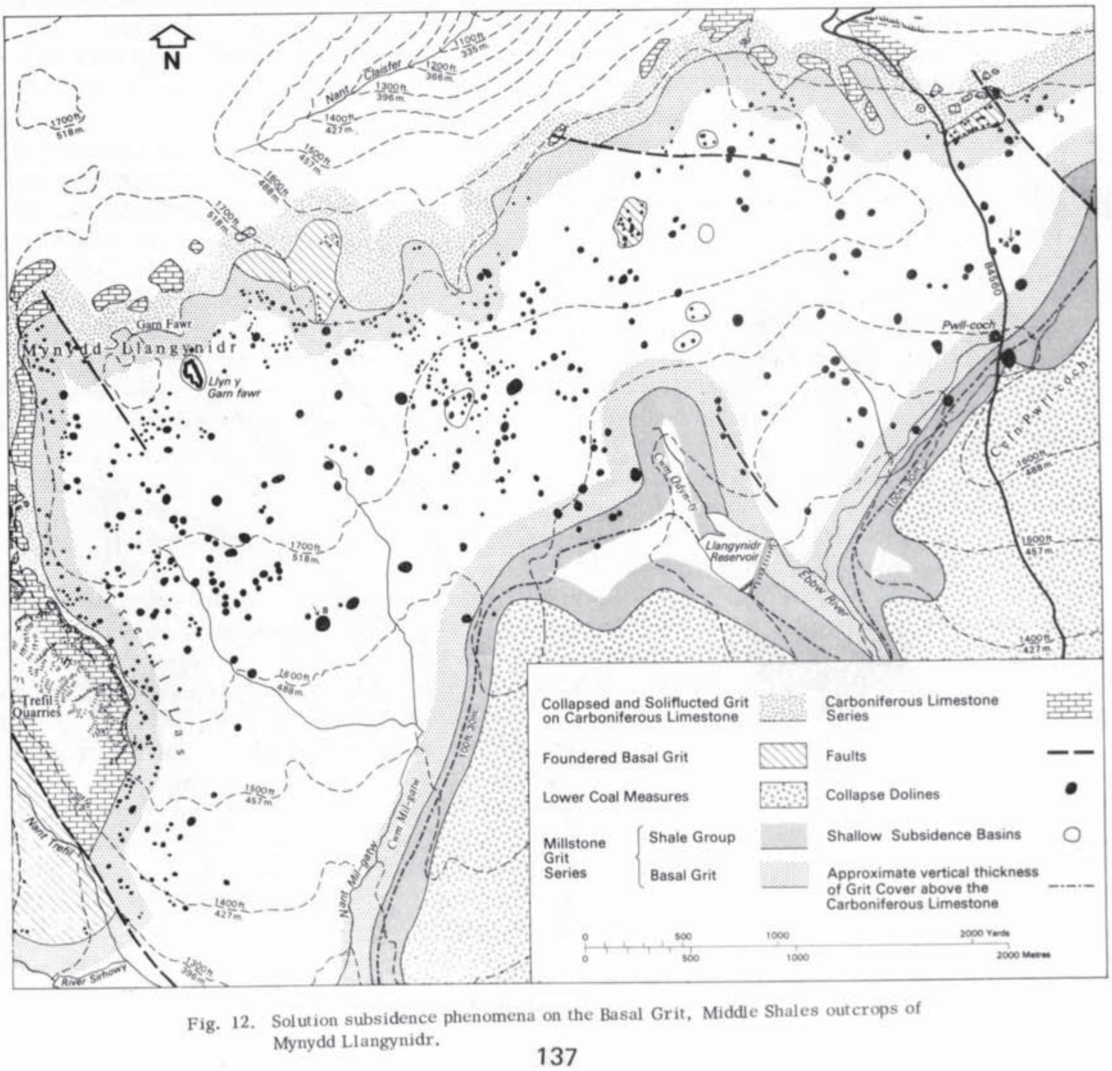

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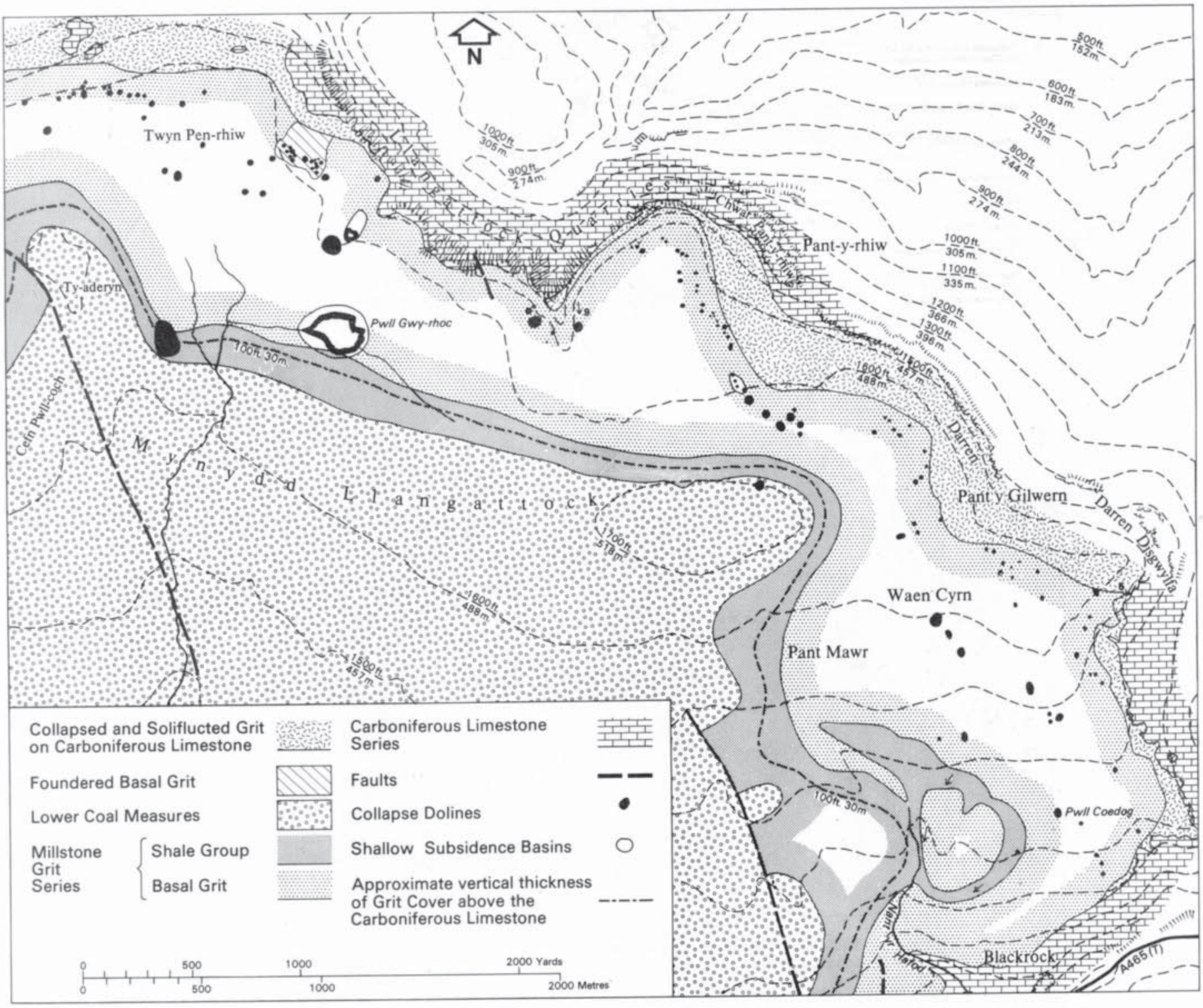

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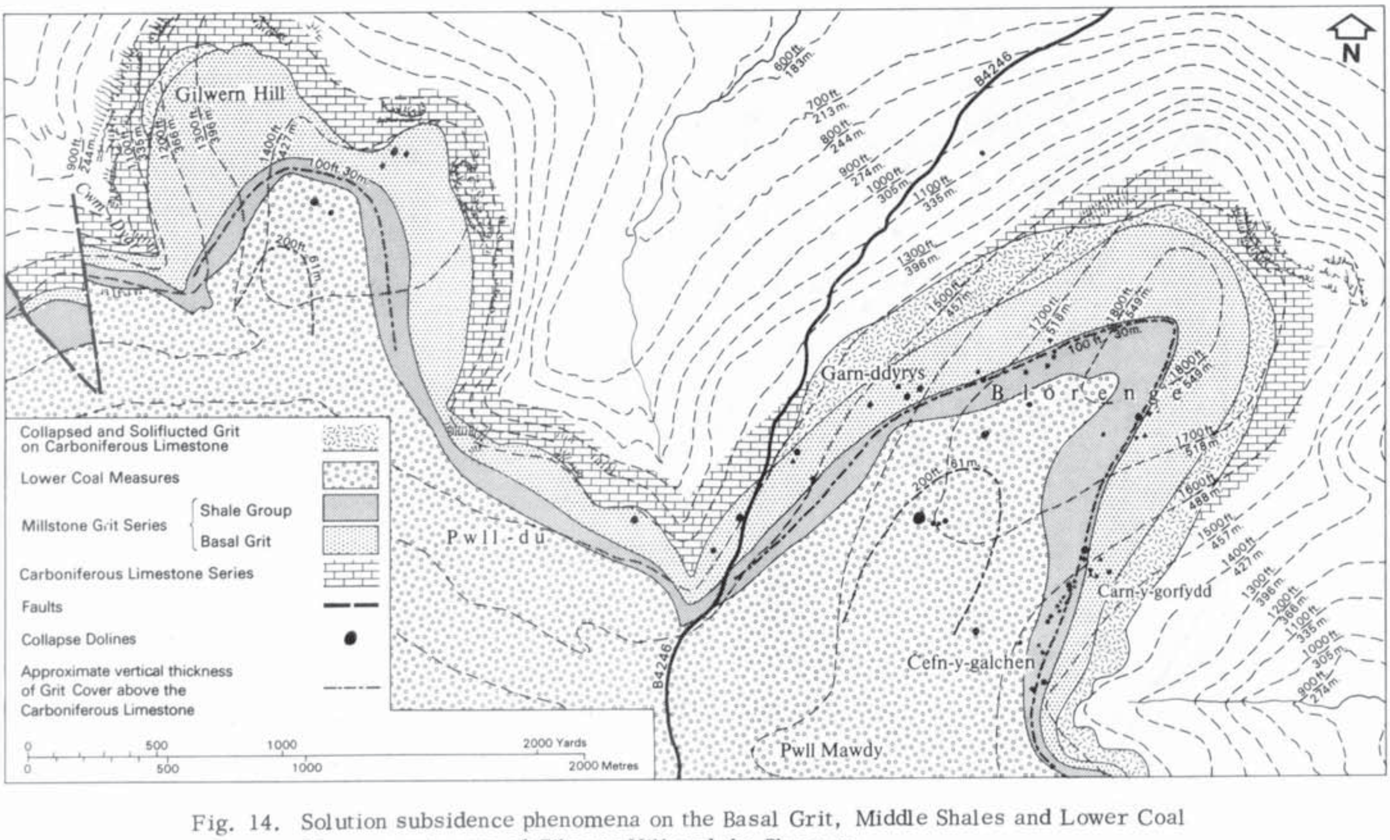


Fig. 14. Solution subsidence phenomena on the Basal Grit, Middle Shales and Lower Coal Measure outcrops of Gilwern Hill and the Blorenge.

Specific landforms which have warranted the description of interstratal karst for a significant proportion of this Millstone Grit tract are, first and foremost, the impressive collapse dolines. To a lesser extent the allied shallow subsidence basins, the zones of foundered strata, both those lying adjacent to the Carboniferous Limestone outcrop and those occurring well within the Millstone Grit country, and the short stretches of dry valley, with local reversals of gradient, are also significant. Collapse dolines of noteworthy size are sparingly distributed on the Basal Grit outcrop lying to the north of Cross Hands in Carmarthenshire where, in the zones concerned, the component quartzites and shales or mudstones have a maximum vertical thickness of 15 to 20m above the Llandyfan Limestone Beds of the underlying Carboniferous Limestone. In the same vicinity Llyn Llech Owen, which extends along the strike of the beds for a distance of nearly 400m, might also be interpreted as being partially attributable to solution subsidence, although in this case the Carboniferous Limestone has a cover of 80 to 200m of Grit beds when allowance is made for their 15 to 25° dip. Between Blaenavon and the Abersychan area of Gwent the greatly attenuated representative of the Basal Grit is also pitted to minor degree by a few scattered collapse dolines where the Grit cover above the Limestone is normally less than 10m. Notwithstanding these peripheral occurrences of karstic phenomena, the western and eastern limits of the South Wales interstratal karst are placed at the western end of Black Mountain and on the Blorenge, respectively. This gives an overall length of 60km. Minor breaks interrupting its continuity are, however, apparent. Such breaks occur on the southern flanks of the Cribarth ridge in the upper Tawe valley, on the terraced upland immediately west of the Nedd Fechan valley, in the Merthyr Tydfil – Dowlais area and on the southern slopes of the Clydach valley to the east of Brynmawr. In all these areas, down-dip traverses show a rapid increase in the Millstone Grit cover above the Carboniferous Limestone and this has curtailed the spread of solution subsidence effects in depth.

3. Stratigraphy and Structure

Rhythmic sedimentation is a well known feature of the Millstone Grit succession of this area. Groups of the beds amalgamated into broad subdivisions also show a generalized cycle of similar type so that for many years the formation has been mapped according to lithology, as follows:—

3. Farewell Rock, so named because it marked the base of the sequence in which workable coal seams were liable to occur: quartzitic or quartzose sandstones with some conglomeratic layers.
2. Shale Group or Middle Shales: blue or black shales showing bands of coarse grit, sandstone or quartzite. The Twelve-Foot Sandstone near the base forms a well-defined minor feature, particularly between the upper Tawe and Neath valleys.
1. Basal Grit: a group of essentially coarse littoral deposits dominated by wedge-bedded quartz grits, quartzites, sandstones and quartz conglomerates. The thin bands of shale locally disrupting these coarse-grained beds become increasingly conspicuous upwards so that differentiation from the succeeding Shale Group is not always readily apparent.

More recent and detailed stratigraphical work has re-emphasised that these broad subdivisions of the Millstone Grit are liable to show abrupt variations and are diachronous when traced laterally. Thus beds of Basal Grit affinity occur higher in the sequence, at the expense of the Shale Group, when followed eastward. The tracing of marine bands with detailed correlation based on their fossil content has offered a more precise means of mapping. Recent re-surveys of the area by the Institute of Geological Sciences have thus placed the so-called Farewell Rock, which lies immediately above the *Gastrioceras subcrenatum* Marine Band, into the Lower Coal Measures. The names of Basal Grit and Shale Group are retained within this study although it should be noted that the latter is no longer utilised in the more recent Six-Inch : 1 mile sheets published by the Institute.

At the western end of Black Mountain the full Millstone Grit succession is 340m thick and the Basal Grit some 180m thick (possibly as much as 210 to 220m). A precise vertical thickness for the Basal Grit cannot be readily determined in this vicinity because of structural complexities, including the existence of subsidiary flexuring on the overall dipslopes and the widespread preservation of sedimentary structures related to wedge bedding which often mask the true dip. In an easterly direction there is a progressive diminution in vertical thickness to 100m in the Merthyr Tydfil district with the Basal Grit constituting 40m of this and to 40m in the Brynmawr area where the Basal Grit is no more than 20m thick.

Forming an integral part of the up-turned flank of the main syncline of the South Wales coalfield, the Millstone Grit of the North Crop shows a predominance of dips directed to the south or south-east. Low dips, within the broad range of 5 to 15°, prevail, but are liable to steepen and show more variable directions within the immediate vicinity of the several NNW-SSE or NW-SE faults which have component horizontal strike slip disrupting the continuity of the outcrops. This simple structural pattern is varied in the relatively narrow disturbed belts associated with the Tair Carn disturbance at the western end of Black Mountain, the Tawe disturbance of the Cribarth-Penwyllt area in the upper Tawe valley and the Neath disturbance in the Penderyn area. Subsidiary folds with axes running between NE-SW and ENE-WSW as well as related faulting have introduced steep to very steep dips within these respective zones.

One cannot present detailed descriptions of the scale and distribution of collapse features on the Millstone Grit cover beds, or theorise on the method of their derivation, without making some reference to the nature of the underlying Carboniferous Limestone Series within whose beds the initiating caverns or passageways were carved by the aggressive action, both chemical and corrosive, of circulating waters. This formation has been subdivided into the broad lithological groups of the Upper Limestone Shales, Main Limestone and Lower Limestone Shales. The Upper Limestone Shales, comprising alternating thin impure limestones and shales, with the limestones weathering to rottenstones within close proximity to the surface, writer has, by mapping the detailed distribution of the associated collapse dolines and in noting the more fundamental variations in the local configuration, demonstrated a wider extent of the foundered strata. With 150 recognisable individual craters this tract of foundered Basal Grit shows the most intense local concentration of collapse dolines to be seen anywhere within the full extent of the South Wales interstratal karst. On the eastern side some coalescence of adjoining small dolines to form sinuous narrow depressions 60 to 80m in length is a feature while many of the more distinct medium-sized dolines display flat floors lined with inwashed peat and occasionally carrying pools of water (Plate 1).

On Black Mountain east of A.4069 the main structural elements have an exceedingly clear topographical expression. Dipslopes, with average southerly inclinations of 8-12° and littered with spreads of Grit blocks, are the major elements within the broader configuration. The major faults of this area have resulted in substantial displacements of the beds so that the various sections of the Basal Grit dipslopes have been provided with a considerable degree of detachment or individuality (Fig. 4). The dipslope to the south-east of Godre'r Gareg-lâs, with an average inclination of 8 to 10° and displaying numerous blocks of loose Grit, is of significance because it holds a collapse doline below which the vertical thickness of the Millstone Grit cover beds above the Carboniferous Limestone is calculated to be 160m. This is the greatest known thickness through which the effects of the collapse of underlying caverns has been transmitted upward to the surface to produce a recognisable landform on the outcrop of the succeeding non-calcareous rocks. There is nothing to compare with this elsewhere in Britain. Nevertheless it is intriguing to observe that this particular collapse doline has a maximum diameter of 36m and a maximum depth of only 4m. To explain this apparent anomaly one might postulate that fragmentation of the underlying Basal Grit into large blocks, with numerous intervening voids, has minimised the surface effect or, alternatively, arguments might be raised favouring the likelihood of a future collapse with more impressive consequences.

The 5km stretch of rugged Basal Grit terrain, trending from north-west to south-east between Black Mountain and the upper Tawe valley, includes the rocky eminences of Carreg-lem, Disgwylfa, Careg-goch and Castell-y-geifr as well as the flanks of the Cribarth ridge (Fig. 5). Viewed from the East (Plate 6) the northern limit of the Basal Grit is seen to form a distinctive step which overlooks Carboniferous Limestone country showing a profusion of collapsed Grit debris. It is within this area that the Basal Grit shows the greatest incidence of glacially-moulded and polished rock pavements. Collapse dolines occur for the most part in those sectors where the Basal Grit cover above the Carboniferous Limestone is less than 30m, as to the south-east of Castell-y-geifr and east of Carreg-lem. They do not normally pit the glaciated rock pavements. They tend to occur along the bases of minor rock 'scars' or edges and in those areas where the Basal Grit is highly weathered to provide bouldery accumulations of rock waste showing some interstitial clay. A few dolines have actually broken through the rock 'scars' or structural steps, and consequently display precipitous, or even slightly overhanging, walls (Plate 7).

East of the upper Tawe valley the Basal Grit lies with slight unconformity on the Carboniferous Limestone, with the degree of overstep increasing in an easterly direction so that the Upper Limestone Shales are cut out east of Carreg Cadno. To the south of Penwyllt an isolated collapse doline, forming a well-defined stream sink, occurs where the Basal Grit cover above the Carboniferous Limestone is around 70m. Elsewhere in this vicinity the rather limited numbers of collapse dolines are confined to the northern edge of the Basal Grit outcrop where the Limestone lies at depths of less than 40m. East of Carreg Cadno, and more particularly in the Sand Hill and Pant Mawr areas, the lower beds of the Basal Grit have little distinctive topographical expression, rock pavements are less conspicuous and the rocky steps, or edges, so prominent as facets of the local relief to the south of Penwyllt, lack continuity. In this more subdued topographic setting a profusion of collapse dolines has been mapped (Plate 8, Fig. 6), more especially where the Grit cover above the Limestone is of the order of 15 to 30m. Along the southern limit of this area two almost perfectly-circular and well-defined collapse dolines partially breach the minor scarp face demarcating the outcrop of the Twelve Foot Sandstone lying within the Middle Shales. Assuming that the former voids or caverns occurred in the topmost beds of the underlying Carboniferous Limestone these cleanly-cut, surface depressions now indicate that subsequent collapse has been transmitted upwards through 75m of non-calcareous beds which includes the complete succession of the Basal Grit. A concentrated NNE-SSW alignment of collapse dolines, extending over a length of nearly 500m, is a notable feature along the western edge of Sand Hill where some coalescence of adjoining holes has been effected. Immediately to the south, on Pant Mawr there are a number of cases where three, or more, large dolines show a WSE-ENE alignment within lengths of territory ranging up to 600m and thus perhaps revealing the significance of major joints of this trend in providing lines of structural weakness adopted as the courses of the main arteries of underground drainage systems.

The Basal Grit country lying between the upper Neath and Mellte valleys to the west and south-west of Ystradfellte is traversed by major NNW-SSE faults (Fig. 7) which greatly complicate the form of the outcrop. Collapse dolines and other karstic features are not very evident.

East and south-east of Ystradfellte the Basal Grit dipslops, comprising Gwaen Cefn-y-Gareg and Gweunydd Hepste, shows a fairly uniform southerly inclination of 4 to 8°. Only a few small collapse dolines may be noted on Gwaen Cefn-y-gareg. One of these (Fig. 8) has an open cave extension of 10m from its lower walls, entirely within the Basal Grit with the Carboniferous Limestone lying at depths of 10 to 12m (SW 942134). Near the western edge of Gweunydd Hepste the large collapse dolines known as Pwll Derw and Pwll y Felin are text-book examples of stream sinks lying on the Millstone Grit cover rocks. Because of the presence of an impervious lining Pwll y Felin holds a more or less permanent pool on its floor. The western edge of Gwaen Cefn-y-gareg forms a magnificent local escarpment, with the uppermost 10 to

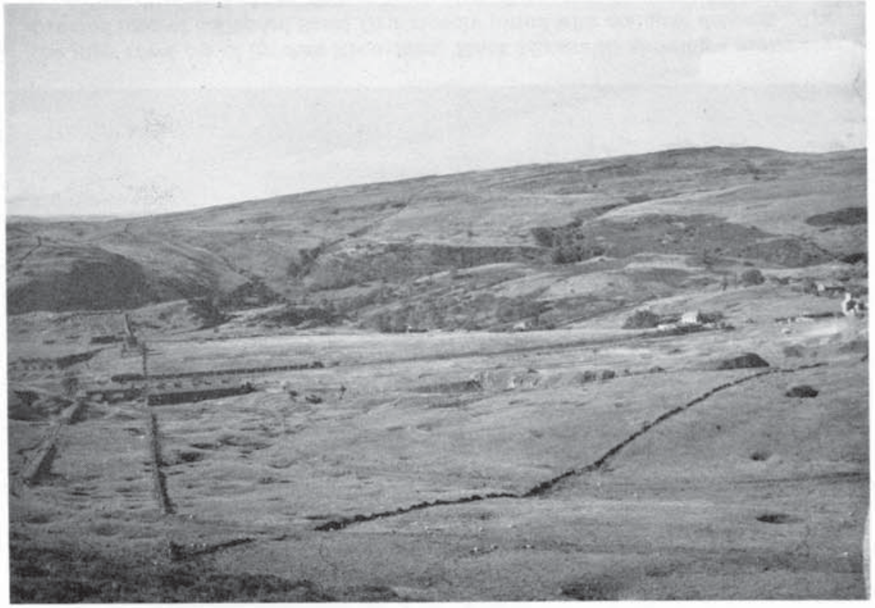
1. Bowl-shaped collapse doline north-west of Tair Carn-isaf, Black Mountain. This example has a maximum diameter of 25m and a maximum depth of 4m.

2. Collapsed outlier of Middle Shales near Carn Cennen, Black Mountain. Despite being let down some 200 to 250m this strike section of soft shales and interbedded siltstones shows only minor flexures.

3. The well-defined col of Pen Rhiw-wen, Black Mountain, floored with an extensive deposit of collapsed Basal Grit which has been worked as a source of silica sand.

4. The high-level col of Bylchau Rhos-faen, Black Mountain, showing a northerly-directed lobe of collapsed Basal Grit closely pitted with collapse dolines. The Basal Grit dipslopes above show a scattering of dolines.

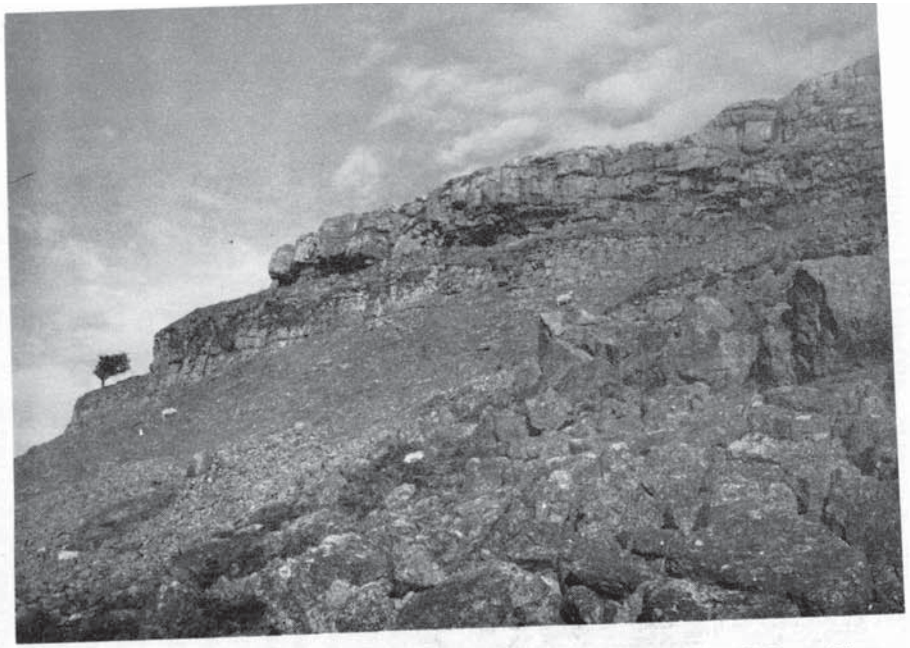
5. Structural and topographical basin on Godre'r Gareg-las, Black Mountain, depicting a zone of foundered Basal Grit. This has a long axis of 240m.



6. View looking westward across the upper Tawe valley. The Basal Grit on the skyline forms a uniform dipslope directed southward from near Castell-y-geifr. Drift-covered Carboniferous Limestone in the foreground is pitted with dolines.

7. Large collapse doline, known as Pwll Wydden, pitting a well-defined "riser" of Basal Grit, west-north-west of Craig-y-nos Castle in the upper Tawe valley. Massive wedge-bedded quartzites and quartz conglomerates are exposed on the western side walls of this doline which has a maximum diameter of 35m and a maximum depth of 12m.

8. Basal Grit dipslopes of Pant Mawr, south of Sand Hill, pitted with large collapse dolines. Beneath the foreground the Carboniferous Limestone lies at a depth of 30 to 35m.



9. The western scarped edge of Gwaen Cefn-y-gareg, near Ystradfellte. The junction of the Basal Grit with the underlying Carboniferous Limestone is defined by a well-marked bedding plane cave.

10. NNW -SSE fault alignment of collapse dolines near Gareg Fawr, Cefn Cadlan, traversing a shallow subsidence basin.

11. Fault-guided NNW - SSE dry valley with collapse dolines pitting its floor on Twynau Gwynion to the north-east of Dowlais.

12. Large collapse doline (maximum diameter 45m, maximum depth 13m) on Mynydd Llangynidr. This was formerly a well-defined stream sink, but the drainage channel has now been diverted to provide additional surface run off for a reservoir catchment.

15m of the freely-exposed rock face being comprised of Basal Grit and the lowermost 15 to 20m showing less massive beds of Carboniferous Limestone. The contact of the two formations is emphasised by a fairly persistent bedding plane cave, with collapse of the lowermost thin beds of the Basal Grit accentuating the vertical dimensions of the cave (Plate 9). This collapse has not reached the top of the escarpment to produce dolines. When traced to the south the plane of contact is seen to show a pronounced synclinal flexure. The field evidence suggests that the latter is an original depositional feature, with solution subsidence having little or no role in its derivation.

To the north-east and east of the village of Penderyn the pronounced lateral displacement brought about by the Dinas fault, the main structural element within the Neath disturbance, has given rise to a major repetition of the Basal Grit outcrop within the same longitudinal zone (Fig. 9). The more northerly outcrop forms the main structural basis of the broken ridge country of Cefn Cadlan while the southerly outcrop straddles the crestline of Mynydd-y-glog, a more upstanding topographical feature whose southerly-directed dipslopes continue uninterruptedly to the North Crop of the South Wales coalfield. Cefn Cadlan shows a good array of collapse dolines, some spectacular ones ranging up to 50m in diameter and 13m in maximum depth. Most of these occur where the Carboniferous Limestone lies at depths of 10 to 25m. A distinctive NNW-SSE to NW-SE alignment of individual dolines is largely related to the faults of like trend (Plate 10) although such a pattern involving the larger examples is still evident where no faulting is apparent. A marked linear concentration of dolines depicting the line of the Cader Fawr fault is traceable over a length of 1,000m. The main axis of the Cefn Cadlan ridge tends to show a WSW-ENE structural grain, but the detailed distribution of collapse dolines does not emphasise this. In the more easterly or upper sectors of Cwm Cadlan the Basal Grit terrain again has a profusion of collapse dolines, but for the most part the individual holes are of rather limited dimensions. Collapse dolines on the Millstone Grit of Mynydd-y-Glog are wholly confined to the Basal Grit and where the cover above the Carboniferous Limestone is less than 30m. Although isolated examples of impressive dimensions may be noted they are not too prolific in this area. There is once more a tendency for them to show some measure of alignment along, or near, the courses of the strike slip faults.

Immediately east of the Taf Fawr valley the Basal Grit is exposed on the dipslopes of Cefn Cil-sanws. The detailed distribution pattern of the scattered and relatively few collapse dolines shows some measure of alignment for adjacent holes along NW-SE to NNW-SSE trends (Fig. 10).

The collapse doline field is particularly extensive on the Basal Grit outcrop lying between the Taf Fechan valley and the Trefil area (Fig. 11). A number of major NW-SE to NNW-SSE faults disrupt the continuity of the outcrop while several minor faults and major joints of like trend are also evident (Plate 11). Isolated dolines are found on the succeeding Middle Shale outcrop where the combined vertical thickness of the two formations above the Carboniferous Limestone is of the order of 30 to 40m. Immediately south of Twyn Pwll Morlais one circular doline with an average diameter of 45m, but with a maximum depth of only 4m, is actually located on the outcrop of the Lower Coal Measures beneath which the top of the Carboniferous Limestone lies at a depth of 55 to 60m. Pwll Morlais itself is an exceptionally large collapse doline with an average diameter of 60m and a maximum estimated depth of some 13m. Lying on a southerly-directed slope averaging only 3°, it originally formed a major stream sink, but in order to conserve surface water supplies Nant Morlais has been diverted around its western rim. Immediately east of Twynau Gwynion, which lies above the steep eastern slopes of the Taf Fechan valley, a new collapse doline of squarish outline, averaging 10m across and up to 8m deep, was produced in the summer of 1973 as an aftermath of a single phase of catastrophic subsidence. This event could possibly be related to exceptional spells of dry weather in the preceding 12 months and a subsequent lowering of the water table.

On the high moorland tract of Mynydd Llangynidr much of the Basal Grit terrain is in the nature of a dipslope directed SSE with an average inclination of 2 to 5°. This has the most spectacular assemblege of collapse dolines within the North Crop area under review. The average north-south width of this doline field on the Millstone Grit cover rocks is 2km. Sample blocks of 250 by 250m contain up to 12 large dolines, 20 to 40m in diameter and 5 to 8m deep. Within blocks of this extent the maximum total volume of doline craters that has been estimated is 180,000m^3; this is equivalent to an average surface lowering of the whole block amounting to no less than 3m. Although the courses of NNW-SSE to NW-SE faults cannot be traced with any degree of certainty across this extensive collapse doline field on the Basal Grit of Mynydd Llangynidr, NNW-SSE alignments of 3, or more, adjacent dolines are more common than those of other orientations, which in order of significance are NNW-SSE, WSW-ENE and WNW-ESE. In the eastern sector of this area (Fig. 12), which is traversed by B.4560, there are a few NNE-SSW alignments of 3 large dolines in each instance occurring within lengths of 600 to 1,000m. Such a distribution pattern could be fortuitous, or on the other hand might be a reflection of some measure of structural control or interesting speleological relationships. Only 7 dolines have been noted as lying on the outcrop of the Middle Shales. One of these, located in the extreme east of the area immediately north of Cefn Pwll-coch, extends in part on to the outcrop of the succeeding Lower Coal Measures. Unlike some of the previous examples described of dolines occurring along the down-dip limits of the collapse doline field, this is an exceptionally large single-cycle crater with precipitous walls and averaging 55m in diameter with a maximum depth of 17m. Beneath the lip of this doline the top of the underlying Carboniferous Limestone lies at a depth of 30 to 35m. The greater part of the collapse doline field of this area falls within the important water catchment areas of the reservoirs providing the respective water needs of Tredegar and Ebbw Vale. A number of the dolines originally formed major stream sinks. In order to increase surface flow to the main feeder streams new minor water courses have now been constructed to by-pass these dolines (Plate 12).

With an average vertical thickness of 20 to 30m, the Basal Grit shows a distinct lack of consistency when traced south-eastward across Mynydd Llangattwg (Fig. 13). This relates both to its irregular plane of contact with the underlying Carboniferous Limestone, which can give rise to abrupt local variations in the overall thickness of the formation, and also to the pronounced lenticularity of its constituent beds. Thus massive competent beds of quartzite or quartz conglomerates may wedge out quickly and be replaced by more varied sequences with fissile soft shales forming a significant proportion of the succession. On Cefn Onnen there are WSW-ENE or E-W alignments of small to medium-sized dolines pitting the Grit scree occurring on the downslope side of minor Basal Grit exposures. To the east the large crater known as Waen Rudd must be the most magnificent collapse doline and stream sink in South Wales. It has an average diameter of nearly 70m and a maximum depth of 21m. Within the Basal Grit succession exposed on its precipitous walls there is a dominance of quartz conglomerates in the uppermost 10m, but these give way in depth to thinner quartzitic beds and interleaved shale bands. A close joint pattern, with no dominant orientation for the component sets being evident, has given Waen Rudd a circular outline while the uniform cross section and an absence of any discernible flexuring of the bedding planes suggests that a single-cycle collapse of major order was the initiating mechanism. The top of the Carboniferous Limestone is estimated to lie less than 10m below the base of Waen Rudd and it would appear that a major cavern, at or immediately below the irregular plane of contact with the succeeding Basal Grit, has been subjected to a roof fall and now probably holds a huge boulder choke of Grit blocks. For nearly 1km to the east of Waen Rudd the Basal Grit outcrop holds no collapse dolines of mappable extent. Within this sector more frequent and thicker shale bands are interbedded with the quartzitic sandstones within the lower half of the Basal Grit succession and these could well curtail the passage of percolating waters and thus inhibit the production of caverns within the underlying Carboniferous Limestone. Collapse dolines within the tract lying to the north, east and south-east of Mynydd Pen-cyrn are largely confined to well-dispersed groupings with a characteristic NW-SE alignment. The larger examples all occur where the vertical thickness of the Basal Grit above the Limestone is no more than 12m.

East of Blackrock the steep southern slopes of the Clydach valley are underlain by Millstone Grit and Carboniferous Limestone successions which undergo rapid diminution in vertical thickness when traced towards the east. Gilwern Hill and the Blorenge are prominent spurs which project north and north-eastward, respectively, off the higher ground of the South Wales coalfield (Fig. 14). towards the Usk valley. Narrow outcrops of both Millstone Grit and Carboniferous Limestone partially encircle the higher and middle slopes of each spur. Under the eastern slopes of the Blorenge the diminishing Main Limestone sequence is eventually cut out by the overstepping Basal Grit, which thus rests directly on the Lower Limestone Shales. The pin-pointing of marker marine bands in stream sections and the interpolated positions assigned to these within the intervening ground (Jones and Owen, 1966) indicate that two isolated collapse dolines on Gilwern Hill occur on the outcrop of the Lower Coal Measures so that in addition to the lowermost beds of this formation they are underlain by the complete Millstone Grit succession, making a combined thickness of some 45m above the top of the Carboniferous Limestone. The northern and western slopes of the Blorenge are thickly plastered with rock debris comprising blocks of quartz conglomerate or quartzitic sandstone derived both from the Basal Grit and the massive arenaceous beds of the lowermost Coal Measures which are exposed on the summit and the higher levels on the south-western side. Small to medium-sized collapse dolines occur at widely-spaced intervals on this block scree, both on the Basal Grit and within the adjacent sectors assumed to be underlain by the Middle Shales. On the south-eastern slopes of Blorenge, in the vicinity of Carn-y-gorfydd, there is a relative profusion of small to medium-sized collapse dolines with adjacent holes having a distinctive NNE-SSW alignment and some measure of coalescence of these having been reached. At first sight this might seem rather surprising because, as previously stated, the stratigraphical evidence from adjoining areas suggests that below this half of the Blorenge the Millstone Grit rests directly on the Lower Limestone Shales. Previous surveys of the Carboniferous Limestone country have, however, revealed that the massive limestone featuring the lower half of the Lower Limestone Shales is very prone to solutional weathering so that the succeeding thin argillaceous limestone and shale bands, not infrequently, are pitted with small dolines. On the high, gently-graded dipslopes north of Cefn-y-galchen there are at least 60m of mainly coarse arenaceous beds lying above the Carboniferous Limestone. In this area there is one funnel-shaped doline, with an average diameter of 32m and a modest maximum depth of 5m, and 4 smaller dolines with diameters of less than 15m.

6. Shallow Subsidence Depressions

In addition to the three main types of collapse doline described above, the South Wales interstratal karst is characterized by more scattered shallow subsidence depressions which merit separate description. These are broadly oval in outline and have no consistent elongation which might reflect possible structural controls. The largest single depression noted is that occupied by the shallow lake, known as Pwll Gwy-rhoc, located towards the northern edge of Mynydd Llangattwg. This has a maximum diameter of 290m. The maximum depth of these depressions rarely exceeds 5m and consequently the depth to diameter ratios normally range between 40 to 1 and 60 to 1. The larger depressions of smooth cross section and which are not pitted with dolines are invariably occupied by pools or small lakes with the extent of water undergoing rapid contraction as a consequence of the accumulation of hill peat. Typical examples include the broad hollows holding Llyn-du-isaf, Llyn-du-uchaf and Llyn y Fignen-felin on Black Mountain and Llyn y Garn-fawr on Mynydd Llangynidr. Where the peat is eroded on the peripheries of these small lakes the Basal Grit is veneered with rock debris. It is therefore not possible to detect any radial patterns of dip although it must be assumed that sagging of no mean amplitude has occurred, more especially on Black Mountain where the Carboniferous Limestone beneath these depressions is underlain by up to 100m of Basal Grit beds. Near the crestline of the eastern segments of Mynydd Llangynidr the floors of a number of shallow subsidence depressions, averaging 100 to 150m in diameter, are pitted with small funnel-shaped dolines. A few of the latter, showing relatively fresh rock sections, actually extend to the rims of the larger features and indicate that they have originated as the consequence of later phases of sharper, yet more localised, subsidence. Descending the rims of a few of the depressions, a number of conspicuous trains of sub-angular Grit blocks may be noted. Individual blocks show average diameters of 0.2 to 0.4m and many have the appearance of being water-worn, even at these high elevations near the crestline of Mynydd Llangynidr. Meltwaters from local snow caps might account for this; as a corollary of this assumption it might be further suggested that the depressions themselves could date from the same immediate Post-glacial period.

In some areas, notably on Black Mountain, there are examples of smaller subsidence depressions which hardly merit classification as bowl-shaped dolines. The flanks of these may show inwardly-directed slopes of no more than 3 to 5°. To the south of Carn Pen-rhiw-ddu the more southerly individual within a south-westerly-directed alignment of smaller subsidence basins has a maximum diameter of 70m and a maximum depth of only 2.5m despite the fact that the Basal Grit shows a vertical cover of more than 120m above the underlying Carboniferous Limestone.

7. Dry Valleys

Short stretches of minor dry valley heads, up to a maximum individual length of some 2km, may be noted in this Millstone Grit terrain. For the most part they define the courses of NNW-SSE to NW-SE strike slip faults most of which tend to die out southward or pass into monoclinal flexures when traced towards the outcrop of the Middle Shales or Lower Coal Measures. These dry valleys are of two major types, firstly, shallow features, whose floors are punctuated by collapse dolines or the broader subsidence forms described above but record an overall fall in level in a down-dip direction, and, secondly, more sharply-incised gorge-like defiles up to 15m deep and occasionally with collapse dolines extending laterally into their walls (Plate 11). The floors of these minor valleys are invariably littered with much Millstone Grit debris in the form of tabular or sub-angular blocks of quartz conglomerates or quartzites. Dry valleys of these two predominant types usually occur where the underlying Carboniferous Limestone lies at vertical depths of less than 50m. The dominant conglomerates and quartzites of the Basal Grit, the lowest member of the Millstone Grit, show a reasonably close network of joints and minor fractures so that in the absence of appreciable thicknesses of clayey head or boulder clay the floors of the dry valleys display no temporary stream courses other than on the lips of individual collapse dolines where the rapid descent of storm drainage can produce a recognisable notching effect.

8. Foundered Millstone Grit Masses

Recent field surveys (Thomas, 1963, 1973), as well as revised mapping by the Institute of Geological Sciences, have indicated that appreciable extents of the adjoining Carboniferous Limestone outcrop within this North Crop area are encumbered with the collapsed and soliflucted residue of a former Basal Grit cover, let down to a maximum depth of around 250m. Similar undersapping processes are at work on the Basal Grit outcrop and are particularly prone to affect the junction of the two formations, more especially in the east. In places therefore it is virtually impossible to define with any degree of precision the exact boundary of these two major formations despite their sharply contrasting lithologies (Fig. 2).

Foundered Millstone Grit masses actually located on the Basal Grit outcrops are of three major types, as follows:

i. Segments of rock pavements which have been disrupted and tilted along the lines of major joints.
ii. Beds which have subsided gradually without major rupturing to form structural basins normally discernible in the surface relief.
iii. Successions which have been subjected to repeated collapse of varying amplitudes and lateral extent so as to provide a jumble of loose blocks preserving no indications of the former structure at least not in the uppermost and visible sections of individual accumulations.

On Cefn y Gareg-lâs (Fig. 4) rock pavements of massive Basal Grit, showing only a low inclination to the south, are traversed by major N-S or NNE-SSW open joints. These form fissures up to 5m deep and averaging 0.5 to 1.5m in cross section but occasionally reaching 3 to 5m. Half a dozen such fissures are traceable over lengths of up to 100m. The underlying Carboniferous Limestone, which here has a vertical thickness of some 200m, lies at depths of 100 to 140m. Tilting of individual pavement blocks on the peripheries of these fissures is likely to be indicative of some measure of solution subsidence having occurred. The fissures are replicas, on a more subdued scale, of the coal mining subsidence cracks which traverse the equally massive Pennant sandstones on some of the mountainous interfluves between the major mining valleys of the South Wales coalfield where more recent extraction of one or more coal seams has taken place at depths of 600 to 900m below the surface. A comparison of these two sets of phenomena, the one natural and the other induced by coal mining, suggests that beneath the upstanding dipslope of Cefn y Gareg-lâs rather extensive low cave systems of bedding plane type could be present. Features of this type may also be noted on Castell-y-geifr (Fig. 5), near Penwyllt (Fig. 6) and on Mynydd Llangynidr (Fig. 12). Where Basal Grit pavements of more limited extent terminate on minor scarp faces many of the gaping joints are obviously more attributable to normal weathering processes and gravitational forces than to solution subsidence effects.

Occurrences of the second type were noted on the inclined high 'tablelands' on both flanks of the upper Twrch valley towards the eastern end of Black Mountain (Fig. 4) and again on the rocky dipslope to the south of Castell-y-geifr (Fig. 5) immediately west of the upper Tawe valley. The dips on the flanks of these structures are normally within the range of 8 to 20°, but in extreme cases can approach 35°. Their major axes generally have a down-dip (ie regional dip) alignment and may be traceable over lengths of up to 320m, although the more normal dimension is of the order of 150m. Cross sections parallel to the regional strike are usually slightly asymmetrical, both in terms of structure and the generally sympathetic relief. As indicated by nearby old shallow diggings for rottenstones, these structures occur in those sectors where the Basal Grit overlies a consistent vertical thickness (2 to 3m) of Upper Limestone Shales (D_3) so there is unlikely to be any solutional emphasis of a sub-Millstone Grit unconformity. On the contrary, the wholesale preservation of Basal Grit bedding planes, clearly apparent on the peripheries of the structures, suggests that the gradual settling of cover beds above extended passageways or bedding plane caves of low inclination, lying at substantial depths within the underlying Carboniferous Limestone, is the more likely interpretation of the initiating mechanism.

Masses of repeatedly subsided loose blocks which display no apparent structure can be differentiated from the widespread Grit head by their highly irregular surfaces, typified by complex mounds and intervening collapse dolines of considerable concentration and displaying a greater degree of elongation than is normal. Individual occurrences of these subsided masses may extend over distances of 2 to 3km. They may be found well within the Basal Grit outcrop, may mask the junction zone with the underlying Carboniferous Limestone and indeed have a widespread distribution, which is outside the context of this paper, on the outcrops of the latter formation. High-level cols breaking the topographic continuity of the Carboniferous Limestone-Basal Grit junction zone often display a veneer of collapsed Grit closely pitted with dolines (Plates 3 and 4). Reference has already been made to the large mass of collapsed Grit lying west of Tair Carn-isaf on Black Mountain (Fig. 3). An even greater extent of foundered Basal Grit beds is assumed to underlie Trefil Ddu (Fig. 11) which forms the western slopes of the Nant Trefil valley. No insitu Basal Grit beds are exposed over a NW-SE length of more than 3km. If the low south-easterly dip of the beds underlying the contiguous dipslopes on the western side are assumed to continue down the full extent of these slopes, the relief is such as to provide for a Basal Grit vertical thickness of 100m, as compared with the known vertical thickness of some 25 to 30m. To account for this apparent anomaly, the Basal Grit debris, in part disposed as solifluction lobes, on Trefil Ddu could be underlain by a series of NNW-SSE faults successively stepping the beds down to the east or, alternatively, the latter may have an east-north-easterly dip downslope which is completely transverse to the overall regional structional tilt. In the present study, Trefil Ddu is tentatively mapped as a large area of foundered Basal Grit. Providing support for this contention is the complete lack of insitu exposures, even on relatively-steep slopes, the chaotic and hummocky configuration and the locally intense concentration of smaller collapse dolines. Between 100 and 150 small dolines, averaging less than 15m in diameter, occur in blocks of 50,000m^2 towards the northern end of this presumed major foundered zone.

Less than 1km to the east of Carn Cennen (Fig. 3) is the most spectacular solution subsidence feature noted anywhere on the North Crop area. This is in the form of an outlier of Middle Shales lying near the northern edge of the Basal Grit outcrop and in part extending on to the adjacent Carboniferous Limestone. The recent mapping by the Institute of Geological Sciences (Six-Inch Sheet SN71NW, 1973) suggests that this outlier has a length of rather more than 360m and a maximum width of 200m, dimensions considerably in excess of previous estimates. About 10m of blue-black fissile shales and interbedded, rusty-weathering siltstones are exposed in a stream section (Plate 2); the total thickness of Middle Shale beds present is likely to exceed 45m. Fossils recovered from the upper beds within the inlier suggest that these belong to a horizon lying approximately 60m above the base of the Middle Shales. Although the outlier straddles the course of the major Cwm Llwyd fault a careful field examination suggests that its boundaries are nowhere fault-controlled. Its anomalous position, at least 200 to 250m below its original level prior to the southward recession of its parent outcrop, is totally unrelated to gravitational slumping. Subsidence above a collapsed cavern or series of caverns in the underlying Carboniferous Limestone seems to be the only plausible explanation for its present location. Even so, allowing for this measure of collapse the cushioning effect of the intervening Basal Grit seems hardly sufficient to have fostered the high degree of preservation of the bedding planes in a deposit of this type which now only shows minor flexures along the essentially strike section provided by the downcutting stream. Initiating major collapses must surely have been followed by a long history of settling with slow negative movement, hardly measurable in the shorter time span but over the long term having a cumulative spectacular effect.

9. Relationship between the Interstratal Karst Surface Features and known Cave Systems

No sizeable cave systems have yet been discovered and recorded below the Millstone Grit country of Black Mountain. Well-known major systems have been surveyed and described in great detail in the Penwyllt-Craig y Nos area of the upper Tawe valley. These are Ogof Ffynnon Ddu (O'Reilly et al, 1969), with a major resurgence point near the east bank of the Tawe, and Dan-yr-Ogof (Coase, 1967), underlying the western slopes of the valley to the north of the Cribarth ridge. The plotting of the main passages of these systems on a geological map reveals that the Dan-yr-Ogof group, at the present state of exploration, underlies only the Carboniferous Limestone (Weaver, 1973). Ogof Ffynnon Ddu II and III penetrate a limited distance, and over restricted lengths, into the Carboniferous Limestone where it is overlain by the

Basal Grit. This is the case in the sector lying south of Pwll Byfre, but a general paucity of collapse dolines on the cover rocks does not allow any valid observations to be made on possible correlation between surface form and underlying cave morphology. Nearer to Penwyllt, Ogof Ffynnon Ddu I extends a little deeper below the Basal Grit and the few collapse dolines pitting the surface of this formation lie almost directly above some of the passages so that the two sets of phenomena do appear to have some measure of inter-relationship.

Substantial cave systems, not yet fully described and completely explored, are known to occur along, or immediately below, the Basal Grit-Carboniferous Limestone junction in the Ystradfellte area as well as under Mynydd Llangynidr and Mynydd Llangattwg. These include Pwll-y-pasc, a cave of 160m on Mynydd Llangattwg, and Ogof Gynnes, a major system traceable for 1,000m under Mynydd Llangynidr (M. Davies, 1971). In these situations the massive quartz conglomerates of the Basal Grit can provide an exceptionally good roof for caverns of considerable span. A case in point is Black Cavern at Pwll-du which lies mid-way between Gilwern Hill and the Blorenge. This was discovered by the Cwmbran Caving Club in October 1967. Black Cavern has a circular outline like that of many of the collapse dolines. It has an average diameter of 25m and a maximum height of 9m. The relatively thin roof is still intact so that there is no recognisable collapse doline on the surface. The thick accumulation of collapsed Grit blocks on the floor of the cavern, however, indicates that the roof is progressively becoming more unstable and the space formerly occupied by the lowermost Grit beds is now incorporated within the orbit of the cavern. It is thus certainly not true to say that voids of this type wholly occur within the Carboniferous Limestone.

On Mynydd Llangattwg the 11½km of passages of the Ogof Agen Allwedd system extend downdip in one bed of oolitic limestone within the Oolite Group (lying well down in the lower half of the Carboniferous Limestone sequence of this area) to a point 110 to 125m below the surface where the complete Millstone Grit succession forms part of the cover (Leitch, 1960). The ramifications of this cave system bear no correspondence whatsoever with the distribution of collapse dolines. In this area and also on Mynydd Llangynidr it appears likely that the bulk of the collapse dolines on the Millstone Grit cover might be attributable to final phases of sharp subsidence transmitted upward from more unstable and shallower-lying cave systems occurring at, or immediately below, the irregular plane of unconformity at the base of the Millstone Grit.

10. Conclusions

The outstanding feature of the South Wales interstratal karst is undoubtedly the collapse doline field. In the preceding account emphasis was placed on the assessment of the maximum thickness of the non-calcareous Millstone Grit cover rocks (including some Lower Coal Measures beds in the east) through which the effects of cavern collapse have been transmitted to the surface. In this context it was perhaps a little surprising to note that many of the dolines lying along the down-dip limit of the field did not display the spectacular dimensions one might have expected. Experience at Llanharry iron ore mine in the Vale of Glamorgan has indicated that the extraction of inclined ore bodies of substantial cross section can be followed quickly by major subsidence of the rock roof to provide for the production of doline-like craters on the surface even where the extraction of ore has taken place at depths as great as 250m. Many of the larger collapse dolines of the North Crop area have obviously been derived by the similar sudden failure of cavern roofs to withstand the pressure of the overlying rock load. The modest depth and lateral extent of some of the dolines lying above the deepest cover to the Carboniferous Limestone does, however, suggest that in a few instances the collapse process progressed upward throughout a much greater time interval so that with the final breakthrough to the surface the form of the resultant surface depression was largely dependent on the detailed lithology and structure at the uppermost levels.

The floors of bowl-shaped dolines are prone to modification through the acquisition of a peat cover and may also show inwashed spreads of silt or sand. Likewise the side-walls of funnel-shaped and well-shaped dolines are progressively modified by the weathering and minor slumping of the normally well-jointed Grit beds. Nevertheless there is no evidence to suggest that the well-shaped, funnel-shaped and basin-shaped collapse dolines of this area represent consecutive major stages within a gradational series. None of the shallower dolines can thus be regarded as relics of much deeper forms.

One must surely be intrigued by the high degree of circularity of outline displayed by so many of these collapse dolines. The controls exerted by NW-SE or NNW-SSE faults and master joints, more especially in the eastern areas, on their detailed distribution pattern has been duly emphasised, but the existence of other joint sets of variable orientation, with individual fractures showing close spacing, has been the major factor in determining the circular or slightly oval (ie with no pronounced long axis) outline of most of the dolines.

The unconformable junction plane separating the Basal Grit and the Carboniferous Limestone is highly irregular, with regard to minor detail, over much of the eastern area under review and solutional effects have obviously emphasised this sharp lithological break. Owen and Jones (1959), however, have shown that in some localities, notably in the upper Neath valley area, the two lithologies are to some extent intermixed through limited thicknesses so that the exact position of the plane of unconformity is difficult to determine. On the other hand in the eastern areas, as on Mynydd Llangynidr and Mynydd Llangattwg, it is possible that the collapsed doline distribution pattern is to some extent a reflection of the detailed form of the sub-Millstone Grit surface in that solutional activities have been concentrated along the bases of depressions within this irregular plane of unconformity and thus subsequently giving rise to the production of major caverns forming the foci of many of the later collapses. Solutional rates could also have been increased along this sub-Grit surface where vein dolomitization, characterised by the presence of numerous small vughs and increased scales of porosity and permeability, is present within the underlying Carboniferous Limestone.

Solutional undersapping of the non-calcareous cover rocks, giving rise to a state of instability at points of varying concentration, is the main process involved in the production of these widespread collapse dolines. Their detailed distribution reveals that there has been solutional emphasis of joint planes, bedding planes and fault zones within the underlying Carboniferous Limestone. The spectacular size of many of the dolines and their general clarity of outline suggest that major elements, such as large caverns or passageways of considerable cross section, within substantial cave systems formed the foci of the main collapses. Some of these cave systems were evolved under vadose conditions, but the upstanding nature of this North Crop terrain and phases of accelerated rejuvenation of the main drainage lines, with a related fall in the general level of the water table, has allowed phreatic forms to play their part in providing for a deeply pitted Millstone Grit surface in some area.

The Carboniferous Limestone tracts of Derbyshire and northern England, notably in northern Lancashire and north-west Yorkshire, lie adjacent to Millstone Grit country, as is the case in the North Crop area of South Wales. One may therefore enquire why the Millstone Grit within these English areas shown an apparent lack of interstratal karstic features. A set of unique conditions exist within the North Crop area. In the first place, there is, for the most part, an abrupt lithological break between the Carboniferous Limestone and the Millstone Grit. In the west the Upper Limestone Shales form an intermediary zone of very restricted vertical thickness whereas in the east massive, jointed quartzites or quartz conglomerates, offering ready access for percolating waters, normally suceed block-jointed limestones showing a high degree of purity in terms of calcium carbonate content. It is instructive to compare this stratigraphical sequence with that prevailing, for instance, in the Clitheroe area where the upper part of the Carboniferous Limestone Series comprises the Bowland Shale Group which shows a variable succession of shales, sandstones and limestones with an overall vertical thickness of up to 350m. Secondly, in the South Wales area there is a state of near-compatability of surface slope with the dip of the underlying beds over wide extents so that there is a progressive slow increase in the vertical thickness of the Millstone Grit cover beds from a fine feather edge. This is only rarely the case in Derbyshire and northern England. Thirdly, and of equal significance, many of the main drainage lines in the South Wales area are directed generally down-dip. Of some pertinence also in the fact that the North Crop of the South Wales coalfield is the wettest major limestone zone in Britain.

One should distinguish between interstratal karst and what might be termed "fossil interstratal karst". The latter term might be utilised to describe the relic deposits of former cover rocks let down by karstic processes and preserved on the outcrops of the main groups of calcareous rocks themselves. Continued solution and subsequent subsidence through lengthy periods of time has meant that some of the cross sections of such deposits will show basinal projections of no mean amplitude into the insitu host rocks. Examples that come readily to mind are the masses of collapsed Millstone Grit preserved on the Carboniferous Limestone of the North Crop area of South Wales (Thomas, 1963, 1973) and the "pocket deposits" of the Brassington Formation, of presumed late Miocene and/or Pliocene age, lodged within the 1,000 ft. planation surface of the Derbyshire Carboniferous Limestone plateau (Ford, 1972; Walsh et. al. 1972).

Rock sections may reveal buried karstic features which have not been reflected through to the surface to provide interstratal karstic landforms. An example of this can be observed in the Grand Canyon in Arizona where the red shales and sandstones of the Pennsylvanian Supai Formation have in places sagged into solutional cavities etched into the upper parts of the underlying Mississippian Redwall Limestone which normally forms a continuous line of vertical cliffs averaging 150 to 175m high on the middle canyon walls. The Cambro-Ordovician Limestone areas of Missouri also show features of this type.

"Fossil" karsts should not be confused with interstratal karsts. Quarry sections, showing the contact of the Millstone Grit and Carboniferous Limestone, in the South Wales area under review preserve remnants of fossil karsts (Thomas, 1973) while in Derbyshire some of the sinks and pots to be found on the margins of the limestone country where the Edale Shales of the succeeding Millstone Grit have been recently stripped off may in part be fossil features re-etched into relief by the removal of their ancient fill (Ford, 1966).

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STUDIES ON THE RESPONSE OF HEALTHY ENGLISH SPELEOLOGISTS TO EXPOSURE TO HISTOPLASMOSIS INFECTION

by John C. Frankland.

SUMMARY

"Eight English speleologists spent six months in a histoplasmosis area. Subsequent skin testing showed five to be histoplasmin positive. No appreciable clinical illness occurred. Conversion to a histoplasmin positive state after cave exploration without any clinical illness appears not to have been described previously in the medical literature. The implications of these findings are discussed and further studies suggested."

The writer has gained the impression that it is part of the folklore of speleology that exploration of guano caves in some regions of the world carries a high risk of contracting histoplasmosis and that this malady is likely to be fatal or of serious consequences. (Aspin 1964, Speleologist 1969).

The 1973 British Karst Research Expedition to Venezuela were aware that they were visiting an area where the caves are known to contain histoplasmosis (Pietri 1957, 1967) and carried out part of their programme of biological research in the Cueva Coy Coy de Uria where the presence of histoplasmosis fungus has been confirmed (Pietri 1957). Less intensive work was also carried out in the Cueva de Guano, another known source of the fungus.

Perhaps one should first explain the nature of the disease. Histoplasmosis describes the colonization of some part of the body, almost invariably the lungs, by the fungus known as *Histoplasma capsulatum*. Histoplasmosis occurs in many areas of the world but appears in greatest concentrations in central Mississippi and the Ohio River valleys of the United States. It has not been described amongst the native population of Great Britain in the three studies carried out, although the most recent of these was twenty-five years ago (Edwards 1971).

How is the disease contracted and diagnosed? In endemic areas certain environments favour the saprophytic growth of the fungus and it is from these that the disease can be contracted, by inhaling the fungal spores. Such environments include caves (Washburn, Ajello) particularly when guano is present, but also silos, underground storm shelters, pigeon lofts and chicken runs have been documented as sites of infection (Murray) 1957.

When the spores are inhaled the body's immunological defence mechanism becomes activated and in overcoming the potentially harmful effects of these foreign cells in the lungs and antibodies or specific defence substances are produced. The presence of these specific defence substances has allowed a skin test to be developed whereby injection of a measured amount of sterile filtrate of a laboratory prepared *Histoplasma capsulatum* culture will demonstrate the presence of the specific antibodies by the development of an allergic swelling. This "Histoplasmin Skin Test" is refined enough to demonstrate whether an individual has had previous exposure to the fungus i.e. has had histoplasmosis. The infection may be contracted without the patient having symptoms, as was the case with this group of speleologists. No immunization or vaccination is available to protect against histoplasmosis.

The disease was first described by Darling in 1906 when the causative organism was described. The only references to the condition in the medical literature over the next forty years were rare descriptions of fatal episodes. However in 1945 Palmer suggested that a benign form of histoplasmosis was widely prevalent in certain American states and in some areas of Ohio it was found to be as high as 86% of the population. Many epidemiological studies have plotted the incidence of histoplasmin positive individuals amongst the populations in most areas of the world. Venezuela has been particularly well studied in this respect the incidence varying between 2.0% in Ciodad Bolivar and an amazingly high 89% in El Callao, Bolivar (Princepe).

Over the past few decades such studies have led to the recognition that histoplasmosis is a wide-spread usually benign infection in millions of persons but causing severe illness and death in relatively few. Of the millions infected the majority have no incident of illness which could be ascribed to the initial infection. The source of their infection is probably spores from the fungus growing in the soil in moist, still and shadowy situations, as 89% of the population of some areas of Venezuela have certainly not explored guano caves.

It was only in 1957 that Murray described the benign form of histoplasmosis in the African continent. His paper entitled "Benign Pulmonary Histoplasmosis (Cave Disease) in South Africa" is of special interest to speleologists in that all the confirmed cases of histoplasmosis occurred in members of the Transvaal Speleological Society. With laudable precision these workers sought out all past and present members of the Society and investigated their histoplasmin sensitivity. With a degree of good fortune that is so infrequently the lot of the medical scientists, these workers were able to study fourteen new members of the society before they had had any experience of cave exploration. Initial histoplasmin skin tests and chest X rays showed no evidence of histoplasmosis but as they pursued their caving careers **in each of the fourteen cases,** after exposure in a cave known to be infected, an attack of atypical pneumonia developed with uneventful but occasionally prolonged resolution and accompanied in each case by a conversion from a histoplasmin negative to a histoplasmin positive state.

The same sequence was described in another fifteen individuals after their first exploration in caves known to be infected in the Potgieterstrust and Thabazimbi areas of the Transvaal. Again an episode of pneumonia was a feature of the conversion to the histoplasmin positive state in fourteen of the fifteen individuals studied.

In a group of thirty nine experienced speleologists in the Transvaal Speleological Association thirty six were histoplasmin positive and of this number thirty two gave a clear cut history of an initial acute illness (pneumonia) following first exposure to infected caves. It became clear that once subjects had suffered from the initial illness they did not again develop it even after repeated exposure to infected caves. There were no deaths and no evidence of complications from the initial episode of pneumonia in this extensive study. This initial illness was apparently not of sufficient severity to deter members of the Society from re-exposing themselves in infected caves or to prevent them taking novices into the same infected caves.

Furcolow (1957) described a typical initial illness with sudden malaise followed by chills, fever and a non-productive cough. Remitting temperatures of up to 37.8°C (100°F) were common with low grade fever persisting for weeks together with tiredness upon slight effort. Chest pains occurring in the early stages might be pleural in type or retrosternal and were aggravated by swallowing. Weight loss was common. On examination there was usually a dearth of clinical signs although sometimes there might be evidence of small transient pleural effusions. Laboratory tests apart from those specific for histoplasmosis were generally negative with the exception of a raised erythrocyte sedimentation rate. X-ray changes were usually well marked showing widespread patchy opacities in the lung fields with or without hilar gland enlargement and indistinguishable radiologically from appearances caused by primary tuberculosis or transient pneumonia. Resolution was usually complete within a few weeks or months. Follow-up studies of these nine later cases have occasionally shown after a few years either scattered pulmonary calcification or calcification resembling a tuberculous primary complex and recent studies in autopsy material by Vanek (1971) have shown that even in benign asymptomatic cases there is commonly evidence of the spread of fungus infection, via the lymphatic system to sites distant from the lungs.

Murray also carried out histoplasmin tests on twenty members of the Cape Speleological Society without finding any positive results indicating that infection is a localised problem in Africa.

The publicity given to Murray's paper and his description of almost all cases of proven infection in speleologists being associated with an initial pneumonia has probably been largely responsible for the sinister associations cavers have with the idea of catching histoplasmosis.

At least five proven cases of fatal systemic histoplasmosis have been reported in the world's medical literature but in none of these is any association with caves or similar enclosed spaces obtainable from the records (Simpson, Lurie & Murray 1951). In 1957 Dean reported a case of acute pulmonary disease developing in an individual who had visited caves in Southern Rhodesia and demonstrated a positive histoplasmin reaction. Through inference, the fatal disease of two police officers who entered a cave used for ritual purposes by the natives in the Matapos area of Southern Rhodesia was considered to have been histoplasmosis, although this appears as a speculative diagnosis only.

Dean further speculated that histoplasmosis was the cause of the death of several archeologists who had opened the tomb of Tutankhamun in Egypt in 1923. This novel explanation of the "Curse of the Pharaoh" is said by Ajello to be contrary to recent knowledge concerning the ecology of *Histoplasma capsulatum* but perhaps such suggestions contribute to the concept of histoplasmosis as a lethal hazard.

The problem arises as to how many millions of individuals acquire the disease without symptoms in endemic areas whereas studies in speleologists acquiring the infection have almost invariably shown a pneumonic episode.

Three factors affect the patients response to the initial fungus infection:—

a) the host's immunological state
b) the size of the infecting dose
c) the virulence of the infecting fungus

a) the young and the debilitated may have abnormalities in body defence mechanisms including serum globulin and serum iron concentrations, which would predispose to a less favourable clinical response (Caroline 1969). There are no grounds to expect this to be a factor in giving speleologists a more severe reaction to infection than the endemic population.

b) Edwards (1971) believes that an unusually large infecting inoculum is required to produce clinical disease and this most often accompanies a history of exposure to an extremely dusty environment heavily contaminated with bird or bat faeces. Much less certain is the source of infection of the numerous persons who do not develop clinical disease.

c) Kaufman (1966) has suggested that variants of the fungus may possibly be responsible for the variability of the response to infection, although this work is as yet conjecture.

The results obtained from histoplasmin sensitivity tests on this expedition (Table 1) show a histoplasmin positive state in five of the eight persons tested. All five of these were free from any period of illness during and after their six months of cave exploration in Venezuela. A further member showed a "doubtful" response to histoplasmin. This individual (M.G.) developed an illness after four months of guano exposure which resembled an upper respiratory infection at the onset with earache and rhinorrhoea. He had a persistent cough with bronchospasm but failed to show any radiological abnormalities in chest X-ray at Coro Hospital at the time. On balance it would seem unlikely that this was a pneumonic episode due to histoplasmosis, particularly in view of the normal radiographic findings: the doubtfully positive histoplasmin skin test, the patient's known susceptibility to allergic asthma, the normal chest X-ray on return to the U.K. and the previous limits of incubation after exposure being recorded as five to twenty one days (Murray 1957; Aspin 1959).

All eight subjects had chest radiograms carried out on return to the U.K. and these all failed to reveal any abnormal findings.

Table 1. Results of histoplasmin tests, chest X-rays and observations on relative exposure to infection.

Name	Age	HISTOPLASMIN TEST Erythema (mm)	Induration (mm)	Result	X-ray chest report	Infected caves explored (see text)	Particular duties carried out	Calculated order of exposure to risk by expedition leader.
PRJC	23	13	13	+	Normal chest radiogram	Coy Coy. Cueva del Guano. Guano sorting	Main biological collector	1
GS	27	13	8	+	Normal chest radiogram	Coy Coy. Guano sorting	Assistant in guano studies	2
DC	25	12	10	+	Normal chest radiogram	Coy Coy. Cueva del Guano	Biological collector	3
RDM	23	14	12	+	Normal chest radiogram	Coy Coy. Huegue Caves. Guano sorting	Exploration work & guano sorting	4
MG	25	10	nil	Doubtful	Normal chest radiogram	Cueva del Guano. Huegue Caves. Coy Coy.	Exploration work & cave surveying	5
MF	25	nil	nil	–	Normal chest radiogram	Coy Coy.	Exploration & general duties	6
JWG	25	15	13	+	Normal chest radiogram	Coy Coy. Guano sorting	Exploration – little biological work	7
JAS	23	nil	nil	–	Normal chest radiogram	Huegue Caves.	Least underground exploration & guano exposure.	8

These results would seem to be unique in the medical literature, a search of which has not shown a comparable series of conversions to a histoplasmin positive state after cave guano exposure without in the vast majority of cases an episode of pneumonic illness.

Murray (1957) in his studies on the Transvaal Speleological Group has previously reported histoplasmin despite exposure in known infected caves but only in four out of twenty six such subjects, the remaining twenty two of whom gave a "clear cut history of illness following exposure in an infected cave". Campins (1956) described eight individuals contracting histoplasmosis in a "hot land" Venezuelan cavern South of Barquisimento in the State of Lara, six of whom had pneumonic illness. Campins subsequently found 38.5% positive reactions to histoplasmin amongst 1836 persons living the neighbourhood of the cave.

Halliday in 1949 described a pneumonic illness with abnormal chest X-rays in all twenty five individuals who had explored a cave at Forman Bluff, Arkansas, U.S.A. Subsequent studies by Furcolow (1953) confirmed this to be histoplasmosis.

In remote central Peru near Tingo Maria is a great limestone cave "La Cueva de los Lechuzas" which harbours immense numbers of Guachero birds. After a new road was driven through the area in 1935 waves of tourists began to explore this "Cave of the Owls" and it was noticed that a few days after their visit some tourists developed an acute respiratory illness associated with generalized weakness and fever with eventual spontaneous recovery. For want of an exact diagnosis the condition become known as "Tingo Maria Fever". Rosell (1958) and Arellano (1955) subsequently showed this malady to be histoplasmosis.

The nearest cases reported to the United Kingdom were Stoker's two cases in Cyprus (1964), where after handling a bat in a cave, two service personnel contracted histoplasmosis the pneumonic episodes being quite severe and one being complicated by the first documented case of encephalitis.

An unusually large infecting inoculum is probably required to produce clinical disease but in the largest documented series (those of Murray (1957), Campins (1956) and Halliday (1949) clinical illness and conversion followed a single cave exploration. Pietri (1956) described his own experience of histoplasmosis contracted after only one hour underground in Na Placida, Miranda State, Venezuela.

The members of this expedition had not previously explored Guano caves or dwelt in areas of endogenous infection. Their duration of exposure was well in excess of that described in previous cases in the literature. In the Cueva Coy Coy de Uria where histoplasmosis spores have been described (Pietri 1957), the party camped underground for eight days. Their programme of biological work involved kneeling in guano with the nose often close to it and occasionally sucking up smaller specimens with a "puffer".

A shorter programme of work was carried out in the Cueva del Guano also known to harbour the fungus and in the Huegue Caves – thought to contain the fungus as one Venezuelan explorer had developed histoplasmosis after visiting this system (Checkley - personal communication).

On the first visit to the Coy Coy cave system masks were worn by all members. These were compact, fairly comfortable and had interchangeable filters, but were not guaranteed by the manufacturers for filtration out of spores below 4-5μ diameter. The smaller variety of spores produced by the fungi mycelia termed the microconidinia and of 2-3μ diameter are probably the infective particles (Loosli & Aspin 1959). In use these masks allowed inspiration of unfiltered air when talking, were found to limit the overbreathing necessary on exercise, made the wearer perspire uncomfortably and were abandoned after only one or two excursions onto the guano beds. The masks were not worn in any other cave systems. Guano sorting at the laboratory at base camp involved further exposure for some members. Table 1 shows the relative exposure of the expedition members to the known infected sites and the relative times spent on guano handling. A fair correlation is seen to exist between these figures as prepared by the expedition leader (D.C.), before skin testing was carried out and the actual conversion to a histoplasmin positive state.

It can be seen to be a reasonable assumption that the members of this expedition had an exposure to infected guano at least comparable and probably well in excess of that described in other individuals contracting clinical disease after exposure in caves.

Why should these cavers have contracted histoplasmosis in an asymptomatic manner in contradistinction to almost all previously described cases of histoplasmosis contracted in cave exploration? The writer suggests that this may be because the problem has previously only been studied when clinical disease has made histoplasmosis obvious and that the likelihood of speleologists contracting clinical illness through histoplasmosis when exploring infected caves may be much less than has been previously deduced. This hypothesis needs substantiating and to do so it would be necessary to skin test large numbers of speleologists who have explored guano caves with a histoplasmosis risk and work out the incidence of positive reactors in this at risk group. From this the proportion who have had clinical or radiological disease could be readily found.

Much is still uncertain regarding the epidemiology of histoplasmosis but this hypothesis would not seem to be incompatible with the accepted calculation of Loosli that there are probably more than twenty millions persons in the USA who have been infected by the small concentrations of the fungus present in the soil and in enclosed spaces, without any symptoms.

Undoubtedly more studies of the true incidence of histoplasmosis in at risk cavers would seem justified. The late Dr. John Aspin proposed such a study in the Cave Research Group Newsletter No.94 (December 1964), his aim being to document those areas where speleologists are at risk. To the writer's knowledge such work has not been published.

It would seem worth while skin testing the now considerable number of British Cavers who have explored systems outside the European continent particularly in caves containing guano. Of particular value would be a study of the results of those who have explored caverns in the Southern States of the USA, Peru, Venezuela, South or Central Africa, Malaysia, Indonesia, Australia or Cyprus from all of which regions histoplasmosis has been documented (Edwards 1971).

The Northern European speleologist would seem to be a particularly suitable experimental animal for such studies coming from a non-infected area and being guaranteed to probe deeply into any underground focus of infection wherever he goes. As there are an increasing number undertaking more distant expeditions yearly they could as a group further epidemiological knowledge regarding histoplasmosis.

The following is suggested as a suitable programme which the medical advisors of expeditions to non-European caves may wish to investigate.

1) All members to submit to a histoplasmin skin test before the expedition.
2) Records to be kept of caves visited by each member.
3) Records to be kept of all illnesses during the expedition and during the month after return.
4) Routine chest X-rays to be carried out on all members after return.
5) Histoplasmin skin test to be repeated after return.
6) Results of the above studies to be published in a reputable caving publication.

Perhaps such studies may confirm the opinion that cave exploration in endemic histoplasmosis areas is not as hazardous as many speleologists have assumed so that expeditions to such areas can be planned with equanimity.

Appendix

The histoplasmin reagent was the Parke Davies preparation obtained from the Dept. of Medical Mycology at St. John's Hospital for Diseases of the Skin, Lisle Street, London, W.C.2. The technique of the skin test is as used in the Mantoux test. An intradermal injection of exactly 0.1 ml. of the antigen is made on the cleansed volar surface of the forearm disposable Mantoux syringes being used to avoid contamination. The results were read at 48 hours the following criteria being employed

Positive – Induration measuring 5 mm or more

Doubtful – Induration measuring less than 5 mm in the greatest diameter with or without erythema; or erythema alone measuring more than 5 mm.

Negative – no induration or erythema measuring less than 5 mm.

(A negative histoplasmin reaction may be obtained in acute or fulminating infections in which case the patient should be tested with histoplasmin repeatedly as conversion to a positive reaction will occur during its development suggesting an improvement in cases of serious illness).

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A MODEL OF THE KARST PERCOLATION SYSTEM OF WATERFALL SWALLET, DERBYSHIRE

by John Gunn

SUMMARY

Observations made on "fast" and "slow" drips in Waterfall Swallet, Eyam, Derbyshire, demonstrate the existence of two flow systems, conduit flow and diffuse flow, with different physical and chemical responses to rainfall

Introduction

Whilst a number of studies have been made on karst water emerging at risings (e.g. Newson, 1972; Paterson, 1972; Chambers, 1973) there are few which present results based on subsurface sampling. (Pitty, 1966, 1968, 1969; Halliwell, 1970). This is unfortunate as spring studies usually deal with compound water. Compounding is threefold: most springs have both swallet and percolation components, spring water may have passed through the phreatic zone, and even within the percolation system there are a variety of flow systems (Shuster and White, 1971). For these reasons a subsurface sampling programme was undertaken to examine the nature of percolation water before it had been subject to the first two constraints and to investigate flow in the two end systems proposed by Shuster and White, conduit and diffuse flow.

Flow Systems on Limestone

Diffuse flow supposedly takes place along joints, fractures, bedding planes, and other small, interconnected openings measured in centimetres or less. It tends to behave as laminar flow in a porous medium, though the medium is extremely anisotropic. Conduit flow, however, supposedly takes place in integrated conduit systems, with water flowing, usually turbulently, in passages measured in centimetres or metres. Flow approximates to that in irregular pipes. (Shuster and White, 1971).

Sampling Design and Technique

The cave chosen for study was Waterfall Swallet, Derbyshire (SK 199771), as this has a vertical range of approximately 50 metres, and is the least visited of suitable caves within travelling distance of the author's home, thus minimizing the chance of interference. The diffuse flow system was modelled by "slow" drips and the conduit system by "fast" drips. The use of plastic containers to collect percolating water in preference to the "drip rate" method of Pitty (1966) enabled "slow" and "fast" to be defined in terms of container capacity. Thus slow drips yielded 20-860 ml. per week and fast drips 250-4350 ml. per day. The initial sampling programme was for 6 slow drips to be sampled for 15 weeks and 6 fast drips to be sampled for 15 days. Certain problems were, however, encountered and these are listed in Table 1, together with the precise sampling period and depth of each station. The position of each station is indicated on a diagrammatic elevation of the cave (Fig. 1). Station depths were chosen to ensure a fairly even distribution through the vertical range of the cave, and at each depth the actual station location was random insofar as the first drip to fulfil the yield conditions outlined above was used. Suitability was determined during the 3 weeks preceding sampling for slow drips and the 3 days preceding sampling for fast drips.

Volume, water temperature, and pH were determined for each drip point and related to surface air temperature and rainfall measured at Waterfall Farm, about 25 m. from the Swallet. Only water temperature was actually measured in the cave, the sampling bottle being then replaced and removed to the surface where volumes were measured and pH determined by B.D.H. Universal Indicator. Facilities to titrate for calcium hardness were not available and as a result the chemical analysis is not as precise as desirable.

Data Analysis

Two forms of data analysis were used. Firstly, the relations between rainfall and drip volume, water temperature, and pH, and between surface air temperature and drip water temperature and pH were analysed by the calculation of cross-correlation co-efficients. This operation was performed on the computer using a programme written by Sampson (in Davis, 1973). Inter-station relations were analysed by correlation matrices for volume, temperature, and pH. Pearsonian correlation co-efficients were calculated using a computer programme written by the author. Levels of significance were discussed with Mr. P. Jackson, Lecturer in Statistics at University College, Aberystwyth.

Results

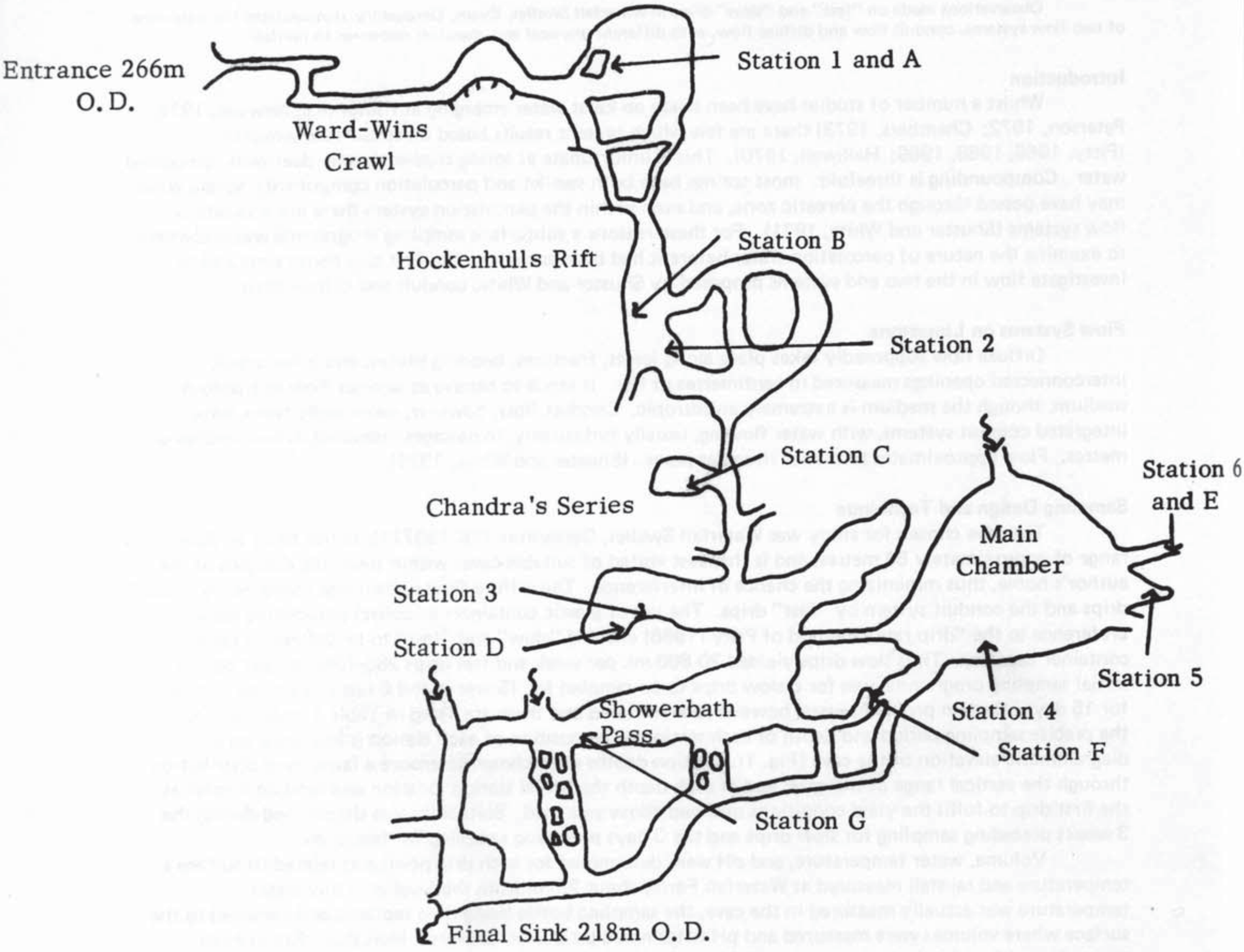
A large amount of data was generated by this study and limitations on space prevent publication. Copies of the raw data are, however, available from the author. Tables 2 and 3 show cross-correlation analyses for stations 2 and C which are representative of diffuse and conduit flow respectively.

All the slow stations, except station 5, showed a similar basic grouping of high correlations in the 3-5 week lag period. This usually consisted of positive rain: volume; negative rain: water temperature and pH; and positive surface air temperature: water temperature and pH correlations. Fast stations, however, showed no overall pattern, though 3 possible lags, 0-4, 5-14 and 15-19 days may be recognised at most stations. There is also a consistent relation between the correlations for each station: positive rain : volume correlations are usually accompanied by positive rain : water temperature and pH, and negative (sometimes

FIG. 1.

WATERFALL SWALLET CAVE, FOOLOW, DERBYSHIRE

APPROXIMATE CROSS SECTION SHOWING POSITION OF DRIP STATIONS



Approximate depth of stations below entrance (m)

1 and A	4	5	35.0
2 and B	14.5	6 and E	36.0
C	20.0	F	39.0
3 and D	27.5	G	42.5
4	34.0		

Table 1

Station Depths and Sampling Periods

Station[i]	Approx. depth below surface (m)	Sampling Period 1973[ii]
1	10.0	w.e. 29th April – w.e. 12th August.[iii]
2	20.5	"
3	33.5	"
4	40.0	"
5	41.0	"
6	42.0	" [iv]
A	10.0	w.e. 23rd July - 5th August [v]
B	20.5	"
C	26.0	"
D	33.5	"
E	42.0	" [vi]
F	45.0	w.e. 27th July - 5th August
G	48.5	w.e. 30th July - 5th August

(i) Slow drip stations were given a number and fast drip stations a letter.

(ii) No sampling was undertaken for week ended 15th July owing to flooding.

(iii) Station 1 was dry from the week ended 17th June to the week ended 8th July.

(iv) Station 6 overflowed week ended 27th May, 3rd June and 17th June – 1st July.

(v) The same drip was used for station A as for station 1 due to lack of suitable alternatives.

(vi) The same drip was used for station E as for station 6 due to lack of suitable alterantives.

TABLE 2 CROSS-CORRELATION CO-EFFICIENTS FOR A REPRESENTATIVE SLOW STATION, STATION 2

SIGNIFICANCE LEVELS OF 20% AND HIGHER ARE INDICATED IN BRACKETS * = NOT SIGNIFICANT

VARIABLES \ LAG (WEEKS)	0	1	2	3	4	5	6	7	8	9	10	11
RAIN & VOL	-0.01 *	-0.08 *	-0.12 *	-0.08 *	0.72(2)	0.22 *	0.28 *	-0.14 *	-0.68(10)	-0.15 *	0.58 *	0.47 *
RAIN & W/T	0.53(10)	0.11 *	0.20 *	0.21 *	-0.77(2)	-0.08 *	0.04 *	-0.54 *	-0.27 *	0.48 *	-0.37 *	-
RAIN & pH	0.14 *	0.08 *	0.44(20)	-0.32 *	-0.51(20)	-0.51(20)	0.01 *	-0.18 *	0.58 *	-0.14 *	-0.96(5)	-0.90 *
SURFAIR & W/T	0.40 *	0.48 *	0.57(10)	0.78(1)	0.36 *	0.62(10)	0.46 *	0.26 *	0.48 *	-0.71 *	0.80 *	-
SURFAIR & pH	-0.11 *	0.04 *	0.05 *	0.44(20)	0.72(2)	0.93(0.1)	0.53 *	-0.06 *	-0.53 *	0.40 *	0.81(20)	0.65 *

TABLE 3 CROSS-CORRELATION CO-EFFICIENTS FOR A REPRESENTATIVE FAST STATION, STATION C

SIGNIFICANCE LEVELS ARE INDICATED AS PER TABLE 2

VARIABLES \ LAG (DAYS)	0	1	2	3	4	5	6	7	8	9	10	11
RAIN & VOL	0.23 *	0.74(1)	0.45(10)	0.06 *	0.33 *	0.41(20)	0.40(20)	0.80(0.1)	0.53(5)	0.03 *	0.28 *	0.43(20)
RAIN & W/T	0.28 *	0.51(10)	0.17 *	0.22 *	-0.04 *	0.55(5)	0.73(1)	0.67(1)	0.41(20)	0.14 *	0.08 *	0.22 *
RAIN & pH	0.17 *	0.17 *	0.22 *	0.34 *	0.41(20)	0.68(1)	0.35 *	0.21 *	0.22 *	0.17 *	0.58(5)	0.63(5)
SURFAIR & W/T	-0.41(20)	-0.14 *	-0.47(20)	-0.24 *	-0.57(10)	-0.67(5)	-0.60(10)	-0.60(20)	-0.60(20)	-0.01 *	-0.04 *	0.91(10
SURFAIR & pH	-0.33 *	-0.44(20)	-0.43(20)	-0.28 *	-0.24 *	0.28 *	0.64(10)	0.66(10)	0.50 *	-0.18 *	0.00 *	-0.58 *

positive) surface air temperature : water temperature and pH correlations. The correlation matrices show that the slow drip stations are highly correlated with each other with respect to water temperature and pH but much less so with respect to volume. The fast drip stations show much less correlation between themselves.

Interpretation

With the possible exception of station 5, the slow drip cross-correlations outlined above support the following conclusions. At 3-5 weeks after rainfall input there is a peak in volume output accompanied by troughs of water temperature and pH which may continue for 1-2 weeks after the volume peak. Peaks of surface air temperature are followed by peaks of water temperature and pH with the same lag. The correlation matrices support the similarity in response of all stations.

The following model of diffuse flow within the limestone of Waterfall Swallet is thus proposed. In dry surface conditions water infiltrates slowly, under unsaturated flow, through the soil and becomes enriched with biogenic carbon dioxide and is thus aggressive (Smith and Mead, 1962; Pitty, 1966, 1968). As diffuse flow, by definition, takes place through very small openings, flow is thought to be analogous to that in soils, that is unsaturated interflow. The water flows through the limestone, taking it into solution, until it is saturated with respect to calcite or the 'karst reservoir' is reached. The existence of this reservoir has been postulated by a number of authoris, particularly Halliwell (1970), to account for the fact that drips continue to flow after long dry periods. Its form is uncertain but this study provides further justification for accepting its existence because all the diffuse stations showed a similar response chemically and physically. It is thought that little, if any, further solution takes place within this reservoir, as final carbon dioxide diffusion is not possible (Jennings, 1971).

After rainfall, flow through the soil will increase, particularly if the soil becomes saturated. This, plus the lower biogenic activity associated with rainfall, results in the water being less aggressive on reaching the limestone. Flow in the limestone will initially be unsaturated, as before, but as the level of the reservoir rises, then this zone of active solution will decrease. The nett result will be that the water reaching the reservoir will have a lower calcite content and thus a lower pH. Thus, when this water reaches the drip point, 3-5 weeks after the initial precipitation and at the same time as the increased volume, a trough in pH will be recorded. The drip water temperatures could not be fitted into this model as they were found to be correlated positively to the cave air temperatures, having stood for a week.

The cross-correlations for the fast drip support the following conclusions. Rainfall is followed, at a lag which varies with station, by peaks of volume, water temperature, and pH. Low surface temperatures are followed at a similar lag by high water temperatures and pH on the majority of occasions but sometimes by low water temperatures and pH. Examination of the rainfall and surface air temperature records over the daily sampling period, shows a significant negative correlation between the two. It is therefore suggested that the peaks of water temperature and pH following low surface air temperatures are due solely to the fact that over the sampling period rainfall tended to occur on cold days, and the negative correlations between surface air temperatures and water temperature and pH are thus not regarded as causal. This being the case the positive correlations between surface air temperature and pH observed at the slow stations and those few observed at the fast stations may be explained by reference to Van't Hoff's Law which states that biogenic activity increases with air temperature. Thus, on a warm day more biogenic carbon dioxide will be produced and thus percolating water will be more aggressive and capable of taking more calcite into solution. It may also be tentatively postulated that the few positive relations between surface air temperature and water temperature shown by the fast drips are due to the water having insufficient time to equilibrate to the areal rock temperature.

The following model of conduit flow in Waterfall Swallet is proposed to account for these features. During dry conditions flow through the soil is as postulated under the diffuse model and when the aggressive water meets the limestone this is taken into solution. Because the conduits are, by definition, considerably larger than diffuse cracks, flow is by free gravity drainage which is considerably faster than the unsaturated flow of the diffuse model. Some form of karst reservoir is again thought to exist for reasons stated in the diffuse model. However, because the conduits are not integrated to the same extent as the diffuse system, the height of this reservoir is thought to vary. The size of the conduit and the number of tributaries, if any, may also affect the height of this reservoir. It is because of this variation in height that different drips show different responses, as flow within the reservoir is analogous to phreatic flow and is thus slower than free gravity drainage.

After rainfall flow through the soil is again identical to that proposed under the diffuse model so that water reaches the limestone in a less aggressive condition. However, the greater volumes and the fact that turbulent flow is possible within the conduits, results in more limestone being taken into solution (Weyl, 1958). The pH may also be increased by the ejection of material which has been stored in the reservoir (Halliwell, 1970). As under dry conditions the precise nature of the flow-through times and pH will depend on the height of the karst reservoir and will thus vary from drip point to drip point.

Both the diffuse and the conduit models postulated above differ from those postulated by Pitty (1966, 1969) and Halliwell (1970), particularly with respect to flow-through times. Limited support for them may, however, be obtained from the work of Drew (1968a, b; 1970), who used Pyranine Conc to trace percolation water. In Central Mendip he found flow-through times of 6-14 days (similar to the proposed conduit model) and at St. Dunstan's Well there was a strong positive response 3 weeks after input (similar to the proposed diffuse model). Drew suggested that the difference between these times might be related to soil cover. In the case of the present study the soil cover around the swallet is homogeneous, with no bare rock outcrops. It thus seems more likely that the differences represent the different speeds of transmission of small partings and large conduits, particularly above the karst reservoir.

Conclusions

A study of the physical and chemical response of a number of slow and fast drips to rainfall and surface temperature inputs, suggested the existence of two flow systems, diffuse and conduit respectively, through the percolation system. Diffuse flow-fed drips had flow-through times of 3-5 weeks and rainfall was associated with low pH, i.e. a dilution effect. Conduit flow-fed drips had flow-through times of 2-8 days in the main, and rainfall was accompanied by peaks of pH, attributed to turbulence of flow and to ejection.

It must be stressed that little work has been done in this field and this was very much a reconnaissance study. As such the sampling periods were short and methods used were simple. As it is hoped to follow this work up with study over a longer time period, with titrations for calcium hardness and tracing work similar to that of Drew, any criticisms of technique, results, or conclusions, will be more than welcome.

Acknowledgements

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SOME CALCRETED DRIP-POT FORMATIONS

by Peter A. Bull

ABSTRACT

The effects of saturated dripping water upon sediment banks result in simple and compound features which form around a central drip-hole tube, itself dependant upon a delicate balance between erosion and deposition.

Introduction

In 1942 Baker recorded a feature in a cave in Western Australia which he called a sand stalagmite. These features were made up of cemented sand and shell fragments which formed under drip holes of saturated dripping water. Lateral spread of downward percolating water through a loose sand layer resulted in "ledge structures" which culminated in "grotesque forms" when released by erosion of the surrounding sand. They varied in width from 25 mm to nearly a metre in diameter.

Baker suggested that the central drip hole which often extended through the length of the feature resulted from the downward seepage of the calcareous solutions being more rapid and more sustained than lateral spread.

The writer, working in South Wales and South West England has recently noticed features that are similar to those found in Western Australia and it is the purpose of this paper to discuss their form and origin.

Previous Literature

Since Baker's work (1942) there has been little written on features that can, with certainty, be regarded as the same features that he recorded.

Calcite "toadstools" were reported in Llygad Llwchwr (Hawes 1960) and these may well be partly eroded speleothems similar to Baker's stalagmites. The apparently analogous structures in mud are well noted in the literature (Lloyd 1956; Osborne 1961) together with other peculiar speleothems such as gypsum stalagmites (Hatton 1971) and sandstone stalagmites (Davies 1969). However, these seem to be formed by processes different from those discussed by Baker.

Forms resultant from dripping water rather than by calcification have been noted in a cave in Northern Ireland (Halliwell, 1970) but are distinguished from sand stalagmites in the paper (in one of the few articles to mention Baker's original work).

Other literature dealing with the cementation of loose sedimentary layers by percolating secondary calcite is scarce, although a recent paper (Ford, 1973 p.13) mentions ideas of cemented cave sediments and their environmental indications.

Morphology

In general the specimens examined ranged in length from about 10 to 30 cm, and in width from 5 cm for individual forms, to 50 cm for the compound forms. They all exhibited a central drip hole tube which extended vertically through most of the feature.

Surrounding this drip hole tube and, as a result of lateral percolation of saturated water, are the ledge structures as described by Baker. These structures are the result of the consolidation of the sedimentary features exhibited within the bank of sandy material in which the feature is formed.

In no specimen studied was it seen that the actual walls of the drip hole tube exhibited the features of the surrounding sediments: in all cases the drip holes had formed with smooth crystalline sides.

The width and shape of the drip hole varied with the specimens found, the causes of which are discussed later in this article, whilst the bottom of the feature exhibited a rounded base, as noted by Baker (see plates included).

The form of the stalagmites examined varied from simple types, isolated within the sediment bank, to compound features welded together by the cementing action of the calcite. This seems directly related to the number of drip souces within an area and to the amount of consolidation and grain size of the sediment bank. Very complex forms incorporating later stalagmite flooring have been examined which show the "hard" stalagmites to be in an opposite attitude to the sand stalagmites (i.e. growing "up" instead of "hanging down").

Terminology

The original terminology of sand stalagmite is misleading as the implication of stalagmite attitude is wrong and it is, therefore, suggested that these features be simple called calcreted drip-pits for the present.

Method of Formation

It seems that the pre-requisite for the formation of the calcreted drip-pit is the presence of a relatively deep, relatively unconsolidated bank of sediment, with water saturated in calcium carbonate dripping onto this bank and time for formation. The dripping water reacts with the cave air in the same manner as in stalagmite formation but the deposit forms within the sediment bank in an attitude similar to stalactites, that is, the feature "hangs" from the surface generally to taper downwards within the sediment bank.

It seems that the rate of drip of the water is fundamental in the formation and shape of the feature. Baker attributed the continuation of the drip hole (the only surface feature of the drip-pit) to the erosional

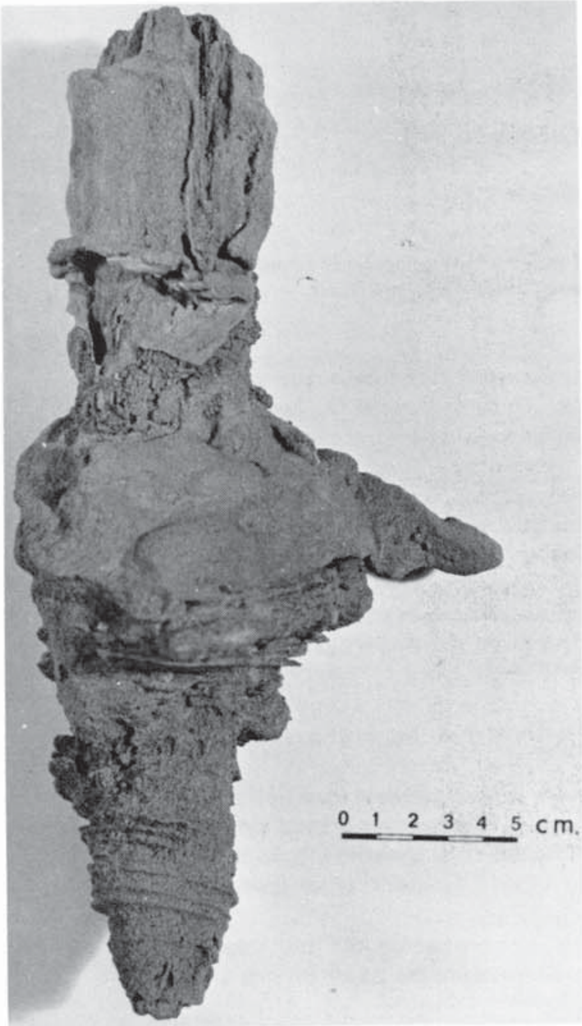

Plate 1a

A drip-pit showing differential lateral cementation.

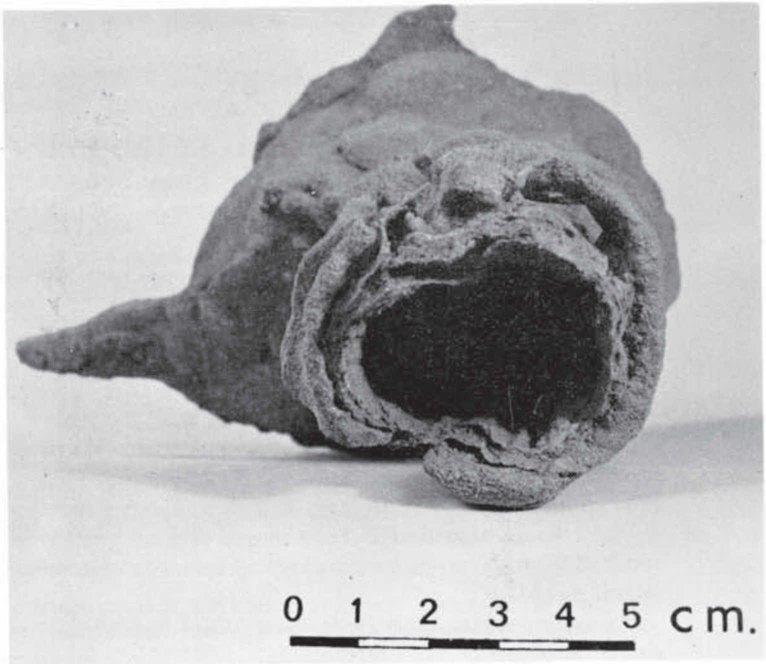

Plate 1b

A view of the drip-pit from above.

Plate 2a

A compound drip-pit structure with an erosional pipe left of the scale.

Plate 2b

A view of the compound drip-pit structure from above.

effect of the dripping water. Combined with this "splash effect" is the deposition of calcium carbonate around the perimeter of the drip hole. The combined effect of erosion and deposition leads to a calcite "tube" being formed from the cementation of the particles within the sediment bank. The force of drip, controlled by the rate of supply of dripping water and to the height of the ceiling immediately above the feature, and the consolidation of the sediment layer immediately below the dripping water, controls the rates of erosion of the drip hole and deposition of calcium carbonate, the latter both vertically and horizontally. Any lateral variation in source area may also affect the shape of the drip hole.

As the saturated water percolates through the sediment layer, it cements together the grains and incorporates any sedimentary features within the sediment body, as a result the calcreted drip-pits often exhibit a banding inherited from the sediment bank, reflecting layers with different grain size.

Unlike those features that Baker analysed no drip lip has been found (i.e. the surface splash area around the drip tube) perhaps destroyed in later disturbance within the specimen that the author examined.

Despite strong structural control of the sedimentary features in the sand banks, no drip-pits have been found in anything other than a vertical position, although it seems from a preliminary survey that the sedimentary structures, grain size in particular, control the amount of lateral cementation producing the often irregular shapes that are formed (i.e. ledge structures).

Calcreted drip-pits examined in Cwm Dwr Quarry Cave, South Wales, show features similar to those mentioned by Baker in that the fossil, dry, formations had consolidated and hardened enough to be removed from the surrounding sediment without much trouble. However, those formations that were wet and presumably still being formed could not be examined without considerable care. Even in a wet, unconsolidated form the tubes showed a crystalline coating of calcite. Baker mentions that the features he found hardened on drying and this seems to be in general agreement with those found in Cwm Dwr.

In no place was the formation of the drip-pits associated with a drip fall of more than about one metre. Drip-pits were noted in various parts of Cwm Dwr and Swildons Hole, Upper Series.

The time factor involved for formation of these structures is not really known, although an indication of scale can be had from an example in Swildons Hole, Upper Series, in which the drip hole, partly coated with a secondary calcite skin, was seen about one to two centimetres deep and forming in sediment undoubtedly redeposited by the July 1968 floods on the Mendips. However, this only indicates the formation of the surface drip hole and may not be on the same time scale of development as that of the complete feature.

It seems that from a preliminary analysis that the calcreted drip-pits form in a predominantly sandy sediment but often incorporating a high proportion of finer sediments.

Whether or not a drip hole will consolidate into a deep drip-pit depends on a number of factors. Primarily, that the initial requirements for formation already mentioned are present; secondly, that the dripping water be saturated in calcium carbonate and thirdly, that time be given for the formation to develop fully.

The various environmental implications of calcreted drip-pit formation include changing conditions initially from a probable vadose stream phase to a reduction in water level which enables drops to affect the sediment bank. For fossil drip-pits to form a termination of the drip is required, which in a cavern environment may indicate the onset of drier conditions. More complicated implications exist relating time of formation to known environmental conditions, however, they are not dealt with within this paper.

It is hoped that in future greater protection will preserve the drip holes; "digs" within soft sediments should take care not to destroy one of the less easily seen formations within a cave.

The author is at present carrying out further research on the detailed sedimentary characteristics of the drip-pits.

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HYDROLOGICAL INVESTIGATIONS IN NORTHERN VENEZUELA

by M. Gascoyne

SUMMARY

A tropical limestone region in Venezuela, South America was the object of exploration and study by the British Karst Research Expedition, "Venezuela '73", from February to August 1973. In this paper, after a brief description of the area, the hydrological work of the Expedition is outlined and the results are summarised.

Special attention is given to the use of optical brightener dyes as water tracers, the factors affecting limestone solution and deposition both above and below ground, the classification of resurgence waters, and the effects of floods on the whole hydrological system within the limestone. The mechanisms of cave development in the area are proposed, with particular reference to the caves formed in non-calcareous rocks.

Introduction

The Expedition, led by Dave Checkley and organised mainly at Lancaster University, had two main objectives for the period of six months spent in Falcon State, Northern Venezuela. These were the exploration of the caves in the jungle area of the Serrania de San Luis and, equally important, a scientific study of the caves and the region. This study was to consist of a biological programme, examining the animal life in the caves and a hydrological programme of water tracing and chemical analysis.

Description of the Area

The Serrania de San Luis is a mountainous limestone ridge rising to 1,500 metres above sea level, and is the most northerly extension of the Venezuelan Andes (Figures 1 and 2). It is surrounded by areas of semi-desert and scrubland, but it itself, is covered by a dense tropical jungle. This is due to the high rainfall brought throughout the year by the north-easterly Trades, as they rise over the area. Resurgences abound on the lower slopes and form the only source of water for much of Falcon State. In many areas the jungle has been cleared and the fertile soil used for growing crops of bananas, maize, beans, sugar cane and oranges. These clearings have also helped to reveal the nature of the land surface and the types of karst exhibited there. Many caves and potholes are known throughout the area, generally in the more inhabited parts and most of these have been documented and in some cases surveyed by Venezuelan speleologists (Bellard, 1970; Sociedad Venezolana de Espeleologia, Caracas).

In the centre of the Serrania lies a small village, Curimagua, which was the Expedition's 'home' for the six months. A Dutch-barn-like building with lockable rooms at either end, was made available as a 'campsite'.and provided admirable facilities for the establishment of a laboratory for the scientific work. At this 'camp', measurements of rainfall, evaporation and temperature were made as part of a simple climatic study. Further camps were established in more remote areas as the need arose, and often much of the laboratory equipment was transferred to them. Linking the villages in and around the Serrania are a few good asphalted roads, and many dirt tracks lead off these into the cultivated valleys and smaller settlements. Hence access to the region was good except for the easternmost areas.

a) Geology

The limestone is of Oligocene age and of reef origin. It is up to 500m. thick, but its structure gives an apparent thickness of 1,400 metres. The limestone is capped towards the north and west by conformable sandstones and contains some grit and conglomerate beds towards the south and east. Otherwise it is well exposed in most regions. Towards the north, the limestone undergoes a facies change where non-calcareous sandstones and shales become interbedded as part of the back-reef facies zone (the Patiecitos facies). The underlying rocks outcrop on the south-eastern slopes of the Serrania and are known as the Pauji shales (Shell files).

The area has been strongly influenced by tectonic movements since its uplift. Major faults running north-south dissect the limestone into a series of blocks, and because of their repetitive downthrowing to the east, give a step-wise appearance to the region. Folding is also much in evidence, the fold axes generally being aligned in an east-west direction. Little horizontal limestone is found in the Serrania and the strata usually dip at between 10° and 25°. The north-facing slopes are in fact dip slopes which plunge down towards the Caribbean coastline at about 30°.

b) Geomorphology

The principal morphological feature in the area is the completely enclosed Curimagua valley. It can be recognised as three distinct basins, Uria, Acarite and Curimagua (Figure 2). Its existence is due mainly to the Uria syncline whose axis runs approximately east-west along the valley and whose ends are uplifted by fault action. The valley floor lies near the 1,000m. contour, with its lowest part in the east. On all sides are steep slopes of densely-jungled limestone ridges and plateaux. Cliffs up to 100m. high are a common feature, especially in the small branch valleys of Camburales and Acarite, and usually denote the lines of the major faults.

c) The Karst

In the Serrania there is no one specific type of karst that extends over most of the area as is found in Jamaica ('cockpit karst', Sweeting 1958) and Puerto Rico (tower karst, Monroe, 1968). This is because of the strong influence of structure on the region. Frequent dissection by faults has made the identification, genesis and even exploration of the more remote regions a mammoth task.

FIG.1
Location of the Expedition.

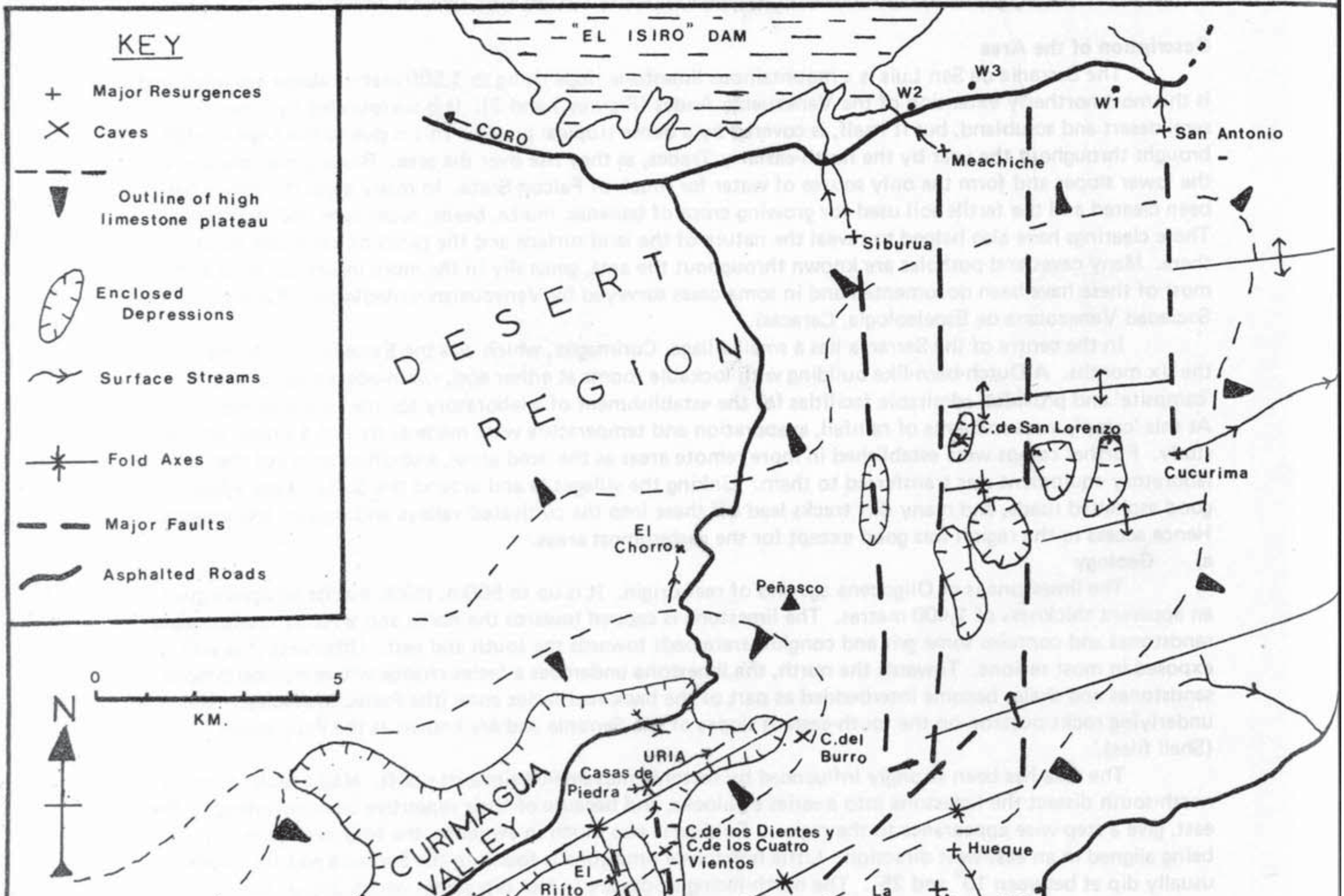

FIG.2
The Serrania de San Luis, Estado Falcon.

Doline karst exists in many regions, particularly in faulted zones. The funnel-shaped doline, generally circular or elliptical in shape is the most common type of doline. Often there has been coalescence of dolines to form uvalas. The genesis of these features is probably one of initial solution lowering down lines of weakness, followed by extensive collapse. This results in dolines with steeply descending boulder floors, often dropping away into cave entrances on one side of the doline. The dolines also frequently contain vertical cliff faces up to 70 metres high and the floors of cave entrances within them may be as far as 100 metres below the lip of the doline.

In the alluvial valley of Uria are several ridges of limestone, which cross the valley. The Uria stream runs through these ridges forming the Casas de Piedra (Houses of Rock), a series of three short caves. The ridges resemble the mogotes of Puerto Rico, but are on a much smaller scale.

Much of the doline karst of the Serrania is separated by areas of densely-jungled pinnacle karst. In some regions, where the vegetation has been cleared, a 'subdued' pinnacle karst is revealed. More remote and wetter areas contain a better developed karst with individual limestone pinnacles rising to sharp points as high as 20 metres above the ground. Two areas of these formations were found in the eastern part of the Serrania, and both were contained in ravine-like depressions over 150 metres long by about 30 metres wide. Possibly they represent karst dolines with strong superficial features, which are relatively intact structurally. This is because they seem to be some distance from any major faults, and so the fracturing of the blocks and general 'rounding-out' of the doline topography is at a minimum. Also, their development is undoubtedly aided by the high rainfall and the dense tree canopy of the area, both factors preserving the permanent high humidity near ground level. Thus, the bare rock surfaces are always damp and readily available for erosion. The 'subdued' pinnacle karst may have developed to the same extent as this more jagged form, but has since been rounded-out by block fall and the build-up of a soil cover.

There seems to be a general decrease in pinnacle karst forms, with doline karst predominating, as the rainfall decreases across the Serrania. Once into the limestone desert regions, as on the Paraguana peninsula to the north, there is little karst topography to be seen. A well-jointed sub-horizontal reef pavement is exposed on much of the peninsula, but only has its joints etched out in dry river beds. Some groundwater solution appears to have taken place in the past, because occasionally the surface bed of the pavement has collapsed to reveal large chambers, generally bat-infested, as in the case of Cueva del Guano.

The Caves

Of the caves explored five basic types could be recognised.

The first type is the large nearly-fossil, horizontal tunnels, with passages up to 50m. wide, 15m. high and 1km. long. The point of entry into these tunnels is usually in the bottom or side of a doline, the latter forming a complete blockage in the downstream direction of the cave. The upstream passage also invariably ends in a similar boulder pile out of which a small stream often resurges. These caves all generally follow the strike of the limestone beds, and are mostly found to occur in the Curimagua valley at about the 1,000m. contour.

The development of these tunnels was probably due to the existence of a higher constant-level resurgence than there is today. Also, within the valley are found some recent active vadose caves. These generally take small surface streams and end in a boulder collapse after a few hundred metres. They appear to be formed by the channelling of surface drainage by dolines, plant debris, inwashed soil and boulder blockages.

Probably for these reasons also, a small number of phreatic caves exist in the Curimagua valley. One in particular, El Riito (Little River) lies at the floor level of Acarite valley, its entrance partly dammed up by a hummock of soil and boulders. It contains a long flooded section of passage, which during the Expedition, drained sufficiently to permit exploration for 400 metres to a sump. The water was static and over 2 metres deep for most of the way in a passage up to 10m. wide, occasionally dissected by high cross rifts.

In the northern part of the Serrania, in areas of steeply dipping rocks, a fourth type of cave is found – the 'dip-tube' cave. The best example of this is Cueva de San Lorenzo, which has a rounded, vadose passage descending at a constant angle of 28° for about 0.5km. The depth reached is 237 metres, when a sand and pebble-choke blocks the way on. The cave direction is slightly oblique to the true dip direction, guided by a joint. The most interesting feature about this cave is the fact that apart from its entrance and two narrow sections in the cave being limestone, the whole of the cave is formed in sandstones, siltstones and shales. The passage is generally about 3 metres high and 1 metre wide with a narrower trench in the floor.

The final cave type recognisable in the Serrania is the 'haiton', the local name for pothole. These shafts are liberally distributed about the Serrania, but some plateau areas with strong joint development were found to contain high densities of them. Five separate entrances within one 30 metre square of terrain were once observed. These areas also appear to have a high rainfall. These shafts range between 10 and 200 metres deep and most are choked with boulders and vegetation. Occasionally some of the haitones enter vadose cave systems, as in Cueva del Guarataro, and descend down-dip to a depth of over 300 metres, Once again boulder chokes terminate the passages.

HYDROLOGICAL WORK

1) Water Tracing

Fluorescein and optical brightener dyes were used in water tracing investigations. To avoid the problems experienced in Jamaica (Fincham and Ashton, 1967) when using fluorescein in tropical streams, it was hoped to use the dye as a short distance tracer only. This involved cave-to-cave or surface sink-to-cave tests. Although little was known about the adsorptive properties of optical brighteners, successful results had been had in England using them as long distance tracers (for references see Glover 1972, also Gascoyne 1973). Thus, it was intended to use the two dyes, Leucophor C and BS liquids as long distance cave-to-resurgence or surface sink-to-resurgence tracers. Detection of fluorescein was either done by sight or by activated charcoal markers, and of optical dye by cotton wool markers.

Results

a) Fluorescein

During the Expedition, the dye was little used in any quantity and only one positive result was obtained – testing the main surface stream in the Serrania, in the Uria basin (2 litres/sec discharge) to the stream in Cueva del Burro (17 l/sec.) nearby. A cave-to-cave test was later attempted using a kilogram of dye, but two weeks after its introduction in the downstream sump of Cueva de las Abejas Acarite, it was found to be still lying in the pools of the extension of the cave, discovered when the sump drained.

Although no adsorption of the dye was observed as a result of a negative test, there was still a good chance of adsorption taking place as the organic debris content in the stream was high. Also, as the discharges were very low, the time spent in the caves was longer allowing much opportunity for adsorption.

b) Optical brighteners

The first test of Cueva del Burro to Hueque resurgence succeeded within two weeks of introducing 2 kgms. of Leucophor BS into the cave stream. The distance involved was 4kms. and a 200m. drop. A cave-to-cave test (Cuatro Vientos to Dientes) was also positive using Leucophor C. However, on three occasions using Leucophor C on surface sink-to-resurgence tests, no results weresobtained. Furthermore, towards the end of the Expedition, when 50gms. of Leucophor C was introduced into the Hueque resurgence, the cotton markers placed downstream were all negative when examined. The likely reasons for the failure of these tests are thus:

1) Adsorption of the dye by organics (particularly natural celluloses)
2) Low detector efficiency.
3) Degradation by diffuse light and/or organics, once adsorbed on the detector.
4) Low discharges.

For the sink-to-resurgence tests adsorption is the most likely reason for failure, indirectly caused by low discharges. However, the surface test suggests that the detector design may require 'steeping' in the dye for some time for adsorption to take place onto the cotton. This may also account for some notable failures that have occurred in England when the dye was introduced just before a flood. Rapid elution through the system probably prevented adequate time for adsorption of the dye onto the cotton detectors suspended in the resurgence waters. An increase in efficiency could be brought about by channelling the water to flow through the marker, if only slowly. Mounting it in a wide plastic tube and holding it in place by plastic gauze would cause this flow to occur when the tube is directed into the current.

The tracing results also seems to indicate a higher adsorptive rate of Leucophor C than BS liquids. This can be expected, as the former is a 'cold water dye' – maximum exhaustion onto cellulose (cotton) taking place between 20° and 40°C, whereas the same figures for BS liquid are 40° and 60°C. Since most of the waters tested were over 20°C, it is quite likely that all the Leucophor C had adsorbed onto natural celluloses in the water before reaching the resurgence. Leucopher BS however absorbed less readily and gave a positive result at the resurgence.

Probably the most important factor hindering successful water tracing results was the lack of substantial flow at the input points. This is not the norm for the Serrania, however, as the period of the Expedition lay within the driest on record for 25 years.

2) General Water Chemistry

Introduction

To get an idea of the different types of karst water in the Serrania, a programme of general water sampling was undertaken during the whole of the Expedition. This involved sampling resurgences, cave streams and surface streams. A good deal of analytical apparatus and chemicals was taken to Venezuela and analyses of calcium, magnesium and alkaline hardnesses; chloride; sulphate; nitrate; nitrite; aggressivity; chemical oxygen demand (COD); and biological oxygen demand (BOD) were made. Use of a flame photometer at the Shell refinery in Punto Fijo nearby, permitted analysis for sodium. This was especially useful for analysing samples taken for dilution gauging work (Gascoyne 1972). Most water samples were analysed for hardnesses, chloride and sulphate content, and the other analyses were made occasionally. A representative table of results, of the types of waters encountered is given in Figure 3.

The analytical techniques used are those described by Bray (1969, 1972), Stenner (1969) for hardnesses, COD and aggressivity, Klein for chloride and sulphate. BOD was determined by a comparison of two COD results, taken 4 hours after sampling, and then again 5 days after sampling. A full description of the methods will be given in the Expedition report due to be published in 1974.

Results

a) Variation of Temperature

Throughout the Expedition, the temperatures of all the resurgences were never found to vary by more than 0·3°C, but there was a wide range of temperatures from one resurgence to another. For the main 'cold water' resurgences, a plot of total dissolved solids (TDS) and total and alkaline hardnesses against resurgence temperature (Fig. 4) shows surprising linearity. The points for the Meachiche resurgence are notably off the lines drawn and this is probably due to the difficulty of measuring the exact resurging water temperature. The water enters at the bottom of a deep pool and so is affected by surface heating before measurement. The other resurgences all come from boulder piles and are thus easily measured. Only one sample was ever obtained from Siburua resurgence, as it dried up soon afterwards.

b) Ionic Balance

When converted into equivalents, the values in Fig. 3 all balance within acceptable limits. Also in most cases, the values of the calcium and alkaline hardnesses are very similar suggesting that magnesium hardness is of the non-alkaline type and exists probably as chloride and sulphate. Also a plot of total hardness against alkaline hardness for all water samples shows linearity for resurgences and cave streams, but curves off in surface streams. These facts show that non-alkaline hardness is a fairly constant value for all waters and probably originates from the sandstone capping or soil and vegetation layers.

c) High Alkalinity Results

These occur especially in the thermal waters of the artesian wells (Figure 2). Here, the value of alkaline hardness (a measure of carbonate and bicarbonate) is higher than the values for total hardness. This is due to the presence of sodium carbonate (from soda beds in the back reef facies presumably); the high sodium value supports this idea.

d) Depositional Features

At all the resurgences calcium carbonate is deposited from solution, forming tufa beds downstream of the resurgence point. This is a well-documented phenomenon for highly mineralised karst waters. However, for the first 100 metres or so of turbulent streamway there is no sign of tufa at all. This is probably due to the need to build up the dissolved oxygen content in the water after resurging before displacement of the CO_2 – bicarbonate equilibrium by aeration can take place.

In the cave streams also, there are large gours formed by calcite deposition. In the pools in Cueva de Cuatro Vientos calcite ice has formed on the surface. Between the resurgence of the stream through boulders, in the cave, and its final disappearance in Cueva de Dientes nearby, the water loses up to 55ppm of calcium carbonate hardness over about 200 metres of slow moving streamway. Although, there is little turbulence, the wide shallow pools and good ventilation of the cave enhance the rapid removal of CO_2.

e) Cooling of Cave Streams

Another interesting property of the stream in Cuatro Vientos is the decrease in temperature as the water passes through the cave. The main stream resurges at 21·2°C and sinks near the entrance at 20·4°C. Since the stream is initially very high in dissolved solids and of a moderate discharge (gauged at 3 litres/sec) for the prevailing conditions then it must certainly have been in contact with, and at the temperature of, the bedrock for some time. Thus, its temperature drop should not be caused by the rock temperature being lower than the water. Similarly, the cave is ventilated by warm moist air from outside, and so this cannot cool the water. One reason may be the evaporation of the cave stream by the air currents, although the relative humidity of the air in the cave is very high. Calculations show that an evaporation rate of 3.6 mls/sec is needed to accomplish the measured cooling. An alternative and more unusual reason is the endothermic process of calcite formation by loss of CO_2 from the water, although preliminary calculations show this to be small in magnitude.

f) The San Antonio Resurgence

This resurgence lies at the base of the steep northern slopes of the Serrania, on a strong fault line. It is a hot spring, the waters resurging at 38°C (at about 40 l/sec) and bubbling hydrogen sulphide. A deep blue-green weed grows in the clear waters of the resurgence pool, but a few metres downstream after some rapids, the weed and rocks become white and the river turns milky for about 200 metres. Extraction of the white substance with carbon disulphide revealed that amorphous sulphur was being deposited by oxidation of the hydrogen sulphide in solution. This is a characteristic quite common to hot springs. However, what seems surprising is that the resurgence has a 'cold-water' limestone chemistry especially in the alkalinity and total hardness values. To maintain these high concentrations, the CO_2-bicarbonate equilibrium must be under some constraint (i.e. pressure) for it to exist at 38°C. Furthermore, on releasing this constraint at the resurgence, only 10ppm of alkaline hardness is lost after 300 metres of travel downstream. These figures seem to suggest that temperature may not be as important in the rate of change of the CO_2-bicarbonate system as previously thought. Much more sampling work must be done before this can be verified.

g) Aggressivity and Oxygen Demand

Most results for aggressivity of waters in the Serrania were either very low or slightly negative. The only exceptions were a small number of streams, which run off the sandstone capping as in Figure 2. Their alkaline hardnesses were also low, and if the two values are added together the result is still not up to the level of most resurgence waters. However, their COD value is quite high in comparison to resurgence waters and so it is likely that further oxidation takes place in the drainage routes, producing CO_2 which then increases the alkalinity by solution of limestone, (as proposed by Bray, 1971).

Fig. 3. Selection of Analyses of Various Karst Waters in the Serrania.

SOURCE	Type	Temp. °C.	HARDNESS Ca	Mg	Total	Alk	Agg.	Cl^- ppm	SO_4^{--} ppm	Na^+ ppm	COD [2] mgO_2/l
			in ppm $CaCO_3$								
El Chorro	S	18·2°	56	8	64	52·5	6	–	–	6·3	2·0
Uria streams	S	20·5°	64	28	92	60	68	20	–	10·0	–
Uria streams	S	18·7°	76	24	100	55	30	–	–	12·0	8·0
Uria ford	S	23·0°	79	30	109	42·5	–6	–	–	15·0	9·0
Camburales	S/R	21·3°	293	–	–	300	–5	17	–	7·1	1·0
C. de Cuatro Vientos (rising)	C	21·2°	240	44	284	205	–	16	13	8·0	–
″ (sink)	C	20·4°	205	40	245	190	–	16	13	8·0	–
C. de Dientes	C	20·0°	185	39	224	165	–	19	13	8·6	–
C. del Burro	C	–	144	28	172	145	–2	–	–	6·1	2·0
C. de los Abejas	C	–	183	24·5	207·5	175	–	24·5	8	–	–
Cucurima[1]	R	–	98	11	109	98	–	10	0	2·0	–
Hueque	R	19·8°	127·5	17·5	145	125	0·5	13	5	4·0	0·8
La Caridad	R	21·3°	152	31	183	154	–	16	11	7·0	1·0
Mitare	R	21·7°	169	36	205	171	–13	17·5	12·5	8·3	0·4
San Luis	R	22·8°	197	50	247	196	–4	24·5	25	12·0	0·0
Meachiche	R	21·9°	122	20	142	127	–	12	6	4·6	–
San Antonio	R	38·0°	164	39	204	223	–	39	10	39·0	–
Well 1	–	33·0°	209	34	243	222·5	–	23	13	14·0	–
Well 2	–	40·3°	85	39	124	160	–	17	14	38·0	–
Well 3	–	43·0°	117	44	161	264	–	34	6	70·0	–

1 From Shell Files (Caracas) 1952.

2 For surface streams and caves, 4hr. COD at 22°C approx. For resurgences 8hr. COD at 22°C approx. (No incubator available).

S = Surface, C = Cave, R = Resurgence.

Discussion

The general lack of aggressivity in most of the karst waters sampled, points to a very rapid rate of limestone solution in the Serrania. Similarly, the results of deposition from solution show that water, when exposed to a lower CO_2 level gas (e.g. the atmosphere), will almost as rapidly **lose** its dissolved carbonate load. The cooling of cave waters, their depositional characteristics and the marked relationship between resurgence temperature and ionic content, all suggest a means of determining the likelihood of finding cave passages within the resurgence catchments. Two basic types of underground drainage are proposed to exist.

The first is a closed conduit type – the classicial percolation water system – whose conduits may well be vadose in places, but where there is no circulation of the outside air. Such systems are typified by the resurgence water of San Luis. Its high water temperature (nearly 23°C) and total ionic content (over 500ppm) suggest that there has been little cooling by exposure to air currents in cave passages and little opportunity for deposition to take place.

The second type of conduit is still largely a percolation water system, since the surface streams in the Serrania are of very low discharge in comparison to the resurgences – less than 3%. However, this time it is an open type of conduit, where many of its branches contain massive air circulation. Thus the cave streams, although perhaps being very high in ionic content when first seen in the cave, rapidly lose CO_2 to the air currents, deposit calcite and cool, (in the manner of Cueva de Cuatro Vientos). Because of their chemistry, the resurgences of Hueque and Cucurima (north of Hueque) probably drain this sort of system. Therefore, the possibility is that there are many other caves comparable to Cueva del Burro which contain streams draining to Hueque. They are likely to be open, and just waiting to be explored!

The resurgences of Mitare and La Caridad have ionic contents and temperatures between those of Hueque and San Luis and may represent an intermediate type where there is some open cave passage in the drainage system. The seepages in the many shafts on the ridges above these resurgences probably unite and drain to them thus giving these properties.

One major problem in the application of this theory is that of homogeneity of the catchment. Towards the north and west of the Serrania, sandstone capping and interbedding becomes more prevalent in the limestone, thus affecting its availability for solution. Similarly the type of vegetation and overburden changes, generally to give a drier regime, making less soil CO_2 available. This problem of changing lithology may affect any interpretation put on the chemistries of Meachiche and Siburua resurgences, as they are both low in hardness. However, their rapid response to rainfall and flushing through of jungle leaves and fruits in flood, points to the likelihood of them draining open cave passages.

FLOOD WATER CHEMISTRY

A study of the general water chemistry of an area gives some idea of the types of processes (both chemical and morphological) that go on under the conditions in that area. However, a better idea of the processes, and particularly their rates of reaction, is given by a study of the variations in watér chemistry for a change in discharge. Work done previously in tropical climates (Fincham and Ashton, 1967) has shown that in limestone regions there is a rapid and often violent chemical response to a sudden change in discharge.

For the Venezuelan work, two flood periods were studied for the Hueque resurgence. This resurgence was chosen as its stream bed gave evidence of frequent and violent flooding. For the study, two special camps were set up; one near the houses of Hueque for analytical work, and the other, a more temporary fixture, amidst dense jungle at the resurgence itself. This latter camp enabled hand sampling to be undertaken on the second flood along with frequent river level (stage) and temperature readings. The first flood was sampled by autosampler alone (installed at the resurgence). The rainfall over the two periods and the stage, were monitored by a recording rain gauge and stage recorder respectively. Water samples were taken at between half hour and two hour intervals depending on the stage, and analysed for calcium, magnesium and alkaline hardnesses, and chloride in both cases. On the second flood, sufficient sample was taken to permit analysis for aggressivity and COD also.

The first flood was caused by high intensity rainfall (over 50mms. in 2 hours) after a dry spell and resulted in a discharge change from 80 to 2,500 l/sec within 12 hours of the rains. The second flood was caused by less intense rain over a longer period giving a maximum discharge of 900 l/sec. The change in the parameters (excepting COD) are presented graphically in figures 5 and 6.

Results

1) The values for the first flood show a rapid change of all hardnesses with increase in discharge. The 'flushing-out' of phreas waters at the beginning of the flood (as observed – chemically – by Ashton in Jamaica) was not encountered to any degree, and only a gradual decrease in concentration of hardnesses was apparent. This decrease reached a minimum about 6 hours after peak discharge and then returned slowly to pre-flood concentrations.

2) For the second flood, very little change in chemistry occurred, although the monthly plot (figure 7) shows that a definite change did in fact take place. This is because a small flood prior to this one probably caused the first decrease in concentrations, and after the floods, frequent rainfall periods maintained the 'diluting' effect.

3) For both floods, chloride concentration was found to increase slightly, and remained quite high for some period after the flood.

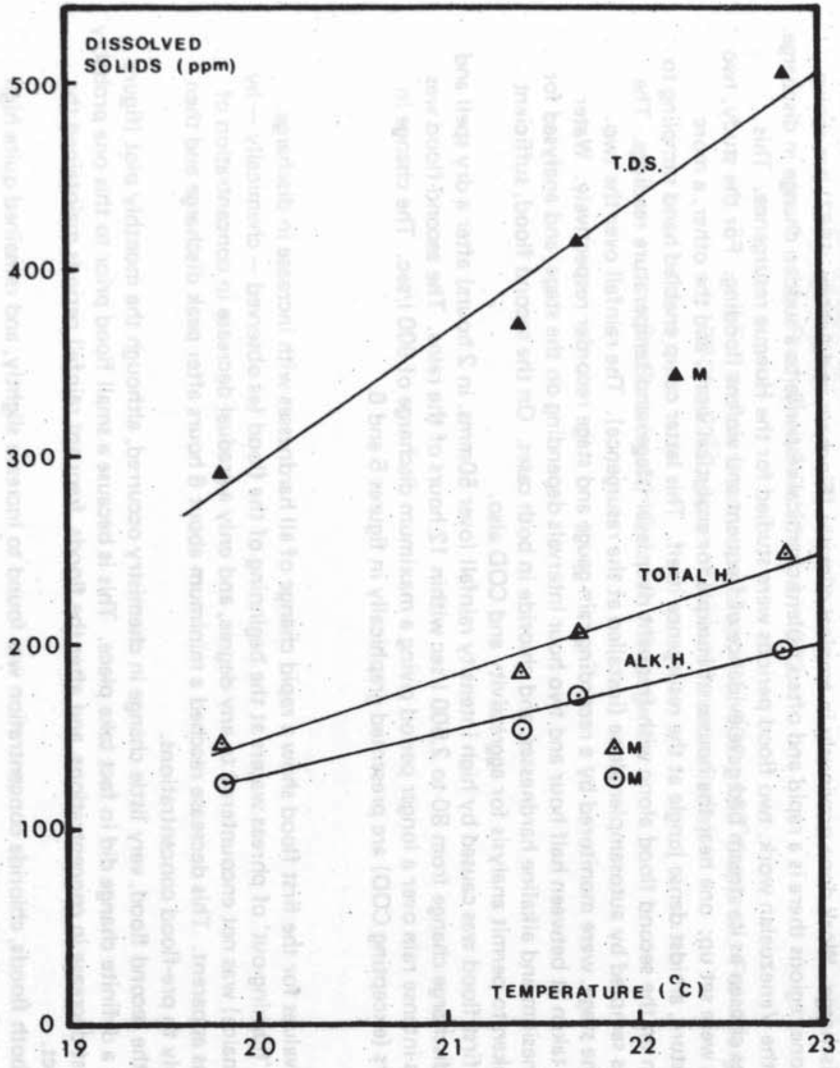

Fig. 4. The Relationship between Hardnesses, Dissolved Solids and Temperature, for resurgences.

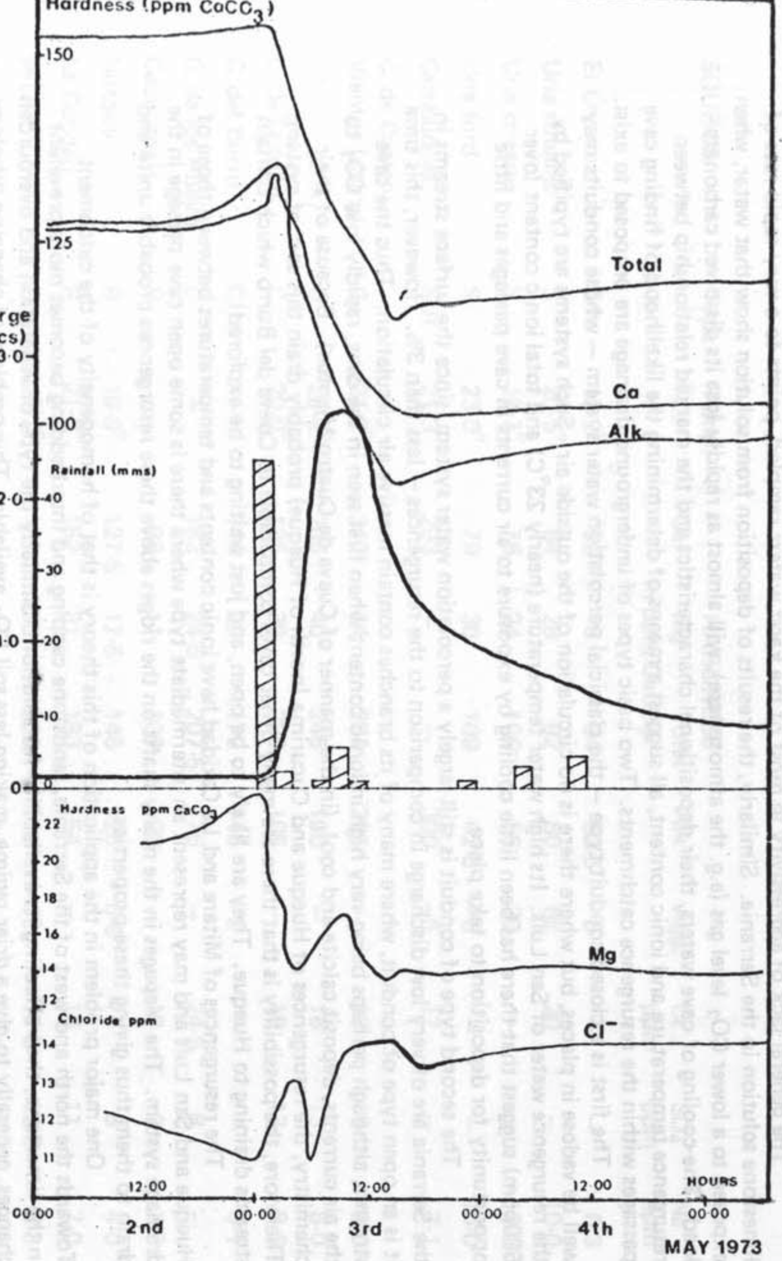

Fig. 5. Chemistry and Discharge changes for the first flood (May '73) of the Hueque resurgence.

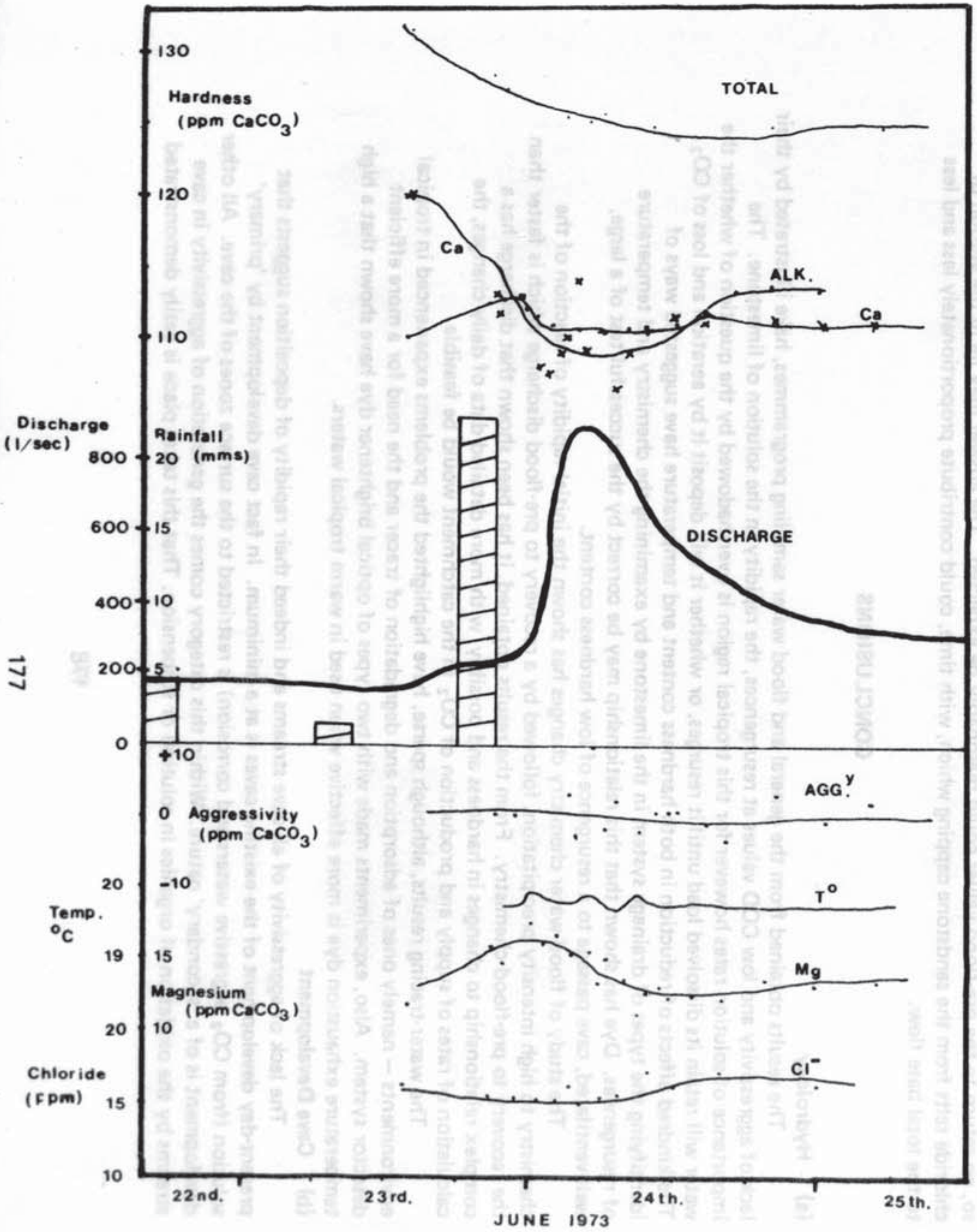

Fig. 6. Chemistry and Discharge changes for the second flood (June '73) of the Hueque resurgence. (COD changes not shown).

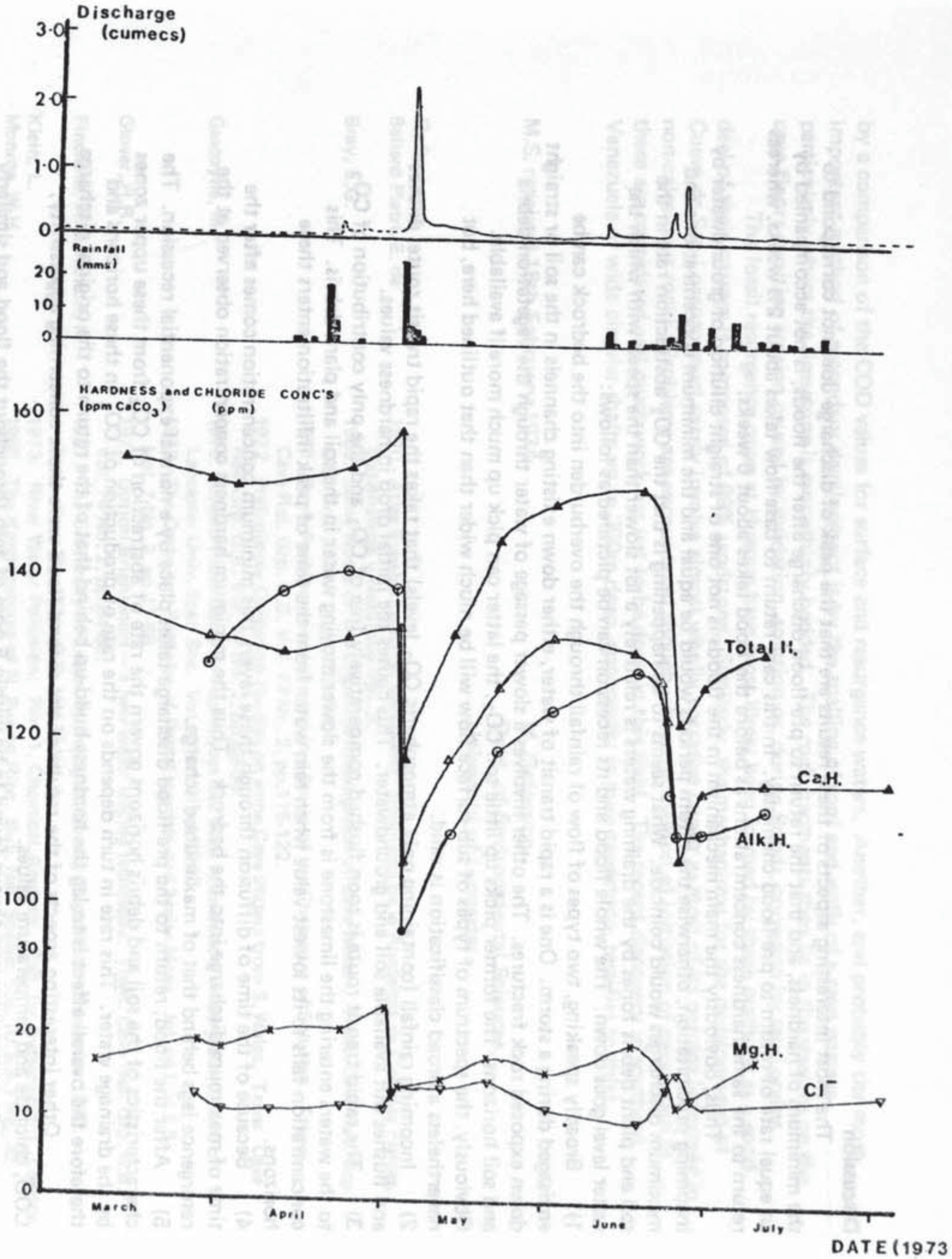

Fig. 7. Chemistry and Discharge changes for the period March to August '73 for the Hueque resurgence.

Discussion

The most interesting aspects of these results are that the peak of discharge does not correspond to the minimum of hardness, and that the return to pre-flood discharge after the floods, is not accompanied by an equal rate of return to pre-flood chemistry. In this case return to base flow takes about 2½ weeks, whereas return to the same hardness concentrations as before the flood takes about 6 weeks.

Thus, obviously the main mechanism in the floods is not one of straight dilution of groundwater by incoming precipitation, otherwise the return periods would be equal and the minimum concentrations and maximum discharges would coincide. What seems to be happening is that the CO_2 abstraction rate in the soil and plant debris zones by the draining waters is relatively a lot slower than the speed with which the water level goes down. The whole flood and its recession can be pictured as follows:

1) Broadly speaking, two types of flow of rainfall through the overburden into the bedrock can be envisaged during a storm. One is a rapid transit of water, either down existing channels in the soil or straight down exposed rock fractures. The other involves a slower passage of water through the vegetation debris and soil horizons. The former picks up little soil CO_2, the latter can pick up much more if available. Obviously, the spectrum of types of sub-surface flow will be much wider than that outlined here, but nevertheless a broad classification is valid.

2) Incoming rainfall (containing only atmospheric CO_2 levels) that takes the rapid transit route, dilutes and flushes out available soil and groundwater. This causes the initial drop in hardness values.

3) The rapid transit route is soon flushed comparatively free of CO_2 and the only contribution of CO_2 to the waters entering the limestone is from the slower moving water in the soil and plant debris. This concentration falls to its lowest value when rain water from the time of peak infiltration enters these horizons.

4) Because of the time of diffusion through these layers this minimum concentration comes **after** the time of maximum discharge into the bedrock. Thus the minimum hardness concentration observed at the resurgence lags behind that of maximum discharge.

5) After the flood, return to the pre-flood discharge takes place by a normal exponential recession. The characteristics of the soil and debris horizons govern the rate of abstraction of CO_2 from these upper zones by the drainage water. This rate in turn depends on the rate of production of CO_2 in these horizons and therefore the overall effect is to lag the hardness build-up behind that of the return to the original discharge.

Other interesting aspects of the results of the second flood were those concerning aggressivity, COD, chloride and temperature values.

The aggressivity was always found to be within 5 ppm of zero throughout the flood and similarly little change was observed in the COD, even when the turbidity of the water increased. Temperature also was a remarkably constant feature of the flood and only fluctuated over a range of 0·3°C. Chloride, however, for both floods increased by up to 3 ppm and returned to its pre-flood level in a similar manner to that of the hardness values. A high chloride content rainfall was at first thought to be responsible, but if so, no return to the pre-flood values could reasonably be expected. The answer may lie in the elution of chloride salts from the sandstone capping which, with time, could contribute proportionately less and less to the total base flow.

CONCLUSIONS

(a) Hydrology

The results obtained from the general and flood water sampling programmes, have illustrated by their lack of aggressivity and low COD values at resurgences, the rapidity in the solution of limestone. The importance of solution rates however for this tropical region is overshadowed by the question of whether the water will retain its dissolved load until it resurges, or whether it will deposit it by aeration and loss of CO_2. The kindred effects of reduction in both hardness content and temperature have suggested ways of identifying the types of drainage system in the limestone by examining the chemistry and temperature of resurgences. Dye has shown that this relationship may be correct by the successful test of a large, well-ventilated, cave passage to a resurgence of low hardness content.

The study of flood-water chemistry changes has shown the initial rapidity of reaction of the chemistry to high intensity precipitation, followed by a recovery to pre-flood discharge which is faster than the recovery to pre-flood chemistry. From the results obtained, it has been shown that discharge has a complex relationship to changes in hardness and possibly, with more detailed data of daily changes, the calculation of rates of supply and production of CO_2 in the catchment would be feasible.

The water-tracing results, although sparse, have highlighted the problems experienced in tropical environments – namely ones of adsorption and degradation of tracer and the need for a more efficient detector system. Also, experiments made with two types of optical brightener dye have shown that a high temperature exhaustion dye is more effective when used in warm tropical waters.

(b) Cave Development

The lack of aggressivity of all cave streams and indeed their rapidity of deposition suggests that present-day development of the existing caves is at a minimum. In fact cave development by 'primary' solution (from CO_2 aggressive waters and corrosion) is restricted to the surface zones of the cave. All other development is of a 'secondary' nature. Within this category comes the generation of aggressivity in cave streams by the oxidation of organics in solution or suspension. That this takes place is easily demonstrated by a comparison of the COD values for surface and resurgence waters. Another, and probably the most important method of secondary development is by the spalling of roof and walls of a cave passage, particularly where the limestone is more thinly bedded. The rock fragments then lie in the streams on the cave floors awaiting erosion caused by oxidation, solution or, during floods, corrasion by sand grains.

The fossil resurgence caves at Hueque have most likely been formed by these methods as a good deal of their passage is composed of 99% sandstone. Similarly, the mechanisms for the development of Cueva de San Lorenzo must surely involve almost wholly corrasive power as most of its passage is formed in non-calcareous rocks. Problems are encountered though when the method of initiation of caves such as these are considered and much work has yet to be done in this field. The recent discovery in southern Venezuela of wide circular shafts up to 300m deep, apparently in pure sandstone, testifies to this!

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