STREAM CAVES IN THE COASTAL LIMESTONES OF MOIST SOUTH-WEST WESTERN AUSTRALIA

KERRY WILLIAMSON*
Western Australian Speleological Group

Abstract

Current ideas on the formation of stream caves in the higher rainfall areas of south-west Western Australia (S.W.W.A.), Yanchep southwards, are reviewed. The effects of stream flow regime and rate of flow, topography, the underlying basement rocks, pre-limestone marine transgressions and collapse on the three parts of the stream cave hydrologic system (the insurgence area, the between cave, the exsurgence area) and on the resulting karst landscape are discussed.

In the interest of digestibility, I will consider the stream cave systems of the coastal limestone , from Yanchep southwards, of south-west Western Australia (S.W.W.A.) in three sections:

1. the insurgence
2. the "between" cave
3. the exsurgence

This initial discussion is restricted to caves from Yanchep to Augusta in the 760 to 1270 mm rainfall area of S.W.W.A. Further north from Perth the increased aridity and different underlying geology produce, due to the interaction of a large number of resultant factors, a vastly different picture of spelean hydrology.

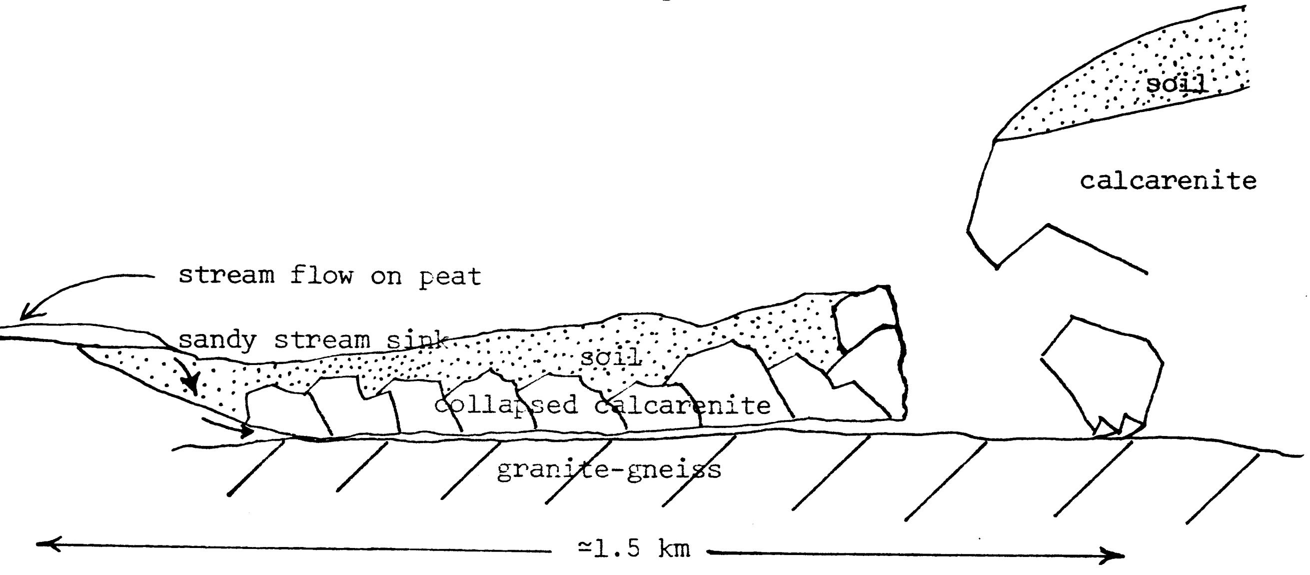
INSURGENCES

In the 760 to 1270 mm rainfall area of S.W.W.A., present cave streams are all small (0.014 cumecs) streams with small catchment areas. Larger streams were able to maintain a path through the encroaching dunes which later became limestone (Jennings, 1968). The only exception to this would be Ellensbrook which only traverses the limestone for the short length of Meekadorabee Cave (MR-9), the only through cave in the coastal limestone (from insurgence to resurgence). In most of Witchcliffe the streams entering the limestone drain swamps to the east. There is a gradation from inflows where streams flow freely into the limestone, to those where part of the stream course is blocked by sediments (sand, collapse boulders), to those where the entire stream drainage is sand covered.

(1) Mammoth Cave (WI-38) best represents the first type of inflow: here the stream, which drains the Nindup Plain, flows freely into a large open cave. When the swamp feeding the stream is full and 50 mm or more of rain falls in a short period, for example two hours, a flood pulse will move through the cave causing rises in water level up to a metre and damage and inconvenience to the tourist operation (Yates, 1973). Only in low flow conditions does the stream flow under the sediments of its bed (sand, breccia, organic matter). The stream is very seasonal and dries up completely in Mammoth Cave in summer. Further downstream in Terry Cave (WI-47) and Conference Cave (WI-44) the stream will continue to flow even in summer (indicating sub-bed flow at the inflow), though in late summer '77/'78 the flow was only a trickle in Terry Cave.

*90 Highland Terrace, ST LUCIA, Qld. 4067

Fig. 1. Schematic section, Boranup Motel inflow to Block Cave.



(2) Breakneck Gully (WI-54), the inflow to the Arumvale system, represents the next stage in the gradation. Here the stream does not flow freely into the cave but sinks into rockpile in the base of a steeply sloping blind collapse valley. Stream flow regime in Breakneck Gully is similar to that of Mammoth. There is circumstantial evidence for flood pulses (evidence of recent scouring near the inflow point and evidence of 2.3 m high floods between recent caving trips (Hart & Williamson, 1975)) in Arumvale Cave (WI-57), downstream from the inflow. In low flow this stream also flows below its bed as evidenced by flow in Arumvale Cave and Arumvale Pipe (WI-56). Flood flow is perched on humic material above sand. There is a 3 m waterfall in this material just upstream of the inflow point.

(3) The next stage in the gradation is represented by WI-88, the inflow behind the old Boranup Motel. Here a stream which drains the swamp to the east of the old Boranup townsite flows south of the townsite to sink in a circular sandy depression (WI-88) at about the contact with the limestone. From this point to Block Cave (WI-106) there is a blind collapse valley of subdued relief (so subdued it was not noticed before the clearfell). Little outcrop or rockpile is is visible as most of the eastern slope of the roughly north-south fossil dune ridge is covered in thick yellow sand as is the blind collapse valley. Schematically the situation may be represented as in Fig. 1.

(4) The next stage in the gradation is represented by the blind valley leading to Mill Cave (WI-59). The valley is off the limestone and shows no appreciable upward slope towards the limestone except for the last 30 m where collapse limestone blocks may be found. The stream draining the west end of the swamp near the Boranup townsite flows across Caves Road and becomes lost in deep yellow sand. A subtle general depression leads in two directions: one to the inflow near the old mill site (near which water has been seen to collect in winter), the other further north to a sand filled valley (WI-76) leading to Mill Cave. No surface water has been observed in this latter valley. This all occurs within a broad westward indentation into the limestone filled with quartz sand.

The sand fill or the inflow valley in this system acts as a damper on flood pulses; rather the stream in Strong's Cave (WI-63) rises and falls in response to the general seasonal increase in runoff associated with the winter rains. The response is delayed by the sand fill and the highest flow rates are seen in early summer in distinct contrast to the Mammoth Cave system where flood pulses can occur within hours of heavy rain.

This gradation could be taken to represent a chronological sequence with the free inflow representing the youthful stage and with collapse and downslope movement of sand plus dissolution of the collapse material alternately producing the Mill Cave inflow situation. However factors other than time must be involved as all these systems are, to the best of my knowledge, of approximately similar age. The two main factors thought to be involved in determining inflow type are:-

1. flow regime of the inflow stream and
2. relief of limestone behind the inflow.

Mammoth Cave stream, although seasonal, shows a relatively large prolonged surface flow over the wet season. Breakneck Gully stream is slightly less reliable. The stream flowing into the Boranup Motel inflow is rarely seen to flow.

In southern Witchcliffe, for example Mill Cave to Breakneck Gully, there is limestone of high relief just inland of the inflow points in the form of a fossil dune ridge running from Nannup Cave (WI-60) to Breakneck Gully. Large amounts of B horizon yellow quartz sand have moved downslope off this ridge, blocking with sand the inflow of all but the large Breakneck Gully stream. In northern Witchcliffe (Mammoth Cave to Swamp Inflow (WI-87)) the relief is much reduced and even small, intermittent streams such as the Rudduck Cave (WI-51,52) stream are not blocked by sand and instead sink into a smaller version of Mammoth Cave.

The only area of the northern Leewin-Naturaliste where inflows have been investigated is the Quinninup area in Cowaramup. Here no surface streams are apparent, the water flows through soil cover off a limited catchment on a gneissic hill to the east of the limestone. The only evidence of inflows (Williamson, 1977) are two indentations into the limestone caused by collapse and dissolution with an area of dark seasonally boggy soil nearby. These two inflow points may correspond to the two streams on gneiss in Quinninup Lake Cave (CO-1) to the west of these points. Recent observations at Yallingup and Margaret River suggest leak in the creek situations may play an important role in these areas.

In the Blue Rock Cave (WI-58) area in central Witchcliffe, a series of fissure caves parallel the contact which itself is a steep scrubby cliff. Here, it is thought that, rather than a discrete stream entering the limestone, the groundwater associated with the seasonally rising and falling swamp is, under cover of sand, undercutting the limestone and causing the collapse of massive blocks resulting in the fissures. The fissures are at right angles to the direction of flow which is thought to be westward where this sheet flow collects itself up into a stream as evidenced by the more typical collapse dolines (F. & B. Loveday, pers. comm.).

THE "BETWEEN" CAVE

STRUCTURAL CONTROL BY UNDERLYING BASEMENT ROCKS

Recent underground and surface mapping of the southern Witchcliffe area by the Loveday's has shown the trends of a good sample of stream caves. Bastian (1964) and Jennings (1968) suggested that the streams which predate the limestone are following the old valley system they eroded before the dune cover changed their style. Recent work (Williamson, Loveday & Loveday, 1976) in Strong's Cave has brought into the picture the role of marine erosion forms associated with Pleistocene transgressions determining variations in stream flow within this valley.

The pre-dune topography consists of valleys and ridges of low relief in the granite-gneiss. These were subjected to marine transgression. The high wave energy of this coast cut gutters in the granite-gneiss along the three main joint directions (roughly north-south, northwest-southeast and southwest-northeast). The southwest-northeast set display (and still do on the present coastline) the largest gutters as this is the predominant direction of wave action.

In the regressive phase the sea would cover these gutters in beach sand, then storm ridges, then foredunes. Under the sand cover the granite-gneiss was subjected to deep chemical weathering in inter-glacials. Strong's Cave represents the upper limit of the last transgression.

The deep weathering of the granite-gneiss is a post-dune phenomenon (post-recessional). There is no reason such weathering cannot occur beneath dunes and later limestones. It will resemble the lower levels of the typical laterite profile but the upper levels of the laterite profile will be absent as, under that depth of limestone and near a streamway the interstitial spaces are permanently filled with water and hence not subject to the seasonal wetting and drying necessary for the formation of a laterite profile's upper regions (micro-crystalline fericrete and aluminium oxides). Any deep weathering predating the beach deposit would have been removed by the marine transgression (wave action).

STREAM DIVERSION

Thus the cave stream flows in a broad shallow valley with a system of marine gutters inside it. While its general trend and destination is controlled by the valley shape (itself joint-controlled) its smaller scale movements are along the numerous marine gutters at its disposal. If collapse, blocks a gutter an easier route may be found using another gutter. Thus abandoned segments may be left. This has occurred on a small scale in two places in Strong's Cave and, on a much larger scale, in the case of the Mammoth, Labor (WI-112), Winjan's (WI-113), Kudjal Dar (WI-114), Boya Bouka (WI-115), etc system.

These streams may be pushed around in broad valley systems with a network of marine gutters by repeated collapses. This can produce as an end result quite large collapse depressions, for example the depsession (about 0.5 km across) between Golgotha Cave (WI-13) and the main Kudjal Yolgah (WI-9), Bungle Pot (WI-117), Budjar Mar (WI-144) system.

At Yanchep there is no impervious basement, relief is still more reduced, streams smaller, more sluggish and hence, more easily deflected by collapse with the water table lying closer to the surface. Because of this, large multiple collapse depressions are common and collapse right down to the water table. Generic series, from doline chains and clusters to swampy depressions to large lakes may be recognised (Williamson & Lance, 1979). These large swampy areas and lakes serve as significant areas for recharging the aggressiveness of stream waters in the karst.

PHREATIC FORMS ASSOCIATED WITH STREAMS

When sections of low roof mainly non-collapsed corrosion passage occur in streams with fairly open inflows subject to appreciable flood pulses, spongework pendants are formed, for example Conference Cave, Arumvale Cave and Connelly Cave (WI-48). In some cases these may have formed before downcutting lowered the stream to its present level. This is an active phreatic situation. The most spectacular active phreatic situation associated with a cave stream is Witchcliffe Cave (MR-1). This will be described in detail in the next section on exsurgences.

In other cases, backing up of streams may produce situations and forms which resemble more closely those formed in the nothephreatic condition of the Augusta caves.

Streams can back up in two ways:

(1) By rockfall and constrictions downstream. The main collapse in Calgardup Cave (WI-49) has occurred at the junction of two streams. The southern stream, at present backs up resulting in back waters off to the south of the active stream. There are collapsed side passages above this backwater. A short way into the northern section is a small side passage, initially a collapse chamber which drops down in two places to sections of typical, shallow nothephreatic maze. This is thought to have been due to backing up of the northern stream. Note: Jennings (1968) quotes a laboratory determined pH value for stream water from Calgardup Cave as being pH 5.8. The *in situ* value is probably even lower, as CO_2 may have been lost. This very low pH of stream waters close to the western edge of the contact may be why backwaters can corrode phreatic mazes. The collapse passages off the southern section are thought to have formed by collapse of such a nothephreatic maze.

At Quinninup Lake Cave, the southern stream is restricted to a very small defined course in the basement rocks, there is plenty of evidence of recent flooding in this section presumably when the flow rate became too large for the restricted channel.

(2) By an outside river at the outflow point. At Blackwall Reach, cave streams are backed up by tidal and other actions in the Swan River. The results of this and the Quinninup example will be discussed more fully in the next section on exsurgences.

EXSURGENCE CAVES

Bastian (1964) and Jennings (1968) remarked on the absence of known exsurgence caves in the Coastal Limestone of S.W.W.A. This they attributed to the lack of aggressiveness of stream waters by the time they reached the outflow points. Percolation water would be saturated and play no part in corrosion. Conto Spring (WI-90) and Leeuwin Spring (AU-27) typify this situation. At both these springs water exurges through fist sized tubes in the limestone.

Since that time several outflow caves have been found and documented as well as many more springs. However two of the large stream systems of the Witchcliffe area have yet to be traced to a resurgence.

Bobs Hollow Resurgence Cave (WI-82). This cave was found in 1972 by digging at the base of a cliff where a small stream exsurged (Caffyn, 1972). This gave access to a low, though fairly wide stream passage almost blocked with roof drip derived secondary calcite. Recently the final squeeze has been pushed

(Webb, 1978) and found to open into large chambers upstream. The existance of large chambers so close to the resurgence can be explained by the closeness to the north of the limestone contact and the size of the Bobs Hollow catchment.

Bobs Hollow stream takes water from Connelly Cave and a stream 1.5 km north of Connelly Cave. This insurgence must connect with the Bobs Hollow stream at some point between the upstream limit of Bobs Hollow Cave and the downstream limit of Connelly Cave, approximately doubling the flow rate as well as recharging the stream with aggressive water. This imput would also contribute to the mixing effects of different CO_2 / CO_3 = balances and different temperatures as it would be colder in winter and coming quickly off a largely granulitic hill with little time spent in swamps, it would be chemically different from water entering other imputs of the system.

The Connellys Cave stream is fed with waters from the WI-102 inflow, Swamp Inflow, Rudduck Cave, Arnor Cave (WI-93), WI-94 and the inflow to Calgardup Cave, WI-50. Most of these inflows are relatively free of sediment (exceptions WI-94, WI-102 and Arnor) and a high rate of aggressive flow may be achieved in late summer. Caffyn observed yellow stained (by inference highly aggressive) water resurging from Bobs Hollow Cave during the heavy wet season of 1973.

Quinninup Lake Cave (CO-1). This has large collapse chambers, a large steephead valley with two exurgences in the valley feeding a lake backed up behind the fore dunes of the present beach. The steephead has formed by collapse so at one stage the two streams met underground. The largest chamber in area in the cave occurs between the two streams. The southern stream, the smaller, is flowing 5 m above the larger northern stream. Both streams flow on granite occurs as evidenced by passage morphology) have produced this large chamber. The inflow points for these streams are only 1.5 km to the east; the Coastal limestone belt at this point being only one quarter as broad as in the Witchcliffe area.

Similarly the spring YA-25 at Canal Rocks which has stream sediments in its bed and much collapse just upstream is on the western end of a 1.5 km belt of Coastal Limestone.

Witchcliffe Cave (MR-1). Witchcliffe Cave is a large abandoned outflow cave with evidence of a considerable flow of water under phreatic conditions. This must have been the largest underground stream in the Leeuwin-Naturaliste. The present stream which is 2 m below the floor of the present cave is not of sufficient size to cause such a large corrosion cavity.

The cave exhibits current directed roof grooves, and spongwork, bedrock pillars and pendants at the sides of the flow channel; plus undermined and corroded flowstones. It is developed mainly in a nearly horizontally bedded calcareous sandstone so a considerable quantity of silica sand residue must have been removed by the current. This large upper level may have been a flood bypass for the lower system.

The entrance area is practically choked with columns showing that the stream has been inactive at this level for a considerable time.

This exsurgence is perched high above Boodjidup Brook. That this reflects the relief of the underlying basement is evidenced by the presence of angular feldspar pebbles in the Coastal Limestone at the exsurgence. This corresponds with marine beds in Strongs Cave 51 m above present sea level.

The inflow points for the stream are not known, mainly due to lack of looking, but most likely are east of Blackboy Hollow Cave (MR-2), a very large collapse cavern with a dry stream bed lower level (M. Dall, pers. comm.). There are several appropiate indentations in the limestone contact worth investigating in this region.

BLACKWALL REACH CAVES

On the south bank of the Swan River, at Blackwall Reach, are several lines of cliffs with three known exsurgence caves (LW-8, LW-9 & LW-10). Entrances are either on or slightly above river level with some higher collapse crevice entrances. The Swan at this point is 18 m deep in the main channel which runs near the cliffs.

Each cave has one or two small streams associated with it. LW-8 is typical. The caves are developed in closely (Laminar) bedded calcarenites/calcareous sandstones which dips consistently 11 degrees to the west (Williamson, 1973), and is most likely of marine or beach origin; with some collapse up into overlying aeolian calcarenites.

The caves show processes of wave erosion and undercutting in the entrance areas at river level. Updip from the low presently active stream flattener is a traversible passage with a floor of silicious sandy stream sediment and collapse blocks all covered in mud. The roof and walls to a height of 1.5 m (2 m above present river level) show many examples of nothephreatic spongework. Tidal range in the Perth region is only 0.3 m at most. During periods of strong onshore winds the river level may rise 0.5 m or so. At such times (Williamson, 1978) the entrance area of the cave is filled with river (estuary) water and subject to fairly strong wave action and the cave stream is backed up.

This backing up would result in a mixing of saturated (with respect to carbonate) cave stream waters and similarly saturated marine waters (which in a good wet season may be brackish and not saturated) producing ponded waters capable of nothephreatic corrosion.

Cave development is thus limited to 100 to 150 m back from the entrances, below which, as a result of stream gradient, mixing can occur and this seems to be associated with the smaller streams. The large stream below LW-9 must be able to force back the river water and prevent mixing, thus restricting the extent of cave development, that is the smallest cave has the largest stream.

The presence of stream sediment and spongework 1 m above the present river level suggest the wind assisted backup of the Swan is not the only factor involved. Higher estuary levels were associated with the last sea level maxima or backing up of the river due to barring of the mouth before the removal of the bars by europeans.

CONCLUSIONS

Caves in the moist south-west of Western Australia are not particularly young for caves though their limestones are young for limestones. However they are remarkable in that very large collapse caves have resulted from small streams (0.014 cumecs is large). This is the result of:

(1) the incoherence of the rock and its inability to support even a short span, for example the largest chamber is found in the very friable limestone around Green Cave (WI-2).

(2) the extremely aggressive nature of the streams flowing from swamps to the east of the limestone belt. This is principally the result of humic acids; pH's of 5.8 have been recorded from caves near the swamp. Similar peaty waters in Ireland have produced fast rates (in this case post glacial) of cave formation (Ollier & Tratum, 1956). In the Irish situation high flow rates and flood pulses are common whereas at Witchcliffe chemically similar waters have produced large caverns from streams with lower flow rates over a period of 100 000 years or more.

Further north in the Leewin-Naturaliste, greater basement relief, increased downcutting during the pleistocene and a slightly reduced rainfall, make peaty swamps leaching the limestone less common. Open inflows are virtually unknown and caves generally less common and of a smaller size.

ACKNOWLEDGMENTS

I wish to acknowledge the many Western Australian cavers whose exploration, mapping and documentation has greatly assisted my own investigations. I wish to acknowledge the contribution of the surface and underground mapping of Barry and Fran Loveday especially in the southern Witchcliffe area as it greatly enhanced our knowledge of stream cave form and orientation.

REFERENCES

Bastian, L. (1964). Morphology and development of caves in the southwest of Western Australia. *Helictite* 2(4):105-119.

Caffyn, P. (1972). Bobs Hollow Resurgence - Witchcliffe region - S.W. Western Australia. *The Western Caver* 12(2):33-35.

Hart, R. & Williamson, K. (1975). Trip Report - WI, CO, YA. *The Western Caver* 14(4):144-146.

Jennings, J.N. (1968). Syngenetic Karst in Australia. *Contributions to the Study of Karst*. A.N.U. Press, Canberra.

Ollier, C.D. & Tratum, E.K. (1956). The Geomophology of the Caves of N.W. Clare, Ireland. *Proc. Univ. Bristol Speleo. Soc.* 3:138-157.

Yates, M.J. (1973). Pulse flooding of Mammoth Cave. *The Western Caver* 13(5): 191-192.

Webb, R. (1978). Trip Report - Witchcliffe, March,1978. *The Western Caver* 18(2): 37.

Williamson, K. (1973). Notes on the geology of a cave at Blackwall Reach. *The Western Caver* 13(2):53.

Williamson, K. (1977). Trip Report - Cowararmup, November, 1976. *The Western Caver* 16(4):84-85.

Williamson, K. (1978). Trip Report - Lower West Coast (Blackwall Reach), September, 1978. *The Western Caver* 18(3):68.

Williamson, K. & Lance, K. (1979). The formation of limestone and caves at Yanchep, W.A. *The Western Caver* 18(4):77-82.

Williamson, K., Loveday, B. & Loveday, F. (1976). Strongs Cave and related features. *The Western Caver* 16(3)