HELICTITE, v2(4): 105-119, July 1964.

MORPHOLOGY AND DEVELOPMENT OF CAVES IN THE SOUTHWEST OF WESTERN AUSTRALIA

By L. Bastian, B.Sc.(Hons)
Bureau of Mineral Resources, Canberra, A.C.T.

Abstract

Caves in the coastal aeolian limestone of Western Australia show two major types of morphology due to different groundwater conditions. The first type comprises linear caves with streams, and develops on a watertable which has pronounced relief because of an undulating impervious substratum. Cave systems of this type are thought to start developing as soon as coherence begins to appear in unconsolidated dunes, and develop rapidly by collapse while the dunes are still weakly cemented, to assume more stable mature forms when the rock is strongly cemented.

Systems of the second type are more irregular in plan and typically develop caves with the form of inclined fissures. These systems are developed on a watertable which has little relief, but which may slope appreciably in one direction. They are thought to start much later than the first type in the history of dune consolidation.

Because of the porous rock, development of each type occurs in levels of permanently water-filled pores in a true watertable. When systems are well established, solutional attack is concentrated at the watertable where drainage is easiest, while at greater depths the groundwater tends to stagnate. A third type of cave is developed in shallow phreatic conditions near Augusta.

Local groundwater conditions cause important modifications to these types. The best cave development in any area is found in the more easterly older dunes, and decreasing rainfall from south to north corresponds with a decrease in cave sizes and numbers. Strong development occurs in many localities where drainage from inland country adjacent to the limestone belt passes underground in its passage to the sea.

Introduction

Caves of the southwest of Western Australia have received virtually no attention from scientists as regards their morphology and development. Dr. E.S. Simpson, in the Year Book of Western Australia for 1902, discussed the origin of caves in "coastal limestone", but his comments were not based on intimate knowledge and were very brief. Generally speaking, it seems that their origin has been taken for granted and geologists have assigned to them theories that apply to other regions. Admittedly the basic essential of cave formation still holds, namely, the corrosion of calcium carbonate by percolating water, but the author's observations over the past nine years have shown the mode of operation to be vastly different from that seen elsewhere. The reason for this lies in the unusual origin and character of the coastal limestone. The bearing of these factors upon cave development will be the main topic dealt with here.

Location

"Coastal limestone" is the popular name for a limestone composed of cemented calcareous dune sands found in coastal belts along much of the western and southern coastline of Australia. Such a name is applied to a great diversity of coastal formations around the world, and it is better to refer to it by the term "aeolianite", or better still, "aeolian calcarenite." In Western Australia, the rock is known from Shark Bay in an almost continuous belt southwards, and then eastwards almost to the South Australian border, a distance of about 1,400 miles. Figure 1 shows the portion of it which comes under the author's experience - about 200 miles north and south of Perth. Although in this area it is broken only by river mouths and inlets, and in the vicinity of Busselton by a strip of emerged strandlines, caves are not developed continuously, and there are long distances of limestone with no recorded caves. Reasons for this variation will be presented in the course of this paper. In fact, there is great variation in the numbers and size of caves and amount of karst development from area to area.

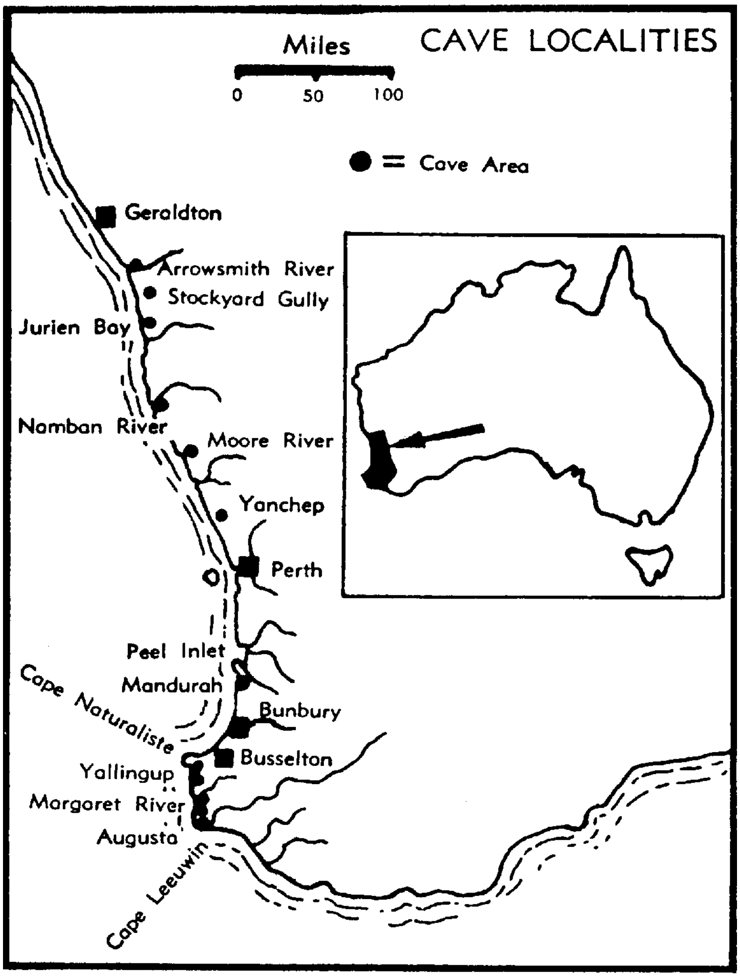


FIGURE 1

The main cave areas (Figure 1) are, from north to south: Arrowsmith River, Jurien Bay, Namban River, Moore River, Yanchep, Mandurah, Yallingup, Margaret River and Augusta. The last three form an almost continuous belt between Cape Naturaliste and Cape Leeuwin. On the other hand, there are almost 150 miles between Perth and Yallingup with very few known caves.

Origin of Limestone

The origin of the limestone is well-known, but is still subject to controversy in some aspects. The limestone is made up of a cemented, fine, calcareous sand composed mainly of shell fragments and foraminiferal tests, plus minor clastic detritus. The sand is fine and easily blown, and the resulting dunes are extensive and quite high. In places where successive incursions built the dunes one above the other, they have reached as much as 700 ft. above present sea-level.

The widespread occurrence of aeolianite in the Pleistocene Epoch doubtlessly links its origin with the eustatic sea level changes associated with glaciation. Fairbridge (1954) gives a comprehensive review of ideas on the coastal formations, mostly aeollanites, around the Australian coastline and has suggested (Fairbridge and Teichert, 1952) that the dune lines now preserved were probably laid down during interglacial arid periods, which were times of high sea level. This contrasts with the older popular idea that it was necessary for the glacials to cause sea levels to drop so that extensive areas of sand could be laid bare, thereby allowing it to be blown into dunes. The same conclusion had been reached by Hossfeld (1950) and Sprigg (1952) for aeolianites of South

Australia, and Bretz (1960) came to an identical conclusion for the periods of emplacement of Bermudan aeolianites.

A few Western Australian dune lines are now partly or completely submerged, which suggests that they were emplaced not only at sea level maxima, but also at lesser stillstands during lower sea levels. Hossfeld (1950) noted this also for South Australian dune lines. Contrasting with all these ideas is a paper by Butzer and Cuerda (1962) on Mallorcan aeolianites in which the older idea is assumed, apparently without question. Hossfeld also suggested that numerous inland dune belts in South Australia were younger than belts nearer the coast, the sea having for a time encroached over the older belts and turned them into islands. While this condition is actually seen today in the Rottnest and Garden Island dune lines west of Perth, the main cave areas are developed in a strip in which up to four dune lines can be distinguished in close Juxtaposition, even overlapping considerably in many places. Thus, for these dunes at least, there must be a regular progression in age from oldest in the east to youngest in the west.

One feature which can be an important factor in later cave development is the ease with which these dune belts, migrating northwards by the action of the prevailing winds, threw barriers across smaller river systems which lacked water flow in summer. This is discussed more fully in the paper at a later stage.

Consolidation is caused by water seeping downwards to the watertable. During its movement the water dissolves out small amounts of calcium carbonate, and then reprecipitates it as a cement around sand grains at lower levels. Presumably, if this process carried on for a long time, a tough and impermeable limestone might be formed eventually, but it seems that the age of the material is so low that the cementation has done little more than to impart coherence to the material, often barely enabling it to be called "rock" instead of "sand."

The limestone still retains a high porosity, a feature which is important in that a true watertable is developed, unlike most limestones. The high porosity is general throughout, even in well-consolidated rock, with the possible exception of the strongly cemented "caprock" zone. This caprock is developed in a zone of maximum precipitation; its control and development is not discussed here.

Cave Origin In Aeolianite

Very little has been written about cave development in aeolianites, although the caves are commonly mentioned in passing by writers. Bretz (1960) has made a valuable contribution on the origin of caves in Bermuda, presenting an interpretation differing markedly from views advanced by Swinnerton (1929). Western Australian aeolianite has some differences from Bermudan aeolianite, and these are reflected in its cave morphology.

1. Rapid growth of caves.

The Yallingup-Augusta belt has the biggest cave sizes. Giant's Cave, Crystal Cave, Jewel Cave, and other caves in this region, attain ceiling heights of about 100 ft. and ceilings around 40 to 60 ft. are common. Collapsed caverns in this area indicate that much greater dimensions have been attained. Cave formation in most other regions is generally initiated along joint planes or bedding planes, and occasionally on faults, as these are the only fissures penetrable to water in hard impermeable limestone. Dissolution is particularly active at the intersection of two joints, but the process is slow nevertheless. Given sufficient time, a large cave may develop eventually. If we allow that caves are not initiated in a marine limestone until it has reached a suitable elevation in a rejuvenated landscape, that is in a landscape that has not been in existence very long, a substantial period must normally be envisaged for caves of these dimensions. Yet here the time available for cave development must be less than the age of the oldest aeolianite, which itself is no older than earliest Pleistocene, and possibly much less.

Karst development is taking place rapidly today in the most cavernous areas. Some examples from Yanchep and Margaret River will illustrate this. A small grotto with a gently flowing stream at Yanchep, about 30 miles north of Perth, has been known to the author since 1949. In 1954, the grotto suffered a roof fall and several blocks fell into the stream. By 1960, these had disappeared completely and the grotto was more than twice its size of eleven years earlier. Another large grotto with a stream at Yanchep fell in about ten years ago - a source of some consternation to the would-be explorer! One caver of the 1930's records in his notes a visit to the collapse basin of a fallen-in cave near Margaret River which old residents recalled as being formerly a pretty cave with a lake. With longer experience in that area we shall undoubtedly have more examples of cave falls.

While this speedy development obviously characterises both Yanchep and the Yallingup-Augusta belt (and presumably other areas as well), there is a vast difference between typical cave sizes in the two areas. The latter area has a higher rainfall but hardly enough to account for the difference. Some added mechanism seems to be demanded.

2. Cave initiation before consolidation.

Such a mechanism is available and will be described here. It leads to satisfactory answers, not only to the great variation in extent of karst development, but also to the variations in cave forms and types of karst topography.

An important feature of the aeolianite is that, because of its sub-aerial deposition, it has been above sea level from the beginning, when it was soft sand. Minor submergences during interglacial times have only affected the seaward fringes.

Water, doubtlessly, was draining through it while it was still sand and hence, where groundwater conditions were favourable to the concentration of drainage into underground streams, these must have developed. While they were active the major part of the material was hardening gradually by cementation. Thus, as soon as it became coherent enough to hold together above even small cavities, the streams could begin to carve out free channels - embryo caves. Therefore it was not necessary for the dunes to have been converted to solid limestone before caves could be started.

For such a mechanism there must be a precipitation of carbonate to harden the rocks, and simultaneously dissolution along stream lines to create caves. The coincidence of these opposed processes depends on the differing nature and rate of water flow in different parts of the dunes. Water seeping downwards from rainfall is moving very slowly and becomes saturated with carbonate. This is reprecipitated at greater depths when the seasonal summer desiccation occurs. An underground stream, on the other hand, is moving many times faster, is being continually replenished, and as a result is usually under saturated, except perhaps in times of stagnation due to drought. The result is a regular annual cementation in the body of the dunes, while carbonate bathed by stream waters suffers continual solution.

In the initial stages of cave development outlined here we see a curious departure from the normal sequence of events. In old marine limestones, the lithification of material must come first and caves later, after the limestone has been raised above sea level to a suitable elevation. In these aeolianites the streams are beginning to develop caves even when the sand is barely coherent. Cave development can, in fact, begin a very short time after deposition of the material itself.

The concentration of early drainage into definite streams in some areas will be dealt with later; this is important, for in areas lacking this type of drainage the mechanism cannot be applied for reasons which will be elaborated.

3. Enlargement by collapse.

This idea points logically not only to an early start, but also to rapid growth of caves in areas that have watercourses.

In the early stages of cementation, cave development can be very rapid, the major enlargement of cavities taking place by repeated collapses of barely coherent rock into streams. Fallen blocks, lying in the water, are then open to attack by the streams which also widen by continually undermining their walls. Meanwhile the bulk of the rock is steadily hardening and thus becomes stronger. As a result, collapses gradually decrease in frequency until finally the caves reach fairly stable mature forms.

Cave development thus shows three general phases:-

(i) A period preceding rock coherence, when material removed along streams is immediately replaced by settling of sand from above and growth is nil.

(ii) A period when rock is poorly coherent, sufficient to support small cavities only, and cavern enlargement by collapse is rapid.

(iii) A final period when rock is strongly coherent and collapses very infrequent.

The third phase does not necessarily lead to a final cave form, for as long as there is stream action the sides of a watercourse are corroded wherever wall-rock is in contact with flowing water. So a cave must periodically increase the size of its stable arch to fit the widening base. Cave development can only cease if the stream is diverted from the course it has created. This may occur as a result of a massive collapse damming back the water upstream. Such dammed water usually finds its easiest route through the collapsed material, but if alternative routes are available, it may use these and abandon a downstream section of cave. The section of cave abandoned in this manner becomes permanently stabilised, excepting perhaps for a few minor collapses from weakened parts of the ceiling. A series of lesser collapses may also lead to abandonment by sufficiently impeding the flow of water for the stream to use an alternative route.

There are examples of caves that have been permanently stabilised by collapses, still retaining their original linear form as created by the streams that once flowed through them. Giant's Cave is one of the best. Stream piracy is also a feasible mechanism for diversion of a watercourse, but no examples are known in these areas.

The cave history outlined here is almost entirely a vadose one, but not vadose in the original manner proposed by early cave theorists. These theories either picture water entering at the surface, or percolating waters gathering above levels of completely water-filled passages. Such underground streams may be at different levels which are not related to a water-table. On the other hand, in the aeolianite, streams run at the true water-table level and, but for the collapses, would be completely water-filled passages. It is only when free air surfaces are created above the streams with the very first collapses that the passages become vadose caves in the broad sense.

It must be noted nevertheless that there is, ultimately, a stage reached of fully coherent rock when collapses are not the rule. If new caves were then to be initiated, there is no reason why a normal phreatic history might not ensue. Such, in fact, appears to have taken place in the Augusta cave area where an extensive system of small cave passages shows abundant evidence for a shallow phreatic history. This system will be the subject of further study.

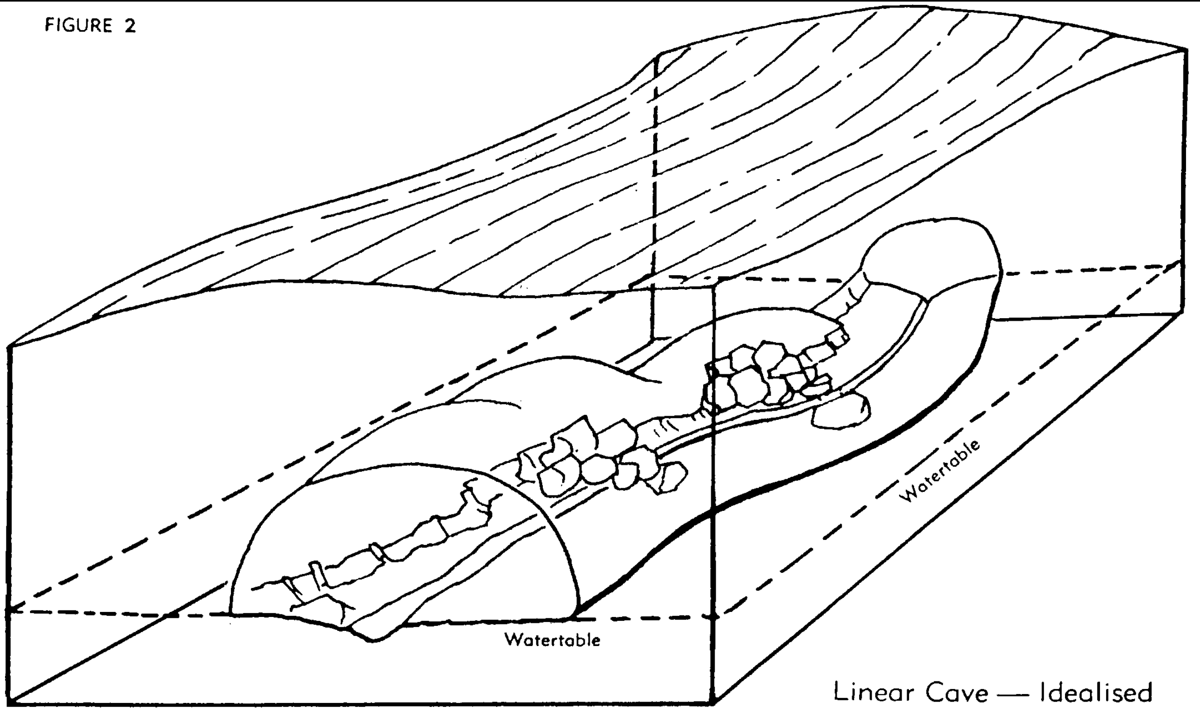
4. Cave form types.

Cave forms in aeolianite differ markedly from area to area due to the different growth histories resulting from the particular drainage characters of each area. All, with the exception of the Augusta system mentioned above, are essentially secondary forms due to collapse. Two main types can be distinguished: -

(a) The linear cave form with arched roof outlined above is very common. Even in cases where the cave is very "tumble-down" and does not reach water-table, it is usually sufficiently long and sinuous to indicate that a stream once flowed underneath. A fairly common variation is an isolated cavern without extensions. Such caves have high, domed ceilings and jumbled masses of roof blocks making up the floors, often partly blanketed by sand and soil washed in from the surface. The rubble piles have merely blocked off access to the main stream courses. Such caverns are not really different in any essentials from the linear type. Often a small passage may be found connecting with the parent cave and the origin of such an isolated cavern becomes clear. In Crystal Cave, 14 miles south of Margaret River, there are two large domed caverns which open off by small tunnels onto a watercourse which has obviously bypassed them.

(b) The second type is seen in small caves having the general form of an inclined fissure, often with floor and roof neatly matching. These again are the result of collapses upon an active cavern at watertable level. If an inclined fissure cave leads into a linear stream cave at a lower level, its origin becomes obvious, but more commonly such fissures close up at their lower ends because the original cave development was directly beneath the part of the fissure showing the greatest length of fall; the closed end of the fissure is off to the side of the original cave. The two cave types are depicted in Figures 2 and 3.

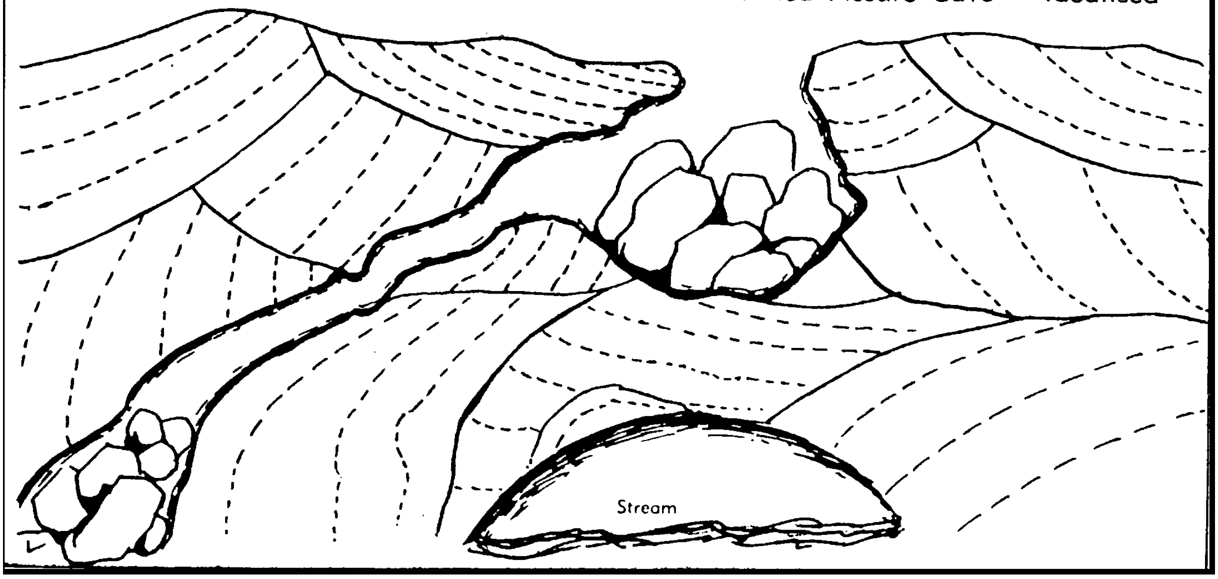
FIGURE 2



Linear Cave — Idealised

FIGURE 3

Inclined Fissure Cave — Idealised



5. Relationship of drainage to cave forms.

From area to area the relative proportions of linear caves and inclined fissure caves varies widely. In the Yallingup-Augusta belt the linear type predominates, and fissures when found can often be related to fall-outs on a linear cave nearby. Yanchep area has good examples of both types, but inclined fissures predominate and the great majority do not lead to a linear controlling system. Namban River area has extensive caves made up wholly of ramifications of connected inclined fissures having the general form of many broad intersecting low-roofed domes.

The linear type, it has been noted, is formed by collapses onto a well-defined stream. It is characteristic of these caves that the streams vigorously corrode the bases of their rubble piles which continually settle until, in the absence of fresh falls, high and spacious caverns are created. The streams are apparently not easily diverted.

On the other hand, the broad systems of fissure caves, with their collapsed material lying virtually untouched, indicate that concentrated attack by streams has not taken place. Watercourses in such oblique fissure systems are apparently easily diverted by collapses.

It is evident that the inclined fissure systems represent collapses upon very broad and ill-defined waterways. These waterways apparently began as complicated systems of wide but very low, cavities at the watertable. These collapsed gradually in sections, each section at a different time. Because of this, alternative routes were always available in a system of this type. Since the water was not limited to the necessity of attacking directly through a collapsed section, the rubble remained relatively untouched. Nambibby Cave at Yanchep is a good example of such a well-developed fissure cave system.

The two cave types point to two distinct watertable conditions:-

(i) Linear types indicate a watertable with strong relief carrying defined streams along its lowest parts; the streams are obviously restricted to these valleys and this explains why they must attack through any collapses that land upon them for they cannot be diverted to the flanks, which are upslope. This undulating watertable is controlled by an impervious stratum which itself has strong relief.

(ii) Inclined fissure cave systems indicate a watertable which has very subdued relief, even if an appreciable fall in one direction is present. Water flows in broad belts because it is not affected by an undulating impervious substratum.

Originally there are no defined streams in areas with a watertable of subdued relief, but it is as a result of extensive collapses in the cave systems that water becomes temporarily confined to streams. Such a stream, however, is typically small, easily accommodated in whatever route is available, and obviously not forced to maintain that course. It tends to cut off its temporary meanderings by eventually finding a shorter course through another part of the collapse system. Thus these streams follow many courses within the broad limits of a cave system at various times. The final state of such a system is a broad area of settled ground within which are scores of oblique fissures, small collapse dolines, and occasionally a sight of a stream here and there.

It follows that only caves built along definite stream lines could have the early start outlined in this paper, as concentrated solution along a definite stream line is required to create cavities in poorly consolidated sands. Broad flow, by dissolving throughout the breadth of a dune, would only cause the whole mass to settle slightly, and so caves cannot get started in this case until the dunes have hardened considerably. Inclined fissure cave systems are indeed much smaller than linear caves. Since they also lack concentrated follow-up attack upon collapsed material, one may wonder that within the short time available they were anywhere ever developed to the extent that man could enter and penetrate far. In fact, it seems apparent to the author that they are never developed to this extent unless substantial amounts of water are added to the dune belts from outside sources. Dune belts lacking such added volume of drainage are exceedingly poor in caves.

Causes of Local Variation in Cave Development

1. Effect of bedrock.

The Yallingup-Augusta cave belt differs from other areas in having a bedrock of igneous rocks upon which an appreciably hilly topography had been developed before the dunes were emplaced. This impermeable basement, by creating the undulating watertable outlined above, appears to have imposed its old stream patterns upon the limestone above so that underground streams today follow similar lines to the original surface watercourses. An excellent example is the Mammoth Cave system, where a surface stream continues directly into the limestone barrier, obviously following its original valley. As has been outlined above, this area has through its concentrated drainage attained much bigger cave dimensions than elsewhere.

In other limestone areas there are only flat-lying alluvial beds of the old coastal plain beneath the limestone. The watertable is consequently much nearer to the horizontal and the broad, sheet-like water movement produces systems of the second type.

2. Rainfall.

The average annual rainfall of the region ranges from about 50 inches in the Karridale area near Augusta, to 10 inches around Shark Bay. This is a considerable variation and has a direct bearing on the rate of growth of caves and there is a decrease in both size of caves and amount of decoration from south to north. Since there are several other factors at work the trend is, of course, a very rough one.

3. Age of the limestone.

Aeolian calcarenite ranges right through to Recent in its age and shows progressively poorer cementation and less cave development in younger occurrences. The caprock is very early to develop and gives no idea of the degree of coherence of the main body of the limestone beneath. Limestone belts beneath Fremantle and Mandurah have tough caprock, but the material beneath is friable, and caves are almost unheard of in this belt. Likewise at Yanchep, the numerous caves are all seen in an old dune belt several miles inland, whereas younger dune belts nearer the coast have no known caves, even though drainage passes through them.

4. Height above watertable.

In some areas, such as Yanchep, the dunes did not reach a great height and the watertable may commonly be as little as 30 ft. below the surface. Caves can never attain impressive dimensions; they have only to reach a ceiling height of 20 ft. or so for the next collapse to take a cave right to the surface. There tend to be a great number of fissures, open collapses and insignificant rubbly chambers without extensions, which elsewhere might never open to the surface. On the other hand, the Yallingup-Augusta belt has areas with a watertable more than 200 ft. deep, and its depth is mostly over 100 ft. Here caves have room to grow larger before collapses reach the surface, and minor changes of stream path have space to rejoin, to enlarge and simplify the systems. When a collapse does reach the surface, the result is often an impressive pit. Lake Cave and Bride's Cave, about eight miles south of Margaret River, are excellent examples. Such pits are common in spite of the depth to water because of the additional factors here.

5. Drainage from back country.

Whereas in many areas rainfall on the limestone belt is the only source of drainage water, there are some in which drainage from inland country, lacking a surface connection with the sea, adds considerably to the volume of water passing through. Such are the localities where dune belts have completely blocked off river outlets, as noted earlier. If an area, otherwise dry, is receiving large quantities of such water, then caves may develop here much faster than in adjoining areas and may even approach in magnitude those of the wettest parts. Perhaps the best example of this is the Arrowsmith caves area which is developed where the Arrowsmith River, draining an area of about 300 square miles in a 20 inch rainfall belt, terminates in a string of lakes a few miles from the sea, some 20 miles south of Dongara. In flood times, the lakes overflow into several caves, the largest (Arramall Cave) being a mile in length before becoming impenetrable. The floods in each cave spread out into systems of distributaries, each taking a fraction of the flow and dividing repeatedly down into a ramification of tiny passages, until finally the drainage is spread through a wide area of limestone and slowly travels the remainder of the distance to the sea.

Twenty-five miles south of this system, Stockyard Gully Cave drains a small belt of inland country, and 40 miles further south the Namban River (sometimes spelt Nambung on maps) is associated with a very extensive system of inclined fissure caves in the vicinity of its blocked downstream end. At Yanchep no proof of added drainage is available, but an area of about 200 square miles between the dunes and the Darling Range is sandy country completely lacking watercourses. Undoubtedly, drainage from a large portion of this area must pass into the limestone. In the Yallingup-Augusta belt there are a number of small streams entering the limestone. The Mammoth Cave system has already been mentioned, and Calgardup and Arumvale Caves are other good examples of caves developed on such streams.

By contrast with all the areas outlined above, there is a long strip of coastline between Perth and Bunbury lacking added water. Swan and Canning Rivers and their associated swamp lines, then Serpentine River, Harvey River, and Wellesley River in turn, drain coastal plain country behind-the dune belts, reaching the sea via narrow passages through the dune systems. Caves are virtually unknown in this region, although a few very small caves are recorded on the western side of Harvey Estuary on the inland edge of a dune belt. Springs issuing into the estuary indicate that the caves are developing only by drainage from rain falling onto the limestone itself. The relative friability of rock, and the configuration of Peel Inlet, Harvey Estuary, and the interdune lakes, Clifton and Preston, suggests that many of the dune belts are quite young anyway in this region. A small patch of limestone of very low elevation on the south side of Peel Inlet may be the only dune remnant of comparable age to the main cavernous dunes elsewhere. A cave of reasonable size has been found there.

6. Variations in solutional capacity of groundwaters.

In any one area, even within a single dune, the biggest cave development is seen adjacent to the eastern edge of the dune belt. This is particularly obvious wherever large amounts of drainage from inland country are undoubtedly entering the limestone, as in the examples cited above. Caves may begin large, but invariably become smaller and smaller, in an irregular fashion, westwards through the limestone. In the case of the Arrowsmith system, the trend is obviously due to spreading of the drainage, but this cause is not evident in any other system.

Elsewhere the trend can only partly be attributed to the ages of the dunes. Every area has multiple dune lines showing a progressive drop in age from east to west. Thus one would expect a step-like drop in cave size from dune to dune, but the actual picture is a far more rapid drop in size and, in fact, there is not a single cave known anywhere from the youngest dune line. Much of the cause must be simply credited to increasing saturation, and consequent loss of dissolving power, of the water as it flows westwards.

Conclusions

The caves in Western Australian aeolianite and their origins as pictured here show quite wide differences from the Bermudan caves, due largely to their different groundwater conditions. Bretz described true phreatic caves from Bermuda, but it seems that the main cave development in Bermuda occurred in marine limestone which underlies the aeolianites and would presumably, have been fairly solid when solutional attack began. The main factor preventing solution much below watertable here is simply that collapses are so rapid and release so much insoluble quartzose sand, that the floors of watercourses just keep filling up. Furthermore, once continuous open passages for water are established at watertable, this would have a further inhibiting effect upon any solution at depth as the easy drainage at watertable level would cause the flow to concentrate there, while flow at greater depths must virtually cease. The picture is of a nearly stagnant body of saturated groundwater topped by a thin layer of under-saturated water draining away easily.

These results of observations carried out over the past decade are necessarily only qualitative. Without experimental work to back them, the conclusions cannot be considered proven, but it is hoped that they will furnish a firm basis for future work.

References.

BRETZ, J.H. 1960: Bermuda: A Partially Drowned, Late Mature, Pleistocene Karst. *Bull. Geol. Soc. Am.*, **71**: 1729 - 1754.

BUTZER, K.W., CUERDA, J. 1962: Coastal Stratigraphy of Southern Mallorea and its Implications for the Pleistocene Chronology of the Mediterranean Sea. *J. Geol*. **70:** 398 - 416.

FAIRBRIDGE, R.W. 1954: Quaternary Eustatic Data for Western Australia and Adjacent States. *Proc. Pan Indian Ocean Sci. Gong., Perth, Section F*: 64 - 84.

FAIRBRIDGE, R.W. , TEICHERT, C. 1953: Soil Horizons and Marine Bands in the Coastal Limestones of Western Australia. *J. Proc. Roy. Soc. N.S.W.* , **86:** 68 - 87.

HOSSFELD, P.S. 1950: The Late Cainozoic History of the Southeast of South Australia. *Trans. Roy. Soc. S. Aust*. **73:** 232 - 279.

SIMPSON, E.S. 1906: Geological Features of the Southwest Caves District. *West. Aust. Year Book* **1902-04:** 691 - 696. Perth, Govt. Printer.

SPRIGG, R.C. 1952: Stranded Pleistocene Sea Beaches of South Australia and Aspects of the Theories of Milankovitch and Zeuner. *18th. Int. Geol. Cong., Gt. Brit.*, **1948, Pt.13:** 226-237.

SWINNERTON, A.C. 1929: The Caves of Bermuda. *Geol. Mag*. **66:** 79 - 84.