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THE ORIGIN OF THE KELLY HILL CAVES, KANGAROO ISLAND, S.A.

A. L. Hill

A paper read at a C.E.G.S.A. meeting on 9th April 1957 in the South Australian Museum.

Explanatory Note

Those who got to know A.L. Hill ("Hilly") of Adelaide soon recognised that he not only enjoyed his caving but that he liked to exercise his engineer-trained intelligence on scientific aspects of caves. Amongst the products of that latter facet of his speleology was a paper on the geomorphology of the Kelly Hill caves on Kangaroo Island which he presented to C.E.G.S.A. in 1957. It interested his audience greatly and he sought critical opinions from Drs. P.S. Hossfeld and A.M. Kleeman of the Geology Department of the University of Adelaide. They considered that with some stylistic revision it would be worthy of publication in a scientific journal. Later he asked my opinion and I concurred in this. Unfortunately, amongst his manifold caving and cave science activities, he did not find time to pursue this before his untimely death.

My estimate of his paper was such that I made use of it in a general paper on karst in aeolian calcarenite in Australia and I included a figure from it in my book on karst. I would probably have made more reference to his ideas if the article had been published. More than once I contemplated seeking its publication posthumously. Recently Sue White found it helpful when investigating the aeolian calcarenite karst of Bats Ridges, Victoria, and she urged this step also.

I have therefore edited the paper along the lines I think a journal would have required if it had been submitted in the late fifties or early sixties. Nevertheless I have neither abridged his ideas nor revised the writing in the light of advances in knowledge since that time. To a degree this latter course will render it an historical document on its appearance. I believe it is worth publishing as a significant item in the history of Australian speleology, which would otherwise remain unavailable to most people. More than that it is my opinion that even now it can still help us towards a better understanding of cave origins and evolution. The Editors of Helictite join in this assessment and publish it on both counts.

J.N. Jennings

Abstract

The Kelly Hill caves in soft, homogeneous, extremely porous dune limestone differ markedly in morphology from those in the more usual, dense, bedded limestones. Solution occurs at depth with great lateral spread through swamps overflowing into the base of the hill. Development occurs by roof breakdown as areas of solution become so large that the roof cannot support the weight; a theory of the mechanics is presented. Domes and tunnels of collapse rise above the watertable; at maturity there are isolated infalls from the surface. Water percolating down from the surface only builds secondary calcite deposits.

INTRODUCTION

Solution along joints and bedding planes predominates in the formation of caves in compacted limestone such as the Silurian rocks at Jenolan, N.S.W., capillary action preventing movement in its pore spaces. Earlier writings on the Kelly Hill caves have assumed that the same mode of origin applies there also. However, here almost pure calcareous sands have formed rocks of high porosity (about 30%) without significant joints. On the basis of visits by the Cave Exploration Group of South Australia (C.E.G.S.A.) in the last two years a different hypothesis for the origin of the caves here will be presented which could lead to the discovery of more caves in the area (Figure 1).

GEOLOGY

Two caves are shown on the Kingscote Geological Map (Sprigg, Campana & King, 1954) at approximately 35˚59' S lat., 136˚55' E. long. The Kelly Hill system is the more northerly of the two; the other, discovered during the 1942 Cave Reserve Survey was relocated and named K-11. On the map, the caves are shown as occurring in Pleistocene 'Consolidated dune limestone (aeolianite)'. These deposits are found extensively in the coastal areas of southern Kangaroo Island, Yorke Peninsula, and the Southeast of the State. (Tindale, 1933; Hossfeld, 1950; Sprigg, 1952).

In the Kelly Hill area these wind-blown, calcareous sands form minor ranges with a dense vegetation and with occasional limestone outcrops. They rise to a height of about 25 m above the low plain of Recent sand and clay to the north.

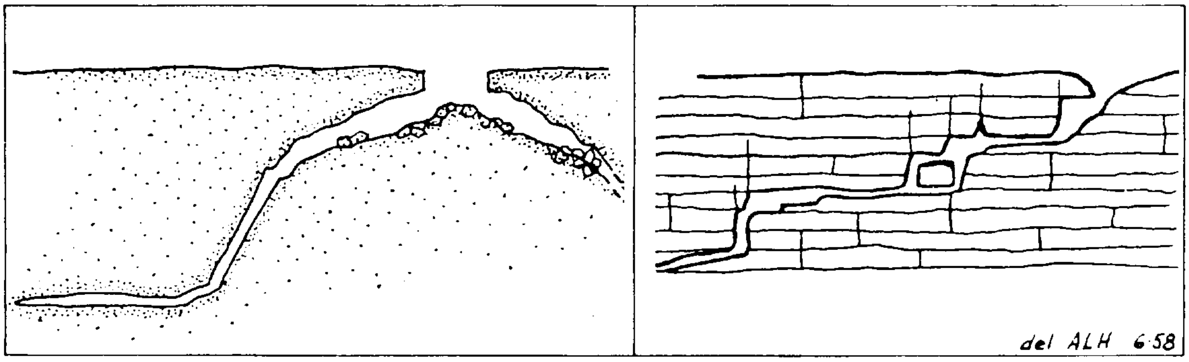

Figure 1. Comparison between Kelly Hill Caves and generalised solution cave.
Left: Kelly Hill Caves, generalised cross section.
Right: Solution cave, generalised long section.

The main group of caves is located in a hill 150 m south of the boundary of the Pleistocene aeolianite. Of major importance is the drainage to the north of this boundary. The drainage across these relatively impervious Recent beds is northwards to South West River, except along their southern margin where there are occasional low-lying areas. There are no signs of surface runoff channels on the aeolianite ridge and consequently no sedimentation results in these marginal areas. The climate of southern Kangaroo Island is strongly seasonal (Figure 2). Swamps develop in these low-lying areas and water is known to rise regularly to a level where it drains southwards visibly into inflow points on the aeolianite ridge. Never has it been observed draining out of these points.

GROUNDWATER MOVEMENTS

There are two groundwater sources for the hill that are of importance. First the seasonal rise in water level gives long periods of exposed surface water in the adjacent low-lying area. A major lateral movement towards the hill causes a corresponding rise in the water table under it. Being mainly surface water, this has a negligible amount of carbonate in solution and the southward movement through the base of the hill is accompanied by a considerable rise in calcium carbonate content in the winter months, but only at a level of 25 m below the top of the hill and below. By the usual process of solution this has led to the evacuation of large areas rather than channels as the very porous nature of the dune limestone would permit easy entry of this water in all directions.

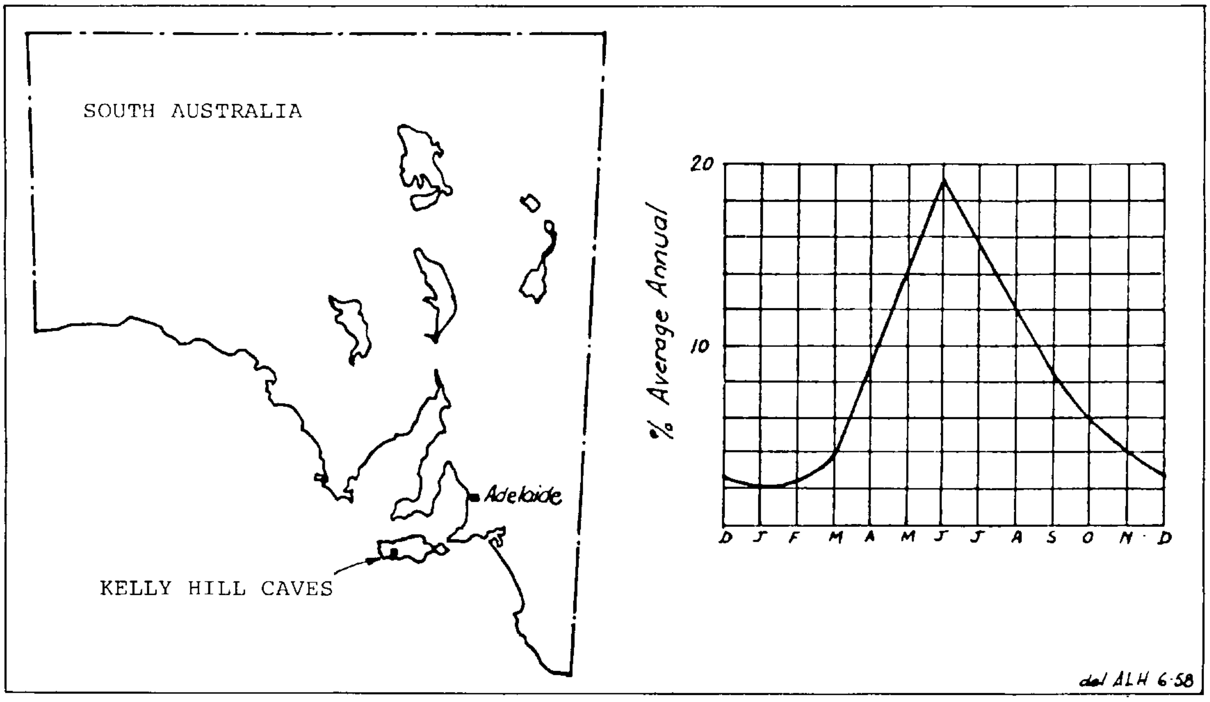

Figure 2. Location map and mean monthly distribution of rainfall at Kelly Hill Caves.

Only four chambers, all more than 25 m down, which have formed in this manner remain – the Mud Chamber, the Bone Chamber and two other less developed sections as yet unmapped. Both of the named caves show few secondary calcite deposits in their lower areas and have flat to slightly domed roofs, possibly waterworn walls and an abundance of recent inwashed mud.

The second source of groundwater is a vertical component resulting from direct rainfall on the hill. It is the only source of supply above the 25 m level and as there is a thick soil mantle on the limestone over the greater part of the hill the surface water soaks evenly into the rock below.

Where localised surface hardening occurs, the thickness is only a metre or two and is quite openly fissured by solution, thus allowing the surface water to be evenly distributed in the fresh rock below the surface. As the rock is so porous and as there is a complete lack of jointing in the underlying material, the vertical water movement has no preferred water channels to single out for cave formation. However, this second source of supply has been responsible for the many beautiful and varied secondary deposits for which the Kelly Hill caves are mainly known.

INFLUENCE OF LITHOLOGY ON THE CAVES

Given the two distinct groundwater movements and the extremely porous nature of the rock, the lateral water movement can dissolve out areas of considerable lateral spread below a particular level and this leads to large, unsupported, flat roofs (Figure 3).

Had the bedrock been more dense and jointed, then ,no doubt self-supporting tunnels would have been created. The aeolianite is unable to support itself after a certain stage of cave development is reached and roof collapses occur. These will continue until the resulting caves take up a shape that is structurally stable. To accomplish this, wide arches are formed at a higher level than the 25 m level with lateral spreads of up to 60 m but with only a few metres clearance between floor and roof. Since the chambers are now raised above the normal limits of the fluctuating watertable and associated solution effects, the vertical component of the groundwater can now have effect and a magnificent display of clean secondary calcite is created. The process of lateral solution continues at the bottom and further falls may occur.

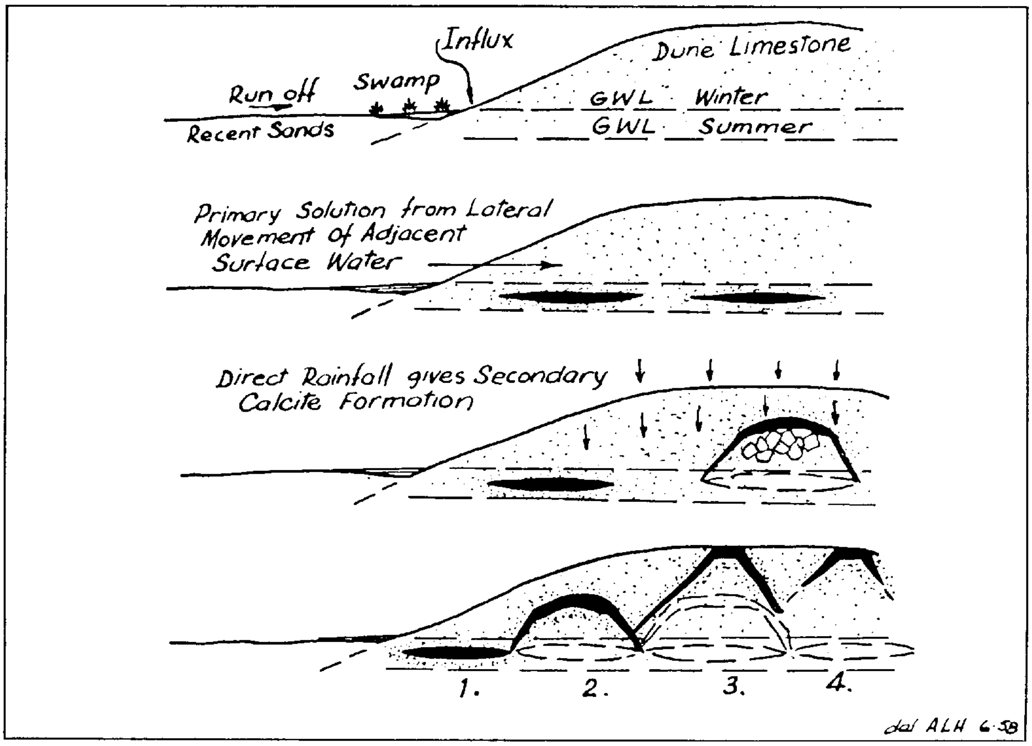

Figure 3. Relationship between groundwater and cave development (N-S section).

Finally there is the morphology of today, a series of collapsed domes with varying heights above the 25 m level primary area, extending at maturity to the surface when the last roof collapses occur.

In the mature stage there is some resemblance to the common type of doline developed by solution from above but examination of the interior of the cave shows marked differences. In dense, well-jointed limestone surface water may enter the rock along some plane of weakness and dissolve some of it. In this way the catchment area is increased and water enters in larger quantities. The doline develops in this way and a cave is produced below right down to the watertable. In this type of doline the growth is from above downwards but at Kelly Hill the growth seems to be from the lateral zone of solution at 25 m below the surface upwards.

Again, with the doline due to solution from above, the material on the floor of the caverns developed from them will often be mainly material washed in from the surface, with occasional loose rocks fallen from inside. In the dune limestone caves, the floor material is entirely rubble fallen from inside the cave.

At Kelly Hill, domes have been entered from below, which have not been opened to the surface as yet. As there is here no evidence of disturbance of the covering rock at all, this disproves formation by solution from above.

MECHANICS OF ROOF COLLAPSE

In the Kelly Hill caves, the cross-sections through any of the main passages are remarkably similar, beginning with a cleanly broken, presumably shared fissure at the side, varying in slope from 45 to 60 from the horizontal (Figure 4). In places where they give access, they have been traced from the 25 m level of solution chambers but more generally the clearance between the hanging and the footwall is very small and choked with fallen rubble. At the top of the fissure the cave arches across a distance between 10 and 20 m, averaging about 15 m in a roughly fractured roof, occasionally with loose, hanging blocks of rock.

This part appears to have fallen out purely as a tension rupture. The floor is mostly covered in this section with broken material from the roof. Symmetrically disposed on the opposite side is another sheared fissure.

The known areas of the cave chambers were projected down to the 25 m level on the assumption that the visible part of the cross-section was continued. The resulting projections showed that the system consisted of seven circular areas of complete breakdown, ranging in diameter from 40 to 60 m at the 25 m solution level, and having a mean base of 52 m. At no point did the projected collapse areas overlap the known solution areas, and in some places where these circles approached one another collapse tunnels have occurred, connecting the circles. There are two major tunnels about 35 m across at the base.

The ratio of the diameters of the circular areas to the width of the tunnels, 52:35, is consistent with mechanical principles as the undisturbed walls in the circular base areas are arches self-supporting across all diameters, whereas the tunnel arches are supported across the width only, there being no support along the axis of the tunnel.

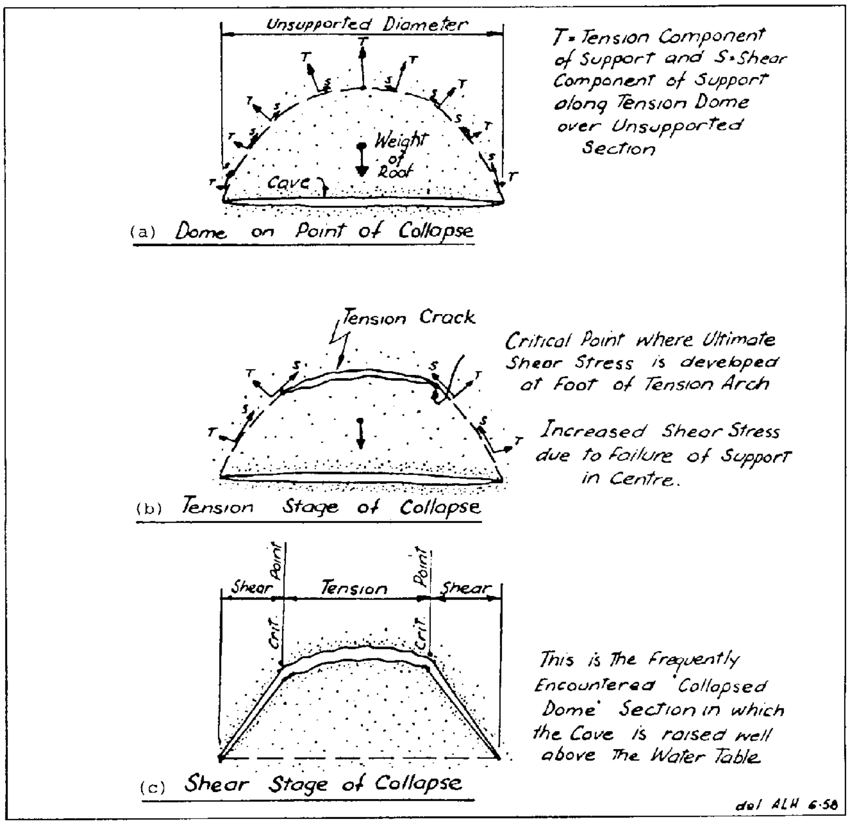

Figure 4. Mechanics of roof collapse.

This arch hypothesis needs substantiating by relating these spans to the laboratory test strength of the Kelly Hill dune limestone, though this is a complex task.

A simplified example of cavern breakdown and roof collapse has been treated by Davies (1951). In this case, however, the collapse is thought to be a two stage process of tension and shear. Davies refers to a 'tension dome' in bedded rocks of ellipsoidal shape over an unsupported area. If such a dome on the point of collapse is considered, the main stress pattern will be as shown in Figure 4 (a). The roof section forms a complex beam supported around the tension dome by a combination of tension and shear.

The first stage of collapse probably occurs with tension cracks appearing towards the top of the tension dome (Figure 4 b). Once this occurs, the cracked section gives no support and the load is transferred around the arch where the shear stress is increased. This continues to a critical point when the increasing shear stresses equal the ultimate shear stress of the rock and a shear on both sides of the arch takes place as the second stage of collapse (Figure 4 c).

Whether an interval of time is possible between the two stages or whether the collapse is continuous once it has begun is uncertain. The true stress pattern has been generalised for the purpose of this preliminary explanation. However, it appears that an uncracked flat roof is safe up to about 30 m in width at Kelly Hill and that the presently arched areas are safe from further collapse except for minor roof falls and where weaknesses are introduced by the presence of adjacent domes.

CONCLUSION

This hypothesis was originated in 1956 after the second expedition of C.E.G.S.A. and the third expedition has shown that every cave in the area so far investigated can be assigned to one of the four stages shown in Figure 3. Several of these water inflows occur along the edge of the ridge and could be indicators of new caving areas in the Kelly Hill Reserve.

It is even more important to test this hypothesis in other porous, soft, limestones in Australia which house caves from western Victoria to Naracoorte in South Australia, Eyre Peninsula, possibly in some cases in the Nullarbor, and in the Southwest of Western Australia.

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