

Karst and cave development at Kelly Hill Conservation Park

Dr David Gillieson¹, Heiko Maurer² and Dr Gabriel Crowley³

¹School of Geography, Earth and Atmospheric Sciences, University of Melbourne; ²PO Box 325, Macclesfield, SA 5153; ³PO Box 131, American River, SA 5221

Email: ¹david.gillieson@unimelb.edu.au

Abstract

Following extensive bushfires in early 2020, during which just over 50% of Kangaroo Island (approximately 211,000 ha) was burnt, a project was established under the South Australian Speleological Council to relocate, document and map caves on Kangaroo Island. To date 100 caves have been relocated and 55 new caves found. This paper is based on the preliminary results of the project.

The west and southern coasts of Kangaroo Island are blanketed by a sequence of dune limestones of Pleistocene age. The formation of the dune limestone along the coast impeded the central plateau's pre-existing drainage and led to the development of a shallow lagoon at Kelly Hill, along the contact with the limestone. It is likely that a process of mixing corrosion was involved, with preferential cave development at the interface of the lagoon water and rainwater infiltrating down through the limestone. This resulted in a maze of passages forming at the water table, seen today in Kelly Hill Cave. Subsequently, valley incision and slight uplift on the south coast drained the lagoon, and an ongoing process of collapse ensued in the caves. The loss of hydraulic support for the cave roofs resulted in a series of tensional arches in which the cave roofs became too wide to support their own weight. This process continued until the caves formed structurally stable arches, some of which open to the surface as dolines. This unusual process of cave development is primarily controlled by the soft, porous nature of the limestone and its lack of jointing.

Introduction

Kangaroo Island is a continental island located 14 km across the Backstairs Passage from Cape Jervis on the Fleurieu Peninsula of South Australia. The island is approximately 145 km east to west and 60 km north to south, with a land area of approximately 4400 km². It is a geologically diverse environment with rocks ranging in age from the Palaeozoic through the Mesozoic and Cainozoic. Roughly 16% of the island is karst, principally on the western and southern coasts and extending inland up to 5 km. Multiple episodes of coastal dune migration during Pleistocene high sea stands resulted in the formation of dune

limestones or aeolian calcarenites which achieve a maximum height of 65 m above present sea level at Cape Bouguer. Karst features are well developed including major and minor caves, sea caves and dolines.

The most extensive karst area forms the Kelly Hill Conservation Park on the southwest coast of the island. Caves have been known in this area since 1885, with the area becoming a reserve under the Flora and Fauna Board in 1926. Later in the same year, guided tours of the Midnight Cave commenced by the light of hand-held candles. Exploration, surveying and mapping of the caves on Kangaroo Island by the Cave Exploration Group of South Australia Inc. (CEGSA) has been ongoing since 1955, and electric lighting was installed in K1 Kelly Hill Cave in 1956. The karst area is now under the control of the National Parks and Wildlife Service South Australia (NPWS SA). Extensive bushfires in early 2020, burnt just under 50% of the island (approximately 2110 km²), including almost all of Kelly Hill Conservation Park, and its entire above-ground infrastructure. Fire intensities were very high resulting in widespread spalling of limestone outcrops to a depth of 2-5 cm, baking of soil and washing of soil and charcoal into dolines. Sediment and charcoal washing downslope across the main road diverted water flows and partially blocked three main water sink points along the northern side of Kelly Hill. As part of the post-fire recovery efforts, a project was established under the South Australian Speleological Council – with the assistance of the Cave Exploration Group (SA), Flinders University Speleological Society (FUSSI) and Scout Cave Group (SCG) – to relocate, document and map caves on Kangaroo Island.

A Friends of the Karst group was formed in 2021, approved and funded under the SA Parks volunteer scheme to locate, document and map both known and new caves in the Kelly Hill karst. The project also involves a cave invertebrate survey to be carried out by Dr Stefan Eberhard and an archaeological survey by Dr Keryn Walshe.

The project will also develop Kangaroo Island geoheritage interpretation and geotrails, with a website hosted by the Kangaroo Island Tourism Alliance (KITA).

have produced strontium isotope ages of 1.18 and 1.2 million years (Belperio, 1995). At Kelly Hill Caves, an amino acid racemisation age of 835,000 years has been obtained on dune limestone and an optically stimulated luminescence date on included quartz sand grains (OSL) returned a date of 1.3 million years (McDowell et al., 2013). The Middle Pleistocene limestone has an associated strontium isotope age of 0.52 million years (Belperio, 1995). A trace fossil site at Boar Beach on the Dudley Peninsula has associated OSL dates of 135,000 and 137,000 years (Camens et al., 2017).

Surface Geomorphology of Kelly Hill Karst

The dune limestones of Kangaroo Island provide a good example of syngenetic karst, a term coined by Jennings (1968) for karst features and caves that form within a soft porous sediment at the same time as it is being cemented into a rock. Thus lithogenesis and speleogenesis are essentially concurrent (Grimes, 2006). Syngenetic karst is widespread in the Quaternary dune limestones of southern Australia and South Africa (Marker & Sweeting, 1983). In recently deposited calcareous dunes, percolating rainwater gradually converts unconsolidated sand to limestone by dissolution and redeposition of calcium carbonate. This process is enhanced by both bacterial and fungal action in the root zone of vegetation stabilising the dunes (Warren, 1983). Within Pleistocene dunes and especially within calcrete zones, sand grains are often coated with a rind or envelope of micritic calcite. At the base of the developing soil profile, carbonate is precipitated to form a calcrete or hardpan, which may be exposed following erosion. Beneath the calcrete or rock shallow, caves may form. These are typically short horizontal mazes of low wide interconnected chambers with widespread collapse.

At depths in the calcareous dune, there may be buried palaeosols and also calcretes which indicate former

water tables. Below the hardpan layers, percolating water can become focussed around tree roots to form solution pipes, with enhanced carbonate cement in the surrounding sand. These are known as rhizomorphs. Mixing corrosion occurs where the percolation water meets the water table, which is often controlled by the level of nearby swampy plains. The interface between the percolation water and the static brackish water is the zone of enhanced carbonate solution. At the coast, laterally moving groundwater forms a freshwater lens overlying seawater resulting in further mixing corrosion. This can result in mazelike flank margin caves. These have a characteristic form with interconnected mixing chambers that attenuate as one moves away from the coast.

Surface exploration (Figure 2) taking advantage of the reduced vegetation cover has clarified a number of aspects of the geomorphology of Kelly Hill Conservation Park. The flat area to the north of the ridge is the remnant of a marginal lagoon traversed by stream channels from the north. At the eastern end of the karst ridge the underlying Cambrian metasandstone is exposed at the surface, marking the limit of the dune limestone. In the same location there are unloading joints in the limestone, up to 50 m long and 6 m deep, which are a consequence of the erosion of the valley leading to the Southwest River. The schematic cross-section below is a first attempt to understand the geomorphology and hydrology of the Kelly Hill area, including the Cape Bouguer karst to the south. Height data are derived from the 1m resolution LIDAR data flown by AAM Hatch in 2020 and supplied by the Department for Environment and Water. The cave locations and height range data come from the Friends of Parks Kelly Hill Caves group of the South Australian Speleological Council.

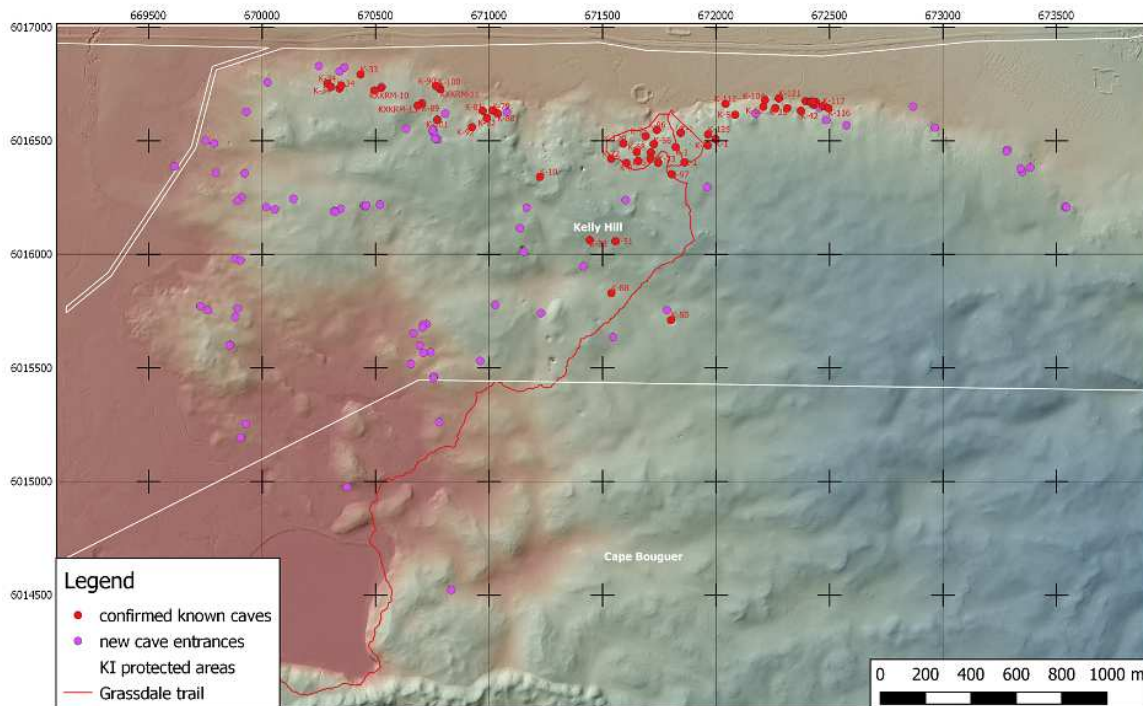


Figure 2: LIDAR terrain model showing known dolines and cave entrances as at May 2022. Data from AAM Hatch Pty Ltd, courtesy of South Australian Dept. for Environment and Water.

The main driver for cave development in the Kelly Hill ridge has been water flowing off deeply weathered Cambrian metasediments to the north, in the catchment of the South West River (Figure 3). There are several water sink points along the northern side of the Kelly Hill ridge, and these are today at altitudes between 18 and 19.5 m above sea level. Water sinking into the limestone would have dissolved an extensive network of passages forming a maze with solutional spongework. The base level for these caves would have been controlled by the

contact with the underlying Cambrian metasandstone, which effectively forms an aquiclude below the limestone. Water flows down gradient to the coast and is also fed by active water sinks on the margins of the Grassdale Lagoon at 4.5 m above sea level. This karst water emerges at the base of a bluff 1km upstream of the coast on the South West River, as well as seepage springs at the base of the sea cliffs, and periodically as freshwater upwelling's reported off the coast by fishermen (Mike Bald and Peter Davis, pers. comm.)

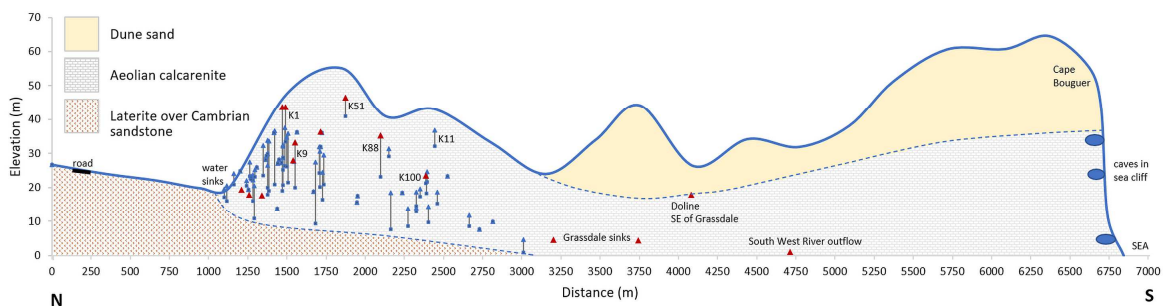


Figure 3: North-south geomorphological cross-section through the Kelly Hill karst

On the high ridge to the south of the Kelly Hill tourist cave (K1) is an extensive deposit of lateritic gravels which may have been washed from the ridge to the north prior to the incision of the South West River. This would suggest that the initial cave development may have occurred by water sinking at a

much higher level (40-45 m ASL) in the landscape than it does today. Following uplift and lowering of the water table, collapse domes formed in the relatively weak and unconsolidated dune limestones. To the south of the Kelly Hill ridge, near Frosted Floor Cave K11, the limestone is overlain by

Holocene dune sand of variable thickness which reaches a maximum height of 65 m at Cape Bouguer. There are several large enclosed depressions to the south-east of Grassdale Lagoon, and water sinking there is also likely to drain to springs at the coast. These have been briefly investigated but no cave entrances have yet been found.

The majority of mapped caves on Kelly Hill have a vertical range of 4-6 m, while a secondary group has a range of 10-12 m (Figure 4). The few caves with a

vertical range from 16 to 20 m include K1, K11 (Frosted Floor) and K34 (New Year's Day Cave), all of which are located high on the Kelly Hill ridge. The heights of cave entrances in the Kelly Hill ridge appear to fall into four groups, with the highest entrances between 40 and 47 m above sea level, a group between 32 and 36 m, and another group on the western side of the ridge whose entrances are around 24-28 m above sea level (Figure 5).

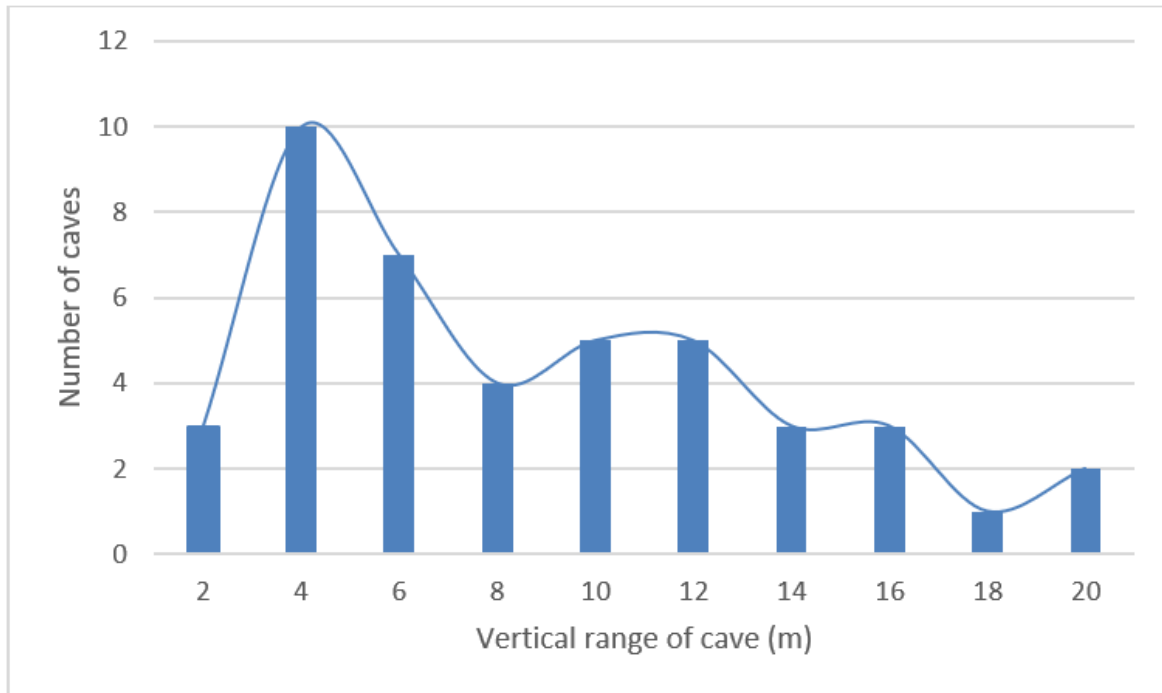


Figure 4: Histogram of vertical range of individual caves on Kelly Hill

In the sea cliffs at Cape Bouguer and elsewhere (Myroie & Myroie, 2009), there are flank margin caves developed at altitudes of 35, 20 to 25 and 6 m above sea level. The higher caves are most likely to be relict features as the result of uplift over the last two million years. The caves at +6 m relate to the Last

Interglacial sea level, some 125,000 years ago. There are several sea caves at this level along the coast between Cape Bouguer and the Stun'sail Boom River mouth. It is interesting that the base levels of caves in the Kelly Hill ridge appear to approximately correlate with both the 32-35 m and 20-25 m cave levels.

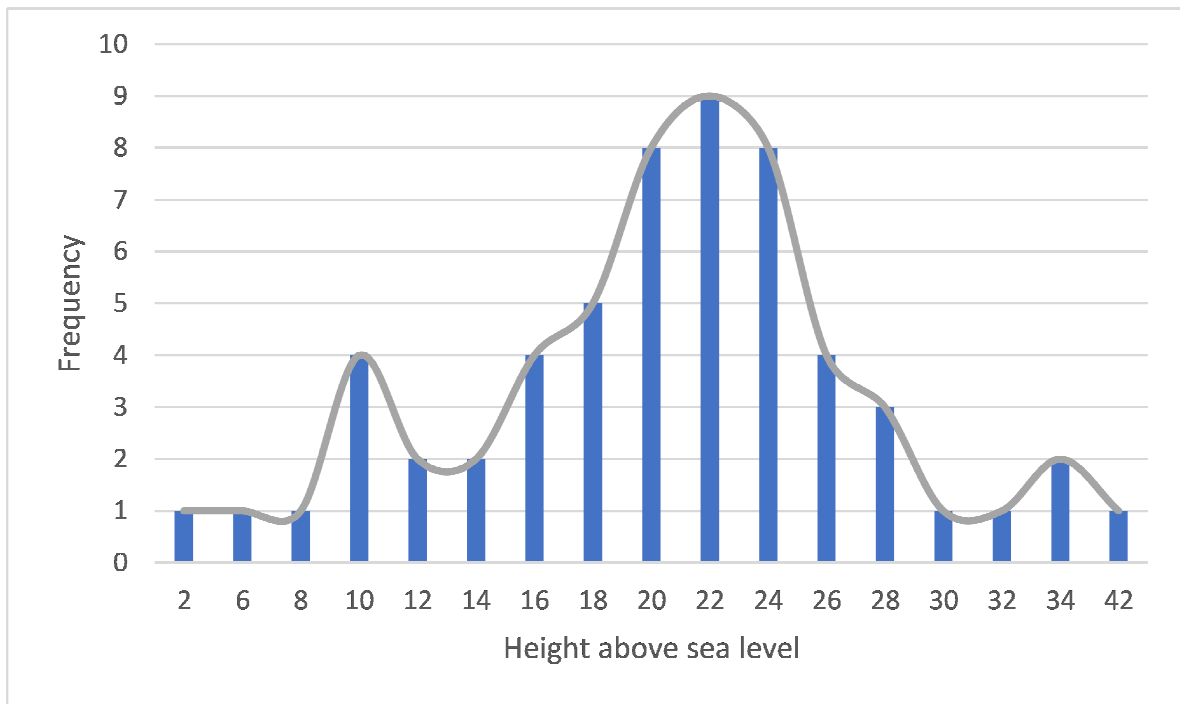


Figure 5: Histogram of lowest point in caves above mean sea level

Subsequently, valley incision and uplift on the south coast drained; the lagoon drained, and an on-going process of collapse ensued in the caves. The loss of hydraulic support for the cave roofs resulted in a series of tensional arches (Hill, 1984) in which the cave roofs became too wide to support their own weight. This process continued until they formed structurally stable arches, some of which open to the surface as dolines (Hill, 1984). This process of cave development is primarily controlled by the soft, porous nature of the limestone and its lack of jointing. Hill's pioneering work has now been applied to many caves formed in dune limestone in southern Australia.

In the Kelly Hill caves, the cross sections through the main passages are remarkably consistent, with tensional collapse domes linked by short rift passages (Figure 6). The domes are all between 15 and 20 m across and the rift-like sidewalls are generally choked with collapse debris. Subsequent to the collapse, there has been extensive speleothem decoration and the varied orientations of stalagmites would suggest that the sinking or rafting down of limestone blocks on the floor is ongoing. In many places, the collapse domes have breached to the surface to provide sinkholes while in other places, solution pipes, probably associated with tree roots, provide access to the domes.

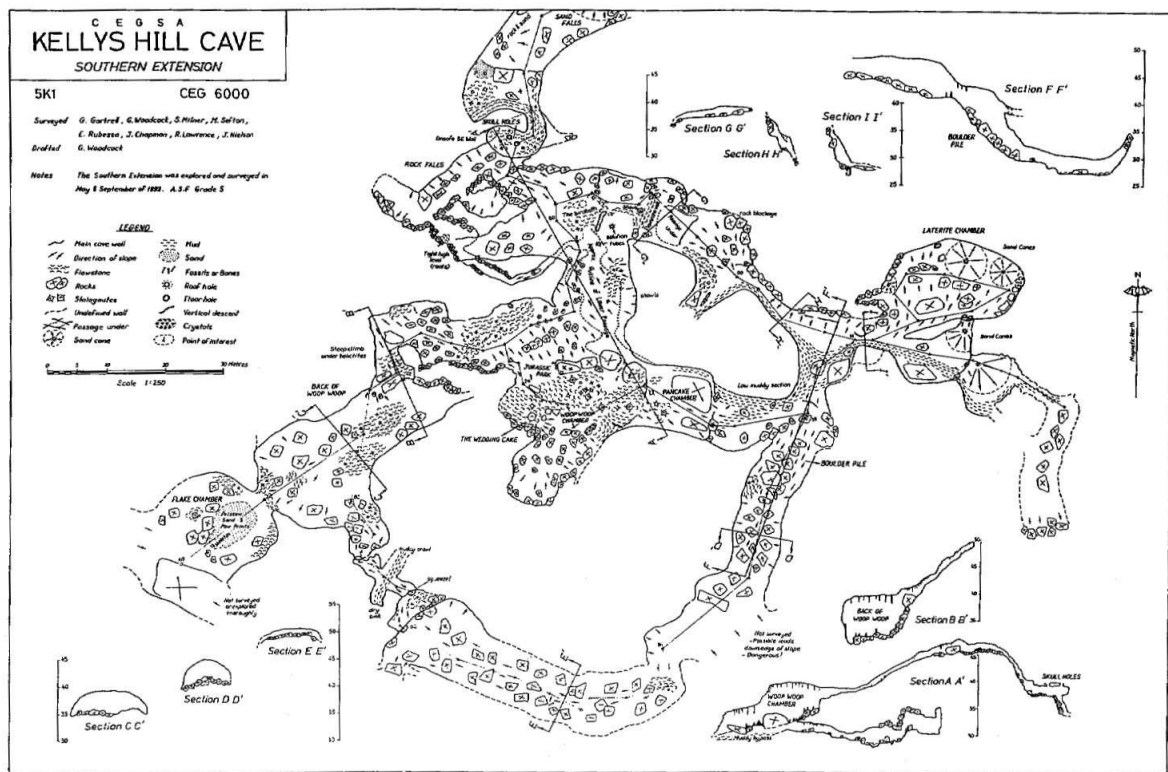


Figure 6: Map of Kelly Hill Cave's southern extension, courtesy of CEGSA

Conclusions

The Kelly Hill karst is a syngenetic karst with marginal mixing corrosion, and collapse domes in many caves. The underlying Cambrian metasandstone acts as an aquiclude, with water flows down gradient to the coast also fed by active water sinks on the margins of the Grassdale Lagoon. Pleistocene uplift has driven landscape incision and development of caves at several levels in the dune limestone from 10-12 m, 20-25 m and 30-35 m ASL. There are

multiple caves at +3 m to +4.5 m ASL, probably of Last Interglacial age, and – from this – it would seem no uplift has occurred since then. Coastal springs and submarine upwelling's are active after heavy rain.

Acknowledgements

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