# QUATERNARY GEOLOGIC INTERPRETATIONS FROM FLANK MARGIN CAVES, KANGAROO ISLAND, AUSTRALIA

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**ABSTRACT 27- 4**

Flank margin caves have been observed in Quaternary Bridgewater Formation eolianites on Kangaroo Island, South Australia. High wave energies on exposed coasts have stripped sufficient eolianites from the underlying Kamantoo Group basement rocks, where present, that flank margin caves have also been removed. In embayments and stream outlets, protected conditions have resulted in flank margin caves being preserved. At Snake Lagoon on the west coast, flank margin caves are found in horizons at approximately 25, 30 and 35 m elevations. These cave horizons demonstrate tectonic uplift in the 30 m range (given prior glacioeustatic sea-level positions of up to +6 m), and that such uplift was partially episodic. A wave-cut notch at Hanson Bay on the south side of the island, at 35 m elevation, also supports this cave interpretation. Admirals Arch at Cape du Couedic on the southwest tip of the island, previously presented as forming solely by wave erosion, is a flank margin cave breached and modified by wave erosion working upward along the slanting Bridgewater Formation/Kamantoo Group contact. Point Ellen on the southeast side of the island, contains a Pliocene subtidal carbonate unit, the Point Ellen Formation. Wave-rounded boulders of the underlying Kamantoo Group basement rocks in the lower beds of the Point Ellen Formation indicate that the unit formed within the reach of wave base. Bridgewater eolianites overstep a cliff in the Point Ellen Formation, with a paleotalus in between. Elsewhere in the outcrop, a well-developed epikarst and terra rossa paleosol separate the Point Ellen and the Bridgewater Formations. These features demonstrate that the Point Ellen Formation was uplifted, cliffed by wave processes, and then was karstified before being buried by Bridgewater Formation eolianites, and that the paleokarst surface marks the Plio-Pleistocene transition. A possible flank margin cave at 3 m elevation here supports interpretations of last interglacial notching of the nearby coast, and therefore no tectonic uplift in the last 125 ka. The granite tafoni of Remarkable Rocks on the southwest coast contain interior cuspate bedrock forms, presenting a cautionary note on the use of cave wall characteristics as proof of dissolutional origin.

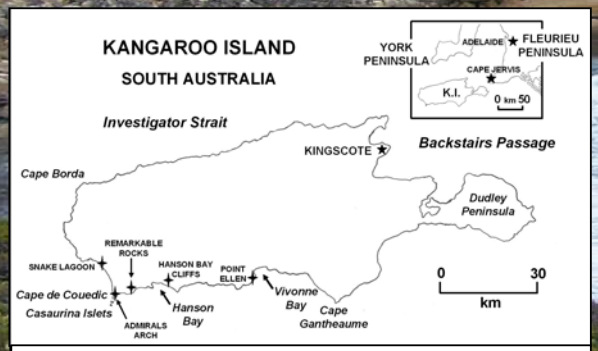


Figure 1. Map of Kangaroo Island, SA, showing locations of the study sites.

Kangaroo Island is located 16 km southwest across the Backstairs Passage from Cape Jervis on the Fleurieu Peninsula, South Australia (Figure 1). The island is a rectangle roughly 145 km east to west, and 60 km north to south, with an area of 4,350 km$^2$, and a coastline length of 457 km (Short and Fotheringham, 1986). Kangaroo Island is a geologically diverse environment, with rocks present from the Proterozoic through the Paleozoic, Mesozoic and Cainozoic (Belperio and Flint, 1999). The island is considered geologically to be an extension of the Fleurieu Peninsula on the Australian mainland (Belperio and Flint, 1999; James and Clark, 2002). Although isolated Paleozoic outcrops of carbonate rock exist on Kangaroo Island, the dominant carbonate units are Cainozoic (James and Clark, 2002). Especially prevalent, primarily along the southern and western coasts, are eolian calcarenites of Late Pliocene through Holocene age (Ludbrook, 1983; Short and Fotheringham, 1986).

Flank margin caves form by mixing dissolution in the distal margin of the fresh-water lens, under the flank of the enclosing landmass (Mylroie & Carew, 1995). These cave types have been described extensively from the eolian calcarenites of the Bahamas (Mylroie & Mylroie, 2007), and the research reported here describes the first record of flank margin caves in eolian calcarenites on Kangaroo Island, South Australia. This research also describes how flank margin caves can assist in answering some questions regarding Quaternary processes on Kangaroo Island.

Flank margin caves must be differentiated from pseudokarst caves, such as sea caves (Waterstrat, 2007) and tafoni caves (Owen, 2007). They must also be differentiated from traditional turbulent-flow (epigenic) caves (Mylroie & Mylroie, 2007). As flank margin caves develop in a coastal setting, they mark sea-level position when they formed, that setting also means they are vulnerable to coastal processes (Figure 2). Flank margin caves on Kangaroo Island are preferentially preserved in areas of muted wave energy, as in lagoons and protected bays (Figure 3).

Figure 4. Breached flank margin cave with speleothems altered by open-air exposure, Snake Lagoon.

Flank main caves can be differentiated from sea and tafoni caves by the presence of speleothems and dissolutional rock surfaces (Figure 4). Bedrock notches produced by wave action (Figure 5) occur at the same elevation as flank margin caves (Figure 3).

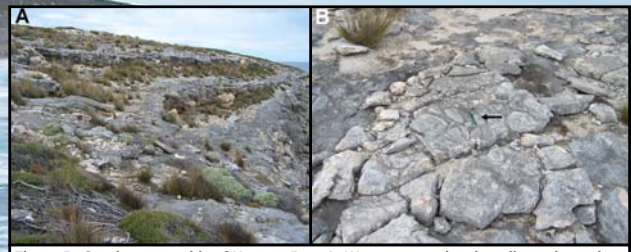


Figure 5. Southeastern side of Hanson Bay. A: Wave-cut notches in eolian calcarenites ~35 m above sea level. B: Cemented rubble facies of sub-rounded clasts in a white and gray matrix, typical of a wave rubble facies, and unlike a terra rossa paleosol.

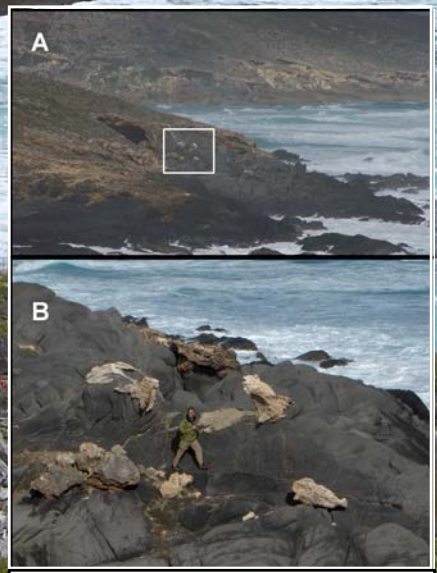


Figure 2. West coast of Kangaroo Island. A: Kamantoo Group basement rocks with Bridgewater Formation eolian calcarenites stripped back by wave action. B: Close up (white square) shows remnant eolian calcarenite outcrops.


Figure 3. Flank margin cave horizons at Snake Lagoon. A: Caves at ~25 and ~ 30 m elevation, north side of Snake Lagoon. B: Caves at ~25 m, ~30 m and ~ 35 m elevation on the south side of Snake Lagoon.


Figure 6. Overview of Cape de Couedic and Admirals Arch. Background islands are the Casaurina Islets, Admirals Arch east entrance in foreground. Arrow locates cave in Figure 7A.

Admirals Arch is a large void penetrating a rocky point composed of Bridgewater Formation eolian calcarenites overlying Kamantoo Group basement rocks (Figure 6). The steep eolianite cliffs to the east contain a number of breached flank margin caves (Figure 7). The public display on the tour path presents Admirals Arch as a product solely of wave erosion. However, visual examination of the north wall of the Arch reveals that it has a series of phreatic dissolution pockets (Figure 8C), and that the original floor of the arch was horizontal, and developed in eolianite above the dipping contact with the underlying Kamantoo Group basement (Figure 8A and 8D). The cave has abundant calcite speleothems. Admirals Arch is a breached flank margin cave, modified by wave action on the current (and perhaps last interglacial) sea-level highstand(s). The phreatic dissolution surfaces and abundant calcite speleothems indicate a cave that formed by phreatic, mixed-water dissolution, then was drained such that vadose speleothems could develop in a sealed cave chamber.

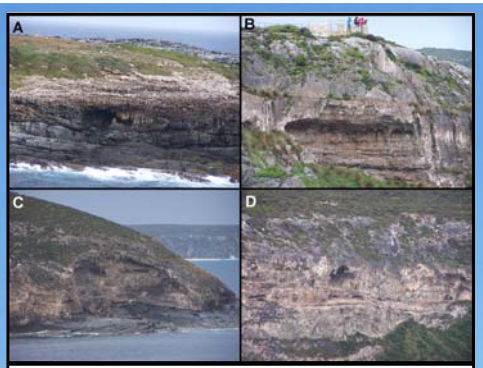


Figure 7. Caves in the Admirals Arch area. A: Cave at the eolianite-basement contact, Casaurina Islet. B, C, and D: Breached flank margin caves in cliffs east of the Arch.

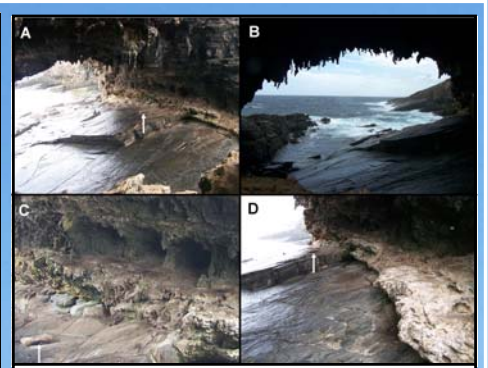


Figure 8. Images from Admirals Arch. A: View NW into the Arch. B: Silhouette of stalactites. C: Phreatic pockets in north wall. D: Original flat eolianite floor. Arrows show seals 1.5 m long.

The Point Ellen Fm, Vivonne Bay, is a fossiliferous Late Pliocene limestone with a cave formed in it (Figure 9A). The cave's origin is uncertain, it may be a Holocene sea cave or perhaps a Late Pleistocene flank margin cave.


Figure 9. Point Ellen outcrop. A: Outcrop panorama. B: Mollusc shells diagnostic of the Point Ellen Formation (pencil 15 cm). C: Kamantoo Group basement rocks overlain by Point Ellen Formation subtidal facies, overlain in turn by Bridgewater Formation eolian calcarenite.


Figure 11. Cave outcrops at Point Ellen. A: Eolianite cave roof with solution pits penetrating the Point Ellen Fm. B: Horizontal Contact of the Bridgewater Fm with the underlying Point Ellen Fm (vertical arrow). C: Solution pipe vertical contact, post-Bridgewater Fm pipe fill on left, Point Ellen Fm on right. Pencil 15 cm long.

The rock units above and below the Point Ellen Fm, and their contacts with that unit, reveal a shallow water origin for the Point Ellen, its passage up through wave base, and karstification of its surface.

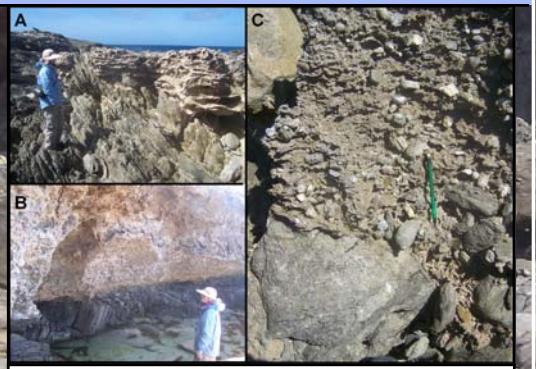


Figure 10. Outcrop contacts. A: Eolianite directly on Kamantoo Group rocks. B: Planated Kamantoo Group rocks under Point Ellen Formation; Kamantoo boulders higher in the section. C: Basal Point Ellen Formation with molluscs and Kamantoo Group rubble.

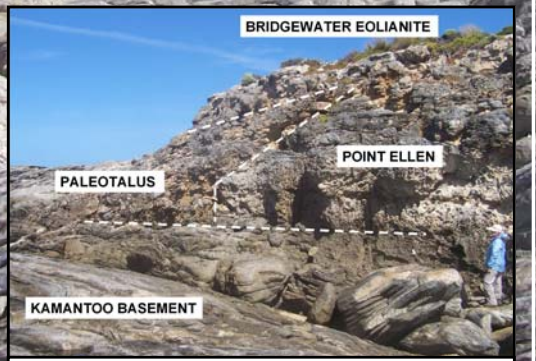


Figure 11. Outcrop showing Kamantoo Group rocks on the right overlain by the Point Ellen Fm, in turn overlain by the Bridgewater Fm. To the left, the Point Ellen Fm has been cliffed, and a paleotalus separates the Bridgewater and Point Ellen Fms.


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The identification of flank margin caves requires study of cave morphology and contents (Figure 12). Confusion can occur, as Figure 13 shows.


Figure 12. Flank margin cave features, Snake Lagoon. A: Abundant speleothems in a breached cave. B: Interconnecting cave chambers. C: View of cave location at the coast, high above Kamantoo Group rocks. D: Smooth back walls and speleothems of breached caves.

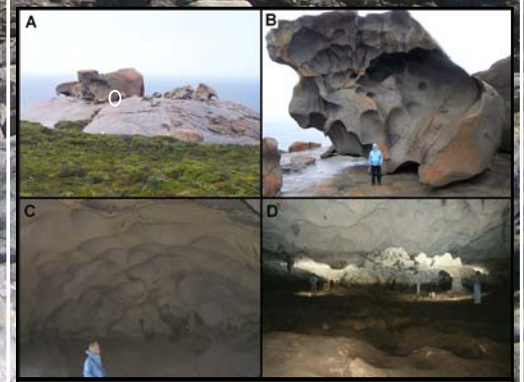


Figure 13. Remarkable Rocks, tafoni development in granite. A: Overview of Remarkable Rocks. B: Tafoni with irregular pockets. C: Roofed tafoni with cuspate interior. D: Salt Pond Cave, Long Island, Bahamas, showing a cuspate ceiling similar to (C).