Syngenetic Karst in Australia: a review

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Abstract

In syngenetic karst speleogenesis and lithogenesis are concurrent: caves and karst features are forming at the same time as the lose sediment is being cemented into a soft, porous rock. "Eogenetic karst" and "soft-rock karst" are closely related terms for features developed in soft, poorly-consolidated limestones. The distinctive features of syngenetic karst are: shallow horizontal cave systems; a general lack of directed conduits (low irregular chambers occur instead); clustering of caves at the margins of topographic highs or along the coast; paleosoil horizons; vertical solution pipes which locally form dense fields; extensive breakdown and subsidence to form collapse-dominated cave systems; a variety of surface and subsurface breccias and locally large collapse dolines & cenotes; and limited surface sculpturing (karren). These features are best developed in host sediments that have well developed primary matrix permeability and limited secondary cementation (and hence limited mechanical strength), for example dune calcarenites. Certain hydrological environments also assist: invading swamp waters or mixing at a well-developed watertable; or, near the coast, mixing at the top and bottom of a freshwater lens floating on salt water. Where these factors are absent the karst forms tend to be more akin to those of classical hard-rock or telogenetic karst.

keywords: syngenetic karst, eogenetic diagenesis, soft-rock karst, dune calcarenite, solution pipes, Australia..

Introduction and terminology

Syngenetic karst is a term coined by Jennings (1968) for karst features, including caves, that form within a soft, porous, soluble sediment at the same time as it is being cemented into a rock. Speleogenesis and lithogenesis are concurrent. Jennings based his discussion partly on prior observations reported in Bastian (1964) for Western Australia in Sexton (1965) and Hill (1984) for South Australia (Hill's paper was written in 1957, but published posthumously).

Jennings was describing the active karst geomorphology of the Quaternary dune calcarenites of Australia. Concurrent studies by sedimentologists of paleokarst horizons at unconformities in the stratigraphic record used the related concept of **eogenetic diagenesis:** processes that affect a newly-formed carbonate or evaporite sediment when it is exposed to subaerial weathering and meteoric waters (Choquette & Pray, 1970). The resulting eogenetic karst (or "soft-rock karst") is distinguished from telogenetic ("hard-rock") karst that has developed on hard, indurated limestones that have been re-exposed after a deep burial stage.

Choquette & Pray (1970) defined three major stages in diagenesis of limestones (Figure 1). **Eogenetic diagenesis** refers to processes affecting recently deposited sediments prior to deep burial . The processes include cementation and solution (with brecciation) by meteoric waters with aragonite being dissolved or replaced by calcite. **Mesogenetic diagenesis** starts after the sediment is buried; and for limestones involves further cementation, re-crystallisation and pressure solution (e.g. styolites). **Telogenetic diagenesis** occurs after uplift and erosion returns the limestone to the surface where meteoric waters can dissolve the (now well-cemented) limestone to form "classic" (hard-rock) karst.

The porosity or permeability of any limestone can be represented as a ternary diagram (Figure 2a) showing the relative amounts of intergranular, fissure and conduit permeabilities. These proportions change during the diagenetic evolution of a limestone. For the dune limestones discussed in this paper, permeability tends to be proportional to porosity, but that is not necessarily so for some other lithologies, such as the European Chalk.

During eogenesis the initial intergranular permeability of the sediment is typically partly occluded by cement, and partly replaced by solutional porosity – which can be of various types, both fabric selective (e.g. moldic) or non-fabric selective (e.g. solution channels), as discussed by Choquette & Pray (1970). Some fracture permeability may locally result from brecciation. In the case of a soft-rock karst, which has never been deeply buried, that is generally as far as the permeability evolution goes (lower arrow in Figure 2b), though the details can be more complex than the simplified overview given above.

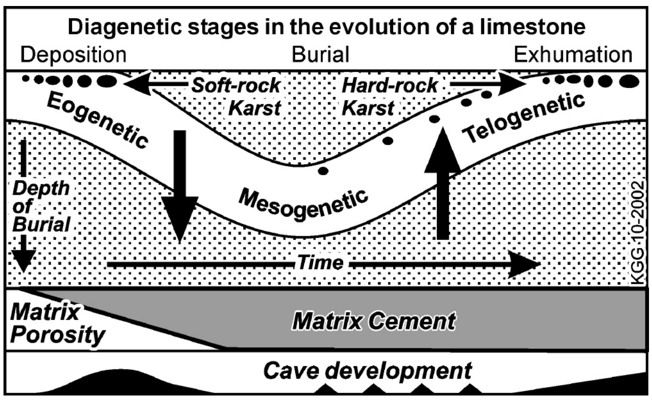

Figure 1: Diagenetic stages in the evolution of a limestone, and of its karst. Black dots indicate possible cave formation.

Syngenetic Karst.

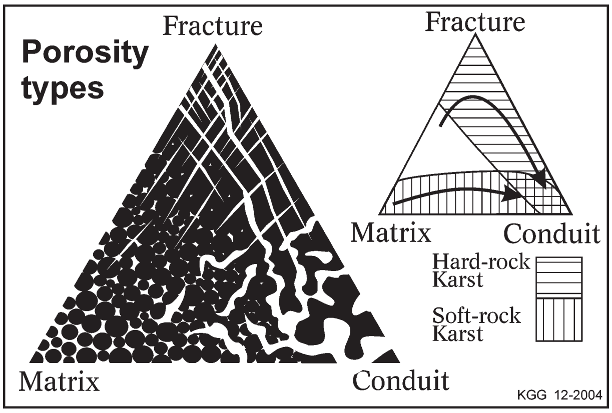

Figure 2: Limestone porosity types,
A: (left) the three types of porosity and permeability which can each contribute to the overall karst porosity; and
B: (right) evolution of the dominant permeability in hard-rock and soft-rock karsts.

In a hard-rock karst, further cementation and compaction during mesogenesis completely destroys the primary permeability and a secondary joint-controlled fracture permeability replaces it. If deep-seated aggressive waters are present (during mesogenesis) or on re-exposure to meteoric waters (telogenesis) the proportion of conduit permeability becomes progressively greater (upper arrow in Figure 2b).

Early diagenetic effects can be preserved within later diagenetic textures. These include paleokarst cavities, infills and breccias. Dissolutional permeability generated during the eogenetic stage of paleokarsts can direct water flow and further dissolution during the later mesogenetic and telogenetic stages, and can also host ore minerals or hydrocarbons. Large solutional cavities (i.e. caves) can form in all three diagenetic stages, but are most common in the eogenetic and telogenetic stages. Those formed in the mesogenetic burial stage are generated from deep hot waters, or from acidic waters derived from oxidation of hydrogen sulphide or pyrite. Repeated cycles of uplift, exposure and reburial can form multiple ages of telogenetic paleokarst features (e.g. Osborne, 2002).

With reference to karst, the terms "syngenetic" and "eogenetic" overlap in their meaning, but involve different viewpoints. I suggest that the former is best used for geomorphological studies of modern soft-rock karsts; whereas the latter is best retained for diagenetic studies of paleokarst permeabilities, where the sequence of dissolution and cementation events is much more complex. Some, but not all, paleokarst is eogenetic (Figure 1): the separation of eogenetic, mesogenetic, and telogenetic features requires a detailed study of cement morphology, mineralogy, chemistry, and related dissolutional and brecciation features; at both the microscopic and macroscopic scale (Moore, 1989, 2001). Recently some authors have applied the term "eogenetic karst" to modern syngenetic karst features (e.g. Mylroie & others, 2001) – I recommend retaining "syngenetic" for that setting.

Soft-rock Karst is a more general concept that includes both early and late syngenesis (see below), and also more mature sediments that have not been deeply buried and indurated, but in which the early, weak, cementation is essentially complete. In addition to the dune limestones, examples of soft-rock karst include the mid Tertiary marine calcarenites of Australia (Lowry & Jennings, 1974, Grimes, 1994, Gillieson & Spate, 1998, Grimes & others 1999, White, 2005, Grimes & White, 2006), as well as some of the limestones of the Yucatan (Lesser & Weidie, 1988; Beddows, 2004) and Florida (Miller, 1990). The Cretaceous chalk of Europe is a special case of a moderately consolidated limestone that has both a very fine-grained matrix porosity and well-developed fractures – forming linear caves (Rodet, 1991; Gunn & others, 1998).

Quaternary dune calcarenites, or aeolianites, show the best development of syngenetic karst. Examples include those of Australia (e.g. Bastian, 1964, 1991, 2003; Sexton, 1965; Hill, 1984; Jennings, 1968; White, 1994, 2000; Grimes & others, 1999; Grimes, 2002; Eberhard, 2003, 2004), South Africa (Marker, 1995), Bermuda (Mylroie & others, 1995), the Caribbean (e.g. Mylroie & others, 1995, Lundberg & Taggart, 1995), and parts of the Mediterranean (e.g. Ginés, 2000, Marsico & others, 2003).

However, other permeable calcarenites, such as beach and shallow marine sands, can also develop distinctive syngenetic features; in particular solution pipes, calcreted caprocks and extensive collapse modification. Examples include the mid Tertiary Gambier and Nullarbor limestones in Australia cited above. For less permeable facies, such as micritic lagoonal limestones of oceanic islands, cementation is stronger and there is greater joint control so the syngenetic karst is more akin to the classical hard-rock karsts (Mylroie & others 2001, Grimes 2001). Other soluble sediments (gypsum, halite) can also develop syngenetic karst when exposed to subaerial conditions shortly after their deposition (e.g. Sando, 1987) but these will not be discussed here.

In the following discussion, Australian dune calcarenites in a "Mediterranean" climate are used as an example.

The Development of Syngenetic Karst

In calcareous dunes, percolating rain water gradually converts the unconsolidated sand to limestone by dissolution and redeposition of calcium carbonate. Initial solution at the surface forms a terra rossa or similar soil depleted in carbonate but enriched in the insoluble grains (e.g. quartz). At the base of the soil precipitation of carbonate forms a cemented and locally brecciated calcrete layer or hardpan, also known as caprock, which follows the contours of the surface (Figure 3). In some places cemented bands also occur deeper within the dune body: some of these may be buried paleosoils, others may indicate levels of saturated groundwater. Within and below the hardpan the downward percolating water becomes focussed to dissolve characteristic vertical solution pipes (Figure 12), and simultaneously cements the surrounding sand. Early cementation tends to be localized about roots to form distinctive rhizomorphs or rhizocretions (Figure 8). Cementation can progressively occlude the primary inter-granular permeability, but simultaneously dissolution can generate localized secondary permeability of a moldic, vuggy or cavernous character.

Mixing corrosion occurs where percolation water meets the water table, which, for dune calcarenites, is commonly controlled by the level of a nearby swampy plain that also provides acidic water. In coastal areas, water levels fluctuate with changing sea levels and further complexity results from a fresh-water lens floating above sea water which results in two mixing zones, above and below the thin lens (Mylroie & Carew, 2000, Mylroie & others, 2001; Figure 4). Solution is strongest right at the shore where the lens thins so that, firstly, the two zones overlap (within the fluctuating zone of the sea level) and, secondly, the thinning of the lens causes stronger flow rates which also promotes solution. Tidal pumping may also assist. The result is a "flank margin cave" (Mylroie & others, 2001) that has an irregular form of interconnected "mixing chambers" (Figure 5). The name refers to the tendency for these caves to cluster at the island margin. Similar clustering can occur along the edge of dune ridges adjacent to swamps that provide aggressive water (e.g. Eberhard, 2003,2004).

In the early stages of dissolution (**Early Syngenesis**, Figure 9a) the loose sand subsides at once into any incipient cavities, possibly forming soft-sediment deformation structures (Figure 11). Subsidence dolines may form without caves (as described in South Africa by

Figure 3: Calcreted caprock formed on a sloping dune surface from which the loose soil cover has been stripped. Note the small cavities resulting from erosion of soft sand from beneath it. Cape Dombey, South Australia.

Marker, 1995). An exception is that beneath the caprock, which appears to form quite early, some shallow caves may form. Once the bulk of the rock is sufficiently hardened to support a roof (**Late Syngenesis**, Figure 9b), caves can develop. The presence of buried caprocks (and associated paleosoils) may also assist in cave development. The uniform matrix permeability, slow moving groundwater, and lack of joint control means that directed linear conduits seldom form. Instead, horizontal cave systems of low, wide, irregular, interconnected chambers and passages (Figures 5 & 7) form either in the zone of maximum solution at the water table, or by subsidence of loose material from beneath stable caprock layers. Flat cave ceilings are common (Figure 6): either marking the limit of solution at the top of the water table, or where collapse has reached the base of an indurated (caprock) zone. Bastian (1999) coined the term "watertable slot" for broad horizontal slots, too narrow for humans to enter, that form at the top of the watertable at Yanchep, Western Australia. Where a shallow

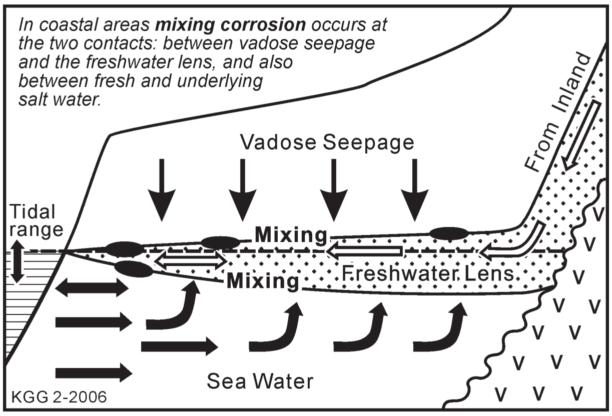

Figure 4: The coastal freshwater lens, and its mixing zones. Caves shown as black ovals. Note that the vertical scale is strongly exaggerated in all diagrams of this type. The lens is thin and the slopes are not as steep as they appear.

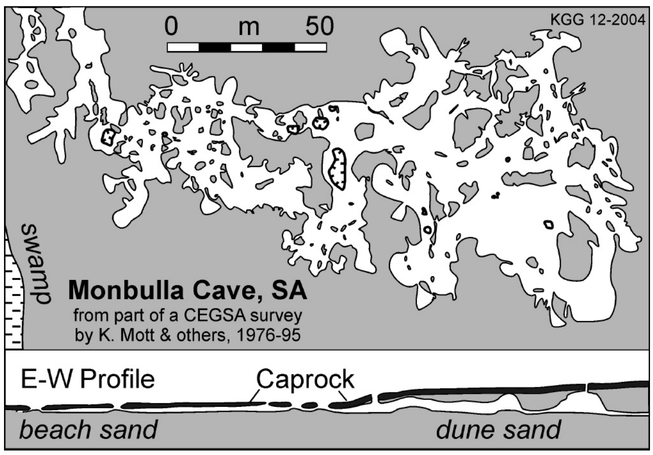

Figure 5: A typical horizontal syngenetic maze cave in dune and beach limestone adjacent to a swamp.

Syngenetic Karst.

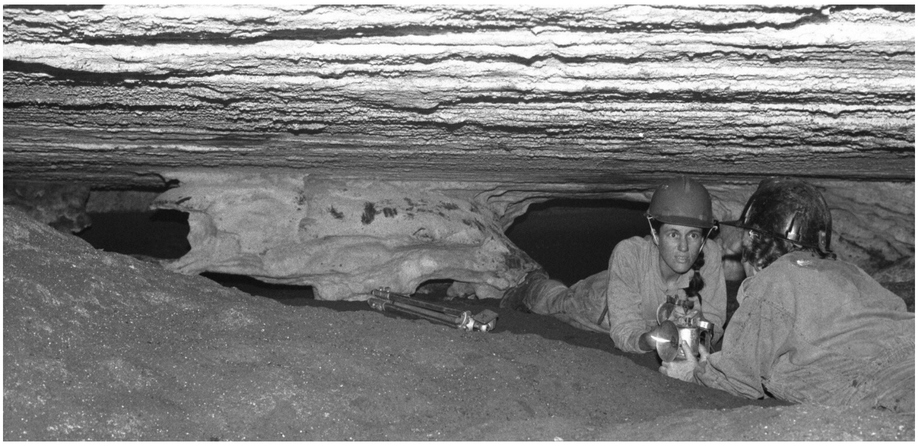

Figure 6: A flat ceiling, with pendant, formed at an old watertable in a syngenetic cave adjacent to a swamp. Bats Ridge, Victoria.

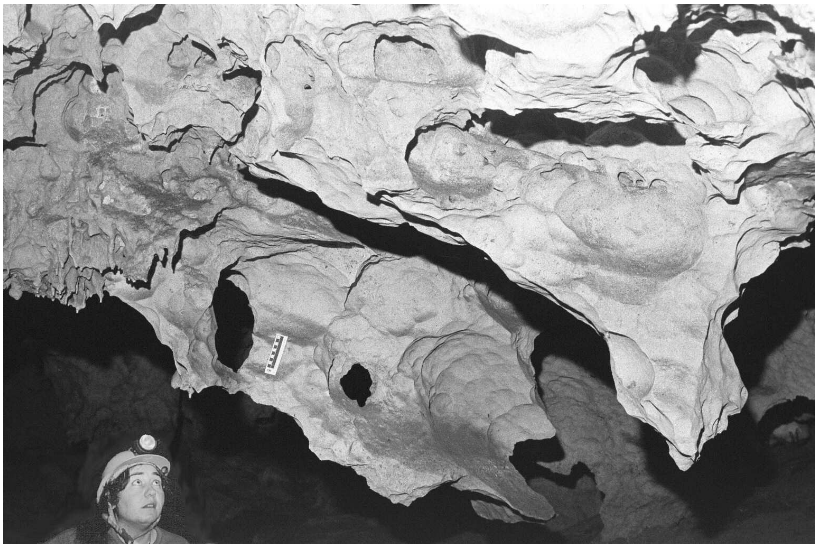

Figure 7: Phreatic spongework in a cave at the margin of a dune. Mt. Burr Cave, 5L-69, Gambier Karst, SA.

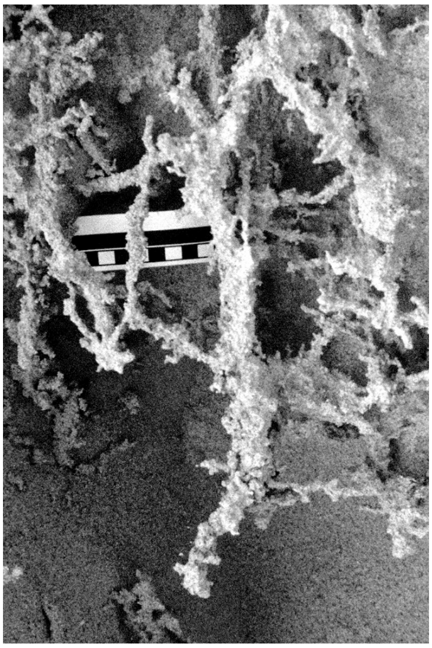

Figure 8: Rhyzomorphs are formed by cementation around roots (Cape Buffon, SA).

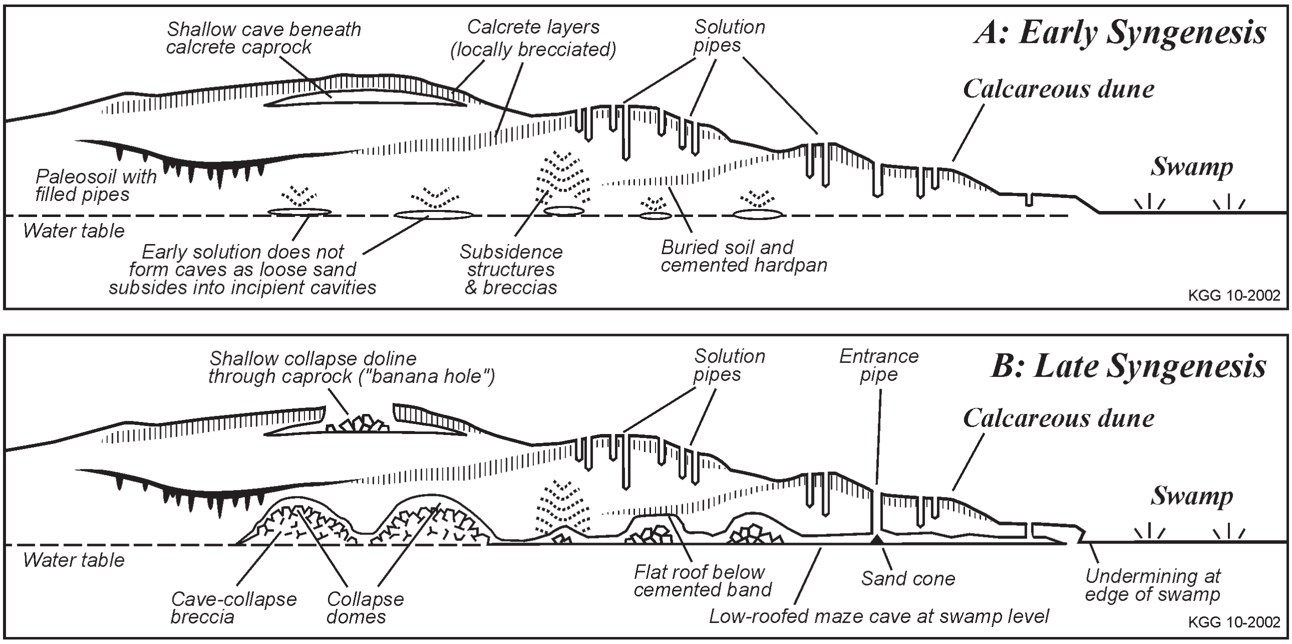

Figure 9: Features of syngenetic karst developed on a calcareous dunefield adjacent to a swamp.
Part A is Early Syngenesis – before the sand is sufficiently cemented to support a cave roof.
Part B is Late Syngenesis – the limestone is now strong enough to support a cave roof.

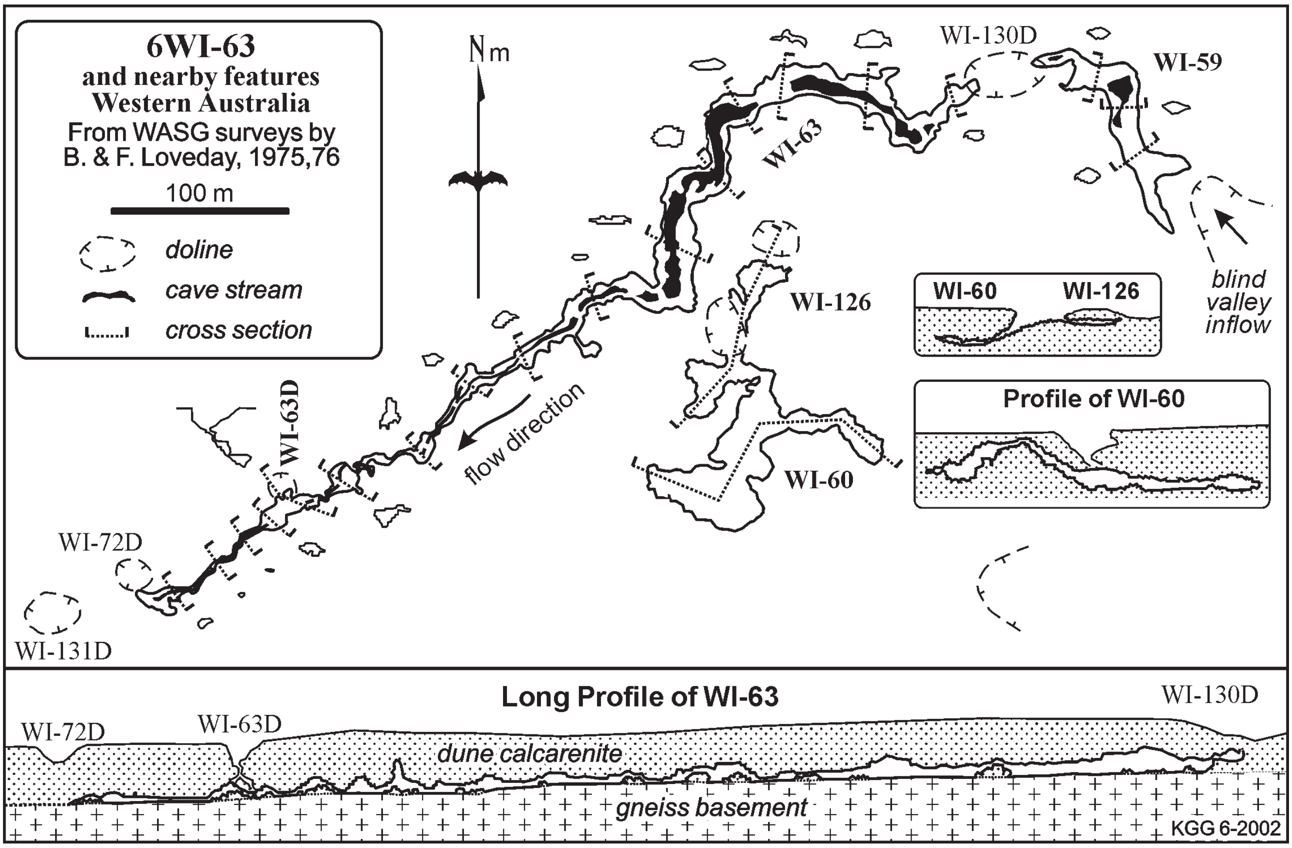

Figure 10: A linear stream cave that follows the basal contact between the porous dune limestone and impermeable gneiss. Note the downstream decrease in passage size, away from the source of aggressive water

impermeable basement occurs, as in southwest Western Australia, the paleo-topography may concentrate water flow along buried valleys to form linear stream caves (Figure 10). Strong flows, in areas of steep gradients, can also concentrate flow into linear paths and form stream caves, as at Yanchep (Bastian, 2003).

Collapse is ubiquitous in these soft rocks and large collapse domes commonly obscure much of the original solutional cave shape (Figure 17). Breccia structures are common in paleokarst exposures, and are also sometimes seen in the walls of modern syngenetic caves or in the calcrete caprocks. Sequences of marine sediments undergoing cyclic emergence can develop eogenetic breccia layers and karst surfaces at the top of each cycle. In coarse-grained sediments preferential dissolution of aragonite fossils (e.g. coral) can form a coarse moldic permeability. Where soluble evaporites are interbedded with carbonates they may be removed completely to undermine the overlying carbonate beds and form extensive intrastratal brecciated layers (e.g. Sandow, 1987). However, such breccias can also form in later mesogenetic and telogenetic settings so are not necessarily eogenetic.

Sizable syngenetic caves can form in less than 100 thousand years (Mylroie & Carew, 2000).

Surface solutional sculpturing (karren) is rare, as there is little solid rock for it to act upon. However, some sculpturing can occur on exposed calcrete layers and sharp fretted phytokarst can form in coastal exposures (e.g. Moses, 2003).

Variations on the above-described styles can occur in different climates, hydrological settings and host sediments. For example, calcrete is supposedly best

Figure 11: Subsidence structures in early syngenesis. The original bedding was horizontal and, after partial cementation of the beds, solution and subsidence of the underlying sand caused the plates to rotate and slide against each other. Further cementation has stabilised the material and allowed a younger cave to form beneath it. 5L-23, Quarry Cave, Monbulla area, South Australia.

developed in semi-arid or seasonally arid climates, whereas dissolution and brecciation are thought to be more abundant in wet climates (Esteban & Klappa, 1983).

Some Features of Syngenetic Karst

Syngenetic karst has several distinctive features as well as many that are shared with classical (hard-rock) karst.

Solution pipes (or, more strictly, dissolution pipes) are distinctive features of syngenetic karst on porous host rocks (Lundberg & Taggart, 1995, Grimes, 2004, Figure 12). They are vertical cylindrical tubes with or without cemented walls, typically 0.3 to 1.0 m in diameter, which can penetrate down from the surface as far as 20 m into the soft limestone. The top is the present surface, or a buried paleosoil (Figure 16). The bottom, where seen, is generally abrupt and hemispherical. The pipes may contain soil and calcified roots (and root growth may

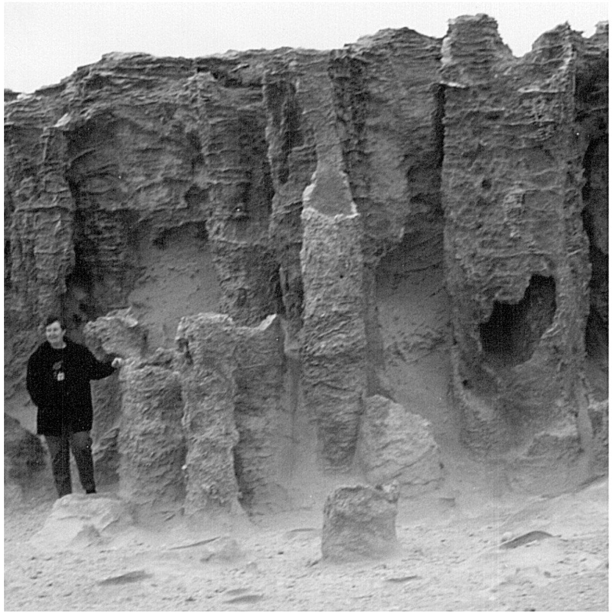

Figure 12: Solution pipes with cemented rims, "The Petrified Forest", Cape Bridgewater, Victoria.

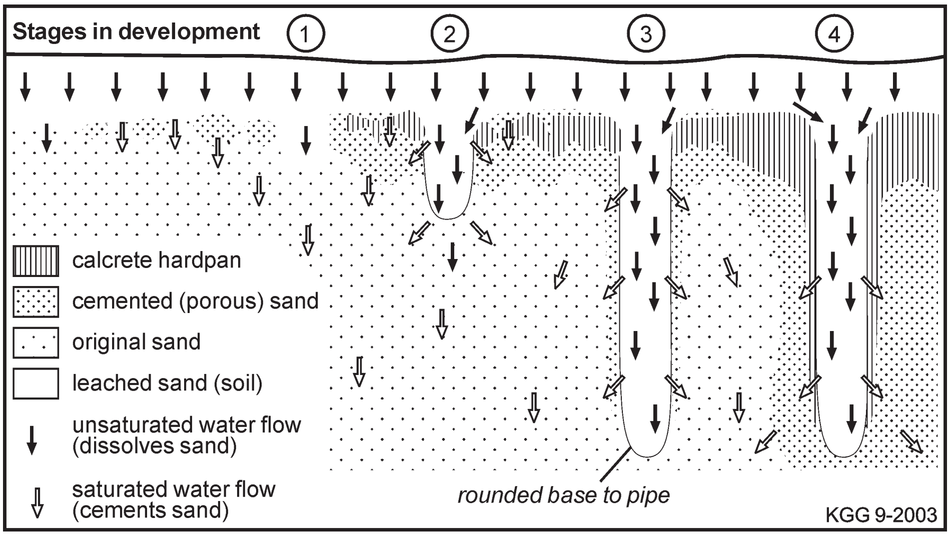

Figure 13: How a solution pipe deepens and develops a rim (from Grimes, 2004).

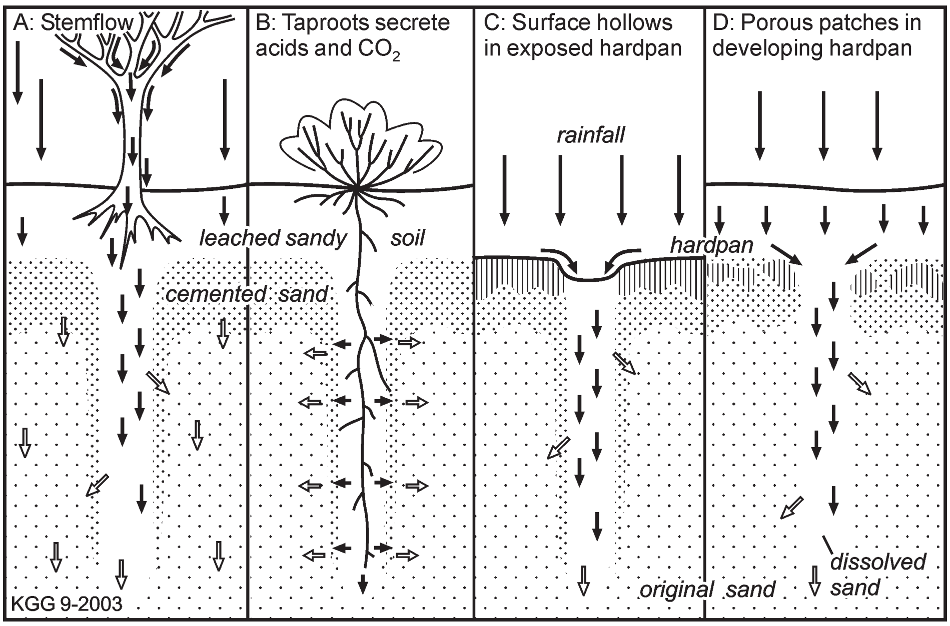

Figure 14: Alternative ways to focus downward flow and generate solution pipes. Note, the alternatives are not mutually exclusive, they could all contribute in different settings (from Grimes, 2004).

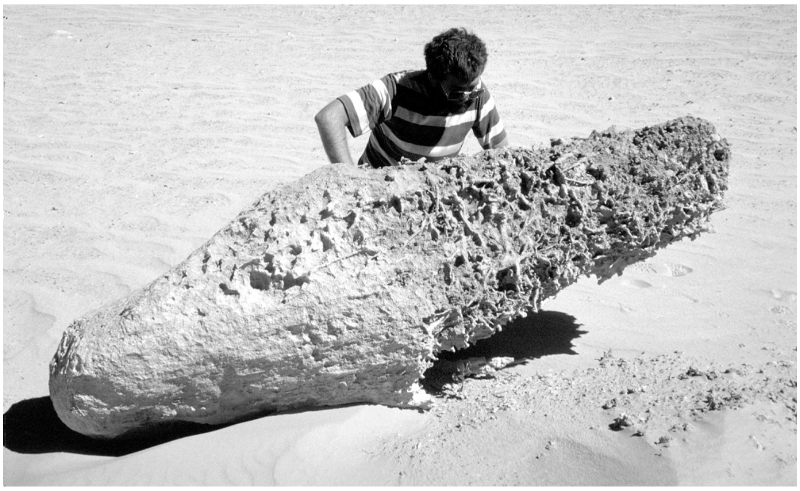

Figure 15: Nambung Pinnacles, WA.

Above: smooth cylindrical pinnacles are developed in a hard calcrete band.

Below: a toppled pinnacle shows a smooth, strongly cemented, upper part and a rougher area below that is less cemented, and mainly composed of rhizomorphs.

have occurred hand-in-hand with dissolution of the pipe). They occur as isolated features, or in clusters with spacings that can be closer than a metre. In the Bahamas they have been referred to as pit caves, but that term also includes larger and more complex vadose features (Mylroie & Carew, 2000). The pipes form by focussed vertical vadose flow through the permeable sediment (Figure 13). The focussing may be spontaneous and associated with partial cementation of the hardpan of the soil, or it may be guided by other factors such as concentrated stem-flow beneath trees, or along tap roots (Figure 14, Grimes, 2004). Solution pipes can also occur as 'cryptokarst' features by focussed solution beneath a permeable but insoluble cover sediment (e.g. Marsico, & others, 2003).

The pinnacles at Nambung (Figure 15) and other parts of the coastal dune limestone in Western Australia might be an extreme case resulting from the coalescence of closely spaced solution pipes in a calcrete band (Lowry, 1973; McNamara, 1995), but they might also involve focussed cementation. The upper part of this band is a hard pedogenic calcrete in which the primary depositional structures have been destroyed, but it grades down into a less-cemented dune sand, with rhizomorphs, where the dune bedding is still visible. The pinnacles have been exposed by wind erosion of the softer sand.

The influence of an impermeable basement: In the southwest of Western Australia, the dune limestone lies on a basement of impermeable gneiss. This has an irregular buried palaeo-topography of old valleys and rises which channels the groundwater flow at the base of the limestone – forming linear stream caves (Williamson, 1980). Figure 10 shows an example taken from Williamson & others (1976). At the coast, if the contact is above sea level, springs may build up tufa terraces (Scott, 2003). Similar basement effects are seen in South

Figure 16:
Red paleosoil with filled solution pipes at the junction between two dune units.
Boozy Gully, SA.

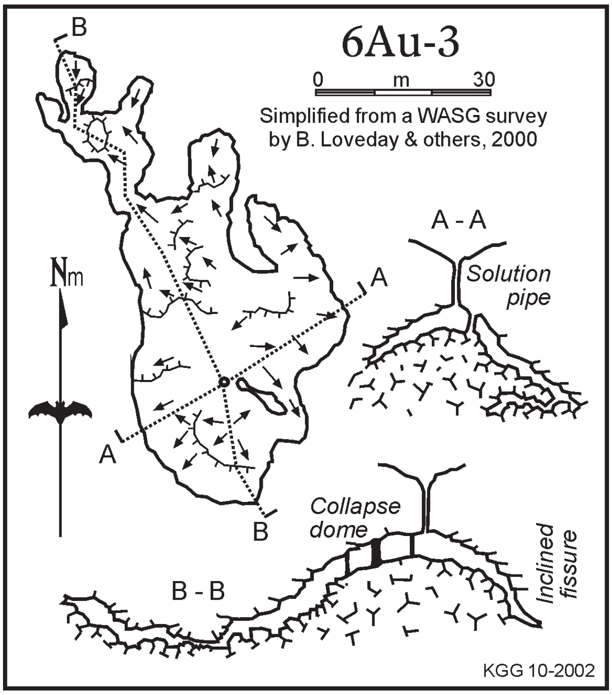

Figure 17: An example of a small breakdown cave with a collapse dome, inclined fissures at the edges, and a solution pipe entrance.

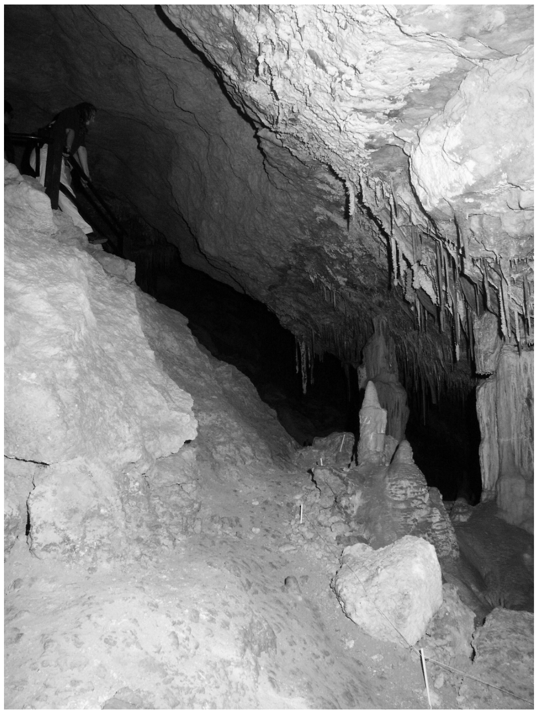

Figure 18: An "Inclined fissure" left at the side of a rubble mound in a collapse dome. Grant Hall, 5U-1, Naracoorte, South Australia.

Australia on the Eyre Peninsula and at Kangaroo Island (Sexton, 1965); and in Victoria at Cape Bridgewater.

Dune swales: Where the watertable is at or above the land surface in the swales between dune ridges, swamps or lakes will form. The aggressive swamp waters can undercut the edges of the dunes to form small cliffs (Figure 6b), and "sharpen up" the topography to form a steep sided, flat floored depression not unlike a polje (e.g. at Codrington, Victoria; Berryman & White, 1995). The analogy to a polje is further emphasised in some places, e.g. Yanchep, where springs feed into the hollow from the inland side, while the swamp water sinks into ponors on the coastal side of the same depression (Figure 20).

Collapse modifications: The subsidence of partly-consolidated material can form a variety of breccias and sag structures; these can be further cemented as diagenesis continues (Figure 11). Mantling breccias can occur as part of the surface soil. Within the caves breakdown of the soft rock is extensive. In many cases the original solutional cave system at the water table is largely replaced by rubble-filled collapse domes (Figure 17). Where the base of the rubble lies within aggressive groundwater the broken material can be dissolved and removed as it falls so that a large open dome will result. If not removed, the growing rubble pile rises faster than does the roof above and eventually meets it. Collapse will stop at this point but narrow spaces may be left around the sides of the domes (Figures 17 & 18). These have been called "inclined fissures" in Western Australia (Bastian 1964), and similar collapse domes and narrow fissures have been described in South Australia (Hill, 1984) and elsewhere (e.g. Ginés, 2000). Subsidence may reach to the surface to form dolines. A special type results from the collapse of the near-surface calcrete band above a shallow cave to form a shallow overhanging doline – the cave could have formed directly from solution at a shallow watertable, or from subsidence of soft unconsolidated sand during the early syngenetic stage. Examples of similar shallow, thin-roofed and partly collapsed caves in the Bahamas have been referred to as a "banana holes" but are attributed to solution at a shallow watertable, without reference to any caprock (Harris, & others, 1995). S.Q. White (pers comm., 2006) reports that there is a caprock effect in the Bahaman banana holes. In extreme cases mass subsidence of broad areas can generate a chaotic surface

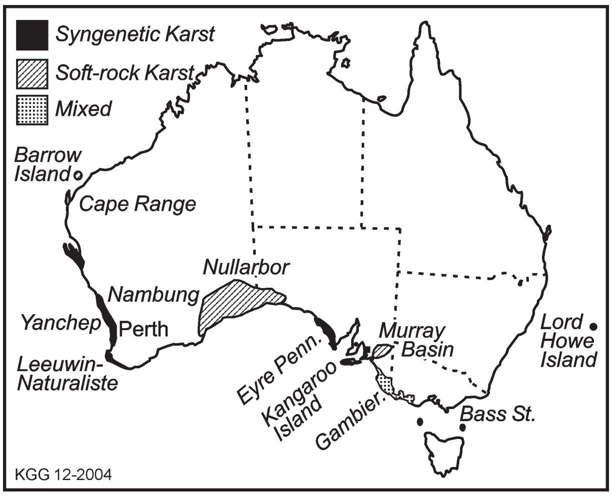

Figure 19: Areas of syngenetic and soft-rock Karst in Australia.

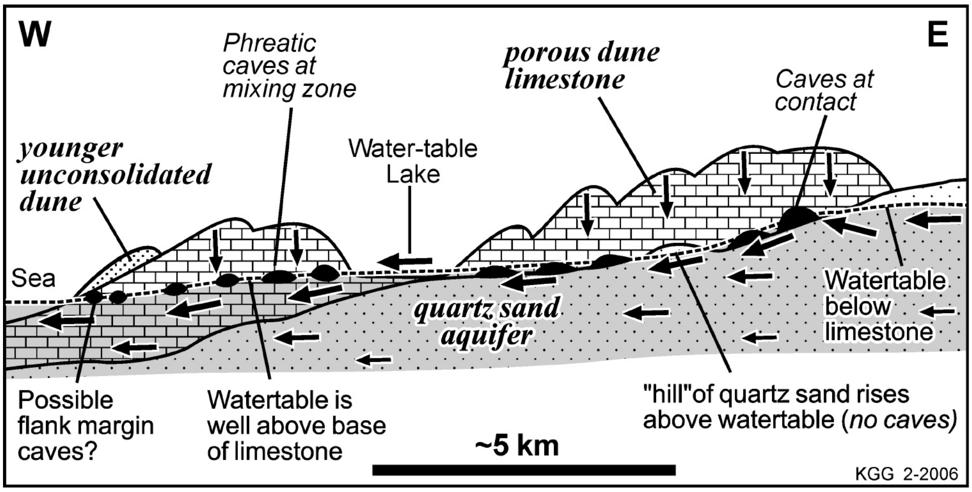

Figure 20: Hydrology of the Yanchep area, WA. A porous dune calcarenite overlies an insoluble quartz sand aquifer (based on Bastian, 1991, 2003)

of tumbled blocks and fissures (Bastian, 2003, p.43). In paleokarst exposures these collapse areas appear as both discordant and concordant (intrastratal) breccias.

Multi-level systems: Fluctuating water tables, possibly controlled by sea level or climatic changes, can result in stacked sets of horizontal cave systems. Rising watertables can flood and partly redissolve speleothems, then re-expose them when the watertable drops (examples occur at Codrington, Victoria).

Syngenetic Karst in Australia

In Australia, syngenetic karst and soft-rock karst are largely restricted to a coastal belt running from Barrow Island down the western coast, and then along the southern coast into Bass Strait (Figure 19). There is an isolated occurrence on Lord Howe Island, off the eastern coast. Within some regions there are local concentrations of caves - possibly controlled by variations in age or purity of the limestone, or by local hydrological effects such as aggressive allogenic streams entering from the hinterland. However, caution is needed in interpreting such concentrations as they may be merely a consequence of non-uniform exploration.

In **Western Australia** the Barrow Island caves in the north are in a marine Tertiary soft-rock limestone, though a small area of Quaternary dune limestone is present. Cape Range caves are also mainly in Tertiary limestone, but south from that there is a long belt of Quaternary dune limestones that continues all the way to Perth. Within this the most interesting karst areas are the Nambung Pinnacles (see above) and the Yanchep area which has a special hydrological setting detailed below.

At Yanchep dune limestone overlies a quartz sand aquifer and aggressive water enters from below to dissolve caves at the base of the limestone (Bastian, 1991, 2003, Figure 20). A belt of caves forms along the eastern threshold where the water first rises into the limestone. Bastian (2003) used the term "paraphreatic" for this type of cave. The increased transmissivity of the caves captures diffuse flow from the adjoining permeable calcarenite as well as from the quartz sand below and forms local cave streams which follow the base of the limestone. This high conduit transmissivity maintains the water table at the dipping contact (Figure 20, right-hand side). The left-hand side of Figure 20 shows the situation closer to coast where the contact dips below sea level and the water table is controlled by sea level and lies within the dune – there we find mixed-water caves at the vadose/phreatic contact (c.f. figure 4).

South from Perth there are a few caves and springs where the Swan and other rivers cut through the dune ridges. In the Leeuwin-Naturaliste region a belt of dune limestone up to 6 km wide contains numerous caves (Bastian, 1964, Williamson, 1980, Williamson & Bell, 1980, Eberhard, 2003, 2004). The caves are best developed in the older more-cemented dunes and are of three types: linear caves formed by cave streams above an impermeable basement (e.g. Figure 10); the inclined fissure type, which also includes other breakdown forms (e.g. Figure 17); and the horizontal maze caves of the Augusta area (Eberhard, 2003) – which are relatively rare in Western Australia. The allogenic streams to the east of the dune barrier have mostly been dammed by the dunes and sink into the limestone to feed the stream caves, however some of the larger streams may have managed to keep their channels open and flow through gorges of construction (Jennings, 1968). However, Eberhard (2004) queries this interpretation for the commonly cited example of Deepdene Gorge, suggesting underground stream piracy and subsequent collapse as an alternative explanation. Some springs are known on the coast, but much of the underground water flow seems to be lost offshore.

On the Nullarbor, the soft-rock caves are hosted by the Tertiary marine calcarenites (Lowry & Jennings, 1974). However, Quaternary calcareous dunes overlie the Tertiary limestones in the coastal areas. Calcrete bands (kankar) are common (Lowry, 1970) but there is little information on other syngenetic karst features in the dune limestone. The Roe Calcarenite is a thin

Pleistocene marine shelly calcarenite that mantles the Roe Plain. However the known caves on the Roe Plain appear to be all in the underlying Tertiary limestone. Entrances through the Roe Calcarenite are probably accidents of collapse.

In **South Australia** the karst of the discontinuous dune limestones of the Eyre Peninsula is not well documented (but see Sexton, 1965). Kangaroo Island was the base for the work by Sexton (1965) and Hill (1984), which parallelled that of the West Australians. Most of the caves there are large collapse domes, but Hill and Sexton also documented the influence of allogenic water derived from the swampy flats on the inland side of the dunes.

The Gambier Karst Region is best developed in South Australia, but extends eastward into Victoria (Grimes, 1994, Grimes & others, 1999). Here we find both calcareous dune limestone, and the older Tertiary soft-rock limestone (Grimes & White, *this volume*). Caves occur in both types and some caves have their entrances in the dune limestone but their main horizontal development is in the underlying Tertiary limestone. In the South Australian part of the Gambier Karst the dune limestones form a series of discrete ridges separated by extensive swampy plains that extends up to 100 km inland (see map in Grimes & White, *this volume*). However, to the east in Victoria the dune ridges become confined to a narrow belt close to the coast with only thin swampy swales between them. In some of the older ridges in South Australia minor joint control becomes apparent. Many syngenetic caves in the Gambier region are dominated by collapse but where the original solutional parts are preserved the typical form is a horizontal maze (e.g. Figure 5). This differs from southwest Western Australia where linear stream caves are considered more typical and mazes are the exception.

In the **Victorian** part of the Gambier Karst, Bats Ridge and Codrington are two particularly densely cavernous areas (Berryman & White, 1995; White, 1995, 2000). Caves also occur in the Tertiary limestones. Some of the islands in Bass Strait have dune limestone, but there only a few small caves have been reported (Kiernan, 1992).

In **eastern and northern Australia** the coastal dunes and beach-ridges are dominantly quartzose, but there are some local exceptions, mainly on offshore islands, where calcareous sands occur and may show minor syngenetic karst effects. On Lord Howe Island, off the New South Wales coast an isolated area of dune limestone hosts a few small caves and coastal karren (Standard, 1963; Moses, 2003; and H.Shannon, pers. comm.). Further north, calcareous beach-rocks occur on many islands of the Great Barrier Reef and Torres Strait, and blue holes in the Great barrrier Reef indiate karst development at times of lower sea levels (Backshall & others, 1979). In the Gulf of Carpentaria some islands have small patches of calcareous sand. Minor karst features, for example coastal karren, have been briefly reported but no definite karst caves.

Conclusion

Syngenetic karst shows a number of distinctive forms as a consequence of its formation from soft porous sediments that are being consolidated and cemented at the same time as karst cavities are forming within them. These include: solution pipes, shallow caprock caves, brecciated zones, irregular horizontal mazes, "flank-margin caves" in coastal situations, and caves that are dominated by collapse domes and "inclined fissures" – with little or none of the original solutional passage remaining.

Syngenetic karst is quite different to classical "hard-rock", telogenetic karst. The related term "Eogenetic karst" is best kept for diagenetic studies of paleokarsts. Recently some authors have applied the term "eogenetic karst" to modern syngenetic karst features (e.g. Mylroie & others, 2001) – I recommend retaining "syngenetic" for that setting.

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