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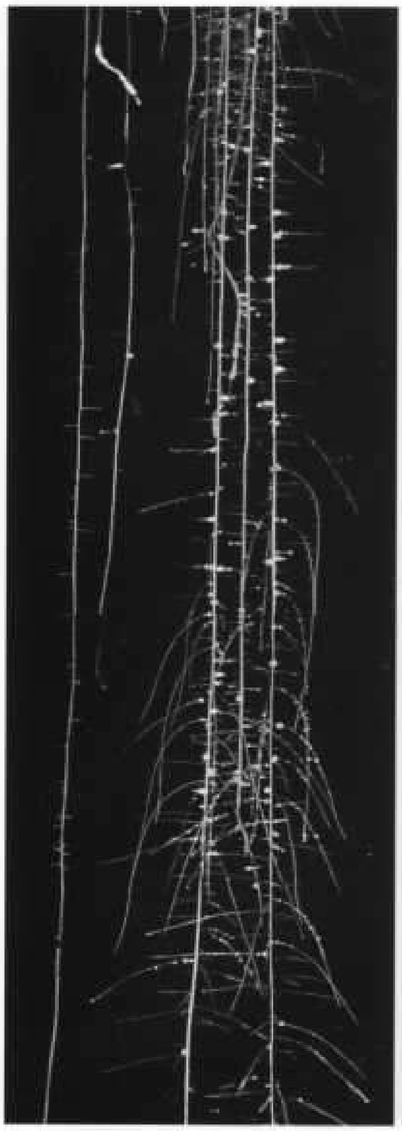
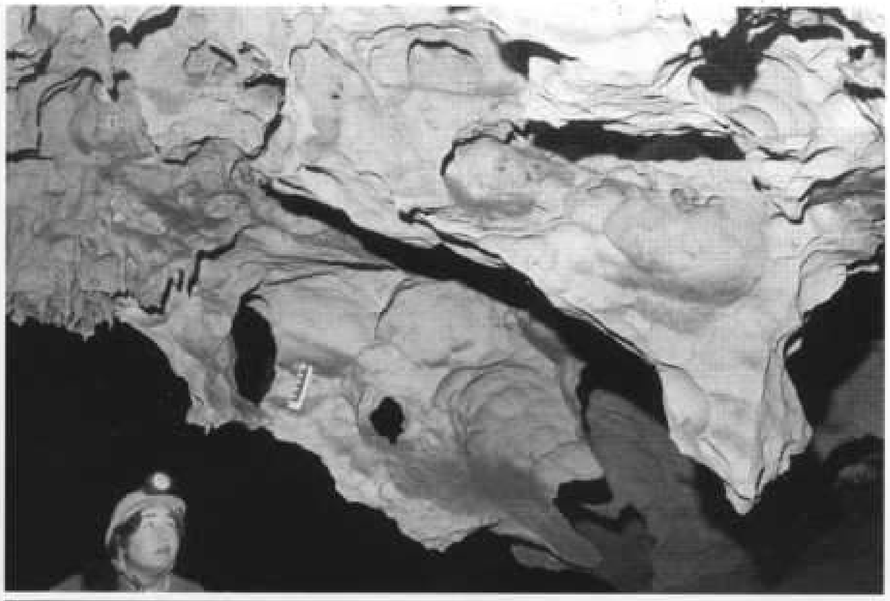
Helictite

Journal of Australasian Speleological Research





LIMESTONE COAST 2004

The Closing Workshop of IGCP 448 - Global Karst Correlation

and

The First International Workshop on RAMSAR Subterranean Wetlands

Proceedings

Abstracts and Submitted Papers.

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Contents

Cover Photos: Left, plant roots in a cave (Ken Grimes); Top, phreatic sculpturing in a dune limestone cave (Ken Grimes); Bottom, an amphipod from the Roe Plain, Nullarbor (Stefan Eberhard).

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Editorial

Ken Grimes and Susan Q White

This issue of *Helictite* contains the proceedings of the *Limestone Coast 2004* conference – four full papers, and the abstracts of most other presentations. Unfortunately, although several other papers were offered, they did not eventuate, and most presenters declined to supply a full paper. However, a few did supply revised or extended abstracts.

The conference was held at Naracoorte, South Australia, in October 2004. It was a joint effort involving both the closing workshop of IGCP 448 - *Global Karst Correlation*, and the First International Workshop on *RAMSAR Subterranean Wetlands*. This joint workshop was attended by about 50 people. As well as the presentations the group participated in field visits around the Gambier Karst Region. An Abstract Volume and Field Guide were produced. This workshop pursued the overall concept of understanding the relationship between karst resources, the biotic environment and the human situation. It emphasised the relationships between earth sciences and biosciences and between scientific understandings and human activities. This closing meeting of the IGCP 448 supported the establishment of another karst related IGCP project (IGCP 513 Global Study of Karst Aquifers and Water Resources) and made several suggestions for further karst related projects.

Commencing with this issue, we are providing what will become a regular service: a listing of papers published in recent karst journals from around the world. This is a cooperative effort - we also supply the contents of *Helictite* issues to the other journals.

Helictite web page

The *Helictite* web page is maintained by our Business Manager, Glenn Baddeley.
The URL is: http://home.pacific.net.au/~gnb/helictite/

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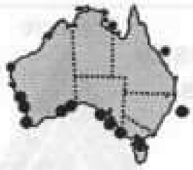
Helictite, (2006) **39(2)**: 27-38

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 loose 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 and 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 Bain (1962a,b) and Bastian (1962, 1964) for Western Australia and 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 and high-Mg calcite 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 (matrix), 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 limestone, which has never been deeply buried, that is generally as far as the cement and permeability evolution goes (lower arrow in Figure 2b), although the details can be more complex than the simplified overview given above.

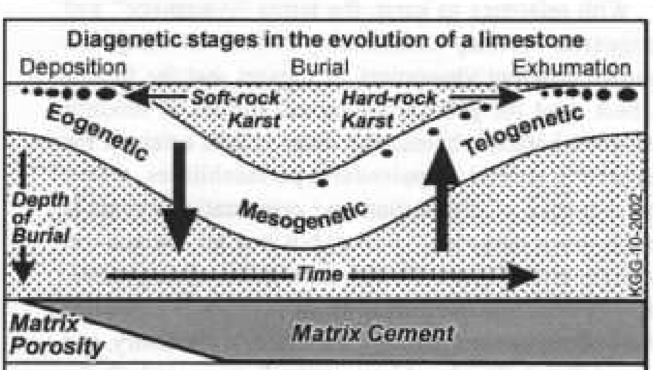


Figure 1: Diagenetic stages in the evolution of a limestone, and of its karst. Black dots indicate possible cave formation.

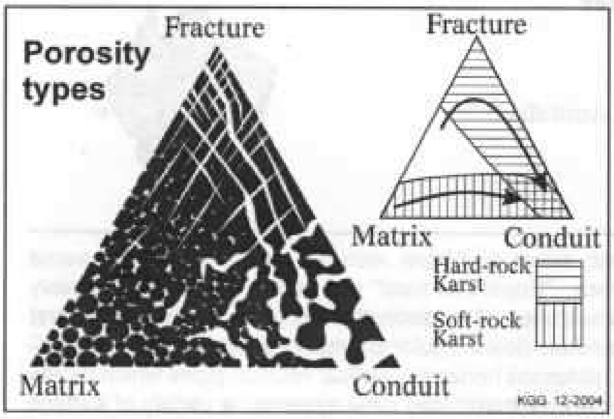


Figure 2: Limestone porosity types,
a: (left) the three types of porosity and permeability which can each contribute to the overall karst porosity; and
b: (right) evolution of the dominant permeability in hard-rock and soft-rock karsts.

In a hard-rock limestone, 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 considerably 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), 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 from the start and there is greater joint control so the karst is more akin to the classical hard-rock karsts even though the rock is still in the eogenetic stage (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 (Warren, 1983; 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

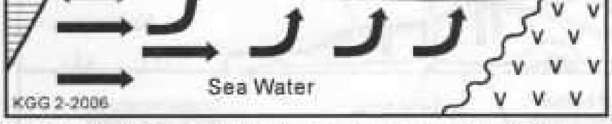


Figure 4: The coastal freshwater lens, and its mixing zones. Caves shown as black ovals. Note that the vertical scale is strongly exaggerated in all diagrams of this type. The lens is thin and the slopes are not as steep as they appear.

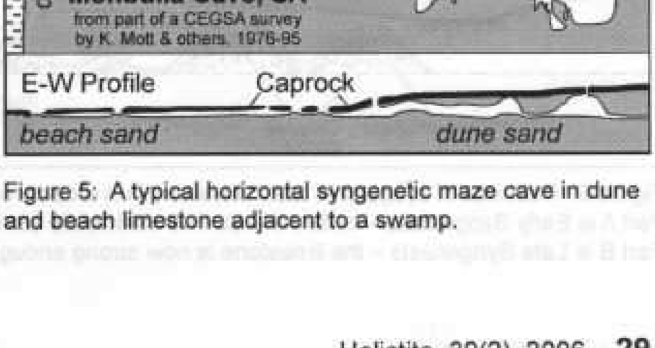


Figure 5: A typical horizontal syngenetic maze cave in dune and beach limestone adjacent to a swamp.

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

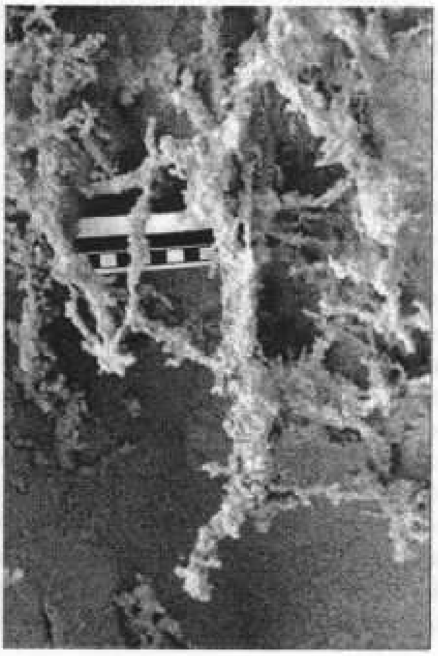


Figure 8: Rhyzomorphs are formed by cementation around roots (Cape Buffon, SA).

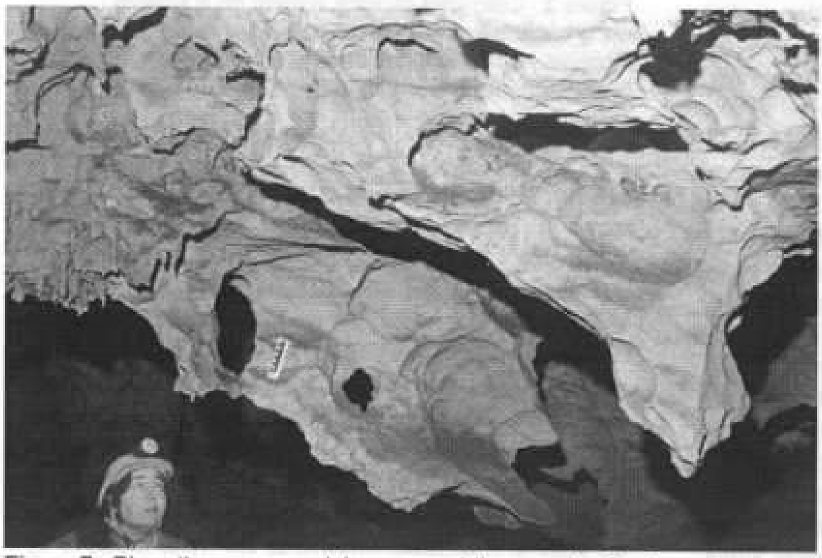


Figure 7: Phreatic spongework in a cave at the margin of a dune. Mt. Burr Cave, 5L-69, Gambier Karst, SA.

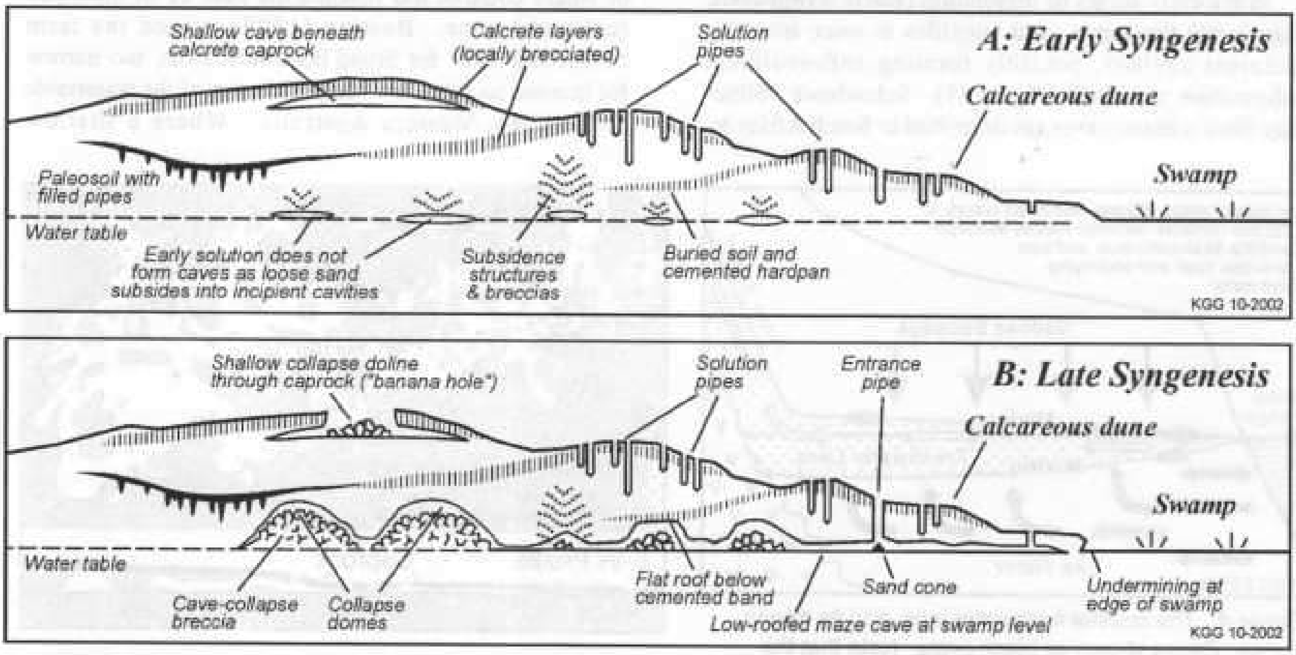


Figure 9: Features of syngenetic karst developed on a calcareous dunefield adjacent to a swamp.
Part A is Early Syngenesis – before the sand is sufficiently cemented to support a cave roof.
Part B is Late Syngenesis – the limestone is now strong enough to support a cave roof.

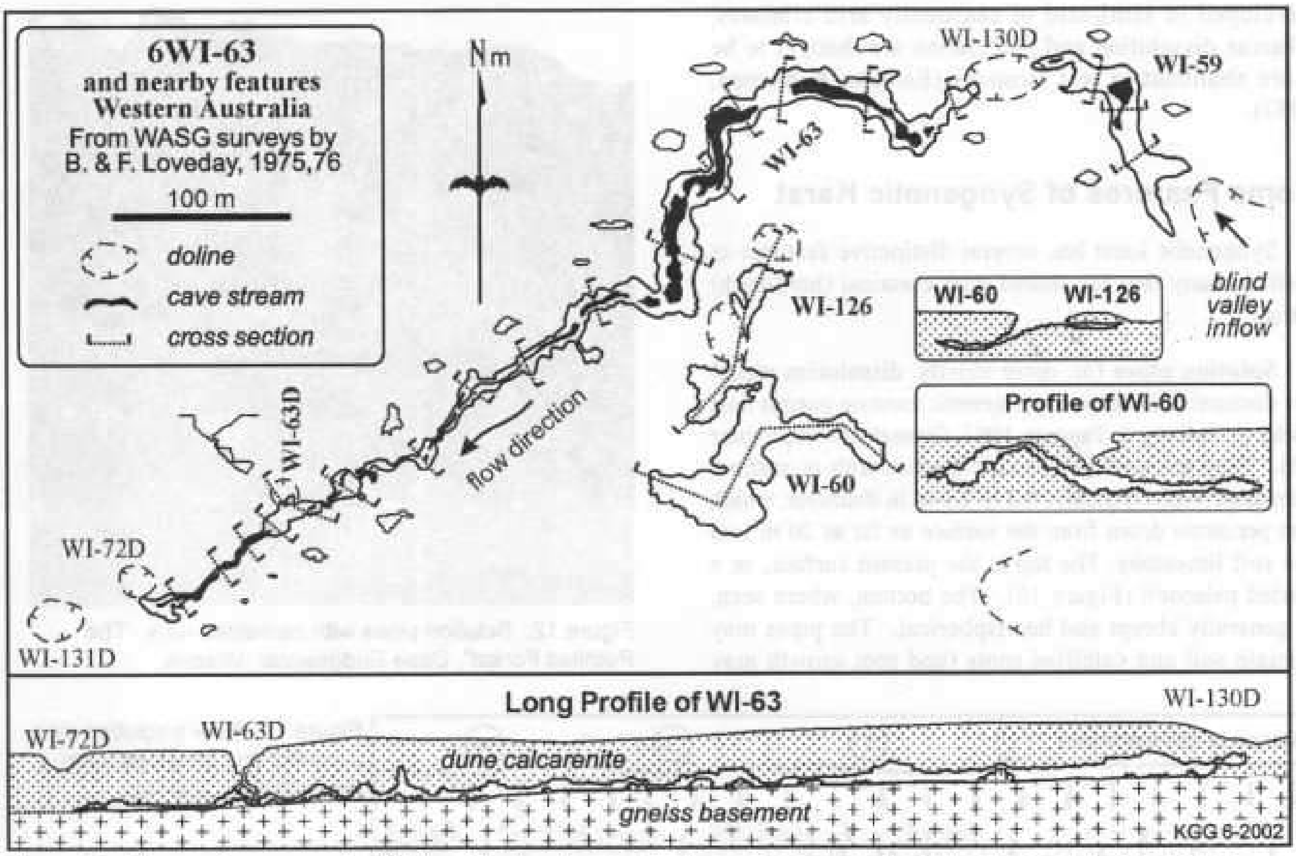


Figure 10: A linear stream cave that follows the basal contact between the porous dune limestone and impermeable gneiss. Note the downstream decrease in passage size, away from the source of aggressive water

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 (Warren, 1983). 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 ten 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, 2004a, 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.

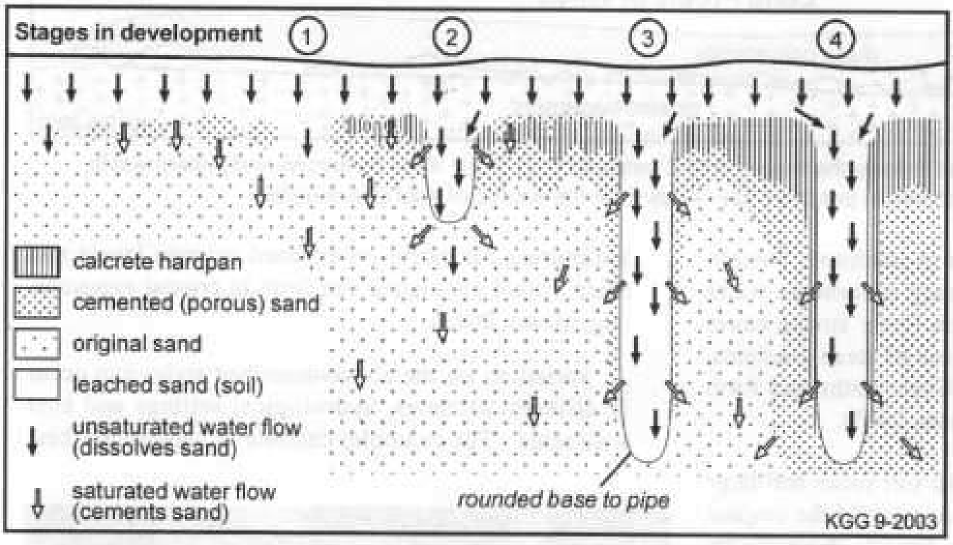


Figure 13: How a solution pipe deepens and develops a rim (from Grimes, 2004a).

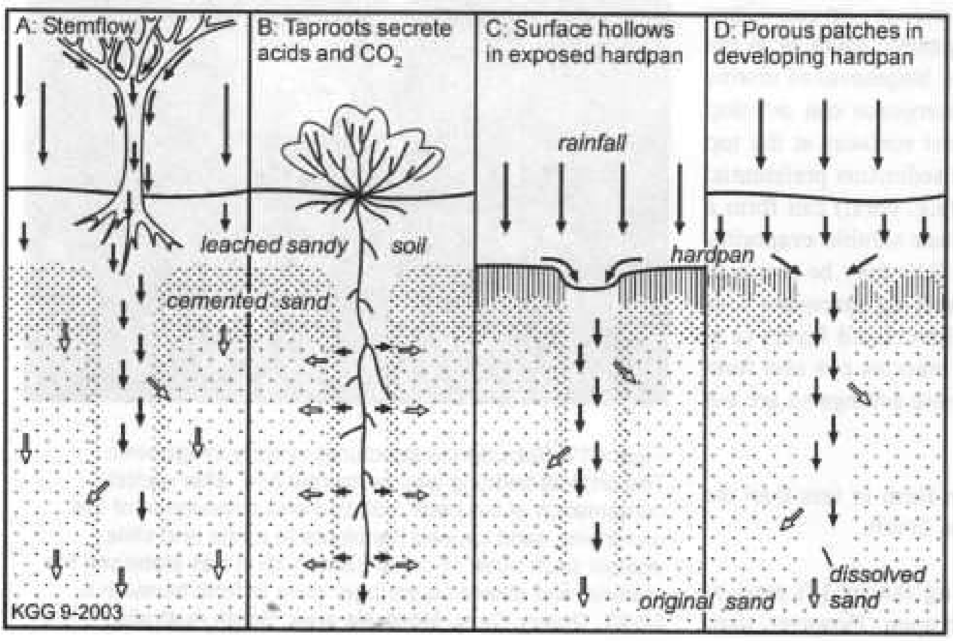
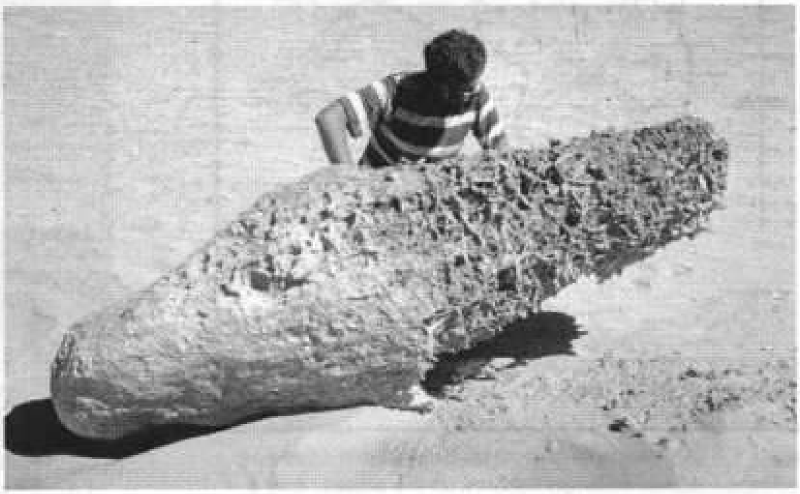


Figure 14: Alternative ways to focus downward flow and generate solution pipes. Note, the alternatives are not mutually exclusive, they could all contribute in different settings (from Grimes, 2004a).

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.

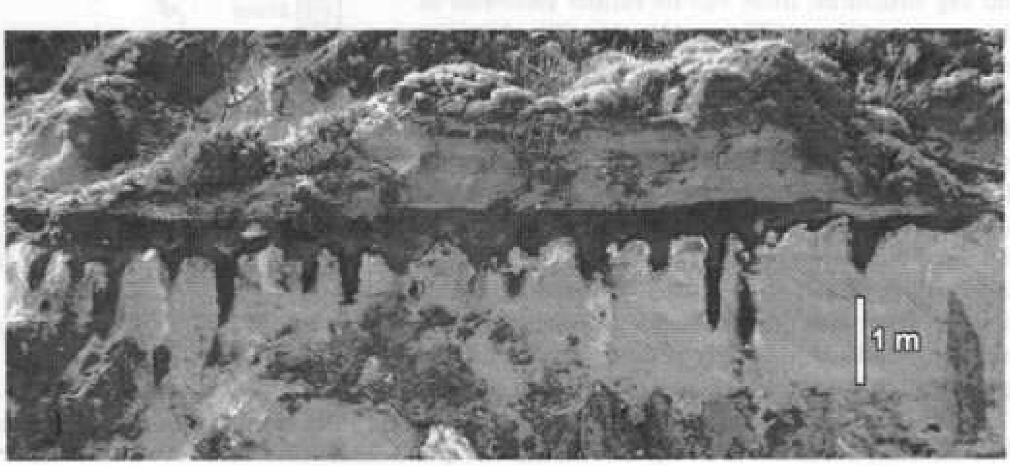


have occurred hand-in-hand with dissolution of the pipe). They occur as isolated features, or in clusters with spacings that can be closer than a metre. In the Bahamas they have been referred to as pit caves, but that term also includes larger and more complex vadose features (Mylroie & Carew, 2000). 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, 2004a). Solution pipes can also occur by focussed solution beneath a permeable but insoluble cover sediment (e.g. the "cryptokarst" pipes described by 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.



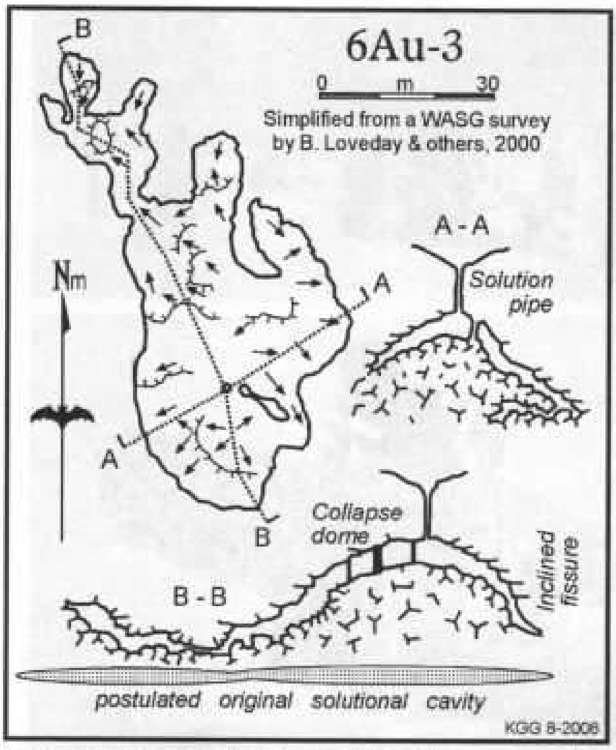


Figure 17: An example of a small breakdown cave with a collapse dome, inclined fissures at the edges, and a solution pipe entrance. The original solutional form is completely obscured

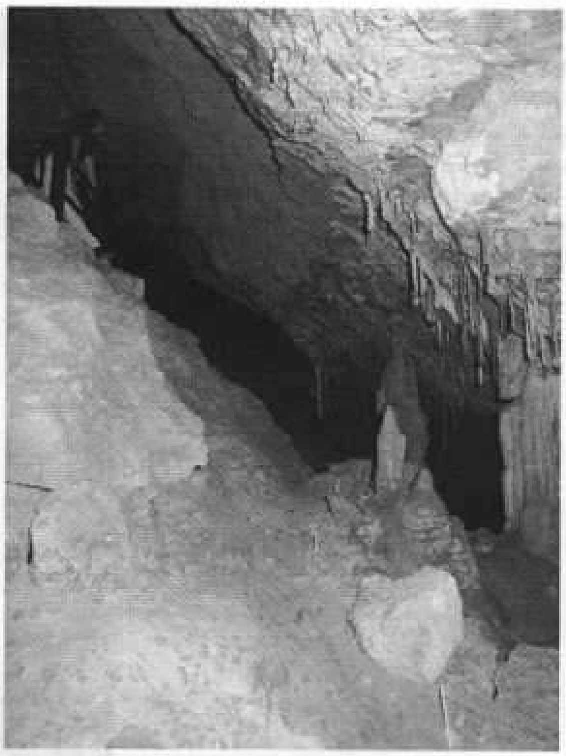


Figure 18: An "Inclined fissure" left at the side of a rubble mound in a collapse dome. Grant Hall, 5U-1, Naracoorte, South Australia.

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 9b), 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

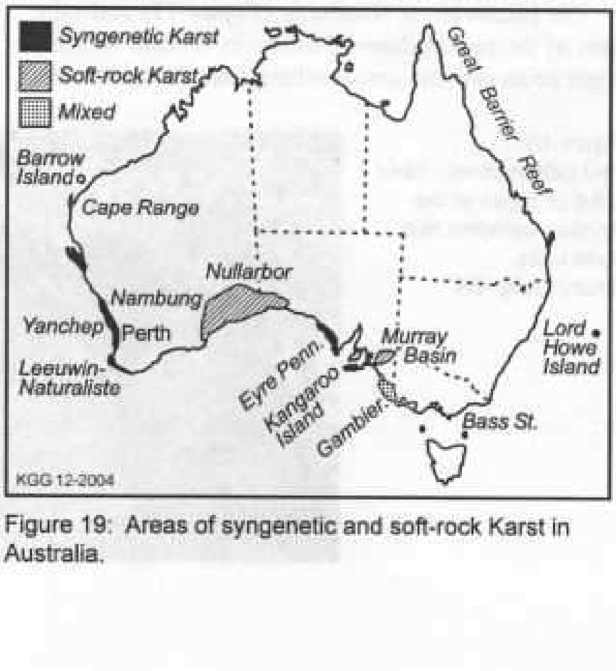


Figure 19: Areas of syngenetic and soft-rock Karst in Australia.

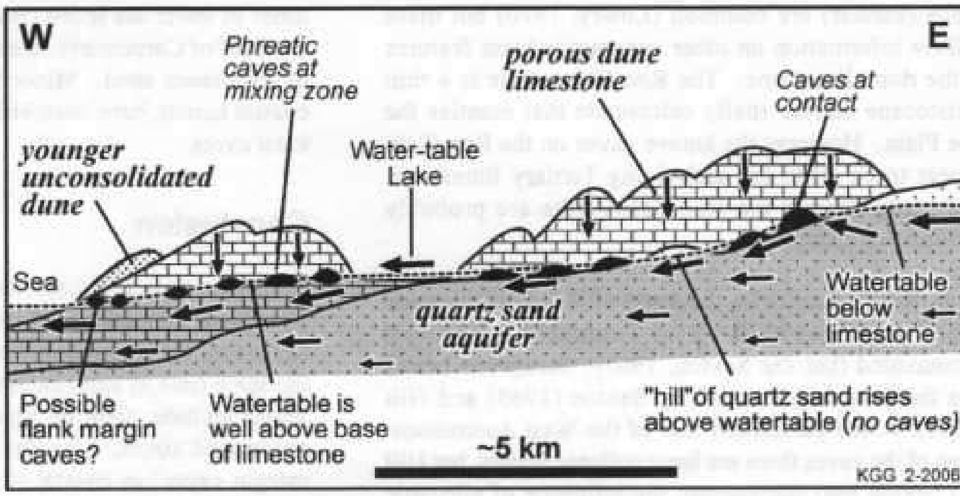


Figure 20: Hydrology of the Yanchep area, WA. A porous dune calcarenite overlies an insoluble quartz sand aquifer (based on Bastian, 1991, 2003)

in the Bahaman banana holes. In extreme cases mass subsidence of broad areas can generate a chaotic surface 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 more strongly indurated than usual (W. Humphreys, pers comm). South from 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 (Bain, 1962a,b, Bastian, 1962, 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. There is also at least one linear stream cave (West Bay Hollow Cave, 5K-17, Sexton, 1965).

The Gambier Karst Region is best developed in South Australia, but extends eastward into Victoria (Grimes, 1994 & 2004b, Grimes & others, 1999). Here we find both calcareous dune limestone, and the older Tertiary soft-rock limestone. 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. 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.

Acknowledgements

My thanks to Lex Bastian and Susan White for critical comments on the text and discussions in the field. This paper merely builds on the work of numerous cavers and speleologists who have mapped and documented the syngenetic caves of Australia – in particular Joe Jennings, Lex Bastian, T.D. Bain, R.T. Sexton and A.L. Hill.

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Seasonal Karst Lake Cerknica (Slovenia) – 2000 Years of *Man Versus Nature*

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Abstract

The Roman geographer Strabo (63 BC – 21 AD) was probably the first to mention Lake Cerknica (Cerkniško Jezero) and the first printed record was published in 1537 (G. Leonberger). The early authors (16th–17th C.) just admired it. The next phase can be called the research one. Authors of the 18th century tried to explain the lake's hydrographic regime. With the rise of physiographic movements, the first proposals to change the regime, i.e. to dry up the lake, appeared. Many projects have been suggested; a lot of research and even some practical works were done until the middle of the 20th century. No project was fully implemented because of fear of flooding the capital, Ljubljana. After World War II, the situation changed. Instead of draining the lake, it was proposed to make the lake permanent. The first experiments were not successful and in the 1980s attitudes towards the lake changed. Green and environmental movements prevailed and work began to protect the lake as a natural phenomenon.

Keywords: polje, engineering works, karst research, history, Slovenia, Cerknica.

Lake Cerknica (Cerkniško Jezero) is the part of Cerknica Polje (Cerkniško polje), which is regularly flooded – a seasonal lake. It lies in the central part of the Slovenian Dinaric Karst in the tectonic depression along the Idrija Fault, one of the most important tectonic lines in Slovenia. There are four other poljes in the same depression besides Cerknica Polje: Babno Polje and Loško Polje at a higher elevation (600–800 m a.s.l.) and Planinsko polje and Logaško Polje at a lower elevation (450–400 m). Cerknica Polje lies in Jurassic and Cretaceous limestone with less karstified Triassic dolomite in the centre of the lake bed. Lake Cerknica receives its water from higher lying poljes as well as from the neighbouring karst plateaux. The more or less flat bottom of the polje covers an area of about 38 km^2.

The highest water levels occur with the rainfall maximum (November–December) and with melting of the snow cover (March–April). The lake is full at these times and can cover up to 27 km^2. During high summer (July–September), the water remains just in the lowest part of the polje or dries up completely. Between these two extremes, the water level (and the area of the lake) varies according to the weather. The long-term average water regime is a lake for 10 months of the year (but not at maximum level) and the bed completely dry for 2 months (Kranjc, 1986).

Over the years, people have organised their life, work and land-use in response to the water regime. Throughout the cold part of the year, the lake was used for fishing and the transport of timber (by water or over the ice), while during the dry period, the bed was used for pasture and reeds and rushes were harvested as litter for animals.

In karst countries poljes are a sort of green oasis with water, soil and vegetation. It is therefore not surprising that from the beginning of settlement in karst lands people have had close relationships with poljes. Numerous examples of poljes can be found in the works of ancient authors. Herakles' third work, to chase the bronze birds of Stymphalia Swamps, is set in Stymphalia Polje. People began to drain Lake Kopais (a polje) in Beotia as early as the 13th century BC. A 25 km long and 40 m wide canal was dug to the "Great Katavothron (=ponor)" for this purpose (Schneider & Höcker, 1996).

The Roman geographer Strabo (63 BC – 21 AD) first mentioned Lake Cerknica (Arheološka najdišča Slovenije, 1975) and there are some indications that the Romans started to drain the polje. The first printed record of Lake Cerknica is a poem by a young German student from Regensburg, Georg Leonberger, written in 1537 (Shaw, 1994). G. Wernher (1551) described Lake Cerknica more realistically. His book was dedicated to Sigismund Herberstein (1486–1566), a native of Vipava and a diplomat at the Vienna court. Wernher's remark "…I will describe it from what you yourself have written…" is very interesting. It means that Herberstein himself had already published, or at least described in a written form (letter to G. Wernher?), Lake Cerknica before 1551. But this description has yet to been found (Shaw, 1994a). The period of these early descriptions can be called the "admiration" one. The authors admired the lake, its "miraculous" appearance and disappearance, its abundance of fish when a lake and its fertile land when dry. They did not care why this was so nor where the water came from.

The second phase can be called the "research" one. The scholars did not just describe Lake Cerknica and admire it, but tried to explain its unusual behaviour. One of the first and maybe the best known is A. Kircher, "near-legendary Jesuit polymath" (Cutler, 2004, p 67), who published his book *Mundus subterraneus* in 1665. To explain the phenomena of large karst springs he invented

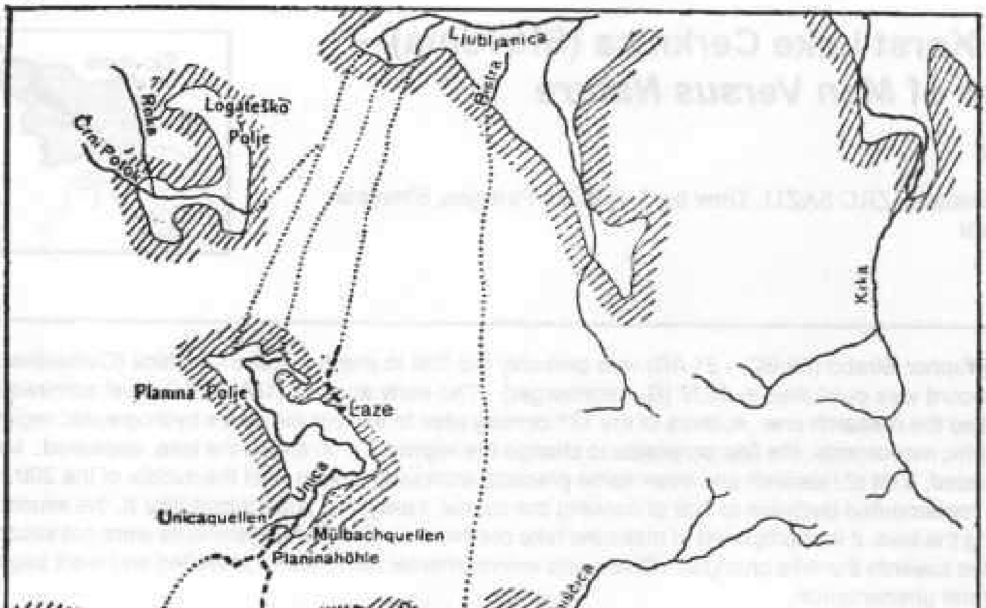

Fig. 1. — *Ober- und unterirdische Flussläufe im Gebiet der Innerkrainer Kesseltäler,* 1 : 300 000

Figure 1: Location of Cerknica Polje and its hydrological relationships with neighbouring poljes, after Löhnberg, (1934).

the theory of *hydrophilatia.* These are underground reservoirs in the mountains, filled by pumping up water from the sea through underground channels and siphons (Kircher, 1678). He used Lake Cerknica as an example of this idea.

The next important researcher was J. V. Valvasor who became a member of the Royal Society of London because of his explanation of the hydrological functioning of Lake Cerknica. He knew Kircher's theory well, but he did not agree with it. Valvasor published a more elaborate explanation in his topography of Carniola[1] in 1689. He invented five additional underground lakes to explain not just the filling and emptying of the lake, but also the order in which different springs or different ponors start to function. According to him, they were at different levels and connected by underground conduits and siphons. This seems to a modern researcher unnatural and even ridiculous, but if we compare his views with Kircher's, who was the great authority of the time, they are much less fantastic. Valvasor was an accurate observer of nature and he did not succumb to views of "a giant among seventeenth-century scholars" (Cutler, 2004, p 68). Valvasor also cites Kircher, but at the end of XLVI chapter of Book IV he states: "By my opinion it is no need to take into the account the oscillation of sea or its connection by underground channels..." (Valvasor, 1689, p 630). If we use instead of Valvasor's "underground lakes" a modern term of aquifer, his views are not so far from the modern ones. Valvasor's topography includes tens of pages dedicated to Lake Cerknica.

Half a century later Valvasor's Carniolian compatriot F. A. Steinberg (1758), who lived many years in a manor on Cerknica Polje, published a whole book related to Lake Cerknica. He described the life and farming on the

1 The Duchy of Carniola was hereditary (core) land of Austria and the part of the Austro-Hungarian Empire that included much of what is now the territory of Slovenia.

Figure 2: W. Putick and his team carry out hydrological and speleological research at the end of the 19th century.

polje and a great part of the book touches the question of hydrological function. His views are much nearer to Valvasor's than to Kircher's. His illustrations show numerous experiments he carried out to prove his views. Maybe it is not emphasised but it is important to note that the illustrations showing his experiments depict rain. So according to him, rain is the main factor filling up the lake.

It was J. A. Nagel, head of the Emperor's cabinet of rarities, who definitely stated that intermittence of the lake is due to precipitation. Nagel was sent to Carniola to see and report on the truth of the curious phenomena in Carniola and to bring back some rarities for the Emperor's collections. He decided that the changes in the water level in the lake are not due to precipitation only, but explained and showed by a sketch, that the ratio between water input and output is crucial. When the input is bigger than output (outflow), the polje is flooded and vice versa. Nagel's (1748) report remains in the form of a manuscript, deposited in the Emperor's library, and had practically no influence on contemporary and subsequent scholars.

The Jesuit scholars, brothers Gabriel and Tobias Gruber, came to the same conclusions as Nagel but T. Gruber (1781) published their ideas. In addition, they said that precipitation in the basin should be measured to find out the details of the intermittence mechanism.

The scholars of the second, research, period tried to find out the reasons for intermittence: from Kircher's fantastic underground conduits pumping sea water up into the mountains to Gruber's more realistic views about the role of precipitation.

The 18th century saw the rise of enlightenment and of physiocracy[2]. This is the third phase of research on Lake Cerknica, which can be called the "applied" or "utility" phase. This phase ended only 30 years ago. A typical representative from the beginning of this period in Carniola was B. Hacquet, who was also the predecessor of modern karstology. His views upon the functioning of Lake Cerknica were similar to Nagel's and Gruber's. However, there was a big difference. The first volume of his *Oryctographia carniolica* (1778) contains quite a long chapter on Lake Cerknica. Parenthetically he mentions that he made a three-month "economical[3]" travel across the Inner Carniola (Notranjsko) "Kesselthäler" (=poljes) with the aim of finding a measure to prevent the flooding. He presented his views about the problem in a lecture to the members of the Agricultural Society of Carniola at Ljubljana. We do not know if the lecture was ever published, and it is not known what measures he proposed to solve the question. In any case, B. Hacquet is the first person known by name that made such a proposal, but the proposal itself remains unknown.

As population and agricultural pressures increased, so did demands to increase the extent of arable land. All eyes turned towards the flat bed of Cerknica Polje with its relatively deep sediment and soil. Suggestions,

2 "Physiocratic" derived from Physio- (Greek, Physis = nature) meaning "pertaining to nature". "Physiocracy: Government according to a natural order, taught by Francois Quesnay (1694–1774), founder of the physiocrats" [Concise English Dictionary]. Physiocrats (in Austria) tried to develop better agricultural methods, they formed "Agricultural Societies".

3 "Economical". In "Austrian" German of 18th century "economic" means "agricultural". Hacquet's voyage was to find out how to drain poljes to use them for agriculture.

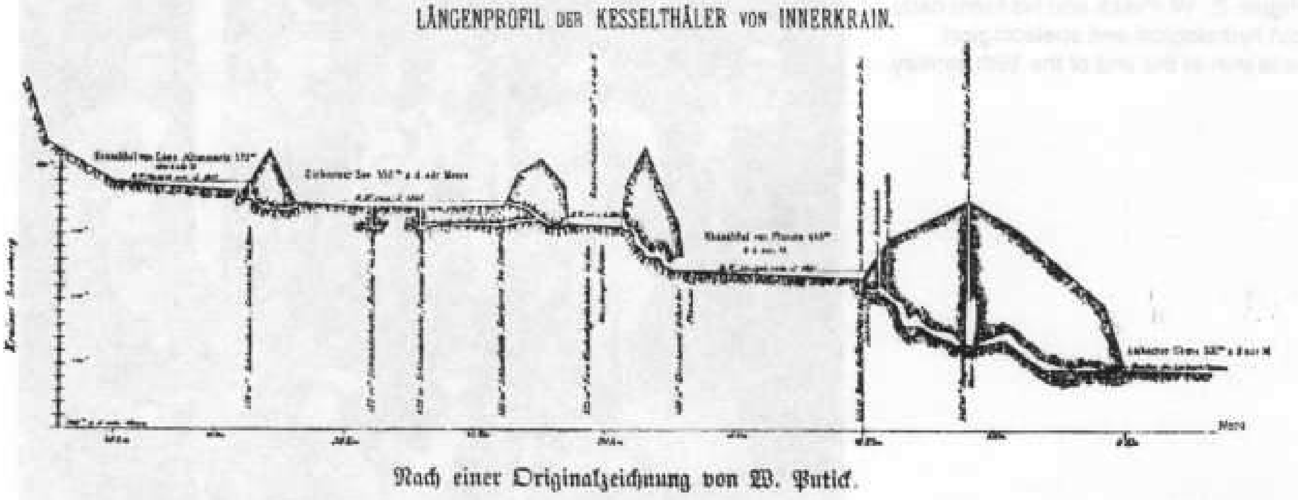

Figure 3: Longitudinal section of poljes, from Putick (1889).

proposals, and plans for its development and draining became more frequent. Both individuals who acted from their own will and interest, such as B. Hacquet, and the authorities became involved. In the beginning, these were mostly local but as we will see later, in the end the ministry from Vienna interfered. One of the first officials to become involved was A. Schaffenrath of Postojna, a district engineer, known above all for his pictures of Postojna Cave and his work in its development. He made a proposal in the first decade of the 19th century but nothing came from it (Kranjc, 2002).

A. Schmidl, the author of a famous book (1854) on caves and karst of Carniola that gave him the flattering name the "father of modern speleology", also made a proposal in the middle of the 19th century. As with Schaffenrath's proposal, nothing came from it. The same happened to the next plan of R. Vicentini (1875), although he took into account not only Cerknica Polje, but also upper and lower lying poljes, including Ljubljansko barje (Ljubljana Moor). The main reason was the fear of Ljubljana inhabitants that their town would be flooded more frequently and that the water would reach higher levels, if the poljes lying in the upper basin of Ljubljanica River drained faster.

F. Kraus, a geographer from Vienna, tackled the problem from a different point of view. He was one of the founders of the first speleological society, Verein für Höhlenkunde. One of the aims of this society was the study of Carniola's poljes to find ways to drain them. He studied the floods himself (Kraus, 1894), he organised a sort of net of field observers and succeeded in persuading the Vienna Ministry to engage and pay a young forestry

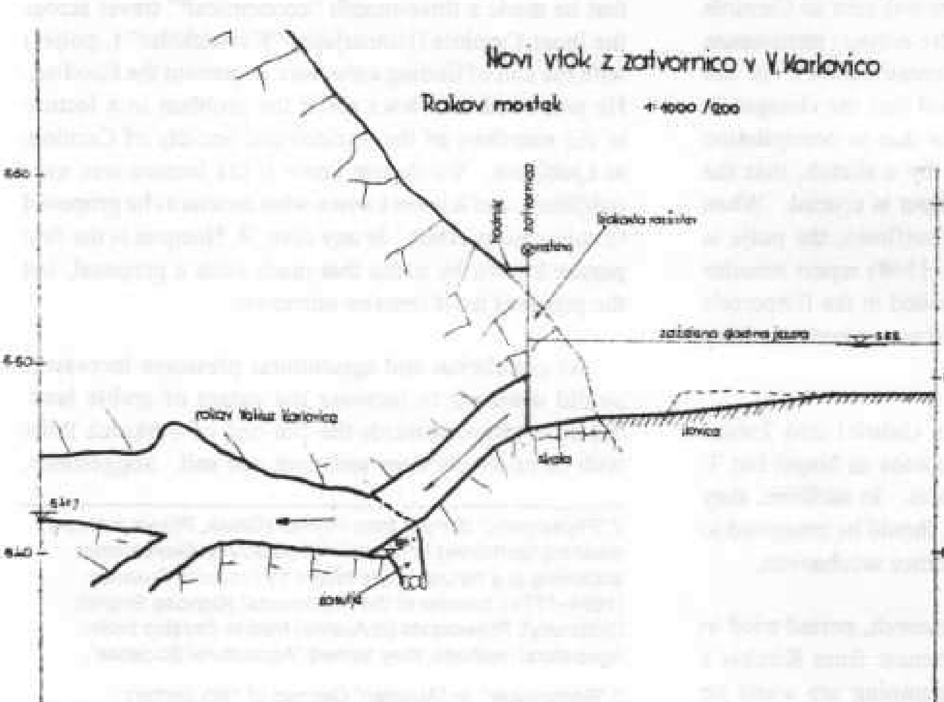

Figure 4: Section from Jenko (1965) showing tunnel connecting polje bed to the ponor cave Velika Karlovica.

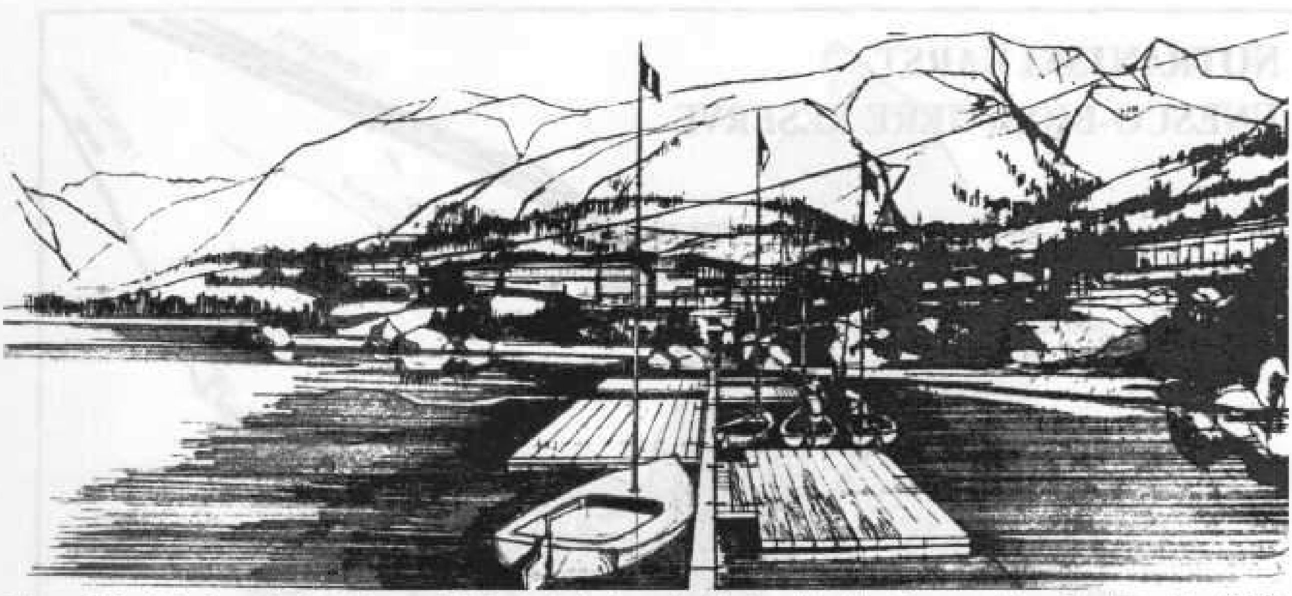

Figure 5: Yacht harbour (marina) planned at the foot of a hum. Architectural sketch of proposal from Berdajs et al. (1972).

engineer to study the problem seriously. This engineer was W. Putick who dedicated three years to these studies, mainly working in the field. The result of his research was a project with the noteworthy title "Harmless high water drain of kettle-valleys in Inner Carniola" (Putick, 1888). The project took into account the whole system, Loško Polje above Cerknica Polje and Planinsko Polje downstream in the background of the springs of the Ljubljanica River. The water from all these poljes rises in the Ljubljanica Springs. Nevertheless, Ljubljana, the capital of Carniola, interfered again. Only some elements of the project were implemented particularly on Cerknica Polje. The effects on Cerknica Polje were that the dry period was a little longer, the flood (lake) period shorter and the highest water level did not reach quite as high as before. Otherwise, the lake functioned as it did before.

A few decades later, in the 1920s the locals organised a "water co-operative" which was responsible for more drainage work following Putick's previous designs. With public funds, they straightened some streambeds, put a wooden grill (rake) in front of the swallow-holes, and lowered entrances to the main ponor caves by 2.5 and 1.2 m respectively. They blasted some siphons and they cleaned and enlarged some minor swallow-holes. They regulated (straightened) the beds of the main stream across the polje and its tributaries, for a length of nearly 8 km. There were some positive (in terms of the plans) results, but the lake was far from being drained completely:

- catastrophic floods were moderated,
- middle and high water levels drained faster,
- "sweet" grass began to grow on the ameliorated lands (Jenko, Mrak & Čadež , 1954).

During the driest period, however, agricultural fields were still not possible on the alluvial bed.

There were two more projects for draining the polje. A. Hočevar (1940) simply proposed an amelioration of floods in time and area. Tortolino's (1943) "General Plan of use of the Rivers Unica, Pivka, and Vipava, from Planina to the Sea" (regional) plan, made under the Italian occupation, proposed complete drainage.

Completely opposite projects, proposing to make a permanent lake instead of a periodical one, appeared relatively soon. In Vienna, F. Schenkel (1912) published the book "Karstgebiete und seine Wasserkräfte" (The Karst region and its water forces). He proposed converting Cerknica Polje into a reservoir. During World War II, two similar projects were developed at the Ljubljana faculty. One proposed that the accumulation lake should cover 1100 ha.

After World War II, private agriculture was increasingly neglected and other branches of the economy came into favour. V. Šlebinger's project proposed a small accumulation lake, dams, a surface channel, regulated underground outflow and a small hydropower station on Cerknica Polje. In a study by F. Jenko et al. (1954), the authors stated that the results of the previous works were insignificant. They planned major works: two accumulation lakes, a hydroelectric power station, and a drained (ameliorated) bed of the polje itself with an area of 2400 ha. The proposed works included a grout curtain under Cerknica, a surface drainage channel along the polje and a tunnel between Cerknica Polje and the lower lying Planinsko Polje.

But things changed. In 1965, F Jenko wrote in the introduction to his next plan that regulation and amelioration of 3000 ha of the Cerknica Polje bed would be too expensive and uneconomical. Therefore, he proposed his "Project of the permanent Cerknica Lake" (Jenko, 1965). The implementation of this project would develop tourism and fishery, and equalise the Sava River regime. Regarding the degree of permanence, three

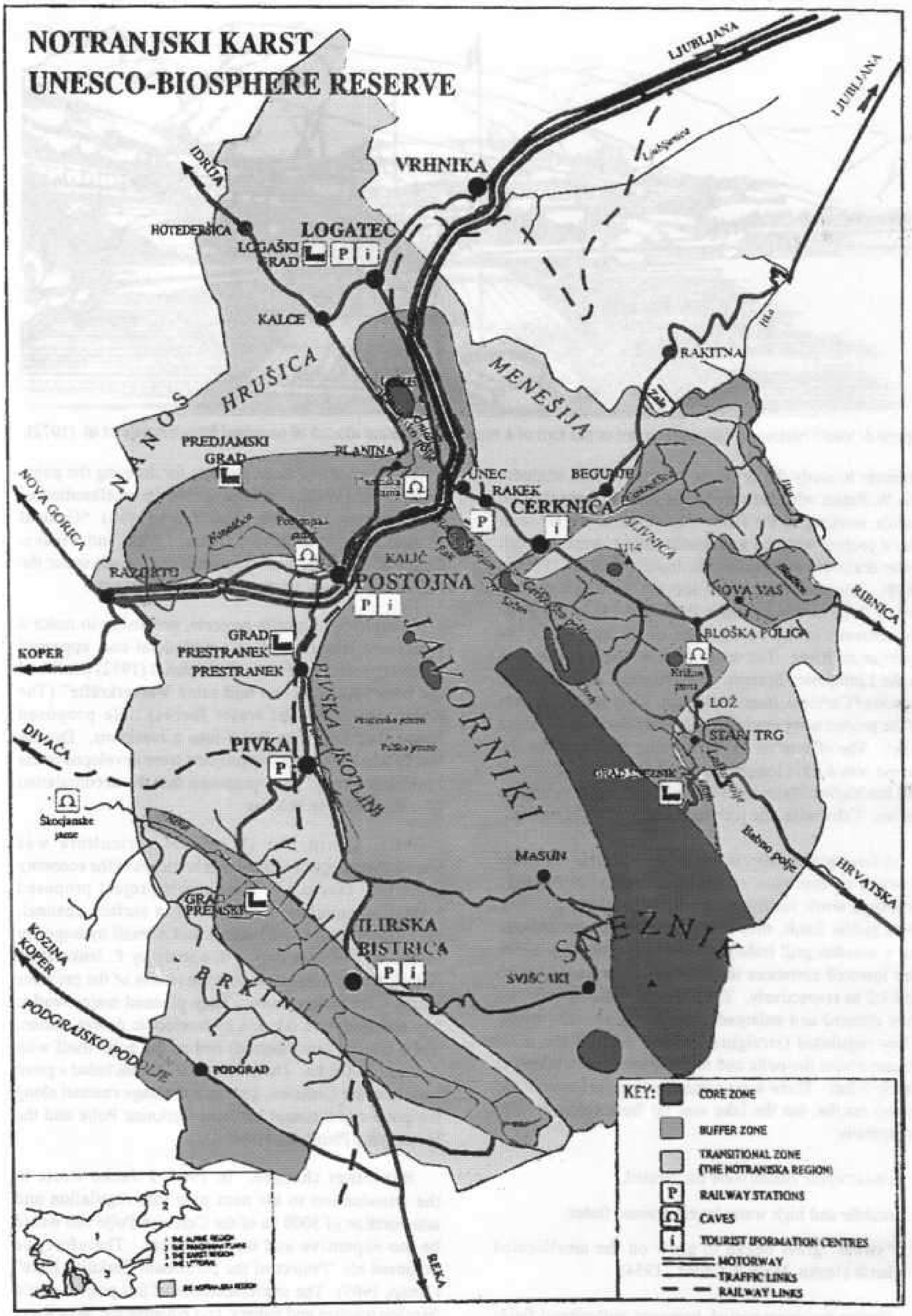

Figure 6: Lake Cerknica "Man and Biosphere Reserve" proposal, from Berce-Bratko (1994).

variants were foreseen: the lake would dry every 5 years for 1 month on average; the lake would dry once in 30 years; and complete "stabilisation", which meant a real permanent lake.

Numerous objections arose from different specialists and Jenko's project changed into "3-years experimental closing of swallow-holes". Some ponors were blocked completely, the lower part of the entrance to the main ponor cave was dammed by a concrete wall, a 30 m long tunnel, 3.7 m in diameter, connected the lake with the inner part of the swallow-holes. To regulate the runoff, a 4 m square gate-valve was constructed at the end of the tunnel. An impact on the water regime of the polje was achieved, but not a fundamental one: despite all these works, the lake dried up!

Despite this unsuccessful experiment, Cerknica Polje was included into "The Upper Adriatic Project" (Berdajs & Kern & Lesourne & Orožen Adamič & Rossi Crespi, 1972). This envisaged a tourist zone with 1000 tourist beds and tourist-facilities like bathing, boating, sailing, motor-boating, hunting, fishing, skating, skijoring[4], etc.

All the facilities and constructions required a permanent lake. In case the lake did dry out, navigable channels were to be excavated in the lake bed and pontoon swimming pools were planned. However, the project remained just a project on paper.

In 1983, Breznik was the author of the last accumulation lake project. He stated in the introduction that flooding could not be prevented without damaging land downstream. The nucleus of the project would be a dam and grout curtain across the polje bed to separate the inflow side from the outflow (ponor) side. At that time a perception of the necessity of nature protection and safeguarding developed, the "green" movement started and a trend towards "renaturalisation" of the polje appeared. Breznik's project was rejected without a lot of opposition.

Daily reports in the newspapers show that nobody was satisfied with the lake as it was. Here is an example from the hydrologically normal year 1985. In spring, the lake was full. According to the newspaper reports, the water caused great damage to infrastructure (roads, cart tracks) and to farmland. In summer, when the lake dried up, there was great damage again, this time to fishing societies. This clearly shows that Lake Cerknica was regarded as being more harm than good, as a noxious phenomenon. Regretfully, Valvasor seems to be the last person who admired the lake and praised its abundance of fish when there was water and of grass and game when it was dry (Kranjc, 1987).

4 Skijoring is skiing on flat land while being drawn along by horses.

5 Local government area.

During the 1980s, people began to talk about the "primary" state and regime of the lake, which is also difficult to attain after centuries of human interference. At the same time, protection measures were envisaged. At the beginning of the 1990s the idea of the "Notranjski (Inner Carniola) Karst - UNESCO Man and Biosphere Reserve" was born (Berce-Bratko, 1994). The central part of the lake would belong to the central or core zone. Then the idea changed into the "Notranjski natural park". Both ideas failed.

Lake Cerknica is now protected as a regional park, but just within the limits of the Cerknica commune[5]. The major part of its recharge area is out of the park, and unprotected. As far as its water regime goes, one must be glad to be able to say that Lake Cerknica remains a typical intermittent lake. During autumn and winter-spring it is a lake, full of water, while during the summer drought it is dry, just like it was 2000 years ago when people tried to change it for the first time.

Acknowledgement:

I would like to thank Armstrong Osborne for smoothing the English for me.

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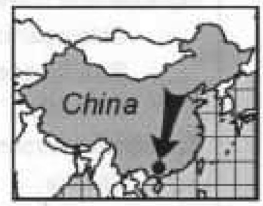
Environmental Reconstruction of Karst using a *Honeysuckle* species widely used in Traditional Chinese Medicine.

Case Study: Lower Donggangling Formation in Mashan County, Guangxi Province, Southwestern China.



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Abstract

As in the deserts of Northwestern China, there is a need to reconstruct the fragile karst of Southwestern China using sustainable techniques that protect the environment and develop the economy. One means of achieving this is to plant species used in traditional Chinese herbal medicine. The characteristics of Honeysuckle used in traditional Chinese medicine, when produced on the Donggangling Formation at Nongla Village in Mashan County, in Guangxi Province of Southwestern China, match those of Honeysuckle grown in traditional production areas of China, and comply with the specification set for the Honeysuckle by the P.R. China Codex. Added properties of the Honeysuckle are the accumulation of phosphorus and potassium, in addition to the accumulation of elements such as calcium, magnesium, copper, zinc and so on. Further discussion considers extending the areas in which this Honeysuckle is currently grown, and its limitations in the karst region of Southwestern China where 60% - 70% of calcareous soil may be suitable for its cultivation.

Keywords: karst, environmental reconstruction, Honeysuckle used in traditional Chinese medicine, Donggangling Formation.

Introduction:

The karst of Southwestern China is as fragile as the desert of Northwestern China, where rocky desertification in karst and desertification in desert comprise the two main environmental problems. The restoration and reconstruction of the karst environment has become one of the most important aims of the people who live and work there. If the protection and conservation of karst can be linked to the economy and to the improvement of living standards, then local people have an excellent incentive to preserve their natural environment. To be successful, it is important to select plant species that will provide both ecological and economic advantages.

For mountainous karst peak-depression areas which are deficient in both water and soil, it is important to select species with above-ground stems and leaves which will protect the limited soil resources. At present, there are a number of species of *Honeysuckle* (*Lonicera spp.*) which are being planted to protect karst environments. However, the question of which species of *Honeysuckle* is appropriate for each particular area is a problem which has been long neglected. One species of *Honeysuckle* as a component of understory has been used successfully to restore the environment which is in secondary forest stage now at Nongla Village, Mashan County, Guangxi Province, Southwestern China. This area has typical karst peak-depression landforms shaped by combined limestone and dolostone of the Lower Donggangling Formation (DGLF) of the Middle Devonian. Growing in the fissure soils among carbonate rock blocks, *Honeysuckle*'s vines stretch 5–6 metres long and cover up to 3–4 metres wide (Figure 1). In May, *Honeysuckle* flowers are picked but its other parts, especially roots, are not used, which keeps the soils undisturbed.

Figure 1: *Honeysuckle* growing in the fissure soil and covering the carbonate surface

Table 1: Characteristics of Honeysuckle from TPA	
Traditional production area	Shandong, Henan Provinces
Ingredients of flower	
Chlorogenic acid in buds	≥2.2–2.46% (>1.5 % in the Codex)
Total flavonoids	2.14% (Not in untraditional production area)
Elements	High Ca, low Cr and Pb, accumulation of Zn and Cu
Ecological environment	
Climate	Semiarid
Precipitation	≤1000 mm
Sunshine time and temperature	2400–2600 hours and10-15 °C
Soil	
texture	Sandy loam
pH	7–8.5
Salinity saturation	>85%
CEC	>10 me/100g
Elements	High K, Na, Ca and Mg
DNA fingerprint	Genetic distance 1.2% among traditional species

The aim of this paper is to discuss why *Honeysuckle* can be successfully used in the reconstruction of the karst environment.

Materials and Methods

The characteristics of *Honeysuckle* used in traditional Chinese medicine are summarized from published references in Table 1 (Shi, J.Y. et al., 2001; Li, P. et al. 2001; Tian, J et al. 2002, Zhang, Z.Y. et al. 2003; Liu, Y.E. et al. 2003, Zhang, Z.Y. et al. 2003). The *Honeysuckle* species traditionally recognized for their role in Chinese medicine are *Lonicera japonica* Thunb. mainly distributive in Northern China, *Lonicera confusa* D.C. mainly in Southern China, *Lonicera dasystyla* Rehd. and *Lonicera hypoglauca* Mig. all over China. They are grown in traditional production areas (TPA) and have been shown to be effective in medicine, as recognized by P.R. China Codex (P.R. China National Pharmacopoeia Committee, 2000) TPA are found in Shandong Province and Henan Province of Northern China. Fenqiu County of Henan province has already been awarded the Certificate of Origin by General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China.

The composition of flowers of *Honeysuckle* grown at Nongla Village was compared to that of flowers from TPA (Table 3).

At the Centre for Analysis in the Henan College of Chinese Medicine, chlorogenic acid in the flowers of *Honeysuckle* was tested with LC-10AD and SPD-10A. It is an effective ingredient for resisting pathogenic microorganisms, enhancing immunity, diminishing inflammation, detoxification and stopping bleeding and so might become a hopeful pioneering compound against HIV virus. So, *Honeysuckle* flowers as a form of traditional Chinese medicine played a significant role in fighting SARS in the Spring of 2003.

The elements of *Honeysuckle* flowers and their soil at Nongla village, including Ca, Mg, P, K, Na, S, Si, Fe, Mn, Cu, Zn, Ba, Co, Sr, Ni, Li, Ti, Ge, REE, Cd, As, Cr, Pb, Hg, were respectively analyzed by the National Laboratory of Environmental Geochemistry of Institute of Geochemistry of Chinese Academy of Sciences and the National Research Centre of Geo-analysis of Chinese Academy of Geological Sciences.

Results

Comparison of environments

Nongla Village has a humid monsoon climate with annual precipitation of 1,246–2,063mm, averaging 1,667 mm. After the end of September each year, there is a pronounced dry season, and because karst reduces retention of surface water, the effective rainfall can be in the vicinity of 1,000 mm per annum or less. The area receives 1,600–2,000 hours of sunshine per year, and has an average annual temperature of 21.3°C, the figures of which are lower and higher respectively than those of TPA (see Table 1). The properties of DGLF soil basically meet the requirements for cultivation of *Honeysuckle* (Table1), except for the lower level of potassium in DGLF soil than in the soil of TPA (Zhang, Z.Y. et al. 2003). Thus DGLF soil is suitable for planting *Honeysuckle*, but growth may be limited on the northern slopes of peaks where temperatures are lower than elsewhere.

Selection of *Honeysuckle* species

The *Honeysuckle* planted at Nongla Village is *Lonicera hypoglauca* according to the listing in the P.R.

Table 2: Comparison of the Honeysuckle soils of the DGLF and TPA (ppm)

Elements	Ca	Mg	P	K	Cu	Zn	Fe	Mn	Pb	Co	Al
DGLF	5257	18230	577	8270	24.9	138	67352	1383	56.9	23.9	134471
Traditional	27405	9380	733	18200	25.6	69.8	33950	405.7	13.0	10.3	69647

Table 3: Analysis of flowers of *Lonicera hypoglauca* growing in DGLF Soil and its comparison to TPA's (ppm)

Elements	Ca	Mg	P	K	Cu	Zn	Fe	Mn	Pb	Cr	Sr	Ni	Ti	Co	Ba
DGLF	4600	2930	2610	20700	19.2	26.5	277	42.3	0.44	0.66	5.1	1.4	26	4.9	5.4
Traditional	3733	2603	3446	22520	14.5	18.8	351	37.6	0.29	0.85	23.6	3.9	5.4	0.21	15

China Codex. It has a high content of chlorogenic acid (1.9%) in the flower, determined from the analysis of samples that included about one third flower buds. More than 30 elements were tested (Table 3) with the results matching those obtained for *Honeysuckle* grown in TPA (Zhang, Z.Y. et al. 2003).

Discussion

Suitability of *Honeysuckle* for cultivation on karst peak-depressions at Nongla Village

As indicated previously, the DGLF soil is suitable for the cultivation of *Honeysuckle*. We were informed by local people that *Honeysuckle* grown on the southern slopes of peaks where radiation is higher and hours of sunlight longer than on northern slopes, is likely to die several years after planting, and thus often needs to be replanted. This appears to indicate a relationship between temperature and the growth of *Honeysuckle*. However, availability of moisture and temperature are usually related. High temperatures increase both evaporation from the soil and the rate of water loss through transpiration from plants leaves. Although *Honeysuckle* can cope with a certain level of aridity, it is likely that the plants are stressed by the combination of high temperatures and associated increase in evaporation of moisture from the soil.

Limitations to the extension of the area planted with *Honeysuckle*

Extension of the area in which *Honeysuckle* can be planted is evidently controlled by the combination of the availability of water (effective precipitation), temperature range and soil characteristics. For the karst region of Guangxi Province in the southern subtropical to tropical zones, temperature will be a more limiting factor than soil. In Guizhou Province in the subtropical zone and along the Upper Yangtze River, soil and water are the dual factors affecting the production of *Honeysuckle*. The soils most suited to production of *Honeysuckle* in Guizhou Province are yellow and black calcareous soils of about 255×10^4 km^2, in Guangxi Province brown calcareous soils of about 79×10^4 km^2 and in Yunnan Province red and black calcareous soils of about 76×10^4 km^2, accounting for 65.4%, 61.8% and 69.7% of the area of calcareous soils respectively.

Suitability of *Honeysuckle* for cultivation in karst regions of southwestern China.

Levels of K and P are very high, up to 2.07% and 0.261% respectively, in the flowers of *Lonicera hypoglauca* indicating that *L. hypoglauca* may accumulate P and K elements, with high absorption coefficients of 4.5 and 308 for total and available P, and 2.5 and 30 for total and available K (Table 4). When managing *Honeysuckle*, local people of Nongla village generally don't apply fertilizer, but usually gather its fallen leaves and withered branches and then use them to cover the ground around the *Honeysuckle*. So, maybe it is the return of P and K from *L. hypoglauca* litter to the soil

Table 4: Absorption coefficients of elements in the flowers of *Lonicera hypoglauca* growing in DGLF soils.

P	K	N*	Mg	Ca	As	Cu	Fe	S
4.5*(308)	2.5*(30)	5.4(81)	0.16(43)	0.88(31)	0.01(22)	0.35(19)	0.004(17)	(15)

Zn	Cd	Si	Co	Na	Mn	Sr	Hg	Ge	Ba	Ni	Pb	Cr
0.09(7.6)	0.07 (3.3)	(1.8)	0.16	0.16	0.03(0.13)	0.12	0.10	0.08	0.03	0.01	0.01	0.01

The numbers in round brackets show the available forms of elements in soil.
*Data from Li Wei, Zhang Cheng and Li Enxiang

that can compensate the P and K removed by harvesting the flowers and needed in next growing season. In the topsoils where *Honeysuckle* had been planted, available P and K increased from the background of 7.05 μg/g, 47.1 μg/g, to 8.28 μg/g and 137.2 μg/g respectively. In other places near to the north of Nongla village, some persons ever fertilized the *Honeysuckle* to raise the production. It resulted in yield improvement within 1–2 years as they had wished, but subsequent death of the plant. This shows that *Honeysuckle* can grow well with its strong accumulation of P and K in karst deficient of P and K. Thus the accumulation of P and K by *Honeysuckle* could be listed as one of the benefits of the cultivation of *Honeysuckle*. This point is significant. It is well known that karst regions lack macro-elements, such as P and K, especially in their available forms and this may be one of the major causes impacting the successful reconstruction of karst ecosystems. Because of 54×10^4 km^2 karst in Southwestern China, where most people are still very poor, fertilizing the soils is unrealistic and not economically permitted. It is suggested that the identification, cloning and transfer of genes controlling the uptake of P and K into other plant species which have been growing slowly on karst and can conserve soil and water, could well accelerate the restoration of karst ecosystems in southwestern China.

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Thinking about Karst and World Heritage

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Abstract

Various aspects of the operation of the World Heritage Convention have been reviewed over the last several years. The actual inscription criteria and process have been changed to reduce the differences between natural and cultural sites This may well be of benefit to those seeking recognition of karst sites as many such sites have both natural and cultural values. At the same time, every effort is being made to reduce the number of new inscriptions, while at the same time endeavoring to ensure that the list is balanced, representative and credible. Efforts are being made to establish frameworks to enable more adequate assessment of representivity, and this paper will propose and examine a potential framework for cave and karst sites.

The Basis of World Heritage

The World Heritage Convention, initially adopted by UNESCO in 1972, was established in order *to provide for the proper identification, protection, conservation and presentation of the world's irreplaceable heritage* (Convention 1-2.). It first came into operation in 1976. Any governments that are signatories to the convention may nominate potentially appropriate properties; the World Heritage Committee shall consider such nominations, and if the committee considers a nomination meets the established criteria, then the property concerned is inscribed on the World Heritage register.

The basic rules of the World Heritage program are established within the Convention (www.unesco.org/whc/world_he.htm). A further document, named *Operational Guidelines for the Implementation of the World Heritage Convention,* sets out the principles upon which judgments and decisions are made. Since 2000, the Guidelines have been thoroughly reviewed and amended (some details below) and the amendments were formally adopted in February 2005 (http://whc.unesco.org/opgutoc.htm).

The main change in the guidelines lies in the merging and integration of the cultural and natural criteria for assessment. Beyond this, they provide a detailed description of the role and responsibilities of each of the partners (State Parties, General Assembly, Committee and Advisory Bodies). They emphasise the participatory role of all stakeholders. Many concepts and definitions are clarified, including Global Strategy, thematic studies, comparative analysis, serial and trans-boundary properties, boundaries and buffer zones, referral and deferral, and procedures for boundary extensions or name changes.

A Balanced, Representative and Credible List

A paper from IUCN (April 2004) spelled out the principle that there should be a more systematic strategy in place to ensure a more balanced, representative and credible list. However, it is based upon acceptance that the essential and most basic criterion required for inscription is that any property must be of *Outstanding Universal Value (OUV)* (Convention 1.). Any other strategy must be subsumed within this basic and universal criterion, and so it is also recognised that genuine representation of all natural systems will be neither feasible nor desirable. Current Initiatives include:

- A palaeontological sites study (Wells 1995) which reviews existing sites and identifies gaps,
- A process now working towards developing a similar report on geological sites and many other parallel studies of various groups of sites,
- The recently distributed broadly based Strategy Paper which discusses general principles and then examines representation across biomes and biogeographic regions.

At present, the only karst-specific lists are in the Proceedings of the Asia-Pacific Forum on Karst Ecosystems and World Heritage Mulu (2001) and the Proceedings of the 2004 Lipice Forum on the European region.

This paper will

- Identify the extent to which most karst sites have wide-ranging multi-dimensional values,
- Summarise characteristics of the currently inscribed karst sites,
- Examine the feasibility of categorising karst sites as a basis for identifying significant gaps.

World Heritage

Some 50 karst sites have been inscribed. Many of these have other values and in some cases, the nomination and assessment processes, and hence management, give little attention to karst values. Only three are listed as mixed (natural and cultural) sites, while another nine are inscribed only as cultural sites.

Karst properties are often complex and dynamic, with multiple values. A seminal paper by Yuan Daoxian (1988) emphasised the interactivity and complexity of the karst environmental system. This concept was neatly summarised by an Australian karst scientist as "an extensive network of hydrologically integrated karst conduits fed by numerous tributary streams. This conduit network forms part of a karst system, incorporating component landforms, as well as life, energy, water, gases, soils and bedrock" (Eberhard 1994: 8).

So, karst often has . . .

- Invaluable geological data (particularly in the cave floors),
- Important geomorphic structures and processes,
- Characteristic surface and often significant landscapes,
- Important surface ecosystems,
- Even more important subterranean ecosystems,
- Fossils,
- Cultural heritage: pre-historic, historic and living.

Towards Categories of Karst

It is extremely difficult to establish simple neat categories for such a multi-dimensional phenomenon as karst. What follows is still a draft, despite papers, displays and discussions on a number of occasions. Further comments will be indeed welcome.

Potential opportunities are listed as examples of the kind of sites that might be considered. Some are currently undergoing preparation for submission of a nomination, others have been formally recommended for nomination (e.g., at the Mulu and Lipice forums) while still others are simply outstanding examples. However, their inclusion in this list is not an endorsement or recommendation for inscription on the World Heritage List but serves to provide illustrative examples. The list has been compiled by the author following consultation with a large number of international karst experts and is not an official position of IUCN or WCPA.

In the listing of sites that follows, already inscribed World Heritage sites are shown in **bold type** at the first reference, other potential site opportunities in regular font and second or even further appearances in the list are in *italics*.

Obviously, there are two major categories at the beginning which each comprise a diversity of sites, but it has been difficult to identify further key categories within these. Several people have commented that one or more of these sites should be considered as being in a category of their own as unique locations. But because of its multi-dimensional complexity, this is true of virtually all karst sites! However, Osborne (in press) has identified the extent to which some of these sites and some others have a distinctive character. This results from the complex multiphase and multi-process evolutionary processes to which the sites concerned have been subject. The sites that he has identified include the Eastern highlands impounded karsts of Australia together with sites in the Czech Republic, Slovakia and Hungary.

Acknowledgements

In addition to its presentation at the IGCP 448 conference: *Limestone Coast 2004*, this paper was also presented at the Trans-Karst 2004 meeting in Hanoi, and discussed on both of these occasions and also informally at the Lipice Forum. I am indeed grateful to all those who commented, and in particular to Boris Sket of Slovenia, who contributed greatly to this version of the paper.

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Proposed Category	Site Names / State	Examples of Potential Opportunities
Particularly large and complex sites	**Mammoth Cave, USA** **Carlsbad Caverns, USA** **Three Rivers, China** **Aggtelek & Slovak Karst, Hungary & Slovakia** **Gunung Mulu, Malaysia** **Western Caucasus, Russia** **Skocjanske Jame, Slovenia** **Phong Nha Ke Bang, Vietnam** **Puerto Princesa, Philippines**	Nullarbor Plain, Australia Postojna-Planina, Slovenia Moravian Karst, Czech Republic Ghar Alisadr, Iran Kahurangi, New Zealand Hin Namno, Lao PDR (as a transboundary park with Phong Nha Ke Bang) Maros Karst, Indonesia Niah Great Cave, Malaysia Gomantong, Malaysia Various Papua New Guinea, including Kikori-Darai, Muller Plateau, Nakanai-Whiteman Ranges, Hindenburg Wall
Impounded Karsts [often relatively small areas of karst surrounded by other rocks, and receiving (allogenic) water drainage from those other rocks]	**Canadian Rockies, Canada** **Nahanni, Canada** **Pyrennes-Mont Perdu, France & Spain** **Grand Canyon, USA** **Tasmanian Wilderness, Australia** **Blue Mountains, Australia** **Eastern Rainforests, Australia** **Te Wahipounamu, New Zealand** **Pirin, Bulgaria** **Durmitor, Yugoslavia** **Thung Yai Hua Kha Khaeng, Thailand** **Lorentz, Indonesia** **Lake Baikal, Russia**	
Geodiversity on Towerkarst, Cone karst, and similar	**Tsingy de Bemeraha, Madagascar** **Ha Long Bay, Vietnam** **Wulingyuan, China** **Vinales Valley, Cuba**	China (proposed serial nomination): Guizhou, Shilin, Guilin/Yangshuo, Mt Jin Fo, Wulong, Fengdu, Fenjie. Gunung Sewu, Indonesia Sangkulirang, Indonesia West Kimberley ranges, Australia
Desert Karsts		*Nullarbor Plain, Australia* Namibia Various Central Asia
Aeolian or Syngenetic sites	**Lord Howe Island, Australia**	Margaret River and Limestone Coast, Australia
Karst in non-limestone rocks	**Purnululu, Australia (quartzite)** **Cainama, Venezuela (quartzite)** *Wulingyuan, China* (sandstone)	Brasilian quartzite caves Ruined City, Arnhem Land, Australia (quartzite) Italian gypsum karst Kungur Ice Cave, Russia (gypsum) Thai halite karst
Sulphur-based Karst	*Carlsbad Caverns, USA*	Cueva de Villa Luz, Mexico Movile Cave, Romania
Travertine Terraces	**Huanglong, China** **Jiuzhaigou, China** **Plitvice, Croatia** **Pamukkale, Turkey**	
Island Sites	**Alejandro de Humboldt, Cuba** **East Rennell, Solomons** **Henderson (Pitcairn), UK**	Fiji Niue Palau Trobriand Is., Papua New Guinea
Marine / Coastal sites	**Desembarco del Granma and Cabo Cruz Terraces, Cuba** **Shark Bay, Australia**	Blue and Black Holes, Bahamas Cape Range & Ningaloo Reef, Australia (Nomination pending) Huon Peninsula, Papua New Guinea Submerged caves of the Pacific and Caribbean

Proposed Category	Site Names / State	Examples of Potential Opportunities
Hydrological Diversity	**Sian Ka'an, Mexico** *Skocjanske Jame, Slovenia* *Phong Nha Ke Bang, Vietnam* *Puerto Princesa, Philippines*	Katavores of Argostoli, Greece
Cenote Karst	**Chichen Itza, Mexico**	Yucatan, Mexico Florida, USA Limestone Coast, Australia
Mineralogically diverse sites	*Carlsbad Caverns, USA*	France (Serial nomination pending) Cupp-Coutunn, Turkmenistan Black Hills, USA
Climatologically rich sites	*Skocjanske Jame, Slovenia* *Aggtelek & Slovak Karst, Hungary & Slovakia*	*Nullarbor Plain, Australia* *Kungur Ice Cave, Russia*
Biodiversity	*Mammoth Cave, USA* *Skocjanske Jame, Slovenia* *Gunung Mulu, Malaysia* *Sian Ka'an, Mexico* *Tasmanian Wilderness, Australia* *Blue Mountains, Australia*	*Nullarbor Plain, Australia* Cape Range & Ningaloo Reef, Australia (Nomination pending) Postojna-Planina, Slovenia Vjetrenica, Bosnia & Herzegovina Cueva Guacharo, Venezuela *Niah Great cave, Malaysia* *Gomantong, Malaysia* *Sangkulirang, Indonesia* *Submerged caves of the Pacific and Caribbean*
Palaeontological sites	**Fossil Mammal Sites (Naracoorte and Riversleigh), Australia** **Atapuerca, Spain** *Grand Canyon, USA*	*Nullarbor Plain, Australia* Kahurangi, New Zealand (especially at Karamea) Bärenhöhle, Switzerland
Archaeological sites	**Zhoukoudian, China** **Altamira, Spain** **Fossil Hominoid Sites, South Africa** **Caves of the Vézères, France** *Grand Canyon, USA* *Atapuerca, Spain* *Chichen Itza, Mexico*	*Nullarbor Plain, Australia* Piatra Altarului, Romania Grotte Chauvet, France
Socially or culturally rich sites	**Vinales Valley, Cuba** **Sodra Olands Odlingslandskap, Sweden** **Luang Prabang, Lao PDR** *Chichen Itza, Mexico*	

ABSTRACTS *Limestone Coast 2004*

The closing workshop of IGCP 448 (Global Karst Correlation) and The first International Workshop on RAMSAR Subterranean Wetlands.

Naracoorte, South Australia, October 2004

HORIZONTAL AND SUBHORIZONTAL WALL NOTCHES, FLAT ROOFS AND FLOORS: MORPHOLOGY, TYPOLOGY AND HYDROGRAPHICAL FEATURES OF CAVE DEVELOPMENT (poster)

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From a point of view of the reconstruction of palaeohydrographical development and genesis of caves in solution rocks wall notches, solution flat roofs, flat floors or cave terraces belong to the most remarkable geomorphological forms of cave georelief. They refer to the phases of underground water lateral corrosion / erosion or planation in consequence of the long-lasting stable erosion base on the surface terrain at the spring cave part, long-lasting floods of cavities or the long-lasting increase of water table caused by hydrogeologic or sedimentary barrier.

Wall notches: Corrosion horizontal waterline notches in vadose standing water with an open air surface, inclined vadose and paragenetic wall notches formed by alluviated streams cutting laterally into passage walls, and corrosion notches related to the Laugdecke and Laughöhle profiles as standing phreatic water features formed by slowly moving cells of density-driven currents are distinguished by Lauritzen & Lundberg (2000). According to the morphology, spatial configuration and variations of notches simple (one-phased) and composite (more-phased) notches, series of simple uniform or different notches, series of composite uniform or different notches, also combined series of simple and composite notches are known.

There are various types of simple notches with mainly horizontal developmental dimension deepened into cave rocky walls: lateral meandering channels, lateral one-sided or double-sided longitudinal channels, lateral upward enlarged paragenetic channels, lateral downward enlarged channels, lateral one-sided oval runnels, small or larger half-cylindrical notches without or with small between-ribbed or irregular hollows modelled by waves of water, nick water-level notches (water-level lines), slotted water-level notches, symmetrical wedge-shaped notches, one-sided downward asymmetrical wedge-shaped notches or half-heart-shaped notches (Laugdecken type), one-sided upward asymmetrical wedge-shaped notches, one-stepped notches (type of above-sediment corner) (after Lange 1963), overhanging one-stepped notches (type of water-level corner) (after Lange 1963), quasi-prismatic notches, and other similar types. Composite notches present more-phased equivalent united notches, more-phased floor stepped notches, more-phased overhanging stepped notches, combined more-phased floor and overhanging stepped notches, and other composite types. Neighbouring lateral notches are united into morphogenetically and dimensionally monoform or polyform series. From a morphological point of view the polyform series of notches are differentiated into gradational and irregular series.

Flat roofs and floors. The origin of cave solution flat roofs and floors in connection with the long-lasting stable erosion base on the surface terrain can be correlated with the development phases of surface terrain in the surrounding area during the phases of tectonic stability and lateral planation of georelief. Fluviokarstic cave passages with solution flat roofs or floors in the side valley position and in the spring position of underground stream present cave levels of river bed type (after Bögli 1978). Their roofs are remodelled and enlarged by planation of georelief. Fluviokarstic cave passages with solution flat roofs or floors in the side valley position and in the spring position of underground stream present cave levels of river bed type (after Bögli 1978). Their roofs are remodelled and enlarged by planation of slowly running or stagnant water in relation to the stable erosion base. Cave solution flat roofs correspond to cave levels of water table type if ones are formed along a water table, in several cases in the hydrographical position below surface streams in the surrounding area.

Several morphogenetic types of solution flat roofs are known (Bella 2003): 1. flat roofs formed by natural water convection (Laugdecken), 2. flat roofs formed by planar remodelling and enlargement of permanently or repeatedly flooded cavities (water-level planes), 3. flat roofs formed by remodelling of cave roofs after the paragenetic developmental phases of fluviokarst passages in the conditions of slowly flowing or stagnant water between floor sediments and a rocky roof, 4. flat roofs formed by lateral corrosion and erosion of meandering underground stream without the relevant morphological features of paragenetic development and planation roof surfaces of undercut meanders. In many caves with solution flat roofs, the active phreatic or epiphreatic phase of cave rocky georelief development is finished by roof planation. Flat roofs in several fluviokarstic caves were remodelled and dissected during the younger paragenetic phase of their development. Terraced flat roofs present lateral flat roofs under the step of inverse terraces or last non-paragenetic passages.

Larger floor planation forms are originated in the connection with the development of cave levels of river bed type. From a genetic point of view erosion-denudation, erosion-accumulative and accumulative flat floors are known in caves. From a morphological point of view flat floors and terraced flat floors (cave river terraces) are distinguished (Bella 2004).

Horizontal flat roofs and floors are formed in ideal water table caves or caves with mixture of phreatic and water table levelled components (after Ford 1988, 2000; Ford & Ewers 1978). The origin of several small forms with planar surfaces (planar cupolas, planar plates, planar niches) is the result of local micro-planation without a relation to an erosion base. If lateral water table or floor notches deepened into cave rocky walls belong to cave levels, their development is correlated in connection with a stable erosion base. In other cases, these lateral notches are produced by local lateral corrosion / erosion on rocky walls in individual cave parts.

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DOMICA CAVE - THE RAMSAR SUBTERRANEAN WETLAND IN SLOVAKIA (CENTRAL EUROPE): NATURAL PHENOMENA AND PROTECTION (poster)

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The Domica Cave (Silica Plateau, Slovak Karst National Park) presents a very important cave with many remarkable geomorphological, mineralogical, hydrological, biospeleological and archaeological features. It is a part of the bilateral Slovak-Hungarian site "Caves of Slovak and Aggtelek Karst" inscribed in the World Heritage List in 1995.

The Domica Cave (Slovakia) and the Baradla Cave (Hungary) constitute one hydrological system directed from Slovakia to Hungary. Occasionally active cave streams flow from several border sinkholes at the contact of non-karstic and karstic surfaces in the catchment area. The underground hydrological system is supplemented mainly by occasional allogenic streams from rainfall or snow melting waters. Its spring is situated in Hungary near the Josvafo village. This genetic cave system is a typical example of water table level cave. Its total length is ca 25 km.

The Domica Cave (424 m a.s.l.) was formed in Middle Triassic limestones by corrosion and erosion by the underground stream named Styx and its tributaries at three developmental levels with the relative height span of 8 - 12 m. The lowest cave level is filled up by fluvial sediments. From the morphological point of view, horizontal oval passages with distinct paragenetic ceiling channels and epiphreatic lateral notches, widened to halls and domes in several places, are dominant. Other passages are characterized by vadose meander features. The length of the cave is 5,358 m. Shields, rimstone pools (cascade pools), onion-like stalactites, pagoda-like stalagmites and columns are the most characteristic and important forms of carbonate speleothems in the cave. The Domica Cave was discovered in 1926 and opened to the public in 1932. The underground boat trip in the artificial pool (constructed also in 1932) is very attractive for visitors but it is realized only during suitable hydrological conditions after a longer wet period.

The underground hydrological system forms specific conditions for the existence of ecological system and diversity of rare and threatened organisms. The Domica Cave and its surroundings were declared a Ramsar site in 2002. It is a representative example of a natural subterranean wetland in the Carpathian region (Central Europe). It is a very important chiropterological locality (16 species of bats, dominant *Rhinolophus euryale*). Special values of the site are given by rare, vulnerable and threatened terrestrial and aquatic animal species (e.g. palpigrade *Eukoenenia spelaea*, amphipod *Niphargus tatrensis*, millipede *Typhloiulus sp.*, springtails *Arrhopalites buekkensis*, *Arrhopalites slovacicus*, *Deuteraphorura cf. kratochvili* and *Pseudosinella aggtelekiensis*, beetle *Duvalius hungaricus*).

This Ramsar site is represented not only by the Domica Cave but also the whole surface catchment area of underground streams (621.76 ha). The Domica Karren National Nature Reserve is situated above the cave. After intensive rains or snow melting, occasional surface streams flow from the non-karstic area of the Bodva Upland (formed by Neogene gravels, sands and clays covered by Quaternary sediments) to border karstic sinkholes. The non-karstic part of catchment area is used for agricultural activities producing several negative impacts. The risk of soil erosion after intensive rains in the catchment area was reduced by the changing of arable land to grassland in 1988. The quality of underground waters is monitored in the cave. The contamination of underground waters after intensive rain and snow melting is caused by organic, anorganic and microbiological substances. The optimization of land utilisation in the non-karstic surface part of catchment area is necessary for the geoecological stability of cave geosystems. Restricting and minimizing of agriculture influences improve the quality of underground waters.

On the basis of the law on nature and landscape protection (2002) and actual scientific knowledge, the project of protected zone of the cave has been prepared. The proposed protected zone includes almost the total cave catchment area. The complex approach of the Ramsar site protection contributes to the conservation and improvement of the variability of rare animal populations occurring within the Slovakian and Hungarian Hucross boundary underground hydrological system.

SYNGENETIC KARST IN AUSTRALIA: A REVIEW

Ken G. Grimes

See full paper in this issue, pp 27-38

GEOLOGICAL DEVELOPMENT OF THE NARACOORTE CAVES, SOUTH AUSTRALIA.

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The geological evolution of the Naracoorte Caves and surrounds is described up to the stage in the mid-Pleistocene in which the fossiliferous sediments began to form within them.

The Naracoorte Caves, in the East Naracoorte Range (ENR), are part of the broader Gambier Karst Region of south-east South Australia and western Victoria. This is a 'soft-rock' karst developed on poorly consolidated Oligocene to early Miocene marine limestones (calcarenites) and Quaternary dune limestones. The ENR is an old coastal dune range at the edge of the Naracoorte Plateau (see Figure 1). Much of the early development of the caves is poorly understood but the main factors in cave and karst development since the late Miocene have been:

- the nature of the host rock (a soft, porous and permeable calcarenite, with a NNW joint trend);
- eustatic sea-level changes coupled with ongoing regional uplift (at about 65-70 m per million years) formed a sequence of old coastlines;
- local movements in the Kanawinka fault, bounding the ENR, which had an important influence on the local hydrology;
- and climatic changes.

The Tertiary limestones at Naracoorte were first exposed by a drop in sea level in the late Miocene coupled with local upwarp of the region which continued through to the present. Karst and caves would have formed at that time (about 11-12 Ma). However, early (6-4 Ma) and late (2 Ma) Pliocene and early Quaternary transgressions of the sea may have destroyed or extensively modified that early karst.

The ENR was formed at an old, possibly faulted, coastline about one million years ago, but the caves

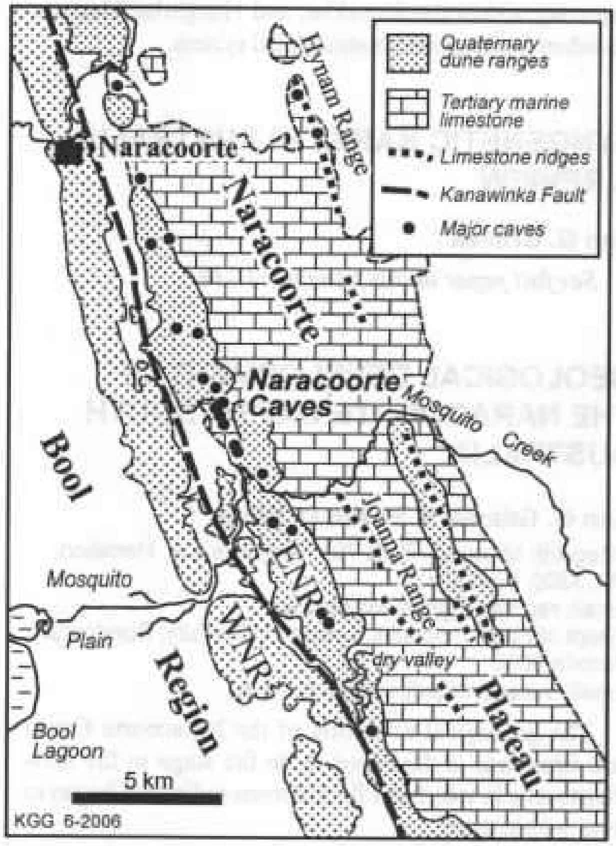

Figure 1: Naracoorte Caves area - modified from a map by Ian Lewis, 2004. The position of the buried Kanawinka Fault is only shown approximately.
WNR = West Naracoorte Range,
ENR = East Naracoorte range.

may partly predate that. The Naracoorte Caves are concentrated beneath the ENR where there has been an overall drop in water level following initial cave development which has left two drained levels of the present cave systems. The lowest level is a horizontal phreatic maze only just above the present watertable. The larger but less common upper level chambers have massive speleothem deposits beneath thin roofs which suggest that there has been some denudation of the surface since they formed.

Several suggestions have been proposed to explain the localisation of the caves beneath the ENR, and their clustering along the range (shown on Figure 1):

- The caves may have developed in a flank-margin setting from mixing between a fresh-water lens and sea water from the adjoining coast (White, 2005);
- Input of aggressive waters from the swamps of the adjoining swale, and/or from Mosquito Creek;
- A steepening of the watertable upflow (northeast) of the fault scarp, with the steep-gradient zone migrating upflow as conduits developed;
- A slight incision of Mosquito Creek might have caused local steepening of the water table towards the creek;
- Rhythmical variations in joint density might explain the clustering along the ENR (Lewis, abstract in this volume).

Dating of speleothems shows that 500,000 years ago the solutional cave systems were complete and had already been drained and extensively modified by collapse to form large chambers. Cave development since then has been an alternation of collapse and internal sediment formation, speleothem formation, and the introduction of surface sediments and bone material.

White, S.Q., 2005: *Karst and Landscape Evolution in parts of the Gambier Karst Province, Southeast South Australia and Western Victoria, Australia.* PhD Thesis, Department of Earth Sciences, La Trobe University Bundoora, Victoria. 247 pp.

PROTECTING GROUNDWATER ECOSYSTEMS: WILL SURFACE WATER QUALITY GUIDELINES DO THE JOB?

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Despite increasing awareness of groundwater contamination issues, our understanding of the response of groundwater ecosystems to contamination remains limited. Water quality guidelines are a critical management tool for protecting ecosystems from changes in water quality, but there are currently no water quality guidelines designed specifically to protect groundwater ecosystems. It is assumed water quality guidelines for surface waters will also protect groundwater ecosystems and their fauna.

A review of groundwater contamination by pesticides in Australia shows that concentrations can exceed surface-water quality guidelines. However, the biological characteristics of stygofauna make them very different to surface aquatic fauna thus surface water quality guidelines may not be appropriate. The fauna of groundwater ecosystems includes crustaceans, rotifers, mites, oligochaetes, nematodes and microbes. Insects, fish, and photosynthetic organisms are rare or absent. Groundwater ecosystems thus represent a truncated biodiversity.

In the absence of sufficient toxicity data for groundwater organisms per se, I used data for surface dwelling organisms of these groups (where available) to derive water quality guideline trigger values. In doing so there is an assumption that there is no difference in the sensitivity of surface-dwelling and groundwater-dwelling species of the same taxonomic group. Using species sensitivity distributions and available acute toxicity data, I show that surface water quality guidelines for most pesticides will protect groundwater taxa, but a notable exception is Chlorpyrifos, suggesting a groundwater specific guideline is needed. Furthermore, the water quality trigger value for Atrazine was several orders of magnitude less in surface water than groundwater ecosystems, suggesting the guideline value for Atrazine in groundwater may be relaxed.

Alarmingly, the trigger values for several pesticides were below the concentrations recorded in the field. These findings suggest groundwater fauna are at risk from current levels of groundwater pollution, but to truly understand the significance of these results, this critical question must be answered; do surface and true groundwater faunas have similar sensitivities to toxicants?

CONSERVATION OF KARST AND GROUNDWATER DEPENDENT ECOSYSTEMS IN TASMANIA

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In comparison with mainland Australian states, the proportion of Tasmania's land area which is karst or potentially karstic carbonate rock is high, approaching the world average. Much is located in humid temperate zones, however the state's highly diverse physiography provides a large range of contexts for over 300 separate karst areas. Much of the karst is found in wilderness or undeveloped areas, with new systems being continuously discovered, however some areas are used for intensive agriculture and forestry. Karst systems interact with regional groundwater systems in many ways, although far less information is available regarding the nature and dynamics of non-karst groundwater systems.

Recently developed management tools include:

- A multilayered digital karst atlas combining spatial information on karst and catchment boundaries, hydrogeological systems, distribution of various classes of surface features, cave systems, associated land tenure etc.
- A geomorphic regionalisation of the state which allows definition of the regional context of individual systems to be made, to allow comparisons for conservation assessment and definition of template areas for rehabilitation of degraded areas.
- Predictive statewide groundwater flow system mapping and groundwater prospectivity mapping.

The Conservation of Freshwater Ecosystem Values project is currently underway. A major aim is to comprehensively document the state's freshwater conservation values, in the context of a well-defined biophysical context. The georegionalisation referred to above, in combination with biological data derived from macroinvertebrate distributions, native fish, macrophytes, crayfish assemblages and riparian vegetation data forms an integrated context in which both geoconservation and biological conservation priorities may be established. Karst and groundwater dependent systems form a major subset of the CFEV program, karst being defined somewhat separately in order to incorporate those parts of the karst system not necessarily dependent on groundwater. Various tools ranging from formal reservation at various levels through covenanting and conservation agreements on private land will be used to implement the program.

SOUTH EAST CATCHMENT WATER MANAGEMENT BOARD

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Background

The South East Catchment Water Management Board (SECWMB) is responsible for setting management direction of water resources in the South East of South Australia. One of the responsibilities of the Board is to protect and enhance the ecological character of water dependent ecosystems through the appropriate allocation of water. The SECWMB was established by the Government of South Australia in May 1998 under the Water Resources Act 1997. Under the Water Resources Act 1997 the Board is required to prepare a catchment water management plan that takes into consideration the:

- health of the ecosystems that depend on water; and
- need for water of those ecosystems.

Project Outlines:

Reviewing the Environmental Water Requirements of Groundwater Dependent Ecosystems in the South East Prescribed Wells Area

The purpose of this project is to investigate elements such as the confirmation/definition of regional key groundwater dependent ecosystems and threats to them, analysis of the implications of groundwater allocation policy on groundwater dependent ecosystems and the definition of an approach to evaluating the impacts of water allocation policy on groundwater dependent ecosystems. A key outcome will be the establishment of options for policy definition in relation to groundwater dependent ecosystems management.

The Dependence of Near Shore Marine Ecosystems on Groundwater Discharge

The purpose of this project is to determine whether any near shore marine ecosystems are wholly or partially dependent on the discharge of groundwater to the marine environment, define their groundwater requirements, determine whether these ecosystems face any specific threats in relation to the way in which groundwater is allocated, used or managed and define the social, economic and environmental values of these ecosystems. This project is being delivered through a PhD student at Flinders University.

Rehabilitating Aquatic Groundwater Environments

The SECWMB is partially funding this project undertaken by the South East Natural Resource Consultative Committee. The intention of this project is to rehabilitate important karst sites, encompassing coves, sinkholes and rising springs, that have been degraded through the deposition of waste materials, and that have the potential to pollute regional water resources. The project is proposed to commence an education / awareness program to inform the community of the risks of such waste disposal practices in these karst sites.

SUBTERRANEAN WETLANDS OF ARID AUSTRALIA: REMIPEDES, SPELAEOGRIPHACEANS AND DIVING BEETLES

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Over the last decade a surprising range of subterranean wetlands has been unearthed in arid Australia that contain a diverse fauna, largely comprising short-range endemics, which often have close intercontinental affinities. These findings have led to a marked resurgence of research into groundwater biology throughout Australia, as well as significant consideration of subterranean fauna by both regulatory agencies and the conservation movement. In Western Australia subterranean fauna is now routinely considered in the environmental approvals process.

Two major types of subterranean wetland will be discussed, an anchialine (anchihaline) system in a classic karst of northwestern Australia, and groundwater calcrete deposits of the arid interior.

The anchialine system, centred on Cape Range peninsula, is the only continental anchialine system described in the Southern Hemisphere. Such groundwater estuaries are typically highly stratified, becoming suboxic with depth and supporting large colonies of sulphur and nitrogen bacteria which contribute chemoautotrophic energy to the deeper levels. Below the halocline, in seawater, occurs the characteristic anchialine fauna, the composition of which is predictable wherever it occurs, often at the generic level, comprising atyid shrimps, thermosbaenaceans, hadziid amphipods, cirolanid isopods, remipeds, thaumatocypridid ostracods, and an array of copepods, the affinities of which mostly lie with taxa from anchialine caves of the North Atlantic.

In the arid interior, the chains of salt lakes (playas) along the palaeodrainage channels are associated with groundwater calcretes deposits. These carbonate deposits occur largely on the 'Western Shield' (the Pilbara and Yilgarn cratons and associated orogens) which has reportedly been a single emergent landmass since the Proterozoic. Despite this, the northern and southern parts contain diverse but distinct groundwater faunas that may result from different origins of the calcretes. Notable amongst the northern stygofauna are Spelaeogriphacea, a diverse array of endemic genera of candonine ostracods, copepods and amphipods (Melitidae, Paramelitidae, Bogidiellidae, Hadziidae), Phreatoicidea and Tainisopidea (WA endemic order).

Notable amongst the southern stygofauna are the low number of endemic genera of candonine ostracods, the diversity and affinities of the copepods (31 species in 5 families), amphipods (Ceinidae, Neoniphargidae, Perthiidae, Paramelitidae) and Bathynellacea (Bathynellidae and Parabathynellidae). Most distinctive in these calcretes is a diverse array of stygobitic diving beetles (80+ spp), and oniscid isopods, each endemic to a specific calcrete deposit. Notably, some of the sites contain typical freshwater lineages in high saline groundwater.

The significance and diversity of subterranean wetlands in Australia has been grossly underestimated, even in recent reviews.

A short list of references is given that will allow entry into the literature that is summarised in the presentation.

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CAVE STROMATOLITIC STALAGMITES FROM SKOCJANSKE JAME CAVES, SLOVENIA (poster)

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There is almost no literature on freshwater cave stromatolites. In one of the entrance halls of Skocjanske Jame Caves, named Schmidlova dvorana, unusual stalagmites were found. These structures resemble the crayfish-like stromatolites which were described from the cave entrance from South New Wales, Australia (Cox et al. 1989). Some authors consider crayfish-like stromatolites as biostalagmites because cyanobacteria are at least partly responsible for their growth. First preliminary researches were performed: speleothems location in the cave, its head-tail orientation, surface and internal morphology, as well as thin sections of the stalagmite. A stromatolite's surface was aseptically scraped and mixed algal culture in liquid and on solid Jaworski media after several weeks of cultivation in the laboratory was obtained. Cultures were regularly screened for the presence of the algae. Culture data and formaline fixed stromatolite samples now showed that among green algae and diatoms filamentous cyanobacteria prevail.

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PERIODICAL KARST LAKE OF CERKNICA (CERKNISKO JEZERO)- 2000 YEARS OF MAN VERSUS NATURE

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See full paper in this issue, pp 39-46

GENETIC ASSESSMENT OF GROUND WATER DEPENDENT FAUNA IN SOUTH AUSTRALIA

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Compared to the other Australian states knowledge about the groundwater dependent fauna of South Australia is limited to the some studies of Boulton in the Flinders Ranges and some isolated findings in the North of the state (Dalhousie Springs) and the South-East (Mount Gambier area)

So far, four blind amphipod species are described from the South Australian region (one from Dalhousie Springs, one from the Flinders Ranges and two from the Mount Gambier area). Additional sampling in the Gammon Ranges, Flinders Ranges and Mount Lofty Ranges showed however, that there exists a rich groundwater-dependent fauna associated with the hyporheic of creeks and rivers and with springs. Stygofauna has also been found in pastoral wells. Representatives of most fauna groups that are expected to occur in groundwater have been found. eg. melitid and hyalid amphipods, asseloid isopods, syncarids, copepods, ostracods, turbellaria and hydrobiid snails. The crustacean groups Amphipoda, Isopoda and Syncarida all consisted of de-pigmented, blind species, which indicates that the species are obligate groundwater species. Preliminary phylogenetic research (using mtDNA sequencing) at the South Australian Museum showed some very interesting patterns in the representatives of the two amphipod families from the Flinders Ranges and Gammon Ranges area. Specimens of each family from localities in different catchment areas showed deep phylogenetic divergences, indicating that species are probably restricted to individual river systems, and that these species have been separated from each other for millions of years. Although the only described species from the Flinders Ranges (Brachina Gorge: *Brachina invasa*, a melitid amphipod) is morphological very similar to specimens from other creeks, the molecular data suggest a range of undescribed species.

I will demonstrate, using data from two amphipod families, that the application of genetic methods can considerably speed up the recognition of significant biological units which may be important for biodiversity assessment and conservation of the groundwater habitat. Such an approach will also provide supplementary information, not obtained through conventional alpha-taxonomy, eg. estimates of how long species have been isolated in the groundwater, as well as phylogenetic relationships with other groundwater and surface species.

ORIGIN & GENESIS OF THE MAJOR CAVES AT NARACOORTE, SOUTH AUSTRALIA

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Of the 1000 numbered cave and karst features across the Gambier Karst in the South East of South Australia, 150 are known in the area around Naracoorte. Most of these are small and shallow, but 20 caves are deeper and longer than the rest (Lewis, 1976). They are the subject of this study and are here referred to as the "major" caves.

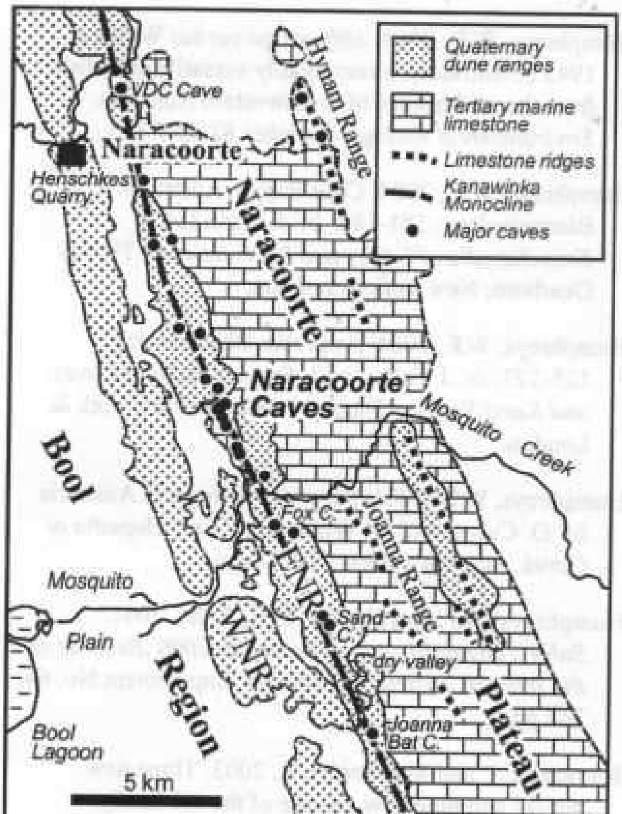

Figure 1: Position of major caves and Kanawinka Monocline at Naracoorte, SA.

An accurate GPS levelling survey of many cave entrances across the Naracoorte area in 2004/5 coupled with cave survey data established a base level of 61 m ±0.5 m ASL for the floors of the 11 deepest caves in the area. The other 9 major caves either approach this depth or contain large chambers.

The major caves all occur within a tightly-defined zone 20 km long but only 600 m wide, running along the East Naracoorte Range (ENR on Figure 1). Such a pattern on a broad flat karst plateau is remarkable – all the more so when they occur in equi-spaced "clusters" at approximately 2.8 km intervals along the zone.

The main passages show a dominant NNW-SSE direction. Previous karst researchers related this to the regional jointing trend (Marker, 1975 & Grimes, 2004). The sub-dominant passages are shorter and run almost at right angles to the main passages – NNE and ENE. Another small group of shorter secondary passages run N-S (Figure 2a). These sub-dominant directions are rarely found across the karstfield but are concentrated in the major caves at Naracoorte. The resulting regularly-angled passage array implies a structural preparation of the limestone in the major cave zone before hydrological processes developed them. Cave passage directions and proportions correlate almost exactly with regional faulting patterns (Figure 2b), effectively proving this claim.

The dominant regional structural feature is the 120-km long Kanawinka Fault, running from south-west Victoria over the SA border to Naracoorte. There has been much debate about its actual nature and location in both States with early workers regarding it as a retreated marine escarpment and not a fault at all. However it is now considered to take a monoclinal form for most of its Victorian section (Kenley, 1971). SA geologists have described it as a normal or shear fault at Naracoorte but with no evidence (Sprigg, 1952). Due to this uncertainty, even its location had not been clearly established with relation to the East Naracoorte Range although accepted to be within its vicinity.

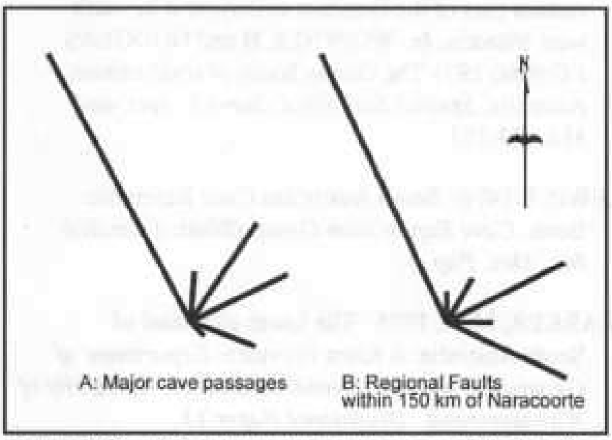

Figure 2: Simplified structural comparison of the lengths and directions of regional faults and the linear passages of the major caves at Naracoorte

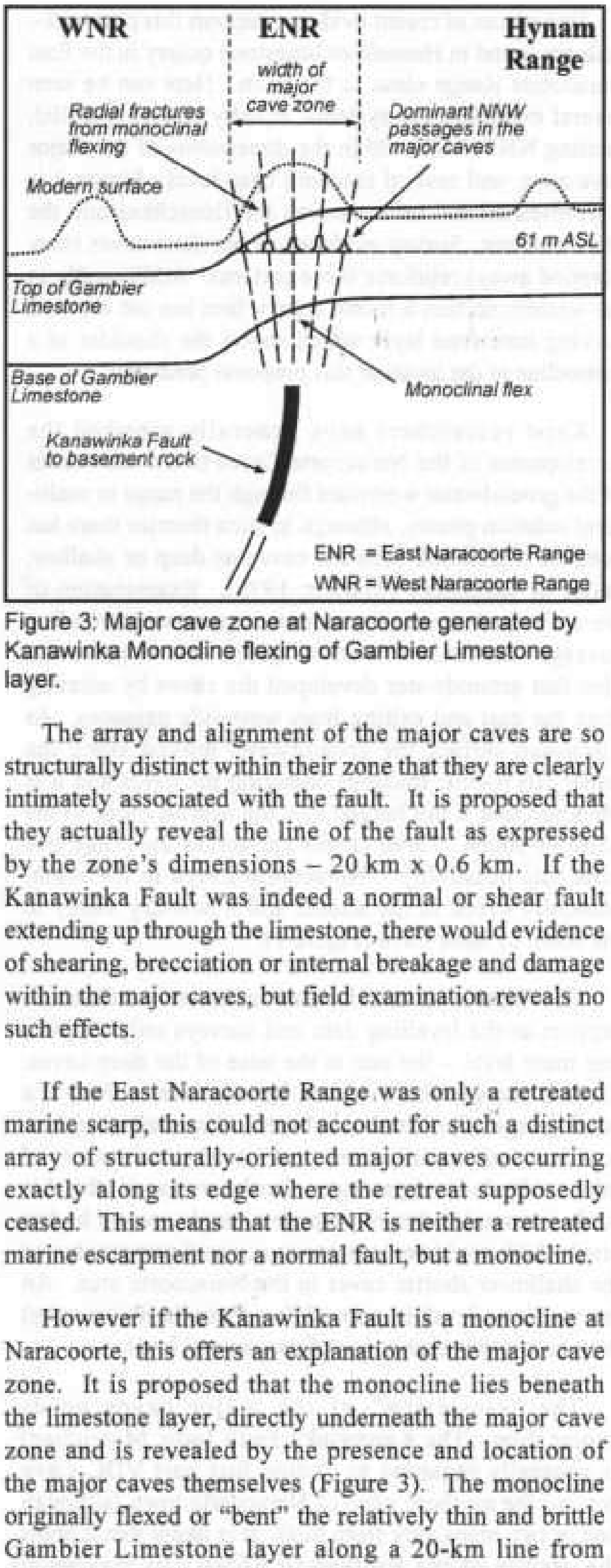

Figure 3: Major cave zone at Naracoorte generated by Kanawinka Monocline flexing of Gambier Limestone layer.

The array and alignment of the major caves are so structurally distinct within their zone that they are clearly intimately associated with the fault. It is proposed that they actually reveal the line of the fault as expressed by the zone's dimensions – 20 km x 0.6 km. If the Kanawinka Fault was indeed a normal or shear fault extending up through the limestone, there would evidence of shearing, brecciation or internal breakage and damage within the major caves, but field examination reveals no such effects.

If the East Naracoorte Range was only a retreated marine scarp, this could not account for such a distinct array of structurally-oriented major caves occurring exactly along its edge where the retreat supposedly ceased. This means that the ENR is neither a retreated marine escarpment nor a normal fault, but a monocline.

However if the Kanawinka Fault is a monocline at Naracoorte, this offers an explanation of the major cave zone. It is proposed that the monocline lies beneath the limestone layer, directly underneath the major cave zone and is revealed by the presence and location of the major caves themselves (Figure 3). The monocline originally flexed or "bent" the relatively thin and brittle Gambier Limestone layer along a 20-km line from Joanna Bat Cave in the south to VDC Cave in the north. The resulting radial fracturing opened a series of close parallel fissures along this line running NNW-SSE along the spine of the range. When westward-moving groundwater in the area intercepted these fractures, it moved along their lengths as a line of least resistance and began the phreatic solution processes which initiated the base level now found at 61 m ASL. Thus the large passages developed along the major fractures caused by the monoclinal flexing.

Two pieces of recent evidence support this proposal – both are found in Henschkes limestone quarry in the East Naracoorte Range close to the town. Here can be seen several exposed cave systems, equally spaced, parallel, running NNW-SSE, within the dimensions of the major cave zone, and several reaching base level. Figure 3 is a representational cross section for Henschkes and the other clusters. Survey evidence of previous caves (now quarried away) reinforce these patterns. Additionally in the western section a recent quarry face has cut across a curving limestone layer which shows the shoulder of a monocline at the location this proposal predicted.

Karst researchers have generally ascribed the development of the Naracoorte Caves to the movement of the groundwater westward through the range in multi-level solution phases, although in such theories there has been no distinction between caves as deep or shallow, major or secondary (Marker, 1975). Examination of the caves and the surveys show no westward-trending passages on their western edges. This negates the idea that groundwater developed the caves by entering from the east and exiting from west-side passages. As discussed earlier, the groundwater moved along the major NNW-SSE fractures enlarging the caves and it is proposed that it discharged into the nearest creek to the north or south. Three creeks cut across the range and offer this possibility – Naracoorte Creek in the north, Mosquito Creek in the middle and a now-dry valley to the south of Sand Cave (Figure 1).

The multi-level development concept is difficult to support as the levelling data and surveys only indicate one main level – the one at the base of the deep caves. There is considerable evidence for solutional activity at a whole range of levels above this but almost all are minor roof and wall modifications, not lateral development of other multiple-level passages. Further research after this study is completed may propose a single second higher level which could be common to a significant number of the shallower shorter caves in the Naracoorte area. An intermediate level in part of Fox Cave (a major cave) may be another expression of this second level.

The "clustering" of the major caves needs explanation. The Kanawinka Fault (now Monocline) is generally regarded as ending just past VDC Cave beyond the northern edge of Naracoorte town (although one or two maps vary from this). It is likely that it abuts the granite of the Padthaway Ridge. Its maximum displacement (90 m) occurs at its extreme south-eastern end in Victoria while at Naracoorte its displacement is at a minimum (40 m). This indicates that its flexibility is restricted at its northern end.

It is proposed that at the time of flexing the limestone, the monocline also arched slightly over a span of 20 kilometres, rising from near Joanna Bat Cave in the south, cresting at the Caves Reserve and dipping downwards again near VDC Cave in the north. This would have only been a matter of a few degrees. The brittle shallow nature of the limestone layer (only 50 metres deep) was therefore susceptible to transverse fracturing at regular intervals when the arching occurred. These regular cross-fractures show as the evenly-spaced clusters of major caves along the range. They are also expressed as the non-dominant cross-passages in each major cave. The point of maximum arching, which is at the Caves Reserve, would therefore be expected to have the largest number of cross-fracturing weaknesses; and it has – they are the 7 major caves found clustered there, ranging from Sand Funnel to Cathedral Cave and centred on Blanche Cave. Further, the east-west alignment of Blackberry, Blanche and Bat Caves (all major caves) may be the centreline of the crest of the arch.

This analysis has been based on the application of geology and geomorphology to the problem rather than karst hydrology. The identification of major caves as a distinct subset of the 150 caves recorded in the area around Naracoorte revealed distribution patterns previously obscured by the overall area pattern. The primary role of the Kanawinka Monocline was in setting the geological conditions for the origin and development of the major Naracoorte Caves. Without this structural preparation, deep and large caves would not exist at Naracoorte, just the more random shallow shorter ones.

Finally a speleological prediction – prospects for large passages and major caves within each cluster are very high, but between clusters there is no likelihood. This needs to be field-checked.

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CONTROLS ON THE WATER CHEMISTRY OF CENOTE LAKES IN SOUTHEASTERN AUSTRALIA

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The karst waters of 14 cenotes (deep lakes within cliffed collapse dolines), formed within the Gambier Limestone of the Mount Gambier region, South Australia, were sampled every month for a year. Five different patterns of seasonal change in karst chemistry in the surface waters of the lakes were identified.

The waters in the pattern 1 cenotes show relatively large drops in Ca^{2+} (> 40 ppm), HCO_3^- and CO_2 levels over summer, associated with increases in pH, SIc and temperature. These cenotes are well exposed to sunlight and undergo summer heating, resulting in thermal stratification and enhanced CO_2 degassing. This in turn raises the pH and SIc of the waters and causes calcite precipitation, reducing Ca^{2+} and HCO_3^- concentrations over summer. The pattern 1 cenotes are comparatively well protected from wind action by their surrounding walls and small size, so they have stable but relatively shallow thermal stratification, facilitating a relatively large CO_2 loss and calcite precipitation.

The waters in pattern 2 cenotes show a lower summer decrease in Ca^{2+} (20ppm), HCO_3 and CO_2 concentrations than at pattern 1 sites. Pattern 2 sites are more exposed to wind action, resulting in greater turbulent mixing and deeper, less well developed thermal stratification. The greater epilimnion depth/volume at these sites and the comparatively lower surface area to volume ratio retards CO_2 degassing. This results in reduced calcite precipitation over summer compared to the pattern 1 sites. Phytoplankton blooms occur at both pattern 1 and 2 sites over summer, but have only a minor impact on calcite precipitation.

Pattern 3 lakes display a similar drop in summer Ca^{2+}, HCO_3 and CO_2 concentrations to pattern 2 cenotes. The summer SiO_2 drop at these lakes, however, is much greater than at the other sites, indicating a relatively larger impact of diatom blooms on the chemistry of their waters.

At the single pattern 4 site there is only a minor decrease in Ca^{2+} (10ppm), HCO_3 and CO_2 levels over summer. This cenote is small and the lake has restricted exposure to sunlight and undergoes only limited summer heating.

Pattern 5 sites do not exhibit any summer change in Ca^{2+}, HCO_3 and CO_2 concentrations. These cenotes are well protected from sunlight by a relatively small area, pondweed cover, and/or dense shading by trees, so no summer thermal stratification occurs and CO_2 loss is not sufficient for calcite precipitation.

The results of this study, the first comprehensive examination of cenote waters, indicate the primary role of abiotic versus biotic factors in calcite precipitation for oligotrophic hard-water lakes in temperate climates. They also extend the knowledge of the groundwater chemistry of the Mount Gambier Limestone aquifer waters potentially contributing to the long-term effective management of this valuable agricultural, biological and economic resource.

Keywords: Calcite; Cenote; Gambier Limestone; Karst hydrochemistry; Thermal Stratification; Unconfined aquifer.

COMPUTATIONAL METHODS FOR SYNTHESISING IMAGES OF STALACTITES (poster)

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The chemical and physical processes that occur to form speleothems in nature are quite complex. Approximations can be made, however, in order to model certain characteristics of speleothem growth. A topic of major interest in speleology is the morphology of speleothems. If the morphology of speleothems can be modelled computationally with the input of various parameters, one could easily explore the vast variety of potential shapes that may arise from different conditions in a cave.

Our research aims toward the goal of a general computational model for growing geometric models of speleothems. We have investigated two models for generating geometries of stalactites, with a view to subsequently rendering them in realistic images.

The first of these models is based on a rigorous model of the thermodynamic and kinetic theory of calcite deposition. It first generates geometry for a calcite straw, based on a linear approximation of the rate of deposition. It then blocks the straw and builds up the sides and tip of the stalactite. The same linear approximation is used to calculate deposition rate, although the calcium concentration in solution is decreased over time exponentially.

The second model for generating stalactite geometry is a stochastic particle-based approach from computer graphics. This model starts off with a cylindrical mesh, representing the straw speleothem, made up of calcite particles joined together by edges in the geometry. Water particles are produced at the top of the straw and allowed to flow along edges between calcite particles. Deposition occurs on every calcite particle visited by a water particle, according to the length of time the water particle is present there. The water particles accelerate down the sides of the stalactite until they reach the tip, where they are removed, causing new water particles to be created back at the top of the stalactite.

Stalactite meshes from both models were rendered to images with realistic texturing and lighting in a ray tracer. Although the first model provided a more chemically accurate approach to generating geometry for a stalactite, the images produced by the second model appear much more realistic. We expect that hybridisation between the two approaches may result in a realistic, more accurate model.

CHANGING LANDSCAPES OF THE LIMESTONE COAST DURING THE HOLOCENE

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The landscape of the Limestone Coast dramatically altered its vegetation composition prior to the last glacial maxima due to generally arid conditions in southern Australia. Prior to the Holocene pollen records indicate increasing dominance of *Eucalyptus* and grasses due to lower rainfall and a more intensive fire regime resulting in drier vegetation stands with an open understorey. During the Holocene the climate became wetter, especially between 6,500 and 5,000 before present allowing the low areas between rises to collect water runoff, resulting in swamps dominated by large stands of sedges and removing extensive grass areas. The terraces were densely covered in ironbark, she-oak (*Casuarina equisetifolia*) and stringybark (*Eucalyptus obliqua*) with an understorey of fine grass and scrubby undergrowth. The shores of the Mt Gambier Lake were thickly covered with the coastal *Banksia integrifolia*.

The replacement of large grass-dominated swale areas with sedge-dominated swamps resulted in a reduction of habitat for many of the grazing mammals and the fauna became dominated by smaller marsupials although grazing animals such as eastern grey kangaroo (*Macropus giganteus*) and the eastern wombat (*Vombatus ursinus*) were still present on the open scrubby rises. The development of extensive swampy areas, such as Bool Lagoon during the Holocene provided extensive feeding grounds for insectivorous bats. Although bats have been present in the area through much of the Pleistocene, increased feeding areas during the Holocene enabled very large breeding colonies of the southern bent-wing bat (*Miniopterus schreibersii bassanii*) to establish in the nearby Naracoorte caves and specifically Bat Cave. This predictable seasonal input of guano into the cave has enabled the establishment of Australia's most diverse guanophilic arthropod community, comprising some 33 species. Habitat changes and losses of bat feeding areas threatens the bat population and therefore the unique guanophilic arthropod community.

THE GUANOPHILIC ARTHROPODS OF BAT CAVE, NARACOORTE - AN ISOLATED COMMUNITY?

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The most diverse guanophilic arthropod community known in Australia is found in the maternal chamber of Bat Cave, Naracoorte, and presently comprises of 33 species from 12 orders and three classes. Despite the high species richness, the chamber contains only a single endemic species, the pseudoscorpion *Protochelifer naracoortensis* Beier. The pseudoscorpion genus *Protochelifer* is widespread in both epigean and hypogean environments across eastern and southern coastal Australia and New Zealand. Hypogean species are believed to have some degree of guano dependence as they are commonly found in association with bat guano deposits. Invertebrate sampling from other caves within the Naracoorte World Heritage Site has revealed further populations of *Protochelifer* from Fox and Robertson caves, and preliminary allozyme electrophoresis and morphology data indicate these populations are 2 new species. However, no populations of *Protochelifer* have been found in nearby Alexandra, Blanche or Cathedral caves. This is unexpected considering the likely connection at micro and meso scales between local caves. At a regional scale however, *Protochelifer* specimens have not been collected in any caves in the southeast, despite some caves containing considerable guano accumulations from over-wintering populations of the southern bent-wing bat (*Miniopterus schreibersii bassanii*). The only other species of *Protochelifer* recorded from the continuous Otway karst region is *P. australis* (Tubb) from Starlight Cave in western Victoria. This data suggests *Protochelifer* has speciated in the local Naracoorte area but these species have not dispersed widely through the Otway karst area.

KARST CORRELATION AND GONDWANA/LAURASIA COMPARISONS

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The geological, geomorphic and climatic history of the northern continents has been quite different to that of the Gondwana fragments for much of the time period of interest to researchers in both karst and palaeokarst. This has great significance not only for attempts at karst correlation, but also for understanding the nature of karst phenomnea themselves. Is a karst equivalent of sequence stratigraphy possible and can major global events such as the P-R and K-T boundary events be recognised in the karst record? These issues are discussed using illustrations from the karsts of central Europe and eastern Australia.

RATIONALE OF ANCHIHALINE (ANCHIALINE) WATERS AS RAMSAR SITES

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Anchihaline (= anchialine) waters can be defined as subterranean or partly subterranean water bodies connected underground with, and influenced ecologically by the sea. Even if open to the sunlight they exhibit some characteristics of subterranean habitats: limited accessibility, comparatively limited food resources, total or partial darkness, stability of climatic conditions. The water may be marine, mixohaline, or fresh. Mixohalinity itself makes the environment additionally worse. Usual salinity stratification prevents mixing of the water column and often causes deoxygenation of certain layers. Anchihaline waters are regularly inhabited by some troglobiotic animal species. Some of them are even specialized for anchihaline waters. Most known anchihaline sites are on karstified coasts or in coastal lava fields; some are completely below sealevel. They appear as waters in horizontal karst caves or in lava tubes, in cracks or other fissures in lava or in the karstified rock, in natural or artificial wells in such rocks, or in open pools. They are always connected with a sometimes extensive and netlike system of narrower, inaccessible for men, corridors or fissure systems.

The reasons for protection as "Ramsar wetlands", are beside the uniqueness and a comparative diversity and rarity of these habitats, is the unique inhabiting fauna. The anchihaline fauna is not particularly rich, less than 500 specialized species have been discovered and hardly more than twice this number can be expected. Of this, 90% are and will probably remain Crustacea. Local faunas consist mostly of far less than 100 species; fauna in a single cave is around 10 species at the highest. On the other hand, these species exhibit comparatively high degree of endemism, although many of them belong to widely spread, even circumtropical, genera. These are mainly the last survivors in "marginally marine" refugia, from formerly marine groups, otherwise extinct (some groups of Mysidacea) or generally successful in freshwater (shrimps Decapoda: Atyidae). Groups exist, which are ecologically endemic in anchihaline habitats; the most remarkable is the crustacean group Remipedia. These and other characteristics are scientifically very important for understanding the process of colonization of subterranean (and also of fresh) waters.

Following selection criteria for area protection are suggested: higher number of species, higher phylogenetic diversity of species; presence of particularly interesting or endemic species; presence of a wider spectrum of ecological parameters; geographical isolation from other anchihaline systems; connections with other interesting habitat types; the man dependent importance (e.g. cultural, educational, historical, aesthetic, elements, suitability for research), including exposure to actual threats. Threats to anchihaline habitats and/or their fauna include: infrastructure development (particularly for the booming "tourist industry" in coastal sites); inappropriate landscape shaping (for the same purpose); extraction of the rock (limestone in limestone poor areas); extraction of other earth born goods in the area (oil, phosphates...); pollution of groundwater and dumping in caves or karst depressions; damming up of coastal underground water corridors; excessive pumping of fresh water in hydrographically closed areas; use of any pesticides within the drainage area. Some areas and caves will be described as possible targets for Ramsar protection.

GROUNDWATER DEPENDENT ECOSYSTEMS IN NEW SOUTH WALES - POLICY DIRECTIONS AND PROJECTS

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The Council of Australian Governments water reforms initiatives lead to a number of national and state initiatives to identify and protect ecosystems dependent on groundwater.

The NSW Water Reforms created a large number of committees representing community and government interests. There were three targets of these committees - regulated and unregulated rivers, and groundwater. These committees were charged with developing a large number of water-sharing plans across the State.

The terms of reference for the groundwater committees included the need to consider water for the environment - for groundwater dependent ecosystems.

As the concept of groundwater dependent ecosystems had largely escaped those charged with managing water - let alone the water-using community or even conservation organizations - the committees and their supporting departments.

This paper describs the process which lead to the development of the NSW State Groundwater Dependent Ecosystems Policy and reports on the current situation of its implemetation.

SPELEOGENESIS OF EOGENETIC CARBONATE ROCKS IN THE TECTONICALLY ACTIVE MARIANA ISLANDS (poster)

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The tectonically active carbonate islands of the Marianas are composed of late Tertiary and Pleistocene limestones that mantle Eocene volcanic edifices. Island karst development occurs in carbonate rocks that have not undergone deep-burial diagenesis (i.e. eogentic rocks), which produces distinct cave morphologies. Original models for island karst speleogenesis were based on observations on the tectonically quiescent Bahamian Islands and Bermuda, where the mixing of fresh and saline waters in association with the freshwater lens produces hypogenic, mixing zone caves. However, the complex tectonic and depositional environment of the Marianas produces diverse karst features that exhibit variable controls on dissolution (lithologic, chemical, and structural). Fieldwork on the islands of Tinian, Rota, and Aguijan has identified three distinct classes of caves based on primary controls on dissolution:

1: contact caves,
2: mixing zone caves and
3: fissure caves.

Contact caves (stream caves) are lithologically controlled and form at carbonate/non-carbonate rock contacts where allogenic recharge is focused by perennial streams developing on non-carbonate terrains. Mixing zone caves form where the mixing of waters of differing chemistry, fresh and saline waters, increases dissolution at the margin of the freshwater lens (flank margin caves) and at the top of the lens (water table caves) where vadose and phreatic waters mix. Additional dissolution enhancement occurs at the lens boundaries where the water density horizons trap organic material that subsequently decomposes. Fissure caves are structurally controlled and form by the preferential flow of water along planes of brittle deformation (faults and fractures) produced by regional tectonism and margin failures. Fissure caves provide fast flow routes for increased recharge and discharge, which can distort the fresh-water lens morphology.

Previous work on other carbonate islands predicted speleogenesis controlled by lithology and freshwater/saltwater mixing; however, the influences of brittle deformation observed in the Marianas provides additional complexity for island karst development. Individual features in the study area exhibit distinct primary controls on dissolution, but specific sites that exhibit variations in lithology, geologic structure and freshwater lens position in close proximity show the influence of multiple controls on dissolution. The complex geology of the Mariana Arc produces an environment where multiple controls on speleogenesis occur, demonstrating that island karst is not strictly controlled by the position of the freshwater lens as originally theorized.

ECOLOGY AND EVOLUTION OF TROPICAL TROGLOBITES: MANAGEMENT IMPLICATIONS

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Until the 1970s, biospeleologists considered that troglobites did not exist in tropical caves. Since then, discoveries in Hawaii, Galapagos, Jamaica, Southeast Asia, and Australia have revealed a rich fauna of highly cave-adapted invertebrates in tropical caves. However, they are restricted to specialized deep cave habitats with organic matter, saturated humidity and some times high carbon dioxide levels. In this regard these deep cave habitats are to some extent transitional between terrestrial and non-specialised cave habitats on one hand and aquatic on the other.

Management of tropical karst and caves requires an understanding of the relation between surface ecosystems and cave communities and a careful attention to cave conformation and microclimate in relation to cave species. Surface management requires preservation and regeneration of the native plant and animal commuities of the karst area. Trees send roots into the caves and become the basis of many cave communities. Bats, swiftlets, crickets and other trogloxenes import organic matter. Water brings organic matter from the surface. Modification of the cave entrances and passages alters the airflow patterns and may eliminate the high humidity habitats. Any change that effects surface drainage, the water table, or the interior of the cave can potentially destroy the specialized cave ecosystems.

MICROCLIMATIC AND BIOLOGIC CONTROLS OF MORPHOLOGY AND PETROLOGY OF STALACTITES (poster)

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Karst waters commonly precipitate $CaCO_3$ as they drip or seep from limestone. Inside the enclosed, humid atmosphere of caves, this process is driven by CO_2 degassing and typically produces dense, well-organized macrocrystalline calcite deposits. At the land surface, however, the effects of increased evaporation cause much more rapid precipitation of calcite, resulting in porous, poorly arranged, randomly oriented microcrystalline aggregates. Concomitantly with the physico-chemical precipitation, living organisms can exert their influence on calcite precipitation. Inside caves, biologic effects are minimal and precipitates are largely abiotic, but at the land surface, they often control carbonate precipitation and can produce biogenic deposits.

Working in caves in Guam, Mariana Islands, we have seen that microclimatic and biologic gradients that exist between cave entrances and cave interiors are closely reflected in the morphology and petrology of actively forming stalactites. Ranging from highly porous and largely biogenic calcareous tufa stalactitic accretions growing at the entrances to the dense coarsely crystalline stalactites in cave interiors, and spanning the microclimatically most variable and the most stable parts of the caves, these vadose precipitates form a morphologic and petrologic continuum and display a wealth of distinct microfabrics.

Following long-term microclimate and irradiance monitoring and analyses of stalactite samples, we have demonstrated that a series of parameters, including macromorphology, texture and porosity, organic and microbial content, and crystal size and fabric, are related to each sample's position in the cave and the local microclimate. As diurnal oscillations in microclimate alleviate, light levels decline, and humidity rises along transects spanning cave entrances and interiors, stalactitic deposits form a gradation from biogenic tufas to classic abiotic speleothems. They become progressively firmer and more regular, crystals grow to be larger and arranged in ordered fabrics, and incidence of microorganisms and organic matter drops. These observations promise to be a useful tool in paleoenvironmental interpretation.

STYGOFAUNA DIVERSITY AND DISTRIBUTION IN THE EASTERN AUSTRALIAN HIGHLANDS AND THEIR POTENTIAL AS SUBTERRANEAN RAMSAR SITES

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This paper reviews the diversity and distribution of the stygofauna of Eastern Australia. Most of the known stygofauna is concentrated in the highland karsts of New South Wales and Tasmania. Two hundred and thirty-eight taxa are present and amphipods, syncarids and hydrobiid gastropods are the dominant and most widespread groups. Nearly half of the total fauna are stygobites (82 taxa) and stygophiles (34 taxa). Also present are taxa with Gondwanan and Pangaean affinities, taxa that are phylogenetic and distributional relicts, and locally endemic taxa. Diversity and distribution at a local scale is also discussed using a case study of Wombeyan Caves, one of the richest stygofauna sites in Eastern Australia.

A number of sites have potential for nomination as subterranean Ramsar wetland sites. Two sites in New South Wales, Wombeyan and Wellington Caves, are discussed.

SUBTERRANEAN WETLANDS AND GROUNDWATER DEPENDENT ECOSYSTEMS OF THE LIMESTONE COAST

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A diverse array of subterranean wetlands are present on the Limestone Coast ranging from frehswater springs, cenote and volcanic lakes, swamps, and surface and underground lakes and streams. These environments host significant ecosystems, including stromatolite communities that are globally important due to their high biodiversity and potential for comparative studies with similar communities in the Northern Hemisphere. This paper will review our knowledge of these wetlands and their associated ecosystems, and will explore current issues in the management of these sites.

LIGHT-ORIENTED KARST PHENOMENA IN JAPAN AND SLOVAKIA (poster)

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Light-oriented limestone corrosions and calcareous depositions developed at the entrances of many limestone caves in Japan and Slovakia were observed and studied. The morphology of limestone corrosion included pinnacles, pits and grooves. Most pinnacles, pits and grooves seemed to develop along with the direction to the entrances of caves, suggesting the contribution of sunlight to the corrosion. The calcareous depositions consisted of several kinds of speleothem (calcite deposits) including stalactites, botrioids and rimstones. It was observed also that these depositions had developed along with the direction of entrances of caves. In these corrosions and depositions almost all the limestone was associated with slight growth of green algae and/or cyanobacteria. It is likely that photosynthetic products (probably organic acids) of green algae and cyanobacteria would accelerate the formation of these calcite corrosions and depositions. It is concluded that these bio-karstic phenomena are common not only in the tropical and subtropical regions but also in the temporal and even cold regions.

APPLICATIONS OF HYDROGEOCHEMISTRY IN QUANTIFICATION OF KARST WATER CIRCULATION

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In subtropical southeast China, carbonate rock is continuously distributed over a wide area and large thickness. Karst topography in the area is fully developed because of appropriate temperature and abundant precipitation, and this forms the special structure for the contained groundwater. Water resources are mainly stored in the underground rivers, which leads to the lack of surface water (river water).

The water cycle in the southeast karst area is relatively complicated. Because the epikarst layer is well developed, it plays an important role in groundwater regulation and storage. During the water circulation, precipitation firstly recharges epikarst zone. One part of the recharge reaches ground water through the fissures of deep-saturated aquifers, and the other part overflows out of the ground from springs and flows into karst caves, recharging the groundwater directly. When precipitation is greater than the regulation capability of epikarst zone, the surface slope flow forms and influxes into the karst cave, then replenishes the underground river. Therefore, underground river water has three recharge sources: epikarst water, fissure water from deep-saturated aquifers and surface water. The contribution of different sources to underground rivers is significant for water resources evaluation.

The interactions between groundwater and its wall-rock determine groundwater components. Based on the groundwater flow system, groundwater components vary according to recharge and runoff conditions and time for water-rock interactions. Carbonate rock is rich in calcium, magnesium and strontium. Water samples of the four kinds of groundwater of Langshi underground river system, Guilin are analyzed from July to October 2003. The results indicate that $Ca^{2-}Sr^{2-}$ concentrations are different in the four kinds of groundwater, but they have positive linear correlation. Generally, the order of the $Ca^{2-}Sr^{2-}$ concentrations of the four kinds of groundwater from the highest to the lowest is epikarst water, underground river water, crack water of deep-saturated aquifer and surface slope water (precipitation). Concentrations of Mg^{2+} and Sr^{2-} are negatively correlated. This shows that underground river water is a mix of the other three types of groundwater. By Ca/Sr, Mg/Sr and the water chemistry mix model, it can be concluded that the contribution of epikarst groundwater to Langshi underground river varies from 20% to 33%, and that of crack water is between 50% and 80%. The surface slope water recharges the underground river only when precipitation is abundant enough. The average runoff modulus of epikarst water is $1L/s{\cdot}km^2$. Thus, epikarst water resources have potential significance in karst water circulation and application for its abundance.

GRAFFITI AT LOCH ARD GORGE, PORT CAMPBELL NATIONAL PARK, VICTORIA (poster)

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Port Campbell National Park with its striking coastal scenery of rugged cliffs and stacks is one of Victoria's icons. It is promoted in all tourist literature and Loch Ard Gorge is one of the featured attractions with a car park, developed walking tracks along the cliffs and a track with a timber stairway down to the beach in the Gorge. Loch Ard Gorge was the scene of the shipwreck of the Loch Ard in 1878 from which there were only 2 survivors. The two caves in the gorge are named Pearce Cave (3SW-2) and Carmichael Cave (3SW-3) after these survivors, who reputedly sheltered in the caves before being rescued. Many people however, do not realise that this is a karst

landscape developed on Tertiary limestone. The gorge is now showing signs of wear and tear and graffiti is accumulating on accessible cliff areas and within the caves. Recently this was brought to the attention of Parks Victoria and steps are being taken to address the problems.

KARST DEVELOPMENT AT NARACOORTE, SOUTH AUSTRALIA: WHEN? WHY? & HOW?

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The Lower Southeast of South Australia and a substantial part of southwestern Victoria is a limestone karst province, which comprises extensive areas where cave and karst development is limited, interspersed with areas of atypical intensive karst development, such as at Naracoorte.

At Naracoorte dolines, uvalas and blind valleys characterise the surface karst. The caves range from simple single passages to complex mazes, and passages trend predominantly northwest/southeast. Cave walls retain evidence of solutional features. The caves contain a range of fossiliferous clastic sediments and dated speleothems. The fossils accumulated through pitfall entrances in several episodes during the Middle Pleistocene (100,000-400,000 years ago).

The development of the Naracoorte karst is constrained by the age of the enclosing Gambier Limestone (Oligo-Miocene), and probably post-dates the maximum sea-level transgression at ~7 Ma. The following Pliocene-Pleistocene regression deposited a series of subparallel beach dune ridges, progressively younging seaward. The East Naracoorte Range is of reversed polarity (Idnurm and Cook, 1980) and is therefore older than 720 ka. Attempts to obtain thermoluminescence ages have been unsuccessful (Huntley and Prescott, 2001), but the dune is thought to have been deposited between 900 ka and 1.1 Ma (Banerjee et al., 2003; Huntley and Prescott, 2001). The West Naracoorte Range is a composite feature that contains four well-defined palaeosol horizons in the Naracoorte area (Cook et al., 1977). It has proved difficult to date reliably (Banerjee et al., 2003), but Huntley and Prescott (2001) have argued that deposition began during the Matuyama reversed magnetic chron. If this is correct, the expected depositional age of the West Naracoorte Range is between 780 and 880 ka. This is consistent with the most satisfactory of the problematic TL and OSL dates obtained, which is 710±62 ka (Banerjee et al., 2003).

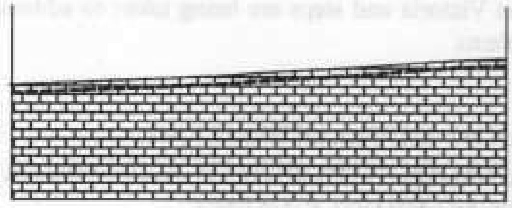
Cave formation probably occurred in a relatively narrow window of time between uplift along the Kanawinka Fault in the late Pliocene, and draining of the caves as a result of the lowering of the water table as the sea level fell at ~800-900 ka., during deposition of the West Naracoorte Range. The caves have a general northwest-southeast alignment, more or less parallel to the fault, and representing the predominant joint direction. The main period of cave development probably began during deposition of the East Naracoorte Range at ~1.1 Ma, as prior to this the cave area was flooded by the sea, and no cave formation could occur. Sea levels can be estimated from the position of the coastal strand-line dunes. The caves may have initially formed along the freshwater/seawater interface extending inland from the East Naracoorte Range, and were subsequently enlarged by groundwater flow as sealevel fell between 1.1 Ma and 800ka. Because the water table was not stable for any substantial period of time, only two preferential development of passages developed at ~70 m and ~61 m above present sea level. The upper cave level (~70 m ASL) developed first, possibly at ~1 Ma. The lower level (at ~61 m ASL) developed later as water tables dropped when sea levels lowered. The four superimposed dunes of the West Naracoorte Range show that sea level dropped in the Naracoorte area between 880 ka and 780 ka but did not retreat to the southwest until some time later.

Naracoorte cave passages were partially, then completely drained as the water table fell; thus, the solutional notching on the cave walls reflects this progressive fall in water level. Most collapse probably occurred progressively as water drained from the passages. These caves have not been completely flooded since they were drained, because sea level has not risen again to the base of the West Naracoorte Range during the Pleistocene. Redissolved speleothems are rare at Naracoorte, and their formation reflects specific conditions rather than a general flooding of the caves. The grey/brown clay filling small phreatic spongework cavities in some caves, e.g. Victoria Fossil Cave (U 1), Sand Cave (U 16), Fox Cave (U 22), and the thin mud coating on the walls and floors of lower passages in Brown Snake Cave (U 14) and Sand Cave (U 16), represent only localised flooding of passages.

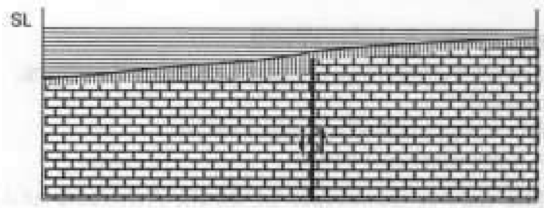
The incision of Mosquito Creek postdates uplift along the fault and occurred during the 1.1 Ma to 800 ka sealevel fall. As the water table dropped due to sea level fall and creek incision, the caves partially, then completely drained. Most of the collapse that characterises many of the Naracoorte caves probably occurred progressively as the water drained from the passages; at least some collapse entrances could have formed at this time.

In Victoria Fossil Cave (U 1), the oldest dated flowstones, which are not growing directly on the floor of a chamber, are over 500,000 years old (Ayliffe et al., 1998). The cyclical wet and dry conditions over the last 500 ka (Ayliffe et al., 1998; Moriarty et al., 2000) caused some cave modification, including the development of solution pipes and the deposition of

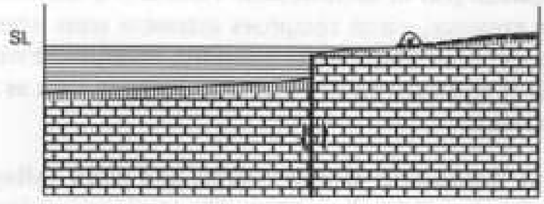
MIOCENE 10 Ma
Low Sealevel
Exposure of Gambier Limestone to subaerial weathering
Rise in sealevel at ~ 8 Ma



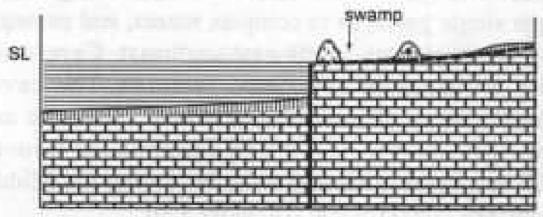
LATE MIOCENE - EARLY PLIOCENE 6 Ma
Maximum sealevel at ~7 Ma and deposition of marine sands
Marine regression after maximum sealevel
Deformation and uplift e.g Dundas Tableland
Uplift along Kanawinka Fault
Change from coolwater carbonates to siliciclastics



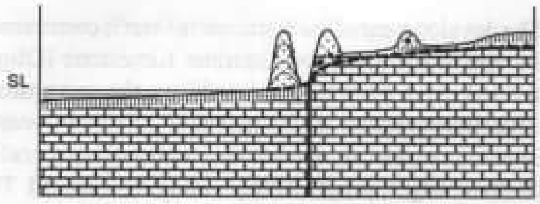
LATE PLIOCENE - EARLIEST PLEISTOCENE 2 Ma
Marine regression continues
Deposition of carbonate strandline dunes e.g. Hynam Dune
Syngenetic karst in dunes initiates.



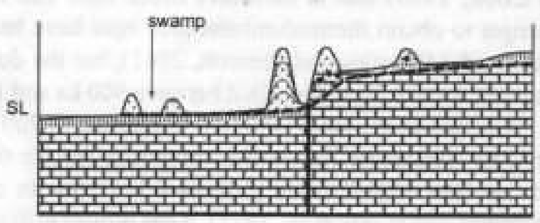
EARLY - MID PLEISTOCENE 1 Ma
Deposition of East Naracoorte Range as strandline coastal dune, except in the estuary of Mosquito Ck.
High groundwater level related to sealevel
Solution and initial conduit development especially in the estuarine area



MID PLEISTOCENE 800 ka
Bruhnes- Matayama magnetic reversal
Sea level dropped and West Naracoorte Range deposited as 4 stacked dunes
Incision of Mosquito Ck
Water table lowering associated with drop in sealevel drains caves and collapse occurs



MID - LATE PLEISTOCENE 250 ka
Regional uplift continues
Fluctuating sealevels but marine transgressions never reurn to West or East Naracoorte Ranges
Further strandline dunes deposited
Cyclic wet and dry phases
Solution pipes form
Caves fill with fossiliferous clastic sediments and speleothems
Small amount of collapse contiues
Episodic flooding



Caves contiune to modify to present day

Key: | Kanawinka Fault — Water table • Cave
Pleistocene Bridgewater Group | Pliocene Sands | Miocene Gambier Limestone

clastic sediments. From the latest mid Pleistocene until the Last Glacial Maximum (LGM) the glacial maxima were periods of relative aridity (Ayliffe et al., 1998), when aeolian sediment mobilisation and deposition occurred (Bowler, 1982) and cave clastic sediments were deposited. The wetter periods were times of speleothem deposition, localised minor flooding and solution pipe development. Minor modification of the caves, such as collapse, speleothem deposition and sediment reworking by surface water sinking underground, continues to the present day.

The overall landscape history of the Naracoorte area during the Pliocene/ Pleistocene shows the speleogenesis was controlled by oscillating sealevel, coastal deposition and tectonic movements on the Kanawinka Fault.

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THE RAMSAR CONVENTION AND KARST WETLANDS

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The issue of karst wetlands was first identified in discussions of the Ramsar convention in COP6, Brisbane 1996, and followed up by further decisions at COP7, in San Jose 1999. Karst wetlands are now firmly on the agenda of all Ramsar discussions, with an aim to see included on the list of Wetlands of International Importance most characteristic karst wetlands. But it is not just about listing sites, the main aim is to assist the conservation and wise use of subterranean wetland functions and values and thus implementation of Ramsar principles and strategic guidelines.

The Convention can play a key role here, as appropriate management (conservation and sustainable use) is crucial to maintain the functions and values of the interacting karst surface and subterranean hydrological systems in whole catchment areas, to prevent or mitigate threats to karst wetlands. And because karst systems have hydrological connections to much wider groundwater resources, well managed karst systems means well managed water resources, a critical issue for the next decade!

KARST ECOSYSTEM TYPES

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A karst ecosystem is an ecosystem configured by a set of karst features. It is on the interfaces of lithosphere (soluble rocks and fractures), hydrosphere, atmosphere and biosphere. Because of the development of underground space in karst terrains, a karst ecosystem is composed of both surface ecosystem and subsurface ecosystem. The karst ecosystems in different parts of the world are quite different, in accordance with their particular climatic, geologic, pedological, hydrological, topographical, vegetation and anthropological conditions

For a proper understanding and management of karstland, it is necessary to distinguish the ecosystems in different karst areas of the world into different types. A better understanding on the characteristics of each type of karst ecosystem will benefit the protection of karst areas and the rehabilitation of deteriorated karstland. For example, in the subtropical karst areas of southern China and southeast Asia, and some Mediterranean karst, the most important problems are the leakage of water and the shortage of soil. Rock desertification is usually a problem. However, in some boreal karsts, the development of underground drainage systems is helpful in draining away and buffering excess acidic water in bogs, therefore beneficial for the development of agriculture.

ANALYSIS ON THE SHORT-TERM SCALE VARIATION OF TYPICAL EPIKARST SPRING IN SOUTHWEST CHINA, TAKING NONGLA MONITORING SITE, MASHAN COUNTY, GUANGXI AS AN EXAMPLE (poster)

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Nongla, a typical karst dynamic system (KDS) monitoring site, is located at Nongla Village, Mashan County, Guangxi, southwest China. The data from a Greenspan CTDP300 multichannel data logger indicate that the KDS is highly sensitive to environmental change. Multi-day and diurnal physico-chemical variation of epikarst spring water is quite different under the different climatic conditions.

In a normal day (no rainfall), water temperature and air temperature have about the same variation. Electrical conductivity(EC) has a good positive correlativity with pH value and water temperature.

During rainstorms, the physico-chemical variation of the spring is mainly controlled by dilution effects at the beginning when pH and EC drop rapidly. But 0.5-1 hours later, the EC rises and the CO_2 effect will occupy the dominant position due to the high fissure rate and permeability in epikarst zone. Dilution effects were involved in the entire rainstorm period, whereas it only acts on the earliest period of light rain. It is necessary to take water-rock-CO_2 as a whole (system) to explain the hydrochemical behavior of epikarst processes.

Key words: Epikarst system; Physico-chemistry; Precipitation effects; Sensitivity; Nongla Village, Guangxi, China

HIGH RESOLUTION PALEOCLIMATIC ENVIRONMENT RECORDS FROM A STALAGMITE OF DONGGE CAVE SINCE 15 000 YEARS IN LIBO, GUIZHOU (poster)

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The time sequence of high resolution paleoclimatic change since 15,470a B.P. has been reconstructed by dating ages of the high precision TIMS-U series and the analysis of the carbon and oxygen isotopes from a stalagmite of Dongge cave in the area of Libo, Guizhou. The study results show a record of the warm and cold events from a stalagmite since 15,440a B.P. in the area of Libo. These reflect the paleoclimatic change which can be divided four stages:

(1) The late stage of the late Pleistocene Epoch-Heinrich event H1 and Younger Dryas event from 15,440a B.P. to 11,350a B.P. indicating that the East Asian winter monsoon is the stronger in this stage, the air temperature is lower, and the available rainfall is less in summer season and represents a dry and cold climate environment.

(2) The early Holocene Epoch: the dry and hot stage from 11,350a B.P. to 9190a B.P. indicates that the East Asian summer monsoon is the stronger in this stage, the air temperature is the higher, the available rainfall is relatively lower in summer season and represents the dry and hot climate environment.

(3) The middle Holocene Epoch - Climatic optimum from 9190a B.P to 3320a B.P shows that the East Asian summer monsoon is relatively stronger in this stage, the air temperature is the higher, the available rainfall relatively higher in the summer season and represents a warm and humid climate environment.

(4) The late Holocene Epoch - cooling temperatures from 3320a B.P. to 130a B.P. shows that the East Asian summer monsoon became weaker and the winter monsoon became stronger. The air temperature gradually decreased, the available rainfall is very high in winter, and the frequency of climate undulation increased. The time interval of the recent cold phase and the warm or hot phase changes the shorter trends.

The record of carbon and oxygen isotopes from a stalagmite reveals the last two cold or cool events during the late stage of the last glacial period. Their ages in the coldest deep valley are 15,440±130 a B.P. (H1) and 11,910±70a B.P.(Y.D) respectively. We also confirm that the borderline age of the termination I during the last glacial period is 11,350±70 a B.P. through the precise dating by TIMS-U series from a stalagmite in Dongge cave at Libo, Guizhou. We confirm the cold events in the Eastern Asian monsoon climate region of the South China during the last glacial period could correspond to the Heinrich cold events H1 and Younger Drays event in the North Atlantic Ocean. The palaeo-monsoon circulating current changes in the area of Libo reflect the East Asian summer monsoon changed from the weak to strong and then from strong to weak trends. The available rainfall trends were from low to higher and then from higher to low and from low to high again. The air temperature trend was from the low (or cold) to high (or hot) and from high to low again. The palaeo-monsoon circulating current changes in this area are clearly affected by the climate oscillation of the North Atlantic Ocean, and indicate that they have strong tele-connections with the palaeo-climate changes occurring in the North pole region.

Key Words: Stalagmite, Dating ages of TIMS-U series, high resolution, paleoclimate environment, Dongge cave of Libo.

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