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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

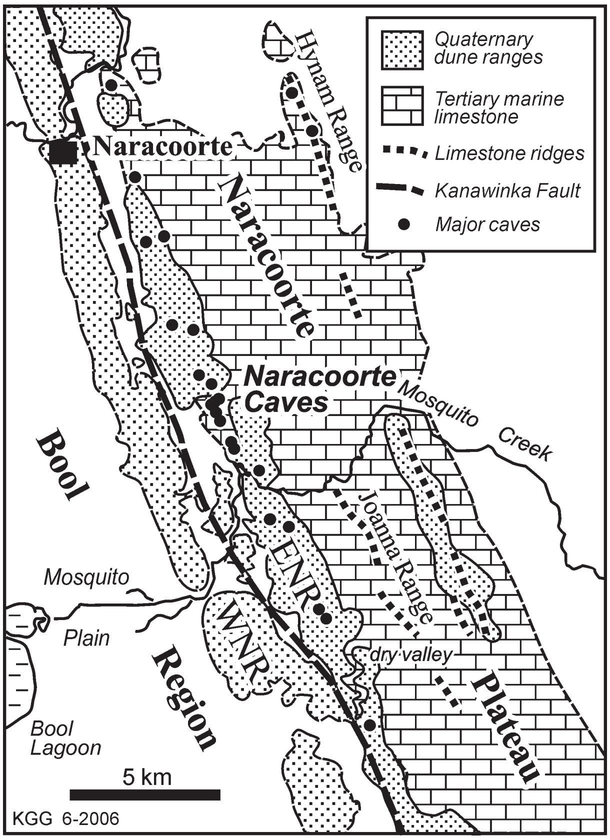

Figure 1: Naracoorte Caves area - modified from a map by Ian Lewis, 2004. The position of the buried Kanawinka Fault is only shown approximately.
WNR = West Naracoorte Range,
ENR = East Naracoorte range.

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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Conference Abstracts

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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.

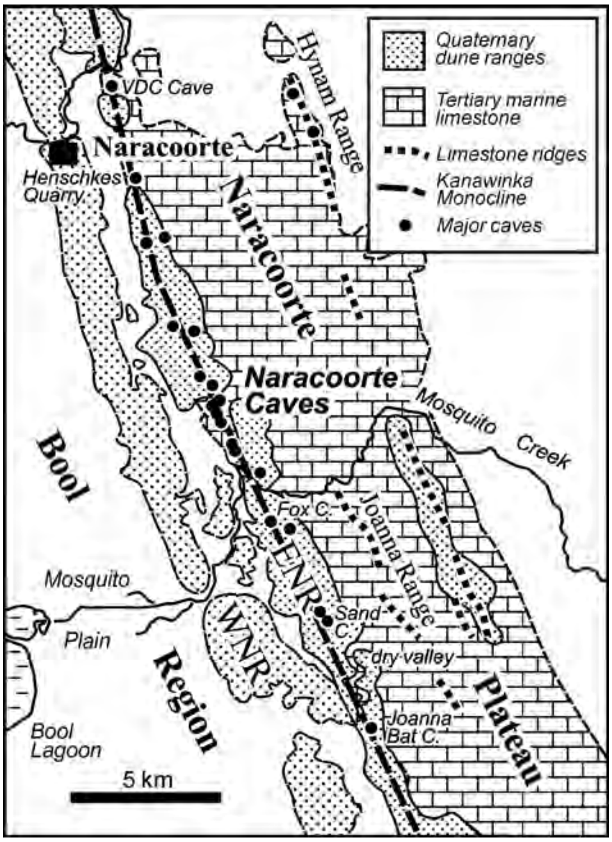

Figure 1: Position of major caves and Kanawinka Monocline at Naracoorte, SA.

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.

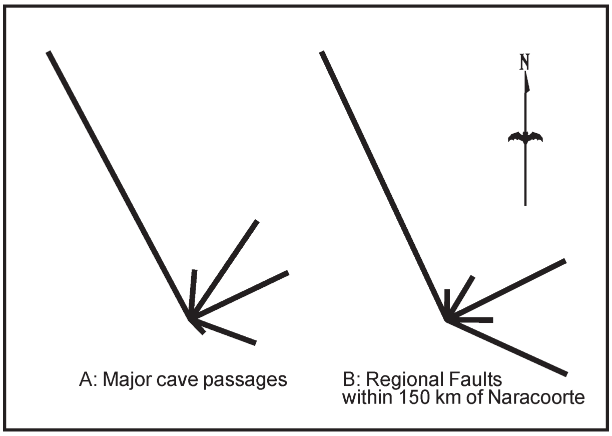

Figure 2: Simplified structural comparison of the lengths and directions of regional faults and the linear passages of the major caves at Naracoorte

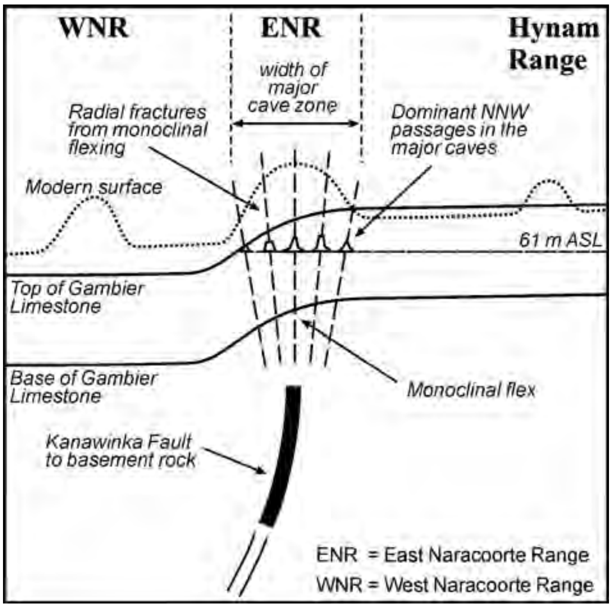

Figure 3: Major cave zone at Naracoorte generated by Kanawinka Monocline flexing of Gambier Limestone layer.

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 $1 L/s{\cdot}km^2$. 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).

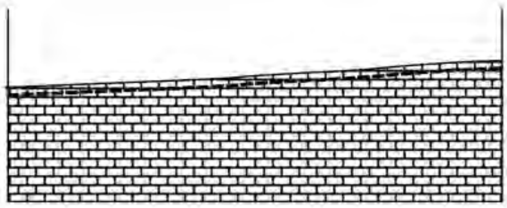
Cave formation probably occurred in a relatively narrow window of time between uplift along the Kanawinka Fault in the late Pliocene, and draining of the caves as a result of the lowering of the water table as the sea level fell at ~800-900 ka., during deposition of the West Naracoorte Range. The caves 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.

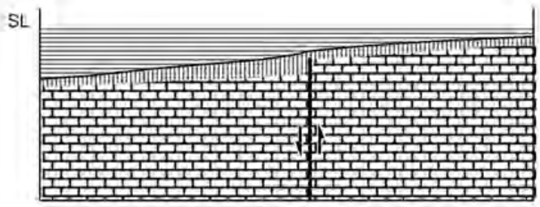
The incision of Mosquito Creek postdates uplift along the fault and occurred during the 1.1 Ma to 800 ka sealevel fall. As the water table dropped due to sea level fall and creek incision, the caves partially, then completely drained. Most of the collapse that characterises many of the Naracoorte caves 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

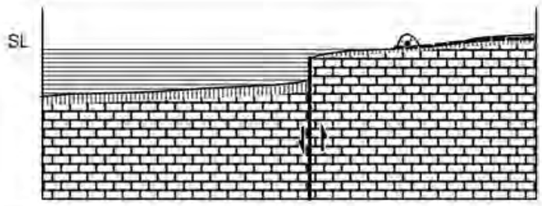
MIOCENE 10 Ma
Low Sealevel
Exposure of Gambier Limestone to subaerial weathering
Rise in sealevel at ~ 8 Ma



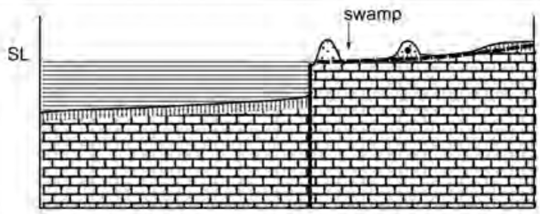
LATE MIOCENE - EARLY PLIOCENE 6 Ma
Maximum sealevel at ~7 Ma and deposition of marine sands
Marine regression after maximum sealevel
Deformation and uplift e.g Dundas Tableland
Uplift along Kanawinka Fault
Change from coolwater carbonates to silciclastics



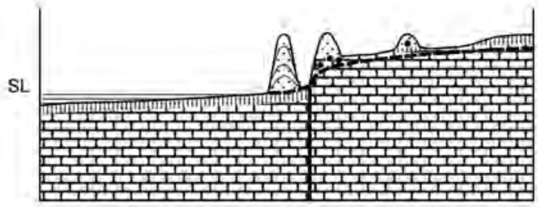
LATE PLIOCENE - EARLIEST PLEISTOCENE 2 Ma
Marine regression continues
Deposition of carbonate strandline dunes e.g. Hynam Dune
Syngenetic karst in dunes initiates.



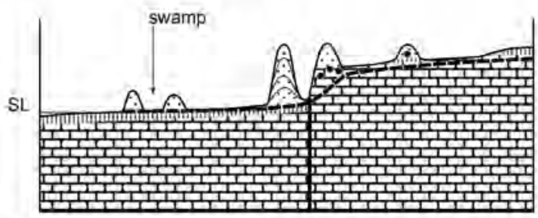
EARLY - MID PLEISTOCENE 1 Ma
Deposition of East Naracoorte Range as strandline coastal dune, except in the estuary of Mosquito Ck.
High groundwater level related to sealevel
Solution and initial conduit development especially in the estuarine area



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.