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Session: Karst

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STATE OF THE ART

In assessing the «State of The Art» in any area of scientific studies, it is essential to judge how adequately specific problems can be solved. Thus this «State of The Art» discussion with respect to karst will be illustrated by examples from studies on the Nullarbor Karst. It will be divided into three sections which will cover the latest developments in the available techniques, the understanding of processes and the methods for examining whole karst systems. The final two sections are the newer areas of karst research-geomicrobiology and the management of karst areas.

The Nullarbor Karst is located on the southern edge of the Australian continent extending over parts of both West and South Australia. The term Nullarbor plain is used to describe the region as a whole. It comprises the world's largest arid and semi arid karst and the world's largest contiguous karst 200,000 km² (Davey & alii, 1992).

TECHNIQUES

A vast array of techniques have become available to karst investigators in the last decade.

Imagery

Improved air photography and satellite imagery have allowed the surface, catchments and short term changes in karst areas to be investigated, in some cases without associated field studies. Satellite imagery has been used by

Western Australia's Conservation and Land Management (CALM) service on the Nullarbor to assess the changes and rate of change in vegetation patterns due to pastoral practices on the plain. This has enabled CALM to offer advice to the pastoralists on managing their flocks and herds in ways to reduce soil erosion.

Exploration

Cave exploration is an immense advantage to any detailed study of a karst. There have been two important advances in this nexus between the scientific and sporting fields of speleology. More of the cave explorers capable of penetrating far below the karst surface have scientific training, and other cavers have become increasingly willing to be trained to bring back samples, observations and photographs that can be used to support and in some cases confirm hypotheses as to the karst processes taking place deep below the surface.

On the Nullarbor, cave divers are essential to any study of the flooded caves. The classical cave diving photograph (fig. 1) is of a diver suspended in the middle of a flooded passage, showing sparse detail of floor, roof and walls. Details which are critical to any geomorphological study. Fig. 2 shows one of photographs originally discarded by the divers that revolutionised the speleogenesis hypothesis for the Nullarbor Caves.

Physical

Many karst - related questions are problems in physics, questions which in the past have been studied mostly by a theoretical approach. The age of electronics has made instrumentation for the collection of data, portable. Miniaturised instruments run on batteries and use so little power that they can accumulate data unattended for long periods.

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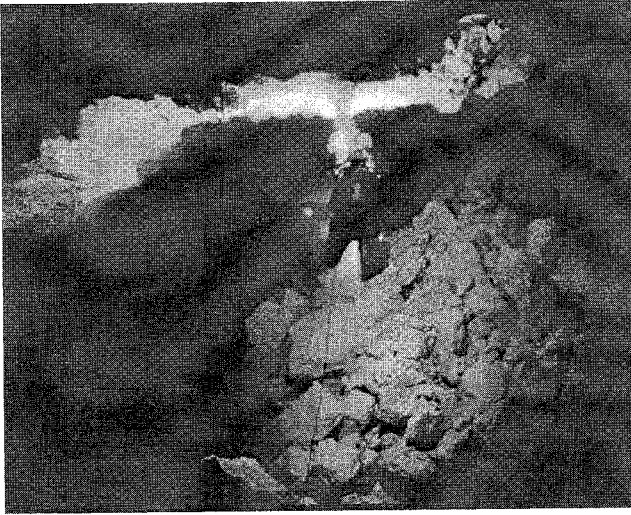


FIG. 1 - Cave Diver, Tommy Grahams. Photo P. Rogers.

In addition, they are considerably more reliable than the older larger versions in the harsh conditions encountered in many caves and karst areas.

On the Nullarbor, bore holes drilled for water have encountered numerous voids in the limestone indicating a considerable volume of cave passage inaccessible to the cave explorer. Geophysical methods for scanning the karst surface beneath the sediment fill and for detecting caves have now reached such a degree of sophistication that they could be used on the Nullarbor to detect cavities beneath major infrastructure sites. The main W-E highway in southern Australia passes over Pannikin Plain Cave. Located 100 m further north it would have passed over Concord Landing, a huge chamber that reaches within 20 m of the surface, instead of its much smaller and deeper approach



FIG. 2 - Cave Divers amongst the rock spikes on the floor of Tommy Grahams Cave. Photo P. Rogers.

passages. The use of geophysics would have completely removed the possibility of the highway being located where subsidence into the cave below was a possible hazard.

Halite (fig. 3) and gypsum (fig. 4) are common secondary minerals in the dry Nullarbor Caves. These delicate and beautiful decorations are very sensitive to changes in the microclimate of the caves. The measurement of pres-



FIG. 3 - Halite, Thampanna Cave. Photo N. Poulter.

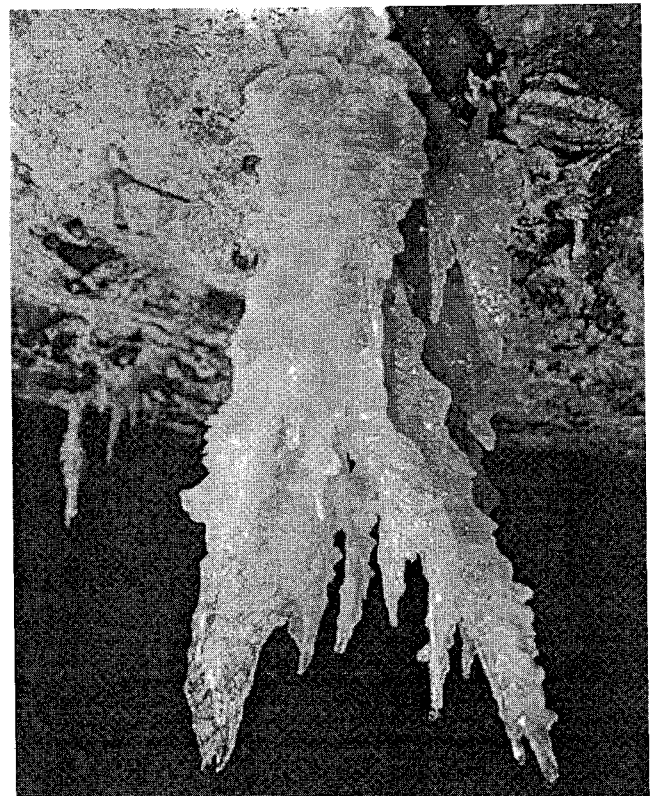


FIG. 4 - Gypsum, Thampanna Cave. Photo J. James.

sure, humidity, temperature, and wind direction and velocity is fundamental to understanding the ventilation and microclimate of the caves. There are now available a vast array of sensitive instruments that can be left unattended in the caves for long periods in order to measure microclimate data.

Chemical

Sophisticated instrumentation is now available to the karst investigator for measuring all elements of interest in a wide range of concentrations. The greatest advance in karst analytical chemistry in the last decade has been the ability to measure ions and molecular species by chromatography. However, with all analytical methods both modern and older, caution must be exercised. Frequent calibration and specially prepared standards are required. As a general rule, the more sensitive a method the more prone it is to interference.

The most intriguing speleothems on the Nullarbor are those composed of black calcite (fig. 5). Chemical techniques have identified the black chromophore as a high molecular weight humic acid (Mackenzie, 1995).

Dating

Dating and paleoenvironmental studies of karst are now extremely sophisticated. These still focus largely on calcite speleothems, which preserve the history of landscape evolution and climate change in great detail. The absolute methods using radioactive decay have been improved both in terms of reducing sample size and isotopes used. These improvements can be attributed to the replacement of alpha counting by mass spectrometry. In addition, techniques based on racemisation and luminescence of organic materials now make possible highly detailed paleoclimatic and ecological reconstructions (Ford 1997).

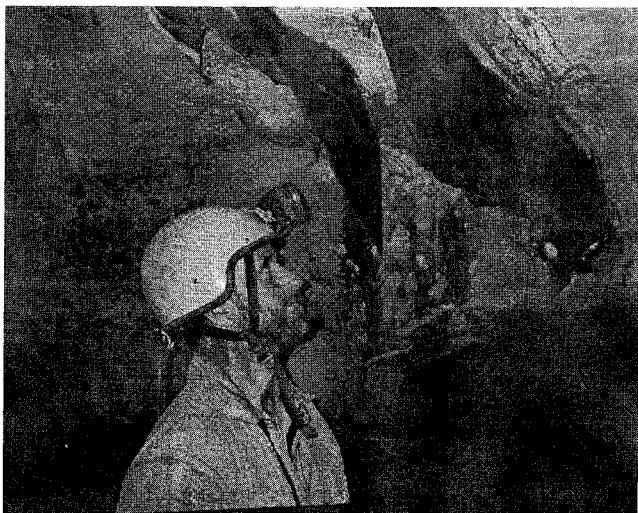
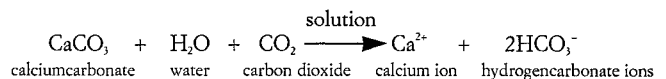


FIG. 5 - Black Calcite, Thampanna. Photo J. James.

The Nullarbor halite speleothems have been dated using uranium series disequilibrium techniques and the results have shown that there have been two periods when the climate was sufficiently dry for halite deposition (Geode & alii, 1992). Unfortunately, to date there is no method, either absolute or relative, that has enabled the age of the intriguing black calcite deposits to be established.

PROCESSES

The horizons and understanding of the processes of speleogenesis and karst erosion are expanding as investigators look for explanations for solution of carbonate rocks beyond those of the classical approach, which can be represented by the following equation.



The importance of water in the above equation and karst dissolution must be stressed. It has been found that the amount of carbonate rock dissolved (usually expressed as surface lowering per unit area per unit time) is directly related to precipitation falling on the karst area (Ford and Williams, 1989). In addition, in areas of high precipitation, mechanical erosion by fast flowing rivers carrying abrasive sediments is also a potent means of rapidly eroding the karst. Lowry and Jennings (1974) in order to explain the large caverns beneath the Nullarbor invoked a pluvial period at some time in the past, the increased rainfall being necessary to both swell the rivers to excavate the caverns, and to remove the debris created by subsequent breakdown. They also maintained that substantial rainfall was necessary for the rich soil and ample vegetation which are required to generate CO₂.

Two other processes operational in arid areas are now being shown to be active in cavern excavation. One is condensation corrosion, where the condensation waters which are largely free of dissolved common ions can erode the limestone. The other is salt weathering. On the Nullarbor it is a major excavator of caves and disintegrator of limestone cliffs. The crystallisation of the evaporite salts – halite and gypsum – is causing fragmentation of the ancient calcite speleothems and bedrock. Floors of caves are covered in calcite fragments, and large piles of gypsum sand build up below erosion domes in the caves (fig. 6).

The variety of chemical processes invoked to explain karst evolution has expanded (Ford and Williams, 1989). A number of these newer processes can be shown to taking place in the Nullarbor Karst:

Effect of Acids: The weak acid carbon dioxide has always been recognised as important in karst processes and the extensive deposits of black calcite show that it has had an important role in the past. However, the black calcite also shows that at the same time other weak acids, mainly the organic acids produced in the soil, must have been eroding the limestone. At present, the strong acid, sulfuric

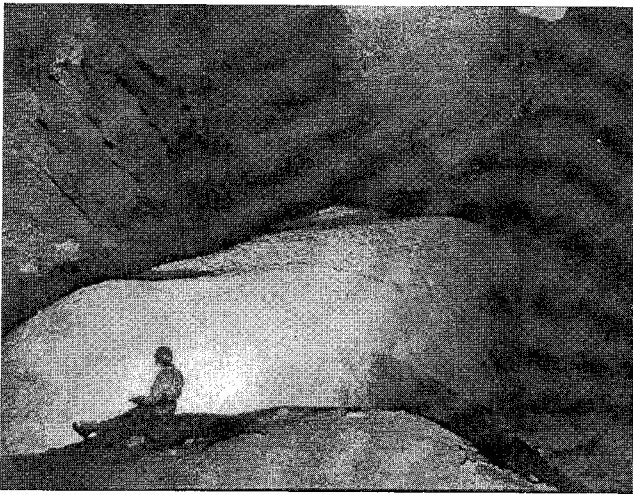


FIG. 6 - The Dune. Mullamullang. Photo A. Warild.

acid is being generated by the oxidation of organic and inorganic sulfides, resulting from both inorganic and microbial processes.

Effect of Ionic Strength: The greater the number of ions in a solution (ionic strength) the greater its potential to dissolve calcium carbonate. Non-common ions must exceed the common ions. The concentration of calcium carbonate in the Nullarbor cave waters varies from 250 mg L^{-1} in fresh water to 2500 mg L^{-1} in hypersaline water. The potential for concentrated sodium chloride brines to dissolve limestone is illustrated in a number of caves where the saline drips falling from gypsum speleothems have carved channels in the limestone bedrock below.

Effect of Mixing: Mixing corrosion has been recognised as an important phenomenon in carbonate waters and has been incorporated into the theory of karstification (Dreybolt, 1981). Beneath the Nullarbor, James (1992) has identified three mixing zones. Two zones where potential corrosion is taking place, and one zone of mixing precipitation.

The mixing of different waters that occurs in the caves of the Nullarbor region is a prime factor in continuing development of the landscape and cave systems in the present the semi-arid to arid climate.

SYSTEMS

It has now become increasingly possible to examine karst systems as a whole - a «total catchment» approach. Observations and measurements are made and karst processes modelled. Hydrogeological modelling and the modelling of speleogenesis by using chemical equilibrium codes have become increasingly sophisticated. Models are available that incorporate advanced analysis allowing mixing of input solutions, calculating reaction path speciation

and inverse modelling. The existing models are based on thermodynamics and at present there are tentative approaches being made to modify them to include the reaction rates (kinetics) of the $\text{CaCO}_3 - \text{H}_2\text{O} - \text{CO}_2$ system.

Beneath the Nullarbor the modelling of mixing predicted the presence of a mixing zone where calcite precipitation should be taking place. This was confirmed by the cave divers who brought back photographs from this mixing-zone showing extensive calcite deposits (fig. 7).



FIG. 7 - Mixing-zone calcites, Tommy Grahams. Photo P. Rogers.

GEOMICROBIOLOGY

One of the fastest expanding areas of karst studies is the area of microbiology and its influence on karst surface evolution, speleogenesis and cave mineral formation. Throughout the Nullarbor Aquifer is an organism known as the «Fungus» (fig. 8). The situation in the organism is ideal for the presence of a «sulfureta» with sulfide-oxidising bacteria being present as well as sulfate reducing bacteria, thus recycling sulfur species. The sulfate reduction step in the cycle favours precipitation of calcite and the sulfide oxidation step solution of calcite or limestone.

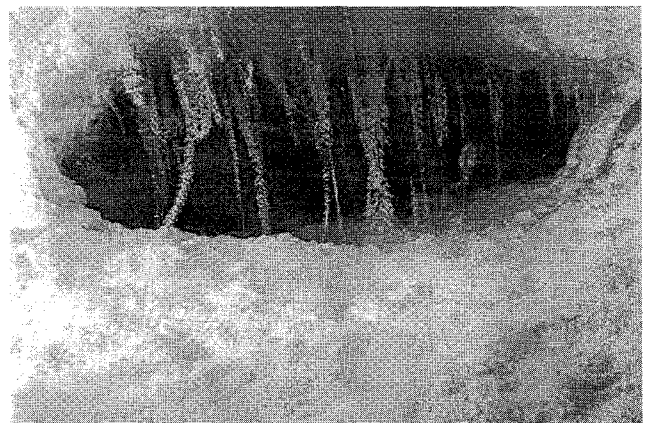


FIG. 8 - The «Fungus», Weebubbie Cave (0.5 m strands). Photo P. Rogers.

When microbes are active in the CaCO_3 - H_2O - CO_2 system they do not change the thermodynamics of the processes, but do alter the order by which the reactions take place, and significantly change the rate of the karst chemical processes.

MANAGEMENT

The management of karst demands specific interdisciplinary expertise and this is now being used in most developed countries, and where possible being extended to karst projects in the developing countries.

Karst researchers have a long history of being involved in risk management in karst, a terrain which is prone to subsidence and collapse and which may transport pollutants over long distances. The users of this expertise are legion, for example, miners, dam builders, urban planners, and agriculturalists.

Over the last decade, there has been an increasing involvement of karst scientists in many other aspects of karst management. Particularly rewarding are the projects which concern the conservation and preservation of karst. An interdisciplinary group of Australian karst scientists prepared the World Heritage nomination for the Nullarbor (Davey & alii, 1992). A bid which was never submitted not because of the significance of the karst, but because there was strong political opposition led by the pastoralists.

The cave and karst tourist industry is now the largest user of karst expertise. Particularly controversial are some of its recent initiatives which have been classified as ecotourism and claim that such use of the resource allows for sustainable development. There is a great debate emerging as to whether this is possible in caves or even on the karst surface.

1997 has seen a significant contribution to the special management considerations essential for protection of caves and karst. *The Guidelines for Cave and Karst Protection* was published by IUCN-The World Conservation Union and prepared by its World Commission on Protected Areas working group on Cave and Karst Protection. It is the first time that such an overview has been produced at a global level.

CONCLUSION

The «State of the Art» is such that with only minor refinements the detailed study and understanding of karst is possible anywhere in the world. There is now a vast array of techniques available which ideally should be used in combination for complete karst studies. This is rarely practicable because of the cost. At the moment the technology available has far outrun the money that most researchers have to spend on it. The next decade should see not such a dramatic increase of the technology available to the karst scientist, but rather in the use of existing methods to understand the processes taking place in the great variety of karsts that are spread throughout planet Earth.

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PAOLO FORTI

PLENARY LECTURES AND POSTERS

POSTER PRESENTATIONS

Derek Ford of Canada presented a visual feast on the principal features of evaporite karst in Canada. This review summarised what is known and understood concern-

ing modern karst landforms occurring on evaporite rocks in Canada. The climax of this photographic review was a visit to the syngenetic breccia karst landforms on the Bear Rock Formation in the Northwest Territories.

The second plenary speaker was Leonardo Piccini of

Italy, who presented a study of the karst in the Alpi Apuane. This paper summarised the authors observations in the numerous caves of the Alpi Apuane, which include both the deepest and longest caves in Italy. As a result of these observations made on numerous speleological expeditions, Piccini concluded that there have been at least three major karst development phases in the Alpi Apuane.

Both of the plenary lectures are published in full in the proceedings (James & Forti, 1998), unfortunately without the numerous excellent illustrations.

The posters for this session were presented in four groups: karst denudation, exokarst morphology, human impact on karst and endokarst morphology.

Karst Denudation

These posters focussed on the measurement of karst denudation rates by a variety of techniques and in karsts as varied as limestone, gypsum and halite. F. Cucchi, P. Forti & F. Finocchiaro measured the degradation rates of gypsum in Italy using a Micro Erosion Meter (*Gypsum Degradation in the Mediterranean area with Respect to Climatic, Textural and Erosional Conditions*). This study was carried out over 8 years and covered the whole Italian territory, making it the first systematic study of this type carried out in the Mediterranean area. They found an average degradation of 0.7 mm/year, providing the first experimental evidence that the karst cycle in gypsum is normally extremely young.

K. Urushibara-Yoshino & F.D. Miotke analysed the relationship between the dissolution rate of limestone tablets and CO₂ content in seven locations in Japan, showing that the dissolution rate of tablets in soil is consistently higher than in the atmosphere. (*Solution Rate of Limestone Tablets and CO₁ Measurements in Soils in Limestone Areas of Japan*).

A. Frumkin presented *Radiocarbon Dating of a Karst Terrain Exposure*, in which he reported use of ¹⁴C dating to estimate the age of wood fragments embedded in alluvial deposits in caves in the salt diapir of Mt. Sedom, Israel. He used this information to date the salt karst exposure, which is estimated to have started to rise above base level approximately 7100 yr B.P.

A Simple Growth Model for Limestone Pedestals: Determination of Surface Karst Denudation was presented by S.E. Lauritzen. This is a mathematical model of karst denudation based on the height of limestone pedestals preserved beneath non-karst boulders, taking into account the shape of the boulder, its short horizontal axis and the degree of condensation corrosion beneath it. This model has been tested in the Svartisen Karst of northern Norway.

Exokarst Morphology

The first four papers in this group analysed the relationship between karst and climate. R. Drysdale presented *The Biogeomorphology of Meteogene Travertines from a Tropical Karst: the Role of Hydrodynamics and some Impli-*

cations for Interpreting Travertine Fabrics, analysing the effect that hydrodynamic changes brought about by trichoptera cases and silk nets had on travertine deposition in Louie Creek, Northern Australia.

Fossil Periglacial Phenomena on Karst since the Last Glacial Stage in Akka Karst, Northeastern Japan, presented by T. Okamoto, investigated periglacial fossils in aeolian deposits sedimented inside dolines and caves in Attika karst, Japan, characterising climatic changes in the karst over time.

J. Lin in the *Analyses on Karst Development Responses to Climate and the Problems of Climatic Change*, considered the parameters affecting the development of karst morphology in China and presented an equation relating the solution rate to rainfall, lithology and relief morphology.

In *Influence of Climatic Changes on Travertine Deposition during Holocene: a New Hypothesis*, F. Dramis, M. Materazzi & G. Cilla presented a new hypothesis on the deposition of travertines during Holocene based on the temperature difference between spring waters and the colder infiltration waters. They suggested that the increased temperature causes enhanced CO₂ loss and hence travertine deposition.

The following four papers studied main karst features in particular areas.

A. Mihevc studied the development of a large series of dolines between the cave of Skocjanske and the village of Divaca in the «classical karst» of western Slovenia (*Dolinas, their Morphology and Origin, the Case of Dolinas from Kras, W Slovenia*). These dolines are numerous (up to 240/km²) and may be divided into four types, based on origin.

M. Lehotsky in *Exhumed karst - Geomorphic and Environmental Aspects (Case Study Hybe Village Surroundings - Slovakia)*, made a detailed geostructural and morphological study of a system of sinkholes in Slovakia which probably developed during the Pliocene and were subsequently buried by glaciofluvial deposits during the Quaternary.

F. Krutaj & E. Frasher presented *Some Particular Features of the Albanian Karst.*, the first general overview of the karst features of Albania, where karst studies have commenced only recently.

In *The South-German Muschelkalk-Karst and its Impact on the Landscape System*, B. Sponholz described the main large-scale morphologies of a wide area of southern Germany characterised by the presence of halite-gypsum interbeds. Dissolution of these interbeds is the main karstifying factor for the area.

The last two papers in this section dealt with unusual forms in exokarst morphology.

L. Song & F. Wang presented *Pinnacle Karst and Shilin Karst in Tropical and Subtropical Climatic Zones in China*, an overview of the morphology and mechanisms of generation of the Pinnacles and Stone Forests in Southern China.

T. Macaluso & U. Sauro presented *Aspects of Weathering and Landforms Evolution on Gypsum Slopes and Ridges of Sicily*, the first description of the weathering forms which develop on gypsum slopes and ridges in Sicily.

Human Impact on Karst

Geomorphological Heritage Evaluation in Karstic Terrains was presented by L. Boyer, S. Fierz & M. Monbaron. It provided a new methodology for the evaluation of geomorphological heritage in karst areas. The method was tested in several areas in France and Switzerland, and may be generally applicable.

In *Connection between Morphology and Ecological Factors of Karstdolines (Aggtelek Hills, Hungary)*, I. Bárány-Kevei studied the evolution of dolines in the Aggtelek Hills World Heritage area in Hungary, showing the influence that human activities such as deforestation and cattle grazing have had on their evolutionary history.

C. He, K. Xiong, X. Cheng & X. Li presented *Karst Geomorphology and Agricultural Implications in Guizhou, China*, in which they considered the complex relation between agriculture and karst geomorphology in Guizhou Province, China, where over 73% of the province is karstic.

Endokarst Morphology

In *Water Shape Factor in Process of Speleothem Deposition*, X. Cheng, C. He & K. Xiong analysed the influence of the water-air interface on CaCO_3 deposition, confirming that CaCO_3 deposition increased with interface size due to faster CO_2 release.

K. Barta & T. Tarnai, *Relation between the size of non-karstic catchment area and the connecting caves' sizes in a Hungarian Study area*, studied a karst region in Hungary and showed a direct relationship between catchment area and the size of drainage galleries, with the amount of

drained water being the main speleogenetic factor in areas with the same climate, although several different parameters may affect the dimensions of the karst tubes.

In *Karst of the Cainozoic Limestone of the Otway Basin, Southeastern Australia*, S. White described both endo- and exokarst features of the Otway Basin, Australia, where the high porosity of the calcareous Pleistocene dunes have allowed the development of several peculiar morphologies.

L. Luna, A. Serafin & J.J. Zamorano presented *Detailed Geomorphological Cartography of «La Palma» Cavern, Veracruz Mexico*, a detailed survey of the cave «La Palma», Veracruz, Mexico, which is a large subhorizontal karst system consisting of two superimposed subhorizontal galleries where structural settling and hydrogeological conditions have controlled the geomorphological evolution.

K. Xiong, C. He & X. Cheng presented *Analysis of Structural Features of Rimstone in Karst Caves*, a study of the morphology of rimstone dams in China, dividing them into three types based on the type of water feed. Rimstone dams may also be classified according to profile, dip angle and inner structure.

Of the 22 papers presented as poster only 17 have been later submitted in full to the Editors, 12 of which were accepted for publication in the Proceedings (James & Forti, 1998).

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