

# **Cave and Karst Science**

*The Transactions of the British Cave Research Association*

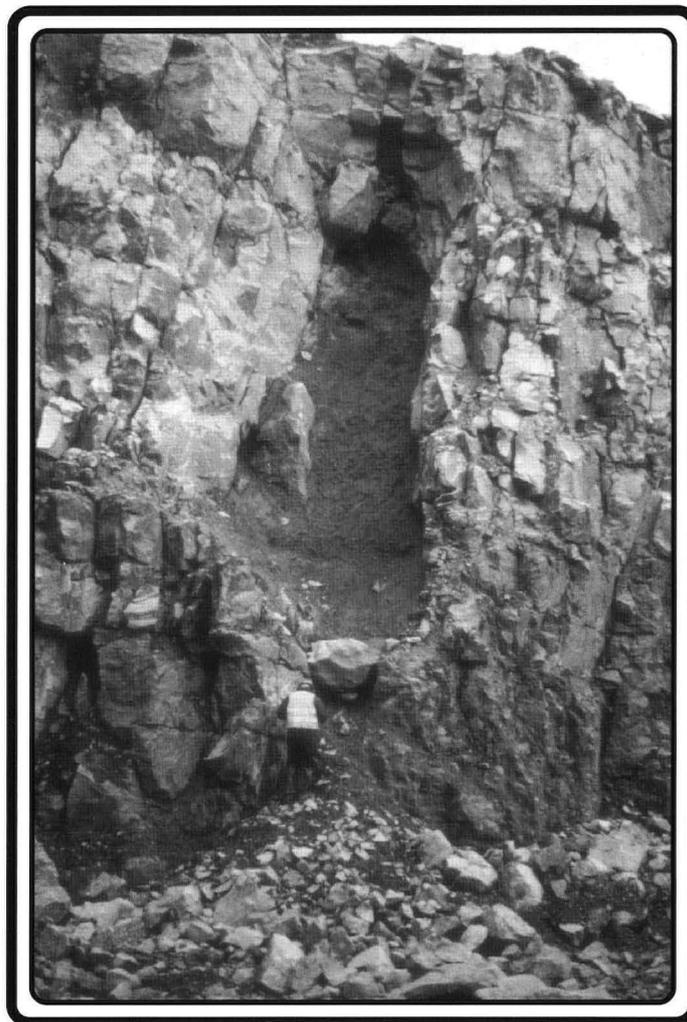
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**BCRA**



## **Conference Abstracts**

# Cave and Karst Science

Authors are encouraged to submit articles for publication in the Transactions of the British Cave Research Association under four broad headings:

## 1. Mainstream Articles

Scientific papers, normally up to 6,000 words, on any aspect of karst/speleological science, including archaeology, biology, chemistry, conservation, geology, geomorphology, history, hydrology and physics. Papers should be of a high standard and will be subject to peer review by two referees.

## 2. Development Articles

Shorter papers, normally 500-3,000 words, on aspects of karst/speleological science listed above, or more descriptive material such as caving expedition reports and technical articles. These will be reviewed by the editorial board unless the subject matters is outside their fields of expertise, in which case appropriate expert assessment will be sought.

## 3. Forum

Personal statements up to 1,000 words on topical issues; discussion of published papers and book reviews. Statements should put forward an argument and make a case, backed-up by examples used as evidence.

## 4. Abstracts

Authors (or supervisors) of undergraduate or postgraduate dissertations on cave/karst themes are asked to submit abstracts for publication. Please indicate whether the thesis is available on inter-library loan. Abstracts of papers presented at BCRA and related conferences or symposia will also be published.

Manuscripts may be sent to either of the Editors: Dr. D. J. Lowe, British Geological Survey, Keyworth, Nottingham NG12 5GG, UK, and Professor J. Gunn, Limestone Research Group, Department of Geographical and Environmental Sciences, The University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK. Intending authors are welcome to contact the Editors, who will be pleased to advise on manuscript preparation.

## NOTES FOR CONTRIBUTORS

These notes are intended to help the authors to prepare their material in the most advantageous way so as to expedite publication and to reduce both their own and editorial labour. It saves a lot of time if the rules below are followed.

All material should be presented in a format as close as possible to that of *Cave Science* since 1985. Text should be typed double-spaced on one side of the paper only. Subheadings within an article should follow the system used in *Cave Science*; a system of primary, secondary, and if necessary, tertiary subheadings should be clearly indicated.

**Abstract:** All material should be accompanied by an abstract stating the essential results of the investigation for use by abstracting, library and other services. The abstract may also be published in *Caves and Caving*.

**References** to previously published work should be given in the standard format used in *Cave Science*. In the text the statement referred to should be followed by the relevant author's name and date (and page number, if appropriate) in brackets. Thus: (Smith, 1969, p. 42). All such references cited in the text should be given in full, in alphabetical order, at the end. Thus: Smith, D. E., 1969. The speleogenesis of the Cavern Hole. Bulletin Yorkshire Caving Assoc., Vol. 7, p. 1-63. Books should be cited by the author, date, title, publisher and where published. Periodical titles should be abbreviated in standard style, or, where doubt exists, should be written out in full.

**Acknowledgements:** Anyone who has given a grant or helped with the investigation, or with the preparation of the article, should be acknowledged briefly. Contributors in universities and other institutions are reminded that grants towards the cost of publication may be available and they should make the appropriate enquiries as early as possible. Expedition budgets should include an element to help publication, and the editor should be informed at the time of submission.

**Illustration:** Line diagrams and drawings must be in black ink on either clean white paper or card, or on tracing paper or such materials as Kodatrace. Anaemic grey ink and pencil will not reproduce! Illustrations should be designed to make maximum use of page space. Maps must have bar scales only. If photo-reduction is contemplated all lines and letters must be large and thick enough to allow for their reduction. Letters must be done by stencil, Letraset or similar methods,

not handwritten. Diagrams should be number in sequence as figures, and referred to in the text, where necessary, by inserting (Fig. 1) etc. in brackets. A full list of figure captions should be submitted on a separate sheet.

**Photographs** are welcome. They must be good clear black and white prints, with sharp focus and not too much contrast; prints about 15 x 10 cm (6 x 4 inches) are best; if in doubt a selection may be submitted. They should be numbered in sequence, but not referred to in the text, except where essential and then after discussion with the Production Editor. A full list of plate captions, with photographer credits where relevant, should be submitted on a separate sheet.

**Tables:** These should not be included in the text but should be typed, or clearly handwritten, on separate sheets. They should be numbered in sequence, and a list of captions, if necessary, should be submitted on a separate sheet.

Approximate locations for tables, plates and figures should be marked in pencil in the manuscript margin.

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Speleological expeditions have a moral obligation to produce reports (contractual in the cases of recipients of awards from the Ghar Parau Foundation). These should be concise and cover the results of the expedition as soon as possible after the return from overseas, so that later expeditions are informed for their planning. Personal anecdotes should be kept to a minimum, but useful advice such as location of food supplies, medical services, etc., may be included, normally as a series of appendices.

Authors will be provided with 20 reprints of their own contribution, free of charge, for their own private use.

Manuscripts on a disk are welcome, as text may be set directly from them. Please submit a hard copy to the Editor in the normal way, and advise him that you have a disk, which you can submit after any editorial corrections.

If you have any problems regarding your material, please consult either of the Editors in advance of submission.

# Cave and Karst Science

TRANSACTIONS OF THE BRITISH CAVE RESEARCH ASSOCIATION

Volume 21 Number 1 July 1994

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### Cover photo:

**Truncated, sediment-filled cave passage, Eldon Hill Quarry, Castleton, Derbyshire.**

It is well known that caves are important "museums" preserving evidence of changing environments at the surface of the earth. At Eldon Hill quarrying has intersected large relict cave passages containing a considerable variety of sediments. Research by Peter Smart and colleagues has shown that these were deposited over 730,000, and possibly over 910,000 years ago under cold climate conditions. Quarrying on Eldon Hill has already totally destroyed several caves and although the site is now within the Castleton Caves Site of Special Scientific Interest (SSSI) a pre-existing planning consent means that there is nothing to prevent these possibly unique deposits, and the remnant cave passages, from being totally destroyed. Photo by John Gunn, University of Huddersfield.

Editors: Dr. D. J. Lowe British Geological Survey, Keyworth, Nottingham, NG12 5GG  
Prof. J. Gunn Limestone Research Group, Department of Geographical & Environmental Sciences, The University of Huddersfield, Queensgate, Huddersfield, HD1 3DH.

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## EDITORIAL

David J Lowe and John Gunn

After 20 years as Editor of *Cave Science*, the Transactions of the British Cave Research Association (BCRA), following 10 years of editing its predecessor (Transactions of the Cave Research Group of Great Britain), Dr Trevor Ford has decided to retire from editorial duties to devote more time to writing! BCRA Council have accepted an offer from Dr David Lowe and Prof John Gunn to take over as editors, beginning with this issue. Trevor will be an incredibly hard act to follow and we would like to take this opportunity to acknowledge his hard work, professionalism and dedication to the science of speleology.

Subject to appropriate refereeing, *Cave Science* has always accepted a wide range of papers and articles originating in Britain and overseas. We believe there is scope to improve upon the already high standard of publication established by Trevor, extending the range of topics covered and attracting relevant contributions from throughout the world. In short, we wish to edit a truly international journal, publishing high quality articles on all aspects of cave and karst science.

In keeping with this ideal, as well as marking the first editorial change in its 20-year history, the name of the journal has been changed to **Cave and Karst Science**, reflecting the intention to include material dealing with karst-related investigations above, as well as those beneath, the ground. The subject matter will reflect the interdisciplinary nature of cave and karst science, including aspects of archaeology, biology, chemistry, conservation, ecology, geology, geomorphology, history, hydrology, physics and resource issues. The geographical coverage will be equally wide and we will welcome the submission of papers on any of the world's caves and karst. As required by many grant-awarding bodies, including the Ghar Parau Foundation, we encourage caving expedition members to submit reports on their scientific achievements and discoveries. However, most cave exploration reports are considered more appropriate to more popular journals such as *Caves and Caving*. We recognise and stress that the exploration of caves lies at the heart of the science of speleology, and that many aspects of speleology have wider importance in the broader study of karst processes and landscapes. Hence, amateur workers as well as professional scientists are encouraged to submit papers and articles.

As indicated on the inside cover, *Cave and Karst Science* will include four types of material:

### 1. Mainstream Articles

Scientific papers, normally up to 6,000 words, on any aspect of karst/speleological science, including aspects of archaeology, biology, chemistry, conservation, geology, geomorphology, history, hydrology, physics and resource issues. Papers should be of a high standard and will be subject to review by external referees.

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### 3. Forum

Personal statements of up to 1,000 words on topical issues; discussion of published papers and book reviews. Such statements should put forward an argument and make a case, backed-up by examples used as evidence.

### 4. Abstracts

Many University cavers have undertaken projects which could lead to Development Articles but which often go unrecorded. We wish to publish abstracts of all theses (undergraduate & postgraduate) on cave/karst themes. Abstracts of papers presented at BCRA and related conferences or symposia will also be published.

We intend to establish an International Editorial Board, whose members will solicit material in their own countries and provide a pool of varied expertise for the refereeing of submitted articles. Of necessity our initial approaches will be to individuals that we have met and worked with over the years, but if you have time, energy and expertise that you are willing to contribute, please let us know.

Abstracts of Papers presented at:

**Changing Karst Environments:  
Hydrogeology, Geomorphology and Conservation.  
An International Symposium held at the  
Universities of Oxford and Huddersfield,  
September 1994**

**SYMPOSIUM INTRODUCTION**

John Gunn, Limestone Research Group, Department of Geographical & Environmental Sciences, The University of Huddersfield, England.

Karst environments, and the caves which frequently run through them, are particularly complex and fragile, and their study involves a wide range of scientific disciplines. In no other environment do the skills of the geologist, geomorphologist, hydrologist and hydrogeologist overlap to such a marked extent. Moreover, it is impossible to understand the formation and development of caves and karst without also considering the hydrogeochemical processes which operate within these environments.

Caves of dissolutional origin are a feature of most karst environments and since, by definition, they are conduits accessible to humans, they provide a unique opportunity for scientists (speleologists) to examine the inner workings of the system. Hence, caving is unique amongst sports and recreational pursuits in that many of its adherents become, by accident or design, amateur scientists.

Despite the obvious areas of overlap, karst scientists have too often worked in isolation from each other, remaining within subject boundaries. As a result, there are three main international groupings of scientists with a specific interest in karst phenomena: The International Geographical Union Commission on Environmental Changes and Conservation in Karst Areas; UNESCO International Geological Correlation Programme Project 299 (Geology, Climate, Hydrology, and Karst Formation) and The Karst Commission of the International Association of Hydrogeologists. In addition, the International Union of Speleology has a range of Commissions covering the whole spectrum of the physical and biological sciences.

Inevitably, some scientists are members of only one group, and some of several groups. However, there has never previously been a formal opportunity for members of all groups to meet together at the same time. In view of this, it was decided to organise a symposium in England and to seek formal sponsorship from each of the three karst organisations listed above, and the informal support of the International Union of Speleology.

The Symposium was organised by the Universities of Huddersfield and Oxford, with support from the Universities of Durham and Reading, and from the British Cave Research Association. Field visits were organised to areas representing

each of the main types of karst in England: the Cretaceous Chalk (led by Dr Mike Owen, National Rivers Authority); the Jurassic Limestone (led by Dr Tim Burt, Oxford University); the Magnesian Limestone (led by Dr Chris Hunt, Huddersfield University); and the Carboniferous Limestone in the Peak District (led by Prof John Gunn, Huddersfield University), the Yorkshire Dales (led by Dr Tony Waltham, Nottingham Trent University), and Great Asby Scar (led by Dr Helen Goldie, Durham University).

50 academic papers and posters were presented by 70 scientists from 21 countries, and the abstracts of these are published on the following pages. It is intended that full versions of some papers will appear in future editions of Cave & Karst Science.

I am extremely grateful to Matthew Wood and Michael Wilson for typing in all the following abstracts and to Paul Hardwick for editorial assistance.

**ALPINE KARSTS: GENESIS OF LARGE  
SUBTERRANEAN NETWORKS: THE  
TENNENGEIRGE (AUSTRIA) - THE ILE DE  
CRÉMIEU, THE CHARTREUSE AND THE  
VERCORS (FRANCE)**

P.A. Audra, Institut de Géographie, Université Michel de Montaigne, Bordeaux 3, France.

In the high limestone Alps of Salzburg, the karst of the Tennengebirge has undergone modifications since the Tertiary, with the development of a cone karst, and vast tiered cave networks. The Cosa Nostra-Bergerhöhle system came into being in the Plio-Quaternary period as a consequence of the combined effect of upthrust and glaciation. The low plateau of the Ile de Crémieu conceals an ancient karstic topography obliterated by glacial deposits. The cave of La Balme has evolved at least since the early Pleistocene in accordance with variations in the base level of the Rhône. In the Prealps, the Dent du Crolles and the Moucherotte conceal sub-horizontal perched conduits dating back to the Pliocene. Their development went on during the Pleistocene. In the Vercors, the Vallier cave contains sediments of the lower Pleistocene, unique alpine evidence of the glaciation of the time.

Underground deposits permit the reconstruction of the history of these networks and their environment. The U/Th method and paleomagnetism provide ages in the early and middle

Pleistocene. Sedimentology, mineralogy, and the anisotropy of the magnetic susceptibility of detrital deposits are studied. Reshaping of weathered rocks and glacial sediments, notably varves, are the most typical.

Corrosion in the temporarily phreatic zone plays a major part in the speleogenesis. The implications above and below the base level are analysed as well as the role of structure and neotectonics. Conditioned by the alpine upthrust followed by glaciations, the horizontal networks have been supplanted by alpine shafts.

Sheltered from erosion, the subterranean karst has immunised the traces of evolution over a period of millions of years. It is of major interest in paleogeographical reconstructions.

## **COMMERCIAL EXPORT OF NORWEGIAN SPRING WATER - EVALUATION OF A PECULIAR KARST SPRING**

S. Bakke and S-E. Lauritzen, Dept. of Geology, Bergen University, Norway.

A. Misund, Geological Survey of Norway.

The possibility of exporting reputedly clean and pristine spring water from Norway, has recently attracted considerable commercial interest. Numerous springs and seepage, among them a few karst springs, have been screened for quality, quantity and logistics. One logistically interesting site is the Kattaldalen springs in Rognan, north Norway, where we, together with the local community, have initiated a monitoring program.

Apart from testing against standard drinking water quality criteria, discharge, conductivity and water temperature have been logged at hourly intervals since December 1992. A water tracing program is planned for the 1994 season to define the catchment area in greater detail. Most of the catchment area (0.32 km<sup>2</sup>) is autogenic with respect to marble, and is situated in the western, 440m high wall of Saltdal valley at 67°N. Part of the surface of the catchment is extremely steep (61°) and partially devoid of vegetation due to frequent avalanches and rockfall. Guiding voids are generally east-west sub-vertical fractures and steeply dipping north-south foliation. The Kattaldalen springs are situated at the present valley floor, in contact with fluvioglacial fills at 25 m a.s.l. Although several intermittent and abandoned springs are known, no explorable caves have yet been found, which otherwise would have given clues to the aquifer geometry.

Discharge responds rapidly to snowmelt events, with corresponding changes in conductivity and colour (i.e. content of aquatic humus and iron). Although a similar, very weak temperature response occurs, the temperature is almost invariable at 4.8-4.9°C, approximating the annual mean air temperature of the area. Rapid snow-melt floods in the spring should expectedly give much larger temperature shifts than 0.1°C. Systematic errors, like instrumental drift in the data logger system, can be ruled out as the results are consistent with parallel, manual readings on site during the same period. Thus the spring displays characteristics of both conduit flow (rapid discharge and chemistry response) and diffuse flow or long residence time characteristics (temperature invariability). One of several possible interpretations of this enigmatic

behaviour is that the aquifer may be much larger than originally anticipated from the surface outcrop, as recharge is possible from streamsinks that are situated more than 5 km away.

## **AN INVENTORY OF KARSTIC CAVES IN THE TAURUS MOUNTAIN RANGE (SOUTHERN TURKEY): PRELIMINARY EVALUATION OF GEOGRAPHIC AND HYDROLOGIC FEATURES**

C.S. Bayari and T. Kurttas, International Research and Application Center for Karst Water Resources, Hacettepe University, Ankara-Turkey.

A. Temel, Dept. of Geology, Hacettepe University, Ankara-Turkey.

The Taurus karst range, extending along the Mediterranean coast of Turkey, has been dominated since the Pliocene by a humid and semi-humid climate which favours cave development. An inventory of karstic caves distributed through the Taurus range has been prepared, using the data from available published and unpublished reports. Although there are more than 600 caves reported in the Taurus range, only 283 caves presenting reliable data have been included in the inventory. Data concerning the location, altitude, depth, length, types, and age of the lithology in which the caves are formed have been compiled. Information regarding hydrologic features such as sinks, sumps, resurgence, and underground streams have also been added into the inventory.

Most of the caves (c. 180 caves) have lengths ranging between 50m and 250m, while many (c. 230 caves) have depths ranging between +25m and -50m. The maximum length and depth of the caves evaluated was +10 000m and -400m respectively. Although several caves exceeding these limits were reported in recent years, these have not been considered in this study.

Caves occur at any elevation between sea level and altitudes exceeding 3000m. The evaluation of mean cave length and mean cave depth for every 500m elevation interval indicates that there is a sharp boundary between elevation ranges in which the length and depth dominated caves are clustered. This boundary extends roughly along the 1750m altitude, also the upper limit of the tree-line. Length dominated caves are characteristic below this altitude, depth dominated caves prevailing at elevations greater than 1750m. The mean cave length and depth between the 0m and 1500m altitudes is 200m and -50m, respectively. However, between 2000 and 3000m, the mean cave length and depth are 10m and -80m respectively. The highest mean cave length and cave depth (350m and -100m) occur between 1500 and 2000m.

Almost all the hydrologic features such as sumps, sinks, underground streams and resurgence are observed in caves below 2000m in elevation, and are concentrated in caves located between 1000m and 1500m.

Many of the caves evaluated were developed in carbonate rocks that are mostly limestone, few caves were observed in carbonate cemented conglomerates, or in travertine associated with karstic springs. The lithology of 15% of the caves is unknown.

Among the caves having reliable geologic information, the

majority (65%) were found in Mesozoic carbonates, with 10% being developed in Paleozoic and 10% in Tertiary formations. A detailed evaluation of the distribution of cave lithology by geologic age indicates that 55% of Mesozoic-aged caves are developed in Jurassic-Cretaceous and Cretaceous carbonates.

## **HYDROGEOLOGY, HYDROGEOCHEMISTRY, AND GEOCHEMISTRY OF THE BIOGENIC TRAVERTINES IN THE LOWER ZAMANTI BASIN (EASTERN TAURIDS-TURKEY)**

C.S. Bayari and T. Kurttas, International Research and Application Center for Karst Water Resources, Hacettepe University, Ankara-Turkey.

A. Temel, Dept. of Geology, Hacettepe University, Ankara-Turkey.

The Lower Zamanti Basin located in the Eastern Taurids, Southern Turkey, is a mountainous karstic area with an elevation range between 400m and 3500m. 2000m thick Paleozoic and Mesozoic carbonates constitute the karstic aquifer. An ophiolite nappe with an average thickness of 1000m overlies the aquifer in the middle part of the basin. There is a strong tectonic control over the regional groundwater flow in the basin, and all karst springs are located along tectonic discontinuities.

The regional groundwater flow path extends from the mountainous recharge area to the major stream, the Zamanti River. Through the regional flow path, a series of karstic springs, fed by shallow and deep-regional circulation, discharges at points where tectonic barriers block the groundwater flow. The shallow-flow springs are located between the recharge area and the major stream. On the other hand, the deep-regional flow springs are located along the Zamanti River that makes up the regional karst erosion base. The latter deposit travertine, while no deposition is observed in the shallow-flow springs. Regional hydrogeologic structure suggests that both the long residence-time and great hydrostatic pressure existing in the aquifer are the primary factors governing the evolution of travertine depositing groundwater. The characteristic values of temperature, electrical conductivity, carbonate alkalinity, log pCO<sub>2</sub> and tritium-based residence time of the shallow-flow springs are 8°C, 80µS/cm, 1.5meq/l, 10<sup>-2</sup>atm and 12 years. However, higher values, such as, 15°C, 455µS/cm, 5.0meq/l, 10<sup>-1</sup>atm and 17 years, are observed in the travertine depositing springs. These have a stable chemical composition throughout the year. However, the observations carried out along shallow creeks fed by travertine springs indicate an apparent daily oscillation in dissolved oxygen content. These oscillations are attributed to the daily variation of air temperature, atmospheric pressure, and the biological activity of algal species. The aquatic plants and the algae seem to have rather effective physical and chemical role in the deposition of travertine. The tapered ends of the leaves of aquatic plants are good nucleation sites for calcite precipitation. The calcite micro-crystals formed from supersaturated spring water are rapidly transported away downstream if they are not trapped in mucous strands secreted by algal species.

XRD analyses of travertine samples show that calcite, up to

98%, is the major mineral forming along the travertine creeks. Quartz and clay minerals are also observed in minor amounts. An inverse correlation exists between the SiO<sub>2</sub> and CaCO<sub>3</sub> contents of the travertine samples. The amount of CaCO<sub>3</sub> increases with age, while the SiO<sub>2</sub> content decreases. It seems that infiltrating super-saturated water precipitates secondary calcite during seepage through initially formed pore spaces of the young travertines.

## **HYDROLOGY OF KARST SPRING GRADOLE (ISTRIA - CROATIA)**

O. Bonacci, Civil Engineering Faculty, Split University, 58000 Split, Croatia.

The results of a hydrogeological and hydrological analysis of the Gradole karst spring are presented. The main goal of the investigations was the determination of catchment boundaries and area in order to protect spring water quality. The underground watershed has been determined by geological and hydrogeological methods. The control used was a hydrologic water budget analysis appropriate for karst basins with limited data. The catchment of the Gradole spring is defined as 104 km<sup>2</sup>. The spring water has been used as a drinking water supply. The capacity of the spring is limited, and does not exceed 10m<sup>3</sup>/s. All discharges which exceed this amount flow to the surface through other intermittent springs in the vicinity. Measured minimum, average and maximum discharges in 1987-1992 period were: 0.28m<sup>3</sup>/s, 1.80m<sup>3</sup>/s, and 8.68m<sup>3</sup>/s respectively. During the hot and dry period of the year there is a shortage of water for supply. In this period an attempt to recharge the karst underground aquifer was made.

## **HIGH AND MODERATE RESOLUTION PALEOENVIRONMENTAL DATA FROM SPELEOTHEMS AND CLASTIC SEDIMENTS IN DROTSKY'S CAVE, NGAMILAND, BOTSWANA**

G.A. Brook, Dept. of Geography, University of Georgia, Athens, U.S.A.

A moderate resolution 25ka record of environmental changes in the Ngamiland region of the Kalahari Desert has been developed using evidence from Drotsky's Cave and the nearby Gowihaba Valley. The record is based on <sup>14</sup>C-dated archaeological, faunal and sedimentological information from a 1.3m deep test pit excavated in the northeast entrance chamber of Drotsky's Cave and a Holocene pollen record obtained from U-series-dated speleothem column in the southwest entrance. A freshwater diatom assemblage from a <sup>14</sup>C-dated calcrete has provided information on the past streamflow in the presently dry Gowihaba Valley. The faunal, diatom, and sedimentological evidence, suggests increased moisture availability at c. 25-23.5, 20-18.5, 16-11, 9-6, 4.5-3.5 and 1.5-0ka BP. Intervening periods were apparently drier than at present.

Speleothem pollen spectra indicate that 10-7ka BP, the site was surrounded by an arid grassland with dry-adapted trees and shrubs. An increase in pollen of Combretaceae and Cyperaceae

and the appearance of pollen of some mesic savanna plants c. 7-6ka BP suggests the onset of slightly wetter conditions. These pollen types increase between c. 6-3ka BP but the late Holocene record appears variable, with the period c. 5-4ka BP somewhat drier than the millennium before and after.

A high resolution environmental record for Drotsky's Cave has been developed by analysing annual layers in a 40cm high stalagmite. Work on the stalagmite, with an estimated 1500 layers, has shown that the annual layer thickness may be a proxy record of precipitation. In a study of the most recent 600 layers in the deposit, covering the period A.D. 1374-1973, periodicities at 10, 20, 30, 40, 75, and 150 years, were isolated. The 10 and 20 year periodicities were also apparent in rainfall data for four stations near the cave. Spectral models, used to predict rainfall variability beyond 1973 to A.D. 2100, accurately predicted the drought of the 1980s, and suggests that from A.D. 1973-2100, precipitation will only be above normal in the period A.D. 2010-2060.

As caves are present over 12% of the Earth's land area, and occur in all climatic regions, cave speleothems and clastic sediments could be a major source of moderate and high paleoclimatic information, with few opportunities to obtain such information by traditional methods. They may thus provide a means to fill spatial and temporal gaps in the global paleoclimatic database.

## **GEOPHYSICAL BOREHOLE LOGGING - A TOOL FOR INVESTIGATING AQUIFER VARIATION AND VULNERABILITY IN KARSTIC LIMESTONE AQUIFERS**

D.K. Buckley, Hydrogeology Group, British Geological Survey, Wallingford, U.K.

M. Pino Villasuso, Facultad de Ingeniería, Universidad Autónoma de Yucatán, Yucatán, Mexico.

R.V. Cant, Water and Sewerage Corporation, Nassau, Bahamas.

Relatively simple geophysical borehole logging techniques can provide critical information on lithology and structure and the hydrogeological properties of limestones. In limestones, certain logs frequently reveal a consistent variation or layering of physical properties. This is thought to be due to regular porosity changes arising from processes of dissolution, reprecipitation, and cementation, linked to sediment diagenesis, fluid movement, and sea level history.

The porosity variations recognised are important hydrogeologically because they focus and divert groundwater movement through the rock mass and may be capable of locally supporting head differences between aquifer units, and of ponding pollutants. This fundamental control of groundwater exists in all aquifer types, but is more readily observed in soluble rocks such as limestones because of the development of solution cavity horizons by preferential groundwater flow.

Geophysical logging is also capable of correlating the limestone units between boreholes and of examining the lateral continuity of solution horizons in the sequence. Fluid and flowmeter-logging techniques may further identify the groundwater-active flow horizons present, and establish their relative contribution to borehole yield.

Examples of logging techniques that have been applied to examine groundwater movement, and factors influencing the fate of pollutants are given for Pliocene and Pleistocene limestones of the Yucatan (Mexico), the Bahamas, and for Cretaceous limestones (Chalk) in the United Kingdom.

## **CHEMISTRY OF WATERS IN THE CAVE OF NERJA SYSTEM (ANDALUSIA, SPAIN)**

F. Carrasco and B. Andreo, Dept. de Geología y Ecología, Universidad de Málaga, 29071 Málaga, Spain.

J. Benavente, Instituto del Agua de la Universidad de Granada, 18071 Granada, Spain.

The cave of Nerja (Costa del Sol, Málaga province) is visited each year by approximately 500,000 persons. The main influx of visitors - some 5,000 per day - is during the summer period. Visit tours are restricted to the touristic galleries (one third of the total cave volume: 850 000m<sup>3</sup>). The climate outside the cave is Mediterranean with dry tendency: 490mm precipitation and 16.5°C (yearly averages). The cave is located in Triassic dolomite marbles and vegetation and soil cover over the cave is scarce. Adjacent to the cave entrance exists a calcareous-cemented conglomerate Pleistocene formation. The neotectonic uplifting of the marbles has resulted in the lowest parts of the cave now being perched 10m above the water table.

Three groups of waters in the cave system have been considered for a chemical control started in 1991: (1) Precipitation, (2) Infiltration (leaks) in different points of the cave roofs, and (3) groundwater from two nearby points: the Maro spring - the most significant of the area (average discharge 170l/s), associated with which there exists a cascading structure of Pleistocene travertines, and a well used for irrigation and supply in the cave installations. Some results of the control (over the 1991-1992 period; most of the following bracketed numbers represent average values during this period) can be pointed out:

The groundwater flow is characterised by HCO<sub>3</sub>-SO<sub>4</sub> Ca-Mg type waters with E.C. values from 550 to 800µS/cm. The spring waters (19.2°C) are slightly oversaturated with calcite (S.I. = 0.31) and present pCO<sub>2</sub> values of 0.40%, while those from the well (21.2°C) are in equilibrium with this mineral (S.I. = 0.03) and present pCO<sub>2</sub> values of 1.4% that could reflect deeper flow contributions through an active nearby fracture. The influence of more dilute waters that induce lesser calcite S.I. values is observed after relatively intense rain events.

Infiltration waters correspond to the HCO<sub>3</sub> Mg-Ca type and present E.C. values in the 390-550 µS/cm range. The calcite S.I. (> 0.5) indicates a general state of oversaturation, as can also be noticed from the recent speleothem precipitates associated with the leak points. The highest E.C. values, as well as those of the pCO<sub>2</sub> (0.2%), are found in the touristic galleries. The temporary evolution observed in the visited sectors shows the maximum pCO<sub>2</sub> values (up to 0.4%) during the summer months, especially in the period when the cave hosts a Music & Dance Festival, while in the restricted sectors this variable remains nearly stationary. These features illustrate the effects of visitors on percolation water chemistry.

The unsaturated flow into the cave also induces a

homogenization of the relatively variable rainfall chemistry. Moreover, the climatic concentration of some constituents ( $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SiO}_2$ ) clearly influences the chemical evolution of infiltration waters into the cave, due to the leaching effect after the first significant rainy episodes in autumn.

## **CARBONATE ROCKS AND KARST WATERS IN VIETNAM**

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Carbonate rocks are widespread in Vietnam, especially in the north. The area covered by these rocks is about 50 000 km<sup>2</sup>. Within the territory of Vietnam, carbonate formations occur in many forms and can be grouped into the following types:

1. Carbonate beds or lenses occurring in metamorphic rocks.
2. Carbonate-terrigenous sediments.
3. Terrigenous-carbonate sediments.
4. Carbonate sediments.

The karst waters in Vietnam are characterised as follows:

1. Karst waters not forming a continuous hydraulic system in carbonate massifs but occurring as separate and karst-fracture aquifers.
2. Abundant karst waters but with availability unevenly distributed. Potential is high along tectonic faults, low topography areas and near local river networks, but waters are scarce or absent away from faults or on the water divides of limestone massifs.
3. Fresh karst waters of  $\text{HCO}_3$ -Ca type, with total mineralisation usually 0.5g/l, pH 7-8, high  $\text{CO}_2$  concentrations and low iron content (<0.05mg/l).
4. Salinised karst waters of Cl-Na type, usually in the coastal zone, with total mineralisation usually 3-16g/l.
5. Thermo-mineral water sources associated with tectonic faults, such as Kenh Ga, Dam Thi.

The recharge source of the karst waters are mainly rain, surface water, and groundwater from other waterbearing units occurring above or adjacent to the karst systems. Karst waters emerge as springs and discharge along local river networks.

Within the karst, water velocities may vary by several orders of magnitude depending on flow paths. The flow regime also changes greatly depending on season, rainfall, and topographic conditions.

Karst waters play a very important role in domestic water supply and for other economic requirements.

## **VULNERABILITY TO POLLUTION OF AN IRISH LOWLAND KARST AQUIFER, AND THE IMPLICATIONS FOR MANAGEMENT OF GROUNDWATER RESOURCES**

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It is increasingly being recognised that groundwater protection in karstic areas cannot be handled in the same way as conventional aquifer protection, due to the short underground

residence times and the extreme vulnerability to pollution of karst aquifers. This paper details a study of one such area, the lower Fergus catchment, County Clare, Ireland. The Carboniferous limestone aquifer in this catchment has a thin, patchy cover of glacial deposits, and has rapid underground flow velocities (more than 150m/hr along some routes). Thus it is extremely vulnerable to pollution yet it is an important resource which provides the public water supply for the town of Ennis (9000 m<sup>3</sup>/d) in addition to many private water supplies, so issues of groundwater resource management and protection planning must be tackled.

The research work currently in progress involves basic hydrological investigations including water tracing experiments, and studies of spatial and temporal variations in groundwater quality. In addition, geological and soils data compilation, and mapping of karstic features is being carried out to determine spatial variations in aquifer vulnerability; and a hazard assessment takes into account these variations and the locations of major potential sources of contamination, in order to predict where pollution is likely to occur.

Water quality problems in the aquifer are both natural and anthropogenic, including sporadic incidences of high iron, colour, and turbidity, associated with point recharge of the aquifer by runoff from Namurian shales to the west, and faecal bacterial contamination associated with septic tank effluent and farm wastes. Both problems are more severe in springs than in boreholes, reflecting the association of the springs with point recharge and lines of high permeability.

Nine water traces have been carried out using optical brightener. The tracing has defined the catchment area of Drumcliff springs (which provide the Ennis water supply) and has highlighted their vulnerability (with a travel time of only 7-9 hours between one swallow hole and the springs). The vulnerability of the Pouladower spring, which is being considered as an additional town supply, has also been established. This spring has a superior quality in terms of iron, colour and turbidity, and it had been suggested that it was fed by more diffuse "true" groundwater. However, tracing has established that this reflects a lower proportion of water derived from the Namurian shales, and rapid underground velocities (up to 163-244m/hr) show it to be potentially as vulnerable to pollution as the existing supply.

Source protection zones have been defined, based on a vulnerability assessment taking into account the cover of soil and glacial overburden and the sinking stream network. A provisional zonation for the Drumcliff catchment developed in 1991 is being re-evaluated in the light of vulnerability guidelines produced by the Geological Survey of Ireland. A difficulty in producing protection zonations illustrated by the research, arises where a very extensive area contributes part of its recharge to a spring: Pouladower spring is fed largely by influent reaches and swallow holes along the course of the River Fergus; its catchment area is c. 260km<sup>2</sup> but it accounts for only c. 15% of the flow from this area via the river. Such issues highlight a need for the development of approaches to groundwater protection appropriate to karstic catchments.

## **KARSTIC HAZARDS IN URBAN AREAS: THE CASE OF MILWAUKEE'S DEEP TUNNELS**

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Begun in 1979 and scheduled for completion in 1995, the Milwaukee Metropolitan Sewerage District's \$2.1Bn Water Pollution Abatement Program (W.P.A.P) consists of 340 separate projects collectively designed to store stormwater and sewage and reduce pollution of Lake Michigan and other waterways. Part of the W.P.A.P. involves boring and lining about 18 miles of 32 foot diameter tunnel within Silurian aged Niagaran Dolostone at a depth of about 300 feet. Construction of the three deep tunnel sections - the North Shore, the Crosstown, and the Kinnickinnic-Lake Michigan - has proven particularly expensive because of unforeseen problems of rock collapse, subsidence, and the groundwater intrusion, which in some sections reached 3500 gallons/minute. Much of the 2.6 million cubic yards of rock excavated from the tunnels has been used to build artificial islands and in other constructions to combat coastal erosion.

## **ROCK HARDNESS AND LIMESTONE VALLEY BEDFORM: AN EXAMPLE FROM NORTH CENTRAL JAMAICA**

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Limestone valleys with irregular flow regimes are developed on the Miocene-aged Montpelier Limestone in north central Jamaica (Day, 1985). Longitudinal valley profiles are extremely irregular over short distances, and the channel bedform consists essentially of a stepped series of varying scale waterfalls. Larger steps and falls are related to the edges of tectonically-raised reef terraces, but smaller steps are lithologically controlled.

A one kilometre stretch of one valley, Thatch Walk Gully, was investigated in detail, with specific attention to step locations and bedrock surface hardness, as determined using a Schmidt Test Hammer. 38 steps were measured, ranging in height from 0.1 to 2.8 metres. Of these, 11 corresponded with outcrops of chert (mean hardness 55) and 27 corresponded with outcrops of limestone beds whose mean hardness was 36. By comparison, mean hardness of limestone strata not forming channel bed steps was 31.

Insoluble residue analyses indicate that the step-forming limestones have a slightly higher non-carbonate content (mean 0.31%) than the other limestones (mean 0.24%). Additionally, qualitative petrographic investigation suggests that the step-forming limestones have a finer texture, lower porosity, and more accessory pyrite, although these differences are not reflected in variations in water absorption capacity.

## **A G R I C U L T U R A L L Y I N D U C E D ENVIRONMENTAL CHANGES IN THE BURREN KARST, WESTERN IRELAND**

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The Burren plateau of County Clare is a classic example of a plateau karst characterised by patchy, thin soils, a lack of surface drainage, and in the instance of the Burren a rich, floristic, archaeological and landscape heritage.

Until recently, land-use and agricultural practice in the Burren conformed to that in other less-favoured areas of Europe, with small land holdings, traditional practices and relatively low standards of living being the norm. However, since accession to the European Union, and in particular as a result of C.A.P. initiatives, attempts have been made to raise farm incomes and to modernise agriculture in areas such as the Burren.

The encouragement of land reclamation: commonly converting scrubland or rocky pastures into uniform, seeded, fertilised, manageable fields, has transformed some areas of the region. To some extent as a result of this, silage making has largely replaced hay making for winter fodder, and larger cattle housing units have been erected. In addition, increased prosperity has allowed the construction of many dwellings, commonly in isolated areas on the Burren plateau. All of these changes, whilst altering the appearance of the area, also pose a threat to water quality, via enhanced leaching of artificial fertilisers or due to organic pollutants.

The effluent generated by freshly cut silage is probably the most significant of these hazards to groundwater, as silage effluent is an extremely potent and concentrated pollutant of water. The Burren is highly vulnerable to water pollution from silage effluent, because of its thin or absent soils and its highly karstified aquifers.

A full survey of silage clamps was made in the summers of 1991 and 1992. In 1991 some 93 clamps were recorded and in 1992 some 110. For each site, the location, altitude, date constructed, size, site preparation / effluent disposal method, site soil cover and type, site slope and aspect were recorded. Data derived from this included: mass of silage, effluent produced, hazard rating of site to groundwater, likely discharge of effluent to groundwater, and groundwater dilution index. Some 60% of clamps were considered to be high risk, and 23% medium risk. Some 92% of all sites probably allow some effluent to reach groundwater.

## INFLUENCE OF HYDRODYNAMIC CONDITIONS AND WATER CHEMISTRY ON THE FORMATION OF TUFA IN HAUNGLONG, SICHUAN

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The Haunglong stream is located in the northwestern Plateau of Sichuan, P.R. China, at an altitude of 3400m asl. It is fed by two types of water, one from snow melt of the nearby mountains, and the other from a series of springs. The first type of water shows low mineralisation ( $SpC = 100\mu s$ ) but the spring water is highly mineralised ( $SpC = 1000\mu s$ ), at equilibrium with calcite, and with a  $pCO_2$  of 0.2atm. The Haunglong stream deposits calcite at rates of a few mm/a along a valley 3.5km long. In order to understand the origin of the local tufa we have carried out analysis of the water chemistry, and in situ experiments to measure the deposition rates of tufa. The evolution of the hydrochemistry was measured at different locations down the stream. pH, specific conductance, and temperature, have been measured in situ, and titrations for Ca, total carbonate hardness, and alkalinity were performed immediately. All control samples were analysed in the laboratory for Ca, Mg,  $SO_4^{2-}$ ,  $Na^+$ , and Cl. The water turned out to be of almost pure  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $HCO_3^-$  type, with a Ca/Mg ratio between 5.5 upstream and 3.5 downstream.  $SO_4^{2-}$ ,  $Na^+$ , and Cl show low concentrations of about  $1 \times 10^{-4}$  mol/l. Due to outgassing of  $CO_2$ , the pH value increases and the water becomes supersaturated with respect to calcite (S.I. c. 1.2). Because of deposition of calcite the  $Ca^{2+}$  concentration drops from  $6 \times 10^{-3}$  mol/l upstream to about  $2.5 \times 10^{-3}$  mol/l downstream. To measure the deposition rates we placed rectangular marble tablets in the stream at each of the sampling locations for a period of a few days, and deposition rates were measured by weight increase of about several milligrams. At all locations, one tablet was put into fast flowing water at the rim of a tufa dam, and the other into its pool with still water. Although there was no difference in water chemistry, deposition rates were higher by up to a factor of four for fast flowing water, indicating that deposition rates were strongly influenced by hydrodynamics. Upstream deposition rates were c. 5 mm/year, whereas lower rates of c. 1 mm/year were observed downstream. Inspection of the deposited calcite by REM and EDAX showed that single crystals of pure calcite about  $10\mu m$  in size grow on the marble substrates. Their average surface is about the fourfold of the substrate surface. The shape of the crystals indicates inorganic deposition of calcite.

Using a recently developed mass transfer model for calcite dissolution and precipitation, we have calculated the deposition rates from the water chemistry of the corresponding locations. The model takes into account the surface dissolution rates of Plummer, Wigley and Parkhurst; slow conversion of  $CO_2$  into  $H^+$  and  $HCO_3^-$ ; and mass transport by diffusion across a boundary layer (Dreybrodt & Buhmann, Chem. Geol. 90, 107, 1991); and qualitatively explains well, why higher deposition rates are observed in fast flowing water. Quantitatively, the calculated deposition rates agree with the experimental results within a factor of three.

## CALIBRATION OF STABLE ISOTOPE AND TEMPERATURE SIGNAL IN THE PERCOLATION ZONE OF A SUB-ARCTIC CAVE, NORTHERN NORWAY

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The stable isotope signal in the speleothem record, when combined with precise U-series dates, provide an important paleo-environment data base. Being a local terrestrial record, it cannot be replaced by deep-sea data, but is rather a valuable complement to it. Paleoclimatic interpretation from cave data imply that the relationship between the cave and surface environment is either very simple, or if more complicated, well calibrated. Occasional studies have investigated the relationship between cave and surface temperature, stable isotopes and other parameters, and found the cave environment to approach the annual mean. When undertaking a broad study of speleothem stable isotope records in north Norway, it was felt that an independent calibration study was needed for this sub-arctic, oceanic environment.

One of the richest speleothem bearing caves in Norway was selected for the study. Previous U-series dating have revealed speleothem deposits in the excess of 350ka. The cave is more than 1.3km long, 104m deep, and occupies almost the total thickness of a steeply dipping marble band. The country rock is mica schists and iron oxide ores. The pristine, inner parts of the cave, which were first opened by digging in the 1960s, were instrumented by a 12-channel Aandreaa data logger with various sensor arrangements (temperature, water stage, drip rates, water conductivity, humidity and atmospheric pressure). The equipment has been running since July 1991 on Li/SOCL<sub>2</sub> cells and solid state RAM that were sufficient for 8 months records at hourly intervals. A similar surface data logger station was established to record the discharge and temperature of an invading stream, precipitation and air temperature above the cave. Precipitation was sampled for stable isotope analyses at a nearby farm. In the cave, 10 individual stalactite drips were collected for stable isotope analysis, and at 5 stations, groups of up to 5 stalactite drips were combined through thin polyethylene tubing into bulk containers, from where volume and chemical composition could be measured. A tracing experiment from the surface, using optical brightener and cotton detectors is in progress.

As expected, the atmospheric precipitation displays large isotopic variations (-3 to -20‰  $\delta^{18}O$ , SMOW), depending on season and stormtracks. Stalactite drips display values of  $10.46 \pm 0.20\%$ , and stable chemistry through all seasons over 3 years. Similar constancy was found in the cave climate. Our conclusion is that, beneath 50-100m of rock, annual variations are sufficiently damped to give reliable annual mean estimates of surface temperature and stable isotope composition of the precipitation. This, in turn, can be tested against modern fractionation temperatures in the respective stalactite tips. Speleothems that can be shown to have grown in isotopic equilibrium with the dripwater, may then provide reliable information of the surface paleoenvironment.

# MONITORING AND EVALUATION OF HYDROGEOCHEMICAL CHANGES IN THE KÖPRÜÇAY RIVER BASIN, SOUTHERN TURKEY

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The Köprüçay basin, comprising spectacular karstic features developed within conglomerates, covers an area of about 6000km<sup>2</sup> in the Taurus Mountain Karst Region in Southern Turkey. The Köprüçay river, with a discharge rate of about 150m<sup>3</sup>/s, has long been attractive to decision-makers for development, particularly for hydropower generation. At present, there are no hydrotechnical structures on the river, but huge dams are planned to be constructed in the very near future as soon as some engineering problems related to karst phenomena are overcome. Due to significant contribution of karstic effluents to the river at certain zones, the hydrochemical changes are not uniform and depend mostly on the hydrological regime prevailing in the basin. For this reason, an accurate knowledge of the relation of the water quality to the complicated hydrodynamic structure in this karstic basin was required for an effective control of water pollution and precise assessment of the related impacts of the environment.

A water quality monitoring network was installed to assess the sources of contamination in this basin and the impacts of the water quality changes on some components of the environment. The topographic, hydrographic, hydrogeologic, and socio-economic structure of the basin were also considered. The water quality was monitored in terms of physical, chemical, inorganic, and heavy metal pollution and/or contamination.

The hydrochemical changes were monitored at 13 Water Quality Monitoring Stations on monthly basis. Results obtained from this study were compared with those obtained during previous research. Evaluation, taking also the lithologic, hydrogeologic, and socio-economic conditions into account, revealed that water resources in the Köprüçay Basin are polluted and contaminated to a certain extent, in some part of the basin. Lithologic contamination is dominant at the upstream part of the basin, while anthropogenic pollution is increasing dramatically at the downstream area where topography favours urbanisation and related activities.

Based on the data obtained from the water quality monitoring network, the authors discuss firstly, the effects of complex nature of karst on water quality, secondly the sources of contamination and the dynamics of contaminants with special emphasis on the hydrological regime, and thirdly the present and future impacts of natural and anthropogenic hydrogeochemical changes on some components of the environment.

# ANTHROPOGENIC INFLUENCES ON KARST SPRING CHEMISTRY IN BUCHAN, VICTORIA, AUSTRALIA

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Seven springs and three cave streams in a small impounded karst at Buchan in eastern Victoria, Australia, have been regularly monitored for flow conditions and physical and chemical water quality parameters over a six year period. The karst is small (c. 100km<sup>2</sup>), with a warm temperature climate (Köppen Cfb), mean annual rainfall ranging from 800mm at 90m elevation to 1500mm at 800m elevation. In such a small and relatively homogeneous area, there is a surprising degree of spatial variability in water quality. For example, there is as much variation in Ca<sup>2+</sup> concentrations among these sites as there is reported in the literature for all karst areas with temperate climates. The sample sites can be categorised broadly into two groups using water quality parameters: those draining largely uncleared catchments, and those draining catchments where the original forest cover has been cleared for agriculture, during progressive occupation of the area by Europeans over the last 150 years. A subset of this latter group can be recognised, which drains an area containing the local garbage dump. Median values of selected water quality parameters are shown in the following table.

Catchment Condition	Ca <sup>2+</sup> (mg/l)	Cl <sup>-</sup> (mg/l)	Na <sup>+</sup> /Cl <sup>-</sup> (molar ratio)	log pCO <sub>2</sub>	Temp (°C)
Uncleared	26	19	1.00	-2.40	13.5
Cleared	98	39	0.75	-2.18	15.5
Cleared + Garbage Tip	167	254	0.54	-1.51	16.5

Cleared catchments have higher log PCO<sub>2</sub> than the uncleared catchments and this has resulted in higher Ca<sup>2+</sup> concentrations. Higher temperatures in the cleared catchments arise from higher soil temperatures as a result of increased solar radiation receipts at the soil surface. The increase in Cl<sup>-</sup> concentrations following clearing are caused by leaching of stored chloride in the soil profile.

The garbage tip exerts a dramatic influence. The observed pCO<sub>2</sub> levels are unlikely to have arisen from natural soil processes, and result from the higher levels of organic material decomposing in the tip. The higher CO<sub>2</sub> levels have led to more carbonate dissolution and higher Ca<sup>2+</sup> values. Contamination from the tip leachates has also caused the higher chloride levels and lower Na:Cl molar ratios.

Most of the variation within the Buchan karst groundwater system can be explained in terms of anthropogenic influences. However, the extent of the influence is surprising, given the low population density, relative remoteness, and low level of human activity.

## REHABILITATION OF DEGRADED KARST ECOSYSTEMS IN SOUTHERN AUSTRALIA

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Rehabilitation of karst landscapes that have been degraded by human activities provides an opportunity to test concepts about karst processes and to demonstrate the scope of positive, constructive ecology in the public arena. In this paper we outline recent experiences in two areas of Australia.

The Nullarbor Plain is the largest arid karst area in Australia (220,000km<sup>2</sup>) and is the subject of a World Heritage proposal. The landscape is divided into extensive closed karstic depressions separated by low rocky ridges, and the dominant vegetation is chenopod shrubland. Wind erosion is most noticeable around stock watering points where grazing and trampling by sheep and rabbits bares the soil. The extent and severity of soil degradation has been assessed using MSS and TM imagery. GPS rectified images at five year intervals from 1972 to 1991 have been compared for two sites on the Nullarbor. Over the 19 years, the total extent of bare soil has reduced significantly, but some areas around water points have degraded. Exceptional years, in which rain falls in the northern plain, allow grazing of ephemeral growth and the development of bare soil patches. There is also a shifting mosaic of disturbance due to fossorial wombats and rabbits, which regenerates rapidly and may promote plant biodiversity. Rehabilitation of bare eroded soil at Koonalda Cave has been accomplished by fencing, hand planting, and soil structural improvement.

The Lune River Quarry overlies Exit Cave in the Southern Tasmania World Heritage Area. Rehabilitation of the quarry has been undertaken as a joint State - Federal government operation to protect the values of the cave (extensive speleothems, glow-worms, endemic cave fauna). The basic concept has been to recreate a polygonal karst landscape similar to that found on wilderness karst in the same area. The construction of small drainage basins on the quarry benches, topsoiling, hydromulching, and revegetation have been subject to detailed monitoring both above and below ground. We review progress after one year of the rehabilitation plan.

## VEGETATION CHANGE, EROSION RISK, AND LAND MANAGEMENT ON THE NULLARBOR PLAIN, AUSTRALIA

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Arid karst landscapes that have been degraded by human activities provide a challenge for rehabilitation and an opportunity to test ideas about the stability and resilience of limestone ecosystems. The Nullarbor Plain is the largest arid karst area in Australia (220 000km<sup>2</sup>) and is divided into extensive closed karstic depressions separated by low rocky

ridges, while the dominant vegetation is chenopod shrubland. Since European settlement there has been considerable change in the vegetation, with significant reduction in shrub and grass cover over large areas of the plain. The nature of this change has been estimated from historic photographs and satellite imagery. These changes are related to a state and transition model of vegetation dynamics which incorporates climatic variability, fire history, and grazing pressure from sheep, kangaroos, and rabbits. Using a GIS approach, soil erosion risk consequent on this vegetation change has been estimated using Bayesian theory. In addition, a partial sediment budget using <sup>137</sup>Cs inventories reveals local and regional patterns of soil redistribution within this arid karst landscape.

Rehabilitation of eroded soil in pastoral lands has been accomplished at several sites but is labour intensive and vulnerable to climate fluctuations. Given the low stock numbers, limited number of people involved, and poor economic returns, it would be sensible to make pastoral activities on the Nullarbor secondary to conservation priorities. This would necessitate a change in land ethic to stewardship, with emphasis on rehabilitation and control of feral animals. Management of increased numbers of visitors to the caves and the karst also requires that resource inventories and management plans for each area be drawn up and used.

## CAVE CONSERVATION PLANS: THE ROLE OF ENGLISH NATURE

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English Nature are the Government's statutory advisor on nature conservation in England, and are charged *inter alia* with the responsibility for designating and safeguarding Sites of Special Scientific Interest (SSSI). There are 48 cave SSSI in England.

Cave conservation must take account of two fundamentally different aspects of caves: caves as dynamic evolving landforms in which natural processes can be studied, and caves as repositories of more static features such as speleothems and clastic sediments, which allow reconstructions of paleoclimatic and landscape development throughout the Quaternary.

Caves face two principal threats: **internal threats** resulting from their use as a recreational and scientific resource, and **external threats** posed by land-use activities within their catchments. Of these, English Nature is best equipped to deal with external threats, since these are generally governed by the statutory planning process. Recreational cavers and cave scientists are the prime users of the underground environment, and as such should take a higher degree of responsibility for cave conservation.

English Nature and the National Caving Association (NCA) are promoting the concept of cave conservation plans as a method of involving cavers and landowners in practical cave conservation. These cave conservation plans involve documenting the scientific resource, considering the likely threats to the cave, producing realistic conservation measures, and continued underground monitoring of their effectiveness. The involvement of caving clubs, individual cavers, cave scientists, and landowners, is vital if such schemes are to succeed.

A number of trial cave conservation plans are currently being developed and these will be used as examples.

## **THE CONSERVATION OF LIMESTONE PAVEMENT IN ENGLAND**

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Limestone pavement forms a rare and distinctive landform resource in upland England. The limited extent of limestone pavement in Great Britain (c. 2,000ha) means that it is under continual threat from removal for building material, rockeries and ornamental gardens. Protection is given to areas of limestone pavement under the Wildlife and Countryside Act 1981. This allows local authorities to serve Limestone Pavement Orders forbidding the removal of pavement in protected areas. The development of the legislation concerning limestone pavement is discussed, and future conservation measures, including the implication of the new EEC Habitats Directive, increasing public awareness, and monitoring of sites, is outlined.

## **THE GEOMORPHOLOGY OF GREAT ASBY SCAR NATURE RESERVE, CUMBRIA, U.K.**

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Great Asby Scar Nature Reserve lies in the central part of an extensive outcrop of Lower Carboniferous limestone of Asbian age, lying west of Kirkby Stephen in Cumbria. The Reserve contains varied intact limestone pavements and other, more broken, limestone surfaces, separated by open grass-covered areas which are sheep grazed.

The limestones crop out on an escarpment which dips gently northwards towards the Eden Valley, which was deformed by Tertiary folding. This has produced a line of low hills aligned from west to east with a maximum height of 412m, at the south end of the Nature Reserve. The escarpment was glaciated, with evidence of ice moving northwards from an ice centre over the Howgill Fells just to the south of the escarpment. The central line of the Nature Reserve runs approximately north-south along the alignment of a gently synclinal structure. Other gentle folds affect the limestone surface to the west and east of this feature, producing considerable variety in the surface slope of the pavement. This has allowed several different limestone beds to form pavements, and caused numerous small scarp cliffs along the edges of the limestone beds.

Extensive varied pavement surfaces outcrop over the whole of the escarpment, from Blasterfields Farm and Orton Scar in the west, to near Little Asby in the east, a distance of nearly eight kilometres. The Nature Reserve includes the most varied and best-preserved limestone pavements, with the greatest variety of solution features on their surfaces. Variations in slope, aspect, jointing, bedding, and length of exposure to either sub-soil or sub-aerial solution and other erosion processes, are responsible for the enormous range of minor surface landforms in this small area. The morphological variety is described and an attempt made to account for it in detail.

There is a long history of settlement of the Orton-Asby area, Castle Folds within the Reserve being an early settlement site. This human occupation may have had effects both direct and indirect on the geomorphology of the area, but it is known with certainty that modern human activities have had an extensive and direct impact on the exposed limestone surfaces. The Nature Reserve was set up in 1976 to protect at least some of the fascinating pavement landforms, and since 1981, Limestone Pavement Orders have been made to protect other areas of the escarpment from removal of the limestone for horticultural purposes.

To the west of the Reserve, Gaythorne Plain has been left as a site from which surface limestone can still be removed, as the activities of the previous three or four decades have removed so much solution-sculptured surface limestone that it is not worth protecting as limestone pavement. This damage, and the protection process are both described and discussed.

## **FORMATION OF SULPHATE-CALCIC WATERS IN KUNGAR CAVE MASSIF**

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Caves are useful environments for investigating hydrochemical processes which take place in the Earth's crust. Since 1992, Perm University together with Kungar Station of the Ural Branch of RAS have been undertaking a complex investigation of the Kungar ice cave according to the program 'Universities of Russia'. The 5.6km long cave was formed in gypsum and anhydrite, interbedded with thin limestone and dolomite of Lower Permian Kungar stage. It is one of the most visited tourist caves in Russia.

The chemical composition of water in the cave massif is mainly a result of gypsum and anhydrite dissolution. The degree of water metamorphisation is indicated by its "sulphateness", that is by the ratio of sulphate ion content to hydrocarbonate ion content. Weakly mineralised waters recharging the cave massif have low sulphateness ratios: 0.5-1.6 snow, 0.5 river water. The sulphateness of atmospheric ice crystals in the cave is 0.6-0.7. In spite of similar sulphate-calcite composition and high mineralisation (1-2 g/l), water and ice in the cave have different sulphateness ratios: 10-21 percolation water, 11-16 karstwater, 3-9 underground lakes and streams, 26-38 old ice, 9-10 young ice. Percolation waters, and karst water formed in rock fractures (i.e. in a closed system) show higher sulphateness ratios compared to open reservoirs. In the latter case, water interacts with bottomset beds. Old ice is notable for the highest sulphateness ratios, caused by "freezing out" of calcium carbonate. Sulphateness is a genetic feature that indicates the sources and centres of karst water recharge, and conditions of their formation. The influence of anthropogenic factors causes the increased mineralisation of atmospheric precipitation input to the cave area, the appearance of nitrites and nitrates in karst water, and changes in cave microclimate and the degree of glaciation.

## CHERNOBYL RADIOCAESIUM IN A KARST SYSTEM, MARBLE CAVE, CRIMEA

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The surface density of radioactive caesium introduced into the environment after an accident at the Chernobyl nuclear plant proved to be high enough in the Crimean Mountains to allow using radiocaesium (Cs) as an indicator of penetration of radioactive contamination into the karst system. The distribution of Cs radionuclides has been studied in soils above Marble Cave, Tchatyrdag massif, in percolation (dripping) waters, and in modern sediments related to percolation waters within the cave. The density of contamination of the massif surface is about 30Kbq/m<sup>2</sup>, approximately 13 times higher than the density of global falls. Besides <sup>137</sup>Cs, almost all samples showed the presence of <sup>134</sup>Cs, with a <sup>137</sup>Cs/<sup>134</sup>Cs ratio corresponding to that of the Chernobyl event.

In modern percolation waters in the cave, concentrations of <sup>137</sup>Cs range from 9 to 15mBq/l. In sediments related to the percolation waters, <sup>134</sup>Cs is detected along with <sup>137</sup>Cs, although the effect of <sup>228</sup>Ac is not ruled out.

Surprisingly, the highest Cs concentrations were measured in old sediments of the lower series which are unrelated to modern percolation, particularly in clay-moonmilk sequences deposited in an old, dried cave lake. Moonmilk layers showed higher Cs contents than clay. It is assumed that Chernobyl Cs had been transported into the cave with aerosols, which had then been deposited mainly in areas where condensation processes occur. The sampling site is located just in the boundary between two microclimatic zones. Active condensation processes occur in this area. In a similar sampling site located within homogeneous microclimatic conditions caesium was not detected at all.

If the above interpretation is true, these results show geochemical importance of aerosol-condensation mechanism of mass transport and localisation.

## VERTICAL TRANSMISSION OF <sup>137</sup>Cs-LABELLED SEDIMENTS TO CAVES THROUGH A SOIL COVER ON CAVERNOUS LIMESTONE: THE ROLE OF SOIL MACROPORES

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Much of the Carboniferous Limestone outcrop of the Peak District is overlain by soils developed on periglacial loess, probably deposited around 20 000 BP. The soils are intensely leached and well-structured, with unusual, broadly tubular, extensions of A and Ap horizons into Eb and Bt horizons and in some cases into the C horizon (bedrock palaeokarst). The nature and origins of these extensions, or soil *macropores*, is discussed, and research on their modern hydrological function: transporting nutrients and clastic sediments to the underlying bedrock and caves is described.

Gamma spectroscopic analysis of radioactive caesium (<sup>137</sup>Cs) concentrations in soil structures and cave sediments was used

to investigate the significance of:

1. Mechanical erosion by autogenic recharge in the soil and subcutaneous zone of a karst geocosystem.
2. The transport of the resulting sediments to an underlying cave in vadose flows.

The presence of <sup>137</sup>Cs in soil macropores, and in clastic sediments washed into the cave by autogenic recharge, indicates that clastic sediments are rapidly transported via macropores and the subcutaneous zone from the soil surface. Vertical migration velocities were c. 0.5m/a, two orders of magnitude greater than previously reported. However, on present evidence, mechanical erosion rates are insignificant in comparison with solutional erosion rates at this site.

Soil macropores play an important role in the fluvial drainage and transport network, and should thus be considered as extensions of karst drainage systems into the soil zone. Unfortunately, the buffering ability of this soil is limited, as macropores function as discrete point sources, transmitting diffuse source pollutants to bedrock, thereby bypassing much of the soil reactor. The implications of soil heterogeneity for groundwater quality and for agricultural practices on covered karsts are discussed, and soil management strategies are considered.

## KARST AQUIFER MANAGEMENT: THE PROBLEMS OF PREDICTING IMPACTS OF SUB-WATER TABLE QUARRYING

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Over the past ten to fifteen years the increasing output of limestone has been paralleled by a decrease in the number of quarries producing stone. The economies of scale, and difficulties in obtaining planning permission, have resulted in fewer, but larger quarries. With limits on the lateral extension of such workings, quarries have tended to move downwards, extracting stone from below the water table, with the resulting requirement for dewatering and design of water management strategies. Due to the nature of karstified limestone, the flow regime can be highly complex, and there is often a requirement for extensive hydrogeological investigations to determine whether it is feasible to predict potential impacts, and to design water management systems. In some instances, such predictions are not possible. Although this paper does not present any radical or innovative methodology for determining the impact of sub-water table working, a conceptual model is proposed which defines the types of problem which need to be assessed, depending upon the nature of the aquifer and the degree of karstification it has undergone. The model is illustrated by discussing the approach adopted in several case studies.

## **PROTECTING SIGNIFICANT FEDERAL CAVES IN THE UNITED STATES**

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Until recent years, caves on federal lands were somewhat protected by various "umbrella" laws such as the Wilderness Act of 1964, the National Park Service Act of 1916, and others. The Federal Cave Resources Protection Act (FCRPA) was signed into law in November 1988. The FCRPA has not been in full force since the signing because additional background work was required after the passing of the Act. First, the two government land management agencies involved (the Department of Interior and the Department of Agriculture) and their subunits were required to produce regulations that permit implementation of the Act in an orderly manner. Until recently, this has not been done. As of May 1994, only the Department of Interior has released its regulations. The Department of Agriculture, which manages many more caves, has yet to produce any regulations. Second, a national list of which caves are "significant" must be compiled.

Lechuguilla Cave was discovered in 1986 within the boundaries of Carlsbad Caverns National Park, and as of this time there is no connection between the two caves. The discovery of Lechuguilla Cave, and the full appreciation of its extent (112km) and uniqueness has federal agencies working to preserve its resources. This internationally significant cave is legally protected under a multiple layering of federal acts and regulations as follows: It is in a National Park and is therefore protected by the National Park Service Act of 1916. It is in a wilderness area and thus protected by the Wilderness Act of 1964. Another layer of protection is the FCRPA. Most recently, the Lechuguilla Cave Protection Act (LCPA) was signed by the President in December 1993. In addition to the above laws, the Bureau of Land Management (BLM) (a subunit of the Department of Agriculture, with lands adjacent to Carlsbad Caverns National Park) has enacted an Environmental Impact Statement (EIS) that will help to protect cave passages that may extend out of the park boundaries onto BLM land. However, the BLM statement will only protect the cave from oil and gas exploration and exploitation. The LCPA is more encompassing in its impact.

The paradox lies in the fact that with all of this multiple layering of legal protection Lechuguilla Cave is still at risk from mineral exploitation. The cave may well extend beyond the set aside protection zone that the LCPA and the EIS mandate.

## **PALEOCLIMATE AND KARST FORMATION IN THE ARID PART OF ISRAEL**

A.S. Issar, The J. Blaustein Institute for Desert Research, Ben Gurion University of the Negev, Israel.

The young topography of the central part of the Negev, (the arid southern half of Israel) caused by the capturing of the paleo Mediterranean drainage system towards the Dead Sea rift valley, includes a section of the karstic phenomenon the Numulitic limestone (Middle Eocene age) and the underlying

chalks (Lower Eocene). In the two sections the solution channels developed along the regional joint system. Due to the older age of the karst phenomena in the limestone, presumably starting during the Neogene, its pattern is obliterated. However, due to the fact that the entire section from the limestones to the shales underlying the chalks is exposed, the continuation of the solution channels from the limestones to the chalks is revealed.

Paleo-spring travertine deposits, and terraces containing artefacts hanging above the river bed, enable the reconstruction of the history of the karst and the surface-drainage systems. The main conclusion is that the maximum flows were during glacial periods, which were characterised by higher rates of precipitation.

## **ASCENDING KARST - AN HYPOTHESIS EXPLAINING KARST PHENOMENA ALONG REGIONAL FAULTS IN ARID REGIONS**

A.S. Issar, The J. Blaustein Institute for Desert Research, Ben Gurion University of the Negev, Israel.

Observations and research in various parts of the world has brought the author to suggest that, in many regions, conventional karst processes follow paleokarst solution channels, developed by ascending water rich in CO<sub>2</sub>. In most cases this water is meteoric water which has descended to great depths, and later ascended due either to hydraulic pressure (in the case of regional faults) or to hydrothermal action connected with plutonic or volcanic activity.

The process of ascending karstification is suggested to develop along the following stages:

- Stage 1 Tectonic volcanic or plutonic episode enabling or forcing water to ascend along fractured zones. The water may contain carbon dioxide from volcanic origin or due to contact between hot magmatic and carbonate rocks. Carbon dioxide can also be obtained from oxidation of organic compounds by the dissolved air in the waters as they ascend.
- Stage 2 While approaching the surface the quantity of carbon dioxide reduces due to reduction of pressure. Deposition of calcite and silica as geodes accompanied by the deposition of iron and manganese and other minerals which were in the state of solutes or hydrous compounds takes place.
- Stage 3 Reduction in heat of ascending water either as a result of decrease of hydraulic head due to release of pressure, climate change or geomorphological changes or termination of volcanic activity.
- Stage 4 Action of conventional descending karstification along prior dissolved passages.
- Stage 5 Deposition of speleothems from descending water.

## **REGIONAL MAPPING OF KARST TERRANES IN ORDER TO IDENTIFY POTENTIAL ENVIRONMENTAL PROBLEMS**

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The Oklahoma Geological Survey (OGS) is mapping the distribution of karst features in the State, in order to understand the potential threats to life, health, and property. Wherever highly soluble rocks such as limestone, dolomite, gypsum, or salt, are near the land surface, karst develops in response to dissolution by circulating ground water. The sinkholes and caverns thus formed are potential hazards because of possible settlement or collapse of the land surface, and because ground water contaminants can travel rapidly without significant attenuation of their noxious qualities. Principal areas in Oklahoma where karst features are present in limestone and dolomite are in the Ozark Mountains in the northeast, and the Arbuckle Mountains in the south. Karst terranes are also present in many areas of western Oklahoma where gypsum and shallow salt deposits are common.

The major philosophic decision made for this project is the recognition that all terranes in which carbonate, sulphate, or halide rocks crop out or are in the shallow subsurface are probably some type of karst. One should operate on this assumption, absent evidence to the contrary. Karst should not be defined solely on the basis of a quota of specific landforms observable on aerial photographs or in the field.

Areas where relatively water-soluble rocks crop out, or are in the shallow subsurface, are being identified as part of the OGS program of mapping the surface geology in all counties of the State. In most areas, the mapping is done through a coordinated study by stereoscopic photo interpretation and field examination. This is a long-term program, with separate reports being released as mapping is completed for each county or area, most maps are being published at a scale of 1:62,000 or 1:63,360. In the interim, we will compile available data onto a 1:500,000-scale map to show areas in the State that may be subject to the consequences of karst development.

## **HUMAN IMPACTS ON THE KARST ENVIRONMENT : A CASE STUDY OF THE TINDALL LIMESTONE DALY BASIN, NORTHERN TERRITORY, AUSTRALIA**

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The Tindall Limestone is one of the formations within the Cambrian - Ordovician Daly Basin located in Australia's monsoonal north. The basin forms a broad, shallow intracratonic structural basin covering approximately 40 000km<sup>2</sup>. The margin of the basin is formed to the west by the Late Proterozoic rocks of the Victoria Basin, and to the east by Early Proterozoic metasediments of the Pine Creek Geosyncline. The

southern margin is obscured by younger Cretaceous cover.

The Tindall Limestone sediments were deposited during an early Middle Cambrian marine transgression, and crop out as a discontinuous belt along the edges of the Daly Basin. The formation consists of shallow marine sediments, comprising grey limestone with lenses of sandstone and siltstone. Bands and nodules of chert are common. The limestone forms landforms characteristic of karst topography, with sinkholes (dolines), caves, towers, and streamsinks. Morphometric analysis of the present sinkhole population was performed using 1:10 000 base maps. The depth distribution of sinkholes in this karst region is exponential. Sink holes are usually shallow and bowl-shaped, although older sinkholes are normally flat bottomed and covered with clay and soil. Recently formed sinkholes are deeper with exposed limestone walls.

Anthropogenic impacts on this fragile karst environment are significant. The Tindall limestone is the main aquifer for agricultural, domestic, and town water supply. During the last 40 years, about 800 boreholes were drilled in this aquifer with some supplying up to 50 l/s. Agricultural development during the last 10 years has resulted in an increase in irrigation from high yielding bores.

It is probable that the main anthropogenic impacts on the Tindall karst environment is rapid sinkhole development in the vicinity of Katherine township: along the Stuart Highway, between the highway and the old North Australia Railway, and in the vicinity of gravel roads SW of Cutta Cutta Reserve.

In 1992, 3 sinkholes formed along the Tindall deviation of the Stuart Highway. These are developed in thickly bedded massive grey limestone, and are 6-8m deep and 1-2m wide but are gradually expanding along vertical fissures striking approximately 150°. In 1991, a 25m diameter and 6m deep sinkhole appeared south of Cutta Cutta Reserve. Six sinkholes which developed in the 1970s are located some 3.5km northwest of the Cutta Cutta Reserve turnoff. The largest of them is 13.8m in diameter and 9m deep.

## **K A N N O N S U I - S P R I N G A N D ENDOKARSTIFICATION OF THE HOKEZU MOUNTAINS, WESTERN SHIKOKU, JAPAN**

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The study area, the Hokezu Mountains, is situated in the western part of the Shikoku at the southern margin of the Sambosan Belt, bounded by the Butsuzo tectonic line. Limestone of Triassic age is a most frequent rock of the endokarstification in this area.

Geological, hydrological, and hydrochemical surveys of the surface of the mountains and a tunnelling route were conducted on a small karst area to assess the aquifer system. Previous

hydrological studies accepted that the Kannonsui-Spring was excavated by meteoric water descending through the weathering zone of the limestone aquifer. However, data from hydrological investigations indicates that this spring belongs to the ascending karst springs (vauclosian springs).

The results of geological investigation revealed that the endokarstification in the Hokezu mountains is situated as deep as 300m beneath the surface and is controlled by tectonic faults.

## **KARST MORPHOGENESIS IN THE EPIKARSTIC ZONE**

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The subsurface (subcutaneous, epikarstic) zone forms in the upper layer of rock, and receives its specific properties due to processes of weathering directly affecting this layer. The structural peculiarities, hydrologic importance, and related hydrologic processes have been shown by many authors. However, the morphogenetic effect of these specific hydrologic processes is less understood, and the present paper focuses on explaining karst landform evolution in the epikarstic zone.

The epikarstic zone is highly fissured and diffusely karstified, causing its high and quasi-uniform vertical permeability. Because of the high absorbing ability of the surface, this zone receives diffuse recharge from precipitation.

Beneath the epikarstic zone, the main unsaturated karst rock mass is randomly fractured, and divided by major joints and faults into large blocks. Vertical permeability of the block zone is sharply heterogeneous, and further downward percolation is localised mainly along large joints. The considerable distinction of structure and permeability between the epikarstic and underlying block zone represents an important percolation threshold, and causes a perched aquifer to form in the top of a karst massif. Initially, diffuse water percolation transforms into much more concentrated shaft flow on passing the threshold. In alpine karsts during the winter period, concentrated inputs of condensation water occur in the same level, where ascending air moisture meets the cool epikarstic zone.

These hydrologic features bring about specific morphogenetic evolution of karst forms in the top of a massif. As flow concentration occurs along major joints at the base of the epikarstic zone, solutional enlargement will also be focussed at this certain depth beneath the surface resulting in shaft development without an open entrance.

A model is presented which explains the conjugate development of karren fields, shafts, collapses, and closed depressions in different stages of morphogenetic evolution in the epikarstic zone.

## **THE INFLUENCE OF CLIMATIC CHANGES ON GROUND WATER REGIME AND RESOURCES OF SOME KARSTIC AREAS OF THE RUSSIAN PLATFORM**

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In correspondence with the scenario of predicting change of climate of State Hydrological Institute (GGI), the amount of precipitation to the beginning of the next century could increase to 100-400 mm/year on the European part of Russia. However, evaporation could also increase and there is no doubt that, closely connected with precipitation, the ground water regime and resources will also change. The intensity of karst processes and their influence on the environment will change also. That is why it is important to estimate the probable direction, scale, and character of changeability of the karst water regime and resources for different areas.

Initial forecasts were carried out for the four karst areas of the Russian Platform: The Izhorskoe Plateau (northwest), Ufimskoe Plateau (east), Upper Oka Hills (centre) and the Crimea mountains (south). These areas are characterised by different types of karst, climate, geomorphology, and karst water regime.

Three methods of forecasting are used for these purposes: (1) established regularities in the percentage of precipitation reaching groundwater (coefficient of ground water flow) from the degree of humidity of years; (2) multiple correlation between groundwater recharge relations and amount of precipitation and temperature; and (3) models of water catchment and concentrated parameters. Correlation analysis is used for predicting intra-annual changeability, and to establish the dependence of ionic flow from discharge yields reflecting intensification of karst processes.

The results showed that to the end of the century, only a small ( $\pm 10\%$ ) change in annual ground water flow will occur on most of the Russian platform. more significantly, minimum annual flows will decrease by 15-20% on average in all areas except the centre. In the latter, in contrast, ground water flows will increase by 20%. By the beginning of the next century (2020) ground water recharge will increase to 20-40% above recent multiannual norms in all areas except the east area.

An increasing number of intra-annual extremes and their displacement to early periods of the year is expected. The activation of karst processes in the Crimea, Izhorskoe Plateau, and in the centre of Russia are predicted. A predicted increase in both maximum and minimum spring yield will lead to a corresponding increase in carbonate removal by 20-30% on average.

The investigation carried out allows us to stress attention on the necessity of such forecastings in each karst area. It will help to promote the most rational planning of water resources use, their management, and preservation.

## ANTHROPOGENIC CHANGES TO KARST POLJES MORPHOLOGY IN SLOVENIA

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The economic and technical development pressure of agrarian population on farming land, including the wishes to protect the cultivated land against floods and to cultivate new lands, increased at the end of the 18th Century. Such trends were especially strong on the karst poljes with larger flat soil bottoms and at the same time more often flooded. During the 19th Century more plans to prevent floods, primarily on the Cerknjškio polje were elaborated.

In 1886, the Ministry of Agriculture entrusted to V. Putick the preparation of projects to abolish floods on the karst poljes of Carniola. In 1888, Putick made a project "Generalproject zur unschädlichen Ableitung der Hochwässer aus den Kesselthälern von Panina, Zirknitz und Laas-Altenmarkt in Innerkrain", but it was not adopted. Nevertheless, some proposals had been already realised under his direction, and some of them much later. Most of the visible changes on our karst poljes are connected with Putick's activity. Putick's influence was also asked to make plans and even to realise them on some other karst poljes in Slovenia. In the meantime, other engineers were recruited to make changes to other poljes, especially in the background of Krka river springs. During the 20th Century, plans for the changes of karst poljes included their use as water storages for hydroelectric power stations (Planinsko polje) or as permanent lakes (Cerknjško polje).

## GEOMORPHIC AND STRATIGRAPHIC DEVELOPMENT OF CAVES IN THE KJØPSVIK QUARRIES, NORTH NORWAY

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Sediment sections of the Kjølsvik quarries (*Norcemgrotta*, *Veigrotta*), north Norway, have yielded an interesting interstadial fauna. The master sequence, which is well-dated, fossiliferous, and stratigraphically complete, provides a tool for correlation into deposits in larger caves nearby, and for linking speleogenesis to the surface environment.

The master cave system of the Kjølsvik karst, *Storsteinhola* (800m long), displays the largest paragenetic gallery known in the country. The main corridor forms an inverted canyon, c. 5m wide and c. 10m high, rising towards defunct, sediment-choked paleosprings at 60m asl. At least two subsequent rejuvenation phases can be inferred from passage morphology, with the present streamway and spring level (20 m asl) as the final stage. Typically, the rejuvenation stages are represented by a maze of epiphreatic tubes underneath the paragenetic canyon. The paragenesis was preceded by one or several past sediment fills, followed by local wall collapse after which the cave was almost totally filled with glaciogenic gravel, sand and clay.

The paleospring choke (*Norcemgrotta*), displays three upwards-coarsening cycles, beginning with laminated silt and clay, followed by well-sorted sands, and capped with one or several gravel beds that are coarsest on the top stratum. The

upper gravel bed in each cycle is capped with a lag of coarser, angular blocks that represents subaerial conditions. The second youngest cycle (*The Ursus horizon*) is fossiliferous. Dating ( $^{14}\text{C}$ , AMS and  $^{230}\text{Th}/^{234}\text{U}$ ) suggest an age of minimum 70 ka for the fauna. Our correlation suggests that the fossiliferous *Ursus horizon*, and the overlaying clay unit, can be lithostratigraphically correlated into a sterile, but otherwise equivalent, horizon in the main cave. This horizon can be traced within the post-breakdown sediments that we find all through the cave. Most of the present sediments in *Storsteinhola* were deposited during the Weichselian or earlier. The youngest (of at least 3) depositional cycles represent the last 70ka.

Consequently, the paragenesis, which must have operated against a stable baselevel over longer timespans (c. 10m vertical amplitude of corrasion, through marble with mica schist and amphibolite bands), predates these sedimentary events. Several external conditions may satisfy these criteria: bedrock, ice-contact damming, or periods of high sea level stands. A stable baselevel against allogenic bedrock is not easily conceived within the present lithologic and geomorphic setting of the fjord. This implies a considerable age for the speleogenesis. In terms of integral speleogenetic history, the mechanism of paragenesis implies a virtual cave diameter of c. 20m. The time required for the total speleogenetic history may then be discussed in the same terms as other, relict (phreatic) caves in Norway, although roof retreat rates under paragenetic conditions remain unknown. These questions are subject to further study.

## QUATERNARY DENUDATION ON THE TINDALL KARST PLAIN, N.T. AUSTRALIA

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The Tindall Karst Plain, SW of Katherine, Northern Territory (developed in Cambrian limestones) is remarkably plain, with residual towers, pinnacles and mesas protruding from 3 to 30m above the plain. In contrast to Jennings and Sweeting (1963), who regarded the karst as a youthful feature, Twidale (1984) advocated the view that the plain is an exhumed, sub-Cretaceous paleokarst surface, as revealed by the unconformity to the overlying (lower Cretaceous) Lees sandstone. The 'enigma' of the landform, is that, in spite of a relatively delicate topography of pinnacles, grikes and tower, very little morphological change appear to have taken place during the stripping of the overlying sandstones. We may add more evidence to this discussion from quite young paleokarst fills, karst morphology, and speleothem dating.

At least two stages of paleokarst fills (i.e. "pink breccias") can be recognised as remnants in grike and pinnacle walls. The breccias are often fossiliferous, displaying Quaternary fauna components, (Megirian, work in progress). U-series dating so far indicates ages of 50-70ka BP for the cements, and paleomagnetic measurements are in progress on them. In

numerous places, outcrops of these paleokarst breccias occur almost at the extreme summit of pinnacles, more than 30m above the modern Tindall plain. The present day drainage area to these fills is almost nil. Their alluvial origin (bedding and sorting) would require a sizeable catchment. We may therefore infer that a considerable amount of karst denudation has taken place since the breccias were laid down.

Unroofed cave systems are often exposed on the summit of hills, displaying sections through large stalagmite bosses and fossiliferous sediments. Judging from present day stalagmite growth in the area, such bosses would require at least 3-5m of vadose percolation to form. The dense and crystalline fabric of these relict speleothems also indicates that they were formed by slow degassing in a deep cave environment rather than by rapid evaporation in an entrance environment. We take this as strong evidence that a considerable amount (>3.5m) of karst rocks have been removed since the speleothems were formed.

All outcrops of sandstone we have visited have failed to demonstrate any pristine sedimentary contact between the Cretaceous sandstone and karst surface, they always form more or less chaotic arrangements, under which the limestone surface may sometimes be found to rise above the plain level. On a smaller level, the Tindall plain is etched (corrosion notches) into dislocated sandstone blocks. We also feel that the age and origin of the red, silcreted smears that appear in bedding planes and on grike walls may still be open to debate, and that they do not necessarily represent the base of the Cretaceous sandstones.

Our results contrast with the idea that the Tindall Plain *per se* is a preserved paleokarst surface, and indicate that it may rather be the result of Quaternary stripping of the overlying sandstone beds, and synchronous karstification down to a stable level. The sub-Cretaceous Tindall Plain was probably situated at or above the level of the highest karst pinnacles.

## **FRACTAL DIMENSIONS OF KARST GEOMORPHOLOGY AND DOUBLE-LAYER STRUCTURE OF FENGCONG LANDFORMS**

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Two opposite academic points of view about whether the evolution sequence for karst geomorphology in the south of China under the tropical and subtropical climate are reviewed. The quantitative and qualitative study of the evolution processes of karst geometries have shown that in most areas there is a consequence of karst landform from Fengcong to Fenglin, and also that the Fenglin may convert to the Fengcong landscape under the condition of karst rejuvenation.

The compass method to study the fractals of karst topography has obtained the good results that the karst geomorphology is with the property of fractals and the fractal dimensions. But the karst landforms are characterised by the self-affine as the geometry is the function of the vertical variation or say the geometry is dependent on the scales. So the fractal dimension  $D = E + 1/s$  for the compass method, where  $E$  = the Euclidian dimension and  $s$  = the slope of the  $\log A - \log R$ . The typical landform study gives  $D = 2.50$  for the Fenglin landscape and  $D = 2.35$  for the closed depressions. The Fengcong landscape is constituted of double layers, the upper part made of conical

peaks with fractal dimension  $D = 2.50$ , and a lower part with closed depressions with the dimension  $D = 2.35$ .

## **THE HYDROLOGY OF THE SOUTHERN CAPE KARST BELT, SOUTH AFRICA**

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The Cenozoic calcarenites of the South African southern Cape coastal belt host a complex surface of karst. Few studies of the hydrology of the karst belt are available, although various unpublished reports on water supplies have been produced. This paper reports recent research on a part of the southern Cape karst belt between  $21^{\circ}00'E$  and  $21^{\circ}50'E$ .

The karst comprises four distinct east-west belts, compartmentalised by south flowing allogenic rivers incised into the underlying Cape System impermeable basement rocks. Well developed karst is associated only with a 90m-150m plateau, and a case-hardened plateau at 200m-250m altitude developed on Pliocene Wankoe Formation calcarenites. Elsewhere, karst development is poor.

The Wankoe Formation contains the main aquifer. Borehole yields range from under 2 000l/h to 90 000l/h. High yields are strongly localised, and springs provide an important water resource. The strongest springs feed direct to the coast, or at low altitude into dry valley systems tributary to allogenic rivers.

A map of the limestone/basement topography was constructed which shows a relatively smooth gradient to the coast, incipient incision underlying the allogenic rivers and steepening inland associated with a marine transgressive notch. The topography of the piezometric surface, diverged considerably from that of the limestone/basement surface. Higher piezometric surface levels occur inland of the coastal Cape System sandstone outcrops which were less easily planed by marine transgressions than the Bokkeveld shales. They serve to pond the groundwater. Both high yielding springs and higher production boreholes are strongly localised. High yielding areas can be correlated with steeper gradients in the piezometric surface and also to ponding inland of the buried sandstone outcrops.

## **MORPHOLOGY OF SHAFTS ON THE TRNOVSKI GOZD PLATEAU IN WEST SLOVENIA**

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On the high karst plateau of Trnovski Gozd, all precipitation penetrates immediately into karst. Potholes and shafts are the dominant element in the morphology of caves. From a morphological and genetical point of view at least four types of shafts can be distinguished, most of them showing strong influence of tectonic settings. They can be connected in different ways, and can also form other features such as large chambers and collapse dolines on the surface.

## THE AÏT ABDI PLATEAU (CENTRAL HIGH ATLAS MOUNTAINS, MOROCCO): A HIGH PERCHED KARST MODEL IN SEMI-ARID ZONE

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The Ait Abdi karstic plateau is located in the heart of the calcareous High Atlas (32°N/6°W). It is situated between 2200 and 3000m a.s.l. with an area of 160km<sup>2</sup>, and consists of a series of massive Bajocian limestones which form a large syncline slowly dipping to the northeast. The limestones overlie a thick series of Toarcian-Aalenian detritic sediments forming the regional aquiclude. The plateau is limited both in the north and south by a strong change in dip towards the vertical of sedimentary layers (ejective thrust anticlines), and in the west and east by deep canyons created by major rivers. Therefore, the plateau is a totally isolated calcareous compartment, from both a morphologic and a hydrogeologic point of view.

The climate of this region is Mediterranean with an altitude influence: maximum rainfall in winter and in spring, snow cover not durable but sometimes important, and dry season with storms in summer. The rainfall comprises only 500 to 700 mm/a and evapo-transpiration is approximately 400 mm/a. Thus recharge of the aquifer is limited, although the large bare surfaces of the plateau with typical well developed karst forms (dolines, poljes, dry valleys, potholes) improve the infiltration rate.

An old cave network with vertical shafts occluded at depth is proof of ancient, more humid climatic conditions. U-Th dating methods indicate ages between 3200 and 220 000 BP, or outside the range of the method (more than 400 000 BP). The horizontal transfer is made by an interstratal network, ancient and dry in the upper part, or recent and phreatic at the base near the regional aquiclude. The water surfaces at hillfoot springs (i.e. the output from this closed system). Large doleritic vertical dykes cut the plateau and form major drainage lines. We have calculated an approximate water balance for this plateau and make some hypotheses about the functioning of this perched and isolated karstic system.

The hydrogeological behaviour has important morphological Pleistocene consequences and gives this karst a reference value. The characteristics of this karst may be of value in the study of other high mountain karst regions in semi-arid or arid climates.

## PROBLEMS OF GROUNDWATER MONITORING IN CARBONATE AQUIFERS

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Problems of groundwater monitoring in all unconfined carbonate aquifers can be grouped into the following four categories:

1. Where to monitor for pollutants: At springs, cave streams, and wells shown by tracing to drain from a facility to be monitored, rather than at non-traced wells selected because of convenient location supposedly down-gradient from it. Wells on cave streams and fracture traces, and randomly-located wells, can be successfully used for monitoring, but only if tracer-test results show a positive connection from the facility to them. Commonly, this can most easily be done several kilometres from a facility, but mapping of the natural potential can be used reliably to find cave streams nearby or beneath the facility itself. Indeed, no other geophysical technique is likely to be successful in finding smaller-diameter conduits at depths ranging from 10 to over 50m.

2. Where to monitor for background: At springs, caves streams, and wells in which the waters are geochemically and hydrologically similar to those to be monitored for pollutants, but shown by tracing or other demonstrable hydrologic relations *not* to drain from the facility during both-base flow and flood-flow conditions, rather than at wells selected because of convenient location supposedly up-gradient from it. This, too, may have to be done several kilometres from a facility, but natural potential can be employed on the facility to site such wells.

3. When to monitor for pollutants and background: Before, during and after some storms or meltwater events, rather than monthly, quarterly, semi-annually, or annually, and often enough to reliably characterise the variation in water quality parameters and prevent *aliasing*, a phenomenon whereby insufficient sampling frequency results in inadvertent misrepresentation and consequent misinterpretation of the range and distribution of values of actual parameters.

4. How to reliably and economically determine the answers to problems 1, 2, and 3:

Reliable monitoring of groundwater in karst terranes can be done, but it is not easy. It is, however, demonstrably dependable and less expensive in the long run than using the conventional practice of siting wells randomly (where convenient) or on fracture traces.

These four problems exist because all numerical models and monitoring systems used for unconfined carbonate aquifers, and employing only wells and springs unevaluated by the results of tracer tests, implicitly or explicitly assume that the aquifer behaves like an equivalent porous medium (EPM). All unconfined carbonate aquifers are dual- or triple-porosity aquifers; none has been shown to behave at the site-specific scale as an EPM. Proper design of a tracer test does not make the insidious, erroneous assumption of an EPM. Documented tracer-test recoveries from around the world support a carbonate aquifer model always having dual or triple porosity with both rapid-flow (non-Darcian) and slow-flow components.

Groundwater tracing (perhaps complemented by mapping of the potentiometric surface, where practical) used to resolve the

first problem is the only valid technique (other than hydrogeologic mapping) for reliably delineating the boundary of wellhead and springhead protection areas in any carbonate terrane, and for reliably predicting groundwater velocities and likely contaminant flux within it. Reliable monitoring of carbonate aquifers can be accomplished without tracer tests, but the probability of success is miniscule, like winning first prize in a lottery. Deliberately attempting to do either by chance is as prudent as investing pension funds in lottery tickets.

## **GEOMORPHOLOGICAL EVOLUTION AND HYDRODYNAMIC PARTICULARITIES OF THE TROPICAL KARSTIC PLAINS OF CUBA IN THE EXAMPLE OF ZAPATA BASIN**

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About 65% of the Cuban territory (71,500km<sup>2</sup>) is covered by intensive karstified limestones from Jurassic to Quaternary age. The most extended karst features in the country are the tropical karstic plains (70%), developed on thick carbonate and carbonate-terrigenous Paleocene-Pliocene transgressive sequences, frequently monoclinals with a gentle dip of strata towards the sea, and a generally low degree of tectonic alteration. Over these sequences there has developed a very evolved Pliocene-Quaternary karst with very large capacity and transmissive aquifer systems, generally unconfined flow, and open sea discharge.

These tropical karstic plain features have some particularities as follows:

1. Complex geomorphological and hydrodynamical evolution in close relation to the Pliocene-Quaternary glacioeustatic sea level oscillation and in a lesser degree with the neo tectonic movements, which gives place to complex polycyclic functional changes in the karstic aquifers from open to close systems and *vice versa* in function of the periodical fluctuations of the base level in a range of 200m. At present, the highly hierarchical endokarstic structures are inundated by the sea level rise are not functional at the lower part of the aquifers.

2. High transmissivity because of the high primary porosity of the rocks increasing by the fracturation and intensive karstification, specially the latter in function of the fresh-sea water mixing effect. Consequently, in these karstic aquifers the salt water intrusion usually penetrate long distances inland.

3. Despite the apparent homogeneity, low hydraulic gradient, and non functionality of these karstic aquifers, the circulation remains flowing through preferential conduits. This is evident in the discharge of many freshwater submarine springs detected in coastal areas.

Karst features with similar geomorphological and hydrodynamical characteristics and evolution can be found in all the Caribbean basin and the Gulf of Mexico peripheral coastal region which have had the same geological history and evolution from the Paleocene to the recent.

The distinctive water circulation particularities of the Zapata aquifers system in relation to such plain karst open sea aquifers and their hydrodynamical behaviour, depend on the presence of the structural depression in the southern part of the basin filled up by very karstified carbonate Pliocene-Pleistocene deposits

over which, the large karstic wetland of the Zapata Swamp (4,520km<sup>2</sup>) was developed.

From a hydrodynamic point of view it is obviously an holokarst basin with 150-200m of estimated karstification thickness, in which several aquifer levels and not less than three superposed drainage systems are found, defined by textural differences in the limestones and frequently interconnected by hydrogeological windows.

Karstic processes of accelerated corrosion by mixed waters, saline effect, and biochemical factors occur, as well as uncontrolled aquifer exploitation, waste water inputs, intensive agricultural use, and other anthropogenic impacts, all of which increase the natural sea water intrusion process and aquifer contamination.

## **THE SOILS ON THE CALCAREOUS SAND DUNES IN SOUTHEAST OF SOUTH AUSTRALIA**

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The sand dunes from Robe to Naracoot (about 100km) in South Australia were dated by Schwebel (1983), using <sup>14</sup>C dating, Uranium series, <sup>18</sup>O and paleomagnetism. In this area, younger sand dunes are composed of fresh sand, but older sand dunes are composed of calcarenite sand. The soil properties of the sand dunes were considered by the age the dunes. The properties of sand particles in soils are as follows:

1. On a sand dune of 4,300 BP, A/C soil profile develops (Rendzina). Soil profiles of A1/AB/B/C are found on a sand dune of 83,000 BP, and well developed A1/A3/B1/B2/C (Terra rossa) soils occur on sand dunes older than 125 000 BP (Blackburn, 1983), and on the plateau of Tertiary limestone.

2. In sand particles of AC horizon on a dune of 4300 B.P., the calcite grains content is c. 64%, and quartz content c. 35%. In B horizons of dunes from 83 000 BP to 347 000 BP, calcite grains were only 1 to 2% but quartz grains were c. 92%. In B2 horizons of a dune of 690 000 BP, and on the Tertiary plateau, calcite was non existent, and quartz about 96%.

3. The average size of quartz is smaller in the soils on the sand dune from 4300 BP to 347 000 BP. But the average size of quartz in the sand dune of 690 000 BP was large, and they were well rounded. On the Tertiary limestone plateau, the average quartz size was small and they were well rounded.

From these tendencies, it is possible to estimate the time scale of weathering of calcite and quartz in soils. Almost all of the calcite grains are subject to dissolution in a short period, but the grains of quartz remain for a longer period. Especially the residual big size quartz remains for a longer period in the soils.

## **EBB AND FLOW BEHAVIOUR OF A KARST SPRING, KINGS CANYON NATIONAL PARK, CALIFORNIA**

L. D. Urzendowski and J. W. Hess, Water Resources Center, University of Nevada, Las Vegas, U.S.A.

Big Spring, the resurgence of the karst aquifer in the Lilburn Cave-Big Spring system (Kings Canyon National Park, California), displays the uncommon phenomenon of ebb and

flow discharge during periods of high runoff. Hydrograph and spectral analyses of stage and discharge time-series data, sediment size analyses, and a bench scale model were combined to elucidate the internal hydrology of this karst aquifer system.

Digital stage data have been recorded almost continuously at two critical hydraulic junctures: the Z-Room (the upstream storage chamber with a 3 year database), and Big Spring (the resurgence of the karst system with a 6 year database). The Z-Room is located within Lilburn Cave approximately 700m north and 10m above Big Spring. Time-series observations of the Z-Room and Big Spring stage levels revealed two distinct flow patterns during the high runoff season (February through June). The first is an ebb and flow, 180° out-of-phase response in which a drop in Z-Room stage results in an instantaneous rise at Big Spring. The second type of flow recognised is a high, sustained flow suggesting an in-phase relationship between the Z-Room and Big Spring stages. The triggering mechanism between these modes of flow is poorly understood, but our initial results suggest that the transition may be chaotic.

Hydrograph analyses indicate that the section of Lilburn Cave between the Z-Room and Big Spring is primarily a conduit flow aquifer, discharging approximately two-thirds of its flow through large diameter conduits, one-quarter in smaller conduits and open fissures, with the remainder through small fissures and fractures.

Power spectra performed on multiple data sets strongly indicate a nonlinear system, with evidence of small-scale quasilinear behaviour. Both types of flow at the Z-Room (input) behave stochastically, possibly the result of flow path blockage from a variable sediment load present within the system. Transfer and kernel function analyses confirm the presence of nonlinear and quasilinear flow regimes, and further indicate that no additional significant inputs or outputs to the system exist.

A bench scale model built to simulate the ebb and flow cycles observed in the Lilburn Cave-Big Spring system was developed, and the results were compared to the currently accepted theories of 1) a natural siphon within the rock matrix, 2) a reciprocating spring, 3) blockage by a sediment plug. Our model, in conjunction with analytical results and observations of diverse Cave Research Foundation scientists, is a large single conduit with a sediment plug in its lowest sump behaving stochastically to cause the ebb and flow behaviour during periods of high runoff.

## THE SENSITIVITY OF TUFAS TO HUMAN INTERFERENCE

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Tufa deposits are a key component of many limestone landscapes, and form in a range of freshwater environments. Work carried out in England, Wales, and Germany, reveals that tufa deposition has declined dramatically over the Holocene, and also that often the tufas become dirtier. Human interference, coupled with acknowledged climate changes, have undoubtedly produced these changes. This paper explores the stresses on tufa deposition posed by human activity,

investigates how tufas respond to such stress, and assesses the possibilities for conservation of tufa deposits.

## ROCKSHELTER FINE SEDIMENT SOURCES AND DEPOSITIONAL PROCESSES IN THE PINDUS KARST OF NORTHWEST GREECE

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Two rockshelters which are developed in the Paleocene to Eocene limestone of the Pindus Mountains karst have been investigated. The Klithi and Megalakkos rockshelters (c. 500m above sea level) are located approximately 500m apart within the Lower Vikos Gorge of the Voidomatis River basin in the Epirus region of northwest Greece. This is a key region of Paleolithic research and the study area contains a wealth of sedimentary evidence for Pleistocene environmental change. Each rockshelter site contains several metres of Late Pleistocene sediments. Klithi is located 30m above the contemporary stream bed of the main Voidomatis River and Megalakkos is located within a right-bank tributary ravine approximately 10m above the tributary stream bed. At both sides the bedrock geology is composed of resistant limestone host rocks overlain by erodible flysch sediments of Late Eocene to Miocene age. Marked contrasts in sedimentation style are apparent between the two rockshelter sites. Late Pleistocene fine (<63µm) sediment sources and depositional environments have been studied in detail at each site. A range of techniques including micromorphology, X-ray diffraction, mineral magnetics, and detailed particle size analysis have been employed to elucidate the dominant fine sediment sources. This work indicates that the rockshelter fine sediments at both sites are mainly derived from *allogenic* sources and that the relative importance of flysch- and limestone-derived materials varies markedly between the two sites. Fluvial and aeolian processes are particularly important at Klithi, whereas vertical inwashing (infiltration) of fine sediment through the internal karst drainage system is the dominant process at Megalakkos. The geomorphological and hydrogeological settings of the rockshelters are particularly important controls on sedimentation style and fine sediment provenance.

## FLOW VELOCITIES IN UNCONFINED PALEOZOIC CARBONATE AQUIFERS

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Paleozoic carbonates are characterised by low porosity, so that flow is concentrated along fractures, some of which may be solutionally enlarged. There are two sharply contrasting ways in which flow in these aquifers has been studied. Many site studies have drilled wells, conducted pump, slug, or packer tests, and assumed that Darcy's Law can be used to calculate groundwater flow velocities. An alternative method is to locate sinking streams or caves, and to conduct tracer tests to springs. Few studies have combined the two techniques, or conducted

well to well tracer tests.

Probability-hydraulic conductivity plots show that most unconfined Paleozoic aquifers test predominantly in the range  $10^{-7}$  to  $10^{-5}$  m/s. Some of these aquifers have well developed surface karst features and known caves, but many do not. Well to well tracer velocities are almost always more rapid than Darcy's Law would indicate, and increase asymptotically as a function of traced distance to a mean long distance ( $>300\text{m}$ ) velocity of 0.2 m/s. On the other hand, a compilation of  $>2000$  conduit traces (e.g. sink to spring) shows that velocity does not vary as a function of distance over the range 10m to 50km.

These data show that well tests and conduit tracer tests give complementary information on flow in carbonate aquifers. The well tests indicate the piezometric surface, and show that most of the water in the aquifer moves slowly on the local scale. This slow-flowing water eventually feeds into conduits, after which it moves rapidly into springs. Conduit tracer tests indicate the direction and velocity of the rapid flow.

Tritium data from several countries show that the "average" residence time in Paleozoic carbonate aquifers is several years. Most recharge is by percolation water, much of which moves slowly downward through the soil zone, and then through narrow fractures and the rock matrix. The water may spend several years just to traverse the first few tens of metres. However, once this percolation water reaches a conduit, it can then traverse the remaining kilometres to a spring in just hours to days.

Aquifers with flow through the matrix and through tectonic fractures are often called double porosity aquifers. The solutional enlargement of a few of the tectonic fractures creates a third component of porosity (and permeability), thus carbonate aquifers may be considered as triple porosity aquifers. This triple porosity is fundamental to an understanding of water (and contaminant) movement.

## **DISTINCTION OF KARST GROUNDWATER FLOW SYSTEMS OF DIFFERENT ORIGIN BY MEANS OF ENVIRONMENTAL ISOTOPE AND HYDROCHEMICAL DATA: DALAMAN BASIN (WESTERN TAURIDS - TURKEY)**

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The Dalaman Basin of SW Turkey comprises autogenic and allogenic karstic carbonate aquifers of Miocene and Mesozoic age, respectively. The basin extending along the Mediterranean Sea towards highlands has numerous karstic springs with different hydrochemical characteristics. Fresh-water springs and brackish thermal springs emerging from the same aquifer are encountered in different parts of the basin. Distinction among the different karst groundwater flow systems existing in the basin has been accomplished by the examination of hydrochemical and environmental isotope data from 18 karstic springs.

The results of both environmental isotope and hydrochemical data revealed that the regional karst groundwater system is rather complex and comprises of three subsystems which can

be described as (1) an upper karst groundwater system, (2) a middle flow system exhibiting slight mixing with sea water, and (3) a lower karst flow system discharging waters composed of sea water and thermal groundwater.

## **KARSTIFICATION AND KARST AQUIFERS IN MOUNT KRÄUTERIN OF THE NORTHEAST ALPS, AUSTRIA**

D. Zhang, Institut für Geographie der Universität Wien.

Mount Kräuterin, lying in the northeast Alps, has experienced karstification and glaciation in rotation since it was uplifted due to Alpine epirogeny. Paleokarstification left large dolines with flat sedimented floors along the upstream of the Nappenback Valley and the Hockgruben Valley on the plateau. There are two vertical zones of modern karstification on the plateau: (1) a zone above the treeline characterised by inclined pavement, kluftkarren, small dolines, and a few small caves; (2) a forest zone subject to biokarstification and characterised by varied karren, large numbers of dolines, and caves. The largest cave extends from the altitude of 1655m down to 988m level with a total surveyed length of 8.5km. Tracer tests in the cave found a high outlet of the cave stream system at an altitude of 850m. Large karst springs appearing at the south foot of the mountain have led to many theories about their genesis. On the basis of geological, geomorphologic, karst, and hydrochemical studies, this paper supports an autogenic theory. Despite intensive vertical karstification, layered structures remain, and result in coextension of unconfined and confined karst aquifers.

# RESEARCH FUNDS AND GRANTS

## THE JEFF JEFFERSON RESEARCH FUND

The British Cave Research Association has established the Jeff Jefferson Research Fund to promote research into all aspects of speleology in Britain and abroad. Initially, a total of £500 per year will be made available. The aims of the scheme are primarily:

- a) To assist in the purchase of consumable items such as water-tracing dyes, sample holders or chemical reagents without which it would be impossible to carry out or complete a research project.
- b) To provide funds for travel in association with fieldwork or to visit laboratories which could provide essential facilities.
- c) To provide financial support for the preparation of scientific reports. This could cover, for example, the costs of photographic processing, cartographic materials or computing time.
- d) To stimulate new research which the BCRA Research Committee considers could contribute significantly to emerging areas of speleology.

The award scheme will not support the salaries of the research worker(s) or assistants, attendance at conferences in Britain or abroad, nor the purchase of personal caving clothing, equipment or vehicles. The applicant(s) must be the principal investigator(s), and must be members of the BCRA in order to qualify. Grants may be made to individuals or small groups, who need not be employed in universities, polytechnics, or research establishments. Information and applications for Research Awards should be made on a form available from Simon Bottrell, Dept. of Earth Sciences, University of Leeds.

## GHAR PARAU FOUNDATION EXPEDITION AWARDS

An award, or awards, with a minimum of around £1000 available annually, to overseas caving expeditions originating from within the United Kingdom. Grants are normally given to those expeditions with an emphasis on a scientific approach and/or exploration in remote or little known areas. Application forms are available from the GPF Secretary, David Judson, Hurst Farm Barn, Cutler's Lane, Castlemorton Common, Malvern, Worcs. WR13 6LF. Closing date 1st February.

## SPORTS COUNCIL GRANT-AID IN SUPPORT OF CAVING EXPEDITIONS ABROAD

Grants are given annually to all types of caving expeditions going overseas from the U.K. (including cave diving), for the purpose of furthering cave exploration, survey, photography and training. Application forms and advice sheets are obtainable from the GPF Secretary, David Judson, Hurst Farm Barn, Cutler's Lane, Castlemorton Common, Malvern, Worcs. WR13 6LF and must be returned to him for both GPF and Sports Council Awards not later than 1st February each year for the succeeding period, April to March.

Expedition organisers living in Wales, Scotland or Northern Ireland, or from caving clubs based in these regions should contact their own regional Sports Council directly in the first instance (N.B. the closing date for Sports Council for Wales Awards applications is 31st December).

## THE E.K. TRATMAN AWARD

An annual award, currently, £50, made for the most stimulating contribution towards speleological literature published within the United Kingdom during the past 12 months. Suggestions are always welcome to members of the GPF Awards Committee, or its Secretary, David Judson, not later than 1st February each year.

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## BRITISH CAVE RESEARCH ASSOCIATION PUBLICATIONS

**CAVE & KARST SCIENCE** – published three times annually, a scientific journal comprising original research papers, reviews and discussion forum, on all aspects of speleological investigation, geology and geomorphology related to karst and caves, archaeology, biospeleology, exploration and expedition reports.

Editors: Dr. D. J. Lowe, c/o British Geological Survey, Keyworth, Notts. NG12 5GG and Professor J. Gunn, Limestone Research Group, Dept. of Geographical and Environmental Studies, University of Huddersfield, Huddersfield, HD1 3DH.

**CAVES & CAVING** – quarterly news magazine of current events in caving, with brief reports or latest explorations and expeditions, news of new techniques and equipment, Association personalia etc.

Editor: Mark Dougherty, 7 Edinburgh Terrace, Armley, Leeds LS12 3RH (0532-639288).

**CAVE STUDIES SERIES** – occasional series of booklets on various speleological or karst subjects.

*No. 1 Caves & Karst of the Yorkshire Dales*; by Tony Waltham and Martin Davies, 1987. Reprinted 1991.

*No. 2 An Introduction to Cave Surveying*; by Bryan Ellis, 1988.

*No. 3 Caves & Karst of the Peak District*; by Trevor Ford and John Gunn, 1990. Second edition 1992.

*No. 4 Introduction to British Limestone Karst*; edited by John Gunn, 1994.

**CURRENT TITLES IN SPELEOLOGY** – annual listings of international publications

Editor: Ray Mansfield, Downhead Cottage, Downhead, Shepton Mallet, Somerset BA4 4LG.

**CAVING PRACTICE AND EQUIPMENT**, edited by David Judson, 1984. Second edition 1991.

**LIMESTONES AND CAVES OF NORTHWEST ENGLAND**, edited by A. C. Waltham, 1974. (out of print).

**LIMESTONES AND CAVES OF THE MENDIP HILLS**, edited by D. I. Smith, 1975. (out of print).

**LIMESTONES AND CAVES OF THE PEAK DISTRICT**, edited by T. Ford, 1977. (out of print).

**LIMESTONES AND CAVES OF WALES**, edited by T. D. Ford, 1989.

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