Problems of Management of Transvaal Caves

Frances M. Gamble
Dept. Geog. and Environmental Studies, University of the Witwatersrand
Jan Smuts Ave., Johannesburg 2001, South Africa

Abstract

The management of karst caves is interpreted as the process which optimises the resource potential of the cave. This process varies considerably between caves, from an undisturbed ecosystem to commercial development. The problems involved in such management vary according to the specific objective obtained (CDevereaux, 1978). This involves the wise use or optimisation of resources. Problems of management are considerable. They vary from common problems of awareness of involved parties and exploitation of the resource to more specific to the Transvaal area. These latter include aspects such as culture, population distribution and mining practices. It is imperative that the most pressing of the problems, in the fields of awareness, distribution and administration, should be minimised as soon as possible. The problems of management are not seen as being insurmountable, but rather as long-term undertakings on the part of all concerned parties.

Zusammenfassung


Introduction

During the last 15 years, Man's perceived need for control has led to a change in approach to the natural environment. Conservation has become strategic management, with a predetermined objective being obtained (CDevereaux, 1978). This involves the wise use or optimisation of resources (Usher, 1973). This process of serving all interests (Wilmut, 1972), but is essential particularly where finite resources are involved. Problems of awareness and implementation of such management are considerable throughout the world, but are perhaps most critical in the developing nations where degradation of the environment is serious.

The awareness of the problems associated with and the necessity for management of karst caves is a relatively new concept involving few of the general population. The general inaccessibility and ecosystem stability of karst caves are such that few people recognize their fragility or resource potential. In the Transvaal cave numbers and locations, and population awareness necessitate management of the ecosystems. Their potential is considerable, but only in as far as it is recognized and optimized. As the population pressures increase (currently at approximately 3.5% p.a.), so do the problems on tourist activities and therefore on wilderness areas. In order to achieve optimal returns (Pletcher, 1980), it is imperative that the carrying capacity of the cave resource, the problems inherent in sound management practices must be minimized. These problems are not unique to the Transvaal area, but serve to illustrate those which must be acknowledged and those of priority.

The necessity for and problems confronting the successful management of Transvaal karst cave are examined in the present paper. The possibility of overcoming such hindrances are alluded to. The general principles are transferable to other karst cave areas.

The Necessity for Karst Cave Management

The necessity for management of karst caves is obvious only to those persons actively involved in scientific studies or recreational pursuits within cave ecosystems. Amongst these few it is generally accepted that management is necessary in order to derive the best possible value from the site, although this value is relative depending upon time, place and circumstances (Whitfield, 1980).

In some of the best and possibly last wilderness resources (Stitt, 1976) available to Man, but unlike natural areas their extent cannot be illustrated. The problem is not a definable one of ownership, but is one of control. The hesitation of the local population to venture underground is an additional positive factor, without which disturbance is likely to have been much greater. The characteristic extension to private property, which is also hesitant about promoting the disturbance by others of their subsurface property. The isolated nature of many individual caves also assists to some extent in the protection of caves.

In all instances at present management tends to be sporadic and uncoordinated. The general public, from amongst whom problems of the casual visitor are derived, are not involved. Where parties are aware of the implications of disturbance, steps are being taken to minimize damage to the ecosystem while at the same time promoting the wise use of the resource. Problems are greatest where commercial gain is involved. In the 'wild' caves there is evidence of wear and tear from cavers, still at a low level as most caving are subterranean (Gray, 1980). In certain particularly vulnerable instances caves have been gated to prevent further wanton destruction.
cooperation between most cave owners, scientists, speleologists, the provincial authorities and conservationists.

The present management situation is one of a lack of coordination, based mainly on limited awareness. The machinery exists for the initiation of a management programme, and the officials are receptive to advice. However, there remain several problems to the successful management of Transvaal caves.

<table>
<thead>
<tr>
<th>Party</th>
<th>Established Area of Concern</th>
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<tr>
<td>Department of Water Affairs, Forestry and Environmental Conservation</td>
<td>Permits to enter forest and water reserves</td>
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<td>National Parks</td>
<td>Act protecting geological forms</td>
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<td>Historical Monuments</td>
<td>Act protecting individual sites e.g. Sterkfontein Cave</td>
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<tr>
<td>Department of Defense</td>
<td>Permits to enter military areas</td>
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<td>Homeland Governments</td>
<td>Permits to enter</td>
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<td>Peri-urban Board</td>
<td>Deterrent notices at caves</td>
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<td>Provincial Nature Conservation</td>
<td>Legislation and ranger control</td>
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<td>Environmental Organizations</td>
<td>Conservation areas e.g. South African Wildlife Society</td>
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<td>University Scientists</td>
<td>Restricted access to sites</td>
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<td>Speleological Organizations</td>
<td>Conservation cleaning, gating</td>
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<td>Gem and mineral clubs</td>
<td>Speleothem supplies</td>
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<td>Gemstone retailers</td>
<td>Subjective control e.g. Sudwala</td>
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Management Problems in the Transvaal

The successful management of karst cave resources is a complex task. It involves both tangible and intangible disturbances. Surface and subsurface intrusions, both intentional and unintentional, must be recognized and controlled according to the merits of each cave. This is obviously particularly difficult where population pressures are high corresponding with complex surfaces alterations and multiple subsurface disturbances.

There are two basic considerations in the management of karst caves (Godfrey, 1976), namely the destruction of the resource itself and the management of people, both of which are interrelated, the more so at the actual management stage. In the Transvaal these problems may be grouped into four main areas.

Geographical considerations:

Geographical problems are some of the most difficult to control in the Transvaal as they are allied to distribution and to politics. The major concentrations of caves are remote from the main population centers, and correspond with areas of rough terrain (Figure 1). The resultant limited accessibility further complicated by the surface climate and vegetation characteristics, and by the small and inaccessible nature of the caves themselves, renders them particularly difficult to control.

Many of the dolomite areas occur within the independent homelands of Venda, Lebowa, Gazankulu and Bophuthatswana (Figure 2). This situation renders decentralized administration and control, as well as appreciation of the problem major issues. Currently, only the Transvaal and Lebowa authorities appear concerned about some of the caves within their jurisdiction - both being directly involved through possession and at least partial recognition of a number of valuable cave resources.

Physical considerations:

Physical and biological considerations relate to the destruction of the resource itself, particularly as it is irreparable and unextendable. Pollution of the system or of the surrounding environment, particularly water and atmospheric pollution, and pest problems. They are usually long-term and initially unnoticed, resulting in the destruction of a habitat especially fauna which by virtue of their small numbers are already endangered (Stitt, 1976). The occurrence of Daughters of Radon, high carbon dioxide concentrations, high ammonium and other physical hazards are regarded as management problems. All of these factors contribute to the carrying capacity of the system.

Social considerations:

Perhaps the most urgent problem facing the successful management of Transvaal caves is that of lack of knowledge and awareness. As with all other facets of the environment, concern is slow to be realized, and is generally manifest only in certain centers. This leads to a failure on the part of most persons to recognize the significance of the cave resource (Nieland et al., 1980). In addition, because of the lack of information and understanding as well as the haste usually involved in resource development (Fletcher, 1980) the details of disturbance are unappreciated. Hence much damage results. The education process is slow in such a situation and time is of the essence in any successful management programme. The dispersal, diversity and non-uniformity of the general population renders their awareness of and concern for the karst cave resource almost non-existent. Three small speological groups in the area provide little contact with persons who are actively involved or concerned. The three tourist caves are taken for granted, and there is little more concern for the issue in general. In addition, speleology is not recognized as a science (Hubart, 1976), and thus has little official support. As Usher (1971) concludes therefore perhaps the most part of any management programme is the education of the educational user. This would obviously be more effective through the use of sound interpretation programmes. At the same time however the short duration of interest of conservation-committed speleologists does not provide continuity for any management programme.

All resource management problems are related to the increased leisure time and mobility of the population. The result is an increased recreational demand from both the greater total population and the changed characteristics of society itself. The situation is further compounded by the paucity of karst caves in the rest of South Africa. Most of the ever-increasing South African population and many foreign visitors are forced to rely upon the Transvaal caves.

Related to the problem of lack of awareness is thoughtless exploration resulting in abuse of the resource. This applies to both the casual visitor and the trained speleologist. Wear and tear on the system is dependent upon organization and control. More severe is the intentional destruction which results from speleothem collection. Industrial and construction impacts, which have economic and political backing, are more difficult to combat, but precedent in terms of the preservation of scientific sites have been set throughout the world.

Local problems are also rooted in the cultural diversity of the area. Peoples of at least six Black and four White groups each with its own language, beliefs, traditions and superstitions occupy the area. Otherwise only the White English-speaking peoples are really involved, thus rendering numbers limited and management practices few.

Economics of control and exploitations are involved in all management problems. A resource which provides an economic return is frequently considered more valuable than one which has no obvious return or requires investment. In addition, the expenditure of large sums on control or other management measures is often regarded as being of limited value because of the low priority rating of the resource.

Management programme considerations:

A sound management programme can only succeed with planning, control and effective implementation.
Management programme problems are essentially those of trained manpower and expertise, although other problems such as economics cannot be ignored. The major manpower source is nature conservation officials and active speleologists. Expertise is required initially for compiling a comprehensive cave resource inventory. Thereafter management alternatives must be considered and priorities established, according to the pre-determined management objectives. Legal protection is of particular importance at this stage. None of these problems are mutually exclusive. They must be considered for the total suite of caves, and for individual systems. They are multiple and complex, far exceeding the prevailing positive factors. With enlightened leadership and the correct controls they are not insurmountable. Given a sound management framework which recognizes the necessity for compromise, the most urgent problem is education, which must form an integral part of the on-going management programme. The initial input must be rapid and thereafter must be long-term and dynamic, and must interpret the cave resource as a viable portion of the total environment.

Conclusion

The problems of karst cave management are similar throughout the world, although each area has certain unique aspects. In the Transvaal the basic has been laid for future management programmes. All concerned parties must be involved in order to enhance the cooperation and communication potential of specialists. Recognition of the urgency for a comprehensive, dynamic, long-term plan for the entire resource is vital, and will provide guidelines for individual systems. The greater the delay the greater the potential for future management initiation and progress.

Acknowledgement

The assistance of Mr. P.J. Stickler in preparing the diagrams is acknowledged.

References

Hubart, J.M., 1976: The need for preserving caves and underground sites in Belgium. Willing Pengelly Cave Studies, 27. 3-16.
Whitfield, P., 1980: Canadian cave management plans. Far West Cave Management Symposium, 1979, Redding. 84.
Figure 1. Morphological Types Associated with the Dolomite.
(1) Plateau type, (2) Escarpment Type, (3) Bushveld type, (4) Vaal River Type. The escarpment topogray (2) is particularly broken and inaccessible. (After: Martini and Kavalieris, 1976).

Figure 2. The Location of Homeland Areas in the Transvaal.
Karst Cave Management Modelling in the Transvaal

Frances M. Gamble
Dept. of Geog. and Environmental Studies, University of the Witwatersrand
1 Jan Smuts Ave., Johannesburg 2001, South Africa

Abstract

The necessity for a management model for use in Transvaal karst cave areas is evident from the occurrence of both intentional and unintentional exploitation of cave resources. Such modelling is complex, depending on the specific region and the individual cave to which it is applied. The concern of the paper is with the general requirements, nature and feasibility of such a model. Both physical and social environment considerations are incorporated. The model is based on the most extreme conditions of suscceptibility to disturbance of a cave system, that is on a static cave. Its nature varies from descriptive to mathematical. The success of the model as a management tool depends upon its dual applications, while demanding that disturbance in the optimisation of any natural resource, particularly those of a finite nature. Management must embrace the whole ecosystem by using appropriate individual subdivisions, as well as the total environment, including the human surface and subsurface impact on caves based on the countryside model proposed by Nicholson (1972), where they have achieved some measure of success (Vansteenwijkje, 1978). Resource systems are always models or abstractions and simplifications of reality. They have great potential value, if only to compare decisions with the optimum situation (O'Riordan, 1971).

To date there have been few attempts to model total environmental systems (Delininger, 1973; McHarg, 1973; Spofford, 1973). Karst cave ecosystems have been particulariy neglected. Systems of classifying caves according to their characteristics has been devised (Larson, 1980; Trout, 1978). Several studies, as for example in the Walto area of New Zealand (Nelson, 1979), have provided recommendations for improvements to individual caves. Forssell (1977) and Stitt (1977) have respectively considered the relationship between the karst, the human surface and subsurface impact on caves based on the countryside model proposed by Nicholson (1972). Such objectives are demanding on the nature of the model for successful resource management.

Construction and Objectives of the Model

The construction of dynamic environmental models involves four fundamental stages (Devereux, 1978; Vansteenwijkje, 1978):

- The determination of model objectives, requirements and structure based on available experience.
- Parameterisation, identification and development of a strategic management plan.

Models are tools used in scientific research or in planning and control to represent reality. They are subjective approximations consisting of a simplified structuring of reality which presents supposedly significant features or relationships in a generalised form (Haggett and Chroley, 1969, p. 42). They are valuable in that they obscure much of the detail of the system, allowing the basic components of reality to dominate, thus facilitating understanding and behavior prediction of the system (Lee, 1973). Models have been used in the environmental field for about the last 20 years (Delininger, 1973), where they have achieved some measure of success (Vansteenwijkje, 1978). Resource systems are always models or abstractions and simplifications of reality. They have great potential value, if only to compare decisions with the optimum situation (O'Riordan, 1971).

The karst cave resource potential in the Transvaal must encompass planning and environmental quality considerations, as well as the total environment, including both physical and social aspects. In the case of cavern ecosystems the disturbance of the physical environment by Man (as part of the social environment), intentionally or unintentionally (Figure 1) is the primary concern of the model. These levels are the undisturbed ecosystem, the controlled or limited access ecosystem, and the commercially developed cave. In terms of an optimisation policy emphasis is on the first two categories, with limited but important recognition of the third class. Such objectives are demanding on the nature of the model for successful resource management.

Requirements of the Model

The requirements of any model involving ecosystems are dependent upon the nature and resource potential of the ecosystem.

The model must be comprehensive in all respects. It must encompass planning and environmental quality considerations, as well as the total environment, including both physical and social aspects. In the case of cavern ecosystems the disturbance of the physical environment by Man (as part of the social environment), intentionally or unintentionally (Figure 1) is the primary concern of the model. These can only be incorporated into a total ecosystem model by invididual subdivisions within the framework of the total management model.

The intention of the model must be to allow for the most extreme case, that of aack cave with restricted entry, a situation typical of most Transvaal caves. Such an ecosystem is particularly vulnerable to disturbance, the major controls being atmospheric and hydrological. This vulnerability is enhanced in Transvaal caves by limited rock porosity and passage dimensions resulting in poor ventilation.

The model must be based on the existing management structure consisting of involved parties and machinery such as commercial control land legislation. Within this context, the model is comprehensive in all respects, including both physical and social environment considerations.
framework. Allowance must be made for any existing levels of management, national and individual clubs, caves and speleologists. These should be viewed as important foundations for the creation of awareness amongst both the general and involved population, and upon which overseas experiences may be based.

It is essential that the model should embrace an understanding of the biology of the women and involved. Relatively little is known about cave management (Gallagher, 1980), a situation which necessitates immediate amelioration through research.

The model must be as objectives as possible. The model should be continual. The model must be flexible in that each system is to a greater or lesser degree unique. However, this flexibility should not supersede the management objectives of the model.

The model must be stringent in its provision of controlling guidelines for all aspects of the resource. However, a balance must be sought in order to preserve the flexibility. Each of interpretation, facilitating utilization and communication is essential in order to optimise the model as a management tool for both laymen and experts. However, oversimplification which reduces the value of the model must be avoided.

These requirements for a karst cave management model may seem contradictory, but on the other hand, if one of the objectives of the model are essential premises upon which to work. In reality some compromise has to be reached, but those at least would provide the initial guidelines.

The Nature of the Model

In accordance with other models of environmental systems, a model of karst cave management requires an heuristic approach (Forssell, 1977), using smaller units in its construction, but being validated in situ against a complete system. The model should essentially be analytical but should include systems analysis and simulation in appropriate sections.

Some of the major modelling problems are encountered in defining and quantifying environmental qualities and other public policy objectives (Deininger, 1973). In an overall framework the model would comprise a number of both descriptive and mathematical sections. The descriptive sections are the most subjective and hence the weakest link in such a tool. They pertain for example to the problem of vandalism. They must be minimised, but are essential members in they provide the only method of including such system features. In addition, they are probably the most easily interpreted sections of the model. Such are vital, particularly to the non-scientist.

Numerical sections are more precise, therefore more objective. They are consequence of any valuable modelling technique. They are dependent upon exact measurements, for example of temperature, humidity and carbon dioxide. On the basis of these measurements various characteristics may be calculated. Thence visitor hazards and ecosystem impacts may be interpreted, prior to compliance with the remainder of the management objectives.

Descriptive and mathematical components contribute to one major management model. The flexibility of the model is a further complication which its subsection stringency is preserved. The application of the model will vary according to the nature of the individual population, and hence the general stringency will be reduced in most systems as vulnerability is decreased through ventilation or management policies. In terms of the Transvaal application will vary through larger systems as conditions, for example in entrance zones, are different from those in deep cave areas.

Feasibility of Successful Modelling


Figure 1

Intentional and Unintentional Disturbance of the Cavern Ecosystem by Subsurface Intrusion and Surface Alteration

Disturbance of the Cavern Atmosphere and Ecosystem

Unintentional

Surface

Alteration: e.g.
pathways, air and water percolation
Pesticides, herbicides: destruction of ecosystem
Construction: e.g. blasting - alter ventilation
Hydrological schemes: e.g. boreholes - dehydration
Sewage disposal: contamination, gas accumulation

Subsurface

Human visitor: heat, moisture, CO₂, compaction, foreign materials
Gate: alteration of air flow and troglobionte activity
Enlarging access points: alteration of air flow-dehydration
Mining and quarrying: access from surface-dehydration
Tourist amenities, e.g. walls, stairs: percolations
Tourist facilities, e.g. lights, heat: photosynthesis
Mining and quarrying: alteration of air flow dehyration
Foreign materials: bacteria, fungi
Enlarging access points: alteration of air flow-dehydration

Intentional

Surface

Subsurface

Hydrology of the Rio Camuy Caves System, Puerto Rico
Arturo Torres-González
U.S. Geological Survey, Water Resources Division, Caribbean District, San Juan, Puerto Rico

Abstract

The Río Camuy, a major river on the northwest coast of Puerto Rico, flows underground for a straight-line distance of about 6 kilometers. This underground journey through part of the 15-kilometer long Río Camuy Caves System is perhaps the most spectacular in the western hemisphere. Analyses of data collected from streamflow and rainfall stations installed within the study area revealed that (1) the travel time of Río Camuy through the underground passages fluctuated from 2 1/2 to 9 hours; (2) the maximum intake capacity of the river's swallow hole was determined to be on the order of 2,000 to 3,000 cubic feet per second, constituting therefore a massive and the most important natural flood control structure in this river basin; and (3) at least two of four recently discovered sinking streams were identified from the stream hydrographs as contributing to the total flow of Río Camuy at the known resurgence of the system. The discovery of a new passage of the cave in February 1980, has demonstrated the existence of a second resurgence through which Río Camuy overflows to the surface. Dye tests, hydrochemical analyses and numerous cave surveys, conducted during the course of this investigation, have proven the existence of two hypothetical connections, and others that were previously unknown.

Resumen

El río Camuy, uno de los principales ríos en la costa noroeste de Puerto Rico, discurre subterráneamente por espacio de unos 6 kilómetros en distancia lineal. Esta travesía subterránea, a través de algunos de los 15 kilómetros de pasillos del Sistema de Cavernas del Río Camuy, es quizás la más espectacular en todo el hemisferio occidental. Datos obtenidos de las estaciones de flujo y precipitación pluvial, instaladas en el área de estudio, indicaron que (1) el tiempo de travesía del Río Camuy a lo largo del sistema de cavernas fluctuó desde 2 1/2 hasta 9 horas; (2) la capacidad máxima de descarga del orificio o cavidad donde el río desaparece está en el orden de 2000 a 3000 pies cúbicos por segundo. Esta construcción ofrece resistencia masiva al flujo y constituye la más importante estructura de control de inundaciones en la cuenca; (3) por lo menos dos de cuatro quebradas que desaparecen subterráneamente han sido identificadas en los hidrogramas y contribuyen así al flujo total del río en la resurgence conocida del sistema. El descubrimiento de una nueva porción del sistema en Febrero de 1980, ha demostrado la existencia de una segunda resurgence a través de la cual Río Camuy desborda hacia la superficie. Pruebas de tinte, análisis hidroquímicos y numerosos trabajos espeleológicos han indicado la existencia de dos conexiones postuladas y otras que fueron previamente desconocidas.
Cave photomonitoring is a term used to describe precise photographs of selected points within the cave taken on a regular basis. These photographs can be used for inventory, as a record of change and as a basis of information for management decisions.

The system discussed has evolved from the work of others, from four years of use in Horsethief Cave, Wyoming plus two additional years of monitoring in the same cave by the author. Items to be considered are: types of equipment, location of photopoints, camera set up, film processing and analysis of results. Some examples of the results are obvious at a casual glance, while others require a thorough knowledge of the system and the subject matter in order to be discerned.

As a record of change within the cave, photographs can be an inexpensive method to withstand the abuse of travel through the cave. Film negatives are almost useless unless they can be related to a map of the cave so that precise locations can be established. For inventory, a combination of photographs and written commentary related to an accurate map should cover the needs of the cave manager.

As a record of change within the cave, photographs can not be excelled. Written descriptions can vary depending on the author and can not approach the detailed accuracy of photos. On a precise photograph, measurements can be made which may be undetected by the human eye. Also, changes such as accumulation of dust on formations and the presence of moisture on the walls or floor of a passage show up much better in color. Transparencies are not recommended because of the difficulty of viewing them and the problem of making measurements on them. Plumb bobs used to locate the camera directly over the photopoint marker.

A tripod is essential for properly locating and orienting the camera. It must be sturdy and compact to withstand the abuse of travel through the cave. For monitoring photos a color print film seems to be the best choice. Color prints show changes in size and shape as well as color changes in the cave environment which are difficult to detect. Changes such as accumulation of dust on formations and the presence of moisture on the walls or floor of a passage show much better in color. Transparency are not recommended because of the difficulty of viewing them and the problem of making measurements on them. Plumb bobs used to locate the camera directly over the photopoint marker.

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Camera selection is very important. A single lens reflex 35 mm camera is useful in certain situations. Tripod-The tripod is essential for properly locating and orienting the camera. It must be sturdy and compact to withstand the abuse of travel through the cave. For monitoring photos a color print film seems to be the best choice. Color prints show changes in size and shape as well as color changes in the cave environment which are difficult to detect. Changes such as accumulation of dust on formations and the presence of moisture on the walls or floor of a passage show much better in color. Transparency are not recommended because of the difficulty of viewing them and the problem of making measurements on them. Plumb bobs used to locate the camera directly over the photopoint marker.

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Additional Equipment for Setting Photopoints

Brass Markers—The material used to mark the photopoints is .375 inch diameter brass rod 1/2 to 1 inch long. Other markers could be used as long as they are permanent and can be relocated over a period of several years. Hammer and Drill—A hammer and a 3/8 inch star drill are used to drill a hole deep enough to place the markers almost flush with the surface. Adhesive—Aluminum solder was used to fix the brass markers in the holes.

Methods

Photopoints can be selected to monitor most aspects of cave use. Trails can be monitored for deterioration, formations can be checked for deterioration or damage and environmental conditions such as water levels or bat populations can be monitored.

When the subject is determined, the camera is set up on the tripod and oriented for the best view. The plumb bob is used to locate the photopoint on the floor and a brass marker is installed (Figure 2). The elevation of the lens above the marker is noted, and the bearing and inclination of the camera are measured and noted. A point is selected for the strobe to give the optimum illumination and this point is also recorded using distance, bearing and inclination from the marker. It is also useful to have distances from the photopoint and from the strobe to the subject. If the cave is surveyed, the photopoint marker is connected to a convenient survey station with compass and tape to aid in the relocation of the marker. If the cave is unsurveyed, distance and bearing from the marker to at least two distinct landmarks should be recorded. The photograph is then taken and information on camera settings is recorded. For the first series of monitoring photographs it may be necessary to bracket the exposures to determine the best one. A subsequent series of photos can be taken from the same set of photopoints by using the recorded data to re-establish the camera and strobe in an identical position.

All photographs should be processed and printed by a competent photo lab. The grey card and/or color scale can be used as a check to determine that all prints are processed to the same standards. All photographs should be analysed as soon as possible and a written report on each photopoint prepared. The report should include any information discerned from the photograph plus any information included in the written field notes.

Examples

The first example is from a Wyoming cave. Figure 3 was taken in 1970 before the photomonitoring system was begun, but was taken from nearly the same location as the photopoint which was established in 1975. Figure 4 was taken from the photopoint in 1979 and shows considerable enlargement of the passage opening. In the color prints a large amount of dust accumulation on the walls can also be detected. The second example was to have shown traffic across the pool. Figure 5 was taken in 1977 while Figure 6 was taken in 1978 and shows that little traffic has crossed the pool as there are no marks or dirt on the wall. However, the water level in the pool has risen several inches. In subsequent years, the water has receded to its former level and, as yet, no signs of traffic have appeared.

There are numerous other examples of monitoring photos showing increased use of areas of the cave as determined by trail width and depth. In another example, an area of flowstone has been observed, by the use of monitoring photos, to have become more active over a period of several years. Other photos show the breakage of formations from one year to the next.

Summary and Conclusions

The use of precise, repeatable monitoring photographs, along with other management tools, has helped managers make critical decisions affecting the cave environment. This system has been used by the Bureau of Land Management in Wyoming and a similar system has been used in the past by private cave owners. The expanded use of cave photomonitoring should be encouraged to aid managers in making decisions involving cave use and will provide a valuable record of caves which may be viewed by future cave users and managers alike.

Bibliography


Uhl, Peter 1979. Photomonitoring. Notes and Comments of the Northern Rockies Regional Cave Management Symposium, Lovell, Wyoming. 5-6.
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<tr>
<th>LOCATION: PP# 31</th>
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|LENSES: 50 mm | f/1.8 |
|APERTURE: #1 A | #2 B | #3 B | #4 B |
|SPEED: #1 B | #2 B | #3 B | #4 B |
|LENS to SUBJECT: Dist 7.2" | Brng 43° | Inc -38° |
|HEIGHT of LENS: 3.5" |
|GREY SCALE LOCATION: Lewis Center |

|LIGHTING TYPE | #1: Strobe | #2: | #3: | #4: |
|FLASHES: #1: 1 | #2: 2 | #3: B | #4: |
|PP to FLASH: Dist 6.10" | Brng 122° | Inc +27° |
|FLASH to SUBJ Dist 5.8" | Brng 59° | Inc -22° |

|LOCATION TO | 4.26 |
|Dist 96.4" | Brng 49° | Inc +2° |

NOTES: hemp was not lighted at time of photo.
The Foot Caves in the Tropical China
Zhao-xuan Zeng
(South China Teachers' College), Guanzhou, China

Abstract
The karst morphological evolution in tropical China may be summed up as following:
In the region where the underground water moves in vertical direction, the karst morphology appears
mainly to be the sinked morphology. When the region is dominated by the horizontal movement of the under-
ground water, the karst morphology appears to be the rivers and plains, while the limestone plateau is
dissected into rock mountains. The foot caves always appear at the foot of the rock mountains.
The morphological characteristics of the foot caves may be summed up as following:
1) The top of the foot caves have a very flat plane, correspondent to the flood level of the under-
ground rivers.
2) There are many "rock bell", "rock kettle" on the top planes of the foot caves,
3) The top planes of the foot caves are lower than that of the river flood level,
4) On both sides of the foot caves there are some "side trough", showing the levels of the underground
rivers alter during different seasons,
5) The dripstone formations are not fully developed.

Résumé
Ma thèse peut se synthétiser en grandes lignes là-dessous:
Dans la région où l'eau souterraine coule verticalement, la topographie du karst se distingue par ses
montagnes rocheuses. Quand la région est dominée par l'eau coulant horizontalement la topogra-
phie du karst se distingue par des rivières et des plaines, alors que le plateau calcaire est divisé en
les pieds de ces montagnes rocheuses.
On peut caractériser la topographie de ces cavernes du pied là-dessous:
1) Le faîte des cavernes a un plafond plat qui reste basé par rapport au niveau de l'inondation,
2) Il y a des "cloches rocheuses" et des "marmites rocheuses" sur le plafond des cavernes,
3) Le plafond du faîte est plus bas que le niveau des rivières débordées,
4) Aux deux côtés d'une caverne, il y a des "anges latérales" où s'altère le niveau de l'eau souterraine
pendant les différentes périodes saisonnières,
5) La stalactite topographique ne développe pas dans les cavernes.

Knots for Single Rope Techniques
Neil R. Montgomery & Donna Mroczkowski
1218 S. Marguerita Ave., Alhanbra, Cal. 91803 U.S.A.

Abstract
This paper deals with the application to SRT of the Bowline, Figure 8 knot, Figure 9 knot, Butterfly
knot, Overhand Bend and the Fisherman's knot. Reference is made to some recent test results.

Résumé
Cet article décrir les noeuds employés pour la technique "SRT" tel le noeud de chaise, le noeud huit,
le noeud papillon, le noeud vahce et noeud de pêcheur. Nous référerons aux résultats quel-
ques tests récents.
Ecology of Malheur Cave Harney County, Oregon

Ellen M. Benedict
Department of Biology, Pacific University, Forest Grove, Oregon 97116

Environmental Protection Agency, 200 SW 35th, Corvallis, Oregon 97330

Abstract

Malheur Cave, a 1100 meter long lava tube, is very unusual in several significant ways. Cave adapted animals discovered there include: a pseudoscorpion, a flatworm, an amphipode, isopods, a pal-pigrade, and several species of collemboles and mites. Malheur Cave contains a lake which has a maximum depth of 7 meters, a length of 400 meters, and a width of 3 to 12 meters. Numerous measurements have been made in this cave since 1971 to understand the presence of cave animals in a region where most other lava caves apparently lack a specialized fauna. The single entrance of the cave is 2 by 9 meters wide and the passage is unobstructed for the first 185 meters of the tube. Air temperatures of the true Dark Zone are 16.0 to 17.5°C, all within the range of the nearby geothermal springs. These unusual temperatures in Malheur Cave come from upwelling geothermal waters mixed with cool ground waters.

Introduction

Of the 230 caves reported for Oregon, 93 are separately named lava cave segments (Larson and Larson, 1975; Larson and Barnhart, 1975) of which only ten have been sufficiently studied. Many of these caves are gradually being discovered in Oregon caves, they are reported from less than a dozen caves (Eyman, 1937; McDonald, 1942; Chamberlin, 1949; Benedict, 1973; Peck, 1973; Kamp, 1973; Holsinger, 1974; Benedict, 1979, 1980). Malheur Cave, an 1100 m long unitary lava tube (Fig. 3) is one of the most unusual caves in Oregon. It contains a specialized subterranean fauna which includes the flatworm, Kenkia rhynchoidea Hyman; the amphipod, Stenobrachius macrocheles; an isopod, a terrestrial isopod; the pseudoscorpion, Apochthonius malheuri Benedict and Malcolm; a pal-pigrade; several species of sites and several species of collemboles. The Malheur Cave Research Project was initiated in 1971 to determine how Malheur Cave differs from other lava tubes of the region. During our study, we have described the geologic features of the cave (Benedict and Barnhart, 1975); determined the physical dimensions; measured direction and velocity of air flow; measured air, water, soil and rock temperatures; calculated relative humidities and analyzed water chemistry (Palmer, 1975). We are currently conducting a survey of the epigean and hypogean invertebrate species of the region.

Malheur Cave is located at 1,250 m above sea level in the semi-arid Northern Great Basin Desert of the western United States. The annual precipitation (ppt) at the surface averages 28 mm, with a low annual precipitation of 1 mm and a high annual precipitation of 41 mm; one third of the ppt falls as snow. The mean annual surface temperature (MAST) is 8°C with a minimum recorded temperature of -32°C and a maximum of 40°C. Frosts can occur during any month of the year. Under such harsh climatic conditions, delicate cave invertebrates have difficulty surviving on the surface.

This cave is a simple, unitary lava tube (Fig. 3) with a single entrance which is 2 m high and 9 m wide. The single large entrance descends almost due north for approximately 60 m and then bends sharply to the east, ending in a large cave lake. The lake is 400 m long, 7 m deep and from 3 to 12 m wide. The lake rises 1 m vertically and 260 m horizontally between the end of October and the middle of May each year. Passage height decreases below -12°. The thousands of measurements taken since 1973 confirm the pattern of cold air drainage in Malheur Cave. Yet despite the evidence that Malheur Cave is a cold air trap, temperatures as much as 11° higher than the MAST occur in the deep interior of this cave (Fig. 4). In August 1976, temperatures as high as 18.9°C were measured at 1 m above the lake surface at 915 m depth in the cave. These temperatures inhabituelles dans la grotte proviennent des eaux géothermiques qui sourdent et qui se mélangent avec les eaux froides de la terre.

Malheur Cave is inhabited by the cryophilic milliped, Plumatyla humerosa, which has been reported from several other caves and mines. Cryophilic species are presumed to be adapted to the cool water which explains why the cave is not warmer than it is. In addition, cool air drains in from the surface, cooling the warm and moist air rising from the cave lake.

Almost all other caves in Oregon have temperatures below the MAST of the region in which the cave is located. Fig. 4 presents comparative horizontal temperature profiles for three descending lava tubes: Malheur, Skeleton and Derrick Caves. Both Derrick and Skeleton Caves trap cold air and exhibit temperatures below the MAST. Derrick Cave is inhabited by the cryophilic millipede, Plumatyla humerosa, which has been reported from several other caves and mines. Cryophilic species are presumed to be adapted to the cool water which explains why the cave is not warmer than it is. In addition, cool air drains in from the surface, cooling the warm and moist air rising from the cave lake.

Acknowledgments

This study was supported in part by 1974 and 1979 Research Advisory Committee grants from the National Speleological Society. We gratefully acknowledge the help of numerous individuals who gathered data for the Malheur Cave Research Project, especially John E. Palmer and Patricia L. Barnhart Silver. We appreciate the use of research facilities at the Malheur Field Station and at Portland State University. Malheur Cave is owned by the Masonic Order of Burns, Oregon, and is currently closed to public visitation.

Literature Cited


Figures 1-2. 1. Index map of the state of Oregon, USA. 2. Local area map showing geographical relationships in the area of Malheur Cave, Harney County, Oregon, USA.

Figure 3. Plan map of Malheur Cave.
Evaporite Karst Gypsum Plain, Culberson County, Texas
A. Richard Smith
Olin Chem. Group, 9900 Northwest Freeway, Suite 212, Houston, TX

Abstract

The Gypsum Plain is a low relief, east-sloping surface drained by a few ephemeral streams and many sinkholes. East-dipping bedrock comprises the Castile and (?) Salado Formations; both are gypsum at the surface. The Castile grades downward into anhydrite, usually below 30 m. Subrosion of two salt beds in the Castile has removed them many kilometers downdip. Unusual linear scarps, some of which are in facing pairs, strike downdip in areas where salt has been removed. The west-facing scarp along the Yeso Hills is the result of solutional undercutting by stream runoff from the Guadalupe Mountains. Caves are generally small, up to 350 m long and 25 m deep. Those found so far occur mainly in clusters ("efforts") with large intervening areas where no caves are known. Base level for most caves is the bottom of incised valleys, where a few small springs occur. Cave development is guided by fractures, both tectonic and hydration, and by sub-horizontal calcite laminae in the gypsum. Enlargement is mostly by capture of surface runoff. Caves in the carbonate rocks above the gypsum resulted from collapse into openings in the gypsum.

Résumé

La Gypsum Plain est une surface de bas relief en pente à l'est, vidangée par quelques ruisseaux éphémères et de nombreux effondrements. Les formations de Castile et Salado comprennent roche de fond plongeant vers l'est. La superficie des deux formations est du gypse. Le Castile se gradue en aval en anhydrite, normalisé au-dessous de 35 m. Subrosion de deux lits de sel dans la Castile les a enlevé sur quelques kilomètres à l'aval-pendage de l'affleurement. Quelques escarpements linéaires insolites (plusieurs desquelles se trouvent en paires en front l'une à l'autre) se dirigent vers l'aval-pendage dans les zones où le sel a été enlevé. Un escarpement faisant face à l'ouest le long des Yeso Hills a été créé par le sous-canage en solution par l'eau de ruissellement des Montagnes Guadalupe. En général, les cavernes dans le Gypsum Plain en Texas sont petites, de 350 m de long et de 25 m de profondeur. La plupart des cavernes connues se trouvent en groupes, séparées par des grands espaces intermédiaires où il n'y a pas de cavernes connues. Niveau de basse pour la plupart des cavernes est le fond des vallées incisées où se trouvent quelques petites sources. Développement des cavernes est gouverné par diaclase, tectonique et hydration (?), et par intécalation fine subhorizontal de calcite dans le gypse. Extension résulte de la prise de l'eau de ruissellement. Les cavernes dans des roches carbonatées furent formées par écroulement à travers cavités dans le gypse.
Ecology of the New Zealand Glowworm Arachnocampa luminosa (Diptera: Mycetophilidae) in Caves at Waitomo, New Zealand

Chris Puglsey
Department of Biology, University of Waterloo, Ontario, Canada N2L 3G1

Abstract

The caves at Waitomo attract tourists from all the world, to view the glowworms' bioluminescent display. My work forms part of a multidisciplinary study in the Waitomo Grotto to investigate various aspects of the biology of Arachnocampa luminosa. Techniques of descriptive information, a more intensive, quantitative ecological approach was followed in the present study, an overview of which is presented in this paper.

Introduction

The Glowworm Cave (Lat. 39° 16'S, Long. 177° 06'E) at Waitomo is one of the main tourist attractions in New Zealand, the highlight being a boat ride through the Glowworm Grotto (Fig. 1, to view the bioluminescent display. A multidisciplinary cave research programme was set up in 1976 in response to growing concern that the cave was showing signs of a deteriorating natural environment. The long term survival of the troglobitic glowworm population, once a prime importance. The cave is developed on three main levels and has upper and lower entrances (Fig. 1). The lowest level (60 m a.s.l.) carries the Waitomo stream through a limestone ridge which forms a natural barrier across the valley. Normal stream flow is about 1 m³ s⁻¹ although rates in excess of 50 m³ s⁻¹ have been recorded. The New Zealand glowworm is a dipterous larva, the blue-green bioluminescence arising from a posterior light organ. The larva is suspended horizontally from the cave roof inside a transparent mosaic tube attached to which are single threads, adorne with droplets of sticky fluid. Some larvae produce over 100 of these 'fishing lines' which are used to trap flying insects, the main food source. Glowworms are common throughout New Zealand, their normal habitat being amongst vegetation on shaded stream banks. Their bioluminescence attracted naturalists towards the end of the last century, which has resulted in an extensive literature on the life cycle, habits, habitat and taxonomy. The cave glowworms at Waitomo were first reported by Humphries (1889), but detailed information was not published until Richards (1956). Starting with this considerable body of descriptive information, a more intensive, quantitative ecological approach was followed in the present study, an overview of which is presented in this paper.

Food supply

Food insects were present throughout the year but with considerable variation in the timing and magnitude of peak numbers. Few insects were recorded in winter. Freshwater insects (mainly chironomids) predominated, the number and biomass falling with increasing distance from the Waitomo stream. Food insects flew very low into the cave entrance, the glowworm population feeding almost entirely on imagos emerging from the Waitomo Stream within the cave system. It is suggested that the reason for the dense population of glowworms in the Grotto is the settling out of stream drift caused by the ponding effects of the cave lake (Mitchell 1980). Air currents that flow between the two cave entrances influence the distribution of food insects, allowing glowworm populations to thrive at considerable distance from the stream, the primary food source.

Life Cycle and Mortality

There is a predominantly annual cycle throughout the cave, with greatest numbers occurring in spring (Fig. 2). There is a considerable overlapping of the five larval instars, with wide variation in the speed of individual development. In the New Zealand insects (Roberts 1977), the glowworms at Waitomo did not diapause. During the study there was a decline in the number of glowworms in the cave (Fig. 3). The relative effects of different causes of mortality, i.e. predation by opiliones, cannibalism and the fungal pathogen Tolypocladium sp., is unknown because of the difficulty in identifying the causative agent. The opiliones Megalopsalis rupestris and Hembda mystica cavernicola, the latter a troglobite, were not considered to cause widespread mortality, their numbers remained low and constant throughout the study period. The fungal disease has been present in the glowworm population for many years. The epizootic that occurred during the summer of 1978-79, is in contrast with the comments made by Richards (1956, 1969) that this a recent problem. Cadavers only appear in summer, and preliminary experimental evidence shows fungal growth and sporulation to increase rapidly over a similar comments made by Richards (1956, 1969) that this a recent problem. Cadavers only appear in summer, and preliminary experimental evidence shows fungal growth and sporulation to increase rapidly over a similar period.

Climate

The mean annual temperatures recorded at intervals through the Glowworm Cave are much higher than would be expected in a typical nontourist cave (Fig. 5). Comparison with the 1955-56 data (Richards 1956, 1969) shows that the present climate is characterised by lower relative humidities (Fig. 6a), wider temperature ranges and colder winters (Fig. 6b,c). These changes, by contrast, have not occurred in another tourist cave (Fig. 6d). High evaporation rates in winter (Fig. 3e) cause noticeable drying of the passage walls. One of the main conclusions of the study is that many of the present problems with the glowworm population can be traced to the unfavourable climate that now exists in the cave.

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References


Fig. 1. Location map and isometric diagram of the Glowworm Cave showing tourist route (nos. 1-6).
Fig. 2. Life cycle of the New Zealand Glowworm Archnocampa luminosa (Skuse) (Diptera: Mycetophilidae) in the Waitomo Glowworm Cave 1977-1980.

Fig. 3. Decline in the glowworm population on a section of the Glowworm Grotto wall 1977-80.
Fig. 4. Relationship between incubation temperature and growth rate of Tolypocladium sp. (Moniliiales) in culture. Unless otherwise stated n=5.
Ished in 1975. Figure 4 was taken Point in 1979 and Shows consider the passage opening. In the coil of dust accumulation on the walls. The second example was taken in 1978 and shows little change. However, the water level in the pool appeared.

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Summary and Conclusions

The use of precise, repeatable too graphs, along with other management decisions affect managers make critical decisions affecting environment. This system has been used in Wyoming and a similar system has been used in the past by private cave owners to aid managers in making decisions and provide a valuable record of use and will may be viewed by future users and managers.

Bibliography


Additiona Equipment for Setting Photopoints

Brass Markers - the material used to mark the photopoints is 3/8 inch diameter brass rod 1/2 to 1 inch long. Other markers could be used as long as they are permanent and can be relocated over a period of several years. Hammer and drill. A hammer and 1/8 inch steel drill are used to drill a hole deep enough to place the markers almost flush with the surface. Adhesive-Aluminum solder was used to fix the brass markers in the holes.

Methods

Photopoints can be selected to monitor most aspects of cave use. Photos can be monitored for deterioration, formations can be checked for deterioration or damage and environmental conditions such as water levels or bat populations can be monitored.

When the subject is determined, the camera is set up on the tripod and oriented for the best view, the plumb bob is used to locate the photopoint on the floor and a brass marker is installed (Figure 2). The elevation of the lens surface of the marker is noted, and the bearing and inclination of the camera are measured and noted. An area of flowstone has been observed monitoring photos to have become more period of several years. Other photo age of formations from one year to the next.

Summary and Conclusions

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Figure 6. a–c. Comparison between the climate (seasonal means) in the Glowworm Cave in 1955–56 (stippled line, unfilled circles) with that during 1977–80 (dashed line).

a. Relative humidity Glowworm Grotto,
b. Temperature Glowworm Grotto,
c. Temperature Banquet Chamber,
e. Evaporation rate measured in the Glowworm Cave (Banquet Chamber).

Richards (1956) - range
Management of a Biological Resource - Waitomo Glowworm Cave, New Zealand

Chris Puglsey
Department of Biology, University of Waterloo, Ontario, Canada N2L 3G1

Abstract

In 1975 the Waitomo Caves Research Programme, a multidisciplinary study, was initiated. This action resulted from the recognition that after more than eighty years of tourist traffic the Glowworm Cave was showing signs of a deteriorating natural environment. A study of the glowworm population was carried out, the aim being to establish management procedures to ensure their long term survival. It was concluded that climate and food were the key factors for the maintenance of a healthy glowworm population. A fungal pathogen, Tolyposcladium inflatum (Moniliales), thrived in the warm, humid conditions found in the cave in summer, and caused a significant reduction in the number of glowworm larvae. Reasons for the closure of the cave for three months in 1979 are discussed. It was recommended that almost continuous air flow through the cave be reduced by sealing the top entrance, except when ventilation was vital during times of peak tourist traffic.

Résumé

En 1975, le programme de recherche de Waitomo Caves, à tendance multidisciplinaire, a été institué; en effet, après plus de 80 ans d'exploitation commerciale, il a été constaté que la caverné présentait de sérieux signes de détérioration du milieu naturel. Une étude de l'écologie des populations de mycétophilides est intégrée au programme afin de mettre au point une méthode d'aménagement qui assurerait leur survie à long terme. Le climat et la nourriture constituent les principaux facteurs de maintien d'une colonie nombreuse et en santé. En été, un champignon pathogène, Tolyposcladium inflatum (Moniliales), est favorisé par les conditions de température et d'humidité du cave et réduit le nombre de larves de mycétophilides. La fermeture de la cave pendant trois mois en 1979 a été imposée par le nombre réduit de larves, normal en cette saison, et par l'absence de bioluminescence chez la plupart des larves présentes. La principale recommandation du programme est de réduire la circulation presque continue de l'air dans la cave en obstruant l'entrée supérieure, sauf lorsque la ventilation est indispensable durant les périodes où la cave est très achalandée par les touristes.

Introduction

Waitomo Caves had been a popular international tourist attraction since the turn of the century. The key to its success is the silent boat ride across the Grotto lake, beneath the star-like display of glowworm lights.

The New Zealand glowworm (Arachnocampa luminosa (Diptera: Mycetophilidae)) is the larvae of a delicate gnat, its blue/green bioluminescence being produced by an organ at the posterior end. The larva is about 5 cm long and breathing takes place through a mucus tube from which it hangs threads, adorned with droplets of sticky fluid. Some larvae produce over 1000 of these 'fishing lines' which are used to catch the flying insects on which it feeds (Richards 1960). The New Zealand Tourist Hotel Corporation (THC) is responsible for the management of the Glowworm Cave (Fig. 1) and surrounding scenic reserves. In 1975 it became clear to many interested groups, that the natural environment of the cave was showing definite signs of deterioration. This resulted from the formation, and funding by the THC, of a multidisciplinary research group, consisting of scientists from universities and government research departments. The terms of reference were "to provide from scientifically sound data, practical advice to the Mini- tourist operation at Waitomo."

Based on the results of a preliminary report, problems requiring research were identified. In the past, the THC sponsored postgraduate students at universities who were supervised by members of the research group. Meetings to discuss progress, formulate management recommendations and future plans were held twice a year.

Of prime importance to the successful management of the cave, was to learn more about the ecology of the glowworm, the long term survival of which was crucial to the whole tourist operation at Waitomo. Other topics included in the research programme were: cave cleaning, cave visitors and calcite corrosion, control of the lampenflora, cave lighting practices and plant growth, Waitomo Stream catchment management, hydrological and sedimentological process in the cave, cave microclimate and glowworm fungal disease.

The aim of this paper is to summarize the main findings from my study of glowworm ecology, and to emphasize management problems and recommendations made to reverse the recent decline in glowworm numbers.

Methods

Fortnightly field visitors to Waitomo were made during 1978 and 1979. Cave climate was monitored using maximum/minimum thermometers, thermohygrographs and evaporation pans, placed at sites throughout the cave. Food was monitored in several ways. Sticky traps, made from stainless steel sheets coated with an adhesive grease 'Tangle-trap' were suspended at various levels and sites. On the Grotto Grotto lake (Fig. 1), emergence traps were used to quantify insects emerging from aquatic larvae from the lake bottom.

Food

The majority of the food supply consists of freshwater insects (mainly chironomid midges), which emerge from aquatic larvae on the muddy bottom of the stream. After 2 weeks or so, most enter as larvae carried into the cave by the stream. The fact that glowworms usually flourish in the cave is almost certainly related to the abundance of food provided by the cave lakes, which act as traps for aquatic insects drifting downstream. Very few glowworms occur away from the stream. Those that do must rely on insects flying from these areas. Air currents may well play an important role in distributing food in the cave.

Results

Climate: The climate in the Glowworm Cave shows much greater variability than would normally be expected in a typical cave environment. Two main factors are responsible: heat generated by the electric lighting and tourists; the ease with which the cave atmosphere mixes with the surface air.

Typically in winter, when the cave is warmer than the surface, cold air flows into the lower entrance and is warmed and moistened by its passage through the cave. Warm air therefore blows out of the upper entrance (Fig. 2a). Besides lowering temperatures, this 'winter' air current causes the drying out of the cave walls, i.e. the rate of evaporation increases. In summer the air flow reverses (Fig. 2b).

Comparison with Richards' (1956, 1960) climatic data, shows that the climate was much more uniform then, than it has been in recent years. At that time, and until 1975, a solid door prevented the free flow of air between the two entrances (Figs. 2c,d). Long term survival. It was concluded that climate and food were the key factors for the maintenance of a healthy glowworm population. A fungal pathogen, Tolyposcladium inflatum (Moniliales), thrived in the warm, humid conditions found in the cave in summer, and caused a significant reduction in the number of glowworm larvae. Reasons for the closure of the cave for three months in 1979 are discussed. It was recommended that almost continuous air flow through the cave be reduced by sealing the top entrance, except when ventilation was vital during times of peak tourist traffic.

Résumé

En 1975, le programme de recherche de Waitomo Caves, à tendance multidisciplinaire, a été institué; en effet, après plus de 80 ans d'exploitation commerciale, il a été constaté que la caverné présentait de sérieux signes de détérioration du milieu naturel. Une étude de l'écologie des populations de mycétophilides est intégrée au programme afin de mettre au point une méthode d'aménagement qui assurerait leur survie à long terme. Le climat et la nourriture constituent les principaux facteurs de maintien d'une colonie nombreuse et en santé. En été, un champignon pathogène, Tolyposcladium inflatum (Moniliales), est favorisé par les conditions de température et d'humidité du cave et réduit le nombre de larves de mycétophilides. La fermeture de la cave pendant trois mois en 1979 a été imposée par le nombre réduit de larves, normal en cette saison, et par l'absence de bioluminescence chez la plupart des larves présentes. La principale recommandation du programme est de réduire la circulation presque continue de l'air dans la cave en obstruant l'entrée supérieure, sauf lorsque la ventilation est indispensable durant les périodes où la cave est très achalandée par les touristes.

Introduction

Waitomo Caves had been a popular international tourist attraction since the turn of the century. The key to its success is the silent boat ride across the Grotto lake, beneath the star-like display of glowworm lights.

The New Zealand glowworm (Arachnocampa luminosa (Diptera: Mycetophilidae)) is the larvae of a delicate gnat, its blue/green bioluminescence being produced by an organ at the posterior end. The larva is about 5 cm long and breathing takes place through a mucus tube from which it hangs threads, adorned with droplets of sticky fluid. Some larvae produce over 1000 of these 'fishing lines' which are used to catch the flying insects on which it feeds (Richards 1960). The New Zealand Tourist Hotel Corporation (THC) is responsible for the management of the Glowworm Cave (Fig. 1) and surrounding scenic reserves. In 1975 it became clear to many interested groups, that the natural environment of the cave was showing definite signs of deterioration. This resulted from the formation, and funding by the THC, of a multidisciplinary research group, consisting of scientists from universities and government research departments. The terms of reference were "to provide from scientifically sound data, practical advice to the Mini-
tourist operation at Waitomo."

Based on the results of a preliminary report, problems requiring research were identified. In the past, the THC sponsored postgraduate students at universities who were supervised by members of the research group. Meetings to discuss progress, formulate management recommendations and future plans were held twice a year.

Of prime importance to the successful management of the cave, was to learn more about the ecology of the glowworm, the long term survival of which was crucial to the whole tourist operation at Waitomo. Other topics included in the research programme were: cave cleaning, cave visitors and calcite corrosion, control of the lampenflora, cave lighting practices and plant growth, Waitomo Stream catchment management, hydrological and sedimentological process in the cave, cave microclimate and glowworm fungal disease.

The aim of this paper is to summarize the main findings from my study of glowworm ecology, and to emphasize management problems and recommendations made to reverse the recent decline in glowworm numbers.

Methods

Fortnightly field visitors to Waitomo were made during 1978 and 1979. Cave climate was monitored using maximum/minimum thermometers, thermohygrographs and evaporation pans, placed at sites throughout the cave. Food was monitored in several ways. Sticky traps, made from stainless steel sheets coated with an adhesive grease 'Tangle-trap' were suspended at various levels and sites. On the Grotto Grotto lake (Fig. 1), emergence traps were used to quantify insects emerging from aquatic larvae from the lake bottom.

Food

The majority of the food supply consists of freshwater insects (mainly chironomid midges), which emerge from aquatic larvae on the muddy bottom of the stream. After 2 weeks or so, most enter as larvae carried into the cave by the stream. The fact that glowworms usually flourish in the cave is almost certainly related to the abundance of food provided by the cave lakes, which act as traps for aquatic insects drifting downstream. Very few glowworms occur away from the stream. Those that do must rely on insects flying from these areas. Air currents may well play an important role in distributing food in the cave.
Discussion

During the winter of 1979 the cave was closed for three months when the glowworm display was inadequate as a tourist attraction. The excellent, but inaccessible display in the Demonstration Chamber (Fig. 1) downstream of the Grotto, indicated that other parts of the cave were unaffected. Although the glowworm population in the Grotto is usually low in winter, this was not the main problem. This was that the few flowworms that were present in the Grotto roof had stopped glowing. The only explanation for this unusual behaviour was that it coincided with very dry conditions in the cave.

Flowworms, unlike those that live in the bush, have no defense against desiccation, in that they cannot retreat from dry air by retreating into 'burrows'. There is a possibility that larvae may turn off their lights in response to high evaporation rates. However, this hypothesis still awaits experimental verification.

The cause of the general decline in the glowworm display in recent years is because of a number of complex interacting factors, some of which are discussed below.

An adequate food supply is provided by the Waitemata Stream, but future planning should ensure that any changes in the catchment do not jeopardize the glowworms' food source. The effects of air currents, and periodic desilting operations to keep the Grotto navigable, may however upset the distribution, quantity and seasonal availability of the glowworms' food supply.

The fungal disease is present in other caves in the Waitemata district, but cadavers are rare. What little is known of the ecology of the fungi suggests that in the Grotto, a combination of draughts, to carry the airborne spores, high summer temperatures and relative humidity, make for ideal conditions in which it can flourish.

Many of the current problems can be linked to the change in climate, caused in part by the opening of the top entrance in 1975. The installation of the open grille was done to relieve an earlier problem, that of the build up of carbon dioxide and stale air in the cave when tourist traffic was high. The increased ventilation and the re-routing of tourist parties away from the Organ Loft (Fig. 1), the main problem area, has been successful. However the decision to erect the grille was made before the full consequences of its affect on cave climate and the glowworm population, were realised. This exemplifies the importance of researching the effects of any manipulation of the cave environment, before and after, it is put into action.

To resolve the cave ventilation problem, a research programme was started to study cave meteorology. Until the results of this work are known, plans for further modification of the top entrance have been in abeyance. It was recommended that the top entrance be kept sealed unless tourist traffic was high enough to warrant ventilating the cave.

The Waitemata Cave research programme has now been running for six years. The liaison between the THC management and researchers has been excellent. The caves are already recovering from the problems of the early 1970's, as results and recommendations from the study group have been put into practice. The interest in, and help given to research work, by THC staff and local people, has resulted in an increased awareness of the problems facing cave management. This knowledge based in the Waitemata community, may well be the most effective defense against future decline in the glowworm population, or deterioration in the cave environment.

References


Figure 1. Location map and isometric diagram of the Glowworm Cave showing tourist route (nos. 1-6). See Figure 1 of previous article.

Figure 2. Diagrams to illustrate typical climatic conditions in the Glowworm cave with and without top entrance open. a. 'Winter' conditions 1977-80, b. 'Summer' conditions 1977-80, c. 'Winter' conditions predicted if top entrance sealed, d. 'Summer' conditions predicted if top entrance sealed.

Figure 3. Life cycle of the New Zealand Glowworm Arachnocampa luminosa (Skuse) (Diptera: Mycetophilidae) in the Glowworm Cave of Waitomo. See Figure 2 of previous article.
Cooperation of Speleologist and Microbiologist
K. Szekely
H-1118 Budapest XI, Budaorsi-U. 26, HUNGARY
Georges L. Nogrady, M.D.
4662 Victoria Ave., Montreal, Quebec, Canada H3W2N1

Abstract
Cave samplings on Easter Island prompted us to develop a co-operation protocol for speleomicrobiological studies. The project clusters the following activities: 1) aseptic samplings, 2) collection of surface data, 3) measurement of cave parameters. To avoid environmental contamination, the microbiologist must have a priority of action. Human and animal activities on the surface should be noted. Animals with day or night activities are often responsible for surface microorganisms in caves. After attachment of the first polygon point by the speleologist at the entrance, the microbiologist proceeds with air, konimetric, floor, parietal and ceiling samplings. The second polygon point marks the end of twilight zone. Temperature, relative humidity, air-current measurements; mineralogical, plant and animal samplings are taken. A sketchy map is prepared. Former samplings and measurements are repeated, with additional measurements of carbon dioxide, gamma radiation and pH of aerosol condensate. If underground water is present, water temperature and current are measured, aquatic plants and animals collected. Among indicator microbes for human and animal fecal pollution, coliforms should be compared to resistant enterococci and yeasts. From pathogenic bacteria the search of Salmonella is recommended. It is compulsory to attempt the isolation of Histoplasma and cultures of amoebas in warm water. Actinomycetes often produce antibiotics, also its isolation from cave flora could yield new, potent producers. A Thermoactinomyces isolated from adhering cave mucus needs further research.

Résumé
Les échantillonnages des cavernes à l'Île de Pâques nous ont inspirés pour développer un protocole pour la coopération dans les études spéléomicrobiologiques. Le projet groupe les activités suivantes: 1) échantillonnages aseptiques, 2) collection de données à la surface, 3) mesurage des paramètres de la cavern. Pour éviter la contamination de l'environnement, le microbiologist devrait avoir la priorité d'action. Les activités humaines et animales sur la surface devraient être enregistrées. Les animaux montrant des activités le jour ou un nuit sont assez fréquemment responsables pour des microorganismes de surface dans les cavernes. Après l'attachement du premier polygone par le spéléologue à l'entrée, le microbiologiste s'avance avec les échantillonnages de l'air, konimétrique, plancher, parietale et plafond. Le deuxième polygone indique la fin de la zone crépusculaire. On réalise le mesurage de la température, l'humidité relative, courant d'air et on prend les échantillons minéralogiques, de la flore et de la faune. On prépare une carte d'esquisse. Les échantillonnages et mesurages antérieurs sont répétés avec mesurage additionnel d'anhydride carbonique, radiation gamma et le pH d'aérosol condensé. Si l'eau souterraine est présente, la température de l'eau et le pH d'aérosol condensé. Si l'eau souterraine est présente, la température de l'eau et le courant sont mesurés, des plantes et animaux aquatiques sont collectés. Parmi les indicateurs microbiens de la pollution fécale, les coliformes devraient être comparées avec les entérocoques et levures résistantes. A partir des bactéries pathogènes, la recherche de Salmonella est recommandée. Il est obligatoire d'essayer l'isolement de l'Histoplasma et de faire des cultures d'amibes d'eau chaude. Les Actinomycées produisent souvent des antibiotiques, ainsi son isolement de la flore cavernicole pourrait fournir de nouveaux et puissants producteurs. L'isolement d'une Thermoactinomyces d'un mucus adhérent dans une cave demande des recherches plus poussées.
Une Méthode Graphique Pour Analyser Les Grottes "Phrétiques"

Jacques Schroeder
Département de Géographie, Université du Québec à Montréal, C.P. 8888, Succursale "A", Montréal, Québec, CANADA H3C 3P8

Résumé

Vu que la grotte "phréatique" ne représente qu'une partie du réseau existant lors de sa genèse sous le niveau de la nappe aquifère, il est proposé d'étudier la géométrie de l'espace qui l'environne horizontalement et verticalement, plus précisément que la grotte phréatique la zone de la roche encaissante où les eaux phréatiques ont creusé. D'un point de vue graphique, ce nous appelons "l'Espace Karstifié" est limité par les extrémités de la grotte et les points les plus hauts et les plus bas. Si cet espace est rabattu dans le plan vertical, il apparaîtrait comme un ou des polygones allongés horizontalement qui peuvent être comparés au pendage vrai. L'analyse des éléments de ce polygone permet de distinguer les diverses phases de creusement du réseau autant "phréatique" que "vadose" lorsqu'il est complexe. La méthode est appliquée à trois grottes du karst subartic de la Nahanni au Canada.

Abstract

Since the "phreatic" cave is only a part of the network that existed at the moment of its genesis under the level of the water table, it is suggested that we study the geometry of the space that completely surrounds it. This space defines more accurately the cave what part of the rock has been escaped by the phreatic water. From the graphic point of view, what is called the "Espace Karstifié" is bordered by the extremities of the mapped cave and by the highest and the lowest points. If this space is projected on the vertical plan, which is parallel to the dip, its looks like one or more horizontally stretched polygons that may be compared to the true dip. The analysis of these polygon elements makes it possible to distinguish the many phases of the "phreatic" or "vadose" escaving of the network when it is a complex one. This method is applied to three caves of the subartic karst of the Nahanni (Canada).

La Méthode

Comme dans beaucoup de grottes, les remplissages bouchent les réseaux, et qu'une partie non négligeable reste en surface impénétrable à l'homme, il faut les étudier en les suppliant statistiquement correspond mieux à l'espace affecté par dissolution et le développement de réseaux "vadoses". Les pentes de pendage, prouvant qu'elles ont été contrôlées non seulement par l'abaissement piezométrique mais aussi par la structure. L'encaissement du réseau a été suffisamment lent pour entraîner son déplacement latéral. Il faut donc distinguer la genèse de creusement "phréatique" sa base dont l'altitude correspond à la fin de la période de creusement "phréatique" locale. L'encaissement de tout le réseau (52,5 m) est proche de celui de la grotte Valérie (41,5 m) et rigoureusement la même hauteur. Ce qui suggère une spéléogénèse régionale de même âge.

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Since the "phreatic" cave is only a part of the network that existed at the moment of its genesis under the level of the water table, it is suggested that we study the geometry of the space that completely surrounds it. This space defines more accurately the cave what part of the rock has been escaped by the phreatic water. From the graphic point of view, what is called the "Espace Karstifié" is bordered by the extremities of the mapped cave and by the highest and the lowest points. If this space is projected on the vertical plan, which is parallel to the dip, its looks like one or more horizontally stretched polygons that may be compared to the true dip. The analysis of these polygon elements makes it possible to distinguish the many phases of the "phreatic" or "vadose" escaving of the network when it is a complex one. This method is applied to three caves of the subartic karst of the Nahanni (Canada).

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La grotte Mickey (47B), longueur 2 270 mètres
La plus grande grotte de la région, proche de la première sur les rives de la Nahanni est entourée de cavités plus petites qui constituent un réseau total de 3 700 m de longueur. La projection verticale de leur E.K. se divise en deux à une altitude nettement inférieure à celle des 2 autres grottes. Le principal polygone englobe les grottes les plus profondément creusées dans le massif (fig. 3, stations 17, 13, 15, 2, 3, 18, 6, 14 et 9) et s'y encaisse sur 30 m de profondeur en suivant le pendage modéré (8,7°), ce qui dénote son origine "phréatique" prédominante. Le haut et le bas du polygone sont quasiement parallèles et distants de 45 à 50 m. Donc, au début de cette phase de creusement, le niveau picométrique était supérieur à 565 m, altitude de la station la plus haute (15), puis s'abaisse progressivement jusqu'à 50 m audessus de la station 18 la plus basse. Le contrôle du pendage modéré est effectif, comme pour la grotte Valérie entrainant aussi un déplacement latéral de la zone en cours de cavernement. Cette adaptation à la structure atteste de la lenteur de l'abaissement de la nappe "phréatique". De plus, entre 515 m et 515 m, les conditions de creusement ont perdu durant tout cette phase de spéléogénèse (fig. 4), ce qui y fait apparaître la plus grande densité de galeries. Enfin, la constance de l'épaisseur de ce polygone (50 m) suggère que c'est dans cette fourchette que la spéléogénèse en condition "phréatique" a été efficace puisque les matériaux sont tout aussi solubles au-dessus qu'en dessous.

Le reste du polygone projeté (fig. 3) consiste en triangles imbriqués sous le polygone principal. S'y retrouvent toutes les petites grottes satellites le réseau profond. La décroissance de ces triangles vers le bas suggère une inhibition progressive des conditions de creusement de type "phréatique" qu'on peut associer à un abaissement plus rapide du niveau de base régional tel que le montre la géomorphologie de surface.

Conclusion
Par le biais du concept nouveau, les "Espaces Karstifiés", l'importance du contrôle du plan de stratification est mise en évidence, d'autant plus dramatique que le pendage est faible, ce qui entraîne un développement latéral du réseau. La spéléogénèse en condition "phréatique" responsable des 3 plus longues grottes de la Nahanni a eu lieu lors de 2 phases de stabilité de la nappe aquifère qu'il a été ainsi possible d'identifier, de même que les seuils d'efficacité du régime noyé et les variation de la vitesse d'abaissement de la nappe durant ces niveaux de stabilité. Pour les grottes inférieures à 1 km de développement connu, les résultats sont aberrants, ces objets karstiques se situant alors sous le seuil de perception de la méthode, ce qui en précise le niveau d'application.

Référence
J. Schroeder, 1979 - Le développement des grottes dans la région du Premier Canyon de la rivière Nahanni-Sud, T.N.O., Thèse de Ph.D., Université d'Ottawa, Canada.
Figure 3. Les 3 "Espaces Karstifiés" rabattus dans le plan vertical du pendage et disposés suivant leurs altitudes.

Figure 4. Dynamique de la spéléogenèse en condition "phréatique superficielle" de la grotte Mickey (47B). La dénivellation de la grotte est d'un bord à l'autre de son "Espace Karstifié" de l'ordre de 50 m. Ce qui illustre l'abaissement faible (30 m) de "l'Espace Karstifié" 1) et par conséquent du niveau phréatique lors de la spéléogenèse. C'est la zone de "l'Espace Karstifié" comprise entre 535 et 515 m qui a subi les conditions de creusement les plus longues 2) (du début à la fin de la spéléogenèse). Donc c'est entre ces altitudes que le réseau doit présenter son développement maximum en plan. Ce qui est le cas et est confirmé par la position horizontale de la limite interne du réseau (St. 17-2-3) dans la projection de "l'Espace Karstifié" (fig. 3).
Les Sédiments Clastiques De La Grotte De Castleguard

Jacobian Schroeder
Département de Géographie, Université de Montréal, C.P. 8888, Succursale "A", Montréal, Québec, CANADA H3C 3P8

Résumé

Au cours de l'expédition d'août 1980, les sédiments clastiques ont été observés du point le plus haut de la grotte ouvert sous la calotte Columbia jusqu'au puits de 80 pieds, les sédiments clastiques ont été observés sur près de 7 km de longueur. A l'amont sous le glacier, le plancher est couvert de débris mécaniques et cryoclastiques incluant des blocs glaciaires émoussés parfois collés aux parois en poudingues. Viennent ensuite, des silts argileux (92 % du total < 37 μm, dont 4 % à 21 % < 4 μm) et des galets de 5 cm à 1,5 m maximum. Les sédiments clastiques ont été observés du point le plus haut de la grotte ouvert sous la calotte Columbia jusqu'au puits de 80 pieds (figure 1). Le point le plus bas de la grotte est presque partout couvert de débris anguleux et des blocs glaciaires isolés (fig. 1). Les plus petits mesurant le minimum de 1 cm et le maximum de 5 cm avec un émoussé évoluté vers l'arrondi (cf. infra). Par contre, les galeries latérales à l'abri des écoulements venant du "Ice Blockage" sont colmatées de matériaux fins stratifiés fossilisant les blocs. Ainsi à l'injection de matériel morainique succède la sédimentation de silts le plus souvent varvés (1 - 3 mm d'épais) ou en lits épais de 10 à 15 cm de vitesse. Ce que confirment et précisent les diffractions de la fraction X sur la fraction < 10 μm en identifiant 60 μm à 85 μm de calcaire. Les résidus insolubles du substratum ont probablement donné les éléments argileux.

Abstract

From the highest point of the cave, that opens up under the Columbia Icefield, to the 80' Pot, clastic sediments have been analyzed on 7 km of gallery. Upstream under the glacier, the floor is covered with mecanical and cryoclastic debris including erratic boulders sometimes adhering to the walls. Then, there is silt with clay (92 to 99% of the total < 37 μm, of which 4 to 10% < 4 μm) mostly varved (1 to 3 mm thick), and sometimes in thin layers (10 to 15 cm thick). The breccia is either grey or beige. Discussion of the calcimetries and the X diffraction data. Despite the local changes in the facies, the sedimentation seems to include three levels. 1) At the bottom level, there are, here and there, local deposits of rounded or angular limestone pebbles (except in the 80' Pot where they are either grey or beige). 2) The middle level is composed of varved and/or massive bedded clayed silts, comprising gravity plications and channels 1 meter wide at the most. The top level is a thin layer of surface cover of carbonatic pebbles. Average total thickness = 1 meter or more. 3) The upper level is also made up of varved and/or bedded clayed silts but it is topped off by a sedimentary surface. Average total thickness = 1 meter or more. A chronology is suggested.

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Département de Géographie, Université de Montréal, C.P. 8888, Succursale "A", Montréal, Québec, CANADA H3C 3P8

Résultats

Du point le plus haut de la grotte, ouvert sous la calotte Columbia, jusqu'au puits de 80 pieds, les sédiments clastiques ont été observés sur près de 7 km de longueur. A l'amont sous le glacier, le plancher est couvert de débris mécaniques et cryoclastiques incluant des blocs glaciaires émoussés parfois collés aux parois en poudingues. Viennent ensuite, des silts argileux (92 % du total < 37 μm, dont 4 % à 21 % < 4 μm) et des galets de 5 cm à 1,5 m maximum. Les sédiments clastiques ont été observés du point le plus haut de la grotte ouvert sous la calotte Columbia jusqu'au puits de 80 pieds (figure 1). Le point le plus bas de la grotte est presque partout couvert de débris anguleux et des blocs glaciaires isolés (fig. 1). Les plus petits mesurant le minimum de 1 cm et le maximum de 5 cm avec un émoussé évoluté vers l'arrondi (cf. infra). Par contre, les galeries latérales à l'abri des écoulements venant du "Ice Blockage" sont colmatées de matériaux fins stratifiés fossilisant les blocs. Ainsi à l'injection de matériel morainique succède la sédimentation de silts le plus souvent varvés (1 - 3 mm d'épais) ou en lits épais de 10 à 15 cm de vitesse. Ce que confirment et précisent les diffractions de la fraction X sur la fraction < 10 μm en identifiant 60 μm à 85 μm de calcaire. Les résidus insolubles du substratum ont probablement donné les éléments argileux.

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Département de Géographie, Université de Montréal, C.P. 8888, Succursale "A", Montréal, Québec, CANADA H3C 3P8

Résultats

Du point le plus haut de la grotte, ouvert sous la calotte Columbia, jusqu'au puits de 80 pieds, les sédiments clastiques ont été observés sur près de 7 km de longueur. A l'amont sous le glacier, le plancher est couvert de débris mécaniques et cryoclastiques incluant des blocs glaciaires émoussés parfois collés aux parois en poudingues. Viennent ensuite, des silts argileux (92 % du total < 37 μm, dont 4 % à 21 % < 4 μm) et des galets de 5 cm à 1,5 m maximum. Les sédiments clastiques ont été observés du point le plus haut de la grotte ouvert sous la calotte Columbia jusqu'au puits de 80 pieds (figure 1). Le point le plus bas de la grotte est presque partout couvert de débris anguleux et des blocs glaciaires isolés (fig. 1). Les plus petits mesurant le minimum de 1 cm et le maximum de 5 cm avec un émoussé évoluté vers l'arrondi (cf. infra). Par contre, les galeries latérales à l'abri des écoulements venant du "Ice Blockage" sont colmatées de matériaux fins stratifiés fossilisant les blocs. Ainsi à l'injection de matériel morainique succède la sédimentation de silts le plus souvent varvés (1 - 3 mm d'épais) ou en lits épais de 10 à 15 cm de vitesse. Ce que confirment et précisent les diffractions de la fraction X sur la fraction < 10 μm en identifiant 60 μm à 85 μm de calcaire. Les résidus insolubles du substratum ont probablement donné les éléments argileux.

Abstract

From the highest point of the cave, that opens up under the Columbia Icefield, to the 80' Pot, clastic sediments have been analyzed on 7 km of gallery. Upstream under the glacier, the floor is covered with mecanical and cryoclastic debris including erratic boulders sometimes adhering to the walls. Then, there is silt with clay (92 to 99% of the total < 37 μm, of which 4 to 10% < 4 μm) mostly varved (1 to 3 mm thick), and sometimes in thin layers (10 to 15 cm thick). The breccia is either grey or beige. Discussion of the calcimetries and the X diffraction data. Despite the local changes in the facies, the sedimentation seems to include three levels. 1) At the bottom level, there are, here and there, local deposits of rounded or angular limestone pebbles (except in the 80' Pot where they are either grey or beige). 2) The middle level is composed of varved and/or massive bedded clayed silts, comprising gravity plications and channels 1 meter wide at the most. The top level is a thin layer of surface cover of carbonatic pebbles. Average total thickness = 1 meter or more. 3) The upper level is also made up of varved and/or bedded clayed silts but it is topped off by a sedimentary surface. Average total thickness = 1 meter or more. A chronology is suggested.
Au-dessus, des silts beiges s'accumulent sur plus d'un mètre avant d'être limités par une surface d'érosion indurée (fig. 1, E-3). La coupe se termine par des silts varvés concordants qui débutent par un lit épais de 15 cm et finissent par une surface d'arrêt de sédimentation (fig. 1, E-4). A partir de cet endroit, chaque fois que la coupe subsiste au complet, ces trois niveaux sont identifiables.

Ainsi, la coupe D débute par des silts varvés beiges, contenant de galets calcaires, au plus pungi-

lares, que limite une surface d'arrêt de sédimentation indurée (fig. 1, D-1); puis on trouve un plancher stalagmitique partiellement redissous, couvert de galets centimétriques calcaires et siliceux et des silts varvés concordants, beiges avec des chenaux de silts gris (fig. 1, D-2). Le niveau suivant débute par une surface d'érosion couverte de galets centi-

métriques calcaires et siliceux puis de varves beiges, arrêtées par une surface de sédimentation indurée (fig. 1, D-3). A partir de cet endroit, les dépôts vont progressivement s'épaissir grâce au nombre croissant de lits épais de 10 cm à 15 cm intercalés dans les varves ou seuls, comme le confirmrent les dépôts de l'extrémité d'aval de la "3e fissure".

Ici, la base de la coupe se compose à nouveau d'un "conglomérat" de plaquettes silteuses (fig. 1, C-1) que surmontent des lits épais alternant avec des varves localement perturbées par des plissements de gravité. Cette fois, ce niveau finit par une surface d'arrêt de sédimentation cette fois cou-

rreusée par un canal rempli de silt gris. Enfin, la coupe et le substrat ont été entaillés par un écoule-

ment subactuel qui laisse une "tranchée vadose" pro-

fonde ici de 1 m (fig. 1, C-4) mais ailleurs atteignant les 10 m (fig. 1, E).

Entre la "2e fissure" et la première, la coupe type se compose de plages cimentées de galets calcaires (fig. 1, A-1), que surmontent des lits épais parcourus par une surface d'érosion qui descend de galets calcaires (fig. 1, A-2) et que terminent des silts varvés et lits subhorizontaux. Dans la "3e fissure", là ou ils subsistent, les dépôts clastiques montrent les mêmes types de faciès, les galets calcaires étant cependant de plus en plus sporadiques à la base.

Les galets présents sous le puits de 80 pieds ont un indice d'émoussé variant de 0,5 à 1,0 (x = 0,7, n = 14, indice de Pettijohn). Ils sont donc arrondis à bien arrondis et proviennent de débris cubiques (8 sur 14) ou parallélépipédiques (6 sur 14, méthode de Zingg) comme on les trouve dans la moraine injectée à l'amont.

Ainsi, au-delà des modalités explicables par la topographie locale, les sédiments clastiques de la grotte de Castleguard s'ordonnent en une séquence qui varie d'amont vers l'aval et de bas en haut. L'injection de matériel morainique est suivie de son lessivage donnant des plages de galets de mieux en mieux roulés mais de plus en plus rares auxquelles s'intercalent une sédimen-

tation fine localement détruite et reposition en "con-

glomérats" de plaquettes silteuses. Suit un arrêt des écoulements irréguliers et violents qui permet, ici l'induration de la surface des dépôts, là l'apparition d'un plancher stalagmitique. La phase suivante se caractérise par des écoulements plus modérés qui fossilisent le premier niveau de dépôts sous des lits plus souvent varvés. Cependant, ces écoulements sont à leur début assez complexes pour trailler localement une surface d'érosion et des chenaux tapisssés de galets et de silts gris. Enfin, après un nouvel arrêt, une troisième phase d'écoulement lent aboutit à la sédimen-

tation d'autres silts varvés et lits avant de se tarir. C'est ainsi que peut se moduler actuellement la phase majeure de remplissage clastique qui semble correspondent à une période anglaciaire où le débit et la compétence diminuent glaiblement. Plus tard, probable-

ment à l'Holocène, la grotte draine à nouveau des eaux fluvi-glaciaires qui entaillent et les dépôts et le substrat.

Remerciements

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Figure 1. La grotte de Castleguard en profil. Les principales coupes observées et leur localisation. Description des coupes dans le texte.
Applications of Speleology in Civil Engineering Works in Turkey
Temucin Aygen
Meda Cad. Rizapaga Sok. No. 1/4, Kadikoy - ISTANBUL - TURKEY

Abstract
Speleological research is extensively used in civil engineering works in Turkey, particularly on applications like the construction of dams and hydroelectric power stations, irrigation projects, water supply for urban settlements. Some examples are examined in the sequel:

1. Detailed investigation of Petek Cave system which is situated on the trajectory of underground water leaking from the large reservoir lake of the Keban dam (Elazig).
2. Speleological explorations related to the construction of the Ozmapinar dam (Antalya), such as:
   a. Dumanli underground river system whose resurgence is in fact one of the largest in the world.
   b. Exploration of the Akpinar Cave situated at 35 Km of the dam and related to it by an underground river.
   c. Investigation of the 6.5 Km long Tilkiler Cave situated at 2 Km from the dam whose discovery played a crucial role in the grouting works which followed.
3. Explorations in the karstic regions around Kadinck II dam (Tarsus) including an aven of 90m depth which substituted a 100m borehold project by revealing the underground geological structure.
4. Exploration of Maraspoli underground river (Konya) which is used as source of energy and water supply for the nearby town Ermenek.
5. Explorations of Karasinir and Felengi caves providing important clues about the underground water system of Konya Plaine.
6. Exploration of YerkoprU Cave (Konya) related to the construction of YerkoprU-GBksu dam.
7. Water supply for the village Dalyan Koby and a neighbouring holiday village is obtained through speleological explorations from an underground lake situated nearby.

Résumé
Les recherches spéléologiques ont été excessivement importantes dans les travaux du génie civil en Turquie. Dans les constructions des Barrages et des Centrales Hydroélectriques, l'établissement des grands projets de l'irrigation et pour fournissage de l'eau potable aux villes et à des villages on a recours souvent à des recherches spéléologiques. Voyons quelques exemples:

1. Après la construction du grand barrage de Keban, il y a eu des fuites d'eau très importantes du lac du réservoir. Une de ces fuites s'ouvrait sur un système de grottes (Grotte de Petek) et pour le calmotage de ces grottes il a fallu faire une carte d'étalée de l'intérieur de ce système souterrain.

2. Le grand barrage-volte que l'on construit actuellement sur la rivière de Manavgat près d’Antalya, on a profité des explorations des Spéléologues; d’abord l’exploration de la grotte de Dumanlı d’où sort une des plus grandes sources karstiques (Vauculsiëna) du monde, ensuite l’exploration de la grotte de Dukanlı qui se trouve à une distance de 35Km du barrage, on a fait un essai de coloration sur la rivière souterrain qui parcourt cette grotte. Troisièmement, l’exploration de la grotte de Tilkiler qui se trouve à 2 Km de là, le barrage, les spéléologues ont démontré l’absurdité du rideau de l’injection. Avant l’exploration de cette grotte qui a une longueur de de 6.5 Km, les ingénieurs du barrage voulaient construire un rideau d’injection, puis par l’ameure et le grand développement de ce système souterrain, ils ont renoncé de ce projet qui était absurde à cause de l'impossibilité de combler les grands vides souterrains avec du ciment ou d'autres matériaux.

3. Pendant la construction de la Centrale Hydroélectrique de Kadinck II il y avaient des grottes et une de ces grottes c'était un aven de 90 m de profondeur. L’exploitation de cet aven a fourni des renseignements de grande importance et ainsi on supprimé de faire un sondage de 100m, pour voir dans quelle profondeur se trouvait le contact de de- faciès du calcaire d'âges différentes.

4. Le village d’Ermenek (Konya) se ravitaille en eau potable d’une rivière souterraine qui circule dans une grotte située sur une falaise, au pied de laquelle se trouve le village. La récupération de l’eau de la grotte par des tuyaux forcés au moyen d’un tunnel de 192m, et son utilisation comme source d’énergie fournit actuellement l’électricité à ce village.

5. Pendant les recherches des eaux souterraines dans les bordures de la plaine de Konya, les recherches spéléologiques dans les grottes de Karasinir (pumra) et de Felengi (Chianbeyli) ont donné des renseignements de grande utilité, et ainsi on a renoncé de faire deux sondages de 200m de profondeur d’au moins.

6. L’exploration de la grotte de YerkoprU a également fourni des renseignements très utiles aux ingénieurs qui ont construit la Centrale Hydroélectrique de GBksu-YerkoprU.

7. Le petit hameau de Dalyan Koby (izmir) et le petit village de vacances qui se trouve à quelques kilomètres de près, prennent leur eau potable d’un petit lac souterrain qui se trouve dans une grotte non loin de la mer. C’est grâce à l’exploration spéléologiques que ce projet fut réalisé. Car, sans cela, par un pompage excessif on aurait invité l’eau salée de la mer qui se trouve à 35 m seulement de la grotte.
Study of Features of the Karstic Depression in South China
Chen Zhiping
(Group of Karstology, Department of Geomorphology, Institute of Geography, Academia Sinica)
Beijing, 100011, People's Republic of China

Abstract
Fenglin and cockpit that widely distribute in South China are characteristic of tropical karst. The cockpit is an isolated hydrological system in which exists a subterranean drainage system formed by seepage water. Especially when flood pours into the cockpit, some features occur in association with the subterranean rivers. The approach to these features developed in this study is called depression analysis which is of some significance in predicting subterranean rivers and investigating the evolution of karst.

a. Features of lower depression zone and their relation to subterranean rivers
Every depression is associated with a subterranean drainage system, and the elevation of its bottom decreases in the direction of the flow. Thus, the contours may be drawn and intensive dissection of the depression may be made by the elevations of the bottom on a topographic map. The zone consisting of depressions with lower bottom elevation is called the lower depression zone. The depressions with higher bottom elevation is called the lower depression zone. The depressions with higher bottom elevation between two lower depression zones form the higher depression zone which implies the subterranean divide. This reveals the main characteristic of subterranean drainage system.

The longitudinal profile of the lower depression zone can be drawn by linking the bottom elevations of all the depressions in it, and all profiles, whether concave or convex, are consistent with and relate to the subterranean rivers. The relation equation is

\[ y = 0.0008 x^3 + 0.81 x \]

and the relation graph is shown in figure 2. The gradient \( \gamma_m \) and length \( L \) of the lower depression zone can be obtained from the topographical map. The elevation of underground water outcrop being known, the elevation of the subterranean river can be predicted by the following relation

\[ H_w' = H_w + \gamma_m L \]

b. The relationship between the gradient of the lower depression zone and the type of karst
It has been found in the investigations of small drainage basin that the size of depression increased downstream in the basin with concave profile and decreases in the basin with convex profile. Of two factors -- gradient and discharge -- influence the size of depression, the former is more important. When the gradient of the lower depression zone is less than 5\%, polje develops; when it is 5 - 13\%, polje is replaced by cockpit and uvala; and when greater than 13\% cockpit is dominant. The characteristics of subterranean passage-way are different from one type of depression to another. It indicates that each type of depression has its particular hydrodynamic process, and is dependent on the strength of downcut of rivers induced by tectonic movement. This hypothesis may also be applied to larger basins. South China is mainly in the Pearl River Basin with the greatest strength of downcut in the Middle reach and the strength gradually in both downstream and upstream. As a result, karst geomorphology may be divided into five zones, that is, a) Guang Tong-Guang Xi karstic plain zone; b) Polje and karstic valley zone in central Guang xi; c) Gui Shou - Guang Xi cockpit zone; d) Yun Gui plateau polje zone; and e) Yun Gui plateau Shen Pen zone. The type of depression in upstream and that in downstream are symmetric with cockpit zone as the central link, but different in evolution directions. Yun Gui Plateau polje zone and Shen Pen zone is in the process of destruction of the retrogressive erosion.
The gradient of low depression zone

Figure 2 The Relation Between Gradient of Subterranean River and of Low Depressive Zone.

Figure 3 The Distribution Map of Tropical Karst in Southern China.

Canonical Analysis in the Genus Troglocharinus Reitter and Some Other Related Taxa (Col. Catopidae)

Oleguer Escolà
Apartat de Corrcus 593, Barcelona 3, SPAIN

Abstract

Application of kluster analysis trying to solve the problem risen by the collection of species of the genus Troglocharinus, REITTER, 1908. Recently before the complex was divided in two genus: Speophilus JEANNEL, 1911 (=Perrinia REITTER, 1885) with 13 species or sspp. and Troglocharinus with 7 species and perhaps 12 or 13 sspp. All these taxa live in the NE of Spain, in Catalonia except two of them in Aragón.
Abstract

It seems that most terrestrial cave invertebrates have evolved from cryptozoic faunas of forests. It is proper to know the histories of the forest patterns and processes of evolution and distribution of cave-associated taxa. Specialization of taxa to montane "temperate" forest litter probably began with renewed uplift of the Appalachians, producing cool-moist forest habitats, in the early Tertiary if not the Mesozoic. Early or mid-Tertiary terrestrial dissection probably drained caves, but few terrestrial species may have occupied them. With major Tertiary penepelation, caves would have become fewer in number. A new set of terrestrial caves would be habitats at this time that Pleistocene or Miocene fluctuations pre-adapted montane litter faunas to come into the cave-containing lowlands during glacia. Faunas were restricted to caves as isolated populations during interglacials. This allowed the evolution of cave-limited taxa, which may have been able to disperse overland in later long-duration glacials.

Introduction

It is my belief that a knowledge of the geological, topographical, climatic, and vegetational history of central and eastern North America, especially in the Tertiary and Quaternary, is necessary to permit a meaningful interpretation of taxonomic and distributional data on terrestrial troglobites. To understand the cave faunas we must understand more than just the cave faunas, I take the view here that the terrestrial cave faunas are a special subset of soil and litter faunas of forests. To understand the faunas requires understanding the ancestors of the faunas and the history of the forests. This seems to me to be a fairly widely held and orthodox view, but discussion and dissent is certainly welcome in this symposium.

Much of eastern North America has been a permanently terrestrial site for the origin and evolution of terrestrial biotas for at least the Paleozoic. It is well known as a major center for the evolution of clams, crayfishes, and salamanders. The caves, of which over 10,000 are known, primarily occur in the Paleozoic limestones in and flanking the major Appalachian geological systems. Discussion will mostly stress the eastern Appalachians, but can be logically extended to the Ozarks and Texas as well. Introductions to regional geology and geomorphology can be found in King (1977) and Thornbury (1965).

The Appalachian's of our concern were uplifted in the Alleghenian orogeny, originating from the collision and marginal crumpling of the proto-European and African plates from about 300 million to about 250 million years ago. This formed the supercontinent Pangea. By this time some higher taxa of terrestrial invertebrates had already evolved in this area such as extant orders and families of land snails (Solem, 1979).

The Mesozoic

Mesozoic events pertinent to cave faunas remain speculative. The most significant was the breakup of Pangea, from about 250 million to about 200 million years ago, resulting in the formation of the Atlantic Ocean, and the separation of the then continuous floras and faunas of eastern North America and western Europe. There are several cave invertebrate groups that show American-European relationships that may date to this time. Evidence is slight in terrestrial settings, but may include the bicultural affinities of Xenotrechus and Pseudopithalmus carabids, and amaurophiine psephild beetles (Barr, 1974), and the cibollicean snail group of Tomocerus mississipiensis. Direct land connection to Europe was last severed by the Eocene rupture of a northern connection via the DeGeer Bridge across the north Atlantic. Predominant habitats were fairly widespread lowland tropical or paratropical forests. The excellent review of Matthews (1979) should be consulted for elaboration of all topics considered here, especially for its best available background summary for an evolutionary biogeography of North American terrestrial invertebrate faunas.

The Tertiary

If North American cave faunas are derived from ancestors most closely associated with mixed mesophytic forests, the history of these forests is a requisite to understanding the impact of change by their faunas. In the early Tertiary, the biotic connections of "Appalachia" were more to the westward, to western North America, and with the "Arcto-Tertiary Geoflora" of the Bering Bridge into eastern Asia. Many examples occur in taxa with such disjunct distributions and are remnants of former and more continuous distributions from the Appalachians (and Ozarks) to eastern Asia. These Tertiary forests lay at mid-latitudes from North America across the Bering Straits to Eurasia (Wolfe, 1975, 1979). Mid and late-Tertiary cooling and drying fragmented these forests through the uplift of the Rocky Mountains, the development of their rain shadow, and the formation of the Great Plains. The mesic forest connections to Mexico were restricted after the Oligocene, increasing aridity in the Miocene and Pliocene, extending (as for the forest itself) it may be that the Appalachians continued a climatically improved biota which has persisted with less change and less extinction.

The Pleistocene

A prevailing view of cave faunal evolution, championed by Jeannel and colleagues in France, sees the fluctuating climates of the Pleistocene as a prime factor in promoting the occupation of caves from ancestors that were (cryptophilic) inhabitants of deep litter or soil of montane forests and which were preadapted for life in caves (Barr, 1967, 1968). The interglacials were the times of isolation of the faunas in caves because of unsuitable epigean temperature and/or moisture conditions. The general biotic impact of the Pleistocene is well documented (in reference to cave faunas see Peck and Lewis, 1977; Peck, 1978, 1980). There is no need of a review of the idea here. These climatic fluctuations have prime responsibility for producing the community makeup and species distribution patterns observed today.

Schools of Geomorphology

If the Pleistocene was important in promoting cave occupation, an implication is that there would not have been much of a terrestrial cave fauna preceding when the Pleistocene climates were not drastically different. Minor fluctuating views of geomorphic history. Following a C. K. Gilbert view (Hack, 1965, 1969) of dynamic equilibrium, caves would have been about as prevalent now. As Mesozoic and Tertiary erosional downwasting of the Appalachians occurred, the elevation of the range was probably maintained by isostatic uplift. The alternate school of W. M. Davis is one of several cycles of uplift and penepelation. With
extensive Tertiary penplanation and low topographic relief, there would be available terrestrial cave habitats. Only with Plio-Pleistocene uplift and downcutting would they become exhumed, drained, and available. How much montane evolution (and preadaptation) of acestral stocks took place in the Appalachians depends on the degree of climatic and geographical characteristics. The Davis interpretation would have discontinuous existence of upper elevations, less climatic zonation, and little topographic relief to support habitat diversity. In the late Mesozoic the Schooley penplain, formed from degradation of the original mountains, was raised to heights reaching well over a kilometer, producing the highland block from which the present mountains were carved. Two Tertiary erosion surfaces were developed at lower levels.

The dynamic equilibrium concept would have continued uplands, more climatic zonation, and a continued rough topography (giving much geographical habitat diversity) — all assuring a higher biotic diversity. The widespread occurrence along the Appalachians of lignitic deposits ranging in age well over a kilometer, producing the highland block gave much geographical topography (giving much geographical diversity) — all assuring a higher biotic diversity. The widespread occurrence along the Appalachians of lignitic deposits ranging in age from Cretaceous to Pleistocene suggest the continued presence of sphagnum peat bogs and thus of uplands along the Blue Ridge throughout the Tertiary (Hack, 1969). The conifers Abies fraseri and Tsuga caroliniana are perhaps endemics of upland Tertiary Appalachian uplands and for many millions of years were the important refugia for this fauna during interglacials, and its replacement by a drier and more open boreal forest.

Glacials-Interglacials

Again, in the face of few invertebrate fossils, it is necessary to refer to the paleobotanical record, which is now allowing generalizations about the biotic stages of the cycles of Pleistocene glacials and interglacials in the southeastern United States. Modern reviews are Delcourt and Delcourt (1979), and Watts (1980a, 1980b). In summary, these show the virtual elimination of mixed mesophytic forests from the Appalachian area during full glacials, and its replacement by a drier and more open boreal forest. The Pleistocene is now generally seen as 1.6 million years in duration. The emerging pattern of climatic cycles is one of more complexity than the classic North American concept of four glacials and three interglacials, but the timing and number of cycles remains undisturbed. Also, the Pleistocene is now being seen (through the record of deep ocean cores) (Wright, 1976; Beatty, 1978) as a sequence of long-lasting to 100,000 years punctuated by significantly shorter interglacials of 10,000 to 15,000 years. We must be careful not to think that present interglacial conditions have been the norm, but rather the exception.

Short interglacials give comparatively short periods of population isolation and genetic differentiation in caves. Long glacials give increased opportunity for overland dispersal through deep forest litter or moss mats. Thus, if the interglacials were the times of maximum population isolation and evolution, the process could have been a rather rapid one. Morphological specialization may not have been so extreme in a low level "troglobite" of an interglacial to prevent it from acting as a troglobine in more favorable habitats, and potential to reoccupy suitable epigean litter or moss habitats and to use them for dispersal.

The upland sites of Tertiary evolution of a preadapted cryophile deep-litter or soil fauna were displaced to lower elevations where they existed for longer (glacial) periods of time. Lowland caves and other protected habitats, like caves and road cuts for gorge forests were the important refugia for this fauna during interglacials, rather than the alternative of retreat to more distant and higher elevations of the Appalachians themselves.

Taxon Pulses

Cave colonists were isolated at about the same time near the beginning of each interglacial. Thus there were synchronous and repeated pulses of cave occupation. This process was repeated and formed a generally repetitive and taxonomically patterned assemblage of species from site to site because of the similarity of the colonizing ancestral species. The whole cave community was sequentially built up this way (Peck, 1980). The relative sequence of the pulsed entry of taxa into caves should be identified by several lines of evidence. Degrees of both morphological and geographical separation from relatives can be used to reflect the passage of time since cave colonization.

In the preparation of a cladogram of the evolution of cave less taxa it should be possible to recognize the sequentially older speciation events. If the climatically controlled speciation model is correct, it should be possible to suggest points in time for the separation of clades of some groups of terrestrial cave occupants with more accuracy than will be possible for most epigean invertebrates. A case of this in Ptomaphagus cave beetles will be given elsewhere.

Community Ecology

The historical scenarios as proposed have implications for understanding the ecology of cave communities. The most significant would be that species interactions have been continually changing through the Pleistocene as new colonists occupy caves and others go extinct. Also, caves may be interglacial refugia, but not interglacial evolutionary traps for they may be ecologically "escapable" in the following glacial. The development of a historical ecology of caves must take into account the differing species mix between each set of glacials and interglacials. Cave communities are additive collections of different species, not intergraded interacting superorganizations, and have not gone through time as a climatically determined "Clementian" climax community with fixed associations. Rather, they are a set of species, each of which acts in an individualistic manner in response to change. The community cannot be considered to be in a state of equilibrium.
Evolution of Cave Cholevinae in North America (Coleoptera: Leiodidae)

S. B. Peck
Department of Biology, Carleton University, Ottawa, K1S 5B1, Canada

Abstract

Staphylinoid beetles with internal antennal sensory vesicles can be grouped into the apparently monophyletic family Leiodidae. The habits of the five subfamilies vary but most are forest litter inhabitants and scavenge or feed on fungi. Only the subfamily Cholevinae has extensively occupied caves. Within the rich cholevine fauna of Europe a remarkable troglobitic radiation has occurred in the tribe Bathycasini. In contrast, other tribes of Cholevinae occur in caves but troglobites are known only from North America, where 23 (out of 58 known) species of Ptomaphagus (Adelops) are troglobites (19 in the southeastern U.S.). Cave occupation has occurred separately in the genus in at least three major lineages. The troglobites are judged to be descendants from five non-troglobitic (edaphophilic) ancestors in temperate and tropical (montane?) forest areas. A phylogeny is proposed. Progress in the evolution of this radiation series is based on shared and reliable transferable complex characters are not easily detected. Species at different levels of cave adaptation can be placed into clusters that may indicate relative times of isolation and adaptation in repeated cycles of vicariant climatic isolation in caves during interglacials. Some distributions are best explained by overland dispersal of low-level troglobites through "boreal" forest moss-litter mats during glacials.

Introduction

Leiodids are the most important and diverse family of scavenging beetles in almost all temperate cave habitats. The family as used here contains the colonoids, catopids and leptinids of European usage. All these share many characters, including the synapomorphic internal antennal sensory vesicles (Peck, 1977a; Vandel and Szymczakowski, 1978) defining a monophyletic family of Staphylinidae. Zeick (1979) shows that Cholevinae has priority over Catopidae. Leiodidae generally are scavengers in soil and litter of forest ecosystems, and as such are eminently suited for cave occupation. More general biogeography of the North American species has been given in Peck (1982). I will discuss cave occupation in leiodoids in a phylogenetic sequence.

Subfamily Leiodinae

Most leiodines are winged and eye soil and inhabitants, feeding on fungi (some wingless and eyeless species are edaphophiles, or parasites of stingless bee nests). Aplytinus occurs as a troglobite in tropical America, especially in the West Indies. A recent population is wingless, while the same species in epigean lowlands is fully winged. With increasing elevation of epigean habitats a greater frequency of winglessness occurs (Peck, 1977b).

Subfamily Catopocerinae

Limited to North America, all members of the group are eyeless. The edaphobitic genus Catopocerus has 14 described species, of which 5 are known only from Alabama caves (Peck, 1974). Gricicaides Westcott, a remarkable example of convergence to European bathysciines, occurs in limestone and lava tube caves in Wyoming (Westcott, 1981a). This has the largest range for a North American troglobitic beetle.

Subfamily Cholevinae

This equals Catopiidae or Leptodirinae of other usage. Jeannel (1936) is the standard reference although many advances have been made since. The tribe Bathycasini is the great group of European cave scavenge beetles. Classifications and counts vary, but a remarkable radiation has produced about 580 species in about 120 genera. Some are soil and littter species, but most (80%) are troglobites (Laneyrie, 1969). Vandell (1965) summarizes their evolution. The only North American species (Platycholes) live with ants and termites in the Pacific Northwest. The most ancestral character states for the tribe. North America is probably not their site of origin, but a refuge for a primitive Asian lineage that made a Tertiary crossing of the Bering Bridge. The nearest known Asian relatives are near Vladivostok. Their absence in eastern North America suggests their presence for origin in Europe after the opening of the North Atlantic at the beginning of the Tertiary.

The tribe Eucatipini of tropical America contains Eucatius which occasionally occur in caves as troglobites.

The tribe Ptomaphagini is the primitive New World cave-occupier, and ecologically mirrors the bathysciines, but not in phyletic diversity. The basal stock seems to be close to Ptomaphagus, but the other derivative genera and other tribes will be discussed first. Adelopsis occurs in southeastern U.S. and Neotropical caves, but only troglobites are known (Peck, 1977b). Ptomaphagus is a relic in litter, soil, and caves in Mexico and the Greater Antilles (Peck, 1973b, Doccu, 1974). Dissochaetes are not known. This genus seems ancestral to Ptomaphagus of southeastern Asia, where some species occur as troglophiles (Peck, 1978a). The tribe Nemadini contains no troglobites, but Dissochaetus occurs as troglophile species in Mexico (Peck, 1977c). The tribe Cholevini, when compared to Europe, is poorly represented in North America, where there are only facultative troglobites. Catops and Sciordopoides occasionally scavenge in caves. Priocatacinus (Say) is a widespread forest inhabitant frequently using caves as climatic refugia at the southern edges of its range (Peck, 1977d).

Ptomaphagus

This genus, with 58 known New World species in the subgenus Adelops, is ecologically varied. Species live in forest litter and in various animal nests and burrows, while some montane forest species have reduced eyes and wings, and others are facultative and obligate troglobites, or troglobites. The genus can be divided into subgenera and species groups based on various characters. The seemingly most-basal hirtus group in the basal subgenus Adelops contains most of the troglobites (19 restricted to the southeastern U.S.). This seems to be a case where troglobites survive as relics of archaic lineages. However, the interpretation is questionable because the group is based on shared plesiomorphies, such as simple spermathecal morphology, rather than non-convergent synapomorphies.

Evolution in the Hirtus Species Group

Much on this subject has been published (e.g., Peck, 1973b. Peck and Lewis, 1978a). I will summarize mostly new information and thoughts. The group seems a descendant of Tertiary forest edaphophiles. A remnant of this line is P. hirtus, an edaphophile of the Ozarks. Two ancestral lineages in the southeastern U.S. speciated during interglacial restriction to caves (or deep soil of climatic refugia). The northern species formed the hirtus species cluster with three members, now in caves in Kentucky, Illinois and Tennessee. A southern species formed the loadingi species cluster with 16 species in caves in Tennessee, Alabama, and Georgia. Unraveling species identities and characteristics has involved electrophoretic analysis of degree of genetic similarity. Some distributions are best explained by overland dispersal of low-level troglobites through "boreal" forest moss-litter mats during glacials.
segregate themselves into distinct allopatric and monomorphic populations in regions where sympatry would be expected (Peck, 1975, and unpublished). A cladogram of species phylogeny is presented, but unfortunately space does not allow a discussion of the characters upon which it is based.

This picture of evolution is very different from an earlier one. There is now seen to be a more elaborate hierarchy of lineage splitting. P. shapardi in the Ozarks, the absence of montane edaphophilic ancestors in the Appalachians, and distribution patterns of other edaphobitic leiodids, indicates that the hirtus group ancestors may have been occupants of medium or low elevation mesic forests, and not necessarily montane forests as earlier stressed. The comparatively few descendant species of limited areal extent suggest that the ancestral edaphobitic species are few (two) and limited to a few areas of the western and southern margins of the Cumberland Plateau (explaining their absence from thousands of seemingly suitable caves, mostly in the Appalachian Valley). Comparatively low levels of troglobitic specialization may indicate cave occupation in only the later half of the Pleistocene. Life cycle studies (Peck, 1975a, and unpublished) would be expected (Peck, 1975, and unpublished).

A cladogram of species phylogeny is presented, but cannot be discussed in detail elsewhere. Out group comparisons with non-troglobitic Ptomaphagus and other Ptomaphagini. Potentially convergent (cave dependent) characters marked with asterisk.

The consobrinus species group
This group, based on a more elaborate spermathecal shape, contains 13 species, mostly in the U.S., but with some in Latin America. Most are free living or nest and burrow inhabitants, but two are montane edaphobites of New Mexico, two are troglobilises in Arizona and Guatemala (Peck, 1973b, 1977c, 1978b, and 1980). Two separate cave restricted lineages occur, and montane preadaptation is questionable.

The cavernicola species group
This group is based on an even more elaborate spermathecal shape, contains two species, and most are seemingly obligately troglophilic. P. cavernicola-like ancestor, and probably represent two cave occupations from one preadapted montane lineage (Peck, 1973b, 1977c).

Table 1. Character state analysis for figure 1. To be discussed in detail elsewhere. Out group comparisons with non-troglobitic Ptomaphagus and other Ptomaphagini. Potentially convergent (cave dependent) characters marked with asterisk.

<table>
<thead>
<tr>
<th>Number</th>
<th>Character</th>
<th>Character State</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>spermathecal shaft</td>
<td>longer, thinner</td>
</tr>
<tr>
<td>2</td>
<td>spermathecal orifice</td>
<td>posteriorly oriented</td>
</tr>
<tr>
<td>3</td>
<td>aedeagus</td>
<td>curved</td>
</tr>
<tr>
<td>4</td>
<td>*mesosternal carina</td>
<td>lower</td>
</tr>
<tr>
<td>5</td>
<td>pronotal stripe</td>
<td>present</td>
</tr>
<tr>
<td>6</td>
<td>*eyes</td>
<td>cluster of facets</td>
</tr>
<tr>
<td>7</td>
<td>spermathecal shaft</td>
<td>not or slightly expanded</td>
</tr>
<tr>
<td>8</td>
<td>posterior end of spermatheca</td>
<td>small</td>
</tr>
<tr>
<td>9</td>
<td>spermathecal crest</td>
<td>straight</td>
</tr>
<tr>
<td>10</td>
<td>aedeagal tip</td>
<td>upturned</td>
</tr>
<tr>
<td>11</td>
<td>hind pronotal sides</td>
<td>curved</td>
</tr>
<tr>
<td>12</td>
<td>*body size</td>
<td>smaller</td>
</tr>
<tr>
<td>13</td>
<td>*antennal segment III</td>
<td>subequal to II</td>
</tr>
<tr>
<td>14</td>
<td>*antennae</td>
<td>shorter</td>
</tr>
</tbody>
</table>

The remaining three, seemingly more advanced, subgenera of Ptomaphagus (Tupania in tropical America, and Morocius and Ptomaphagus s. str. of Eurasia) do not have any cave-specialized species.

Literature Cited

Other Subgenera

mentally limited the capacity for overland dispersal in glacials. The timing of cycles of glacials and interglacials is from Harmon et al. 1977, based on the use of geochemical isotope techniques to determine the time and temperature of deposition of cave stalagmites. However, there is still too much variation to give more than a rough framework upon which to hang biological events (see also Harmon et al. 1978a, 1978b). Interglacials are shown of greater duration than generally indicated by marine cores. The actual picture (including the effects of interstadial climate changes) may be more complex, suggesting greater difficulty in matching biotic and climatic events. If there was a "great interglacial" from 280,000 to 400,000 years BP (Harmon et al. 1977), it would have been a period of pronounced cave restriction and adaptation (or extinction).
Introductions to the Symposium on the Review and Synthesis of the Evolution and Zoogeography of North American Terrestrial Cave Faunas

**S. B. Peck**
Department of Biology, Carleton University, Ottawa, K1S 5B6, Canada

**Abstract**

The purpose of the symposium is to address questions of pattern and process in the evolution and distribution of major groups of cavernicolous terrestrial invertebrates in North America. Participants may review the number and distribution of cavernicolous taxa; the number of independent cave occupations by ancestral stocks; the relative importance of speciation before and after cave occupancy; the importance of predation and extant faunas and the size of the developing cave faunas; if distributions show disjunctions and what caused them (plate tectonic or Pleistocene or other events); if levels of disjunction and specialization show taxonomic changes in time and space; whether these are related to Pleistocene climatic (vicariance) events; if ecological factors like competition prevent sympathy and keep communities simple; if these above factors operate on the troglobitic faunas and their ancestors; and where do we go from here in attempting to seek and synthesize an understanding of the dynamics of the origin of terrestrial cave faunas.

**Introduction**

Twenty-two years ago, in 1959 in Chicago (Barr, 1960), a symposium was held on speciation and raciation of North American caves. Since that time and symposium on the evolution and distribution of our cave faunas have appeared, many involving people attending and participating in these meetings. Also, in the same time, significant advances have been made in the theoretical understanding of faunas in the fields of evolution, systematics, zoogeography, and ecology. These will be familiar to specialists, and the current interest or argument are cladistic analysis of phylogeny, island biogeography, the evolution of community structure, and vicariant biogeography (Platnick and Nelson, 1978; Rosen, 1978).

Additionally, there has been another twenty years of field work in the biological exploration of North American caves. Another new vista has come in this time in allowing perspective on latitudinal gradients in caves with the prolific collections that have come from caves in tropical America, especially in Mexico, Guatemala, and the Greater Antillean Islands.

It is the intended aim of this symposium to summarize advancements in our understanding of various groups of troglobites; in their taxonomic makeup, to see in what patterns these taxa occur, and to suggest what were the processes that produced the taxa and the patterns. It is unfortunately that we do not have specialists available to summarize significant invertebrate groups such as spiders, millipedes, and phasmid beetles. Because of this inability to be with us, I would like to mention some sample work on these groups: on spiders by Gertsch (1973, 1974, 1977) and on millipedes by Shultz (1969, 1971, 1972, 1977) and the late Nell B. Causey (1977). There are groups that contain troglobites that are not because they are extant and with two or fewer species to establish good patterns for analysis. These are mostly aquatic, and may be supportive of the evolutionary hypothesis of Howarth (1980). There are, in addition, many groups that do not have a significant evolutionary association with North American caves, and these too have been excluded. Examples are annelids, chilopods, thysanurans, dermapterans, hemipterans, psocopterans, lepidopterans, dipirens, and staphylinid beetles (even though these may be very significant in an ecological role in cave communities).

The symposium will help to introduce our troglobite faunas in a wide perspective to our overseas visitors, and should do the same for North American specialists. It should be especially productive in helping to make comparisons and contrasts between the rich cave faunas of Europe and Japan with those of North America, especially in features that have not been since the synthesis of Vandel (1965). The information and idea interchange should be stimulating.

The study of the evolutionary biology of troglobites is concerned with two intertwining subjects; process (such as natural selection and the adaptation of organisms) and historical events (the development of phylogenies). I see a need for attempting Hennigian-cladistic analyses of morphological characters, and their transformations in proposing phylogenetic hypotheses of troglobites and their ancestors (Platnick, 1977, 1979). However, this is no easy task. We recognize that the problems of convergence and parallelism are exceptionally manifest in troglobitic lineages, as we see there being a paucity of character specializations (amorphies), which when shared (synapomorphies) give evidence of relatedness (Farris, 1979).

Not until we establish these can we propose hypotheses of evolutionary biogeography based on a sequence of phylectic branching, rather than upon an unsuit "classification". The evolutionary biologist must as well be familiar with historical aspects of geology, geography, and climatology, because all taxa and their characteristics are the result of past events, patterns, and processes. Helpful steps in the sequence of forming biogeographic hypotheses may be: 1. Based on the recency of common ancestry, hypothesize the recency of faunal connections (this may be crudely estimated by summing the distributions of extant faunal elements); 2. Determine if other organisms share the same patterns of recurrence of faunal connection, suggesting a common causal agency; 3. Attempt correlation of the data with historical geology-geography-climatology, using either or both a vicariance and dispersal model, depending on the available vagility and other biological-ecological characteristics of the species; and 4. Prepare to alter the hypotheses in the light of new information about taxa, cladistic relationships, and distributions.

In summary, we should proceed from alpha level taxonomy of troglobites, to examining the phylogeny and distributional patterns of the troglobites and their non-troglobitic ancestors, and then hypothesizing the processes that have produced the taxa and the patterns.

With this as a theoretical preamble, we should review some of the historical considerations that may have shaped the processes and patterns developing the terrestrial invertebrate troglobite faunas of eastern North America, and those of the epigeic ancestors from which they are descended.

**Literature Cited**


The discovery of a Pleistocene fossil hominid from Greece in 1960 proved the existence of the Archanthropic stage in Europe during the Lower and Middle Pleistocene.

The ancestors of the Petralona cave-dwellers did not live in caves (A. N. Poulianos, 1980). Man first entered caves because of the ever-changing climatic conditions.

Systematic excavations of the Petralona cave, where Archanthropus europaeus petralonienis died, were begun in 1968 under the direction of Dr. Aris N. Poulianos, with the participation of this author, and are still under way.

Stratigraphy

The ancient climatic conditions are investigated with the stratigraphy which is revealed in the cave. The sequential deposition of strata corresponding to various geological periods depends on the climate of each period. The various strata which constitute the material in a section of the cave floor vary in color and texture of the earth and the find content (paleoanthropological, palaeontological, archaeological, palaeobotanical etc.). The thickness of the layers uncovered in a section is greatest near the cave's original entrance and least in the interior of the cave. Thus the thickness ranges from 2 cm to approximately 2 m.

As the number of the layers increases, proceeding deeper into the earth, the age of a find within that layer also increases. At the present time 27 layers have been uncovered up to now. Layer 27 remains the deepest and thus the oldest. It is possible that future sections will disclose even older layers.

The Alternations Between Layers

Layer No. 2 is dark brick-brown and within it many local pebbles. There are found many stone and bone tools, food refuse, various big and small mammals, and seeds from trees. The microfauna points to a humid and rather cold climate (M. Kretzoi, 1977, M. Kretzoi and N. A. Poulianos, 1981).

The following layer, 3, is narrow, yellowish-red and relatively hard. In this layer no microfauna or seeds are found. Also human activity is less noticed. Apparently we deal with a pretty warm climate.
and quite dry period, probably an "interglacial" one. Layers No. 4, 6, and 8 look very much alike as the 2nd one, and No. 5, 7, and 9 like the 3rd one.

The 10th layer is a stalagmitic "tile" of about 5 cm thick, which divides the whole cave stratigraphy into two parts: the upper and the lower. Thus the tenth layer is an important landmark in the cave's stratigraphy, corresponding to another long interglacial period. N. Poulianos (1981) named this period Thracic, probably corresponding to the Günz-Mindel interglacial of the alpine nomenclature. Thus layers of the upper part (2-9) are considered of belonging to the Mindel glacial, or Early Middle Pleistocene, while layers of the lower part (1-10) are considered of belonging to the Günz glacial period, or Lower Plistocene. Because it is difficult to apply at all times in new areas the alpine nomenclature, A. N. Poulianos (1977) named the upper group of layers "The Petralonian" period, the lower "The Crenian" period.

The Crenian period begins with the 11th layer, which the known skull and skeleton of Archanthropus europaeus petraloniensis was found in. The color of the soil is also dark brown, and the evidence of human activity is very intense. The microfauna points to a humid and cold period, during which the arcanthropinae preferred to live inside the cave (A. Poulianos and Kurten, b., 1981, in press). The vertebrates of this layer match those of the Biharian period and the Cromer-type vertebrates, which lived in the temporal vicinity of the Brunhes/Matuyama boundary. The following layer is narrow, yellowish-red and relatively hard. In this layer not even traces of microfauna or seeds are found. Apparently rodents remain outside during warm periods or hide elsewhere. This sequence of layers is, to a certain extent, going all the way down to the 27th layer with some exceptions of definite character. It is important here to underline the fact that in most of the layers there are found stone and bone tools, remains of food, traces of fire, and other signs of human activity. Besides the skeleton of the 11th layer, there were found in different layers parts from other skeletons of Arcanthropinae.

The Dating

The relative dating done with the faunal and microfaunal material, as it was already mentioned, gives an age of Late Lower Pleistocene for the Crenian period (including the 11th layer of the "Mausoleum", where the Archanthropus was found), and Early Middle Pleistocene for the upper, the Petralonian period. The absolute dating is mainly based on the stalagmitic material with different methods.

The top stalagmitic layer tested in different laboratories (Canada, England, Germany, Japan) with the U/Th series gives an average of 300,000 years (see extended bibliography). The same result is taken with the ESR (Electron Spin Resonance) method in Japan, and with TL in England and Germany.

The absolute date for the Mausoleum's 10th layer achieved by Ikeya (1980) using the ESR method is 670,000 years. The Uranium/Thorium method (Schwarcz et al., Hennig et al., Lyritzis, 1980) gives Lower Middle Pleistocene for this layer, that is ages of over 400,000 years, which is the upper limit for U/Th.

Recently the paleomagnetic method was used on the stalagmite of the 10th layer from the Mausoleum by Alf Latham, which he tested in the magnetometer at Toronto. It was reversely magnetized. Thus the stalagmite is probably greater than 700 ka, and it is of the Matuyama chronology in age (Letter to the Anthropological Association of Greece from 25-8-1980).

In conclusion, all dating, relative and absolute, point to an age greater than 700,000 years for the skeleton of Archanthropus from the Mausoleum. It is natural, that parts of skeletons, animal and human, found in deeper layers are much older in age. The Petralona cave, up to today, is the best dated cave in the best dated cave in the world. The Archanthropinae of this cave is the oldest people of the European continent, and its lithic technique the oldest "civilization" of Europe. The traces of fire are the oldest traces found up to today in the world.

All data of the excavations, which are still going on, prove that Archanthropus europaeus petraloniensis is autochthonous to the area.

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Poulianos, A. N. and N. A. Poulianos: The age of the Miocene fauna at Micralona-Trillia.
Stringer, Chr.: The Phylogenetic position of the Petralona cranium.
Photo 1: The entrance to the Petralona Cave, Greece.

Photo 2: "Aristotle's Hall" at Petralona Cave, Greece.

Photo 3: *Archanthropus europaeus petraloniensis* from Petralona Cave, Greece.
Karst Development in the Front Royal 7.5 Minute Quadrangle of Virginia

David A. Hubbard, Jr.
Virginia Division of Mineral Resources, P.O. Box 3667, Charlottesville, VA 22903
Department of Biological Sciences, Old Dominion University, Norfolk, VA 23508

Introduction

The Front Royal 7.5 minute Quadrangle is situated primarily in the Shenandoah Valley of the Valley of the Valley and Ridge province of Virginia, U.S.A. (Figure 1). The North and South Forks of the Shenandoah River coverage along the western edge of the carbonate belt. The northeast-trending Cambrian and Ordovician carbonates range in attitude from gently dipping to steeply overturned. Along the south and southeast margins of the quadrangle, noncarbonate rocks of the Blue Ridge Complex, the Catoctin Formation and the Chilhowie Group are thrust over the carbonates. Intermediate scale karst landforms were observed by stereo use of low altitude (6,100 m/ aerial photography and recorded on a 1:24,000 scale topographic map. Patterns of these features, sinkholes and caves, are observed to relate to lithologic and structural trends, as well as geomorphic features associated with the Shenandoah River.

Geologic Control of Karst Development

The karst-bearing carbonate units of Front Royal Quadrangle are bordered to the west by the clastic units of the Front Royal quadrangle are summarized in Table 1. The Rockdale Run Formation dominates the karst development of the area. Abundant sinkholes and numerous caves are found within this unit (Figure 2). North of the confluence of the Forks of the Shenandoah River, karst development in the Rockdale Run Formation extends along the axial trace of a south-southwest plunging anticline into the Lincolnshire, New Market and Edinburg units. A adjacent anticline, which is breached by the Shenandoah River to the east, also shows sinkholes development along its axial trace. In the southwest part of the quadrangle, aggressive surface runoff from the noncarbonates thrust over the Rockdale Run Formation has contributed to the solutional development of this carbonate unit. In addition to the numerous sinkholes observed, 45 of the 60 caves in the quadrangle are located in this approximately five square kilometer area of carbonate. However, much of this solutional development is also due to geomorphic influences of the Shenandoah River.

Geomorphic Control of Karst Development

Lithologic differences may be responsible for much of the karst development observed on the various carbonate units, however, geomorphic features complicate these patterns. Locally, entrenchment of the Shenandoah River has resulted in river bluffs and steepened hydraulic gradients. Sinkhole development is enhanced by these anomalous gradients. The resulting concentration of sinkholes along the river bluffs extend into carbonates units otherwise containing only sparse solutional development (Figure 3). Hack (1963) observed such development of sinkholes along the large streams of the Shenandoah Valley.

Terrace gravels are another geomorphic feature which complicates the pattern of sinkhole development in the Front Royal area (Figure 3). These gravel-covers diffuse infiltration and result in a deep soil development which appears to inhibit surficial expressions of karst activity (Hack, 1960).

References

Table 1
Geologic Formations of Front Royal Quadrangle (adapted from Rader and Biggs, 1975)

<table>
<thead>
<tr>
<th>Age</th>
<th>Rock Units</th>
<th>Thickness (meters)</th>
<th>Lithology</th>
<th>Karst Development</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUATERNARY</td>
<td>Terrace deposits</td>
<td>0-8</td>
<td>pebbles and cobbles of sandstone and quartzite in matrix of clay, silt or sand</td>
<td>sparse, inhibits surficial expression</td>
<td>tb</td>
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<tr>
<td></td>
<td>Martinsburg Formation</td>
<td>914+</td>
<td>shale, some sandstone, minor limestone</td>
<td>rare</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oranda Formation</td>
<td>5</td>
<td>siltstone</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Edinburg Formation</td>
<td>133+</td>
<td>shale, limestone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ODOVICAN</td>
<td>Lincolnshire Formation</td>
<td>8-15</td>
<td>limestone with blocky chert</td>
<td>sparse except on anticline north of confluence of the Forks of the Shenandoah River</td>
<td></td>
</tr>
<tr>
<td></td>
<td>New Market Limestone</td>
<td>0-10+</td>
<td>limestone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rockdale Run Formation</td>
<td>732</td>
<td>limestone, dolomite limestone, dolomite and lenses of sandstone and chert</td>
<td>sinkholes abundant, contains 52 of the 60 caves of the quadrangle</td>
<td>Orr</td>
</tr>
<tr>
<td></td>
<td>Stonehenge</td>
<td>183-198</td>
<td>limestone</td>
<td>rare</td>
<td>Ost</td>
</tr>
<tr>
<td>CAMBRIAN</td>
<td>Conococheague Formation</td>
<td>701</td>
<td>ribbon-banded limestone and dolomite and thin dolomitic sandstone</td>
<td>sparse, except north of Shenandoah River</td>
<td>Gco</td>
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<tr>
<td></td>
<td>Elbrook Formation</td>
<td>610+</td>
<td>limestone, dolomite limestone, dolomite and dolomitic shale</td>
<td>sparse, except blind valley along contact with Conococheaque Fm.</td>
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<tr>
<td></td>
<td>Waynesboro</td>
<td>244+</td>
<td>shale with some sandstone, limestone and dolomite</td>
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<tr>
<td>PRECAMBRIAN-CAMBRIAN</td>
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<td></td>
<td>clastics volcanics and plutonics</td>
<td>none</td>
<td>GpGu</td>
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</tbody>
</table>

Figure 1: Physiographic Province and Location Map of Virginia
Figure 2: Geologic Control Of Karst Development Of The Front Royal Quadrangle
Figure 3: Geomorphic Control Of Karst Development Of The Front Royal Quadrangle
Krarst Development in Rye Cove, Virginia

David A. Hubbard, Jr.
Virginia Division of Mineral Resources, P.O. Box 3667, Charlottesville, VA 22903
John R. Holzinger
Department of Biological Sciences, Old Dominion University, Norfolk, VA 23508

Abstract

Rye Cove is a small karst plain located in the southwestern part of the Valley and Ridge province of Virginia, U.S.A. Intermediate-to-large scale landforms were located by low altitude aerial photography. Lineaments, observed from aerial photographs, correlate with karst features. Patterns of sinkholes, blind valleys, and lineaments correspond to the structure of Ordovician carbonate bedrock. The dominant structure of the karst is the Rye Cove syncline. Karst features are observed to correspond to the resulting skewed parabolic trends of the Ordovician rocks. Blind valleys in the cove transect the Blackford Formation. The overlying Rye Cove Limestone contains the blind valley termini and major caves and is an area of uniformly high sinkhole density.

Karst is sparsely developed in the overlying Benbolt and Wardell Limestones. A notable exception is the surficial expression of the karstic system into the Benbolt-Wardell limestones. The surficial karstic system into the Benbolt-Wardell limestones has a high solubility of this limestone tends to obscure such features. The surficial karstic system into the Benbolt-Wardell limestones is due to the presence of a minor anticlinal fold in the Rye Cove Limestone, south of and adjacent to the Rye Cove synclinal axis. The anticlinal fold laterally channels the waters of the cave system into the Benbolt-Wardell limestones to the north (Figure 2).

The other major caves of Rye Cove, Cox Ram Pump and Franklin, are connected and their waters trend due south. These subsurface waters probably continue to the southeast to join the waters of the AFMJ system upstream from Natural Tunnel. The waters of the AFMJ system have been traced to a series of springs along Mill Creek, just south of its junction with Taylorsville Branch. These springs flow at a rate of 3.8 to 4.2 x 10^4 l/day (Holzinger, 1968, 1975).

Geologic Control of Karst Development

The Rye Cove syncline plunges to the northeast. Surface expression of the various carbonate units of the cave system follow a skewed parabolic curve defined by the fold (Figure 2).

The Mascot Formation, a cherty dolomite containing some conglomerate near its top, is the oldest unit showing karst development in Rye Cove. The upper half of the unit represents the outer edge of the karst plain. A number of blind valleys extend into the unit as a result of headward erosion. Surface drainage is common over the Mascot (Figure 2). The Mascot Limestone is the syncline of the Rye Cove syncline. This unit contains five of the six major caves (Holzinger, 1968) and the termini of most of the blind valleys in Rye Cove. The sinkhole density of this unit is the highest of any of the Ordovician carbonates represented. Subsurface drainage is the rule in the Mascot Limestone (Figure 2).

The Benbold and Wardell Limestones are stratigraphically the highest units containing karst development in Rye Cove. These argillaceous limestones have minimal karst development except in the vicinity of Jackson Creek (Figure 2). These limestones contain a number of blind valleys of the Blackford Formation.

The Mascot Limestone contains the karstic system into the Benbolt-Wardell limestones. The Mascot Limestone is the syncline of the Rye Cove syncline. This unit contains five of the six major caves (Holzinger, 1975) and the termini of most of the blind valleys in Rye Cove. The sinkhole density of this unit is the highest of any of the Ordovician carbonates represented. Subsurface drainage is the rule in the Mascot Limestone (Figure 2).

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An important lineament intersects the edge of the south portal of Natural Tunnel, southeast of Rye Cove, and extends into Rye Cove where it fades out in the highly soluble Rye Cove Limestone. This lineament is also observed on LANDSAT imagery, where it can be seen to continue through an intersection with the resurgence springs on Mill Creek (Figure 3).
References

Figure 1: Physiographic Province and Location Map of Virginia

Figure 2: Geologic Control of Karst Development in Rye Cove
Figure 3: Lineaments In Rye Cove
Les déterminations expérimentales de la solubilité de la dolomite dans l'eau, à la température ambiante et en présence de dioxyde de carbone, ont fait l'objet de plusieurs travaux (cf. par exemple les données rapportées par Muxart et Birot (1977). La dolomite est nettement moins soluble que le calcite et sa cinétique de dissolution est très lente. Dans le domaine de température et de CO₂, rencontré dans le milieu karstique, la dissolution du sel ne semble congruente qu'au-dessus de 25°C. Pour des températures très basses, Mg paraît être plus soluble que Ca. Par ailleurs, la solubilité de chacun des deux sels (calcite ou dolomite) diminue en présence de l'autre, conformément à l'effet d'ion commun bien connu (Muxart, 1974). Dans le milieu naturel, le problème est beaucoup plus complexe et les pulsations de l'activité en nombre de paramètres dont l'importance relative n'est pas toujours bien appréciée (données climatiques, pédologiques, micromilieux...). Les conditions des sédiments et des eaux, de même que l'effet des variations de l'activité végétale, des teneurs du CO₂ et des substances organiques, fluctuent en prises d'autres solubles dans les eaux, etc....). Ces différents paramètres peuvent agir à tour de rôle, ou conjointement, sur la cinétique de dissolution et la solubilité des deux carbonates. D'autre part, selon que le milieu karstique est naturel ou que l'on se tient au dessus ou lègerement au dessous de l'émergence de la source, la dissolution de la dolomite est un phénomène irréversible, puisque seul le carbonate de calcium précipite à partir des solutions. II résulte de ces considérations que le rapport des concentrations des ions Mg et Ca dans les eaux naturelles karstiques (R = Mg(m~1)/Ca(m~1)) peut être très variable. Il dépend tout d'abord de la nature de la roche constituant le substrat et l'on peut considérer que la valeur de R est faible dans les calcaires, supérieure à 0,5 - 0,6 dans les calcaires dolomitiques et égale ou supérieure à 1, dans les dolomies. R est aussi fonction des conditions climatiques et de l'interaction de la température des eaux (dissolution non congruente de CaMg(CO₃)₂). Enfin, dans le cas d'un système karstique donné, la solubilité des minéraux carbonatés dépend de l'interaction des divers facteurs cités précédemment et de leurs fluctuations. On peut en déduire que les valeurs de R des émergences de ce système seront variables au cours de l'année. Plusieurs auteurs ont déterminé les valeurs de R des eaux de sources issues de karst plus ou moins dolomitiques, en fonction des saisons. Selon Marker (1975), qui a travaillé sur les karsts dolomitiques du N-E du Transvaal en Afrique du Sud, R est maximum pour les sources pendant la période des pluies du printemps et de l'été austral; l'inverse se produit pour les eaux de surface. Pour Nicod (1966), qui a étudié de façon très détaillée le régime de quelques sources karstiques de Basse Provence, en France, R est maximum en saison sèche, c'est-à-dire en été ou au début de l'automne. Il nous a paru intéressant de reprendre l'étude de Nicod, sur ce point précis, en comparant les variations du rapport Mg/Ca de deux émergences de Basse Provence dont l'une est alimentée par un aquifère à prédominance calcaire et l'autre par un karst essentiellement dolomitique. Nature des aquifères et localisation des sources Le Basse Provence calcaire, située dans le S-E de la France, couvre deux ensembles pétrographiques distincts soumis à la karstification : les unités du Jurassique et du Crétacé inférieur et la série du Trias. Les travaux de Muxart et Birot (1977) ont permis de préciser l'étude remarquable sur les régimes des sources karstiques de Basse Provence (1969) ont montré que la circulation de l'eau souterraine est différente selon les bassins karstiques. Dans les karsts triasiques, la circulation est du type phréatique et le régime des sources présente des fluctuations amorphes et de débits de base soutenus. Les unités jurassiques se trouvent en position de karst barré. La circulation de l'eau est vadose au dessous ou légèrement au dessous du niveau de l'émergence de type vauclusien. Elle est phréatique dans les zones plus profondes. Le régime hydrologique de ces exergences est varié et dépend de la nature de la roche et de sa porosité et des caractéristiques des conduits karstiques. Ainsi, Nicod (1969) distingue t - il les régimes: domaniaux, atténués, type discontinu, type mixte et de type malé. Ces différents types se retrouvent pour les réseaux complexes adretants ou la circulation profonde plus lente assurant un stockage important. Les deux sources étudiées font partie des exergences des plateaux varois (altitude comprise entre 200 m dans la zone centrale et plus de 500 m dans la partie N-E). La source d'Argens à Seillons est située à l'ouest, à 270 m d'altitude. Elle apparaît au contact du karst barré du plateau de Selves et des argiles vindoboniennes du Bassin de Bruns-Auvisse. Elle traverse les calcaires jurassiques du Jurassique supérieur du plateau de Selves et des plateaux disposés à l'est et au nord de la Montagne Sainte Violette. Nicod (1976) lui attribue un bassin d'alimentation s'étendant sur 3 km². Le régime hydrologique est du type mixte (Nicod, 1969). La source du St Rosaire à Tourtour, jaillit à l'est, à environ 660 m d'altitude, au contact des dolomies du Jurassique supérieur et des marnes du Keuper. Son bassin d'alimentation s'étend sur 135 km² (Montagne de l'Espiguèrèes). Elle est caractérisée par des débits sensiblement constants tout au long de l'année (Nicod, 1969 et 1976), la circulation de l'eau s'effectuant lentement au travers des dolomies très poreuses. Dans les deux cas, la zone en amont des sources est couverte par une maigre fôret composant des taillis de chênes pubescents associés aux buis sur l'ubac et des chênes verts adaptés à la sécheresse de l'été, sur l'adret. Données climatiques Le climat des plateaux varois est du type méditerranéen, et tendance continentale. Les précipitations moyennes annuelles calculées sur une période de 25 ans (1951-1975) dans les trois stations de Barjols (256 m), Cotignac (380 m) et Aups (500 m) (transact SW-NE) sont respectivement égales à 790,4, 830,4 et 822,1 mm. Les valeurs des précipitations annuelles (P) et les courbes de répartition des précipitations mensuelles pendant la période d'étude des sources (1977-1980) sont représentées sur la figure 1. Le maximum du régime pluvial annuel est le plus souvent très marqué. Il se produit généralement en automne mais peut être décalé vers l'hiver (hiver 1977-1978). Le quantifié d'eau tombée ainsi peut atteindre 40 % de la valeur de P (octobre 1979). Les mesures de températures se rapportent à la station de Cotignac. La température moyenne annuelle calculée sur 4 ans est de 12°C. Décembre (6,1°C) et surtout janvier (4,5°C) sont les mois les plus froids, juillet (20,4°C) et août (19,4°C) les mois les plus chauds. Résumé Cette étude a permis de comparer et de préciser le sens des variations saisonnières des concentrations de Ca et de Mg, de la teneur globale Ca + Mg et du rapport R = Mg(m~1)/Ca(m~1) en fonction des débits de 2 émergences de karst karstique en région méditerranéenne, alimentées par des aquifères calcaire ou dolomitique. Abstract The seasonal variations of calcium, magnesium and Ca + Mg concentrations and of R = Mg(m~1)/Ca(m~1) are attempted to be related to the water discharge of two karst springs from mediterranean area, with limestone and dolomitic aquifers.
De l'ensemble des données climatiques disponibles, on peut finalement conclure que le climat des plateaux varois est caractérisé par:
- l'aridité estivale (pénurie des précipitations et fortes chaleurs)
- l'appréciation des hivers (nombre de jours de gelée et alternance gel-dégel élevés, froid accueilli par des vents violents)
- l'irrégualité du régime des précipitations aux plans spatial et temporel (nombre de jours de pluie faible, averses torrentielles déversant en 24 heures une quantité d'eau qui peut représenter 10 à 15% du total annuel).

Cependant, dans les rares cas d'une année mensuels d'été qui sont inférieurs à 0,1-0,2 m³/sec, l'Argens est réalisé depuis 1975 par l'Agrocalcium du Ministère de l'Agriculture. Une ancienne série de variations d'écoulement mensuels qui est attachée à la sécheresse estivale, indique qu'à lui, l'existence de réserves profondes dans la zone phréatique.

Les variations de l'écoulement de la source du St Rosaire ne sont pas mesurées. Selon Nicod (1966) et (1969), les débits sont très réguliers, car le stockage de l'eau s'effectue dans les fissures et les pores de la dolomie qui joue un rôle régulateur fondamental. Le module (M), le débit à l'étéage (DE) et le pourcentage de l'étéage par rapport au module (p) sont respectivement estimés à 0,056 m³/sec, 0,033 m³/sec et à 7%. Des calculs analogues effectués sur la source d'Argens montrent que M = 0,566 m³/sec, DE = 0,030 m³/sec et p = 5,3 % (Nicod, 1976).

Caractéristiques Physico-chimiques des sources d'Argens et du St Rosaire pendant la période 1977-1980

A. Fréquence des prélèvements et méthodes analytiques
Les caractéristiques physico-chimiques des deux sources ont été déterminées en prélèvant les eaux environ une fois par mois, entre fin 1977 et 1980. Dans la mesure, où il ne nous a pas été possible de suivre l'évolution chimique des eaux avec un pas de temps plus court, nous ne prétendons pas que les échantillons analysés soient tous représentatifs du mois écouté. Il n'en est certainement pas ainsi pour l'Argens durant les phases de hauts eaux. On peut néanmoins supposer que les échantillons dosés pendant les longues périodes d'étéage sont représentatifs des eaux de la saison sèche.

Pour la source du St Rosaire, dont le débit est sensiblement constant tout au long de l'année, les concentrations mesurées chaque mois, reflètent assez bien celles des eaux écoulées durant cette période.

Pour chaque échantillon prélève, nous avons mesuré:
- sur le terrain : la température, le pH et le T.A.
- au laboratoire : Ca et Mg par spectrométrie d'absorption atomique.

B. Source d'Argens
Les résultats obtenus sont rassemblés sur la figure 2.

L'étude des variations des débits moyens journaliers montre que celles-ci peuvent être rapides. L'écoulement de l'eau étant différencé de plusieurs jours par rapport aux précipitations, il faut admettre avec Nicod (1969), un stockage temporaire dans les conduits karstiques de la zone vadose réglé par le fonctionnement de siphons. Le non tarissement de la source pendant la sécheresse estivale, indique qu'à lui, l'existence de réserves profondes dans la zone phréatique.

Les variations de l'écoulement de la source de l'Argens, qui joue un rôle régulateur fondamental. Le module (M), le débit à l'étéage (DE) et le pourcentage de l'étéage par rapport au module (p) sont respectivement estimés à 0,056 m³/sec, 0,033 m³/sec et à 5,3 % (Nicod, 1976).

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Figure 3. Variations des caractéristiques physico-chimiques de la source du St Rosaire entre fin 1977 et 1980.

- Mg, Ca, Ca + Mg, SO₄²⁻ ; concentrations des ions exprimées en mg/l ; Ti : température en degrés centigrades.

- Température : En raison de l'importance du réservoir karstique profond, l'homothermie des eaux est de règle. Les eaux les plus tièdes correspondent aux débits d'étiage, période prolongée dans le karst, et les eaux les plus fraîches aux périodes de crues (transit rapide à travers le massif).

- pH : Les variations du pH avec le temps sont faibles. Elles sont le plus souvent comprises entre 7,0 et 7,1 et plus rarement entre 6,93 et 7,19.

- Composition chimique : Elle traduit la nature géologique du bassin d'assimilation de la source, constitué surtout par des calcaires, et les eaux sont à nette prédominance calcique. Le magnesium est présent en faibles quantités (faciès dolomitique de la formation kimméridgienne), ainsi que les ions sulfates (recoupe-ment par le réseau souterrain de la série triasique du Keuper, contenant du gypse).

- Les teneurs en calcium sont toujours très fortes. Les variations saisonnières s'échelonnent entre 107 et 130 mg/l de Ca, soit un écart de 20,8 % par rapport à la teneur la plus faible. Elles ne sont pas en fonction simple du débit. Ainsi, la concentration de Ca peut être élevée en début de période d'étiage (ex: 129 mg/l en août 1978) ou bien en régime hydrologique élevé (128 mg/l en mars 1979), et la valeur est proche de la saturation de la teneur en calcium est plus faible en périodes de crues (118 mg/l en octobre 1979) par suite de l'effet de dilution lié à la montée brutale du débit, ou en fin de régime d'étiage, en raison d'un affaiblissement de l'activité microbienne due à la sècheresse, d'un abaissement de la P CO₂ et d'une diminution de la quantité de CaCO₃ ou d'une légère dépôtisation de CaCO₃ au sein du karst.

- Le comportement du magnésium est différent. Les concentrations de Mg sont plus modérées et les variations saisonnières très accentuées (5,3 ≤ Mg ≤ 20,5 mg/l). Les écarts maxima enregistrés peuvent dépasser 285 % par rapport à la teneur la plus basse. Ces fluctuations se produisent en sens inverse des changements de débits et la teneur en Mg des eaux est systématiquement la plus élevée en fin de période d'étiage (ex: 21 mg/l en décembre 1978) et la plus faible pendant les crues (6 mg/l en octobre 1979) ou en régime de débits soutenus (9 mg/l en mars 1979) ; par suite d'une certaine complémentarité de comportement de Mg et de Ca, en fonction du temps, la somme des concentrations de ces deux ions varie le plus souvent, en sens inverse des débits. On retrouve ainsi le résultat de Nicod (1966) et (1973) qui avait souligné que les variations du Mg de la plupart des sources de Basse Provence étaient inversement proportionnelles aux débits. Il faut souligner que cette règle doit être plutôt considérée comme une tendance et qu'elle souffre de exceptions dans la mesure où, pour des débits analogues, l'origine et l'âge des eaux peuvent être fort différents.

- Température : Les eaux sont plus froides que celles de l'Argens. Leur température varie dans un domaine très limité (11,9 ≤ T ≤ 13,1°C). La variation de Ti est due à l'effet de dilution pouvant être plus ou moins différé, on observe au niveau des températures et selon les cas, des amplitudes saisonnières très accentuées (5,3 ~ Mg ~ 20,5 mg/l) ou des eaux fraîches (pluies torrentielles d'octobre 1979) évacuées en hiver.

- pH : Les variations du pH avec le temps sont plus tranchées (118 mg/l en octobre 1979) et la plus faible pendant les crues (transit rapide à travers le massif) est en mars 1979)

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que R croît avec le débit et sont conformes à ceux de Marker (1973). D'après les données de Nicod (1976), R apparaît cependant indépendant de la température et du débit. Ces divergences dans les résultats concernant les dolomies, montrent que le problème est complexe et non encore résolu et qu'il n'est pas possible actuellement avec les petites séries de mesures dont nous disposons - de définir une loi simple exprimant les variations de R avec celles des débits.

Remerciements

Nous remercions vivement M. Pinta pour les dosages des ions sulfates qui ont été réalisés dans son service de l'Orstom, par Mme Villette.

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A flood pulse study of Russett Well and the associated sink to resurgence system via Speedwell Cavern in the Castleton area of Derbyshire, England, was initially performed based on a classical Ashton type analysis of flow patterns supported by chemical variables. Subsequent work has involved continuous monitoring of flow pH and conductivity at the well supported by quantitative dye traces.

The results clearly show that different bodies of water of either vadose or phreatic type have differing chemical characteristics and can be identified by chemical variables and ionic ratios. Of particular value are potassium, magnesium and silica concentrations.

The overall results can be interpreted to show that Russett Well is a relatively recent and immature karstic spring that represents a complicated series of flow lines converge in Speedwell Cavern with some distributary flow via the nearby Peak Cavern system.

The results have revealed a hitherto unsuspected complexity in the hydrology of the Castleton area, in that the hydrological systems appear to be linked in a fractured rock aquifer rather than a series of separate conduits.
It is also possible that a natural resurgence existed in the area of the present Slop Moll before eighteenth century mining modifications. This is to some extent supported by observations with Speedway Cavern.

Further, positive dye traces were obtained to Peak Cavern previously thought to be a completely separate system, fed solely by percolation water from the south. The flow times were, however, much longer at 10-14 days in each case. This suggests a more complex arrangement than was first thought and summarised in Figure 2.

Following the conclusion of the main programme of dye tests the weather, which had been settled, broke and a heavy flood followed. The conductivity trace at Russett Well was particularly interesting. There was an increase in flow 6 hours after rain began falling, accompanied by a sharp fall in conductivity. The flow was steady for the next 52 hours, but conductivity increased slowly for 27 hours then declined steadily. Thus, this event 33 hours after it began raining is thought to represent the arrival of the main swallet water, which took 36 hours to clear the system. However, further rainfall had occurred in the intervening period and the picture is complicated by multiple pulses.

The flood pulse results showing a very subdued response at Russett Well agree reasonably with the dye test results, but contrast with the more rapid responses recorded in the preliminary study. This may be a reflection of the alterations in the hydrology of Slop Moll since the early study. Overall the results suggest the Castleton aquifer behaves more like a fractured rock aquifer than a typical karst drainage system with piston flow.

This is in accordance with Ford’s 1966 concept of the hydrology being controlled principally by mineralised faults and vein cavities. Any further study will have to involve full monitoring of all three resurgences.

References


Figure 1. Geology and caves of Castleton area, Derbyshire.
Figure 2. A representation of the hydrology of the Rushup sinks—speedwell—Russett Well system, Castleton, Derbyshire, England.
The Classification of Karst Waters by Chemical Analysis

N. S. J. Christopher and J. D. Wilcock
Cheshire, England, U. K.

Abstract

The technique of cluster analysis has been applied to 107 representative chemical analyses of ground and surface waters originating from the Carboniferous Limestone of Derbyshire, England, and surrounding areas to identify the major geochemical controls on the limestone ground water composition. The principal control was found to be biogenic carbon dioxide in conjunction with calcium carbonate. Less dominant but recognisable controls on water composition were soil and interbedded dolomite, shale and lava geochemical compositions. A further control was whether the water had evolved under open or closed system (vadose) conditions.

The limestone ground waters are characterized by a high and relatively stable concentration of calcium bicarbonate. Bacterial increases the concentration of magnesium, sodium and potassium. Low concentrations of calcium, high Pco2 and low SI characterize surface waters. Thermal waters are enriched with magnesiu, sodium and sulphate but impoverished in nitrate due to reduction processes.

Résumé

107 analyses chimiques représentatives des eaux de nappe superficielle et de surface, d'origine du calcaire carbonifère du Derbyshire, G. B., et ses environs, ont été traitées par la technique de l'analyse par groupes; ceci, afin d'identifier les contrôles géochimiques majeurs qui agissent sur la composition de la nappe superficielle.

On a découvert que le contrôle principal est en effet l'acide carbonique biologique conjoint avec le carbonate de calcium. Des contrôles moins dominants mais toujours reconnaissables sur la composition des eaux étaient: la terre, la dolomie et des composants géochimiques qui avaient de l'importance aussi, c'était si les eaux étaient dégagées d'un système ouvert ou souterrain.

Les grands traits perceptibles sont une concentration assez constante du bicarbonate de calcium (avec une augmentation du sulfate de sodium) et une concentration de chlorure (avec une concentration réductrice du nitrate). Ces études de concentration dans l'aquifère. Une concentration augmentée de magnésium provient de contact avec le schiste, le lave et la dolomite.

Introduction

Previous work on the ground waters of the Carboniferous Limestone of Derbyshire has, until recently, been limited. Stephens (1929) principally considered the suitability of the limestone for domestic use. Doming (1967) studied the subsurface ground waters of the deeply buried Carboniferous Limestone in the area of the Eakring oil-field down dip of an area considered here. He found that there was a gradual chemical change, both ionic strength and dominant ionic species with penetration into the aquifer. The dominant species changed from calcium bicarbonate through calcium sulphate to sodium chloride type, and he proposed that these changes occurred as a result of calcite precipitation, sulphate reduction and ion exchange.

Back (1966) developed the concept of hydrochemical facies when studying the ground waters of the Atlantic coastal plain of North America, where waters were classified according to the dominant ionic species. This broad classification is not applicable to this work as all the waters considered here would be classified as calcium bicarbonate type.

The only work to consider adequately the calcium bicarbonate waters of the Carboniferous Limestone of Derbyshire is that of Edmunds (1971). He subdivided the waters into five general groups: grit/shale, general limestone, mineralised areas, perched water-table and thermal waters. The first and last of these are chemically distinct but the remainder show more subtle variations than are suggested by the group headings and the mathematical analysis does not fit easily into the assigned group. Also, some of them overlapped as, for example, when grit/shale water flowed into swallets in mineralised limestone. There was also no attempt to assign "chemical fingerprints" to the various waters. However, more a very comprehensive published set of data it has been used as a basis for this study augmented by additional analyses of the authors.

Bertenshaw (1979) has also studied the ground waters of southeastern part of the Derbyshire limestone, but largely based his classification on that of Edmunds, and, apart from spatial analysis, his groupings of sites do not fit easily into the assigned group. The authors' data is based on multiple analyses at various height stages. The resultant average analyses largely overcame the problems of temporal fluctuations known to occur in karst waters (Bertenshaw 1979); of the total of 107 analyses, 87 were from Edmunds.

The variables considered in the mathematical analysis were the concentrations of the dominant calcium species, namely calcium, magnesium, sodium, potassium. Additionally, two derived variables were also included: these were saturation index to calcite (SIC) and partial pressure of carbon dioxide (Pco2).

Parameters were scaled by the medians of the parameters of the General Limestone Group (Ca 99.3, Mg 5.9, Na 6.6, K 1.3, Pco2 2.03) to produce standardised values, while SIC was scaled on -1, producing an aggressivity value. This procedure essentially allows the comparison of the dominance of the analysis by one or more variables which happen to have the largest numerical values. The similarity algorithm used was Q-mode weighted pair-group average linkage using a form of inverse Euclidean distance.
parameters \( x \) with weight \( w \). The cations were assigned weights of 1, \( Si_c \), and \( Pco_2 \) 0.5.

The results of the clustering are shown as a minimum spanning tree in Figure 1. Attention is particularly drawn to the "chemical fingerprinting" method originated by the authors, a data reduction method which clearly shows the anomalies in chemical properties. For convenience the programming language used was BASIC run on an RML 3802 microcomputer.

Influences on the Geochemistry of Derbyshire Karst Water

The dominant influences can be listed as follows: atmosphere, climate, catchment and soil (including boulder clay and loess) geochemistry, limestone geochemistry, geochemistry of lavas and their degradation products, mineral vein geochemistry.

Results

The results of the data analysis are presented in the form of a minimum spanning tree in Figure 1. This is similar in many ways to the more conventional dendrogram presentation, but in this case gives a more easily understood presentation.

The chemical fingerprint of the individual clusters are presented in Fig. 1 as a 6-figure mnemonic code where three symbols are used to represent the state of the six variables considered: \( O \) represents low, \( X \) normal and \( H \) high values. For the cations values \( \pm 50\% \) of the mean analysis of Edmunds (1971) General Limestone Group were taken as normal. For \( Si_c \), the value was normalised on -1 to give an aggressivity figure, then supersaturated samples were coded O, and unsaturated samples coded 1. The normal limits for \( Pco_2 \) were taken as 90-110% of the mean standard analysis. In all cases the results are presented in the order Ca, Mg, Na, K, \( Si_c \), \( Pco_2 \).

Discussion

Figure 1 shows clearly that the principal geochemical controls outlined above can be picked out from the chemical composition of the ground water draining from particular rock types.

The principal groups identified in this analysis are grit/shale surface waters, general limestone waters, lava or dolomite affected waters and thermal waters. There are also intermediate types between surface waters and general limestone which come from karst resurgences, with a significant component of alloigenic surface water in their discharge, and a mixed thermal and surface water group.

The dominating influence of the combination of biogenic carbon dioxide and limestone is seen in the contrast between the low calcium surface waters and the high relatively stable concentration of calcium bicarbonate in the limestone ground water of the General Limestone Group.

The mixed surface and limestone waters are characterized principally by low \( Si_c \), high \( Pco_2 \) (from vadose conditions in the aquifer) and high sodium (principally from road de-icing salt). The low magnesium of this group is a reflection of the purity of the limestone in the areas where these systems occur.

The dolomite and lava influence is similar in that it is characterized by high magnesium (Figure 1). The latter is what would be expected from the decomposition of olivine basalt by carbonate rich water.

Finally, we have the thermal waters principally characterized by both high magnesium and sodium concentration. This reflects the origins of these waters, as all these sites are at or near the limestone/shale boundary. They are both derived from clay mineral decomposition and also in the case of sodium by ion exchange of calcium only his grit/shale and thermal groups are explained both by the geothermal gradient with deep circulation over at least 15 years (Edmunds 1971) and possibly by exothermic oxidation of pyrite in the shale, as shown by the usually high concentration of sulphate present in Derbyshire thermal water, but not considered in this analysis.

Numerical values for the high and low states can be calculated from data given above.

The ultimate development of these waters is seen in the analysis of the Bradwell thermal spring water, which is high in magnesium, sodium potassium (but has a low \( K/Na \) ratio), sulphate and chloride, but has negligible nitrate concentration reflecting nitrate reduction processes deep in the aquifer.

A fuller discussion of all these points will be found in a later article (Christopher & Wilcock 1981).

Conclusions

Cluster analysis of 110 representative samples of Derbyshire ground water has revealed that they fall into four strong hierarchical groups: surface waters, general limestone waters, dolomite/lava waters and thermal waters; with two groups of intermediate composition and sub-groups differentiated principally by high \( Pco_2 \), reflecting open system (vadose) evolution. This contrasts with Edmunds' subjective classification of which his grit/shale and thermal groups are substantiated. His remaining groups are shown to be a mixture of more fundamental geochemical influences.

References

Cavernicolous Acari of North America

W. Calvin Welbourn
Acarology Laboratory, Ohio State University, Columbus, Ohio 43210 U.S.A.

Abstract

Acari have colonized nearly every terrestrial and aquatic habitat known, including caves. In North America 48 families of terrestrial mites have been reported from caves. A summary of these cavernicolous mites and their role in the cave community is presented. Most cavernicolous mites are troglophiles or guanophiles. Troglobitic species have evolved in several families. The evolution of cavernicolous mites from epigean forms is presented with examples from the family Haplocaridae. The evolution of cavernicolous species from parasitic and phoretic forms is also presented with examples from several families.