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SI - 6230 Postojna, Titov trg 2, Slovenija
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See article by M. Staut and P. Auersperger (photo by Peter Gedei).

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SPATIAL PLANNING AND PROTECTION MEASURES FOR KARST AREAS

PROSTORSKO NAČRTOVANJE IN UKREPI ZAŠČITE NA KRAŠKIH OBMOČJIH

Elery HAMILTON-SMITH[1]

Abstract UDC 551.444:504.054

Elery Hamilton-Smith: Spatial planning and protection measures for Karst areas

This paper presents a brief review of the values and vulnerability of karst systems, and specifically examines issues of water balance, physical destruction, sedimentation and pollution. It then outlines key issues in the protection of karst and the need for continuing vigilance.

Keywords: karst, management, groundwater balance, vulnerability, protection.

Izvleček UDK 551.444:504.055

Elery Hamilton-Smith: Prostorsko načrtovanje in ukrepi zaščite na kraških območjih

Članek prestavi kratek pregled vrednot in ranljivosti kraških sistemov. Posebej se osredotoči na vprašanja vodnega ravnotežja, fizičnega uničevanja, sedimentacije in onesnaževanja. Predstavi temeljne probleme pri zaščiti krasa in opozori na potrebo po budnem spremljanju posegov v kras.

Ključne besede: kras, upravljanje, ravnotežje podzemne vode, ranljivost, zaščita.

INTRODUCTION

. . . a karst system incorporating component landforms as well as life, energy, water, gases, soils and bedrock . . . (Eberhard 1994: 8.)

Any discussion of karst protection must commence with the basic understanding that karst is a complex, dynamic and interactive system. An overall view of karst must engage with that complexity, and so call upon a wide range of insights from a diversity of disciplines. It calls for application of what is usually termed *integrated systems analysis.* This was probably first well recognised in the karst literature by Yuan Daoxian (1988) in his keynote address to the Congress of the International Association of Hydrology.

My own experience over many years has been based in this approach – which is now generally accepted, although some scholars still maintain a narrow disciplinary perspective. In this paper, I will focus particularly upon protective management but this first demands an introductory perspective on the values and vulnerability of karst.

[1] Charles Sturt University, N.S.W., Chair, IUCN / WCPA Task Force on Caves and Karst, P.O. Box 36, Carlton South, Vict. 3053, Australia, e-mail: elery@alphalink.com.au

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COMMENTING UPON KARST VALUES

Many karst systems are places of striking, even sublime beauty (Burke 1756). In turn this is coupled, for many people, with a genuine sense of spirituality. Most such landscapes thus have extremely important cultural values that may even have persisted continually since the Neolithic.

Fig. 1: The famous towerkarst of Guilin in China is famed for its beauty

In turn, cultural values are linked with a great diversity of scientific values in the common claim that *Caves are the Books in the Library of the History of the Earth,* even though we are still striving to fully understand the languages of those books. The very way in which evidence of the past is interwoven within karst echoes both the complexity and integration of the karst system itself, and in so doing, potentially adds a further layer of integration to our understandings. So, karst provides a unique store of knowledge with many features not found in other earth systems.

Finally, there is a wondrous range of economic assets in karst, of which the most significant must be the groundwater reservoirs, which probably provide for the water needs of at least 25% of the World population. Regrettably, the importance of maintaining the quality and quantity of groundwater is all

too often overlooked in the greed for more highly priced and spectacular commodities such as the limestone itself or even the swiftlet nests of Southeast Asia. (Watson *et al.,* 1997)

AND UPON VULNERABILITY

The same complexity and integration of karst, in itself, underlies the vulnerability of the system. A change in any of the major components of the system will inevitably impact upon others. Given that water is the most basic yet most variable of the major components, it is the one most likely to be subject to either changes in volume or to pollution of various kinds. Thus, it is also the most important element in almost any protective management program.

However, the very attractiveness of karst brings with it the impact of human developments with dams, roads, bridges and other constructions. Then the quality of many karst soils or other products of economic value brings both extractive or developmental industries and urbanization, so as a result, both destruction of the rock Itself and often the introduction of pollutants, either as waste products or in the name of chemical management practices, e.g., fertilizers and pesticides.

So, we know we must look towards sustainability, but in practice this may be very difficult and very slow to develop. The Shui people of China have published a text on sustainability over a thousand years ago, and have managed their forest and karst lands at Maolan for at least that long. But more generally, the dominance of simplistic economic thinking (and greed) often defeats the demand for sustainability. Contemporary modernism in resource management was initiated by March (1864) in his rightly famous *Man and Nature*. But far too much of his wisdom still awaits full expression (e.g., Goldie *et al.,* 2005).

MAINTAINING THE WATER BALANCE

The centrality of water as a major determinant of the character and integrity of karst has already been emphasised. Natural variations in water as a result of flooding, increased rainfall, or drought may all arise, and are largely self-balancing over time. But because the cycles of nature may well be gradual in change, we often neglect the potential of permanent change. The process of desertification has adequately demonstrated its capacity

Fig. 2: Temple of Baal, Jenolan Caves, New South Wales

for permanency, and although there is no question that it can be reversed and so restoration may be possible, it is all too rarely attempted. The widespread karst deserts of China are well known, but current research is furthering our understanding of the processes at work, including the formerly neglected role of microbiota.

But the major threat comes from human action. Excessive drawdown of groundwater for agriculture, mining or other industrial activities is all too common. Urbanisation and other forms of construction may well cause major changes in groundwater re-charge. Forests may both impede recharge and increase drawdown through transpiration.

Planning to reduce damage to water balance is vital, and should always be based in accurate delineation of total catchments. It has been recognised for many years that subterranean divides may not coincide with surface catchments. But many protected areas suffer from boundaries that were established in ignorance or neglect of this understanding. Even when the problem is recognised, the political considerations in boundary change may well demand many years of negotiation, and may well prevent re-definition.

Regrettably, even conservation activists may well lack proper understanding of the character and behavior of groundwater. One striking example from this region

Fig. 3: Groundwater is of great value, but often adds to the beauty of caves: Weebubbie Cave, Nullarbor Plain, Western Australia (Photograph Normal Poulter, OAM)

occurred when Croatia first proposed a change of boundary of the Plitvice Lakes World Heritage area in order to encompass (and hence control) the upper section of the catchment area. Many of the referees who were consulted totally failed to recognise the importance of this and argued that the World Heritage Committee should reject the proposal because "it did not add to the biodiversity of

Fig. 4: Khayon Cave, near Mawlamyine, Myanmar (once known as Farm Cave and an important biological site) is a fine example of the religious use of caves

the site" Fortunately, the Committee recognised and accepted the total validity of the proposal that after all was simply putting the case for total catchment management – now a widely accepted principle in karst management.

Another recent development is taking place in Indonesia where the special province of Yogyakarta is undertaking the revegetation and restoration of the Gunung Sewu - one of the world's great tropical karst areas which has been devastated by both total denudation through logging and by uncontrolled limestone quarrying. Research by Professor Suhardi to develop optimal sequencing and timing of re-vegetation and his leadership in implemen-

tation are achieving remarkable results, unprecedented in tropical karsts. Further, his work is now providing a model for other countries with similar problems, albeit often on a less scale, now using his strategies to achieve their own successes

So, in summary, we must strive for total catchment management and on-going monitoring of recharge or of drawdown. The importance of deliberative environmental restoration is at last being recognised, even though Marsh argued back in 1864 that forests destroyed by human action need human action to ensure their recovery.

Fig. 5: One of the examples of sublime majesty: the Xiaozhai Tiankeng of China

Fig. 6: Another majestic sight: Nare Doline (over 300 m. deep) on the Nakanai Plateau, Papua New Guinea

PREVENTING DESTRUCTION

The establishment of protected areas is the most obvious and best-known strategy for protecting natural or cultural resources. These are often established under relevant legislation with such names as national parks, nature reserves, etc. The IUCN has established a standard classification of these (IUCN 1994, Bishop et al 2004) according to the nature and extent of protection that is afforded. Others may exist by long-standing tradition for as long as many thousands of years; still others are established and managed under private commercial ownership.

The underlying assumptions and managerial styles in protected areas have been undergoing a continuing evolutionary development and adaptation. The famous "Yellowstone Model", was long promoted by the United States as the ideal model for protected area management, but has come under massive challenge by alternative models from Eastern Europe, other cultural traditions and in particular from many new countries. Adrian Phillips (2003) at the Durban Parks Congress provided a magnificent summary of the patterns of change and Hamilton-Smith (2005) provided a further overview which incorporated and commented upon Phillips' summary of changes.

Another important contribution from the Durban Congress was a magnificent discussion paper on governance principles for protected areas prepared by the Canadian Institute of Governance (Graham et al 2003).

More vexed questions arise in respect to areas that are not accorded protected area status. Often, politicians, and other public officials, exercising Bierce's (1911: 243) definition of politics as "the conduct of public affairs for private advantage" will hand over major areas for destructive exploitation. In some countries there is little legislative infrastructure to provide a degree of control over the use of either public or private.

Even where there is, conservationists may find themselves forced to appeal against decisions already made – and this can be a difficult and often costly process. A further mechanism that seeks to provide for safer decision-making is the Precautionary Principle (Cooney 2004, Cooney et al 2004), enunciated clearly in the decisions of the 1992 Rio Declaration:

Where there are threats of serious or irreversible damage, lack of full scientific certainly shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

I am glad to say that after two days in the witness box in the course of challenging an application for mining on a particularly important karst area, the judge not only upheld the appeal, but also wrote the precautionary principle into his judgment.

There is also the potential for adoption of minimal impact codes of practice. Speleologists have used such codes in various forms, e.g., the Honour Code of the Swiss Speleological Society and the Minimum Impact Code of the Australian Speleological Federation. At the other extreme of scale there is an excellent example in the Cement Sustainability Initiative (WBCSD 2002).

Fig. 7: One page from the Library of the History of the Earth: Victoria Fossil Cave, Naracoorte Caves WHA, Australia

Fig. 8: Gouldens Hole - One of the Cenotes in the Limestone Coast region, South Australia: both a beautiful place and a point of access to an immense groundwater reservoir through both the nineteenth century excavated ramp and the modern pumping station (Photograph Ken Grimes)

Fig. 10: The terraces on the Northern side of the Huon Peninsula, Papua New Guinea are a wondrous source of geo-climatic history

Fig. 9: The bat flight from Deer Cave, Gunung Mulu WHA, Malaysia

Fig. 11: Buchan Caves, Victoria, preserved as a National Park, now Caves Reserve. (1938 photograph made available by Park Manager D. Calnin)

POLLUTION AND SEDIMENTATION

Both pollution and sedimentation share the characteristic that they can spread over an immense area, sometimes reaching locations that may be hundreds of miles from the point of origin. They may result from ignorance, laziness, cost cutting, genuine accident, unforeseen consequences, and inappropriate use of agricultural or other chemicals. Pollution may well be invisible as when excessive organic wastes are discharged and enter the groundwater, creating a high level of nitrates that may be fatal to infants or young children.

Sedimentation can result from any form of soil erosion or mobilization. In New Zealand, the Waitomo Glowworm cave was threatened when a farmer cleared a hillside some 25 miles upstream of the cave. The resulting muddy run-off entered the river and progressively settled, killing the Chironomid and other larvae which were growing all along the river and which normally provide the food source of the glowworms. In Vietnam, a clumsy road construction mobilized immense amounts of mud into several underground rivers and from there to the major surface streams draining the karst.

Fig. 12: The wonderful Maolan forest of China, managed on a basis of sustainability by the Shui people

Fig. 13: The Havalu Forest of Niue managed as a "National Park" since the original inhabitants first arrived over 1,000 years ago.

Fig. 14: The main pathway through Jeita Cave, suspended well above the floor on pillars, and with all electric fittings concealed under the pathway

Most examples of both pollution and sedimentation can be prevented or remedied but it is much less costly to prevent either or both occurring. It may be useful to note here that the South-east Asian grass *Vetiver zizanioides* provides a remarkable tool in controlling water run-off and in stabilising disturbed soils (Whitten et al 1997: 144-146).

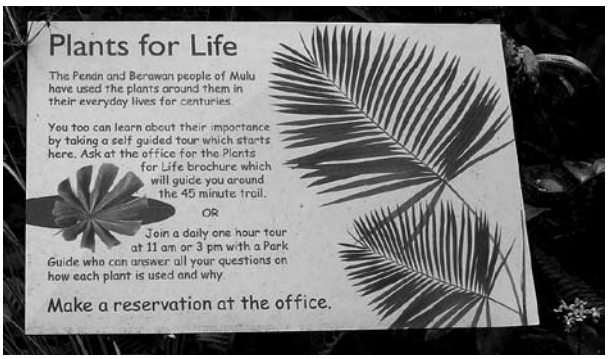

Fig. 15: The commencement of the medical plants trail at Gunung Mulu WHA, Malaysia

Fig. 16: The beauty of the Plitvice Lakes WHA, Croatia

CONTINUING VIGILANCE

It is absolutely vital that land managers do not become complacent, and rather maintain continuing vigilance, as there will always be stupidity, greed and irresponsibility.

But there are two other special hazards:

• The introduction of new and hence little known chemicals or other technology. My personal experience in discovering (by accident) that Metamidophos was being used as a mass pesticide in an Australian karst area is one frightening example.

• Then there are time bombs that will one day explode. The worst example of which I am aware is the massive water storage built when gold mining commenced in South Africa over 100 years ago. When it was built on dolomite, everybody knew that dolomite was insoluble in water. More recently a few geologists started to sound a warning – they were ignored. Then about three or four years ago, the water escaped into the underlying limestones, and then arose through the abandoned mine shafts, bringing an unbelievably dangerous chemical soup to the surface. At present, the government vacillates between 'it hasn't happened, but if it did, it isn't dangerous and we have it all under control'. The result is that it has proved virtually impossible to get any genuine response in place – not surprising when one thinks of the magnitude of the disaster and the ducking for cover of the government response!

• What others might be awaiting attention elsewhere in the world?

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MANAGEMENT MODELS AND DEVELOPMENT OF SHOW CAVES AS TOURIST DESTINATIONS IN CROATIA

MODELI UPRAVLJANJA IN RAZVOJA TURISTIČNIH JAM KOT TURISTIČNIH CILJEV NA HRVAŠKEM

Neven BOČIĆ[1], Aleksandar LUKIĆ[1] & Vuk Tvrtko OPAČIĆ[1]

Abstract UDC 551.44:338.48 (497.5)
65.012.43 (497.5):551.44

Neven Bočić, Aleksandar Lukić & Vuk Tvrtko Opačić: Management Models and Development of Show Caves as Tourist Destinations in Croatia

Touristic valorisation of caves has long tradition in Croatia. Research has been conducted in order to: identify show caves in Croatia (13), make an overview of their basic geomorphologic characteristics and study their role as tourist destinations. Based on Nature Protection Law and current experiences, four different management models have been identified. Management models have been recognized as an important factor for touristic valorisation of show caves. These elements as well as linkages of show caves with local economy have been examined in more details in case studies. Paper concludes with overview on current tourist development of show caves in Croatia and proposes some future actions in that respect.

Keywords: show cave, management model, tourist destination, local economy, sustainable development, Croatia.

Izvleček UDK 551.44:338.48 (497.5)
65.012.43 (497.5):551.44

Neven Bočić, Aleksandar Lukić & Vuk Tvrtko Opačić: Modeli upravljanja in razvoja turističnih jam kot turističnih ciljev na Hrvaškem

Turistično vrednotenje jam ima na Hrvaškem že dolgo tradicijo. Raziskava je želela sledeče: identificirati turistične jame na Hrvaškem (13), napraviti pregled njihovih geomorfoloških značilnosti in preučiti vlogo jam kot turističnih ciljev. Temelječ na Zakonu o varstvu narave in na izkušnjah so bili ugotovljeni štirje modeli upravljanja. Ti so bili spoznani za pomembne dejavnike pri turistični oceni turističnih jam. Tako te sestavine kot tudi povezava turističnih jam s krajevnim gospodarstvom so bili podrobno preučeni v tem prispevku. Članek sklene pregled tekočega turističnega razvoja jam na Hrvaškem in predlaga na tej osnovi nekaj bodočih ukrepov.

Ključne besede: turistična jama, model upravljanja, turistični cilj, krajevno gospodarstvo, trajnostni razvoj, Hrvaška.

INTRODUCTION

Speleological features as special natural phenomena in karst make the components of tourist attraction basis (Kušen, 2002). The caves having geomorphologic, geological, biological, archaeological, paleontological, landscape and/or other significances, can be touristically valorised. People visit caves out of aesthetic-emotional, recreational, educative and sometimes medical reasons. Speleological phenomena can be touristically valorised in several fundamental ways. Classical tourist cave arrangement is the most often. It implies accommodation of a cave and its surroundings to a visitor, who has no experience in walking in the country and by caves (Cigna & Buri, 2000). Tradition of tourist cave valorisation is long in Croatia (Božić, 1984). Gospodska špilja near

[1] Department of Geography, Faculty of Science, University of Zagreb, Marulićev trg 19, 10 000 Zagreb, Croatia
e-mail: nbocic@geog.pmf.hr ; alukic@geog.pmf.hr ; vtopacic@geog.pmf.hr

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the source of the river Cetina can be considered the first touristically arranged cave. It was arranged for organised visits as early as 1855. The longest tradition belongs to the Modra špilja on the island of Biševo (visited since 1884) and the Gornja Baraćeva cave near Rakovica, first arranged in 1892, and reopened in 2003. The research purpose is to state, on the basis of standard criteria, which speleological features in Croatia are included in the category of tourist caves, how and to what extent are they touristically valorised and what possible role they play in the local economy of the surrounding area considering sustainable development. Božičević (1961), Pepeonik (1982) and Božić (1999) published works about tourism valorisation of caves in Croatia, but without analysing the problematics of management of show caves.

METHODS

The first task was to define the notion of a tourist cave on the basis of previous domestic and foreign experiences and to single out such phenomena in Croatia (Cigna & Buri, 2000; Božić, 1999). Dealing with the defined tourist caves we had to collect the data about: their location, total length, length of the touristically arranged path, year of the first opening, number of visits, way of management and protection category. On the basis of the collected data, especially about the management of a show caves, four case studies have been worked out. Besides the basic comparison of geomorphologic and other features, the greatest part of the research was done in the field. By a questionnary survey of the show cave management there were determined initiatives and beginnings of the cave's introduction into the tourist offer, modern way of tourism valorisation (number and structure of visitors, incomes, seasonality, etc.), the cave's role in the tourist offer of the destination, connection with the local area, ways of protection and orientation towards sustainable development.

LEGAL CONTEXT OF CAVE MANAGEMENT IN CROATIA

Nature protection in Croatia depends largely on laws and regulations, which are passed not only to preserve natural resources from exploitation, but also to protect the endangered species. Croatian laws on nature protection have a long tradition. First laws of that kind were Bird Protection Act (1893), Hunting Act (1893) and Cave Protection Act (1900) (Opačić, 2001, Opačić *et al.*, 2004). The basic legal document for nature protection nowadays is Nature Protection Act from 2003.

From the aspect of property and government, and thereby from that of protection and management in speleological phenomena, this law has introduced several essential innovations. The first one is "speleological phenomena are owned by the Republic of Croatia" (par 47, NN 70/2005). In that way all speleological phenomena in Croatia come within the competence of the Nature Protection Law. Some speleological phenomena can be additionally protected by the natural monument status or be located within some other protected areas (e. g. Natural Park, National Park...). The other innovation relates to possible ways of management in tourist speleological phenomena. The Law defines two basic management models: 1) through a public institution, and 2) through concession or concession approval. If a speleological phenomenon is located in the protected area managed by a public institution (Natural Park and National Park), the same institution manages it, too. If a speleological phenomenon is located out of a Natural Park or National Park, it is managed by a county public institution for managing the protected areas. Regardless of the phenomenon's location (whether it is situated in or out of a Natural Park or National Park), a concession or its approval is possible. This Law has put aside a long-standing practice that local tourist societies can manage speleological phenomena. Nevertheless, as the Law is relatively new, we still come upon the mentioned practice.

EXAMPLES OF MANAGEMENT OF SOME SHOW CAVES IN CROATIA

On the basis of the defined criteria (arranged and secured path, lighting, guides, arranged approach and the management body controlling the cave's work) thirteen show caves in Croatia have been determined. It was found that arrangement, way of valorisation, inclusion into tourist destinations, protection and linkages with the local economy primarily depended on the management form

Name of the cave	Location	Length of the cave	Length of the touristic path	Year of the first opening	Models of the cave management	Category of protection
Vrlovka	Kamanje, County of Karlovac	380 m	330 m	1928	Local authorities through local public institution	Geomorphologic monument of nature since 1962.
Veternica	Medvednica, City of Zagreb	7118 m	380 m	1951	Management board of protected area (Park of nature Medvednica)	Geomorphologic monument of nature since 1979., in area of Nature Park Medvednica since 1981.
Donja Cerovačka	Gračac, County of Zadar	2682 m	700 m	1976	Management board of protected area (Park of nature Velebit)	Geomorphologic monument of nature since 1961., in area of Nature Park Velebit since 1981.
Baredine	Nova Vas, County of Istria	120 m	120 m	1994	Private enterpreneur through concession for cave on private (own) land	Geomorphologic monument of nature since 1986.
Gornja Baraćeva	Rakovica, County of Karlovac	520 m	200 m	1892	Local authorities through local public institution	–
Špilja Vrelo	Fužine, County of Primorje-Gorski kotar	310m	180 m	1965	Local authorities through local public institution	–
Lokvarka	Lokve, County of Primorje-Gorski kotar	1 100 m	435 m	1935	Private enterpreneur through concession for cave on public land	Geomorphologic monument of nature since 1961.
Vranjača	Dugopolje, County of Split-Dalmatia	180 m	160 m	1929	Private enterpreneur through concession for cave on private (own) land	Geomorphologic monument of nature since 1963.
Manita peć	Starigrad-Paklenica, County of Zadar	175 m	200 m	1935	Management board of protected area (National park Paklenica)	In area of National Park Paklenica since 1949.
Samograd	Perušić, County of Lika-Senj	220 m	220 m	1903	Local authorities through local public institution	Geomorphologic monument of nature since 1964.
Grgosova	Samobor, City of Zagreb	60 m	20 m	1974	Private enterpreneur through concession for cave on private (own) land	Geomorphologic monument of nature since 1974.
Modra špilja	Biševo, County of Split-Dalmatia	36 m	36 m	1884	Local authorities through local public institution	Geomorphologic monument of nature since 1951.
Biserujka	Krk, County of Primorje-Gorski kotar	110 m	65 m	1967	Local authorities through local public institution	–

Tab.1: Main features of show caves in Croatia

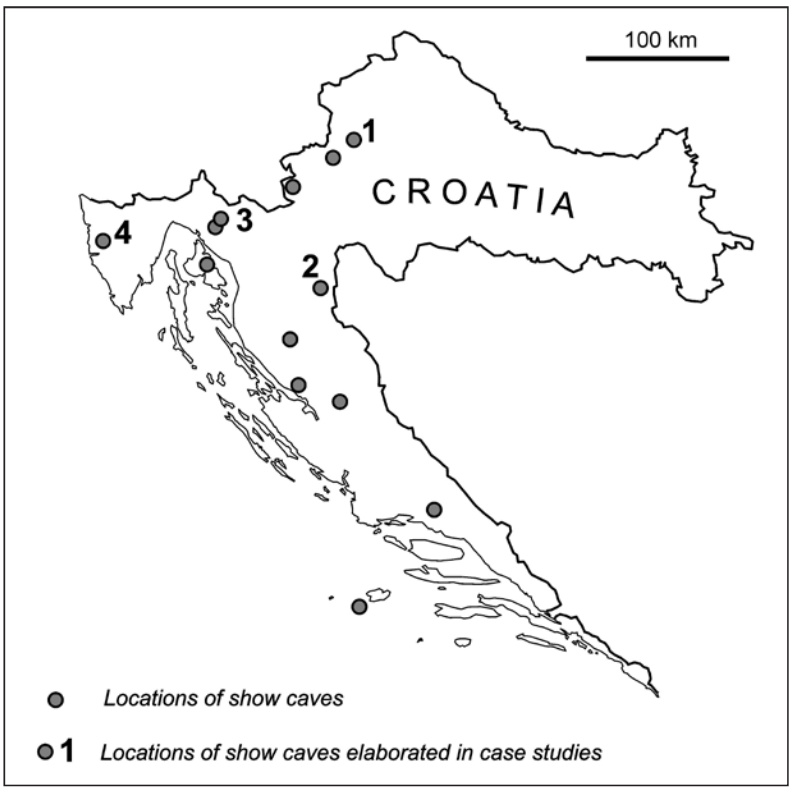

Fig.1: Distribution of show caves in Croatia and location of case-studies

Four distinctive types of cave management have been identyfied: (cave is managed by): a) management board of protected area, b) private enterpreneur through concession for cave on public land, c) private enterpreneur through concession for cave on private (own) land, d) local authorities through local public institution. Because of differences among the analysed parameters, especially dealing with the way of management, there were elaborated case studies for the following show caves: the cave Veternica on Medvednica near Zagreb, Lokvarka near Lokve in Gorski Kotar, Baraćeve caves near Rakovica and the pit Baredina near Poreč.

Example 1. Veternica cave – operated by **management board of protected area**

The cave Veternica, situated on the south-western part of Medvednica is 7,100 m long. In 1951, it was opened for tourists in the length of 380 m. Malinar (1984) wrote about beginnings of tourism valorisation of Veternica cave. Since, as a geomorphological monument of nature, it is situated in the protected area, the Public Institution Nature Park Medvednica is responsible for its management. As this is a protected area, the basic purpose of its management is its protection, then tourist, i. e. educative visits, in the course of which the sustainable development postulates are especially taken into account. Therefore, the cave Veternica should not be considered as a part of the Zagreb city tourist destination, but as a tourist locality in the Nature Park Medvednica, where the sojourn tourism is still in the background. The majority of visitors are organised groups of pupils, families, mountaineers – in one-word hikers, primarily from Zagreb, who visit the cave from the beginning of April to the beginning of November. Maximal number of visits is registered during spring (April, May, the beginning of June) and autumn months (the end of September, October), which corresponds with the school year, as well as with the weather conditions favourable for excursions. Although the number of visits is relatively small (2,500-3,000 in recent years), the Park's management board thinks that in the future cave's management more care should be taken about its protection than about eventual tourist visits enlargement. The share of the Veternica cave in the total independently realised profit of the Nature Park Medvednica decreased from 22% in 2002 to 12% in 2005.

Example 2. Baraćeve caves – run by **local authorities through local public institution**

Baraćeve Caves (Gornja and Donja – Upper and Lower) are situated near the village Nova Kršlja in the municipality of Rakovica. Baraćeve Caves were among the first touristically arranged caves in the continental part of Croatia. Garašić (1989) wrote abot touristic potential of surrounding of Baraćeve Caves. They were opened for tourists in 1892, but did not fill that function for a long period. Owing to the efforts of the Rakovica municipality the Gornja Baraćeva cave was arranged in 2003 and opened in 2004. It is 520 m long, and the length of its tourist path figures out at about 200 m. The main attraction of the cave is a variety of dripstone forms, archaeological and palaeontological remains, as well as an interesting ambience in front of the cave's entrance. Besides the illuminated path in the cave, the surroundings were arranged too (promenade and excursion centre by the karst source Baraćevac). An instructive path about karst is in preparation. In 2004, the Gornja Baraćeva cave was visited by 4,800 visitors. Although it is a matter of increase, this is still a too small number of visitors for such a natural tourist attraction, which lies against the nearby Plitvice Lakes. Owing to its favourable position, the Baraćeva cave relies on foreign guests in high tour-

ist season, and on domestic ones (mostly groups) in the off-season period. The cave is managed by the local government (municipality of Rakovica) through the Public Institution for Managing Protected Natural Values throughout the area of the municipality of Rakovica.

Example 3. Lokvarka cave – managed by **private enterpreneur through concession for cave on public land**

The cave Lokvarka is located in Lokve, a settlement in Gorski Kotar near Delnice. It was discovered in 1911/1912, and in 1935, a part of it was electrified and opened for visits. The cave was arranged on several occasions (1961, 1973-74). The Tourist Community Lokve ran the cave till the first half of the 1990s, when the public institution Croatian Forestry overtook the management for a short time, and by the mid-1990 it was overtaken by a private concessionaire. The concession was approved for three years, and then it had to be prolonged every year. In 2005, the number of sold tickets amounted to some 7,000, although the number of visits was somewhat larger (free entrances for associations, etc.). In that time, the cave was permanently opened from 1 May to 1 October, and the visits accompanied by guide services were fixed from 10 to 19 o'clock. In the remaining months the cave could be visited having made a preliminary announcement. Group visits of the Croatian pupils dominated in the visitor structure. As to the other group visits, we must single out foreign guests (especially the German), who visited the cave in the course of one-day trips to Gorski Kotar organised by the travel agency, which managed the cave. Between 20 June and 1 September (during school holidays), individual guests from the country and abroad dominated. During his management, the concessionaire did only the necessary infrastructure maintaining (staircase handholds, painting, electric power, and similar), because he had no finances for greater interventions, e. g. a complete replacement of three steep staircases. The aggravating circumstance in the cave management was the risk of long-term investments in such a short-term concession (1 year). Since the spring of 2006, the cave has been managed by the Tourist Community Lokve. Considerations about further tourist valorisation and management in the framework of the local government are in progress.

Example 4. Baredine pit – managed by **private enterpreneur through concession for cave on private (own) land**

The pit Baredine is the youngest, but also, by the number of visitors, touristically the most important speleological feature in Croatia. It is also the first touristically arranged pit in the Croatian part of Istria (Dečak, 1994). The Baredine was discovered in the nineteen seventies on a private estate in the village of Nova Vas. The activities of the pit's protection and tourist valorisation was initiated by the estate's owner, who was also a caver. He did it by his own finances. Till the mid1990-s a confined number of visitors was allowed to visit the pit through speleoadventure. In 1995, the Baredine was opened for tourist visits (arranged electric lighting and staircase). Between 7,000 and 8,000 tourists visited the pit that year. The number of guests in 2004 and 2005 amounted to about 50,000. From 1 April till 31 October the pit is opened for visitors every day and during the remaining five months only for announced groups. 8 people are permanently employed there, and some additional guides only periodically. As to the visitor structure, individual guests dominate (especially in the summer months at the peak of the tourist season), and the share of foreign visitors is also very significant, especially that of the German, Danish, Dutch, Russian, Italian… Individual visits, mostly out of the summer season, supplement school and expert excursions from Croatia and abroad (Italy, Germany, Belgium, Denmark…). Besides by the speleological feature itself, the visitors are also motivated by the speleothems and *Proteus anguinus* placed in a natural recess filled with water. The basic function of this pit is tourist, which is also visible from the arrangement of the accompanying attractions (catering establishment, "agro-museum" in the open air, souvenirs sale, sale of original food-stuff, fruit and vegetables, picnic place, exhibition space...). Some 20 families take part periodically in the mentioned accompanying tourist offer. The owner plans to widen the tourist offer and to create a complex tourist product, for which there are corresponding space-planning regulations

MODELS OF MANAGEMENT IN SHOW CAVES IN CROATIA

In view of the analysed examples and actual legal basis we are dealing with four different models of management tourist caves in Croatia (Fig. 2).

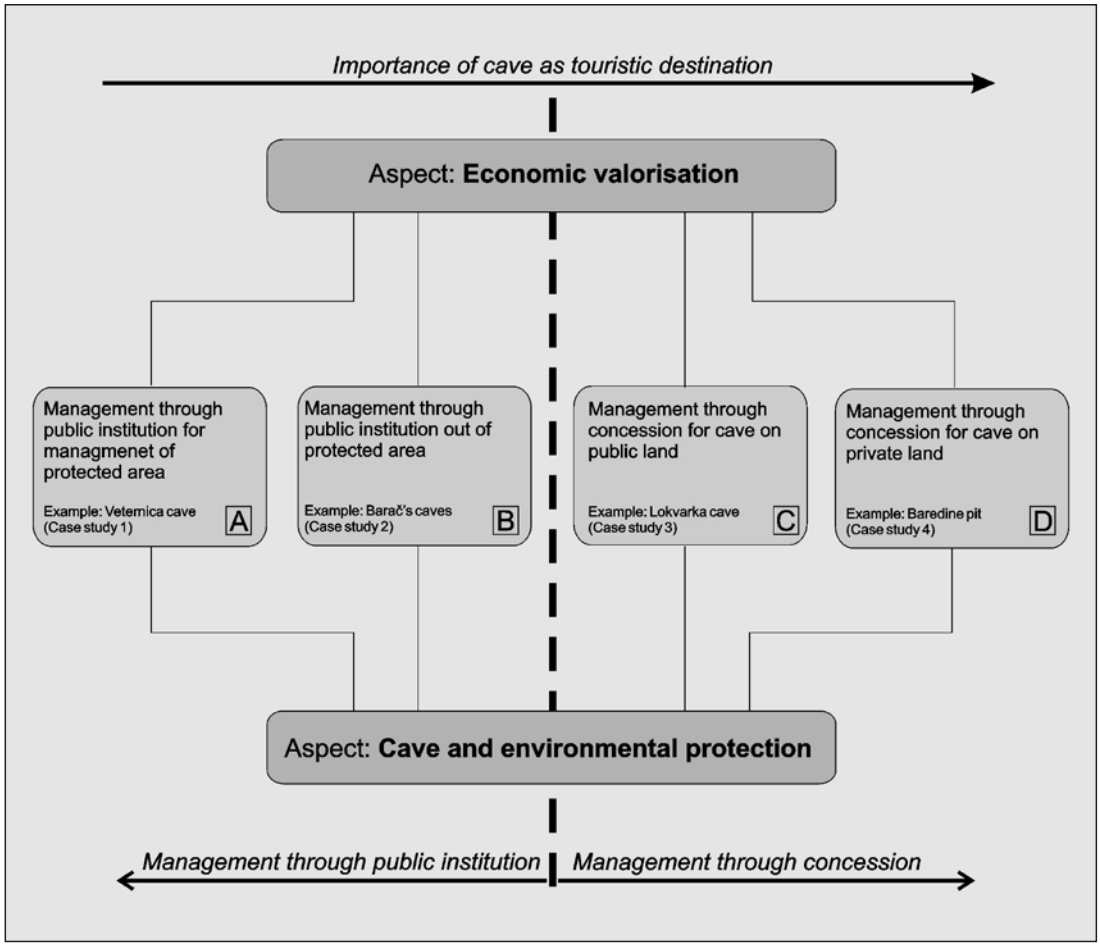

Fig.2: Management models of show caves in Croatia

a) management board of a protected area

The largest part of the area within the protected regions in Croatia relates to two categories. They are natural parks and national parks, which together account for 90 per cent of all protected Croatian regions. Nature Protection Law says that public institutions manage these two categories. Three show caves belong to this type of management, so they are in the competence of public institutions (Veternica in the Natural Park Medvednica, Cerovac Caves in the Natural Park Velebit, Manita Peć in the National Park Paklenica).[1] According to the Nature Protection Law, "public institutions...attend to the business of protection, maintenance and promotion of the protected area in order to protect and preserve authenticity of nature, to ensure an undisturbed development of natural processes and sustainable use of natural goods, and to supervise the execution of conditions and measures of nature protection in the area of their management" (NN 70/2005). National Park and Natural Park are managed on the basis of a special spatial plan introduced by the Croatian National Parliament, the plan of managing a protected area and regulations about the internal order.

These determinants have really defined the way of evaluation of speleological phenomena in the protected regions. The most important is "preservation of significant and characteristic features of a landscape and maintenance of biological, geological and cultural values, which define its significance and aesthetic experience" (NN 70/2005). Therefore, tourist significance of speleological objects in this management type is subordinate to their protection. Moreover, National and Natural Parks become distinctive as peculiar tourist destinations

[1] The Law enables a concession assignment for a speleological phenomenon within National and Natural Parks too. Although there are no such cases in Croatia at the moment, it is interesting to single out the example of the Cerovac Caves. They are located in the Natural Park Velebit, and until recently have been managed by a private concessionaire. Unsatisfied with the management, the public institution of the Natural Park Velebit has overtaken it.

(branding and marketing at the park level), while particular localities in them, e.g. caves and pits, make a part of their attraction offer and have not yet developed into separate tourist destinations. Public institutions make profit out of several different sources: budget, gate receipts in National Parks and speleological phenomena and other own profits. Therefore, dependence on the profits from the "cave" is significantly smaller than under private forms of management.

b) local authorities through a local public institution out of a protected area

Units of local authorities and self-government (municipalities and towns) on whose territory there is a speleological phenomenon, can manage the phenomenon by giving a concession to a private entrepreneur or, more often, to run it through a local tourist community or through for that purpose established public institution (Baraćeve špilje, Biserujka, Lokvarka [2], Samograd, Vrelo, Vrlovka).

Consequently, respecting the Croatian Nature Protection Law, a special stress has been laid upon economic exploitation of a speleological phenomenon. Local authority unit realises earnings, therefore it is interested in transformation of a touristically evaluated cave or pit into a peculiar separate destination. The advantage of this management model is in the fact that the management and marketing are being done from the same centre, which can contribute to a more powerful and more durable definition of the cave as an important segment of local tourist offer – and which is not always the case in relation between a private concessionaire and local community.

c) private entrepreneur (through concession) of a cave on public land

According to the Law a concessionaire can manage a speleological phenomenon. "Concession enables the privilege of economic exploitation of natural resources or that of performing activities of interest to the Republic of Croatia, as well as the privilege for construction and use of facilities necessary for doing those activities in protected areas and speleological phenomena where it is permitted according to this Law (NN 70/2005). Although this way of management was used in Croatia after transfer to market economy (Lokvarka and Cerovac Caves), there is only one speleological phenomenon arranged for tourist visits (submarine Modra Cave on the island of Biševo), where concession has been given to the tourist agencies, which organise visits by vessels. In this case the primary motivation of the concessionaire is financial benefit, while big investments, especially dealing with a contract of short duration, are not profitable. Therefore a concession contract, as well as management supervision, is a necessary measure of protection. According to the available data, a short duration of concessions deepens the gap between financial interests of a concessionaire on the one hand and necessity for a long sustainable evaluation of a cave for tourist purposes on the other. Such situation has resulted in mutual discontents and breaks of cooperation. From the aspect of destination, certain disadvantages of this model can be noticed: the management is in the hands of a concessionaire, and the local authorities take care about development of the destination. Consequently, the relations between the interested parties directly influence tourism valorisation of a speleological phenomenon.

d) private owners of the cave through concession and on his own land

The law says: "The owner or privilege holder of the land where there is a speleological phenomenon has priority in getting concession or compensation for limitations imposed because of using the speleological phenomenon proportionally to the reduced profit." We consider this Law paragraph the key one in this management model analysis, because it enables continuity in managing, which is the prerequisite of a long sustainable use of the speleological phenomenon. This management form, just as the former one, appeared in Croatia after the transfer to the market economy. Three caves in Croatia (Baredine, Grgosova Cave and Vranjača) are managed on the basis of this model. The land owner, also the concessionaire, is interested in transformation of the speleological phenomenon into an independent tourist destination, the notion of which includes a more complex offer (from accommodation and catering services to accompanying elements such as souvenirs, collections, galleries...). It brings diversification of the concessionaire's product, but also the spill-over of economic effects to the local community. The branding process of the total destination product has also been singled out, but under the name of speleological phenomenon. If this is realised, a show cave or pit becomes an important tourist offer of the region.

[2] According to this model, today you can count and Lokvarka cave, although, not so long it was managed through concession on public land (model c). As of such kind it was treated in this work.

CONCLUSIONS

On the basis of the collected data about show caves in Croatia, as well as on the more analysed case studies, it is possible to draw the following conclusions:

- Although there are 13 speleological features arranged for tourist visits in Croatia, we consider that, regarding attractiveness, traffic accessibility and possibility of an average tourist's visit, there are some more potential caves for tourist valorisation (for example Gvozdenica cave).
- Four distinctive management models have been identifyed: a) management board of protected area, b) private enterpreneur through concession for cave on public land, c) private enterpreneur through concession for cave on private (own) land, d) local authorities through local public institution.They have been recognized as an important factor for tourism valorisation of show caves.
- It has been recognised that the model of management by concession on public land under the existing circumstances has turned out as inadequate, so it is disappearing.
- Although the majority of the show caves in Croatia are protected by a category of a geomorphological monument of nature, their tourism valorisation primarily depends on the way of management. Namely, if a public institution runs a cave (e. g., Nature Park or National Park), the protection component is more prominent, which is understandable regarding the basic function of the institution, as well as the fact that the profit from the cave does not make the basic element of the public institution profit structure. On the other hand, if a private concessionaire manages a show cave, the business orientation towards tourism is more marked. Consequently, in these cases the connection with local economy is more prominent, just as the significance of the phenomenon within the tourist destinations.
- Having compared our situation with the experiences abroad (Forti & Cigna, 1989; Ramšak, 2004; Cabezas, 2004; Bartholeyns, 2004), but also on the basis of the specific data about the number of visits, inclusion into the tourist product of destinations and way of valorisation (almost exclusively only a visit), we consider that the majority of the show caves in Croatia are still insufficiently explored.

Actual legal basis, which is the foundation of the cave management in Croatia, is relatively new. Therefore, the presented management models could not completely become a reality. Their continuous observation and evaluation intrudes as an essential factor of the sustainable development of the Croatian karst area.

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TOURISM AND PRESERVATION POLICIES IN KARST AREAS: COMPARISON BETWEEN THE ŠKOCJAN CAVES (SLOVENIJA) AND THE ARDÈCHE GORGE (FRANCE)

TURIZEM IN OHRANJANJE KRAŠKEGA SVETA: PRIMERJAVA MED ŠKOCJANSKIMI JAMAMI (SLOVENIJA) IN SOTESKO ARDECHE (FRANCIJA)

Mélanie DUVAL[1]

Abstract UDC 551.44:338.48(497.4+44)

Mélanie Duval: Tourism and preservation policies in Karst areas: comparision betwen the Škocjan caves (Slovenia) and the Ardèche gorge (France)

This paper presents a comparative study of the Ardèche Gorge Natural Reserve (France) and the Škocjan Caves Regional Park (Slovenia). As major tourist attractions, both these areas have progressively structured their economies around tourism, although they have implemented very different development and karst landscape protection policies. In very simplistic terms, management of the Ardèche Gorge can be described as very laxest, whereas development in the Škocjan Caves is much more strictly controlled. When examined from this preservation/development perspective, the differences in the ways the two sites are managed can be traced through a diachronic approach to the history of their tourism development. *In fine,* this comparative approach illustrates how two processes between tourism and preservation policies structure territories development on karst areas.

Key words: karstic landscapes, preservation, tourism, Škocjanske jame caves, Ardèche Gorge Natural Reserve, France, Slovenia.

Izvleček UDK 551.44:338.48(497.4+44)

Mélanie Duval: Turizem in ohranjanje kraškega sveta: primerjava med Škocjanskimi jamami (Slovenija) in sotesko Ardèche (Francija)

Sestavek predstavlja primerjalno študijo Narodnega rezervata Soteska Ardèche (Francija) in Regionalnega parka Škocjanske jame (Slovenija). Kot veliki turistični privlačnosti sta ti dve območji počasi gradili svoji gospodarski osnovi na turizmu, vendar na različen način in na osnovi različnega pristopa k varovanju kraške pokrajine. Najpreprosteje povedano, Soteska Ardèche je imela zelo proste roke, medtem ko je bil razvoj Škocjanskih jam bolj strogo kontroliran. Če gledamo z vidika ohranjanja/razvoja, opazimo razlike v upravljanju teh dveh znamenitosti na osnovi diahroničnega pristopa k zgodovini razvoja njihovega turizma. *In fine,* ta primerjalni pristop lepo pokaže, kako ta dva procesa, turizem in politika ohranjanja, strukturirata razvoj na kraških območjih.

Ključne besede: kraška pokrajina, ohranjanje, turizem, Škocjanske jame, Narodni rezervat Soteska Ardèche, Francija, Slovenija.

INTRODUCTION

This paper presents a comparative study of the Ardèche Gorge Natural Reserve (France) and the Škocjan Caves Regional Park (Slovenia), thereby illustrating two of the directions tourism development in karst areas can take. As major tourist attractions, both these areas have progressively structured their economies around tourism, although they have implemented very different development and karst landscape protection policies.

Approaches to these karst landscapes have alternately placed to the fore either the heritage dimension or the tourism dimension of the resource, with the resource being defined as that "which can be capitalised upon,

[1] Laboratoire Edytem, University of Savoie, Chambéry, France, e-mail: melanie_duval@yahoo.fr

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conserved or exploited for private or public benefit, a sort of hybrid notion between private goods and public goods. This notion includes the idea of an intergenerational duty of care and responsibility and allows for compromise between the economic exploitation of the resource and its ecological protection and conservation" (Peyrache-Gadeau V., 2004, p.3).

Since tourism began in these two areas, the gradual intensification of the dialectic between preservation and development has led to the creation of two protected tourist areas. Of course, a balance between preservation and development can be achieved in a number of different ways and the approach each area takes to achieve this balance will be governed by that area's own evolving characteristics. By comparing two similar regions, we were able to elucidate the forms this precarious balance can take and to present two different ways of approaching the management of tourism in karst areas.

A comparative approach to geographical research presents the major advantage of bringing together different approaches to a problem, thereby revealing explanatory factors and facilitating the analysis of the processes involved. By comparing "protected tourist karst areas" in France and Slovenia from diachronic and synchronic points of view, we were able to highlight the factors behind the methods currently used to manage these two protected tourist sites. Thus, the presentation of the main characteristics of these two sites is followed by a discussion of the factors that have determined the approaches to managing the balance between preservation and development adopted in the Ardèche Gorge and Škocjan Caves areas.

THE VALUE OF A COMPARATIVE REGIONAL APPROACH

The Ardèche Gorge and Škocjan Caves sites show a sufficient number of similarities for a comparative approach to be valid. Both areas are geologically and geomorphologically very similar, as both are karst plateaux dotted with collapse dolines, caves and potholes. One of the first people to have compared the two areas was Martel, who drew parallels between the karst formations at Škocjan and the Saint-Marcel Cave (cave in the Ardèche Gorge that was the trigger for tourist development in the area) in his book *Les Abîmes* (1894, p.83-84).

As with all karst plateaux, the protection and management of water resources is a question that cannot be ignored. In addition to problems related to water quality, both areas have had to deal with concerns over maintaining water quantities. These concerns have been addressed through large-scale water management projects. In Slovenia, a Ramsar convention was signed in 1999 and a Man and Biosphere (MAB) project was set up in 2004. In France, a General Water Development Plan (Schéma d'Aménagement Général des Eaux – SAGE) has been drawn up. By fixing objectives in terms of quality, quantity and environmental protection, these programmes provide frameworks for consultation and dialogue between the parties involved.

Comparisons can also be made between the measures taken to preserve the karst resource and to develop tourism. Both areas are covered by a number of protection measures: the Ardèche Gorge has been a natural reserve since 1980 and the Pont d'Arc has been a listed site since 1982; the Škocjan Caves have been a UNESCO monument since 1986 and a regional park since 1996.

Both areas are aware of the need to promote a sustainable form of development and have set up educational programmes for young visitors. Hence, since 1997, the Ardèche Gorge Natural Reserve has been recognised by the French Ministry of Education as an educational site for school groups. At the Škocjan site, a nature trail was opened in 2002 and awareness programmes are carried out in conjunction with local schools.

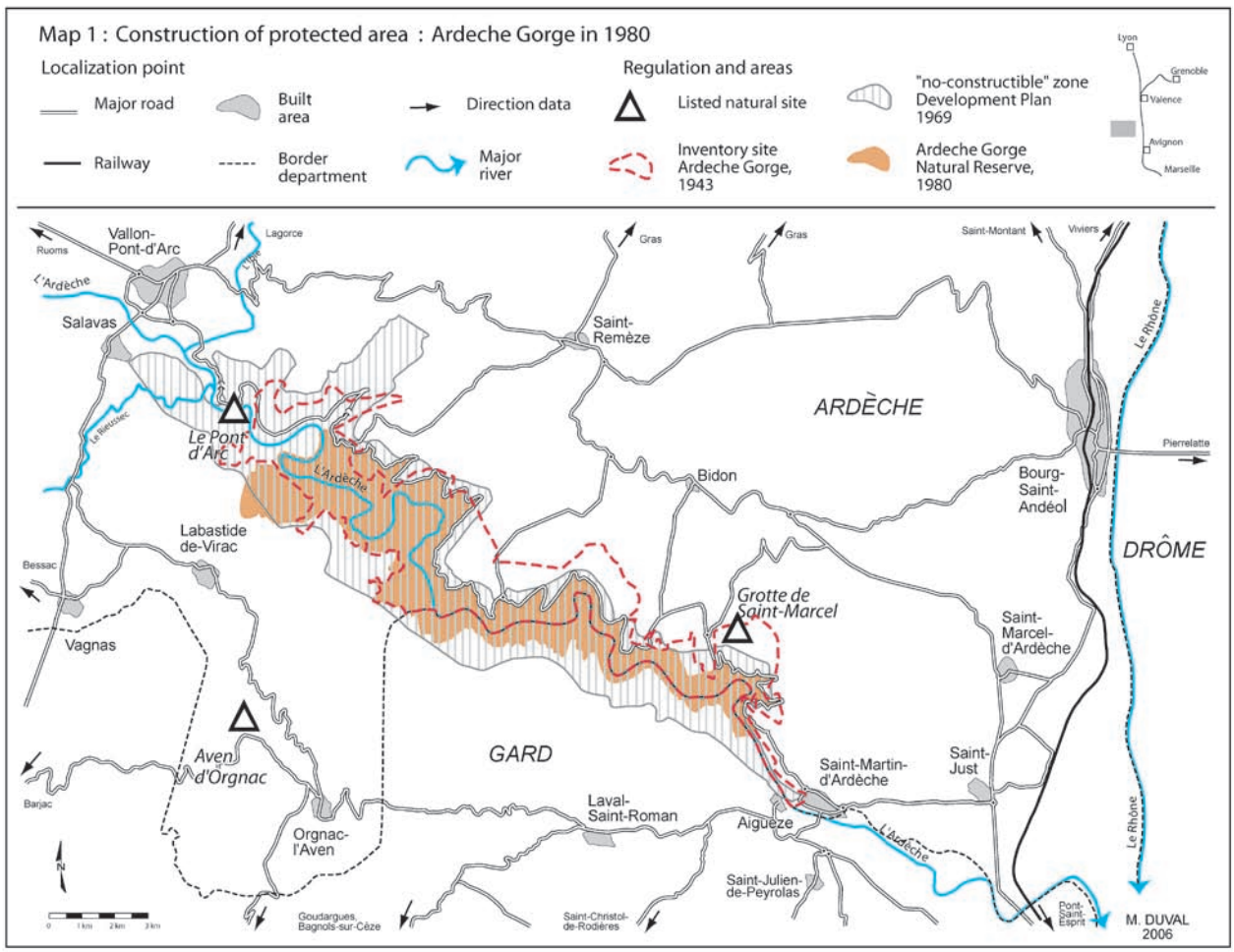
These different protection measures and awareness-raising actions are aimed at developing a more responsible approach to tourism development, which had often been regarded as "anarchic" or "inappropriate" by the authorities responsible for the two areas. In 2004, 89,700 people visited the Škocjan Caves; however, this can only be considered a base figure for tourist numbers, as many people only follow the nature trail to the view points overlooking the collapse dolines: a number that is difficult to evaluate. Visitor numbers to the Ardèche Gorge can be estimated using several different indicators, for example, the number of canoe descents (more than 180,000 per year), the counter on the road through the Ardèche Gorge (245,000 vehicles in 1997, assuming an average of 3 people per vehicle, this gives a figure of 735,000 visitors – according to the reserve management plan, p.21), the number of visitors to the tourist caves (Saint-Marcel Cave: 42,000 visitors per year, Madeleine Cave: 49,000, Orgnac Cave: 125,000 – National Tourism Observatory, 2002). The different government and local bodies generally agree on a figure of 1.5 million tourists per year ('rural excellence pole' report). The Ardèche Gorge and the Škocjan Caves are tourist areas in which tourist flow management and protection measures have progressively been implemented.

THE IMPLEMENTATION OF PROTECTION MEASURES[1]

The need to protect the Ardèche Gorge area became apparent as early as the beginning of the 20th century. In 1913, Martel proposed the creation of a national park in order to protect the gorge from excessive construction. However, the measures introduced to protect the site only covered specific areas; for example, the Pont d'Arc was listed as a natural monument and a site of outstanding artistic, historic, scientific, legendary or scenic interest on 24th January 1931 and the Saint-Marcel Cave was classified on 26th June 1934. As was often the case at this time, only the natural monuments were protected, i.e. the arch of the Pont d'Arc and the area around the entrance to the Saint-Marcel Cave, and no official boundary to these areas was defined (map 1).

This first wave of legislation was completed on 15th January 1943 by the listing of the Ardèche Gorge in the 'Inventory of Sites'. Under article 4 of the Act of 2nd May 1930 regarding the protection of natural monuments and sites of outstanding artistic, historic, scientific, legendary or scenic interest (Official Journal of 4th May 1930), development work cannot be undertaken without the consent of the authorities. However, checks were infrequent and often took place after the work was finished, so this requirement was often ignored and development continued within the protected area, e.g. the creation of a campsite near the Saint-Marcel Cave in 1965.

A further step was taken at the beginning of 1969 with the drawing up of a development plan (Plan Directeur d'Urbanisme) for the Ardèche Gorge. The immediate perimeter of the gorge was given full protection, being declared a 'no-construction' zone in which building of any nature was forbidden. A few months later, on 23rd September 1969, the 'Commission des Sites de l'Ardèche'



Map 1: Construction of protected area: Ardèche Gorge in 1980.

[1] A table summarising these protection measures is given at the end of the article.

decided to classify the development plan's 'no-construction' zone as a natural reserve.

This project took ten years to complete due to opposition from hunters, the mayors of the towns and villages concerned, owners of land within the reserve and members of the local tourism industry (campsite owners, canoe rental businesses). Several proposals were put forward, with the area covered by the reserve being reduced from an initial 2,389ha to 1,572ha. In order to satisfy the demands of all the interested parties, the objectives of the reserve focused on managing the development of tourism within the gorge. For example, two 250-person bivouac sites were set up on the banks of the river, in addition to the existing campsites (Mas de Serret: 100 pitches, La Châtaigneraie: 200 pitches, The Saint-Marcel Cave: 100 pitches, Les Templiers: 300 pitches, i.e. 1200 pitches in total).

In a strange coincidence, it was also at this time that consideration started to be given to the future of the Škocjan Caves. In 1980, Sezana District Council (which managed the cave) approved a protection order for the Škocjan Caves with the dual objectives of preserving the karst environment and of preventing any inappropriate tourism development in and around the caves (Zorman T., 2004, p.114).

This first protection measure was followed in 1982 by a symposium called "Protection of the Karst on the 160th anniversary of Škocjanske jame". Under the guise of a general symposium on tourist caves, the meeting focused almost entirely on the Škocjan Caves, covering their geomorphological characteristics, problems of pollution in the River Reka, the development of the caves and, above all, their future as a tourist attraction. The participants at the symposium were asked to approve a motion that would foreshadow the direction the management of the site would take. The wording of this motion also provided an indication of the motivation behind the site's bid to be classified as a UNESCO world heritage site. The Škocjan Caves were presented as the birthplace of speleology and karstology, as an outstanding monument of international value to be protected against any form of pollution (particularly pollution in the River Reka) and as a tourist attraction with the potential to become a tourism hub for the surrounding area.

In 1986, an area of 200 ha around the collapse dolines was classified by UNESCO under criteria ii, an eminent example of the development of ecosystems, and iii, a superlative natural phenomena or area of exceptional natural beauty and aesthetic importance.

However, the classification documents differed from the motion approved in 1982, as they highlighted the main threats to the Škocjan Caves site. These threats included industrial pollution in the River Reka and the "risk of inappropriate infrastructure development in the area around the caves", in particular the building of car parks for tourists, i.e. it had been deemed "necessary to reinforce planning regulations to ensure the 200ha cultural landscape included in the site remain authentic and natural" (p.96). Between the position taken in 1982 and the application for classification in 1986, it appears there was a change in the way the development of the Škocjan Caves was seen, with the regional development perspective being superseded by a strict control over all tourism development.

POINTS OF COMPARISON AND EXPLANATORY FACTORS

Although measures have been taken to protect both the Ardèche Gorge and the Škocjan Caves sites, there are significant differences in the way the preservation/development balance has been approached. In very simplistic terms, management of the Ardèche Gorge can be described as very laxist, whereas development in the Škocjan Caves is much more strictly controlled. These differences can be explained by a number of factors, many of which are variables effecting the preservation/development couplet.

The history of tourism development

Exploitation of the Škocjan Caves and the Ardèche Gorge for tourism purposes began several centuries ago. Louis François Cassas's illustrations of Istria and Dalmatia show people at the bottom of the collapse dolines, indicating that tourists were already visiting the Škocjan Caves site in 1782 (Keckemet D., 1978), and the opening of a visitor book in 1819 shows that tourism in the Škocjan Caves was becoming more organised. At this time the visit involved descending paths that had been built to the bottom of the Velika collapse doline. (Kranjc A., 2002, p.42): a visit that attracted increasing numbers of tourists, with numbers rising to 3,639 in 1903 (Mihevc A., 2002, p.119).

It was during this same period that Albert Du Boys (1842) published his account of the recreational activities in the Ardèche Gorge, which were mostly concentrated around the Saint-Marcel Cave. The visit of these caves, which was depicted in an engraving by Victor Cassien (p.198-199), consisted of following ladders through the first three chambers: "everyone had a torch, which left behind long trails of flame and smoke". A little later in his book, in a chapter on the Pont d'Arc (p.210-216), Du Boys relates how, for the price of "four or five francs per man", the Ardèche boatmen would take tourists up the river from Saint-Martin to Vallon. At this time, visitors did not descend the river; they went up it!

In both cases, tourists came to admire the picturesque landscape of these karst areas. Publicised by the il-

lustrated writings of previous visitors, both areas quickly became tourist attractions but their tourism development would follow very different routes, leading to the Ardèche Gorge becoming "over-run" by tourists.

Accessibility

The extreme popularity of the Ardèche Gorge can be partly explained by its accessibility. The gorge was quickly made accessible, either by water or by land (construction of the first section of the tourist road past the Pont d'Arc in 1887, completion of the Ardèche Gorge tourist road in 1969). The River Ardèche became the hub of the area, concentrating the flow of tourists to its waters and its banks. This accessibility, combined with other factors such as the development of canoeing, social tourism, naturism and the development of mass tourism (Daudé G., 1986), was one of the key factors in the evolution of tourism in the Ardèche Gorge. In contrast, tourism around the Škocjan Caves did not develop as strongly, despite the area's proximity to the Trieste-Vienna railway (opened in 1857). This contrast can be explained with reference to a second element in the notion of accessibility.

In fact, access has to be considered on a smaller scale, i.e. the accessibility of the individual caves rather than the entire karst area. Although the Škocjan site is easy to get to, the area's major attractions, i.e. its collapse dolines, are less easily accessible than neighbouring tourist caves, such as the Postojna Cave, 25 kilometres to the north-east along the same railway line. The topography of the Postojna Cave is more suited to large-scale tourist development and the authorities responsible for Postojna were very quick to set up a system for controlling the flow of tourists: installation of a door to protect the cave from intruders in 1819, creation of a special commission for the cave in 1823, installation of a system of cars pushed along rails in 1872, which was modernised in 1914 with the introduction of petrol locomotives, and in 1959 with electric locomotives. In 1968, the construction of a circular line increased the cave's capacity to 14,400 visitors per day. To give a comparison, in 1980, when the future of the Škocjan Cave was being considered, Postojna received 827,826 visitors, whereas Škocjan only received 37,500, a ratio of 22 to 1!

The politico-economic context

Although visitor numbers for the Škocjan site were relatively "modest" compared with other Slovenian caves and the Ardèche Gorge, new protection measures, such as the UNESCO classification in 1986, focused on this aspect of the site. This apparent paradox was partially the result of the political context surrounding the decision to apply for UNESCO classification. In order to satisfy the political interests of the different republics within Yugoslavia, the Yugoslav federal committee asked each republic to list potential world heritage sites. Both Postojna and Škocjan were on the list for the Republic of Slovenia. Despite its international reputation, it was decided that the Postojna site was too "built up" and developed and preference was given to the "more natural" Škocjan Caves site.

Thus, distinct approaches to the karst resource preservation/tourism development couplet become apparent. For both the Ardèche Gorge and the Škocjan Caves, the objective of the protection measures that have been introduced is to preserve the fauna, flora, geology and geomorphology of the site. However, in the Ardèche Gorge, these measures have been applied to an area that attracts a large number of visitors and in which river-based tourism is a vital part of the economy. For example, Vourc'h and Natali (2000, p.31) estimated the turnover of the canoeing business in the Ardèche Gorge to be 20 million francs (€3 million). As a result, protection measures were designed to manage the flow of tourists through the area, rather than to reduce the number of visitors. In contrast, the Škocjan site was protected before large-scale tourism existed and the implicit objective of the protection measures was to regulate future development. Although the underlying intention of the UNESCO classification was to structure tourism development for the whole of the Kras Plateau, with the Škocjan site as its hub, precautions were taken to prevent any "unsuitable" development.

This perception of tourism development as needing to take into account the preservation of the entire karst resource can be found in the wording of the protection legislation.

Legislation

The Škocjan Caves are governed by the 'Škocjan Caves Regional Park' Act of 1st October 1996. The Act was worded to comply with the recommendations made in the 1986 UNESCO inscription documents, which stipulated: "the possibility of enlarging the regional park would be a welcome initiative" (p.96). This legislation strengthened the protection of the Škocjan Caves, which are considered a national treasure, both for their natural beauty and for their archaeological and anthropological riches. Going beyond the often obsolete and harmful distinction between nature and culture, the management of the park is based on a global and multi-disciplinary approach. Article I of the Act states, "In order to preserve and research its outstanding geomorphological, geological, and hydrological formations, rare and threatened plant and animal species, palaeontological and archaeological sites, ethnological and architectural characteristics and the cultural landscape, and to ensure conditions for adequate development, the region of the Škocjan Caves is hereby declared a regional park called Škocjanske jame".

Conversely, the legislation creating the Ardèche Gorge Natural Reserve only considers the natural riches of the site, placing the emphasis on the protection of plant and animal species. Moreover, these protection measures do not go very far. For example, articles 3 and 6, designed to limit hunting to wild boar, were strongly opposed by local people and were annulled in 1983. Even though one of the reasons put forward for creating the reserve was to protect the fauna, the legislation protecting wildlife in the park is no stricter than elsewhere. These contradictory currents result in fluctuations between tighter and more permissive regulation.

This is also the case for camping in the gorge, the regulation of which was one of the main reasons for creating the reserve: "as one of the objectives of the reserve is to preserve the natural environment while allowing public access, article 7 of the draft statutory order stipulates that camping is forbidden throughout the reserve; however, two water-sports centres will be set up where visitors may camp for one night" (record 1305W21, 'départemental' archives, Privas). As a result, two bivouac sites were set up, draining most of the reserve's financial subsidies for the first ten years of its existence, with the "light facilities" initially planned being redefined to include giant barbecues, large, marquee-style tents, and over-elaborate sanitary facilities, etc. The planned capacity of 250 campers per bivouac, i.e. a total of 500 people, was often exceeded; for example, the figure of 3,508 campers was reached during the weekend of 26th/27th June 1999 (Consultative Committee Report of 13th July 2004, p.4).

However, during the last ten years the management of this natural reserve has moved in a more environment- and wildlife-friendly direction. The change, which began in 1997 with the drawing up of a LIFE programme for the area, was embodied in the reserve's 1999-2003 management plan, which included a monitoring programme and significant scientific projects. In 2002 a central booking office was set up in order to regulate visitor numbers and the number of people per night per bivouac has been reduced to 700, with the intention of reducing this number to 500 for the 2006 season.

Preservation areas

In concrete terms, the two approaches to managing the karst resource preservation/development couplet have led to the definition of preservation areas.

The Ardèche Gorge includes two preservation areas: the 1,575 ha Ardèche Gorge Natural Reserve and the 1,040 ha Pont d'Arc listed site (map 2).

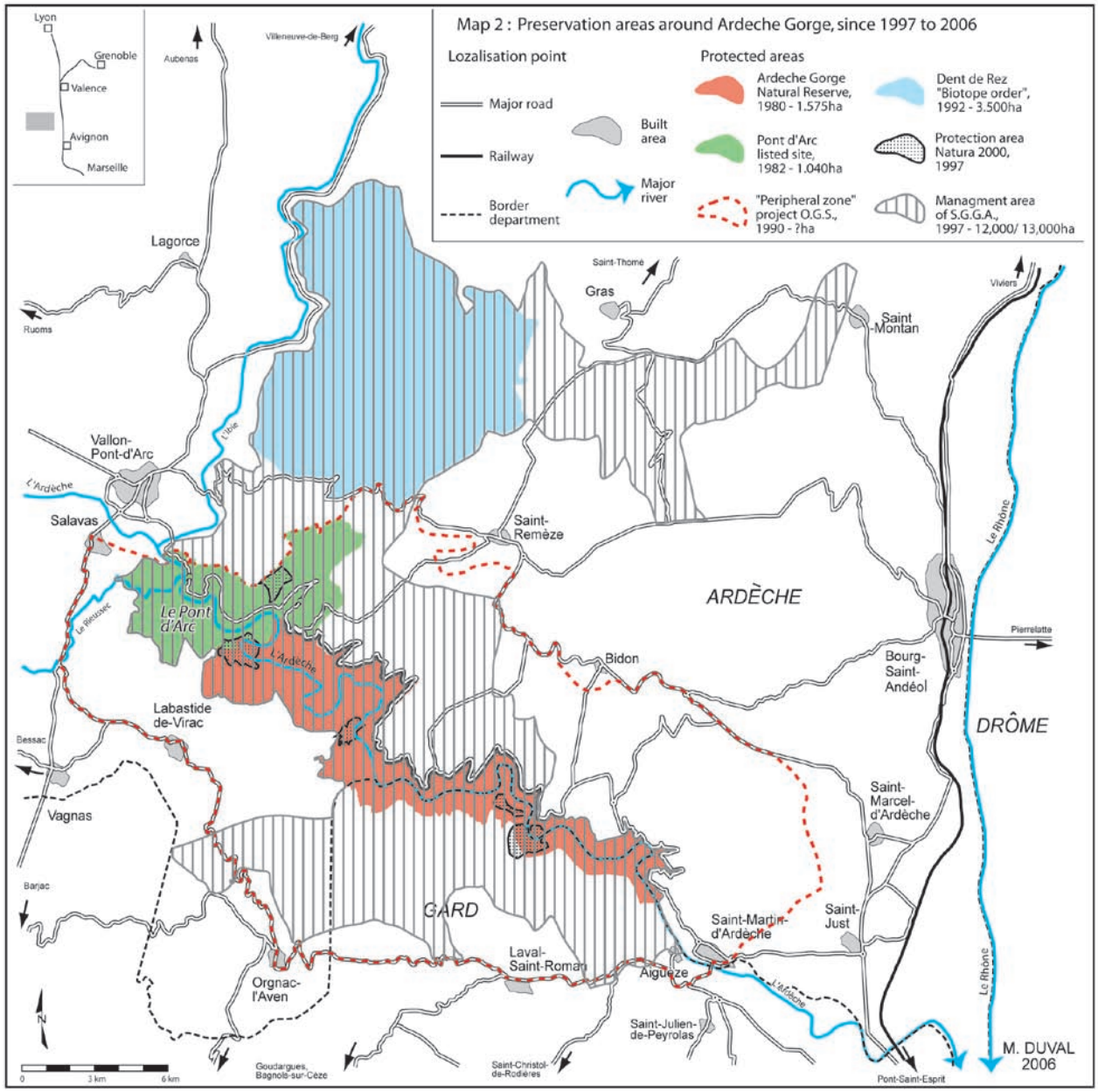
Even though French environmental law allows for the creation of preservation areas around natural reserves, such areas have never been defined in law and cannot be opposable to third parties. Furthermore, no such protection areas have ever been created around the Ardèche Gorge, despite being on the agenda of several consultation meetings, often under the heading of "sensitive zone" or "peripheral zone".

Nevertheless, two protection measures have gradually been introduced for the peripheral area around the Ardèche Gorge. Firstly, in 1992 a "biotope order" was issued for the Dent de Rez, a 3,500 ha area of land on the left bank of the river, upstream from the gorge. This area covers the 'communes' of Gras, Lagorce and Saint Maurice d'Ibie. The 'Syndicat de Gestion des Gorges de l'Ardèche' was given responsibility for the management of this area in 1997, together with those parts of the 'communes' that fall within the natural reserve, i.e. a total area between 12,000 and 13,000 ha (visual assessment after topographic map).

Secondly, the increase in size of the protected areas has been combined with the extension of the responsibilities of the 'Syndicat de Gestion des Gorges de l'Ardèche'. Since 2004, the 'Syndicat' has taken "full responsibility for the land of the 'communes' that falls within areas classified as a natural reserve or as a Natura 2000 site, as well as for an "intervention zone" comprising the 'communes' or parts of 'communes' belonging to the natural environment of the Ardèche Gorge" (Prefectoral order of 26th March 2004).

The terms under which the 'Syndicat' operates and the area for which it is responsible are generally defined by the objectives of the Natura 2000 fauna and flora protection programme. However, there are no real measures for protecting the karst resource itself. Although the protection of species depends on the protection of the environment as a whole, one could perhaps expect that a preservation area would be defined according to geological, geomorphological and karst criteria, taking into account the surface networks to be protected and the preservation of water resources through actions covering the entire drainage basin. None of the protection measures have taken a whole-karst approach to preservation. The karst as a whole has only been considered by other parties, for example through the implementation of a General Water Development Plan, for which the existence of the natural reserve is only a peripheral consideration (map 3). Throughout the Ardèche Gorge area, there is a superposition of preservation areas, which telescope into other programmes without really producing concerted actions in terms of managing the karst resource.

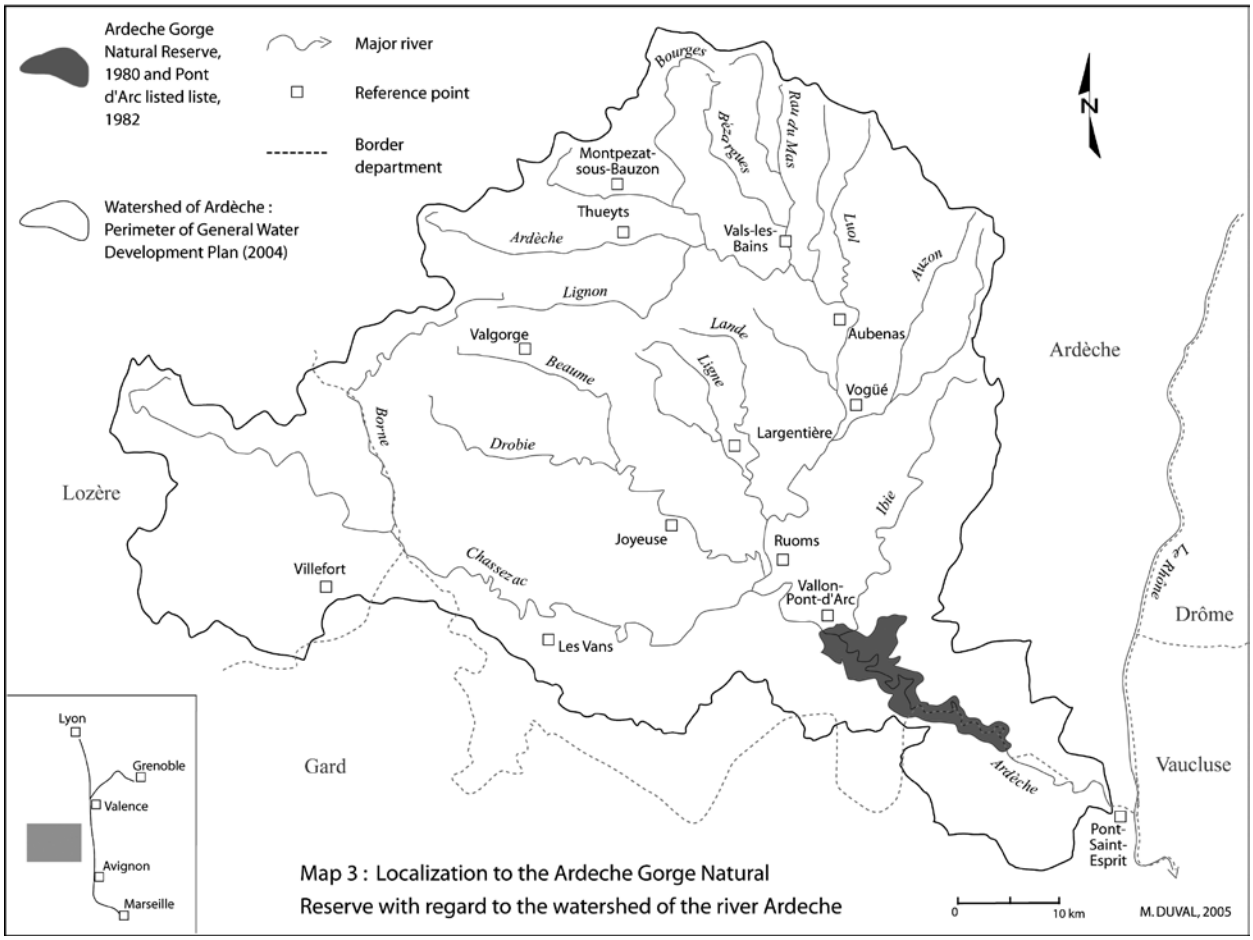
Recently, a regional project based around the Ardèche Gorge natural reserve has started to emerge with the desire to implement a 'rural excellence pole' and a new rural development programme, steered by the DIACT (inter-governmental delegation for regional devel-



Map 2: Preservation areas around Ardèche Gorge, since 1980 to 2006.

opment and competitiveness, new naming of DATAR). The Ardèche Gorge reserve, as a protected tourist area will form the hub of an 'Ardèche Gorge' region. One of the main objectives of this programme is to renovate the tourism offer provided by the Ardèche Gorge and its surrounding area, by creating a network of local tourism industry players. However, this new programme will be superimposed on top of the measures described above, without any real consideration or explanation of how they will be linked.

The structure of the preservation areas around the Škocjan Caves is evidence of a completely different approach to the problem. The Škocjan Caves site is at the heart of several preservation areas (map 4), but subject to a global management system, as stipulated under the 1996 Act. The original, 1986 UNESCO site covered 200 ha around the collapse dolines. This area has gradually been increased, with the 1996 'Škocjan Caves Regional Park' Act defining a central zone of 413 ha around the caves that includes areas around exceptional cultural and historical monuments subject to even stricter protection measures. This Act also created a buffer zone covering the 45,000 ha of the Reka watershed upstream from the central area. Unlike the preservation areas in the Ardèche



Map 3: Localization to the Ardèche Gorge Natural Reserve with regard to the watershed of the river Ardèche.

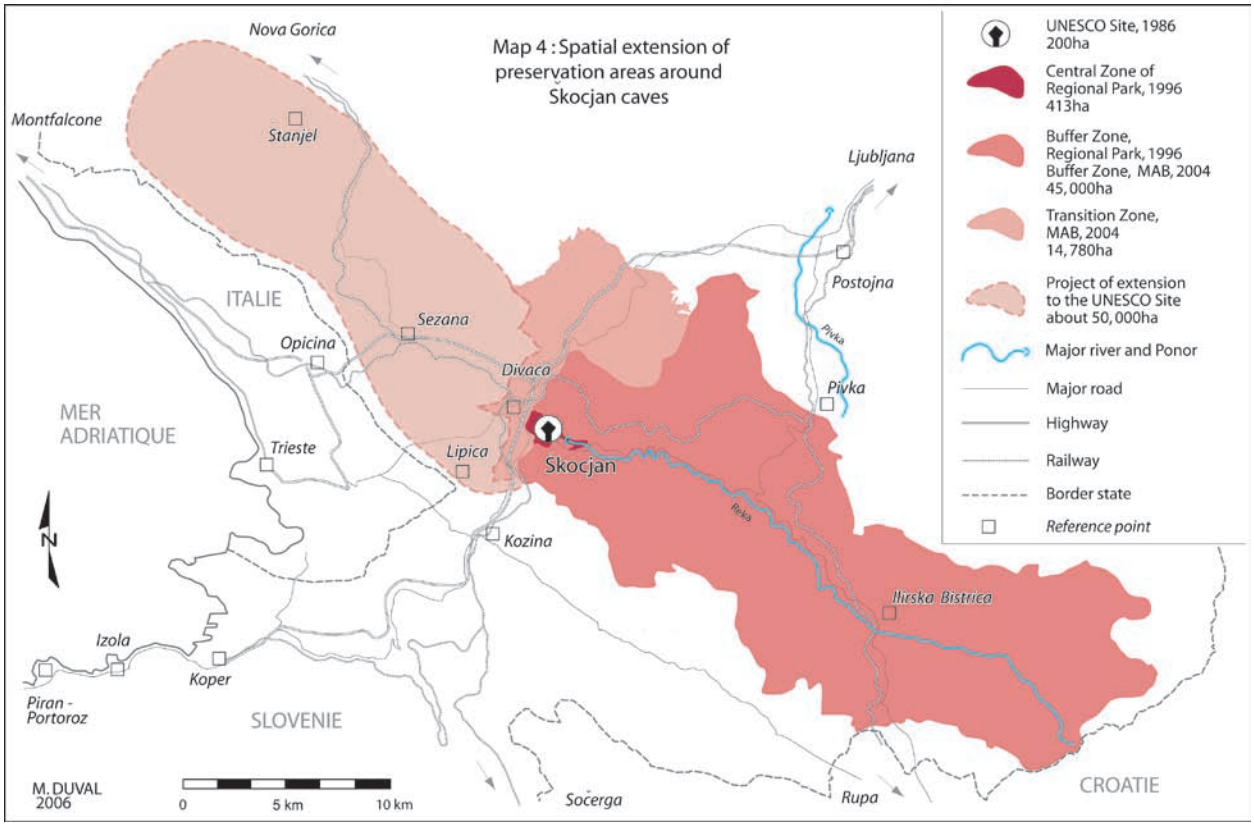
Gorge, this extended zone was defined according to the need to protect the entire karst resource.

In 1999, the designation of a Ramsar zone around the Škocjan Caves confirmed the authorities' commitment to this 'whole-karst approach'. The Ramsar convention was originally drawn up to protect "wetlands that are important on an international scale, particularly as habitats for water birds", but its terms of application were extended in May 1999 to cover all forms of internationally important wetlands. By providing the means to guarantee the quantity and quality of the water feeding the Škocjan system, the managing body has ensured the protection of the karst resource, at least in terms of its underground waters.

In 2004, this action was completed by the launch of a MAB project, which confirmed the status of the buffer zone on the Illirska Bistrica side as defined by the 1996 Act and which set up a new zoning system with creation of a 14,780 ha transition zone. This zone covers the Divaca district (district that contains the Škocjan Caves following the reorganisation of local authority boundaries in 1992), which was not included in the 1996 buffer zone. The MAB programme provides the regional park with the means to coordinate efforts to control local hydrological processes, develop sustainable farming practices and preserve the caves by limiting surface water pollution through the controlled use of fertilizers and the management of waste water flows. As a result, the MAB project covers an area of no less than 60,193 ha.

The 1986 UNESCO classification, the 1996 Act, the 1999 Ramsar Convention and the 2004 MAB project cover all the different facets of the Škocjan Caves karst landscape: the natural monument with exceptional karst formations of archaeological, historical and ethnological value, the protection of underground water resources and the sustainable management of infiltration water on the plateau by maintaining traditional farming techniques.

Currently, two projects for extending this protection dynamic are being studied. The first concerns the enlargement of the regional park's boundaries to include neighbouring districts such as Naklo, Brežec, Gradišče. This extension has been sought by the inhabitants of



Map 4: Spatial extension of preservation areas around Škocjan caves.

these districts, who would like to be included within the park in order to benefit from the subsidies available for renovating housing and farm buildings. Little by little the park is increasing its territory.

The second project involves a major extension to the UNESCO site, increasing its area by approximately 50,000 ha, thereby protecting the entire Kras plateau, which the Slovenian authorities consider extremely vulnerable due to its karst characteristics. This new area could be classified as a cultural landscape, combining the caves and other karst features, traditional architecture, the Lipica stud farm with its Lippizaner horses, and traditional forms of agriculture such as wine growing. With an eye on preparing for this classification, several key projects have been, or are being carried out. Most are aimed at developing small-scale heritage, such as nature trails around collapse dolines (Divaca), livestock farming (Pliskovica) and outstanding monuments (Komen, Štanjel). These projects are gradually providing the area with a tourist structure and creating a network of tourist flows, mostly centred round the Škocjan Caves.

CONCLUSION AND PERSPECTIVES

The Škocjan Caves and the Ardèche Gorge present two faces of the karst resource preservation/development dialectic and their comparative study is interesting on several levels. The two sites present similarities in terms of tourism development and the implementation of protection measures: both sites began to be perceived as tourist attractions at about the same time, i.e. during the 19th century, and both benefit from protection measures introduced at the beginning of the 1980s.

Nevertheless, the numerous differences between the sites give an insight into the different ways in which the preservation/development couplet is viewed. When examined from this preservation/development perspective, the differences in the ways the two sites are managed can be traced through a diachronic approach to the history of their tourism development.

The combination of several factors (accessibility, development of water sports, etc) rapidly led to the Ar-

dèche Gorge becoming what some people have dubbed the "Mecca of canoeing". Although the enthusiasm for water sports was present throughout the 20th century, its development was facilitated by the completion of the Ardèche Gorge tourist road in 1969. Today, the Ardèche Gorge accounts for 2/3 of the 'département's' tourism business, whether it is measured in terms of the accommodation offer, the number of bed-nights, or the turnover of the different sectors of the tourism market. As this thriving tourism industry already existed when the Ardèche Gorge Natural Reserve was created, the reserve's statute had to take into account the interests of all the affected parties. As a result, the reserve appears to be a very flexible compromise between tourism and preservation. To a large extent, this historical and economic context explains the difficulties in setting up the reserve and, most notably, the fact that a management plan was not drawn up until twenty years after the reserve was created!

The context in which the protection measures for the Škocjan Caves were introduced was very different. Confronted with major pollution problems from the industry in the Reka basin upstream from the caves, but benefiting from the Yugoslav Federal Committee's strong desire to obtain UNESCO classification for certain sites within the Yugoslavian Republics, the Škocjan Caves were inscribed on the list of world heritage sites in 1986. This protection measure was then reinforced by a specific law creating the Škocjan Caves Regional Park in 1996.

Tourism in the Škocjan Caves areas is viewed very differently to the way it is seen in the Ardèche Gorge. Firstly, the Škocjan area receives far fewer visitors; hence the economic stakes are much lower. Furthermore, at the beginning of the 1980s tourism development around the Škocjan Caves was carried out with two contradictory objectives: become a structuring tourist attraction for the whole of the Kras region but, at the same time, prevent any "anarchic" development. This dual position led to the drawing up of the 1996 Act, which gave the park's managing body the means to implement a global development programme. The 1996 Act, together with the Ramsar Convention and the MAB programme, enable the Škocjan Caves Regional Park to carry out actions concerning different aspects of the karst resource: natural heritage, cultural heritage, preservation of water resources, maintenance of traditional agriculture, awareness-raising and educational programmes for the general public, etc. Gradually, the Škocjan Caves area is positioning itself as a model site, a shop window onto the principles of sustainable development.

On a more general level, the differences between the two sites are also due to their different approaches to the management of karst resources. A comparison of the general legislation relating to environmental protection in Slovenia and in France shows that Slovenia has taken specific measures to protect karst areas, whereas France considers karsts to be just another part of the natural environment, alongside coastlines and mountain areas. In Slovenian law, specific protection has been given to karst areas both by the Environmental Protection Act of 1999 and by the Nature Conservation Act of 1999. For example, article 4 of the 1999 Nature Conservation Act defines karst phenomena as being part of Slovenia's national heritage and therefore worthy of special protection.

Slovenia's specific approach to karst landscapes could be ascribed to the extent of such formations in Slovenia: more than 44% of the country is composed of karst phenomena, ranging from alpine karsts to dinaric and pre-alpine karsts. As a result, 75% of the protected areas in Slovenia, whether they are national parks, regional parks or other types of protected area, are karst landscapes. However, the extent of karst landscapes is not sufficient to explain Slovenia's readiness to protect this type of resource. In fact, the proportion of karst landscapes in France is similar to that in Slovenia ("karsts account for between a third and a quarter of the land area of France", Nicod J., 1995, p.21), but France's karst resources are not subject to specific protection measures.

In contrast, since 2003, Slovenia has reinforced the protection given to karst areas through a new law governing the protection of caves. The law's objective is to classify Slovenia's 8,726 known caves into three categories: caves open to visitors, caves that are semi-closed and monitored, and caves that are only open to scientists. An approach that has got certain French karstologists dreaming…

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LEGISLATION

In France:

Statutory order n°80-27 of 14th January 1980 creating the Ardèche Gorge Natural Reserve (Ardèche and Gard 'départements')

Statutory order listing the area around the Pont d'Arc as an area of outstanding natural beauty 24th February 1982.

Order relating to the inscription of the Ardèche Gorge in the Register of Listed Sites, 15th January 1943.

Order relating to the classification of the Saint-Marcel Cave, 26th June 1934.

Order relating to the classification of the Pont d'Arc, 24th January 1931.

Act n°76-629 of 10th July 1976 relating to the protection of the natural environment

Act of 2nd May 1930 relating to the protection of natural monuments and sites of exceptional artistic, historic, scientific, legendary or scenic interest, Official Journal of 4th May 1930.

In Slovenia:

Škocjan Caves Regional Park Act, 1st October 1996.
Environmental Protection Act, 1993, The Republic of Slovenia

Nature Conservation Act, 1999, The Republic of Slovenia

Objects	**The Škocjan Caves**	**Ardèche Gorge**
Object(s) covered by the protection	The caves and the collapse dolines+	The gorge and surrounding karst plateaux
Current management body	Public Agency for the Škocjan Caves	'Syndicat de Gestion des Gorges de l'Ardèche'
Beginning of tourism	*1782:* Cassas' engravings	*1842:* "Album du Vivarais" by Albert du Boys
Number of visitors	89,700 visitors in 2004	1.5 million visitors for the gorge and the surrounding karst plateaux in 2005
Protection measures	1*980:* Protection order passed by Sezana council *1982:* motion adopted during the international symposium "Protection of the Karst on the 160th anniversary of Škocjanske jame" *1986:* UNESCO inscription *1996:* 'Škocjan Caves Regional Park' Act	*1931:* classification of the Pont d'Arc *1934:* classification of the Saint-Marcel Cave *1943:* listing of the Ardèche Gorge *1969:* adoption of a development plan: the gorge is classified as a *no-construction* zone *1980:* order creating the Ardèche Gorge Natural Reserve *1982:* classification of the area surrounding the Pont d'Arc *1992:* biotope order for the Dent de Rez
Protected areas	200ha: UNESCO area 1986 413ha: central zone of the regional park 1996 45,000ha: buffer zone of the regional park 1996 14,780ha: transition zone of the MAB programme 2004 50,000ha: project for UNESCO classification	1,575 ha: area of the natural reserve 1980 1,040 ha: area surrounding the Pont d'Arc 3,500 ha: biotope order for the Dent de Rez 1992. Placed under the responsibility of the SGGA in 1997 13,000 ha: area of neighbouring 'communes' 1997
Related programmes	*1999:* Ramsar Convention *2004:* MAB	*2004:* General Water Development Plan (SAGE) *2006:* 'rural excellence pole'?

Table 1: Comparison between the Škocjan Caves and the Ardèche Gorge.

TOURISME ET MESURES DE PRÉSERVATION À L'ÉCHELLE DES AIRES KARSTIQUES : COMPARAISON ENTRE LES GORGES DE L'ARDÈCHE (FRANCE) ET LES GROTTES DE ŠKOCJAN (SLOVÉNIE)

RÉSUMÉ

Cet article a pour objectif de présenter deux des orientations que peut prendre le développement touristique d'espaces karstiques, présentement la Réserve Naturelle des Gorges de l'Ardèche (France), et le Parc Régional des Grottes de Škocjan (Slovénie). Support de flux touristiques majeurs, ces deux espaces se sont progressivement structurés autour d'une activité touristique, tout en étant le théâtre de politiques d'aménagement et de protection de la ressource karstique.

Depuis les débuts de la mise en tourisme de ces deux espaces, un processus dialectique s'est progressivement institué entre préservation et valorisation, amenant à la création de deux espaces touristiques protégés. Pour autant, entre préservation de la ressource et mise en valeur de cette dernière, force est de constater qu'il n'existe pas UN équilibre mais que chaque espace concerné s'auto-régule selon des caractéristiques qui lui sont propres et qui évoluent. Cette approche comparative nous amène ainsi à envisager les formes que peut prendre cet équilibre précaire et à présenter deux manières différentes de considérer la gestion d'espaces karstiques touristiques.

L'intérêt d'une approche comparative en géographie est de pouvoir porter des regards croisés sur un même objet, en vue de faire ressortir des éléments explicatifs et de porter notre réflexion sur des processus. En ce sens, force est de constater que ces deux sites offrent des similitudes tant du point de vue de leur développement touristique que de la mise en place de mesures de protection : tous deux ont commencé à être perçus comme des curiosités touristiques à peu près à la même période, soit courant du 19ème siècle ; tous deux ont bénéficié de mesures de protection au début des années 1980.

Pour autant, nombres de différences peuvent être constatées, lesquelles permettent d'expliciter ce rapport au couple préservation/ valorisation touristique. Dans ce registre, une approche diachronique de l'histoire de leur mise en tourisme permet de comprendre en partie les différences de gestion de ces deux sites. La combinaison de plusieurs facteurs (accessibilité, développement des pratiques sportives d'eaux vives, etc.) ont rapidement conduit les gorges de l'Ardèche à devenir ce que certains appellent la « Mecque du canoë-kayak ». Cet engouement manifeste tout au long du 20ème siècle s'est alors confirmé suite à la construction de la route touristique des gorges de l'Ardèche en 1969. Dans cette perspective, la création de la Réserve Naturelle des Gorges s'est sur-imposée à une activité touristique importante. Ménageant les intérêts de chacun, cette réserve apparaît comme un compromis très souple entre activité touristique et préservation de la nature. Ce contexte historique et économique explique alors en partie les difficultés que la Réserve a rencontrées lors de sa mise en place, et notamment le fait qu'il s'est écoulé pas loin de vingt ans entre sa date de création et la rédaction d'un plan de gestion !

Comparativement, la mise en place des mesures de protection à l'échelle des grottes de Škocjan s'inscrit dans une logique différente. Confrontées d'une part à des problèmes de pollution industrielle importants en amont du bassin versant de la Reka et se situant d'autre part dans le contexte politique d'une inscription Unesco des Républiques de Yougoslavie porté par le comité fédéral Yougoslave, les grottes de Škocjan sont inscrites en 1986 sur la liste du patrimoine mondial ; cette première mesure se doublera par l'adoption d'une loi singulière portant création du Parc Régional des Grottes de Škocjan en 1996.

L'interprétation de la dimension touristique est ici différente de celle constatée à l'échelle des gorges de l'Ardèche. Dans un premier temps, ce site connaît une fréquentation touristique moindre et les enjeux économiques ne sont pas du même ordre que ceux observés à l'échelle des gorges. Par ailleurs, en terme de développement touristique, deux orientations contradictoires sont formulées au début des années 1980 : devenir un site touristique structurant pour l'ensemble du Kras et en même temps, se prémunir de tout développement « anarchique ». Ce double positionnement conduira à la rédaction de la loi de 1996, laquelle donne les moyens à la structure gestionnaire du Parc de conduire une politique d'aménagement globale. Ce dispositif, complété par la suite par la convention Ramsar et le programme MAB, permet aujourd'hui au Parc Régional des grottes de Škocjan de conduire des actions sur les différents volets de la ressource karstique : patrimoine naturel, culturel, préservation de la ressource en eau, maintien d'une agriculture traditionnelle, programmes de sensibilisation et d'éducation à l'encontre d'un large public, etc. progressivement, les grottes de Škocjan se positionnent en tant que site référent, espace vitrine de l'application des principes du développement durable.

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THE CONCEPTS OF HERITAGE AND HERITAGE RESOURCE APPLIED TO KARSTS: PROTECTING THE CHORANCHE CAVES (VERCORS, FRANCE)

ZAMISLI O DEDIŠČINI IN NJENIH VIRIH PRIREJENIH ZA KRAS: VAROVANJE JAM CHORANCHE (VERCORS, FRANCIJA)

Christophe GAUCHON[1], Estelle PLOYON[1], Jean-Jacques DELANNOY[1], Sébastien HACQUARD[1], Fabien HOBLÉA[1], Stéphane JAILLET[1], Yves PERRETTE[1]

Abstract UDC 551.442(44)

Christophe Gauchon, Estelle Ployon, Jean-Jacques Delannoy, Sébastien Hacquard, Fabien Hobléa, Stéphane Jaillet & Yves Perrette: The concepts of heritage and heritage resource applied to karsts: Protecting the Choranche caves (Vercors, France)

In 2005, French Ministry of Ecology started procedure to inscribe 18 Caves of Chorance into the World Heritage list of UNESCO. The application has to answer to three objectives: the scientific interest, definition of the territory, and to propose the management model. For the first all the heritage sources has to be identified, such as flowstone formations, karst water objects and historical curiosities. This are very important and sensitive questions specially because they have been not answered before the procedure of the inscription started off.

Key-words: karst heritage, karst protection, show cave, classified natural site, caves of Choranche, Vercors, France.

Izvleček UDK 551.442(44)

Christophe Gauchon, Estelle Ployon, Jean-Jacques Delannoy, Sébastien Hacquard, Fabien Hobléa, Stéphane Jaillet & Yves Perrette: Zamisli o dediščini in njenih virih prirejenih za kras: varovanje jam Choranche (Vercors, Francija)

2005 je francosko Ministrstvo za okolje pričelo postopek za vpis 18 jam okoli Choranche za vpis v svetovno dediščino pri UNESCO. Vloga mora odgovoriti trem merilom: znanstvenemu pomenu, opredelitvi ozemlja in predlagati način upravljanja. Predvsem je bilo treba ugotoviti vse vire dediščine, kot so kapniki, kraški vodni objekti in zgodovinske zanimivosti. To je zelo pomembno in občutljivo vprašanje, še posebej, ker to ni bilo opravljeno, preden je bil sprožen postopek za vpis.

Ključne besede: kraška dediščina, varstvo krasa, turistična jama, zaščitena naravna vrednota, jame Choranche, Vercors, Francija.

INTRODUCTION

Although France has often played a pioneering role in the exploration and study of caves, the country has done very little to protect the heritage resources of its karst areas. At present, there is no specific legislation covering the protection of karst landscapes – caves and swallow holes can only be protected under general environmental protection laws. Some karsts have been listed as historic monuments, others are protected for their biotopes, four caves have been declared nature reserves and a few hundred others have been classified as "natural sites and monuments". The law relating to this final category dates back to 1930 and applies to lakes, waterfalls, peat bogs and coastal dunes, as well as to caverns. The central tenet of this legislation is expressed in Article 12, which stipulates that the "owner of a classified site cannot destroy or modify the state or appearance of that site" without special authorisation. Thus, protection measures are applied on a case-by-case basis, as opportunities arise, and the choice of sites is strongly influenced by the specific interests of the civil servants responsible for the environment.

[1]Laboratoire EDYTEM-University of Savoie, Chambéry, France. e-mail: christophe.gauchon@univ-savoie.fr

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No better illustration of the conservation situation for France's karst heritage can be found than the Choranche Caves network, in the Vercors Mountains. These caves have been explored for over a century and are the most important underground tourist attraction in the French Alps. They feature in every tourist guide and have been the subject of several television programmes; hence, they are quite well known. Dozens of postcards show the forests of soda-straws hanging from the cave roof reflected in the green waters of Lake Coufin. Despite these attributes, the site is not covered by any protection measures: only the careful stewardship of the site's owner-managers has maintained the caves in their current condition. A catalogue of the area's main heritage resources has been drawn up as part of the process of granting the area listed-status and introducing official protection measures. However, the numerous objections to the protection proposals show how difficult it can be to protect any area, even a site of universally accepted importance, such as Choranche.

CONTEXT

In August 2005, the Rhône-Alpes "Direction Régionale de l'Environnement", acting on behalf of the Minister of Ecology, launched a call for tenders for the production of an environmental protection dossier for the "Choranche Caves, surface and subsoil". At the end of the tendering procedure, the bid entered by the EDYTEM laboratory was chosen.

Unusually, the proposal to protect the Choranche Caves was not a response to a clear and immediate threat to the area or the karst system. In this case, the protection process was started as a preliminary step in achieving UNESCO World Heritage status for Choranche and seventeen other French stalactite and stalagmite caves: UNESCO will only accept nominations for sites already protected by the State sponsoring the nomination and this is not the case for some of the caves concerned, including the Choranche Caves.

The 18 caves nominated for UNESCO listing were chosen solely on the basis of the formations they contain, either for their variety (colours, shapes, mineralogy), fragility, rarity or aesthetic quality. Although concretions are relatively abundant throughout the Choranche network, the UNESCO nomination specifically cites the tourist part of the Coufin Cave because of its rich ornamentation. However, it immediately became apparent that in order to effectively protect the site, the protection measures would have to cover a much more extensive area than this one cave. The Choranche Caves consist of a network of more than 40 km of explored passages, divided into two main and parallel networks (Coufin-Chevaline and Gournier) and containing three underground rivers. The Coufin Cave has been open to tourists since 1967. It remains a popular attraction, although visitor numbers peaked, at more than 200,000 visitors per year, at the beginning of the 1990s. In addition, groups led by State-qualified cave guides frequently visit the Gournier Cave. The network is well understood due to more than 40 years of intense scientific study. On the surface, the Coulmes Plateau also contains a wide range of features that, in our opinion, should be included in the protection dossier.

The environment in which these networks have developed cannot be ignored. The Coulmes Plateau, on the north-western edge of the Vercors, is a true backwater: away from the main through-routes, extremely isolated and with apparently limited potential. The project to give the site listed status is not designed to protect the area from any particular threat; however, it has raised fears amongst some local politicians that it will one day be used to stop future development projects. In fact, the plateau is seen as a neglected area whose development (for example, connection to mains services) is lagging behind that of the villages in the Gorges de la Bourne. The question that arises is whether listing the site will increase the divisions between the gorges and the plateau or enhance their complementarity. This is why any protection measures must take into account social and local geo-political considerations, as well as environmental and heritage aspects.

OBJECTIVES

Given the above context, the specification laid down by the "Direction Régionale de l'Environnement" stipulated that EDYTEM's work should be divided into a number of phases, to ensure the listing procedure is completed as quickly as possible.

Fig. 1: Visitors in a galery in Coufin cave, postcard, beginning of XXth century.

First, it was necessary to establish that the site was of "general interest from an artistic, historic, scientific, legendary or picturesque point of view" (art. 4 of the Act of 1930). As the contract covered both the surface and the subsoil, this assessment work had to be applied to the underground karst networks as well as to the external landscapes. The artistic and legendary aspects were quickly eliminated, as they are of little importance in this case. That left the historic, scientific and picturesque dimensions, for which there is a wealth of documentation establishing the heritage value of the Choranche Caves and the Coulmes Plateau. The heritage resources within each of these categories are examined in more detail below.

Next, it was necessary to establish an appropriate, coherent and acceptable protection perimeter. This turned out to be a very sensitive issue. In France, the protection given to karst areas rarely covers entire karst networks unless the system in question contains caves with exceptionally important archaeological remains or cave paintings. There are no accepted standards in cases where karsts are protected for their aesthetic value and to preserve the landscape. Protection measures are generally determined by the beauty of the site and only the land containing the cave is protected, which is a highly unsatisfactory state of affairs. In order to ascertain how the terms of the 1930 Act can be used to give effective protection to karsts, it is necessary to understand what a karst is and how its different elements interact. Should the entire cave be protected, or only the part seen by tourists? For the Coufin, Chevaline and Gournier springs, should protection be limited to the hydrogeological watershed or should the listed area cover the entire karst, with its numerous caverns, its landscapes and all its heritage resources? These questions were to become central to the ensuing public debates.

The "Direction Régionale de l'Environnement" also recommended writing management guidelines for the listed area, taking into account all the activities carried out in the massif. In fact, the 1930 Act does not specify which types of development should be allowed or prohibited in a listed area. Therefore, listing the site must be allied with a series of recommendations, based on the specificities of the listed area, that will provide the local authorities with criteria on which to base decisions on whether to authorise future development projects. The protection measures must take into account the farming, forestry, permanent dwellings and numerous sports activities (cross-country skiing, hiking, caving, climbing, hunting, etc) that currently coexist in the Coulmes Plateau area, as the aim is not to stop these activities but to ensure they can continue without damaging the environment. Hence, it is necessary to define the rules that will govern each activity, the types of development compatible with preserving the area and those that are totally unacceptable. This work requires detailed consultations with all the parties involved.

Finally, once this work was completed, the EDYTEM team were required to draw up documents presenting the area to be protected and its heritage resources (poster + small pamphlet) for the general public. A certain amount of expertise was needed for determining the karst resources and landscapes to be protected. However, it was also necessary to take into account the affects of the protection measures on the numerous interests impacted by the project.

WORKING METHODS

The EDYTEM team brought together experts with the different but complementary skills that would be needed to successfully complete the various phases of the project. Work began by carrying out a survey of the extensive literature on the massif and its karst network produced by cavers, archaeologists, palaeontologists, ethnologists specialising in local history and, of course, karst geographers. In addition, cavers from the "département" of Isère (Comité Départemental de Spéléologie), with whom EDYTEM has long had a good working relationship, provided cave inventories and topographical surveys.

This data formed the basis for a comprehensive atlas of the network that includes information on the plateau's heritage resources, current protection measures (Natura 2000 zones, special bird protection areas, etc) and existing economic activities, etc. The mapping work was completed by a photographic survey of the area (including work by professional photographers) showing the underground and surface landscapes. These documents were drawn up for use during the steering committee's meetings with the various interested parties, in order to show how work was progressing, as well as for inclusion in the classification dossier.

Compiling the protection dossier and management guidelines required detailed consultations with local interests and numerous information and fact-finding meetings with all the interested parties. Strenuous efforts were made to take into account all forms of land-use and to avoid needlessly upsetting people, so as not to create unnecessary difficulties. The most delicate part of this consultation phase was presenting the boundaries of the proposed protection area, as every interested party found reason to object, based on their own interests and their own perception of the area. Hence, the scientific work had to take into account the local interests that were uncovered as the project progressed.

STAKES

The most important sector to be affected by the project to list the Choranche Caves and the Coulmes Plateau will undoubtedly be tourism. The operator of the Choranche Caves has always supported the protection project because the prospect of being awarded UNESCO World Heritage status is seen as a marvellous opportunity to give a much-needed boost to the site. The Choranche Caves are the biggest pay-to-enter tourist attraction in the Vercors Mountains and the only one to be open all year round; the area's other tourist sites are all highly seasonal with summer and winter peaks. Visitors are also attracted to the area around the caves by outdoor sports, such as rock climbing on the cliffs at Presles (which have been popular with climbers since the 1970s), cross-country skiing and hiking. As a result, there are several accommodation providers on the plateau and in the village of Choranche. When asked, local people are unanimously in favour of these outdoor activities, as they are seen as a source of jobs, but this does not prevent conflicts between visitors and locals over issues such as parking and access to the climbs. The plateau's local councillors sometimes seem more concerned by any nuisance caused to farmers than by the economic benefits gained by the area's accommodation providers. The public debates have shown greater disagreement than expected over the tourism issue, with not everyone in the area considering it a priority.

It has become apparent that local attitudes to the protection project are shaped by individual opinions on tourism. In addition, the introduction of protection measures as a step towards obtaining UNESCO World Heritage status is seen as a double-edged sword. If the French government's UNESCO project succeeds, almost everyone agrees the benefits will be positive. However, opponents argue that if the UNESCO project fails, listing the site will hinder any form of development on the plateau. This standpoint results from a deep misunderstanding of the need to protect this karst environment and the blind opposition of the plateau's politicians and the valley's inhabitants. The biggest fear, which has been expressed very clearly, is that nearly all the project's benefits will go to Choranche, as tourist flows will be channelled through the gorge to the caves. Consequently, the villages on the plateau will be subject to restrictions that will constrain their development, without receiving any of the benefits. These territorial differences in opinion are exacerbated by differences in peoples' mentalities. The people of Choranche have long appreciated the benefits brought by tourism, starting with a spa that thrived from the 19th century until the 1930s. On the other hand, the plateau's inhabitants feel as though they have only ever received the crumbs left after Choranche has eaten most of the tourist cake. Presles' elected representatives have particular difficulty in understanding that it is up to them to find ways in which to reap benefits from

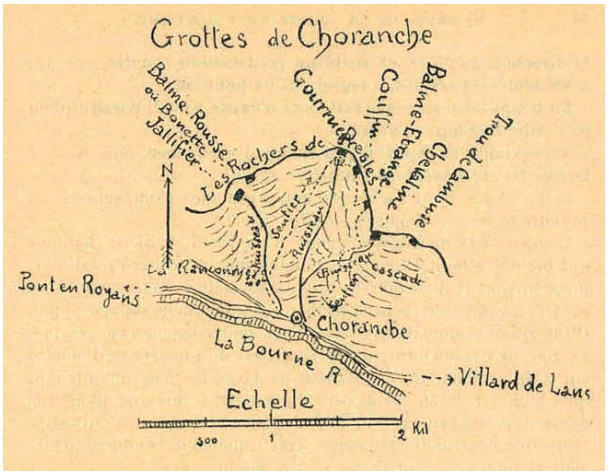

Fig. 2: Choranche cirque and the location of main caves, drawn by Oscar Décombaz, 1898.

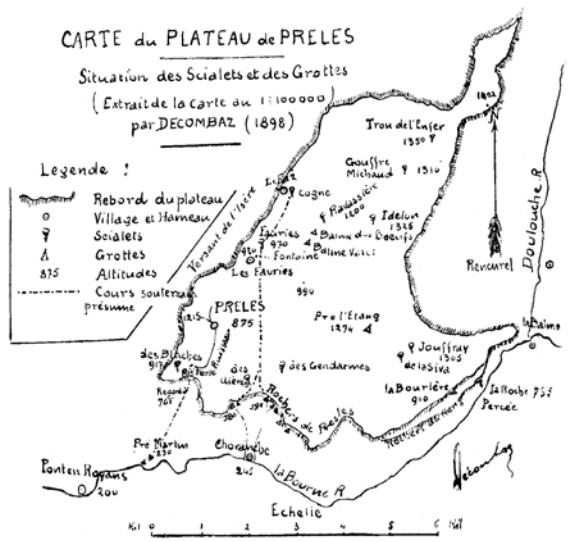

Fig. 3: Sketch of the Coulmes Plateau by Oscar Décombaz, 1899, with location of caves and pot-holes (scialets).

being listed a World Heritage site; it is their responsibility to ensure Choranche does not take all the pickings.

There is also a conflict between the plateau and the gorge over the issue of water, another element that is central to this project. Although everyone agrees on the importance of water, there are deep disagreements about how this resource should be used. Therefore, water's place in the system must be defined: as well as being a resource for the local population, it is an essential part of the area's heritage that must be preserved. For example, during the 1990s, Presles council proposed drilling through the plateau to tap into the Gournier underground river in order to resolve its chronic water shortage problems. The project was only abandoned, albeit provisionally, when local cavers proved it technically unfeasible. This was a bitter disappointment for the plateau's politicians, who are reluctant to definitively discard the idea. However, diverting these waters could not be authorised under any protection scheme, as the Gournier feeds the famous tufa falls that form such an important part of the site's landscape. If a water extraction scheme were to be permitted, the largest reductions in water flows would be in summer and it is in summer, when air temperatures are relatively high, that the Gournier's waters deposit the greatest amount of tufa. There is an enormous gulf between those who perceive water as a resource to protect and those who regard it as a resource to exploit. Although positions on this issue are rarely explicitly stated, they have played a central role in the debates over the protection project. Paradoxically, the waterfalls themselves cannot be protected under the terms of the 1930 Act, as the Act cannot protect water, only the landscape surrounding it. Hence the importance of the management guidelines, which will include precise recommendations on how the water is to be protected. A traditional "water culture", as is found in Mediterranean karst areas, has not developed in the Vercors Mountains. This may be due to the area having a particularly humid climate (Ppn > 2000mm) in which, historically, there has been little need to conserve what is seen as an abundant resource. As a result, when faced with increases in demand, both for agricultural and for domestic use, the only solution local politicians were able to envisage was to find other sources to increase the supply to users.

CHORANCHE'S KARST RESOURCES

A comprehensive inventory, in the form of themed data sheets, of all the karst resources to be found in the Choranche area was drawn up for inclusion in the protection dossier. Without reproducing the full inventory, we would like to give an idea of the diversity and richness of the heritage resources of the Choranche Caves and the Coulmes Plateau.

CAVE FORMATIONS

The original motivation behind the UNESCO World Heritage project was a desire to protect and promote the area's cave formations, including the spectacular Coufin soda straws that have made Choranche famous. Given their aesthetic qualities and the role they play in attract-

ing tourists to the Choranche Caves, agreement on the need to preserve these exceptional formations was immediate and unanimous. Even if visitors to the caves only take away one memory, it is of the thousands of strands of "spaghetti" reflected in the waters of the lake and river at Coufin. For many years, the tourist route through the cave has been screened by windows in order to protect the formations from direct damage. However, a wider preservation area will have to be defined if these formations are to be given more global protection. This has proven to be a very delicate issue. Although the UNESCO presentation dossier only specifically covers the cave formations, these formations cannot be preserved unless the environment in which they formed is protected. But, how extensive should this protected area be? Should it only cover the land immediately above the caverns? Or should it include the area that feeds water to the formations, in so far as it can be defined, bearing in mind that the stratification of the rock will doubtlessly create areas of lateral transfer? Or should it extend to the entire hydrogeological system? Scientists must provide precise answers to these questions – answers on which to base clear and coherent arguments that will convince sceptics. Given the need to protect a large area of the karst in order to protect the cave formations, it is unfortunate that the UNESCO proposal only explicitly mentions the "formation-bearing caves". This has proved to be a major obstacle to the protection process, as it enables opponents to argue that only the soda straws themselves should be listed. However, because of the way in which karst systems work, a much more extensive area must be protected if the formations are to be properly preserved. Hence, the idea of listing the "formation-bearing caves" may actually work against the protection of the karst system: something that the promoters of the project undoubtedly never imagined.

THE KARST SYSTEMS

The karst systems themselves are utterly remarkable. In fact, there are three perched systems, with no saturated zones, cut by the incision of the Gorges de la Bourne. Other similar systems can be found in the French Pre-Alps, but the three aligned springs at the foot of the Coulmes escarpment are particularly spectacular. Cavers have followed and mapped the underground rivers over distances of several kilometres, following the River Gournier, for example, for almost six kilometres under the plateau to its terminus 680 metres above the spring. These systems are made up of highly complex networks of tunnels and chambers of all shapes and sizes. For instance, the Gournier Cave boasts a subterranean river that flows beneath a vast fossil gallery, the galleries of the Coufin Cave form a true labyrinth and the River Chevaline flows over a succession of large gours before emerging at a spring that is uniquely gravity-fed. Although most of the parties concerned by the protection project are aware of these underground landscapes, they have little idea of their diversity. One of the objectives of the photographic survey of the area is to raise awareness of this difficult-to-visualise dimension.

PALAEONTOLOGICAL, ARCHAEOLOGICAL AND HISTORICAL REMAINS

Palaeontological, archaeological and historical remains: Large quantities of fossils, particularly the remains of bears, have been found in some of the caves on the plateau (especially the Pré l'Etang cave) and in the upper fossil levels of the Coufin Cave. The Pré l'Etang deposit has been intensively studied; however, the Bear Gallery in the Coufin Cave, which is at the end of the known network and very difficult to reach, has never been visited by palaeontologists. Despite being discovered by some of the cave's earliest explorers, the species of bears to be found there have never been described. In addition, explorations of some of the cavities in the rocks of the Choranche Cirque have revealed prehistoric remains, but undoubtedly not enough for the Cultural Affairs Department to classify these rock shelters as "historic monuments". As well as these prehistoric remains, there are archaeological relics from the more recent past, such as those left by the plateau's charcoal burners, including settlements that have been abandoned since the beginning of the 20th century. In the caves themselves, and especially in the Balme Etrange, signatures dating back to the 1830s can be found on the walls: proof of the long history of tourism in the Choranche Cirque and confirmation of some of the information found during the literature survey. Therefore, the historic interest of the site cannot be denied.

EXO-KARSTIC STRUCTURES AND FORMATIONS

Exo-karstic structures and formations are extremely abundant, providing a link between the scientific and picturesque interests of the site. The Choranche Cirque contains the most spectacular formations, most notably the large tufa flows that dot the Gournier stream. About ten years ago, the visitor trail was extended to include these tufa flows and signposts were erected to explain how they formed and their palaeoenvironmental significance.

On the plateau, such formations are usually less easily visible because of the dense forest cover, but they are just as interesting. The Pot Siva area contains a group of roofless caves that can be explored and that contain the remains of speleothems. Despite being particularly well developed, the cone karst, which provides evidence of the phases of karst formation during the Tertiary, cannot easily be seen due to the lack of a viewpoint overlooking the

whole area. In fact, this is the only part of the Vercors to contain such a diversity of karst structures, and this alone should provide sufficient justification for listing the area.

THE LANDSCAPE RESOURCE

The landscape resource: In addition to the elements mentioned above, the landscape as a whole exudes a special atmosphere that adds to the area's beauty. This atmosphere mostly comes from the stark contrasts that characterise the area: the juxtaposition of gorge and plateau, barren cliffs and luxuriant undergrowth, narrow defiles and open plateaux, dark caverns and luminous cirques, and the abrupt transitions between the vertical and the horizontal. The spectacular view of the Cirque de Choranche from the caves car park always makes a vivid impression on visitors; however, it is important to make them realise that they will only get a complete picture of the area's natural wealth if they continue their excursion onto the plateau. By doing this, they will also be able to appreciate the variety of the area's vegetation, which changes from the beech-pine forest so typical of the cool and humid Northern Pre-Alps to a sub-Mediterranean boxwood-juniper assemblage. These changes are governed by altitude, as the plateau gradually descends from a height of 1450 metres in the north to 850 metres in the south, before plunging past the Coufin cave entrance (at 590 m) to the bottom of the gorge and the village of Choranche at 270 metres. More than half a century ago, the caver André Bourgin suggested that the "Coulmes area of the Vercors showed the characteristics of the whole massif in miniature" (1950, p. 16). This concentration of karst landscapes in an area of only 40 km^2 is another of the riches of the Coulmes Plateau and further justification for protecting the site – especially in a country that has not, as yet, given official protection to any of its mid-altitude forest karsts.

DIFFICULTIES

Current French law and Department of the Environment guidelines contain five criteria for assessing whether protecting a site is in the general interest. The Choranche Caves and Coulmes Plateau satisfy three of these five criteria; therefore, the task of producing a protection dossier should have been very straightforward. In fact, a number of obstacles quickly appeared, including the refusal by some local people to accept the recommendations of the experts who are compiling the dossier. Surmounting these problems will probably be extremely difficult as they are based on fears that listing the area will seriously hamper development without providing significant benefits.

Although the 1930 Act defines the introduction of protection measures as a purely administrative procedure, in practice it requires a participative approach involving the local population: a reality that does not always make life easy. In addition, the public debate on the protection project provided a forum for expressing old frustrations that were not necessarily connected with the protection project. Reactions may have been particularly vehement due to people feeling that local infrastructure needs had, for many years, been neglected. Many local people could not understand why listing the site was suddenly so important, as there was no immediate threat to the area. They felt that their ability to manage their own area was being called into question. Listing the site quickly became a local political issue that could only be understood in local terms and opposition to the project has been increased by the solidarity between local communities. For example, to avoid angering its neighbours, Choranche, which has everything to gain from the project, has rallied to the cause of Presles, which is hostile to anything other than a very limited protected area. Therefore, the project has lost the support it expected to receive from Choranche. Local politicians and competing institutions (Regional Nature Park, Association of local councils, etc) are also trying to make political capital from the protection project. And no one knows if the hostility of the area's regional councillor is related to him being a quarry owner!

CONCLUSION

At the current time, the Choranche Caves protection dossier is still being finalised and the full listing process is far from being finished. The dossier will be presented for examination by the "Départementale" Commission and the "Commission Supérieure des Sites", and then it will probably go to ministerial arbitration before the listing can be approved by the Conseil d'Etat, France's highest administrative body. To be successful, the protection project will require strong and sustained political support. The importance of this political dimension came as a surprise to both the laboratory's team of scientists and to the Department of the Environment, which had not expected such strong opposition.

Nevertheless, the process has been extremely useful – it has shown the strength of public opinion and the awareness of the local population and their elected representatives of the need to consider the karst area in which they live as a precious resource that must be carefully managed. Even though these communities have been part of a Regional Nature Park for 35 years, despite the fact that there has been more than a century of exploration and tourism in the caves, although the tourist image of the Vercors is based on a preserved mountain environment and despite 20 years' scientific work to explain karst processes in layman's terms, local politicians and a large section of the population are still unable to accept the need to give the karst active protection. Most local people now understand that the individual parts of the karst are merely components in a coherent and fragile whole. However, as soon as an attempt is made to explain what this means in terms of managing the karst, this "whole karst" concept is quickly forgotten if it is contrary to individual vested interests.

France undoubtedly needs to develop a much more active karst protection policy. Forming a National Council for Underground Heritage, as is being considered by the Minister of Ecology, would raise awareness of this need and listing the Choranche Caves would be seen as a major step forward in the management of karst heritage resources.

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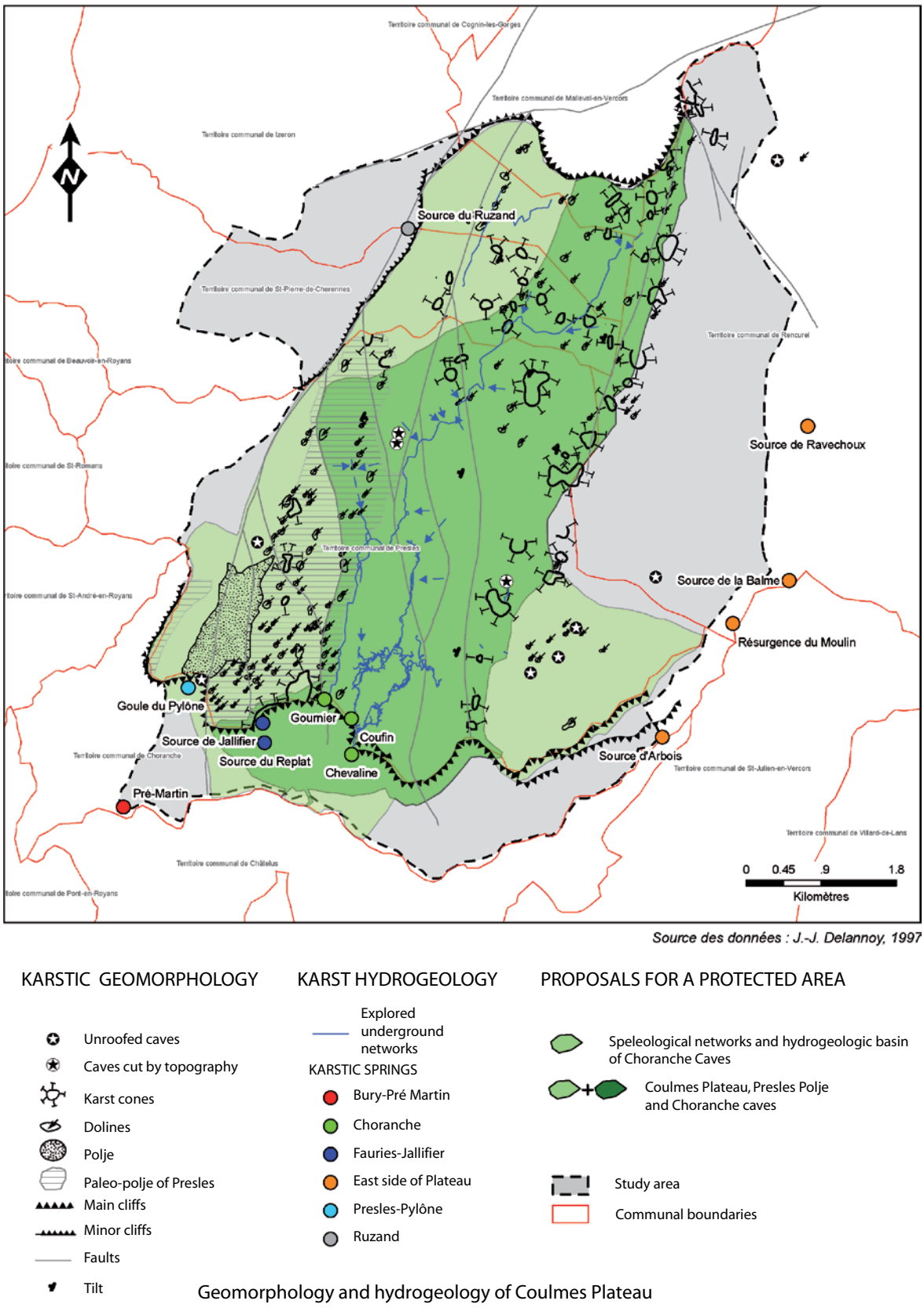

Fig. 4: Geomorphological map of the Coulmes Plateau, with the proposition for the delimitation of protected area.

LES NOTIONS DE PATRIMOINE ET DE RESSOURCE PATRIMONIALE APPLIQUÉES AU KARST : LE CLASSEMENT DU SITE DE CHORANCHE (VERCORS, FRANCE)

RÉSUMÉ

En août 2005, le ministère français de l'Ecologie a lancé la procédure de classement des grottes de Choranche et du massif des Coulmes (Nord Vercors, Préalpes). Dans le cadre de la préparation d'un dossier « Patrimoine mondial » de l'Unesco portant sur 18 cavités concrétionnées, il convient en effet que les biens proposés à l'inscription soient bel et bien protégés par l'Etat porteur du dossier. Or, jusqu'à présent, le réseau karstique des grottes de Choranche ne bénéficie d'aucune protection réglementaire. Il fait l'objet d'une exploitation touristique organisée depuis 1967 et qui s'est avérée plutôt respectueuse de la caverne ; si aucune menace directe ne pèse sur cet ensemble karstique, une commune du plateau a longtemps envisagé de capter la rivière souterraine de Gournier, ce qui aurait de graves conséquences sur la formation des tufs à l'aval de l'émergence.

Le dossier de classement doit répondre à trois objectifs : 1°, établir l'intérêt scientifique, pittoresque, historique, artistique ou légendaire du site, car ce sont là les cinq critères prévus par la loi de 1930 qui régit la protection des sites naturels. Dans le cas des grottes de Choranche, les intérêts artistique et légendaire n'étant pas concernés, c'est sur les trois autres registres que porte le travail. 2°, définir le périmètre de classement, ce qui est une tâche fort délicate car une partie du plateau est peuplée d'agriculteurs qui craignent pour leur activité. 3°, proposer un cahier de gestion de l'espace classé, en prenant en compte toutes les activités présentes, autant économiques que de loisirs.

Il a donc fallu identifier les nombreuses ressources patrimoniales qui pouvaient justifier la mesure de protection. Au premier rang viennent les concrétions, et surtout les célèbres fistuleuses de Coufin, qui valent au site de Choranche de figurer dans le dossier Unesco. Tous les acteurs s'accordent sur la valeur de ces concrétions, mais les conflits apparaissent dès que sont évoquées les mesures de protection à prendre : car il ne suffit pas de classer la parcelle sous laquelle se trouvent les fistuleuses, mais bien la totalité de la zone d'alimentation des concrétions.

Deuxième ressource, l'eau : le nord-ouest du Vercors constitue un karst forestier de moyenne montagne, abondamment arrosé, mais les communes du plateau disposent de fort peu de ressources en eau, d'où de grandes convoitises qui pèsent sur cette ressource.

Mais l'étude scientifique a fait émerger aussi d'autres ressources patrimoniales. Sur le plan scientifique, c'est le karst des Coulmes dans son ensemble qui mérite d'être protégé : trois grandes rivières souterraines coulent en effet sous le plateau des Coulmes et forment un ensemble d'émergences pénétrables, perchées 400 mètres au-dessus du fond de la vallée de la Bourne. Les réseaux spéléologiques explorés (> 40 km) présentent toute la panoplie des formes endokarstiques, alors qu'en surface, c'est un spectaculaire karst à buttes qui est conservé, avec de nombreuses paléo-cavités trépanées. Les cascades de Gournier présentent aussi un complexe de tuf, avec plusieurs dizaines de tonnes produites chaque année. Cette diversité des formes se traduit sur le plan pittoresque car le paysage formé par le cirque de Choranche, dominé par de hautes falaises de calcaires ocres, est grandiose. Ces paysages sont marqués par toute une série de violents contrastes entre le dedans et le dehors, le vertical et l'horizontal, le minéral et le végétal… Enfin, l'intérêt historique, plus discret, n'en est pas moins réel, avec à la fois des gisements archéologiques sous le porche de Coufin, des gisements paléontologiques importants dans plusieurs cavités (Coufin, Pré l'Etang) et les traces d'anciennes visites touristiques, surtout dans la grotte de Balme étrange (années 1830).

L'intérêt patrimonial du site est donc multiple et aisé à démontrer. Tout se complique lorsqu'il s'agit de convaincre les acteurs du bien fondé des mesures de protection à prendre. En effet, si les professionnels du tourisme soutiennent ce projet de classement, il n'en va pas de même des agriculteurs, des chasseurs et d'une partie des propriétaires qui n'approuvent pas cette mesure. On voit par là que la gestion patrimoniale des ressources du karst reste un problème délicat, surtout si un vrai travail pédagogique n'a pas précédé le lancement de ces procédures.

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EVALUATING THE HUMAN DISTURBANCE TO KARST ENVIRONMENTS IN SOUTHERN ITALY

OCENJEVANJE SPREMEMB KRAŠKEGA OKOLJA ZARADI VPLIVA ČLOVEKA V JUŽNI ITALIJI

Fabiana CALÒ[1] & Mario PARISE[2]

Abstract UDC 502.6:551.44(450.75)

Fabiana Calò & Mario Parise: Evaluating the Human Disturbance to Karst Environments in Southern Italy

Karst environments are extremely vulnerable to degradation and pollution. Although the carrying capacity of these natural environments is low, a variety of human activities is implemented on karst settings generating impacts at the surface and subsurface. To evaluate the degree of disturbance to typical karst environments in the Mediterranean basin, two areas have been selected in Apulia (south-eastern Italy). The human-induced effects are being assessed by applying a recently developed Karst Disturbance Index (KDI), based on a categorical framework encompassing physical, biological, and social aspects, and the evaluation of a number of indicators for each category. Scores are assigned to the indicators, to assess the severity and the extent of the human impacts on the karst environment. Knowledge of the study areas derives from a combined use of direct experience and field surveys, and the critical evaluation of data available from research articles and local organization reports. Since this approach is an holistic and comprehensive method, different scientific branches and law issues have been considered. The results so far obtained for the study areas highlight the urgent need of a sustainable management of anthropogenic activities: for example, quarrying and stone clearing, both extensively widespread, are among the most dangerous practices for karst surface and subsurface landforms in Apulia. These activities are heavily changing the original karst landscape and causing the partial or total destruction of natural caves. This study represents a preliminary evaluation of the human disturbance to karst in Apulia, but has to be necessarily integrated by further applications in other areas of the region, aimed at a better understanding of the potentiality of the approach and its feasibility in different karst settings.

Keywords: karst disturbance, human impact, Karst Disturbance Index, Apulia, Italy.

Izvleček UDK 502.6:551.44(450.75)

Fabiana Calò & Mario Parise: Ocenjevanje sprememb kraškega okolja zaradi vpliva človeka v južni Italiji

Kraško okolje je izredno občutljivo za uničevanje in onesnaževanje. Čeprav je »nosilna sposobnost« tega naravnega okolja majhna, so na krasu najrazličnejše človeške dejavnosti, ki vplivajo na njegovo površje in podzemlje. Da bi ocenili stopnjo takih sprememb na značilnem kraškem ozemlju v Sredozemlju, je bilo izbranih dvoje področij v Apuliji (jugovzhodna Italija). Posledice, ki jih je povzročil človek, so bile ugotovljene s pomočjo pred kratkim razvitega »indeksa sprememb na krasu«, ki upošteva fizične, biološke in družbene vidike, obenem pa so bili za vsako skupino ovrednoteni številni pokazatelji. Ti so bili točkovani in tako sta bili ovrednoteni intenzivnost in obseg človekovega vpliva na kraško okolje. Poznavanje obravnavanega ozemlja temelji tako na neposrednem opazovanju kot na terenskih preučevanjih ter na kritičnem ovrednotenju podatkov iz strokovnih člankov in poročil lokalnih združenj. Ker gre za celostno in vsestransko metodo, so upoštevane različne znanstvene panoge in zakonodaja. Tako dobljeni izsledki za preučevana ozemlja kažejo na nujnost sonaravnega urejanja človeških dejavnosti, kot sta npr. lomljenje in čiščenje kamenja, oboje je na široko razširjeno in ki predstavljata najbolj nevarno dejavnost za kraške površinske in podzemeljske oblike v Apuliji. Ti dejavnosti močno spreminjata prvotno kraško površje in povzročata delno ali celotno uničenje podzemeljskih jam. Ta študija predstavlja predhodno oceno sprememb na krasu v Apuliji in bi morala biti vključena v bodoče raziskave drugih ozemelj te regije, da bi lahko bolje razumeli prednosti te metode in njeno uporabnost za različna kraška okolja.

Ključne besede: spremembe na krasu, vpliv človeka, indeks sprememb na krasu, Apulija, Italija.

[1] External collaborator CNR-IRPI, Bari Italy; e-mail: fabianacl@libero.it

[2] CNR – IRPI, Sezione di Bari, Via Amendola 122, I – 70125 Bari, Italia; e-mail: m.parise@ba.irpi.cnr.it

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INTRODUCTION: THE DISTURBANCE INDEX FOR KARST ENVIRONMENT

Karst, with its surface and subsurface landforms such as closed depressions, sinkholes and caves, is among the most fragile natural environments of the world, and extremely susceptible to any change. Karst systems are non renewable resources but, nevertheless, they are increasingly being disturbed by a variety of human activities generating impacts both above and below ground (Williams, 1993).

Many anthropogenic actions cause great transformations and degradation of karst regions, including quarrying and mineral extraction, deforestation, agricultural practices, illegal waste dumps in natural cavities, tourism in caves. All these activities may result in negative effects on karst, such as pollution and depletion of water resources, changes of the natural morphology and hydrology, decline of animal species, etc. (Parise & Pascali, 2003).

Complexity of karst, where several different categories interact in creating the overall ecosystem, requires to consider and analyse any component of karst, both individually and in the reciprocal relationships with the others, in order to safeguard and manage it in a sustainable way. At this aim, only an holistic, comprehensive approach, addressing physical, economic and social factors, can effectively assess the threats to karst areas (Van Beynen & Townsend, 2005).

In order to reduce the karst system to elements easily studied for the evaluator, this article applies the method recently proposed by Van Beynen and Townsend (2005) to measure factors of karst disturbance (Fig. 1) based on a framework divided into five broad categories, each encompassing more detailed attributes: *Geomorphology* that encompasses surface landforms, soil and subsurface karst; *Atmosphere* that deals with air quality; *Hydrology* that

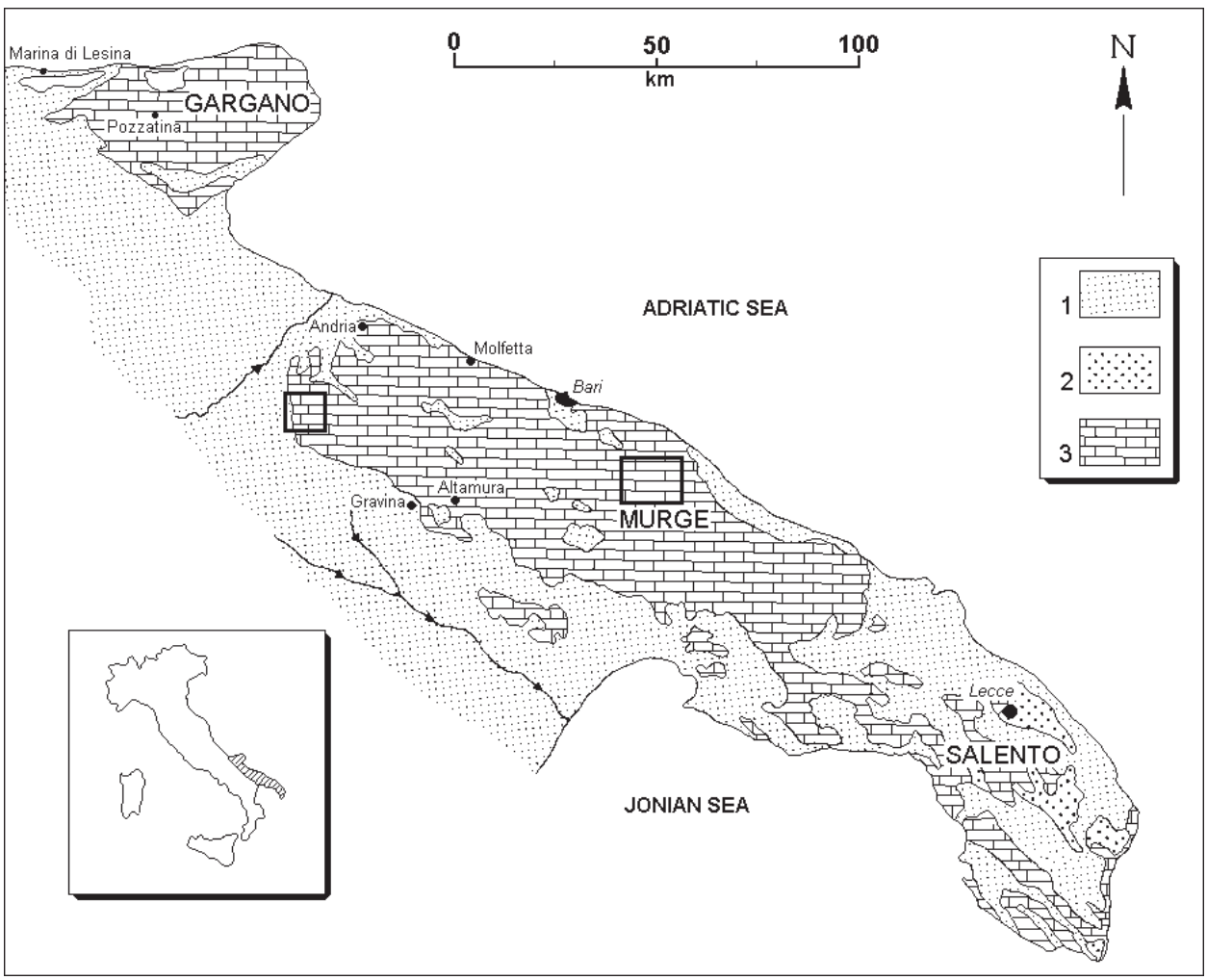

Fig. 2: Geological sketch of Apulia. Explanation: 1) recent clastic cover (Pliocene – Pleistocene); 2) bioclastic carbonate rocks (Paleogene) and calcarenites (Miocene); 3) platform carbonate rocks (Cretaceous). The two insets refer to the study areas.

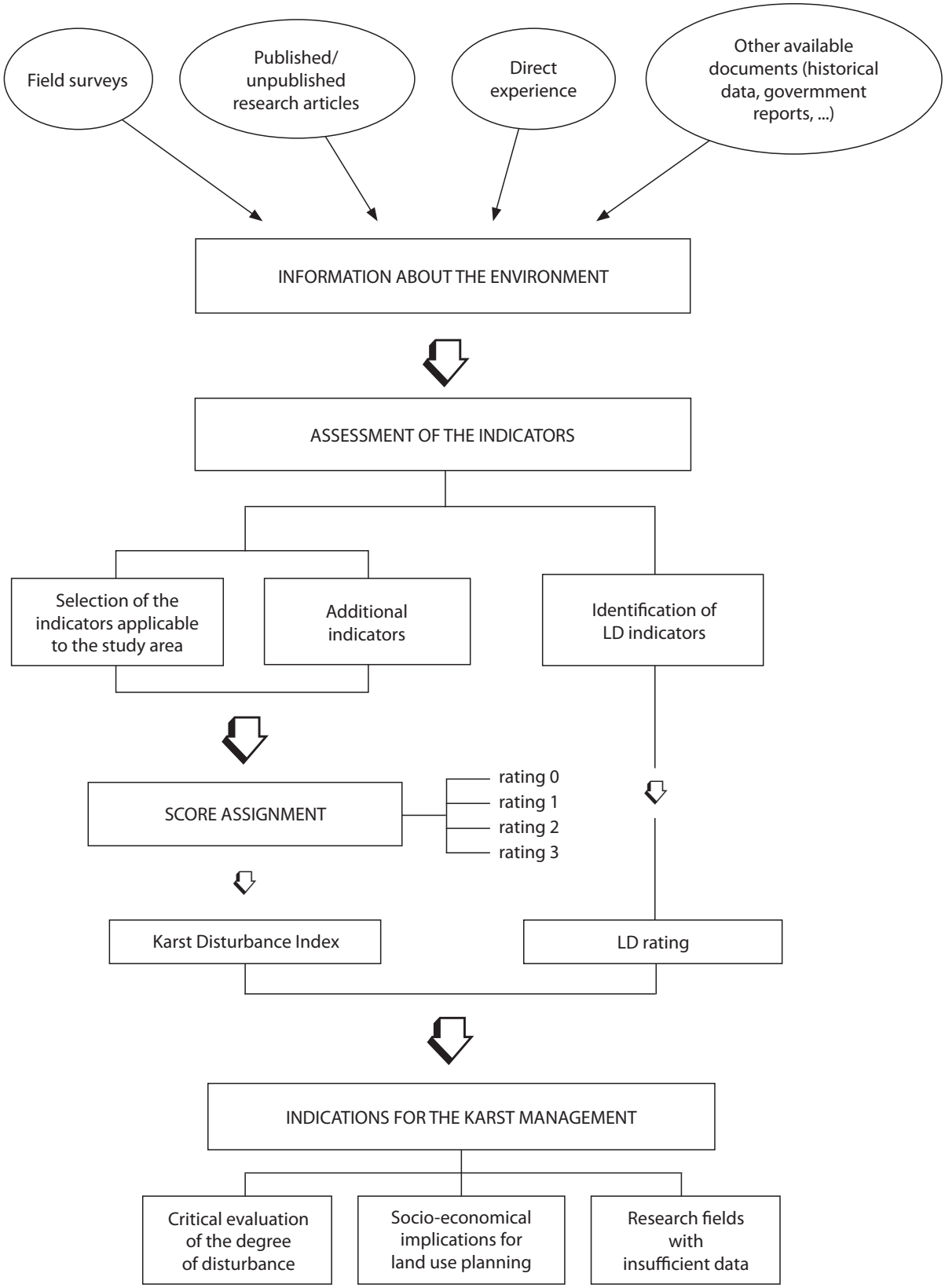

Fig. 1: Flow chart illustrating the methodology followed in this study.

includes surface practices influencing water quality and quantity, and water quality of springs; *Biota* that concerns the vegetation disturbance and the subsurface biota in cave and in groundwater; and *Cultural factors* that include human historical artefacts, stewardship of karst region and building infrastructure.

The degree of disturbance of a certain attribute is indicated through a pre-established set of associated indicators, from those most destructive for surface karst as quarrying/mining (Gunn, 1993), and dumping waste in sinkholes and cavities, to the less apparent but equally dangerous use of pesticides and herbicides in agriculture, and so on. Each indicator, that can be appraised by the evaluator from historical data, field observations, published and unpublished research articles and local government reports, is assigned a score from 0 to 3 based on severity and extent of the variable being considered: rating 0 means no karst disturbance, rating 1 indicates localized and not severe impact, rating 2 widespread and severe impact, whilst when a catastrophic impact is observed rating 3 is assigned.

To determine the degree of disturbance of a particular region, the evaluator should know what an undisturbed karst system is, and assume it as the ideal reference system. This might be relatively simple for some indicators (water quality, extent of quarrying, etc.), but very difficult for others (loss of biodiversity, human-induced condensation/corrosion, etc.). Finding locations without human influence may be extremely difficult, which forces the evaluator to use as baseline those areas with minimal human perturbation.

If an indicator cannot be applied to the study area, it has to be deleted from the evaluation, while if it is relevant in the area but no information is available, a "Lack of Data" (LD) has to be indicated. At the end of the evaluation, the number of LDs divided by the total number of used indicators gives a measure of the confidence of the index: LD rating < 0.1 would inspire high confidence in the determined index, while LD rating > 0.4 suggests that more study is required before application of the index can be carried out in that location.

Once all feasible indicators have been scored, the evaluator calculates the Karst Disturbance Index. Scores are summed and the total is divided by the highest possible score to attain a value between 0 and 1, where the latter indicates an highly disturbed system and the lowest value a pristine system. Classes of Karst Disturbance Index, according to Van Beynen and Townsend (2005), are reported in Table 1.

Score	Degree of disturbance
0.8 – 1	Highly disturbed
0.6 – 0.79	Moderately disturbed
0.4 – 0.59	Disturbed
0.2 – 0.39	Little disturbance
0 – 0.19	Pristine

Tab. 1: Classification of disturbance (after Van Beynen & Townsend, 2005).

CASE STUDIES IN APULIA

Apulia region is the emerged south-eastern part of the Adriatic Carbonate Plate which is formed by Jurassic-Cretaceous limestones and dolostones covered by Tertiary and Quaternary clastic carbonates, mostly calcarenites, and subordinate clays and sands. From the Lower Pleistocene, the region was interested by a general uplifting, until it reached the present configuration (Doglioni *et al.*, 1994). Apulia is fragmented by high dip, NW-SE striking, faults into uplifted and lowered blocks (Ricchetti *et al.*, 1988). Due to the widespread presence of carbonates, surface and subsurface landforms were extremely involved in karst processes that produced an extensive network of underground cavities and conduits. The landscape is generally flat, characterized essentially by landforms of karst origin, whose best morphological expressions are identifiable on the Murge Plateau of inland Apulia (Neboit, 1974; Sauro, 1991). Over large portions of the region, the natural landscape has been strongly modified by man, also thanks to the smoothed morphologies that facilitated land use changes.

The Murge Plateau is a planation surface cut in the Cretaceous limestones during Paleogene and Neogene. From the highest elevations (678 m a.s.l. near Mt. Caccia), the plateau slowly degrades toward the Adriatic Sea to the east, through steps of marine terraces. Two main districts can be identified: High Murge, which corresponds to the inner portion of the plateau, and Low Murge, closer to the Adriatic coastline. In this study, we apply the Karst Disturbance Index method to two areas, located respectively in the two aforementioned districts.

MINERVINO MURGE AREA (HIGH MURGE)

Selection of the area in the surroundings of the town of Minervino Murge for the present study was dictated, be-

sides its very interesting karst features, by the fact that it is comprised within the boundaries of a recently established natural park *(Alta Murgia Natural Park),* which total surface is around 70,000 ha. The park was established with a National Law in 1998, after many years of debate about the boundaries of the park, and many discussions about the permitted activities within its limits. This part of the Murge Plateau was originally devoted to pasture, and characterized by bare karst landscape with limestone rocks protruding from the ground surface. The few areas where residual soils and *terra rossa* concentrated were slightly incised valleys, locally called *lame,* that constituted a sort of oasis where the farmers were able to perform agricultural practices. In the last decades, two main anthropogenic activities spread out in this area, which resulted in heavy changes in the natural landscapes: quarrying, and stone clearing (Fig. 3). Quarrying is very

Fig. 3: Quarrying and stone clearing are the main anthropogenic activities degrading the original karst landscape at Minervino Murge. The photo shows an overall view of the southern slope of Mount Scorzone.

widespread due to the common use in Apulia of carbonate rocks as building and ornamental materials. Advance of quarrying is carried out without any concern for the natural caves, many of which have been damaged or destroyed by quarrying (Fig. 4). In addition, once the quarrying activity ceases, it is very common the use of the abandoned site for illegal dumping of solid and liquid wastes. The considerations above led to assign high values to the indicators **quarrying/mining** (rating 3) and **industrial and petroleum spills or dumping** (rating 2). As regards the latter indicator, we considered as brownfields (heavily polluted sites) any abandoned quarry where the presence of wastes was detected.

Repeated surveys performed in the last years, integrated with interpretation of multi-year aerial photos allowed to quantitatively evaluate the advance of quarrying activities (Fig. 5), and the areas involved in land

Fig. 4: Intense quarrying activities resulted at several sites in the Minervino Murge area in destruction of caves, as shown in this photo.

use change. This was then integrated by field surveys and speleological explorations, that further highlighted the destruction of a high number of caves in the area. The data so collected clearly show that the area around Minervino Murge is one of the most degraded in Apulia as regards disturbance of the karst environment, with loss of the original landscape and destruction of the natural caves.

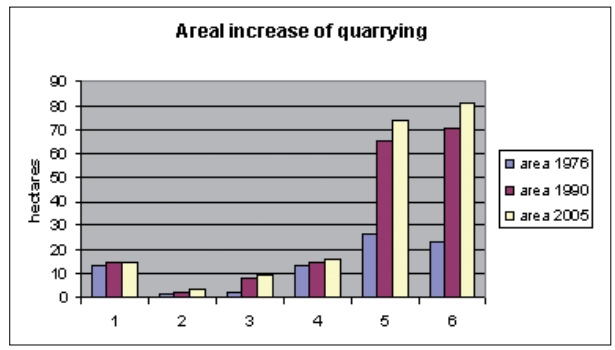

Fig. 5: Areal increase of quarrying at Minervino Murge in the time span 1976-2005. Numbers on the x axis refer to the six 1:5,000 scale topographic maps that were used for air photo interpretation.

The quarrying activity coupled in the last 30 years with intensive stone clearing practices, even favoured by public subsidy from the European Community. These subsidies, addressed to changes in the land use for introducing new crops, resulted in the High Murge in transforming the original bare karst in a landscape which is unnatural for this area, with wide development of cornfields. Most of the rocks resulting from clearing of the fields, and quarrying activity as well, are often dumped into swallow holes and caves (Fig. 6), or piled around karst depressions. Besides the negative effect on the karst landscape, these actions are extremely dangerous for cav-

ers, due to instability of the dumped and/or piled rocks. Thus, the indicators **infilling** and **dumping** were considered, respectively, with rating 2 and 3.

Fig. 6: Stone clearing practices produced the formation of non natural cornfields in the Minervino Murge area, and in piling of rock debris in the proximity of cave entrances (two persons for scale on the rock pile). Other rocks have been dumped as well into the cave, creating a serious danger for cavers, due to instability of the rocks, both outside and within the cave.

At present, thousands of hectares of the original pastures have been transformed, and this has often resulted in later abandonment of the fields, due to intense erosion. In fact, stone clearing is carried out through the use of modern technologies and machinery, able to crush the carbonate rocks destroying the epikarst, and eliminating the soil. When it rains, even on gentle slopes surface runoff develops and intense erosion starts. Erosional processes may be so severe to determine onset of both linear and areal erosion on the slopes, through development of rills and gullies. The indicator **erosion** has been therefore assigned a rating 2. Another consequence of the stone clearing practice is **flooding** in subsurface karst, as a further effect of the land use changes at the surface: similarly than the previous indicator, also flooding was considered to have a severe impact, scored as 2.

Caves in the Minervino Murge area are characterized by vertical entrances, with some meters-deep shafts. Difficulty in accessing the caves, which is limited only to expert cavers, resulted in high protection and safeguard of the caves and the deposits therein from removal and vandalism, and strongly limited other problems related to frequent visits by man. This had important consequences in the attribution of scores to some indicators. In practice, five indicators belonging to different categories were listed as 0.

The category *Biota* was the most difficult to evaluate at the Minervino Murge area. Thorough bibliographical research produced very little results in terms of published articles. Furthermore, nothing was found to allow a comparison at different times of the species richness and density of population, which is required to assign scores to the biota indicators. Thus, four out of the five indicators of this category were considered as Lack of Data.

Vegetation disturbance was the only one that applied to the case study in the Biota category: a score 3 was assigned to this indicator, due to the long history of deforestation in the area, that brought to have today only very few remnants of wood cover (most of these is represented by re-forested areas). Another significant problem is the state of the present vegetation, since lack of maintenance of woods has resulted in a situation highly prone to wildfires, and with several non wealthy trees and plants. To cover even this issue of the vegetation, a new indicator **(State of vegetation)** was introduced, and again a score 3 was assigned.

Many of the problems related to anthropogenic activities in the Minervino Murge area remained unsolved even after establishment of the Alta Murgia Natural Park. This was mostly due to the lack of control by the Local Authorities, combined with a public indifference toward safeguard of the natural environment from large sectors of the population in the area. For these reasons, when evaluating the indicators belonging to the category *Cultural Factors,* some negative scores have been assigned (2 for **Regulatory protection,** 3 for **Enforcement of regulations,** again 2 for both **Public education** and **Building of roads**).

The Karst Disturbance Index in the Minervino Murge area was determined using 26 indicators (Table 2), and resulted in a value of 0.49, which means "Disturbed" (Table 1). Four indicators were considered as LDs, that resulted in LD rating 0.15, corresponding to good confidence.

The difficulty in accessing the natural karst caves in the area, due to vertical entrance of most of the caves, has been before mentioned. This difficulty affects the scores of five indicators (shown in italics in Table 2). Interestingly, if we do not take into account these five 0 scores, the karst disturbance index for the Minervino Murge area rises to a value of 0.6 (see values in brackets in Table 2), falling in the upper range of the "Moderately disturbed" class. Accordingly, the LD rating changes from 0.15 to 0.19 because of the lower number of indicators used, but still indicates good confidence of the data.

CASTELLANA-GROTTE AREA (LOW MURGE)

Castellana-Grotte is worldwide famous due to the remarkable, more than 3 km long and more than 120 m deep, caves, which were explored for the first time in 1938, and soon after that became one of the most visited tourist caves in Europe. Discovery of the caves played an

Tab. 2: Karst disturbance index for the two study areas. The numbers between brackets at Minervino Murge derive from deleting the five indicators shown in italics in the table (see text for explanation). For details about each single indicator, the reader is invited to refer to the paper by Van Beynen & Townsend (2005).

category	*indicator*	**MINERVINO MURGE**	**CASTELLANA GROTTE**
Geomorphology	Quarrying/mining	3	2
	Flooding (surface)	0	1
	Stormwater drainage	2	2
	Infilling	2	2
	Dumping	3	2
	Erosion	2	1
	Compaction	1	2
	Flooding (subsurface)	2	1
	Decoration removal	1	2
	Mineral/sediment removal	1	2
	Floor sediment compaction	0	1
Atmosphere	*Desiccation*	0	1
	Condensation/corrosion	0	2
Hydrology	Pesticides/herbicides	1	2
	Industrial and petroleum spills	2	2
	Algal blooms	deleted	deleted
	Changes in water table	1	1
	Changes in cave drip waters	1	1
Biota	Vegetation removal	3	2
	State of vegetation	3	1
	Species richness (cave)	LD	1
	Population density (cave)	LD	1
	Species richness (groundwater)	LD	LD
	Population density (groundwater)	LD	LD
Cultural factors	*Destruction/removal of historical artifacts*	0	2
	Regulatory protection	2	2
	Enforcement of regulations	3	2
	Public education	2	1
	Building of roads	2	2
	Building over karst features	1	2
	Construction within caves	0	2
TOTAL NUMBER OF USED INDICATORS		26 *(21)*	26
KDI		**0.49** *(0.6)*	**0.57**
TOTAL NUMBER OF LDs		4 *(4)*	2
LD RATING		**0.15** *(0.19)*	**0.08**

important role in the tourist development of this small town of Low Murge, that modified its name in 1950, by adding Grotte, and thus becoming the present Castellana-Grotte.

The show cave is only one of the many features of this part of Apulia, where both surface and subsurface karst landforms are widespread (Parise, 1999). The main differences with the first territory dealt with in the present paper are that Castellana-Grotte and the surrounding territory develop at lower elevations (between 330 and 240 m a.s.l.), and the caves are not prevailingly vertical. As for the anthropogenic environment, the show caves, combined with the vicinity to the Adriatic coastline, a further reason of attraction for thousands of tourists during the summer season, produced in Low Murge a much greater presence of man's activities and infrastructures. Several consequences on the natural karst environment had to be registered, including diversion of the natural runoff, and of the water infiltration rate in the rock mass as well, with greater possibility of occurrence of surface flooding (Fig. 7).

Fig. 7: Surface flooding at Castellana-Grotte, as a consequence of a severe rainstorm.

Without entering into the details of every single indicators, it has to be noted that in the Castellana-Grotte area no score 3 was assigned (Table 2), but, at the same time, none indicator had score 0, which means that some negative effects from human activities had to be registered within each indicator of all the categories. For example, the quarrying activity is not so intense as in High Murge; nevertheless, small quarries are present in the area, locally very close to significant subsurface karst features. In some cases, anthropogenic activities are still producing negative effects, irrespective of the existing laws and prohibitions (Fig. 8).

Due to the easiness in accessing the caves, many of the indicators that in the first study area had score 0, in this case presented problems, because of vandalism, removal of sediments and materials, and floor sediment compaction. At the same time, access of man into the caves also had negative consequences for the biota environment.

Fig. 8: Pozzo Cucù cave (Fig. 8a) is one of the most remarkable caves in the Castellana-Grotte territory. Even though the cave was declared of interest for the European Community, due to its peculiar cave ecosystem, some anthropogenic works (Fig. 8b) strongly altered the natural landscape above the cave in the last years.

Besides these problems, the presence of the Castellana show caves adds further negative effects, as usual in show caves frequented by high number of tourists (Cigna, 1993; Pulido Bosch *et al*., 1997; Aley, 2004): changes in the cave environment, development of lampenflora as a consequence of the lighting system, construction within caves for trails and pathways, and so on.

The Karst Disturbance Index in the Castellana-Grotte area was therefore determined using 26 indicators, and resulted in a value of 0.57 (Table 2), corresponding to the upper range of the "Disturbed" class. Two indicators were considered as LDs, that resulted in LD rating < 0.1, corresponding to high confidence

DISCUSSION AND CONCLUSIONS

Determining the karst disturbance can be very difficult because of the inherent complexity of karst systems, and subjective because it requires interpretation of the karst environment by the expert, depending upon her/his background. For example, a geologist might concentrate on geomorphology, neglecting the subsurface biota or the water quality. Since the method lists all the categories for which data should be collected, and uses pre-established indicators, the need for the evaluator to decide what is important to measure is strongly reduced. Furthermore, the utilized scoring system limited to four possibilities reduces much of the uncertainty associated to multi-level scoring systems, and prevents the evaluator from consistently choosing a middle value, forcing him to be more decisive.

It has to be stressed that this approach is based upon some simplifying hypothesis: first, the index is considered to be applicable for all karst regions, regardless of the difference in karst types; secondly, any change to the karst environment is evaluated as caused by human impact. Karst is, however, characterized by natural variability over space and time (Williams, 1993); application of the index to heterogeneous areas, where two or more types of karst are present, should be performed with great care. In addition, it is sometimes difficult to discriminate between human-induced environmental changes and those caused by on-going natural processes.

A final, but not less important, assumption of the method is the availability of data; actually, this varies from region to region, and depends on the thoroughness of studies and research undertaken for that specific area. Through the Lack of Data, the index includes this aspect and allows to provide a measure of the adequacy of the available information, and to highlight those karst regions where more research activity is needed.

Notwithstanding these simplifications, the Karst Disturbance Index can be adapted to any karst region, and this also contributes to improving the ability to compare the degree of disturbance to karst among different locations. It can serve as a standard tool for the evaluator (a karst scientist having the experience needed to interpret the available data) to provide a quantitative measure of the human impact, and it might help local administrations to contrast the increased human pressure and to address the sustainable management of karst environments.

The present study, through implementation of the Karst Disturbance Index to two areas in the Apulian karst of southern Italy, has shown the usefulness of the approach for a preliminary evaluation of the degree of disturbance in karst, as an help toward a better understanding of the impacts to the natural environment deriving from man's activities. At the same time, the need of more detailed research and analysis in disturbed karst areas was well highlighted in both the areas, where a strong contrast occurs between the existing laws for protection and safeguard of the environment, and their real enforcement. This latter, in particular, has produced and, sadly to say, is still producing as well, heavy degradation, destruction of caves, and frequent loss of the karst landscape in several sectors of the Apulia region

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CHANGES IN THE USE OF NATURAL RESOURCES AND HUMAN IMPACT IN THE KARST ENVIRONMENT OF THE VENETIAN PREALPS (ITALY)

SPREMEMBE V IZKORIŠČANJU NARAVNIH VIROV IN VPLIV ČLOVEKA NA KRAŠKO OKOLJE V BENEŠKIH PREDALPAH (ITALIJA)

Ugo SAURO[1]

Abstract UDC 504.5:551.44(234.3)

Ugo Sauro: Changes in the Use of Natural Resources and Human Impact in the Karst Environments of the Venetian Prealps

In the Venetian Prealps the old model of resources use was for many aspects of sustainable type, in equilibrium with the natural dynamics. Episodes of strong impact occurred only in some particular areas and in specific economical and political situations. After the Second World War dramatic changes in the resources management have taken place, induced by the urban and industrial development. The traditional system of self-sustained economy has completely collapsed and has been replaced by an open economy more dependent on that of the large urban sprawl of the plain. Such development is clearly incompatible with the local environmental dynamics and it is difficult to be modified, because it triggers self-sustaining processes. The problem to individuate new more compatible directions for the development is, for a large part, a cultural problem and it may not be solved without a cultural revolution. Local people must be helped to understand the karst geo-ecosystem, the natural realm, the landscape, the local history, and the cultural heritage. Starting from such knowledge, local people have to develop a strong sense of belonging to their own geographical units and to become and to feel protagonists, responsible of their own development, capable to lead it.

Keywords: human impact, karst, and sustainable development, Venetian Prealps, Italy.

Izvleček UDK 504.5:551.44(234.3)

Ugo Sauro: Spremembe v izkoriščanju naravnih virov in vpliv človeka na kraško okolje v Beneških Predalpah

Nekdanji način izkoriščanja virov v Beneških Predalpah je bil s številnih vidikov sonaraven, v ravnotežju z naravnimi spremembami. Močan vpliv na okolje je bil le občasen, le na nekaterih območjih in v posebnih gospodarskih in političnih razmerah. Po 2. svetovni vojni so se zaradi urbanizacije in industrializacije zgodile dramatične spremembe v upravljanju z viri. Že od nekdaj utečeni način samozadostnega gospodarstva se je v celoti zrušil in zamenjalo ga je odprto gospodarstvo, bolj odvisno od hitrega širjenja mest v ravnini. Tak razvoj nikakor ni združljiv s krajevno dinamiko okolja in ga je težko spremeniti, saj sproži razvoj, ki poteka dalje sam od sebe. Težko je izdvojiti bolj sprejemljive smeri razvoja, saj gre pretežno za vprašanje kulture in teh težav ni mogoče rešiti brez »kulturne revolucije«. Krajevnemu prebivalstvu je treba pomagati, da bodo razumeli kraške geosisteme, naravne danosti, pokrajino, krajevno zgodovino, kulturno dediščino. Pričenši s takim znanjem naj bi krajevno prebivalstvo razvilo močan čut pripadnosti svoji geografski enoti in naj bi postalo in se čutilo odgovorno in sposobno za svoj lastni razvoj.

Ključne besede: vpliv človeka, kras, sonaravni razvoj, Beneške Predalpe, Italija.

[1] Dipartimento di Geografia dell'Università di Padova, Via del Santo 26, IT – 35123 Padova, Italia; e-mail: ugo.sauro@unipd.it

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INTRODUCTION

During the past centuries, nearly until the Second World War, in most of the pre-alpine environments man managed the resources trending to equilibrium with the natural dynamics. In other words, the local human communities were engaged to apply methods of sustainable development. Actually, there was not a real development in the sense of a change of the conditions of life but a kind of steady status. The price to pay not to alter such equilibrium was the emigration of the surplus of the human population.

After the Second World War dramatic changes in the natural resources use have taken place in the karst environments of the Venetian Prealps resulting from the open economy more dependent on that of the large diffuse city of the plain (Sauro, 1977, 1987; 1993; 1994, 1999a; 1999b; 2003; Sauro *et al*., 1991, 1995).

To develop a strategy for a future development, conserving, as possible, an ecological balance with the natural processes it is important to consider the different models of resources use applied in the past and the present day situation.

THE OLD MODEL OF SUSTAINABLE TYPE

A good example of application of a model of this type is represented by the small mountain settlements of Monti Lessini called "contrade", with their surrounding countryside. A "contrada" was a settlement of patriarchal type, a kind of collective farm made up by a few houses and some rustic buildings: the "teda" type, a combination of a cowshed and a hayloft, the pigsty, the hen-house and others collective structures such as the bread oven and the "baito" (a dairy farm managed by the inhabitants of several nearby "contrade").

The inhabitants of each "contrada" owned the surrounding land consisting both of forested plots for wood and charcoal production, and of meadow plots for hay production and cattle or sheep grazing. Minor plots, often near to the houses, were used for agriculture and garden-culture to produce vegetables. The meadow areas were utilized also for fruit trees growing.

The big problem of the absence or scarcity of surface water was solved collecting for the human use the rainfall and snow melting water of the roofs of the buildings, mostly made up by large stone slabs, by conveying it to underground tanks consisting in cylindrical recipes built up with stone walls and clay, called "possi". Surface water was collected for the livestock, inside closed depressions in the meadows realized by the excavation and damming of dry valleys, waterproofed with clay, called "posse".

Each family owned a few cattle, exactly the number that could be sustained by the production of the pertinent meadow area. The production of cheese and butter was managed corporately. During the year, there was a turnover in the management of the "baito". Each member managed the "baito" during periods distributed in all the seasons working the milk produced by all, for a whole quantity corresponding to its own total evaluated yearly production.

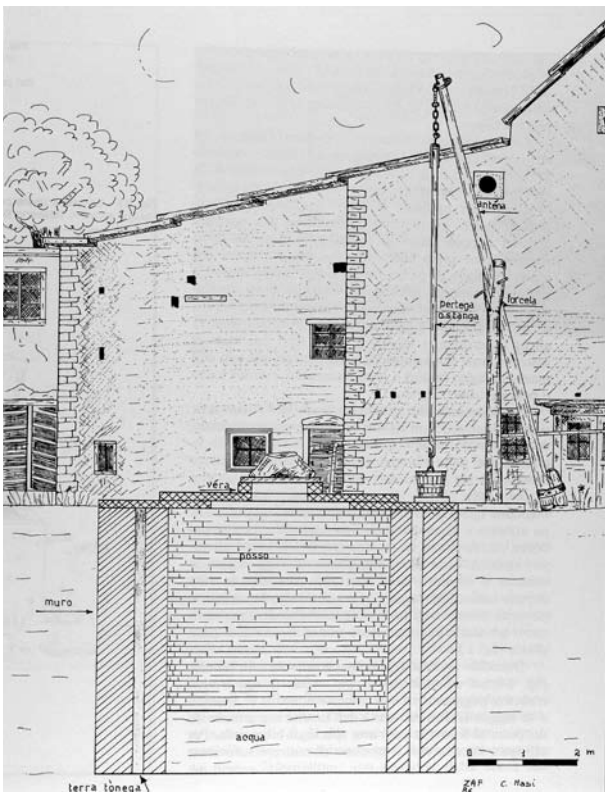

Fig. 1: Sketch of the old system of storing the rainwater of the roofs of the buildings inside cisterns (called "possi") build with stones and waterproofed with clayey soil sediments.
(drawing of Ferdinando Zanini in Avesani et al., 1986)

The butter and cheese were partly sold to get the money necessary to buy products like flour, polenta and wine, and obviously others goods like clothes, etc. But usually the circulating money was really few.

Integrative activities were the production and commerce of charcoal, wood, stone, lime, ice, flints for guns, different types of handicrafts, etc.

In general, the economy was of a self-sufficient type and the impact of man on the environment was very limited: the inhabitants were careful not to alter the delicate equilibrium of the different environments such as the forest, the meadow and the pasture.

Fig. 2: The stony desert created by the bombing of the Sette Comuni Plateau during the First World War.

The white stone fragments created by the explosions are scattered and appear as a snow cover.

SOME "OLD" CASES OF STRONG HUMAN IMPACT

Cases of strong impact are localized and linked with specific economical and political situations.

A significant example is represented by the history of land use of the upper part of the Sette Comuni Plateau, a pasture area of common property of the local inhabitants. When the Sette Comuni Plateau became part of the Republic of Venice in 1404, the special low of "pensionatico" was established to favour the mountain population as a compensation of the duty to control the state boundary. The shepherds of the plateau were allowed to bring the flocks in the plain in the period between October and March (six months of the year), also entering in the private fields. This privilege caused an increase of the flocks' consistency and a surcharge of the summer pastures. In the 18th Century the sheep number reached nearly 200.000 heads corresponding to a density in the mountain area during the summer grazing period of about 500/km^2. The impact on the soil of the pasture was very strong and caused a desertification and a regression of the sheep rearing.

Other episodes of strong impact in some areas are represented by the battles of the First World War. The Piccole Dolomiti, Sette Comuni and Monte Grappa massifs became major battlegrounds of the Italian and Austrian armies. Thousands of kilometres of trenches, tunnels, roads and railways were hastily built. There were large artillery battles. At some times on Sette Comuni Plateau 1500 guns were firing more than 200 tonnes of projectiles each day. Ten of thousands of craters were created by the explosions. In some photographs taken after bombing entire hills made up by a chalk type limestone looked like snowfields because of the rocky fragments.

THE RECENT EVOLUTON

Very rapid changes in the resources management have taken place after the Second World War, according with the new economic styles promoted by the urban and industrial development.

The changes occurring in the last 50 years are relatively complex. Schematising the phenomenon it is possible to note:

- a decrease of population in the mountain areas caused by a rural exodus, affecting especially the minor settlements; most of these and in particular those farthest from the towns and the villages have been abandoned or are utilized only seasonally as second houses or as structures for the agriculture;
- a strong decrease of the percent of population involved in farming activities;
- an increase of the percent of population involved in other activities (services, industry, tourism, etc.);
- a progressive abandonment of the land use of many plots and a corresponding expansion of the forested areas;
- a simplification of the agricultural landscape, with disappearance of some types of land use (a kind of desharpening and homogenisation of the traditional landscape);
- in some areas, the development of systems of large specialized farms, as poultry farms, pig farms, cattle

farms; the poultry farms are located especially in the hilly and low mountain belt, the cattle farms in the middle mountain belt;

- the urbanisation of some of the most valuable mountain areas, caused by the explosion of the mass tourism and in particular by the development of the "vacation homes"; beside the "second houses", many others building and structures have developed as resort hotels, markets, sports grounds, ski complexes, roads, parking areas, etc;

- the building of complexes of ski plants as ski lifts and chair lifts, and the creation of large ski-tracks obtained by the excavation and the movements of large masses of rocks;

- the opening of large industrial quarries of limestone utilized as ornamental stone (Bondesan & Meneghel, 1991).

Fig. 4: New vacation housing in Asiago (Sette Comuni Plateau). In the sign-board (enlarged in the foreground left) the new complex is presented as "La Vecchia Contrada", that is the old type of settlement called contrada (in the reality it is very different).

Fig. 3: Large cowsheds of a modern cattle farm of the Monti Lessini near Bosco Chiesanuova. The old contrada is hidden behind the large hangar-like buildings (centre of the photo).

According with these changes, the traditional system of self-sustained economy has completely collapsed and has been replaced by a more open economy integrated with that of the large diffuse city of the plain. This is evident, considering that most of the fodder to breed the cattle and the pigs, and of the poultry-feed are imported in the mountain area from outside. So a much larger biomass is involved in the environmental system. A large quantity of liquid wastes is dispersed and contributes to the modification of the soils and to the pollution of the surface and underground waters.

During the summer and winter seasons in the urbanized areas of the mountains there is an impressive increase of the human population and a corresponding increase of the liquid and solid waste production. The sewages are partly lost in the environment and drained into creeks and sinkholes. In the last 30 years the nitrate content of the base level waters has more than doubled. Most of the water circulating in the aqueducts is pumped from the base level springs or the alluvial aquifers of the valleys and of the plain.

It is obvious that such development is incompatible with the local environmental dynamic. Also the economic system is less stable than the old one. For instance, the oscillations of the prices of some products like the milk, a product that may be imported from the less developed countries of East Europe, may cause the breakdown of the breeding and dairy farms; recently there has also been a period of collapse of the price of the chicken meat caused by the psychosis of the bird-flu.

THE NECESSITY OF A CULTURAL REVOLUTION

The big challenge of the present time is to individuate a strategy capable to modify the local economic mechanisms, governing them towards better and, if possible, sustainable development models. This is not a simple task, also because some phenomena, like the urbanisation, the quarrying, etc have started positive feedback

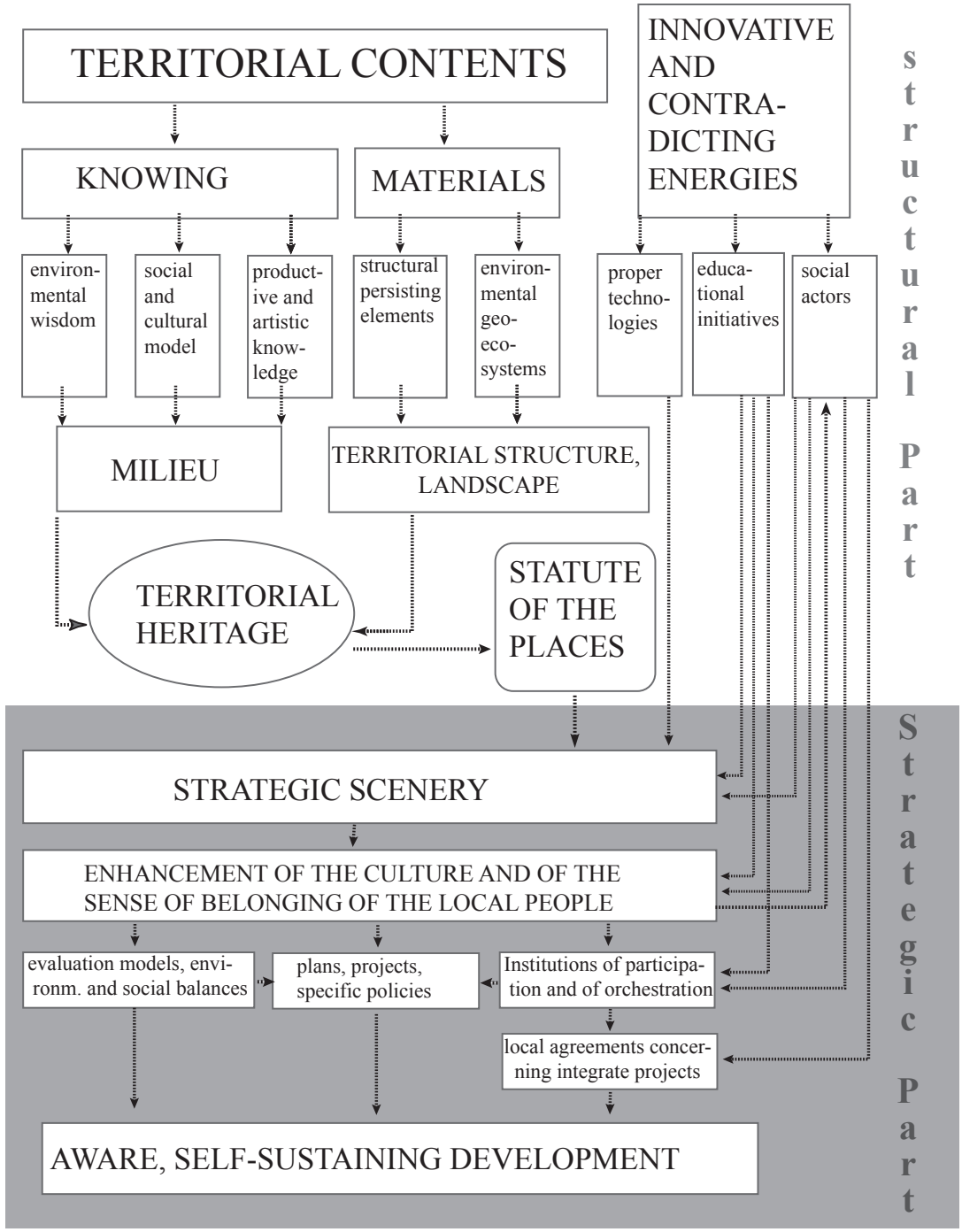

Fig. 5: Sketch of some of the possible components to be considered inside a strategy plan of sustainable local development. The sketch is derived with modifications from Magnaghi (2006).

mechanisms, which tend to amplify in time and to determine favourable economic and political backgrounds to their continuation.

It must be said that something has changed in the culture of the people in the last years and that it is possible to recognize some signs of hope. So, many local and regional administrations have realized the importance of the big karst aquifers as strategic water resources. The karst aquifer of the Sette Comuni Plateau only would be able to furnish something like 300 millions of cubic meters of relatively good water (except for the organic pollution) in a year, about 70 m^3/for each inhabitant of the Veneto Region. While in the past nearly all the liquid wastes were dispersed in the environment, systems of

sewer have been built or are under construction to convey the waters to treatment plants or outside of the karst areas. In general, public opinion is now more sensible to the environmental problems.

In any case, to engage battles against the sprawl of new buildings, the quarrying activities, the construction of new roads and factories could have the opposite effect of the one intended. It is like to become others Don Quijote de la Mancha fighting against the windmills.

On the contrary, it is certainly possible to apply to promote new trends and development styles like to favour the restoration of the old settlements and the requalification of the recent ones instead of the building of completely new structures; or to encourage forms of low impact tourism as the hiking, the cycling, the camping, the agri-tourism, promoting in the meantime the natural and cultural heritage of the areas and the quality of the local products, as the cheese, the agri-biological products, the craftsmanship, etc.

If both the local inhabitants and the tourists will be able to get a good knowledge of the mountain area and will learn to establish a profound relation with this, it will become easier both to stimulate projects respectful of the local heritage and to prevent intervention negative for the environment.

It is important to emphasize that the problem to individuate and to choose new more compatible directions for the development is for a large part a cultural problem and it may not be solved without a cultural revolution.

This revolution needs investment of time by persons well trained in the environmental, historical and geographical research. It is necessary to start learning experiences in the field involving both young and old people (like pensioners). Local people must be helped to understand the karst geo-ecosystem, the natural realm, the landscape, the local history, the cultural heritage (Castiglioni & Sauro, 2002; Magnaghi, 2006). Local people have to develop a strong sense of belonging to their own geographical units. Especially, local people have to become and to feel protagonists, responsible of their own development.

Unfortunately the process of education needs time, while the changes resulting from the human activities are now impressively fast. Some experiences made in the last years are certainly positive (I remember here in particular the experience of the 3 KCl-Project, run inside the Program of the European Union – Culture 2000; see Castiglioni, 2005), but they are not enough. Especially, in the more important areas for the environmental and cultural heritage (natural parks, karst areas, etc.) it is necessary to start with initiatives of permanent education. These have to be carried on especially in the field, through the discovery of the local history, seen also as succession of episodes of human impact and interrelations between the natural and the human processes. In this strategic scenery it is fundamental to improve cooperation between different structures, as political authorities, research and educational organisations, local associations, etc.

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SUSTAINABLE MANAGEMENT OF BRACKISH KARST SPRING PANTAN (CROATIA)

TRAJNOSTNO UPRAVLJANJE BRAKIČNEGA KRAŠKEGA IZVIRA PANTAN (HRVAŠKA)

Ivana FISTANIĆ[1]

Abstract UDC 556.3(497.5 Pantan)

Ivana Fistanić: Sustainable management of brackish Karst spring Pantan (Croatia)

Pantan area is situated in the central part of the eastern Adriatic coast near town Trogir. It presents inseparable unit consisting of Pantan spring, river course with surrounding swamp area and sea coast. Particularity of the area is swamp which is unique example in this part of the eastern Adriatic coast mostly characterized by dry karst areas. Main characteristic of the spring is periodical salinity during the year with the highest salinity during summer months. Spring presents potential drinking water source under consumption that salinization problem is solved. Unfortunately due to bed watershed management water quality of Pantan spring and environment of Pantan area is highly devastated. Today Pantan area presents an example of not preserving balance between natural resources on karst and human interventions in watershed area. All future measures should be directed on rehabilitation and further protection of this valuable karst environment. Paper gives overview of the state of the spring as well as proposed measures of sustainable management directed to the preservation of this distinct karst ecosystem. As the basis for analyzing the inter-related factors that impact on the environment, DPSIR framework is used. This framework provide rational and clear guideline for analyzing the influence of pressures derived from human activities on natural environment, and the way they are changing state of the environment. Results of the analyses showed that DPSIR framework is adequate tool to shape and implement sustainable development strategy for the Pantan area. It is evident that in this process is extremely important to take into the consideration vulnerability of the karst.

Keywords: brackish karst spring, integrated management, DPSIR concept, Pantan, Croatia.

Izvleček UDK 556.3(497.5 Pantan)

Ivana Fistanić: Trajnostno upravljanje brakičnega kraškega izvira Pantan (Hrvaška)

Območje izvira Pantan se nahaja v centralnem delu vzhodne jadranske obale v bližini mesta Trogir. Gre za neločljevo celoto, sestavljeno iz izvira Pantan, površinskega vodotoka z okoliškim močvirjem in obalnega pasu. Posebnost območja je močvirje, edino v tem delu Jadrana, kjer sicer prevladuje suho kraško površje. Izvir kaže periodično slanost, ki je največja v poletnih meseciih. Z rešitvijo problema slanosti, bi izvir predstavljal potencialni vir pitne vode. Žal je, zaradi slabega upravljanja vodozbirnega območja, kvaliteta vode slaba. Območje Pantana je tipičen primer podrtega ravnovesja med naravnimi viri in človekovimi posegi v zaledju izvira. Zato morajo biti vsi bodoči ukrepi usmerjeni v rehabilitacijo in zaščito tega pomembnega kraškega območja. Članek predstavlja pregled trenutnega stanja izvira in predlagane ukrepe trajnostnega upravljanja s tem pomembnim kraškim ekosistemom. Za analizo faktorjev, ki vplivajo na okolje smo uporabili model DPSIR. Model omogoča pregledno analizo vpliva obremenitev, ki so posledica človekovih posegov v naravno okolje. Rezultati so pokazali, da je model DPSIR primerno orodje pri načrtovanju trajnostne razvojne strategije območja izvira Pantan. Nedvomno bo pri tem potrebno upoštevati veliko ranljivost krasa.

Ključne besede: brakični kraški izviri, celostno upravljanje, model DPSIR, Pantan, Hrvaška.

[1]Faculty of Civil Engineering and Architecture, Matice hrvatske 15, 21000 Split, Croatia, e-mail: Ivana.Fistanic@gradst.hr

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INTRODUCTION

Pantan area is situated in the southwest of Kastela bay, between towns Split and Trogir (Fig. 1). It is the area of approximately 40 ha and presents inseparable unit consisting of Pantan spring, river course with surrounding swamp area and sea coast. The area presents green oasis in the mostly karstic area. Spring is a permanent and abundant coastal spring of ascending type. The opening of the spring is located at the elevation of 3 meters above sea level in the contact zone between the limestone and flysch layers while the catchments area is formed of highly permeable limestone rocks (Fritz *et al.*, 1993). Spring discharge oscillates during the year. In summer period minimal discharge is 0,3 m^3/s, while in the winter period maximum discharge is 12 m^3/s. Flysch zone presents incomplete barrier towards the sea resulting with sea water intrusion into the spring aquifer (Bagarić 1973; Bonacci 1995). Therefore, the main characteristic of the spring is periodical salinity during the year with the highest salinity in summer months. Spring makes small lake Pantan with surface area from 35 to 60 m^2 and depth of 13 meters. River Rika flows out of the lake to the sea and into the numeral brackish lateral channels that irrigate surrounding swamp area. Vegetation of the area is favorable for permanent or occasional residence of numeral bird species. Some of these species are unique and threatened of dieing out. Due to the variable ecological factors, temperature and salinity, life conditions in this biotope are very specific making favorable conditions for spawn and growth of particular fish and crab species. Therefore this small area presents unique ecological oasis and urgent protection from harmful human interventions is necessary.

Fig.1: Pantan area location

From the ecological standpoint and according to the Environmental Protection Law, Pantan area presents unique swamp area in wide region and it is evaluated as a highly valuable environment. It should be mentioned that this area except natural values, has significant cultural-historical value. Mill situated in Pantan area according to its oldness and architecture presents valuable historical heritage (Figure 2). Furthermore, recent archeological investigations resulted with assumptions that archaeological remains in Pantan area date from the ancient time. If these excavations really date from the ancient time Pantan mill is unique example of mills built on ancient foundations. Unfortunately, this miniature cultural and nature reservation is almost unknown until today which is a great loss for this area.

Water from Pantan spring has never been used for water supply mainly because of the salinisation problem. Chloride concentration significantly changes during the year, and extreme values variate from 20 mg/l in January, and 10117 mg/l in August. In summer period water can be used only for the purposes of fish-farm since it is not sensitive to the chloride oscillations. Problem of sea water intrusion is widely spread in coastal karst areas of the world. This phenomena has been analyzed by many researchers for large number of locations (Arfib *et al.*, 2000; Bonacci and Roje-Bonacci 1997; Breznik 1973; Breznik 1998; COST Action 621). Pantan spring is not an exception and extensive water investigations have been taken for the purpose of better understanding of complex hydrogeological conditions and finding solution for spring desalinization for the purpose of exploiting fresh water for the water supply (Bonacci *et al.*, 1995; Komatina 1990; Mijatović 1984). Though these investigations gave some assumptions about spring functioning final solution of spring desalinization has never been achieved. Meanwhile, due to bed watershed management water quality of Pantan spring is permanently endangered. In present time, as the result of bad watershed management, salinity of the water is not the main problem comparing to the other water quality parameters.

Unfortunately through the past period many actions have been made that have contributed to the devastation of the whole Pantan area. Close to the spring main road is located. Area on the eastern border line of Pantan area is used as the waste disposal of town Trogir and it significantly contribute to the degradation of this area. On the west side new settlements are growing without any plans. In watershed area unplanned agriculture is developing. Pantan mill which have been well known in the history is due to careless mostly devastated. Fish farm is built without plan and in many ways contribute to the devastation of the area. Concrete bankment has been built making contrast to the surrounding area. Water loaded with fish food and dung is discharging from fish farm. Through the history many owners of the mill have changed and many changes on the historical mill building have been

Fig.2: Pantan swamp area and Pantan Mill

made. All above mentioned actions are presenting an example of bad watershed management as well as bad care of reservation area and cultural heritage. All activities in watershed area of Pantan spring and Pantan reservation itself led to the significant devastation of this valuable natural and cultural-historical reservation.

It can be concluded that Pantan karst spring presents an example of not preserving balance between natural resources on karst and human interventions. Today water quality of Pantan spring is endangered which is mostly the result of the unplanned activities in watershed area and Pantan area. Human pressure and bad spatial planning made serious consequences on Pantan water quality. It is not possible to use water for the water supply but it is still possible to use it for the other purposes as for irrigation and fish-farm. Despite bad resource management even today Pantan has unique beauty and presents tourist potential due to its particular natural and historical values. Therefore all further activities taken in this area should not have the advantage over the environment protection and should be directed on protection of karstic watershed and Pantan area. Above all integral protection that will stop further unsuitable use of this area is necessary. In integral concept problem of karst vulnerability should be involved into the watershed management. This paper presents state of the Pantan spring, overview of recent resource management, as well as further necessary measures directed to the preservation and sustainability of this distinct karst ecosystem.

METHODS AND APPROACHES

Prerequisite for accomplishing sustainable development of natural resources is integral approach – integrated resources management. One of the definitions of the integrated water resources management says that it is the process that promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in and equitable manner without comprising the sustainability of vital ecosystems. Integral concept is particularly desirable and necessary in karst areas which are very sensitive and open to the pollution generated in the watershed area and therefore very vulnerable. Integrated environmental assessment is also defined as the interdisciplinary process of identification, analysis and appraisal of all relevant natural and human processes and their interactions, which determine both the current and future state of environmental quality, and resources, on appropriate spatial and temporal scales, thus facilitating the framing and implementation of policies and strategies (Stanners and Bordeau 1995). For the implementation of integrated assessment system approach is necessary. A system approach recognizes the individual components as well as the linkages between them, meaning that a disturbance at one point in the system will be translated to other parts of the system. System approach is clearly visible through DPSIR framework.

DPSIR framework is system approach that recognizes the linkages between the environment and the socioeconomic domains. Implementation of the DPSIR framework (Driving forces, Pressures, States, Impacts, Responses) is the basis for the efficient and transparent water resources management. Figure 3 presents general technical description of the framework which can be implemented not only on water resources but on any natural environment. It is causal framework for describing the interactions between society and the environment. It was made for the purpose of accomplishing the mission of the European Environmental Agency (EEA) which is 'to support sustainable development and to help achieve significant and measurable improvement in Europe's environment through the provision of timely, targeted, relevant and reliable information to policy-making agents and the public'. Indicators on environmental relevant issues provide information on the DPSIR elements. In its original form DPSIR framework is a general framework for organizing information about the state of the environment. It is a logical and a good way to structure data and information about the environment and information on different environmental problems. DPSIR framework is the basis for state-of-environment reports, consisting of sets of indicators each representing some parts of links within the framework. Furthermore, DPSIR has been adopted as a framework and policy tool to identify management options for a range of environmental options. The DPSIR framework assumes cause-effect relationships between interacting components of the social, economic and environmental system. Framework makes visible the links between the causes of environmental problems, their effects on the state of the environment and relevant societal responses. The DPSIR framework aims at focusing environmental reporting on a set of indicators that represent the different compartments of DPSIR. This reminds on holistic approach including an integrated assessment which is desirable in task of watershed management. DPSIR concept helps in understanding system behavior. It establishes the functional and structural relationships among major elements of the system to understand how the system operates. This framework provides rational and clear guideline for modeling of pressures derived from human activities on natural environment, and the way they are changing state of the environment. It can be concluded that DPSIR approach is a useful tool to shape a sustainable development strategy.

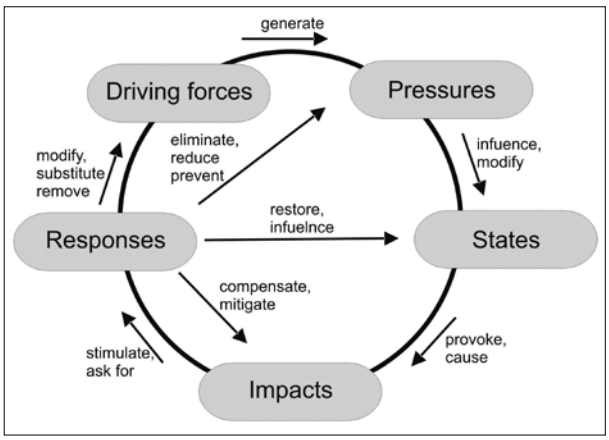

Fig. 3: The DPSIR model

Figure 3 shows interconnection between *Driving forces* of environmental changes (general: population, economy, land use, societal development; Sector specific: industry, agriculture, fisheries, transport, tourism, recreation), *Pressures* on the environment (soil emissions, water emissions, air emissions, waste, use of resources), State of the environment (water, soil, air), *Impacts* on population, economy, ecosystem (human health problems and other functions of the environment), *Response* of the society (environmental policies and measures). Human activities (Driving forces) generate the 'Pressures' on the environment, which in turn influence and modify

'environmental conditions' (State) and therefore provoke and cause environmental problems – 'Impacts' on human beings, natural resources and materials. These problems stimulate and ask for 'Responses' and close the loop back to human activities and also led to policy actions. The Responses may be technical measures, affecting directly pressures or state, or policy instruments directed to the driving forces.

DPSIR framework offers a basis for analyzing the inter-related factors that impact on the environment. The aim of such an approach is (a) to be able to provide information on all of the different elements in a DPSIR chain, (b) to demonstrate their interconnectedness, (c) to estimate the effectiveness of Responses. There have been certain changes in philosophy of analysis specific element of the concept. In past, priority has largely been given to the Pressures, State and Impact. In future, increasing attention will be given to the Forces and Responses. This practically means making more active measures and less passive measures.

Successful implementation of the European Water Framework Directive which aims at improving water quality using an integrated management approach requires appropriate mathematical models and other tools to manage different phases of the planning procedure and to support decision making in various steps of the implementation process. Furthermore integration of these models is needed. DPSIR framework provides a basis to assure that proper tools will be available and selected for defined purposes. It is important to stress out that DPSIR concept helps in achieving transparent representation and understanding of the role of different models in the process of decision making. This practically means that in the place of each arrow (Figure 3) model can be placed showing the interaction between particular models.

In this paper DPSIR approach is used for presentation and evaluation of the seriousness of environment degradation as well as a useful tool to shape a sustainable development strategy for Pantan area.

RESULTS

Insight of the Pantan spring and state of the environment of the Pantan area is presented by the application of the DPSIR framework. Using this framework cause-effect analysis for the Pantan area is made. Figure 4 shows state of the environment of the Pantan area through the framework.

In case of Pantan spring significant number of driving forces is present in the watershed area and Pantan area showing that recent watershed management was very poor and inefficient. Settlements in watershed area are mostly built without any plans. Building was not controlled through the laws which are usually applied for the springs planned for water supply. For these springs sanitary protection zones are proposed which was not the case with Pantan spring. These settlements do not have sewage system but they dispose water directly to the ground. Through the karst channels in the underground this pollution is coming directly to the spring. Main road in the county is placed very close to the spring which is inadmissible from the point of water quality protection. Furthermore, large waste area of the town Trogir is in close vicinity. All driving forces which are above mentioned have the influence/pressure on quality of underground waters flowing to the spring as well as on the environment of the reservation area. This pressure influence and modify water quality of the spring as well as the water quality in the whole swamp area. As the result of above mentioned processes and interrelations is the spring water quality that does not comply standards of drinking water. Water usage for the fish farm is also endangered though these standards are less strict comparing to drinking water. Water quality in swamp area is also changed causing biotope changes. As the result of these changes dieing out of certain unique species is happening.

In integral management measures for achieving sustainable management need to be implemented. These measures are represented in DPSIR concept as responses which make influence on all elements of the concept (environmental, economic and social aspects). There is significant number of measures/responses that could be implemented for the purpose of improving present state and caused impacts. Above all better watershed management should be organized. Present state shows that in the past period watershed management did not have elements of integrated watershed management. Better strategy for reservation area exploitation and protection is necessary. In the past period there was no clear strategy for the usage of this area. First step in this direction is announcing this area as the protected area. These strategies for the watershed area and reservation area would help in preventing growing of driving forces. These measures present active protection measures that could stop pollution in its early start. Partly active measure is the prevention of watershed pollution through water purification directly on the source of pollution and before water dis-

Driving forces	→	Pressures	→	States	→	Impact
• Urbanization • Waste disposals • Roads • Agricultural production • Interventions in the reservation area • Natural conditions: sea-karst interaction		• Waste water • Pollution emission from roads • Discharge of nutrients from agricultural soils • Devastation of natural conditions in reservation area • Sea water intrusion		• Polluted spring water • Changes of biotope • Decrease of swamp area • Brackish spring water		• Inability of using water for water supply and other purposes • Loss of biodiversity in swamp area
↑		↑		↑		↑↓
Responses						
• Watershed protection • Sustainable management strategy • Better plans for reservation usage • Systen of issuing permissions • Analyses of sea water intrusion precesses		• Treatment of discharge waters • Diffuse pollution control • Measure for area water intrusion preservation		• Treatment of spring water • Water desalinization • Conservation and restoration		• Planning water using according to the present water quality

Fig.4: The DPSIR model of the Pantan area

charging into the underground. Responses that eliminate and reduce pressures would be very efficient measure. Firstly this means building of sewage systems as well as building waste water treatment plants. Diffuse pollution control could significantly contribute to the water quality improvement. Since present state is already degraded measures that will influence and restore the present state would be necessary. These measures include treatment of spring water as well as measures with the purpose of the restoration of natural conditions in the swamp area. Last mentioned measure presents totally passive measure that compensates and mitigates the impacts. These are the measures directed to the consequences of the bad watershed management.

There is the other set of indicators included in DPSIR scheme originated not from the human activities but from natural conditions. They present the problem of sea water intrusion. In this problem driving forces present closeness to the sea and natural conditions of karst that make underground aquifer open to the sea intrusion. Sea water intrusion process presents the pressure. Resulting unwanted impact is the inability of using brackish water for water supply. Responses to the sea impact can be made on all levels of presented DPSIR scheme. First step is directed to analyses and better understanding of driving forces, in this case sea influence on fresh aquifer, and it presents analysis of sea water intrusion process. This presumes understanding of hydrogeological conditions in the underground that make sea intrusion process possible. Knowing these conditions is the prerequisite for making adequate technical interventions for the purpose of preventing sea water intrusion. These interventions result with changing of the spring water state meaning that spring water will not be brackish any more. Possible solution is also the one that influence the impact which means changes of quality of brackish spring water. This means desalinization process but it remains a relatively expensive measure.

Presentation of Pantan area through DPSIR concept shows very clear picture of the present state and clear picture of possible measures that can be implemented as well as their influence on certain elements of the concept. Clear presentation of all elements and their interactions is prerequisite for efficient sustainable management of Pantan area.

DISCUSSION AND CONCLUSION

Pantan swamp area gives significant biological and ecological value to the surrounding mostly karstic dry area and contributes to the variability of that uniform area. It presents unique natural reservation, but unfortunately it also presents the area where preservation of brittle balance between natural resources in karst and human interventions has not been achieved. Pantan is the example of degradation of natural environment, as the result of the unsatisfactory interventions in close and wide area. Such treatment is not adequate for this area. This swamp area with significant natural and environmental values, in combination with valuable cultural-historical heritage should be evaluated as valuable location together with town Trogir, which is announced as UNESCO town.

In this paper DPSIR framework is used for organizing information about the state of the environment as well as for organizing management system following the integration principle (environmental, economic and social aspects). DPSIR approach is a useful tool to shape a sustainable development strategy and it is officially accepted as the basis for further adoption and development for the WFD purposes, since many of the tasks required by the Directive refer directly to the elements of the DPSIR framework. DPSIR methodology is applied to this area for the assessment of environmental conditions, elaboration of management plans and design of specific restoration/conservation actions to be carried out.

Presentation of DPSIR concept for Pantan shows that in previous period there were no elements of system approach in the management of environmental resources in this area. Sustainable development does not exist and it is visible that human pressure on natural resources has been made without hesitation about consequences. DPSIR concept clearly shows that existing state can be enhanced through the active measures for prevention of further devastation of the area as well as passive measures for the rehabilitation of the area. Regarding problem of sea water intrusion scientific research projects are necessary.

It is important to notice that in the past period natural and cultural-historical potentials have never been sufficiently estimated which can explain lack of watershed management. It is the question if this zone will be named as protected area or it will be simply ignored and subjected to all other needs such as unplanned growth of settlements in watershed area, as development of fish farm, building coastal swimming zone and other. Fortunately in recent time certain improvements in treatment of this area have been made. According to the Nature protection law in year 2000 Pantan area is named as special reservation since it has particular importance for preserving biological diversities. Idea of using this area for the education-touristic purposes is growing. New owner of the mill is planning to build small hydro-electric power plant and solar system, renovate mill and through all this give new values to natural and cultural heritage of the area.

Prerequisite for above mentioned plans is adequate regional planning of resource exploitation in the whole watershed area of Pantan spring. Analysis of DPSIR concept clearly shows that different Responses influence the elements of the concept. Through response variables it is believed to improve the situation with regard to sustainability. Basis for the further development of this area should be protection of natural characteristics which has its foothold in legislation but it is usually understated and no implemented. This includes adequately regional planning of watershed area and resources exploitation. Through the definition of the regional plans it is necessary to implement regulations that will define preservation of natural conditions and provide their protection. Furthermore, integral project of the rehabilitation of whole area is needed. It is important not to make any actions that could result with changes in water regime since that would result with changes in vegetations and therefore changes in biotope. Since this location is very small it is necessary to estimate capacity for tourist reception visitors to prevent devastation of the area. In order to preserve present state and make certain improvements it is necessary to encourage establishment of natural conditions. In swamp area many activities as devastation of canes, catch of shells and fish should be stopped. In the watershed area, which is very vulnerable karst area, unplanned construction, intensive agriculture and waste dumps should be stopped. All these responses/measures should be controlled through DPSIR framework which is adequate tool to shape and implement sustainable development strategy for the Pantan area.

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KARST WATER MANAGEMENT IN SLOVENIA IN THE FRAME OF VULNERABILITY MAPPING

UPRAVLJANJE S KRAŠKIMI VODAMI V SLOVENIJI V OKVIRU KARTIRANJA OBČUTLJIVOSTI

Nataša RAVBAR[1], Gregor KOVAČIČ[2]

Abstract UDC 556.3:65.012(497.4)
556.3:504.06(497.4)

Nataša Ravbar & Gregor Kovačič: Karst water management in Slovenia in the frame of vulnerability mapping

Slovene karst sources are of great national importance for drinking water supply. Since karst aquifer systems are very susceptible to contamination, these sources require appropriate and careful managing. Unfortunately, in the acts of Slovene legislation, the special characteristics of water flow within karst regions are not very seriously taken into consideration in determining the criteria for karst water sources protection. In contrast, in some other countries, the concept of groundwater vulnerability mapping has been successfully used for protection zoning and land use planning in karst. Regarding the differences between particular karst aquifer systems, data availability and economic resources, different methods of karst water vulnerability assessment and mapping have already been developed. Already these methods have been many times tested and implemented in different test sites worldwide.

However, experience in application using different methodologies for vulnerability mapping of karst aquifers is very modest in Slovenia. The present paper deals with potential methodological problems that might arise while applying the most commonly used methods for karst water vulnerability assessment to Slovene karst regions.

Key words: karst water management, karst sources protection, drinking water, vulnerability assessment and mapping, Slovenia.

Izvleček UDK 556.3:65.012(497.4)
556.3:504.06(497.4)

Nataša Ravbar & Gregor Kovačič: Upravljanje s kraškimi vodami v Sloveniji v okviru kartiranja občutljivosti

Kraški izviri so v Sloveniji izjemnega pomena za vodooskrbo. Ker so kraški vodonosniki zelo občutljivi na onesnaženje, kraški vodni viri zahtevajo primerno in previdno upravljanje. Na žalost pa posebne značilnosti pretakanja voda v kraških pokrajinah niso zadovoljivo upoštevane pri določevanju kriterijev za zavarovanje kraških virov znotraj slovenske zakonodaje. Nasprotno se v nekaterih drugih državah koncept kartiranja občutljivosti podtalnice uspešno uporablja pri določevanju vodovarstvenih pasov in načrtovanju rabe prostora na krasu. Upoštevajoč razlike med posameznimi kraškimi vodonosnimi sistemi, razlik v dostopnosti do podatkov in v ekonomskih zmožnostih so bile izdelane številne metode ocenjevanja in kartiranja občutljivosti kraške podtalnice, ki so bile tudi večkrat uporabljene in preizkušene na različnih testnih poligonih po svetu.

V Sloveniji so izkušnje pri aplikaciji različnih metod kartiranja občutljivosti kraških vodonosnikov zelo skromne. V članku so opisani potencialni metodološki problemi, s katerimi se lahko srečamo pri aplikaciji posameznih običajno uporabljanih metod ocenjevanja občutljivosti kraške podtalnice v Sloveniji.

Ključne besede: upravljanje s kraškimi vodami, varovanje kraških izvirov, pitna voda, ocenjevanje in kartiranje občutljivosti, Slovenija.

[1] Karst Research Institute, ZRC SAZU, Titov trg 2, SI-6230 Postojna, Slovenia, e-mail: natasa.ravbar@zrc-sazu.si
[2] University of Primorska, Faculty of Humanities Koper, Glagoljaška 8, SI-6000 Koper, e-mail: gregor.kovacic@fhs-kp.si

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INTRODUCTION

Groundwater from karst aquifers is becoming more and more valuable for drinking water supply. In many regions worldwide it forms the only available drinking water resource. About one quarter of the global population is supplied by karst waters (Goldscheider 2002), while in some Alpine countries karst water contributes up to 50% of needs. In the case of Slovenia this amount reaches 43% (Brečko Grubar & Plut 2001). Extensive areas on the western, south-western, southern and south-eastern parts of Slovenia are almost entirely dependent on karst water sources (Fig. 1). Therefore karst aquifers are becoming more and more strategically important and should be appropriately and carefully managed.

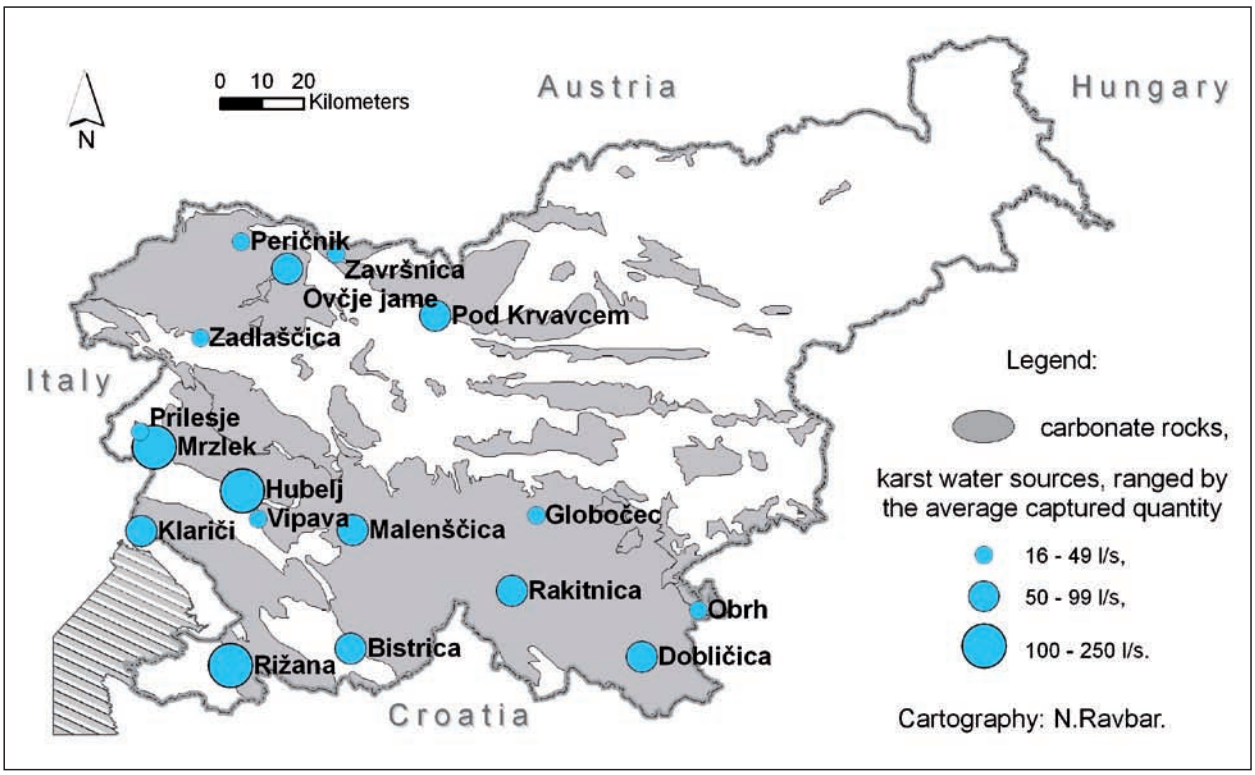

Fig. 1: The map shows the carbonate rocks extension and the most important karst water sources in Slovenia.
Sl. 1: Karta prikazuje razširjenost karbonatnih kamnin in najpomembnejše kraške vodne vire v Sloveniji.

The wide areas of karst regions in Slovenia are either uninhabited or scarcely populated with almost no agricultural activities or only with traditional ones, which is very favourable for water protection. Therefore, the karst aquifers are often considered as an abundant high-quality drinking water resource, though they are very vulnerable to pollution and should be managed and protected on a sustainable basis. Unfortunately, in the acts of Slovene legislation, the special characteristics of water flow within karst regions are not very seriously taken into consideration of determining the criteria for karst water sources protection. Furthermore, experience of karst aquifer protection within the frame of vulnerability assessment and mapping is very limited in Slovenia and more effort should be given to this subject in the future.

KARST WATER PROTECTION IN SLOVENIA

Important karst aquifers in Slovenia are mainly remote and uninhabited areas. The quality of karst groundwater, in general, is still relatively high, though some signs of contamination have already been recorded in some of the

springs (Kovačič & Ravbar 2005). Since the water protection reflects in land-use restrictions, the protection of karst water resources is often neglected in land-use management. Even where the water protection zones and regimes are established, the implementation of regulations is usually not effective and the control over polluters is weak. The example of the Bistrica karst spring illustrates some problems of water management in the area of an uninhabited Snežnik karst plateau (NW Dinarids), where sufficient protection zones have not yet been set up and water protection regulations have not been implemented properly (Kovačič 2003a).

Despite relatively favourable conditions for karst water sources protection in Slovenia compared to some other karst areas worldwide, many of the karst water sources still remain insufficiently protected.

LEGISLATIVE FRAMEWORK

Basic legislative provisions concerning karst groundwater protection policy in Slovenia are based on *Waters Act 2002.* Pursuant to the abovementioned Act it is government's responsibility to establish water protection areas and regimes in karst areas with respective drinking water sources and to ensure the implementation of the provisions in each protection zone.

According to the *Rules on criteria for the designation of a water protection zone 2004,* the hydrological background (i.e. protection area) of a specific captured karst spring or well should be divided in three basic protection zones. The outer zone coincides with the boundaries of the entire catchment area, while the first zone is determined on the basis of transfer time of flow shorter than 12 h. Regarding the abovementioned Rules, the boundaries of water protection zones of karst aquifers should be determined on the basis of data on the velocities of karst groundwater, directions of groundwater flow, depth of water table, attenuation of actual and potential pollutants, chemical characteristics of karst groundwater and the extent and karstification degree of hydrological background. The Rules (2004) recommend several different methodologies for gathering the data. Carrying out a tracer test in the catchment area of a specific spring is not an obligatory one, though it is authors' opinion that it is one of the most appropriate hydrological methods that gives results on the underground flow paths, hydraulic properties of the aquifer and a helpful tool to delineate the catchment area of the particular water source. Such a configuration of legislation, unfortunately, lets the possibility of less accurate delineation of particular water protection zones. The concept of intrinsic vulnerability assessment and mapping is not directly included in the methodology described in the Rules.

PRESENT SITUATION AND PROBLEMS

Since the new Waters Act 2002 has been in force only for a relatively short period, majority of the karst sources are still protected in accordance with old legislation. According to the old *Waters Act of 1981* the designation of water protection areas fell within the responsibility of local communities. Thus adequate protection was hindered by administrative borders between these communities. Due to the conflicts of interest in land use planning between neighbouring municipalities, protection zone extending over a territory of another municipality has usually not been accepted and the protection regime not established. In the case of the Rižana karst springs, which are tapped for the water supply of the Slovene coastal region, most of the second water protection zone extends over the neighbouring municipalities and even over the neighbouring country (Croatia) and hence is not protected (Kovačič 2003a). As with the Rižana karst springs, for the same reasons many other springs like the Malenščica and the Globečec springs are not suitably protected as well. The Malenščica spring is an important and the only source of drinking water supplying 20,000 inhabitants and economy of the Postojna and Pivka municipalities. Even though the water protection zones have been delineated and the necessary provisions defined two decades ago (Habič, 1987), the required decrees have not been accepted due to the conflicting interests in land use.

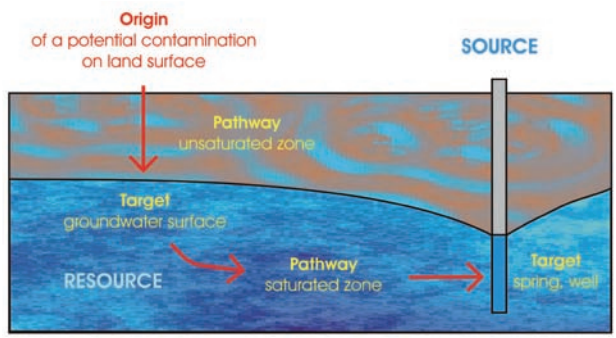

Fig. 2: Illustration of the origin-pathway-target model and the concept of the resource and source protection (after Goldscheider 2005).

Sl. 2: Ilustracija modela izvor-pot-cilj ter koncept zaščite vodnega vira in podtalnice (po Goldscheider 2005).

The Globočec spring is a regionally significant water source, but only protected in the administrative area of one municipality even though more than half of its influential area extends also to the neighbouring administrative areas (Ravbar 2005).

Since different approaches for the designation of water protection zones have been in use in Slovenia in past decades (Breznik 1976; Rismal 1993; Petauer & Veselič

1997), this has resulted in non-comparable water protection areas and regimes of different karst water sources, which is rather problematic for sufficient land-use planning in karst areas (Prestor 2002). Common characteristics of all three approaches are the transfer time delineation criteria, which define different water protection zones, and the division of hydrological background in three basic water protection zones. However, they differ markedly in their method for the determining the extent of individual protection zone, using different parameters. Due to the lack of sufficient data, the individual water protection zones were often not established on a solid hydrogeological basis, and were thus based only on available information on the geological structure. Nevertheless, for proper protection sufficient studies on source recharge, tracer tests in their catchments and other hydrological surveys are needed. Thus such protection zones are often insufficient and may be ineffective.

Nowadays situation in the field of karst water protection management in Slovenia is, unfortunately, more or less a reflection of an old legislation. Since the protection of karst aquifers fell within the responsibility of the government, establishment of karst water protection areas is now not any more hindered by the conflicts between land use and the demands for water protection on a local scale. Not many previously established water protection zones have been recently adapted to the new legislation. Thus some inadequately designated water protection zones are still valid. One of the most unfavourable consequences of unregulated conditions in the field of water protection legislation is that there is practically still no control over potential and actual polluters of karst groundwater.

The concept of karst water protection is still based only on the transfer time from the point of infiltration to the point of outflow (spring or well). Nevertheless, evaluation of different flow velocities (contamination transport times) in a sense of water protection and spatial distribution of different values of flow velocities within the background of an outflow is rather challenging. The characterization of flow and solute (contaminant) transport mechanisms in heterogenous karst aquifers (e. g. different values for diffuse and point recharge) could meet several problems, as well.

Nevertheless, crucial criteria for karst sources protection zones delineation are groundwater velocities. Where groundwater flow velocities are high, protection zones would cover large areas, often the entire catchment. However, it is impossible to require a high protection for large areas. Such spatial planning would be unreasonable and not practical. Above all, in areas with great market value of the land, rigorous land use restrictions would be controversial (Ravbar 2006).

Furthermore, groundwater velocities are not the only crucial aspects to determine higher/lower susceptibility of karst groundwater to contamination. Some other factors affecting the natural attenuation capacity of karst aquifers (e.g. function of protective cover, concentration of flow, karstification rate) are of at least the same importance, but are still not properly included in the karst water protection legislation in Slovenia.

VULNERABILITY MAPPING AS AN ALTERNATIVE CONCEPT

The concept of groundwater vulnerability mapping is an alternative approach for successful protection zoning delineation and land use planning in karst. The concept of groundwater vulnerability indicates the liability of a hydrologic system to contamination, using different colours to symbolize different degrees of vulnerability. The fundamental idea is to show that the protection provided by the natural environment varies at different locations (Vrba & Zaporozec 1994). As a result the most vulnerable areas can be identified, and consequently at least those can be protected. However, this concept is not restricted to karst, but is most relevant when applied to karst landscapes (Goldscheider 2005).

Regarding the differences between particular karst aquifer systems, data availability and economic resources, different methods on karst water vulnerability assessment and mapping have been developed. In addition, these have been many times tested and implemented in different test sites worldwide. The existing methods take into account a variety of factors that control the infiltration of water and contaminants from the land surface towards the groundwater, such as overlying layers, infiltration conditions, degree of karstification and precipitation regime.

The first existing method with special consideration to karst aquifers was the EPIK method (Doerfliger & Zwahlen 1998), which strongly influenced the later methods. Quite a few of the lately developed methods are based on the work undertaken by the COST Action 620 that developed the European Approach (Zwahlen 2004), a conceptual framework for karst groundwater intrinsic vulnerability assessment and mapping. Individual groups and individuals within the COST Action 620 have taken this approach as the basis for the particular methodology development. The European

Approach takes into consideration four parameters (overlaying layers, concentration of flow, karst network development and precipitation regime).

A significant influence to the European Approach came from the previously developed PI method (Goldscheider 2002). It is based on an origin-target-pathway model. The origin is the term used to describe the location of a contaminant release. The term pathway is a flow path of a contaminant from the point of release (origin) to the target, which may be the groundwater surface or a drinking water abstraction point e.g. spring or well (Daly *et al.*, 2002; Goldscheider 2005). There are two general approaches of a water protection: resource protection aims to protect the whole groundwater body and source protection that aims to protect a particular spring or well.

In some of the countries respective vulnerability mapping approaches have also been integrated in the states legislation e.g the Irish Method in Ireland (GSI 1999), the SINTACS method in Italy (Cività & De Maio 1997). The EPIK method (Doerfliger & Zwahlen 1998) has been integrated in Swiss legislation only for karst sources. The GLA method (Hölting *et al.*, 1995) is a supplement to the German groundwater protection schemes.

However, in Slovenia experiences of such application are very modest. Only two karst spring vulnerability studies have been done so far; Janža & Prestor (2002) using the SINTACS and Petrič & Šebela (2004) using the EPIK method.

METHODOLOGICAL PROBLEMS AND SPECIFICS OF KARST AQUIFER VULNERABILITY ASSESSMENT AND MAPPING IN SLOVENIA

GENERAL CHARACTERISTICS OF SLOVENE KARST LANDSCAPES

Direct application of some existing vulnerability mapping methods could meet several difficulties first of all due to the specific characteristics of the Slovene karst. In Slovenia karst regions extend over 43% of the country, spreading from the Karavanke range and the plateaus of the Julian and Kamniške-Savinjske Alps at an altitude of 2500 m to the shore of the Mediterranean Sea and Dinaric karst on the south. Large karst massifs and karst plateaus, intersected by shallow karst areas, karst poljes and valleys, characterize these landscapes. Thick sequences of very pure and deeply karstified limestones and dolomites of the Mesozoic era prevail. The depth of the unsaturated zone can reach several hundreds of meters, in the mountain massifs even 1500 m and more. Carbonate rocks are of very good to medium permeability, the groundwater flow velocities are ranging between 0.02 and 29.6 cm/s, respectively from 0.72 m/h to 1065.6 m/h (Novak 1993).

Less permeable or impermeable deposits traversing karst areas, border karst aquifers and prevent the underground runoff; so do flysch and less permeable dolomite layers caused by folding and thrusting. Slovene karst landscapes are strongly tectonically modified. Fault zones that intersect or border karst areas can act as hydrological barrier as well. Consequently, karst underground water emerges to the surface through numerous efficacious springs at the aquifers edges.

Catchment areas of most of them are very complex, covering karst and non-karst areas as well. Catchments often extend over several tens or even hundreds km^2 and are hydraulically connected over long distances. Watersheds are often overlapping and the flow paths proved by tracer tests often cross each other. Furthermore, it is practically impossible to define the position of individual springs' watersheds, precisely due to their high variability in time and strong dependence on the respective hydrologic conditions. Namely, in dependence on the respective hydrologic conditions in several karst areas frequent and very high groundwater fluctuations appear (several tens up to few hundred meters). Consequently, also variable flow velocities, changing flow directions and surface-underground flow interactions result.

Very thin or mostly absent protective soil cover and common absence of other protective overlaying layers, such as subsoil and non-karst rocks is significant. The average annual precipitation amounts ranges from 1000 up to 4000 mm in the mountainous areas.

METHODOLOGICAL PROBLEMS AND OPEN QUESTIONS

Regarding the peculiarity of individual intrinsic vulnerability mapping methods, the adequacy of the criteria such as parameter selection and the method of parameter weighting, different difficulties might arise when applying a particular method to Slovene karst.

In many of the existing methods the characteristics of the layers lying above the saturated zone are the most important factor controlling natural protection of groundwater against contamination (self-cleaning or carrying capacity). Some among the methods provide assessment schemes, where protective function assess-

ment consists of up to four layers of the unsaturated zone (topsoil, subsoil, non-karst rocks and karst rocks). Such a very detailed system of protective function assessment requires a vast amount of data, which is a special problem in Slovenia, discussed below. The assessment of the overlying layers protective function has been shown to be one of the major problems in one of the previous applications as well (Janža & Prestor 2002).

Because of the common absence of soil and/or sediment cover in Slovene karst, the protective function value would mainly be influenced by the depth of the unsaturated zone. Due to the enormous thickness of the unsaturated zone, the protective values would often be classified as "moderate", not showing the vulnerability differences within the aquifer itself. Therefore, the selection of only two parameters (soil and lithological characteristics of the unsaturated zone) together with a not very detailed system of protective function assessment could be suitable as well (Fig. 3).

Fig. 3: An example of a bare karst surface on Kanin high mountain plateau (2587 m), where the depth of the unsaturated zone exceeds 1500 m (photo: G. Kovačič).

Sl. 3: Primer golega kraškega površja na visoki kraški planoti Kanin (2587 m), kjer je debelina nezasičene cone večja od 1500 m (foto: G. Kovačič).

There is a problem in assessing a hydrological function of epikarst, where storage of water and concentration of flow occur. The first process increases the natural protection of karst aquifer, while the latter increases vulnerability of the karst system. The problem of epikarst is that its existence is not always easily recognizable by the surface karst features. Furthermore, great spatial differences of its development on short distances are present due to heterogeneity of karst landscapes (Kovačič 2003b). The concept of mapping surface karst features indicating the existence of different tectonically crushed zones within karst aquifer and consequently the occurrence of more or less developed epikarst zones was successfully introduced by Petrič & Šebela (2004).

Furthermore, there is still a question how to consider areas with great groundwater level oscillations, where

groundwater level varies for several tens or even hundreds of meters in a short time and causes great change of drainage divides and flow directions. The protectiveness of the unsaturated zone in highly karstified rocks is generally considered to be fairly low. Variable thickness of this zone would consequently have limited impact on final vulnerability value. However, groundwater level fluctuations might alter catchment boundaries, which is crucial for source vulnerability mapping and should therefore be additionally considered (Ravbar & Goldscheider, in press).

Due to great groundwater level oscillations, some karst landscapes in Slovenia are also characterised by surface and groundwater flow alteration that is relevant with respect to groundwater vulnerability (Figs. 4 & 5). Intermittent river flows and lakes, some of which appear several times per year, while others occur only very exceptionally, as well as temporary springs, swallow holes and estavelles are significant. Consequently only in a case when a water body (river, lake) is frequently or permanently sinking into karst, a contaminant release would always and rapidly reach the groundwater without significant attenuation. On the other hand, a contaminant transport and its attenuation capacities might vary drastically where there are no temporary or perennial water flow conditions (Ravbar & Goldscheider, in press).

Fig. 4 and 5: The intermittent lake Petelinjsko jezero is flooded up to six months per year. At low groundwater level a shallow karst depression is dry (left), while at high groundwater level it is flooded and forms a lake (right). The degree of vulnerability of the area may vary drastically depending on respective hydrologic conditions (photo: N. Ravbar).

Sl. 4 in 5: Presihajoče Petelinjsko jezero je poplavljeno do šest mesecev na leto. Ob nizkem vodostaju je kraška depresija suha (levo), medtem ko je od visokih vodah poplavljena in spremenjena v jezero (desno). V odvisnosti od trenutnih hidroloških pogojev se lahko stopnja občutljivosti na tem območju izrazito razlikuje (foto: N. Ravbar).

So far the existing methods do not provide sufficient tools to cope with hydrologic variability. The EPIK method takes into account temporary or perennial water flow conditions (Doerfliger & Zwahlen 1998). Similarly the PI method takes into consideration "average storm rainfall" conditions that occur several times per year (Goldscheider 2002). The degree of vulnerability of the area characterised by surface and groundwater flow alteration may vary drastically in dependence on respective hydrologic conditions. Therefore, when making vulnerability maps, a distinction should be made between zones of concentrated infiltration that are permanently drained into swallow holes and those that are only occasionally drained into karst.

In the vulnerability assessment, special emphasis must be given on the function of the sinking rivers, which occur within karst poljes or recharge in non-karst areas and sink on the contact with carbonates. The latter can have either huge or small catchments, which has to be considered in vulnerability assessment, since swallow holes are points of concentration of flow, causing fast infiltration of surface waters and contaminants towards the groundwater. A question arises, how to delineate the influence area of such surface flow on karst aquifer, since the surface flows have their own self-cleaning capacities (Kovačič 2003b).

Furthermore, Slovene legislation demands individual water source protection. Nevertheless, resembling some European countries, no resource protection policy has been provided so far. For source vulnerability assessment where captured springs and wells are the targets (see the origin-pathway-target model above), the additional horizontal flow path in the saturated zone, the so-called K factor, has to be considered. So far only the EPIK method provided tools for the K factor assessment. The European Approach is foreseeing incorporation of

the K factor into the vulnerability assessment as well, but does not specify how it should be measured or categorized. Therefore in many cases an additional step from resource to source vulnerability mapping should be done if we would like an application to be adequate to Slovene legislation.

When applying the SINTACS method Janža and Prestor (2002) added an extra criterion of cave density for implementing the unsaturated zone attenuation capacity and hydraulic conductivity range of aquifer into the proposed method. However, the information on cave density is not relevant criterion for the karstification degree assessment as it can reflect the degree of research work in a certain area. Furthermore, size, connection and density of karst conduits or caves are often results of previous climate conditions. In general, the conduit size aspect cannot be acceptable criteria, because even a relatively small degree of karstification (e.g. conduits 10 cm wide) can result in very high travel times and very rapid contaminant transport without significant attenuation. On the contrary, for the mostly horizontal pathway through the saturated karst bedrock to the source, the groundwater flow characteristics and distance to the source have to be considered.

The European Approach considers also the assessment of the P (precipitation regime) factor, which modifies other parameters and thus the final assessment of vulnerability as well. Some of the methods (SINTACS, PI and COP) have already introduced the precipitation characteristics into their schemes. The question is, whether it is practical to assess the value of precipitation regime within the small area of the same aquifer, since it is not very likely that the differences in intensity and amounts of precipitation vary significantly between particular parts of a catchment and thus not essentially influence its vulnerability. However, it has already been shown that when applying the COP method in many different aquifers across Europe, the P factor itself has small correlation with the final vulnerability values and shows important differences only when the method is applied to the aquifers with different climate characteristics (Vías *et al*., 2006).

Nevertheless, if introducing the P factor it would be recommendable to consider the effective infiltration instead, since it presents the true amount of water infiltrating into the subsurface. Furthermore, higher vulnerability (i.e. higher transport velocities, shorter transit time, more turbulent flow, more effective transport of sediments and bacteria, mobilisation of DNAPL – Dense Non-Aqueous Phase Liquid, more surface flow etc.) does not only depend on the actual amount of water infiltrating into the subsurface but also on the previous soil and epikarst zone water saturation.

However, there is a methodological problem, how to evaluate the protective function of a P factor as well. Do the greater amounts of infiltrating water increase the vulnerability of a karst system (faster contaminant wash-off, shorter transfer time – less time for appropriate intervention) or do they contribute to the groundwater protection (dilution, faster reduction of contaminants' concentrations, shorter duration of contamination)?

As mentioned before, in Slovene karst many areas drain into several abundant springs at the aquifers margins. In case of springs' watersheds overlapping, vulnerability maps of different sources might show different values of vulnerability due to respective springs. This raises a question, which source vulnerability map/value should be considered as more important. In terms of protection degree and spatial planning, the highest degree of vulnerability should be considered. However, when planning the implementation of sanitary provisions in water protection zones, also an additional parameter indicating the economic and/or social importance of a particular water source should be considered.

Accurate and detailed studies are essential for vulnerability assessment. Several problems are expected and have also been confirmed while applying some of the existing vulnerability mapping methods in Slovene karst landscapes due to poor database, data availability and assessment. If the method requires very large amount of detail data, it does not only makes vulnerability assessment more expensive, but also makes the application less flexible and often unsuitable, as very rarely is a large amount of data available. Particularly scarce are data in remote and mountainous karst areas.

In addition, methods that require grid input information (e.g. the SINTACS method) are not very appropriate for the application in karst areas, since the karst aquifers are very heterogenous systems characterised by great and inherent changes in small area.

CONCLUSION

In Slovenia karst aquifers are of special economic importance. Even though the quality of the groundwater is still relatively high, some sources of contamination have already been recorded, showing the shortcomings of water management even in the uninhabited alpine karst areas, which are ordinarily very favourable for water protection (Kovačič & Ravbar 2005).

In order to protect the quality and quantity of water sources and resources for future generations the concept of groundwater vulnerability mapping and assessment has been in the past decades more and more coming to the fore. Assessment of groundwater vulnerability evaluates the intrinsic characteristics of the aquifer systems and subdivides an area into several units showing different degrees of natural protection. It provides a useful conceptual framework, which could be the basis for the water protection zones and regimes establishment (Vrba & Zaporozec 1994).

Nowadays various methodologies are in use, among which also methods with special consideration of karst aquifers have been introduced. However, experiences on application using methods for vulnerability mapping of karst aquifers are very limited in Slovenia.

In future, application of some of the most commonly used methods should be stimulated in order to subject eventual methodological problems that may arise during the application. Comparison of different methods in a single test site is therefore advisable. Considering specific characteristics of Slovene karst (very thin or mostly absent protective cover, very complex and large catchment areas, lack of quality and representative research, poor database, problem of data availability, etc.) selection among the simplest methods would be reasonable. Methods that require very detailed data on protective cover characteristics or require very thorough database on catchment area should thus be avoided.

Eventually, according to adequacy of particular criteria, such as parameter selection, parameter weighting and final assessment reckoning the most satisfactory among the existing methods should be selected and improved if necessary. To propose a common method for karst water source vulnerability mapping its validation using hydrological and statistical methods is essential.

Finally, a common method, which would be the basis for the water protection zones and regimes establishment, could be used for resource protection and land use planning in karst aquifers. Furthermore, it could be a supplement to the existing legislation for karst sources protection.

According to the Rules (2004), the main criterion for the delineation of the source protection zones is the travel time of groundwater in the aquifer. However, a vulnerability assessment and mapping could be an additional criterion for karst sources protection. It could present a supplement for reduction and/or enlargement in the size of the zones where necessary according to the intrinsic properties of a particular catchment area.

Furthermore, source and resource maps could be practical tool for future land use management, spatial planning of human activities and for the sanitary provisions planning in water protection zones as well.

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TRACING OF THE STREAM FLOWING THROUGH THE CAVE FERRANOVA BUŽA, CENTRAL SLOVENIA

SLEDENJE POTOKA V JAMI FERRANOVA BUŽA NAD VRHNIKO

Miha STAUT[1] & Primož AUERSPERGER[2]

Abstract UDC 556.34.04

Miha Staut & Primož Auersperger: Tracing of the stream flowing through the cave Ferranova buža, central Slovenia

The article discusses the characteristics of the recently discovered ground water stream in the cave Ferranova buža and its possible karstic hydrological system. Its upstream connections have been narrowed to few possible springs by means of logical exclusion and have yet to be confirmed. For the purpose of establishing its linkage to the downstream springs around Vrhnika a water tracing experiment has been performed. Uranine was used as a tracer and sampled in intervals of eight hours at Primc's spring, Bečkaj's spring and Kožuh's spring. The connection was proved in all three observation points, with Kožuh's spring draining the largest quantity of the tracer. The tracer experiment evidenced that the dye was completely flushed downward in single transition curve almost without any retention.

Keywords: karst, hydrology, water tracing, fluoresceine sodium.

Izvleček UDK 556.34.04

Miha Staut & Primož Auersperger: Sledenje potoka v jami Ferranova buža nad Vrhniko

Prispevek obravnava značilnosti nedavno odkritega podzemnega vodotoka v jami Ferranova buža in njegovega kraškega hidrološkega sistema. Njegove gorvodne povezave so bile zožene na nekaj možnih virov s pomočjo logičnega izločanja. Za potrebe dognanja povezav z dolvodnimi izviri okrog Vrhnike, je bil izveden sledilni poskus. Uporabljeno sledilo je bilo uranin z intervalom vzorčenja na osem ur v Primcovem, Bečkajevem in Kožuhovem izviru. Povezava je bila dokazana z vsemi tremi izviri, vendar se je največja količina sledila pojavila v Kožuhovem izviru. Glede na rezultate sledenja je moč zaključiti, da se je uranin prenesel v enkratnem homogenem valu in da obstaja majhna verjetnost, da se je kje zadržal dlje.

Ključne besede: kras, hidrologija, vodno sledenje, uranin.

INTRODUCTION

If a caver asked us what is Ferranova buža like, despite probable sighs from the caving colleagues we would answer him, it is a thankful cave. It is not the intention to delve here into the relation that gradually establishes between the cave and its explorer(s). That relation is undoubtedly something special and needs a separate investigation, but would among karstologists probably sound too "personal" and thus un-scientific. The intention is to emphasize that after all the efforts put into it, it always knew how to return the favour with new and new surprising discoveries and in that way filled the game with satisfaction that lasts for already more that four years. It presented us with one of those gifts after one of our club's meetings when we decided to trace the stream disappearing in the terminal siphon of the cave. With the aid of some pretty rudimentary techniques we managed to achieve at first glance high quality results.

[1] Jamarski klub Železničar, Hrvatski trg 2, 1000, Ljubljana, e-mail: mihastaut@yahoo.co.uk
[2] JP Vodovod-Kanalizacija d.o.o., Vodovodna cesta 90, Ljubljana, e-mail: pauersperger@vo-ka.si

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GENERAL GEOLOGICAL AND HYDROLOGICAL DESCRIPTION

The entrance to Ferranova buža is located about 900 metres eastwards from the summit of Ulovka on the elevation 660 m above sea level (a.s.l.). After Buser (1968), Ulovka is structured by the Zaplanina nappe, where the upper Triassic dolomites are over-thrusted on the Cretaceous and Jurassic limestones of Logatec-Cerknica block. Limestones outcrop only southwards from the valley of Bela and in a narrow strip between Sveta trojica and Ulovka. The surface of the Ulovka massif is therefore dominated by a weakly expressed karstic morphology with a low drainage density and rare dolines.

The upper part of Ferranova buža evolved in the dolomite along one of the regional faults crossing the Ulovka massif in a dinaric direction. On the depth of 160 m, where the cave significantly widens it passes into the limestone which can be traced down to the current bottom at 306 m a.s.l. The narrow upper part of the cave here actually joins a gallery of a completely different character with an active flow that in the direction about 100° passes by (Fig. 1 and Fig. 2). In this second wider part the cave evolved along one or more bedding planes dipping southwards initially under the angle of 40° but towards the bottom steepen up to 70°. With regard to the proximity of the Jurassic limestones it may be deducted that the cave crosses the Zaplanina nappe structure on the junction of the upper and the lower part of the cave. In that respect the cave would be one of the rare known cases of such crossings in Slovenia.

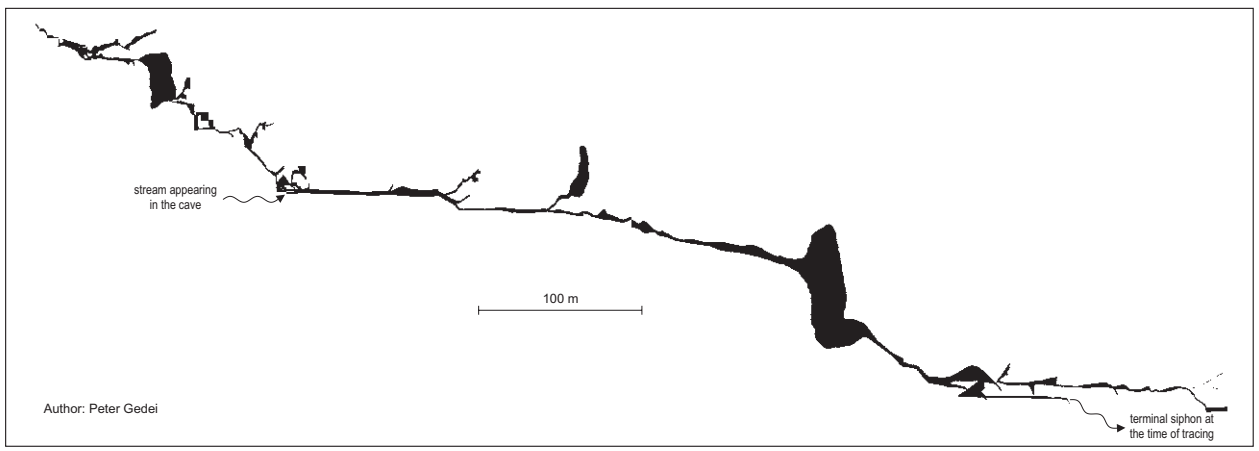

Fig. 1: Elevation of Ferranova buža.

This is why the possible source of the cave stream has to be traced in the same hydrogeological unit and not in the dolomite aquifer of Ulovka. This assumption can be confirmed by sandstone and chert pebbles found in the bed of the river showing its probable allogenic character. Additionally bacteriological analyses of the water showed contamination with faecal bacteria, evidencing that the cave stream is not the consequence of gathering of percolating water through the dolomite, such as in the case of the springs Lintvern and Staje (Habič, 1976). These two spring from dolomite about 1 km south-westwards from the entrance of the cave and were used for the Vrhnika's water supply.

Following the allogenic assumption, the map of sinking streams from Rovte hills (Fig. 2), that were predominantly traced into Kožuh's, Primc's and Bečkaj's springs in Vrhnika (Bauer *et al*., 1976; Habič, 1976; Habič, 1996), indicates possible origins of the water in the cave. The plan of the cave in Fig. 2 overlaps to some extent with the upper reaches of the stream Korita and is therefore difficult to spot. Accounting for the elevation and with regard to the results of extensive water tracing experiments in the catchment of the Ljubljanica river (Bauer *et al*., 1976), ponors on the Planinsko polje can be excluded as possible sources of the water in the cave as the stream appears in the cave exactly on 500 m a.s.l. (metres above sea level). The same is true for the Logaščica sinking at about 450 m a.s.l. as well as the Petkovščica. The later flows into Loška jama with its bottom reaching below the critical depth. The Hotenjka, the Močilka, the Hlevišarka and the Žejska voda were at large traced towards Podroteja and Divje jezero. For the purpose of the Hotenjka tracing the Kožuh spring was sampled for the first time. Due to its too deep sinking cave it can be excluded similarly as the others. Even the nearest stream the Korita sinks much too low for a possible connection with the upper siphon of the stream in Ferranova buža. With regard to its connection with Primc's and Kožuh's spring (Habič, 1996) it can be deduced that water from the Korita joins the stream from Ferranova buža somewhere below the

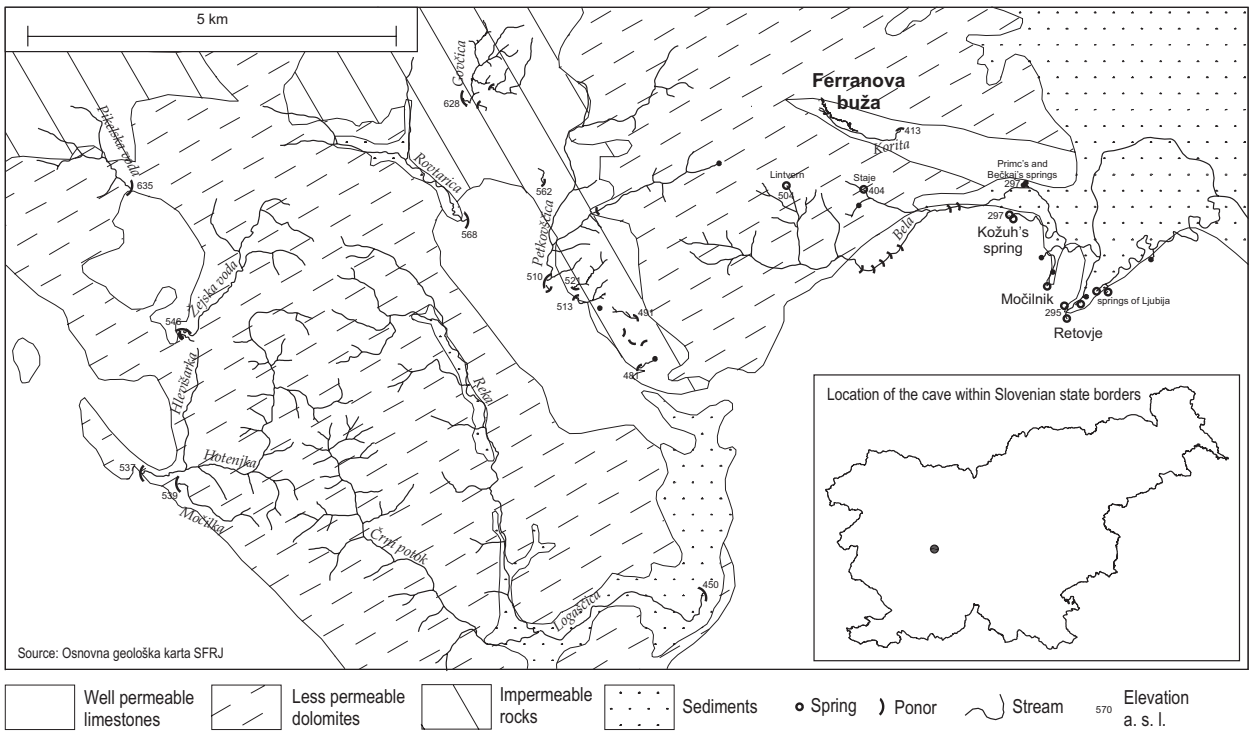

Fig. 2: Sinking streams in Rovte hills.

terminal siphon. By means of logical exclusion it can be established only the Rovtarica, the Govčica and the Pikelska voda sink high enough to be possible sources of the groundwater stream in Ferranova buža.

Fig. 3 shows possible upstream and established downstream water connections of Ferranova buža. It can be seen that the stream in the cave loses the largest part of its initial potential energy. From the elevation of 500 m a.s.l. the stream in only 500 m of horizontal distance falls to the elevation of 306 m a.s.l. The Ljubljana Moor around Vrhnika lies between 290 and 293 m a.s.l. while all three springs with established connections from Ferranova buža are located at 293 m a.s.l. The lowest part of the cave is separated from the corresponding downstream springs by 13 m of vertical and almost 2400 m of horizontal distance. The speleogenetic setting where the cave evolved thus enabled the stream to lose abruptly height. The characteristics of this change can at the moment only be guessed as upstream and downstream from the known parts the character of the cave is not known.

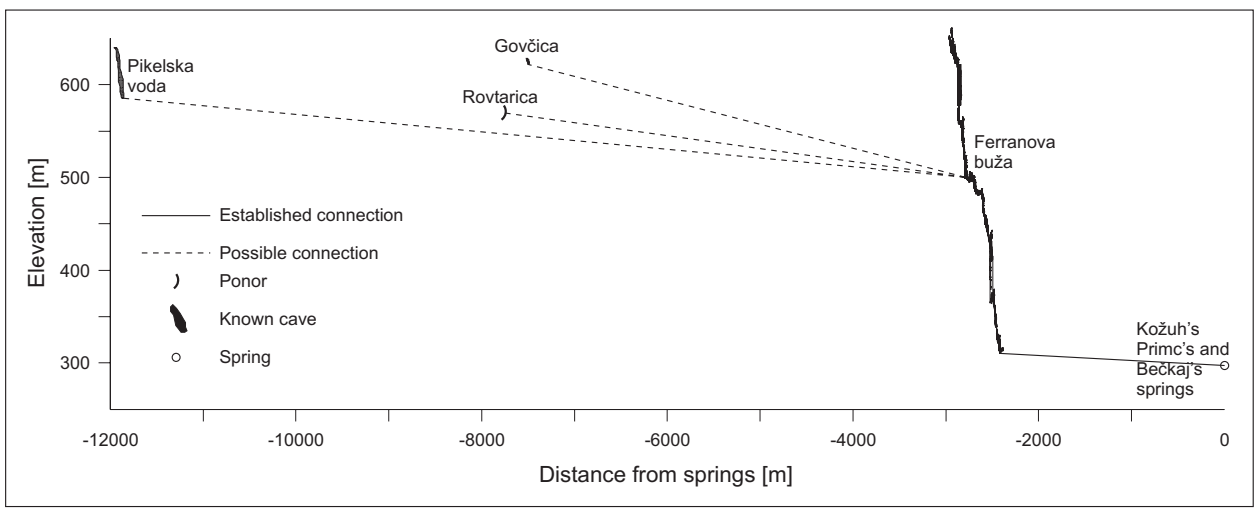

Fig. 3: Possible upstream and established downstream connections of Ferranova buža.

TRACING

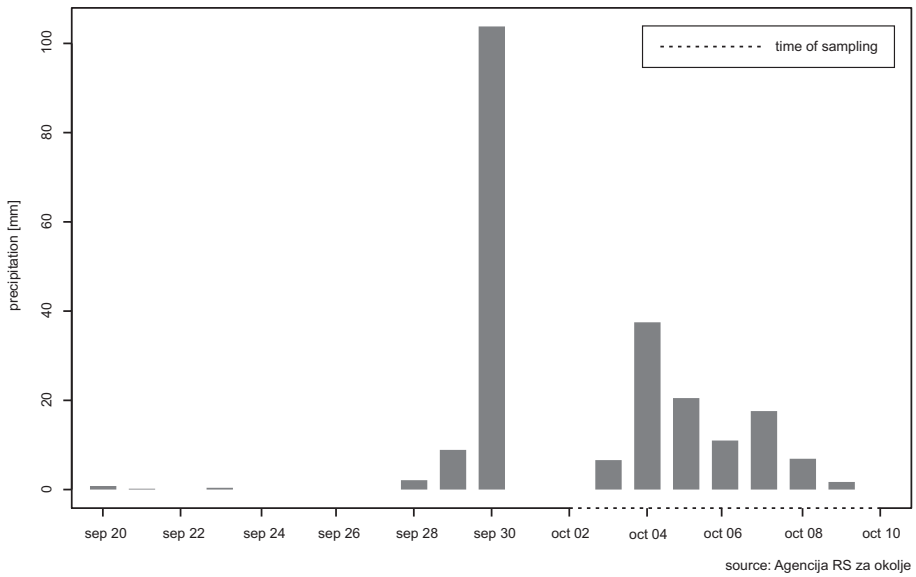

Fig. 4: Precipitation at the time of the tracing and immediately before it (precipitation station Rovte).

For the uranine determination the fluorescent spectrometry was used. Water samples were analysed with the instrument RF 1501 from Shimadzu, Kyoto, Japan. The analytical method has an accredited status according to SIST EN ISO/IEC 17025 (certificate No. LP-023). Duplicate samples were taken to test the precision in sampling and to control possible cross-contamination. For background evaluation water samples were collected before the tracing experiment at all relevant sampling points Primc's, Bečkaj's and Kožuh's spring as well as at the uranine injection point. After the uranine transition the sampling procedure continued until similar background values as before the tracing experiment were observed. From that data, the background changes during the tracer experiment were calculated by means of linear interpolation. Because of a relatively high sampling frequency and an appropriate sampling period after the uranine transition we could conclude that almost all uranine has passed the sampling points.

The discharges on all mentioned locations were estimated by means of a float let down the stream (Shaw, 1994). In that way the volumetric exchange of water in a unit of time on a specified transect can be estimated. On each transect the measurement was repeated three times and the average was calculated. The method is more suitable for small discharges and not very turbulent flows. Its advantages over more elaborate and accurate methods are the inexpensive and volume saving tool set needed for the completion of the measurement. With two hours of restrictive and mind boggling passages, it appears to be the winning method.

Uranine (as 5.0 g/L solution, 50 g of uranine total) was injected on 2nd October 2005 at 16:30 into the stream, which flows through Ferranova buža, at the site called Tartar. At the time of the sampling, this was the lowest known point of Ferranova buža immediately before the siphon. The springs were sampled 8 days on 8 hours intervals.

At the time of the tracing experiment and immediately before it there were two significant precipitation events associated with passing of weather fronts over Slovenia (Markošek, 2005a; Markošek, 2005b). They can be identified in the peaks of the measurements at the precipitation station Rovte (Fig. 4) and Vrhnika (not shown), but the later having about 20% lower precipitation. On 2nd October 2005 the discharge in the cave was estimated to be low. The measurement indicated 11 l/s. After both precipitation events the discharges of sampled springs significantly increased. According to the sampling diary of one of the samplery the water levels of two smaller springs (Primc's and Bečkaj's) during the sampling period did not vary a lot. 8th October the discharges were 62 l/s and 73 l/s respectively. On the other hand Kožuh's spring with a magnitude larger discharge (on the same day as the previous two it was estimated at 1975 l/s) varied a lot during the experiment. The same diary clearly reflected the two precipitation events. On 1st October the lowest water level was recorded and it has increased until 4th October at 6:00 am. The next day it fell for about 20 cm but from 6th to 9th October again started to rise never reaching the first height. After that it levelled off. This narration indicates that the water pulse from Rovte hills employs about four days to reach the springs around Vrhnika.

RESULTS OF THE TRACING EXPERIMENT

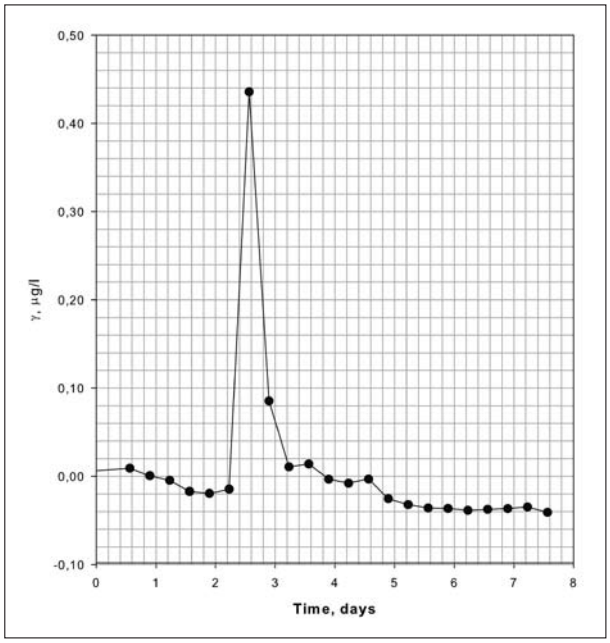

Fig. 5: Concentration of uranine at the Kožuh's spring without subtractions of the background.

At Kožuh's spring we detected uranine on 4th October 2005 at 22:00, 53.5 hours after the injection. The maximum concentration was registered on 5th October 2005 at 06:00 a.m., 61.5 hours after the injection. The last traces of uranine were detected on 9th October 2005 at 22:00 p.m., 173.5 hours after the injection.

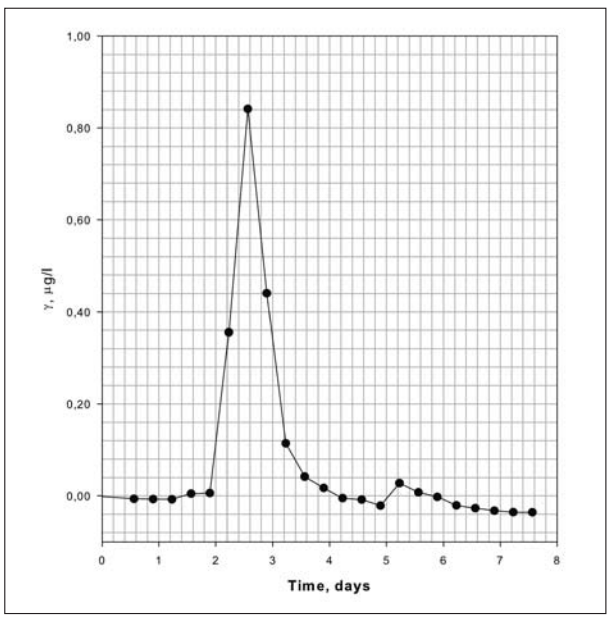

Fig. 7: Concentration of uranine at the Primc's spring without subtractions of the background.

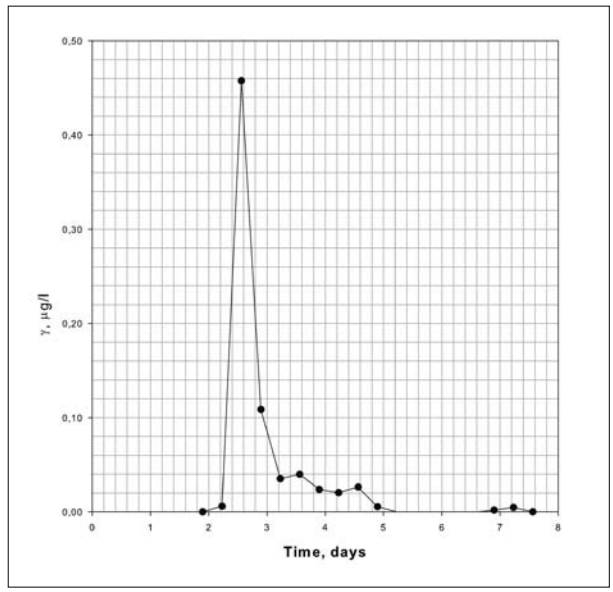

Fig. 6: Concentration of uranine at the Kožuh's spring with subtracted background.

At the Primc's spring we detected uranine on 4th October 2005 at 6:00 a.m., 37.5 hours after the injection. The maximum concentration was on 5th October 2005 at 6:00 a.m., 61.5 hours after the injection. The last traces of uranine were detected on 9th October 2005 at 6:00, 157.5 hours after the injection.

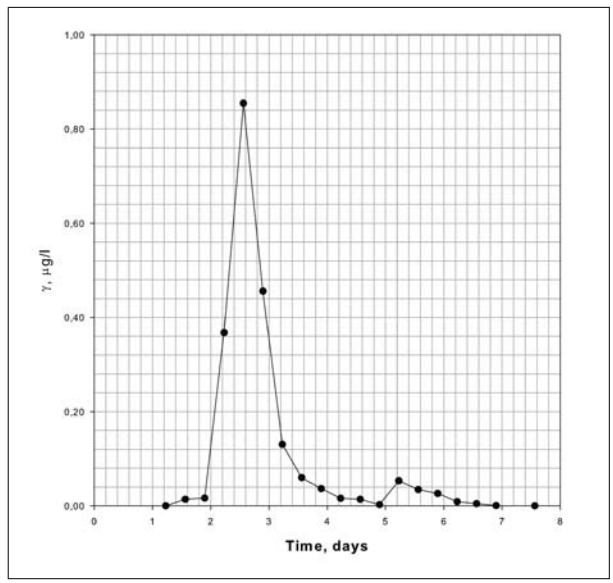

Fig. 8: Concentration of uranine at the Primc's spring with subtractions of the background.

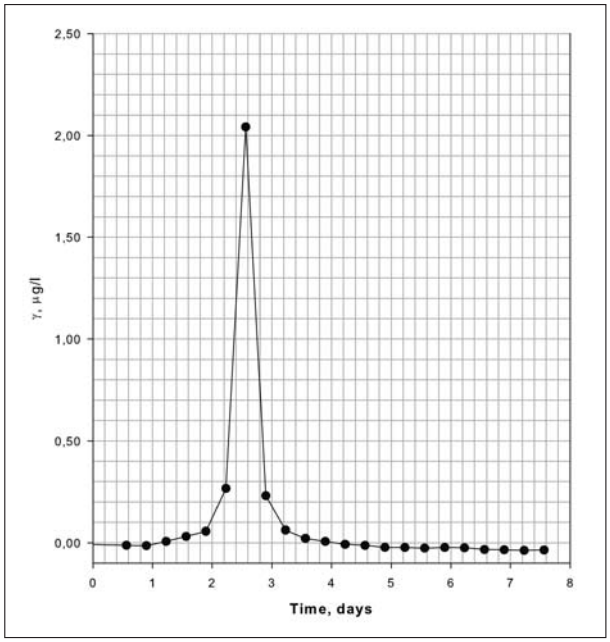

Fig. 9: Concentration of uranine at the Bečkaj's spring without subtractions of the background.

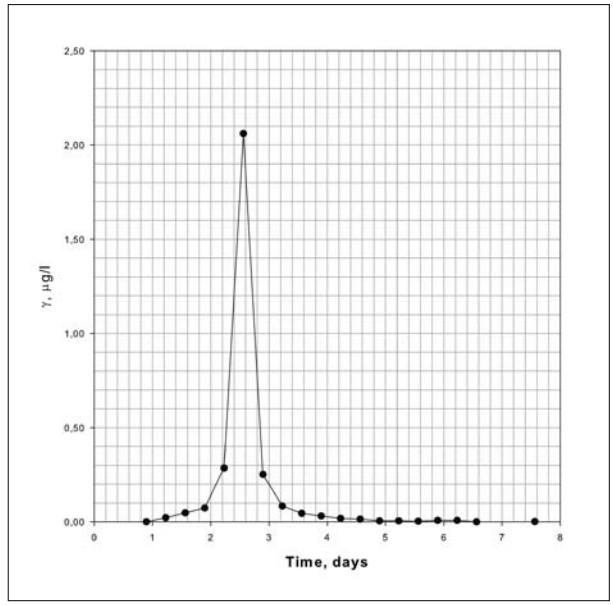

Fig. 10: Concentration of uranine at the Bečkaj's spring with subtractions of the background.

At the Bečkaj's spring we detected uranine on 3rd October 2005 at 22:00 p.m. in 29.5 hours after the injection. The maximum concentration was recorded on 5th October 2005 at 6:00 a.m., 61.5 hours after the injection. The last traces of uranine were detected on 8th October 2005 at 22:00 p.m., 149.5 hours after the injection.

In Table 1, there is a recovery calculation for the injected uranine. The calculation has been performed from the flow data and transition curves for uranine.

Tab. 1: Experimentally determined distribution of uranine across the sampling points and the recovery calculation. Φ – water flow, γ – mass concentration, A – area. m (injected) = 50.0 g.

Sampling site	γ (maximum) [µg/l]	A (transition curve) [µg/l ×day]	Φ [l/s]	m (uranine) [g]	Relative quantity of uranine determined at sampling site [%]
Kožuh's spring	0.46	0.2347	1975	40.05	80.7
Primc's spring	0.85	0.6312	62	3.38	6.8
Bečkaj's spring	2.10	0.9822	73	6.18	12.5
Total	-	-	2110	49.60	100.0

DISCUSSION

From the collected evidence, it appears that a part of waters flowing from Rovte hills towards the catchment of Ljubljanica river flow through Ferranova buža. By analysing the geological characteristics of the area where Ferranova buža has developed and some characteristics of its groundwater stream (bacteriological analysis and river sediment characteristics), it is possible to determine its allogenic source. Additionally supported by the extensive water tracing experiments in the seventies (Bauer *et al.*, 1976) the source can be confined to Rovte hills between Ljubjana Moor and Hotederščica valley. A comparison of the elevation of sinks in Rovte hills and known caves

behind them with the elevation where the stream in the cave first appears leads to the logical exclusion of some possible candidates remaining with only three options.

The results of the water tracing experiment indicated the recovery of 99.2% of the injected uranine. This relatively surprising accuracy could be explained by a fast transport of uranine, without any retardation. The recovery calculation mainly depends on the flow changes, which are connected with the weather conditions at the time of experiment and hydrodynamic conditions of the aquifer before and during the experiment. We presume that the influence of changes in weather conditions at the week of the tracing experiment was relatively weak. This could be explained by an approximate four days shift between precipitation events and significant changes in water flows.

The tracing experiment of the cave stream towards the three springs at the entrance to the valley of Bela proved the connections with all of them. The tracer first appeared in Bečkaj's spring (29.5 h) with the velocity of 2.3 cm/s. Eight hours later with the velocity of 1.8 cm/s, the tracer was confirmed in Primc's spring as well. As the two are only 50 m apart, the time lag confirms Habič hypothesis, which presumes that the channels towards the two springs separate a certain distance from them (Habič, 1996). At the latest, after 53.5 h, the uranine was transported with the velocity of 1.1 cm/s to Kožuh's spring feeding the Hrib's brook. Despite linear distances from the terminal siphon in the cave with to springs show very small differences, the tracer required a much greater time to the third one. Contrary to the first two it is situated on the southern flank of the valley. This indicates the possibility that the channel leading to it, first feeds the smaller two and only afterwards passes below the sediments of the Bela valley to finally spring in it. In all of the sampled springs however peak tracer concentrations were measured 61.5 hours after the injection. Despite slower connections and lower concentrations of the tracer in the Kožuh's spring, about 80% off all the tracer appeared in it. This again indicated the main role of the Kožuh's spring as a collector of ground water drained from Rovte hills in the Ljubljanica catchment.

ACKNOWLEDGEMENT

We wish to thank the company JP Vodovod-Kanalizacija d.o.o. for support of this study.

We thank Andrej Stržinar and Marko Krašovec for unselfish help with time-consuming sampling in the week of the experiment.

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TRACER TEST ON THE MALA GORA LANDFILL NEAR RIBNICA IN SOUTH-EASTERN SLOVENIA

SLEDILNI POSKUS NA ODLAGALIŠČU MALA GORA PRI RIBNICI V JUGOVZHODNI SLOVENIJI

Janja KOGOVŠEK[1] & Metka PETRIČ[1]

Abstract UDC 556.3:504.054(497.4-12)

Janja Kogovšek & Metka Petrič: Tracer test on the Mala gora landfill near Ribnica in south-eastern Slovenia

The Mala gora landfill near Ribnica is one of the nine still active landfills on Slovene karst. According to our legislation the monitoring of its impact on groundwater have to be performed, but this can only be effective when the characteristics of the underground water flow in the area of the landfill are well known. Therefore a tracer test was carried out on the Mala gora landfill and the main underground water connections towards the Tominčev studenec, Javornikov izvir, Debeljakov izvir and Šica springs near the settlement Dvor in the Krka valley were proved. In lower concentrations the uranine was detected in the Podpeška jama and Kompoljska jama Caves, as well as in the Šica near Mala Račna spring and both springs of the Krka river. At high waters the flow from the landfill towards the Globočec spring was proved also, but this important source of water supply is primary recharged from other parts of the karst aquifer. The appearance of tracer is forwarded by favourable hydrological conditions and increased concentrations of uranine were measured at all springs after more intensive precipitation events even one year after the injection. Obtained results were considered in the preparation of the monitoring plan.

Key words: tracer test, landfill, Mala gora, Slovenia.

Izvleček UDK 556.3:504.054(497.4-12)

Janja Kogovšek & Metka Petrič: Sledilni poskus na odlagališču Mala gora pri Ribnici v jugovzhodni Sloveniji

Odlagališče komunalnih odpadkov Mala gora pri Ribnici je eno izmed devetih trenutno še aktivnih odlagališč na slovenskem krasu. Skladno z zakonodajo je potrebno izvajati monitoring njegovega vpliva na podzemne vode, ki pa je lahko učinkovit le ob dobrem poznavanju značilnosti pretakanja podzemnih vod na območju odlagališča. Zato smo izvedli sledilni poskus, ki je pokazal, da je glavna smer odtekanja podzemne vode z območja Male gore proti izvirom Tominčev studenec, Javornikov izvir, Debeljakov izvir in Šica pri naselju Dvor v dolini Krke. V manjših koncentracijah se je uranin pojavil v Podpeški in Kompoljski jami, dokazano pa je bilo tudi sekundarno odtekanje proti Šici pri Mali Račni in izviroma reke Krke. Ob višjih vodostajih podzemne vode z območja odlagališča odtekajo tudi proti izviru Globočec, vendar pa se ta pomemben vir za vodooskrbo primarno napaja iz drugih delov kraškega vodonosnika. Pojavljanje sledila je vezano na ugodne hidrološke razmere in povečane koncentracije uranina so bile po močnejših padavinah zabeležene v vseh izvirih še eno leto po injiciranju. Zbrane ugotovitve smo upoštevali pri pripravi programa monitoringa.

Ključne besede: sledilni poskus, odlagališče odpadkov, Mala gora, Slovenija.

INTRODUCTION

Several tracer tests have been performed recently in Slovenia on landfills on karst with the aim to better understand the directions and characteristics of groundwater flow from these sources of pollution and to prepare an efficient plan for the monitoring of groundwater in the area of influence of the landfill. In the article the results of tracing at the Mala gora landfill near Ribnica in south-eastern Slovenia are presented. In this area several

[1]Karst Research Institute ZRC SAZU, Titov trg 2, SI-6230 Postojna, Slovenija,
e-mail: kogovsek@zrc-sazu.si, petric@zrc-sazu.si

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tracer tests were carried out in the past, but in all cases the tracers were injected into a sinking stream or into a water flow in a cave. This means direct input into the main drainage channels and therefore fast flow towards the karst springs. But for the landfills a diffuse infiltration of precipitation and harmful substances dissolved in it into the upper vadose zone of karst aquifers is characteristic. In the area of the Mala gora landfill the depth of the vadose zone is estimated to approximately 100 m (Kogovšek *et al.*, 2005) and the flow through it can significantly influence the transport of these substances. To test this influence it was decided to inject the tracer on the surface. And to simulate more dangerous and harmful conditions tracing was performed at high waters and the tracer was injected in a well permeable fissure at the border of the landfill.

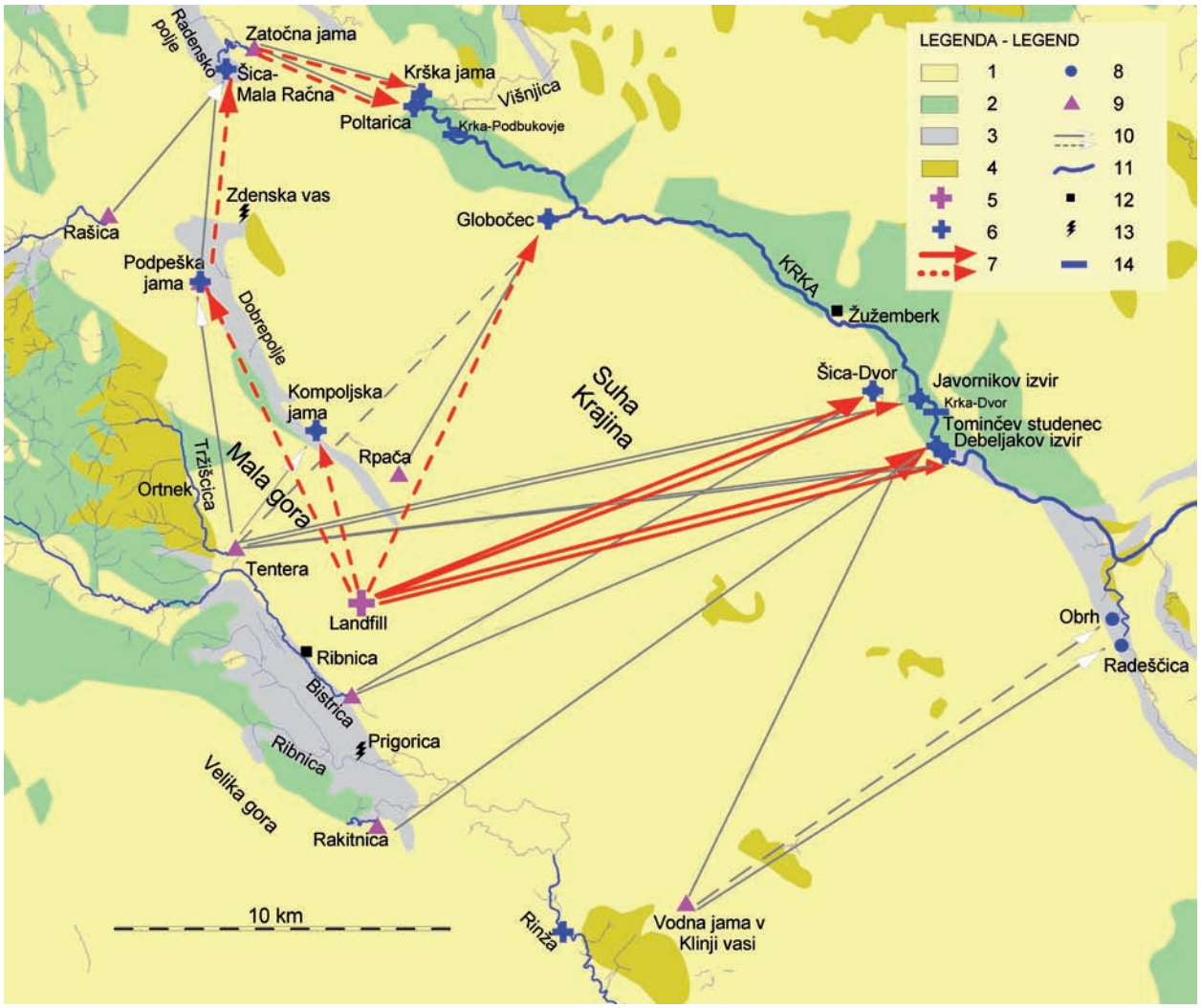

Fig. 1. Hydrogeological map of the broader area of the Mala gora landfill with the results of tracer tests (1. Karst aquifer, 2. Fissured aquifer, 3. Porous aquifer, 4. Very low permeable rocks, 5. Landfill Mala gora – injection point at the tracer test in October 2004, 6. Sampling point at the tracer test in October 2004, 7. Main and secondary groundwater connection proved by tracer test in October 2004, 8. Spring, 9. Injection point at previous tracings, 10. Main and secondary groundwater connections proved by previous tracings, 11. Surface flow, 12. Settlement, 13. Precipitation station, 14. Gauging station).

Sl. 1. Hidrogeološka karta širšega območja deponije Mala gora z rezultati sledilnih poskusov (Legenda: 1. kraški vodonosnik, 2. razpoklinski vodonosnik, 3. medzrnski vodonosnik, 4. zelo slabo prepustne kamnine, 5. deponija »Mala gora« – točka injiciranja sledila ob sledenju v oktobru 2004, 6. točka zajemanja vzorcev ob sledenju oktobra 2004, 7. s sledenjem oktobra 2004 dokazana glavna in stranska smer podzemnega pretakanja, 8. izvir, 9. točka injiciranja sledila pri starejših sledenjih, 10. glavna in stranska smer podzemnega pretakanja, ugotovljena pri starejših sledenjih, 11. površinski tok, 12. naselje, 13. padavinska postaja, 14. hidrološka postaja).

HYDROGEOLOGICAL CHARACTERISTICS

In a broader sense the area of landfill is a part of the karst plateaux Mala gora and Suha Krajina which are built of well permeable Jurassic and Cretaceous carbonate rocks (Fig. 1). Groundwater flow prevails and the only exception is karst polje Dobrepolje on which Cretaceous limestone and Triassic dolomite are covered with alluvial sediments (Buser 1968). During high waters it is temporary flooded.

Groundwater is drained towards the border of the plateux. On the north-eastern side is the Krka river with two main springs Krška jama and Poltarica. Common mean discharge of both springs is 8.3 m^3/s (Kolbezen & Pristov 1998). The Globočec spring is a right tributary near the village Fužina (mean discharge between 1 and 1.5 m^3/s (Novak 1985)) and is the main source of drinking water for the whole Suha Krajina region (Fig. 2). Along the Krka

Fig. 2. The Globočec spring is the main source of drinking water for the Suha Krajina region.

Sl. 2. Izvir Globočec je glavni vir za vodooskrbo Suhe Krajine.

riverbed near the settlement Dvor near Žužemberk there are three bigger springs: Tominčev studenec, Debeljakov izvir and Javornikov izvir. The later is active only temporary. The biggest among them is Tominčev studenec (Fig. 3) with the mean discharge of 1.6 m^3/s (Novak 1987). Higher in the slope is an intermittent spring Šica. After short surface flow it sinks again underground at different points in its riverbed and only at extremely high waters it reaches the Krka river as its surface tributary.

Further towards east is the Radeščica stream which is another important right tributary of the Krka river. It is recharged by several karst springs, the biggest among them are Radeščica and Obrh.

At the south-western side the karst plateaux are bordered by the Ribnica polje with the surface streams Bistrica, Ribnica and Rakitnica. Bistrica is partly recharged from low permeable Triassic rocks and partly from Triassic dolomite (Buser 1968). The recharge areas of Ribnica and Rakitnica are Upper Triassic, Jurassic and Cretaceous carbonate rocks of the Velika gora hills. All three surface streams sink at the south-eastern border of polje, but at very high waters the surface flow can extend to the Rinža river and sinks at the southern border of the Kočevje polje.

At the western part of the studied area the surface streams Tržiščica and Rašica collect waters from dolomite and non-carbonate rocks of Triassic and Permian age (Buser 1968). Tržiščica sinks at the contact with limestone into the Tentera Cave. Rašica flows further on karst area and sinks then into several ponors near the village of Ponikve. At very high waters their swallow capacity is too low and Rašica flows on the surface towards Dobrepolje. At Dobrepolje some intermittent springs are active after heavy raining, the biggest among them emerge from the Podpeška jama and Kompoljska jama Caves. In both caves the permanent water level is approximately 7 m below the bottom of the polje during low waters (Kranjc 1981).

Fig. 3. The Tominčev studenec spring at low waters.

Sl. 3. Izvir Tominčev studenec ob nizkem vodostaju.

The Radensko polje in the north-western side is temporary flooded. Among several springs at its border the Šica spring near Mala Račna is the most important. The springs recharge surface streams which sink into the ponors at the other side of the polje. Šica flows into the Zatočna jama Cave.

PREVIOUS TRACER TESTS

To define the directions and characteristics of groundwater flow in the broader studied area several tracer tests were performed in the past (Fig. 1). Three times the Tržiščica stream at the ponor into the Tentera Cave was traced. During high waters in 1912 one kilogram of uranine was injected and the underground water connection with the Kompoljska jama Cave was proved (Šerko 1946). The springs in the Krka valley were not observed. During low waters in May 1984 uranine was used again (Novak 1985). Surprisingly fast the tracer was detected in the Podpeška jama Cave and in the Poltarica spring (probably indirectly by Šica near Mala Račna). The highest concentrations of uranine were measured at Šica near Dvor, Tominčev studenec and Debeljakov izvir, and in the Globočec spring the tracer was detected also. Apparent flow velocity towards Tominčev studenec was estimated to 10.2 cm/s and towards Globočec to 5.4 cm/s. As the sampling was not fully reliably it was suggested to verify the connections between Tržiščica and Podpeška jama Cave, Poltarica and Globočec (Novak 1987).

New information regarding the characteristics of underground water connections was obtained in October 1998. An accident at the petrochemical depot in Ortnek resulted in an unknown quantity of gas oil entering the Tržiščica stream (Genorio 1999). It was detected in Globočec after 8 days in concentration 0.013 mg/l. Based on these data the apparent flow velocity would be 3 cm/s, but already after 8 hours the concentration dropped below 0.005 mg/l (upper limit for drinking water is 0.01 mg/l) and only a typical odour was present. Allowed concentration was exceeded again only in May 1999 after heavy rain.

The third tracing of Tržiščica with 4.6 kg of uranine was carried out in April 2000 at medium to low recession conditions (Kogovšek & Petrič 2002, Kogovšek & Petrič 2004). The most rapid flow towards the Tominčev studenec (v_{dom}=4.6 cm/s), and somewhat slower flow towards the Javornikov izvir and Debeljakov izvir were proved by the results. In two months approximately 2/3 of the total amount of injected tracer was recovered at these springs. After heavy rain at the end of the two months period of recession, lower concentrations of the tracer were detected also in the Podpeška jama Cave. In the Globočec spring in which the sampling was most frequent the tracer did not appear. So in the described conditions the expected connection with this spring was not confirmed.

The following underground water connections were also proved by tracer tests: flow from Šica at the ponor into the Zatočna jama Cave towards the springs of the Krka river in 1934 (Šerko 1946), from the Rašica sinking stream towards the Šica near Mala Račna and two springs of the Krka river (Poltarica and Krška jama) in 1966 (Habič *et al*., 1993), from the Podpeška jama Cave towards the Šica near Mala Račna and two springs of the Krka river in April 1982 (Novak 1985), from the sinking stream Rpača towards the Globočec spring in April 1987 (Grm & Novak 1989), from the Bistrica sinking stream towards the Tominčev studenec and Šica near Dvor (v_{dom}=8.5 cm/s) in September 1965 (Habič *et al*., 1993), from the Rakitnica sinking stream towards the Tominčev studenec (v_{dom}=3 cm/s) in July 1955 (Gams 1965), and from the Vodna jama v Klinji vasi Cave towards the Tominčev studenec (v_{dom}=6 cm/s), as well as towards the Radeščica spring near Podturn and probably also towards the nearby Obrh spring (Novak 1987).

In all described tracer tests the tracers were injected into a sinking stream or into a water flow in a cave. This means direct input into the main drainage channels and therefore fast flow towards the karst springs. But for the landfills a diffuse infiltration of precipitation and harmful substances dissolved in it into the upper vadose zone of karst aquifers is characteristic. The flow through it can significantly influence the transport of these substances, therefore to simulate the conditions at the landfill a new tracer test with the injection of tracer at the surface was planned and carried out in October 2004.

TRACER TEST IN OCTOBER 2004

Precipitation and hydrological conditions in the time of tracing

The Environmental Agency of the Republic of Slovenia operates with two precipitation stations inside the study area: in Zdenska vas near Dobrepolje and in Prigorica on Ribnica polje (Fig. 1). For both stations similar precipitation regimes are characteristic and therefore averages of both measured values were used as daily precipitation in further processing of data (Fig. 4).

Discharges of the springs in the impact area of the Mala gora landfill are not regularly measured. Only dis-

charges of the Krka river are measured by the Environmental Agency and for the time of tracing till the end of May 2005 we obtained data for two gauging stations: Krka-Podbukovje and Krka-Dvor (Fig. 1). The later were used for the estimation of the discharges of Tominčev studenec. Characteristic discharges of this spring were defined by some previous measurements: Qmin=0.54 m^3/s, Qmean=1.6 m^3/s and Qmax=10 m^3/s (Novak 1992), and by comparison with the measured values for Krka-Dvor the daily discharges of Tominčev studenec in the time of tracing were estimated (Fig. 4). Additionally, at Tominčev studenec the pressure probe for measurement of water levels in hourly intervals was operated by the Institute of Mining, Geology and Geotechnology from October 2004 to May 2005, and occasionally the water levels were read also at the staff gauge, which was installed at the spring by the Environmental Agency several years ago. The correlation between measured water levels and estimated discharges was good, so the later were used in further processing of the results of the tracer test.

At the Globočec spring the gauging station for water level measurements is operated by the Environmental Agency and from them we obtained the data for the period from 12 October 2004 to 15 March 2005. As these were only water level data, we used a series of parallel measurements of levels and discharges carried out by the Agency, based on which the relation between both parameters was defined and then used for the estimation of discharges of Globočec spring for the period from October 2004 to March 2005 (Fig. 4). Additionally, the correlation between these data and the measured discharges at Krka-Dvor was set and then used for the estimation of the discharges of Globočec in the period from 16 March to 31 May 2005 (Fig. 4).

The discharge at the gauging station Krka-Podbukovje is composed by flows from the springs Krška jama and Poltarica, and the tributary Višnjica. In the last years no measurements of individual flows were performed, therefore an average share of the Višnjica discharges in the total Krka-Podbukovje discharges was estimated to 6% based on the comparison of the mean monthly values in the period 1990-2000 (Kolbezen & Pristov 1998). Taking this into account the common discharge of both Krka springs in the time of tracing was assessed based on measured discharges at Krka-Podbukovje (Fig. 4).

The tracer test was carried out in the period of intensive rain before and after injection of tracer. In September and the first half of October 2004 the total amount of precipitation was 163 mm, then after injection in the second half of October additional 190 mm, and in November and December 218 mm. Also the discharges of observed springs were very high, especially immediately after injection with extreme peaks on 18 October 2004 (Fig. 4).

The beginning of the year 2005 was relatively dry and then from March till the end of May four times a more significant increase of discharges was noted. We were not able to get the data on discharges for the period from June 2005 onwards, so we can only asses the hydrological conditions based on precipitation measurements and compare them with the tracer breakthrough curves.

Injection and sampling

The landfill is located on well karstified Upper Jurassic limestone, alternating with dolomite and covered with thin, often interrupted layers of brown soil. After testing its swallow capacity, a highly-permeable vertical fissure at the margin of the landfill at the altitude of 570 m asl was chosen as an injection point for tracer test. After several days of rain, a solution of 7 kg of uranine was injected into it on 14 October 2004 and washed off with 9 m^3 of water (Fig. 5).

The sampling of water was organised at 11 locations (springs, water flow in caves, surface stream). At the Globočec spring an automatic sampler ISCO 6700-A was installed. At the beginning of the test the samples were taken each 6 hours, and later once per day. At other points the water samples for measuring the uranine level were collected manually in dark glass bottles. In Tominčev studenec, Debeljakov izvir, Javornikov izvir, and Podpeška jama sampling was organised once per day, occasionally also twice per day. Frequency of sampling in the later period of the test was reduced and adjusted to hydrological conditions. At other points (Kompoljska jama Cave, springs Šica-Dvor, Šica-Mala Račna, Krška jama and Poltarica, and surface stream Rinža) only separate series of samples were taken.

Fluorescence was measured in laboratory by a luminescence spectrometer LS 30, Perkin Elmer (E_{ex}=491 nm, E_{em}=512 nm) with detection limit of 0.005 ppb (1 ppb=1 mg/m^3). Samples with higher levels of turbidity were initially decanted and filtered (0.45 μm).

Results of tracing

Injected uranine was detected at 10 sampling points, with the exception of the Rinža surface stream (Fig. 1). Already after 5 days and in highest concentrations up to 1.18 ppb the tracer has appeared at Javornikov izvir and Šica near Dvor (Fig. 6). At the same time it was detected in Tominčev studenec in concentrations up to 0.19 ppb, and with a short delay also in Debeljakov izvir. In this spring higher concentrations up to 0.08 ppb were measured in the beginning of November 2004 (Fig. 7).

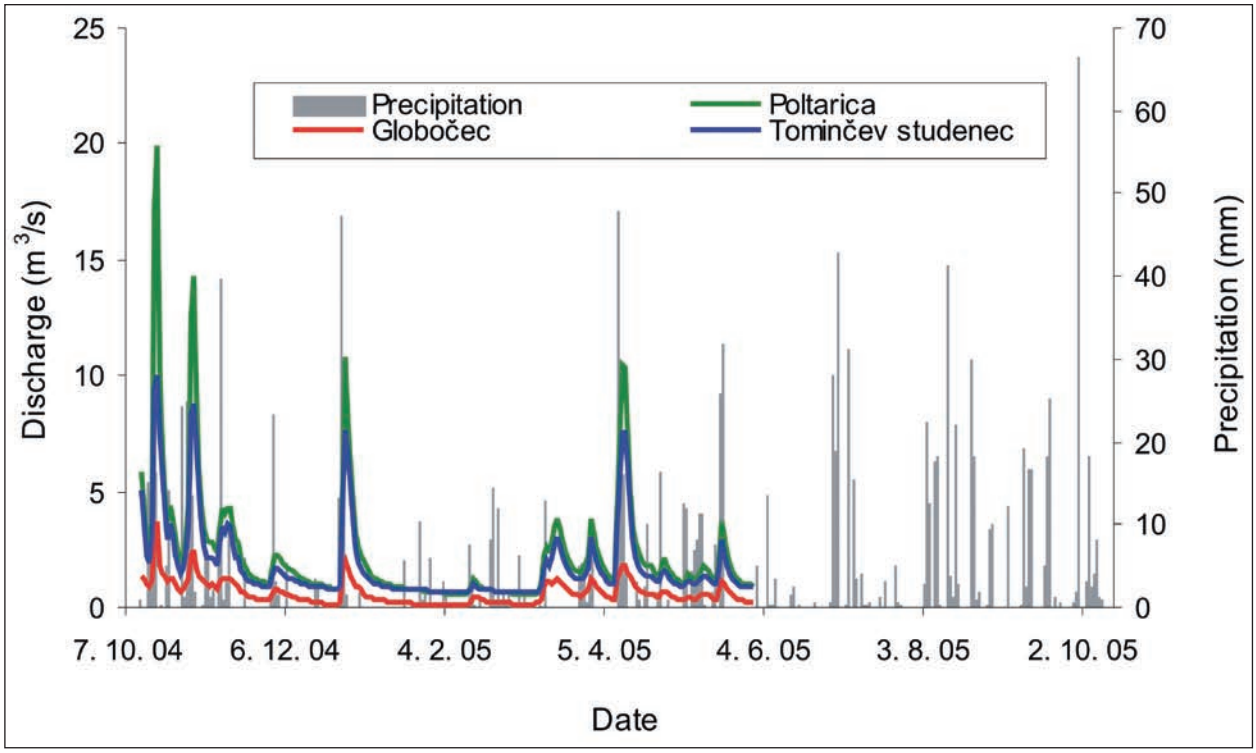

Fig. 4. Precipitation and hydrological conditions in the time of tracing.
Sl. 4. Padavinske in hidrološke razmere v času sledenja.

Strong oscillations of uranine concentrations measured in the Podpeška jama Cave indicate inflows from different parts of the aquifer. First peak appeared already on 17 October 2004, which gives the apparent flow velocity of 4.1 cm/s, but maximum concentration of 0.135 ppb was detected on 31 October 2004. In the Kompoljska jama Cave the signal was occasionally increased and this indicates the groundwater connection, but as there only same separate samples were taken, more detailed analysis of this connection is not possible (Fig. 8).

Fig. 5. A solution of uranine was injected into a well permeable fissure at the margin of the landfill.
Sl. 5. Raztopino uranina smo zlili v dobro prepustno razpoko na robu odlagališča.

The connections with both springs of the Krka river were confirmed also (Fig. 8). In spite of irregular sampling a significant increase and then decrease of uranine concentrations in the Krška jama can be seen after each precipitation event, although at the beginning of the observation some oscillations were present. They indicate the inflow from an extensive recharge area with different influences. The breakthrough curve of the Poltarica spring has a parallel course but somewhat lower concentrations. By longer duration of sampling a significant signal of tracer was observed at both springs in October 2005.

At the Šica near Mala Račna spring the sampling was irregular also (Fig. 8), but the peaks of concentrations of uranine were detected in comparable times as in both springs of the Krka river. Therefore we can presume that at least one part of the tracer flows indirectly through Dobrepolje and Radensko polje towards the Krka springs. But to get a more precise picture about these connections a more detailed observation at all points in a longer period of at least one year would be necessary.

At all observed springs increased concentrations of uranine were detected after each intensive precipitation

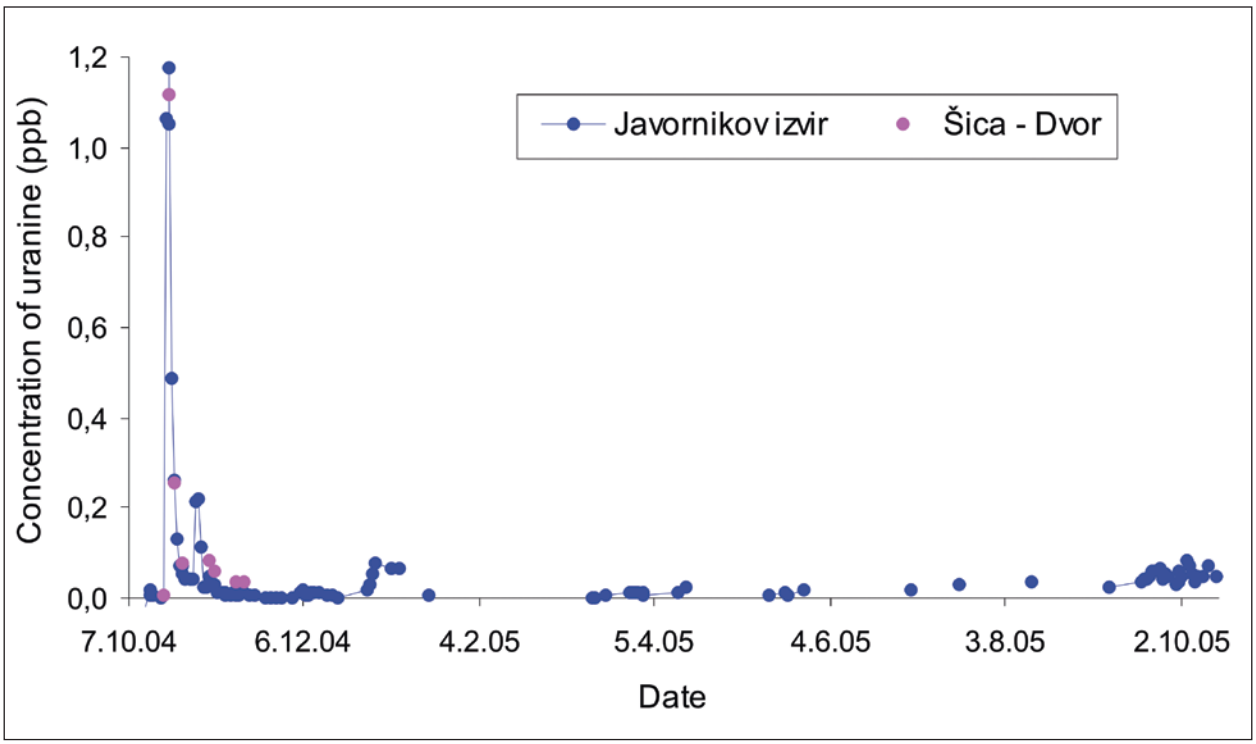

Fig. 6. The highest concentrations of uranine were detected in Javornikov izvir. At Šica near Dvor samples were taken only occasionally and in them similar concentrations of tracer were measured.

Sl. 6. Najvišje koncentracije uranina so bile zabeležene v Javornikovem izviru. V Šici pri Dvoru smo zajemali vzorce le občasno in v njih smo izmerili podobne koncentracije.

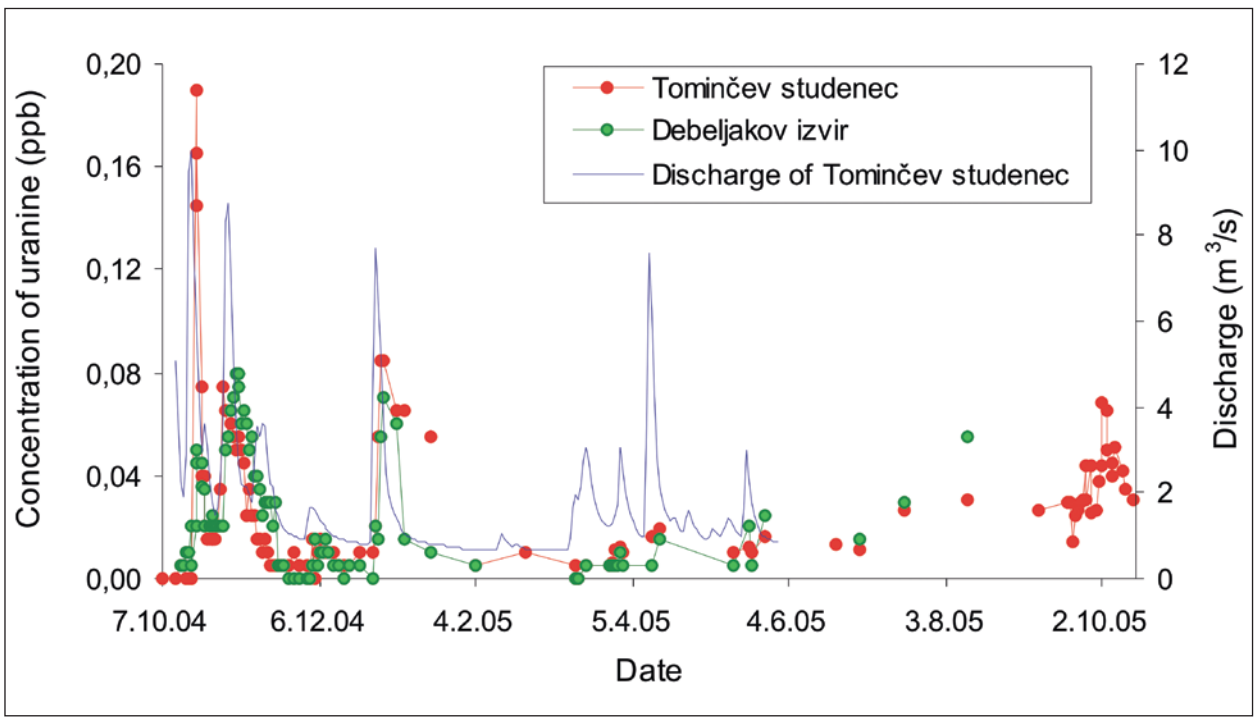

Fig. 7. Concentrations of uranine in the Tominčev studenec and Debeljakov izvir springs, and discharges in Tominčev studenec

Sl. 7. Koncentracije uranina v Tominčevem studencu in Debeljakovem izviru ter pretok Tominčevega studenca.

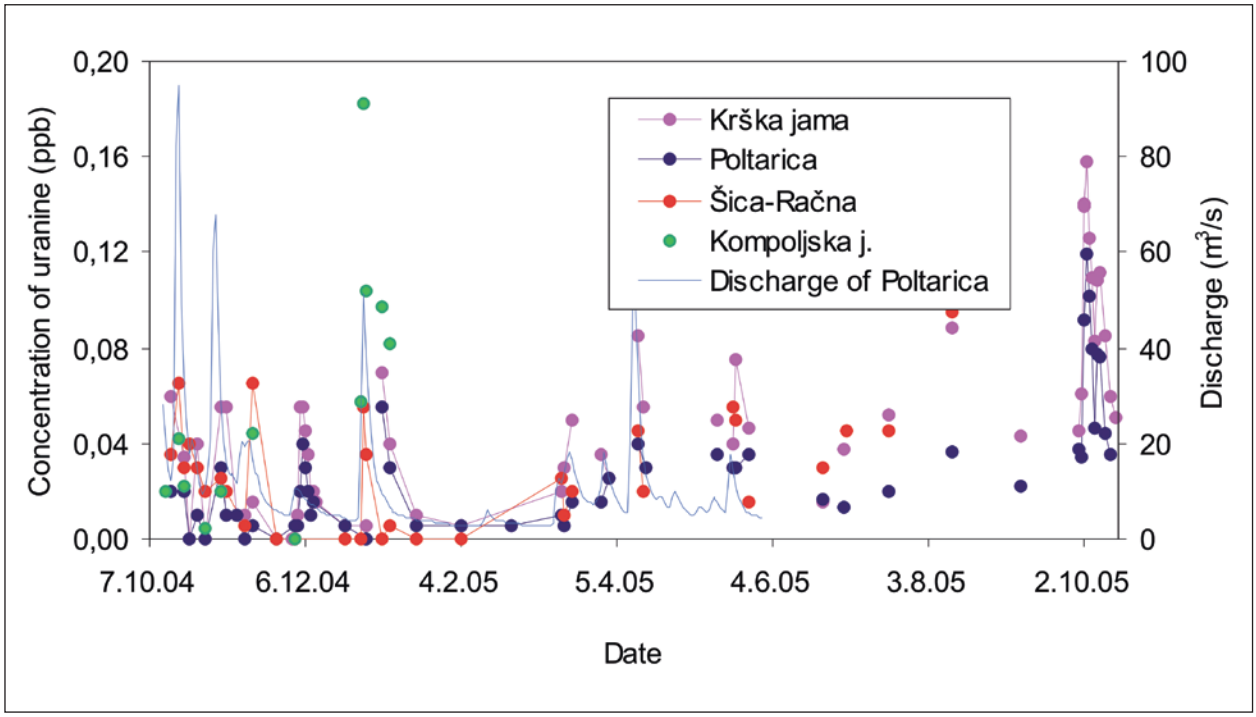

Fig. 8. Uranine breakthrough curves for other springs.

Sl. 8. Krivulje koncentracij uranina za ostale izvire.

event, which washed out the tracer stored in the vadose zone and karst channels. Relatively high concentrations were measured in October 2005 almost one year after the injection of tracer, and such appearances of uranine are to be expected also in the following period.

Table 1. Estimation of apparent dominant velocities of groundwater flow.

Tabela 1. Izračun navideznih dominantnih hitrosti pretakanja podzemnih vod.

Sampling point	Height difference (m)	Distance (m)	t_{dom} (h)	v_{dom} (cm/s)
Tominčev studenec	395	17800	122,5	4,0
Debeljakov izvir	397	18045	142	3,5
Javornikov izvir	390	17710	143,5	3,4
Šica-Dvor	370	16515		3,4
Globočec	322	12740	124,5	2,9

Calculated apparent flow velocities are comparable with those estimated at the tracer test with direct injection into the Tržiščica sinking stream during medium water hydrological conditions in April 2000 (Kogovšek & Petrič 2002). This indicates that in wet periods with intensive precipitation infiltrated rain and the contaminants dissolved in it pass fast through the vadose zone of karst aquifer and further towards the springs.

Measured concentrations of uranine at the Globočec spring were only slightly above the detection limit, but the signal was simultaneous to the one at the other springs (Fig. 9). We can conclude that additional to the main direction of flow towards the springs near Dvor at the existing conditions of high waters also the secondary connection with the Globočec spring was confirmed. Increased concentrations of tracer were detected at Globočec also after later precipitation events, and the maximum value of 0.085 ppb was measured only in October 2005 which is almost one year after the injection. So each more intensive precipitation event is pushing out the tracer stored in the less permeable parts of the karst water system. The observed appearance of tracer at the spring and its concentrations are in such extensive and heterogeneous system a great deal influenced also by hydrological conditions which differ significantly in time but also in space. Obtained information about longer retention time in the direction towards Globočec should be considered in the planning of monitoring of groundwater in the area of influence of the landfill.

In five months long period of more regular sampling from the injection of tracer in October 2004 till the end of February 2005 approximately a half of the total amount of injected tracer was detected at all springs. Along with

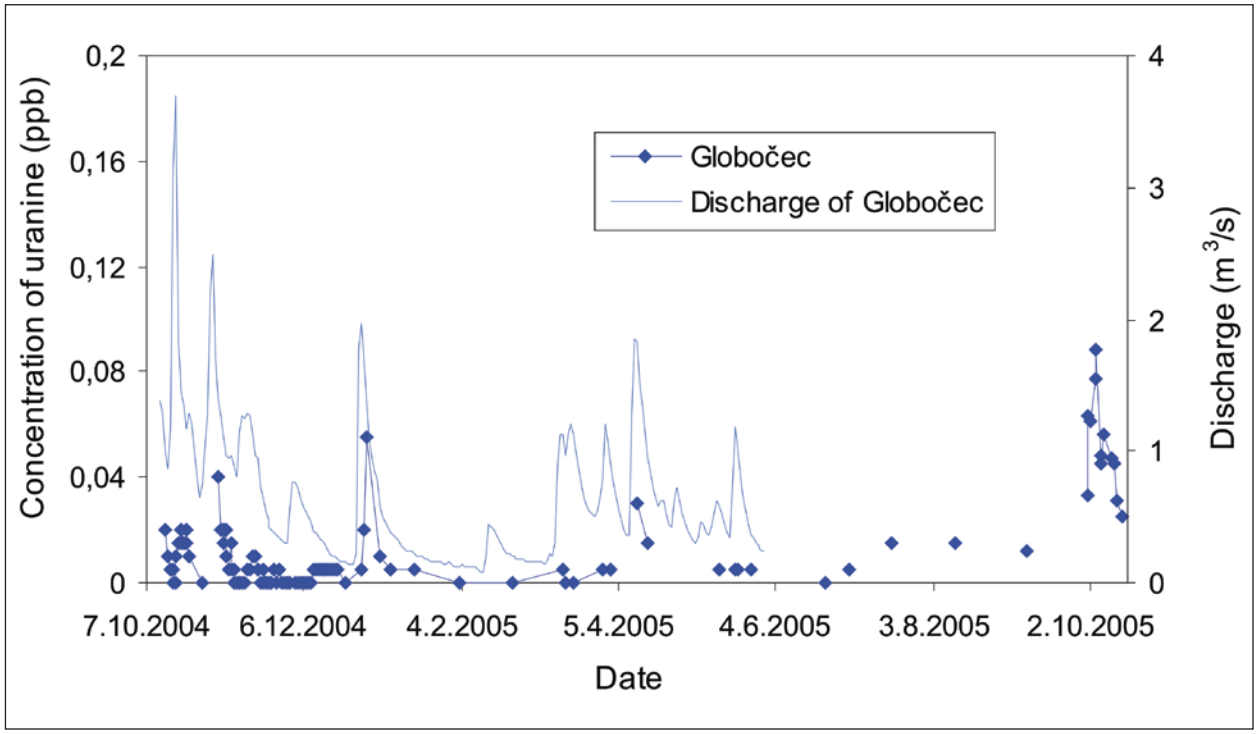

Fig. 9. Concentrations of uranine and discharges in the Globočec spring.

Sl. 9. Koncentracije uranina in pretok v izviru Globočec.

this result we should emphasise that the quality of discharge data applied in calculations was not very high and that several estimations and indirect comparisons were used as described in one of the previous chapters. As the Globečec spring is captured for the water supply, the share of recovered tracer was estimated also for this spring. In one year around 3% of the injected uranine has been recovered there.

CONCLUSIONS

Performed tracer test with the injection of 7 kg of uranine in a highly-permeable vertical fissure at the margin of the Mala gora landfill during high waters in October 2004 confirmed the main groundwater connection with the springs Tominčev studenec, Javornikov izvir, Debeljakov izvir and Šica-Dvor in the Krka valley. In lower concentrations the tracer was detected in the Podpeška jama and Kompoljska jama Caves, and also a secondary direction of underground water flow towards the Šica near Mala Račna spring and both Krka springs was proved.

Special attention was dedicated to the Globočec spring as a main source of water supply in the Suha krajina region. Based on the results of tracer tests we can conclude that groundwater from the landfill area flows during high waters towards Globočec also, but this spring is mainly recharged from other parts of the karst aquifer.

Apparent dominant flow velocity in the main direction towards the springs near Dvor was approximately 4 cm/s. Comparable velocities obtained by tracing of the Tržiščica sinking stream at medium waters in April 2000 indicate that at high waters with intensive precipitation before and after injection transport of tracer is not hindered even in a thicker vadose zone. At the time of injection the karst system was filled with water and in such conditions also the transport of tracer through the vadose zone is fast. Similar results were obtained by the tracer test through approximately one hundred meters thick vadose zone above the Postojnska jama Cave (Kogovšek 2000). This indicates very high vulnerability and a serious danger of pollution with harmful substances from the landfill. Then in the following period of one year the increase of the concentration of tracer was detected after each more intensive precipitation event. Although a part of a soluble tracer flows rapidly through the primary drainage paths, the remainder is retained in the vadose zone and is pushed out by newly

infiltrated water in the following precipitation events over a long time period.

Some valuable information for the proper planning of the monitoring of groundwater were obtained by performed tracer test. A decision was made which springs should be included into the monitoring. As the main monitoring points Tominčev studenec and Globočec were suggested, but additionally also Javornikov izvir could be observed because the influences from the landfill are more intensive there (significantly higher concentration of tracer in a first peak than at other springs). The time and frequency of the sampling should be adjusted to hydrological conditions also, because the pollution signal can be expected at monitoring points after more intensive precipitation events.

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SLEDILNI POSKUS NA ODLAGALIŠČU MALA GORA PRI RIBNICI V JUGOVZHODNI SLOVENIJI

POVZETEK

V zadnjem času je bilo opravljenih več sledilnih poskusov z odlagališč na slovenskem krasu z namenom, da bi bolje razumeli smeri in značilnosti odtekanja podzemne vode z območja teh virov onesnaževanja in pripravili učinkovit program za monitoring kakovosti podzemnih vod na vplivnem območju odlagališč. V oktobru 2004 smo poskus izvedli na odlagališču Mala gora pri Ribnici. Širše območje odlagališča je del kraške planote Male gore in Suhe Krajine, ki se na severovzhodni strani dviga nad dolino reke Krke, na jugozahodni pa nad Ribniško polje. Gradijo jo dobro prepustne jurske in kredne karbonatne kamnine (Sl. 1). Voda se pretaka podzemno proti številnim izvirom na obrobju. Največji so izviri v dolini Krke z njenima glavnima izvirom Krško jamo in Poltarico s skupnim srednjim pretokom 8,3 m^3/s. Izvir Globočec s srednjim pretokom med 1 in 1,5 m^3/s je zajet za vodooskrbo Suhe Krajine (Sl. 2). Južno od Žužemberka pri naselju Dvor so še štirje večji izviri. Največji je Tominčev studenec s srednjim pretokom okrog 1,6 m^3/s (Sl. 3). Poleg njega je prav tako stalen Debeljakov izvir, Javornikov izvir in Šica pri Dvoru pa sta aktivna samo ob visokem vodostaju. Na suhem kraškem polju Dobrepolje sta izvira iz Podpeške in Kompoljske jame aktivna po močnejšem deževju, drugače pa je stalen vodni tok v obeh jamah okrog 7 m pod dnom polja. Na južnem robu Radenskega polja izvira Šica pri Mali Račni, ponika pa na vzhodnem robu polja v Zatočno jamo.

V preteklosti je bilo na tem območju opravljenih več sledilnih poskusov (Sl. 1). V vseh primerih je bilo sledilo injicirano v ponikalnico. Za odlagališče pa je značilna razpršena infiltracija padavin in v njih raztopljenih škodljivih snovi v vadozno cono. Ker je debelina te cone okrog sto metrov, lahko precejanje skoznjo značilno vpliva na transport sledila in po analogiji tudi na transport in zadrževanje kontaminantov v kraškem podzemlju. Zato smo v poskusu na Mali gori za injiciranje sledila na površju izbrali dobro prepustno razpoko na obrobju odlagališča.

Po večdnevnem dežju smo 14. oktobra 2004 injicirali raztopino 7 kg uranina in jo zalili z 9 m^3 vode iz cisterne (Sl. 5). Zaradi intenzivnih padavin v naslednjih dneh so pretoki izvirov zelo narasli in dosegli zelo visok vodostaj (Sl. 4). Vzorčenje smo organizirali na 11 lokacijah, pogostnost zajemanja na njih pa je bila različna. Fluorescenco smo merili v laboratoriju z luminiscenčnim spektrometrom LS 30, Perkin Elmer, vzorce pa smo predhodno dekantirali in po potrebi še filtrirali.

Uranin se je že po 5 dneh in v najvišjih koncentracijah do 1,18 ppb pojavil v Javornikovem izviru in Šici pri Dvoru (Sl. 6), hkrati pa tudi v Tominčevem studencu in nekoliko kasneje v Debeljakovem izviru (Sl. 7). Velike oscilacije koncentracije sledila v Podpeški jami kažejo na prepletanje dotokov iz različnih delov zaledja. Potrjena je bila tudi povezava s Kompoljsko jamo, vendar je bilo vzorcev premalo za bolj natančno analizo. Dokazano je bilo še odtekanje proti obema izviroma Krke in Šici pri Mali Račni (Sl. 8). Na vseh izvirih so se koncentracije uranina povečale po vsakem močnejšem padavinskem dogodku, ki je spiral zaostalo sledilo iz vadozne cone in kraških kanalov. Relativno visoke vrednosti so bile izmerjene v oktobru 2005 skoraj eno leto po injiciranju in podobne pojave je bilo možno pričakovati tudi v naslednjem obdobju. Izračunane navidezne dominantne hitrosti toka okrog 4 cm/s so primerljive z rezultati sledenja Tržiščice v aprilu 2000 ob srednjem vodostaju. Sklepamo lahko, da v namočenih obdobjih z intenzivnimi padavinami infiltrirana voda in v njej raztopljene škodljive snovi zelo hitro preidejo vadozno cono in odtekajo po kraških kanalih naprej proti izvirom. To kaže na zelo ranljiv vodonosnik in resno nevarnost njegovega onesnaženja s kontaminanti z odlagališča.

Posebno pozornost smo posvetili izviru Globočec, ki je zajet za vodooskrbo. Izmerjene koncentracije sledila so bile le malo nad mejo detekcije, vendar je bila oblika signala podobna kot pri drugih izvirih (Sl. 9). Maksimalna vrednost je bila dosežena šele v oktobru 2005. Sklepamo lahko, da izvir Globočec napajajo predvsem podzemne vode iz drugih delov kraškega vodonosnika, vendar ob visokem vodostaju proti njemu odtekajo tudi vode z območja odlagališča.

Ocena deleža povrnjenega sledila je zaradi slabše kakovosti podatkov o pretokih le približna. V času od začetka poskusa v oktobru 2004 do konca februarja 2005 je skozi izvire iztekla približno polovica injiciranega sledila, od tega skozi Globočec okrog 3%.

Na osnovi zbranih rezultatov je bil izdelan program monitoringa. Kot glavni točki opazovanja sta bila predlagana izvira Tominčev studenec in Globočec, dodatno pa še Javornikov izvir, saj se je vpliv z odlagališča tam pokazal najbolj izrazito (značilno višje koncentracije sledila kot v drugih izvirih). Čas in frekvenco vzorčenja je potrebno prilagoditi hidrološkim razmeram, saj lahko signal onesnaženja pričakujemo po močnejših padavinah.

COBISS: 1.01

DOLENJSKA SUBSOIL STONE FORESTS AND OTHER KARST PHENOMENA DISCOVERED DURING THE CONSTRUCTION OF THE HRASTJE – LEŠNICA MOTORWAY SECTION (SLOVENIA)

DOLENJSKI PODTALNI KAMNITI GOZDOVI IN DRUGI KRAŠKI POJAVI, ODKRITI PRI GRADNJI AVTOCESTNEGA ODSEKA HRASTJE – LEŠNICA

Martin KNEZ[1] & Tadej SLABE[1]

Abstract UDC 551.435.8(497.4)

Martin Knez & Tadej Slabe: Dolenjska subsoil stone forests and other karst phenomena discovered during the construction of the Hrastje – Lešnica motorway section

This paper explains the investigation of shallow and sediment-covered areas of the Dolenjska karst discovered during the construction of the motorway section between the villages of Hrastje and Lešnica. Research done during construction has again proved to be very useful; we came to numerous and augmentative conclusions about the development of karst features typical of the Dolenjska region. Again the importance of the participation of karst researchers in planning major activities concerning the karst and in monitoring the work was demonstrated. We have researched the unique features of the karst surface marked mostly by large areas of stone forests and characteristic karstification below the thick sediment beds.

Key words: stone forests, subsoil formation of carbonate rock, Dolenjska karst, Slovenia.

Izvleček UDK 551.435.8(497.4)

Martin Knez & Tadej Slabe: Dolenjski podtalni kamniti gozdovi in drugi kraški pojavi, odkriti pri gradnji avtocestnega odseka Hrastje – Lešnica

Članek obravnava raziskave plitvega dolenjskega krasa med gradnjo avtocestnega odseka med vasema Hrastje in Lešnica. Raziskave med gradnjo so se tudi tokrat izkazale kot zelo koristne, saj smo prišli do številnih novih in dopolnjujočih zaključkov o razvoju tega, za Dolenjsko značilnega krasa. Ne nazadnje se je spet izpostavil pomen sodelovanja krasoslovcev pri načrtovanju večjih posegov v kraško površje in spremljava del. Raziskovali smo svojevrstno oblikovanost kraškega površja, ki jo predstavljajo predvsem velike površine kamnitih gozdov ter značilno zakrasevanje pod debelimi plastmi naplavin.

Ključne besede: kamniti gozdovi, podtalno oblikovanje karbonatnih kamnin, dolenjski kras, Slovenija.

INTRODUCTION

The monitoring of the construction of the Dolenjska motorway by karst researchers has again proved to be of great value in the exploration of our natural heritage through the deepening of our knowledge about the formation and development of this part of the Slovenian karst. This characteristic subsoil karst surface was formed under a cover of sediment of varying depth. Subsoil formation of carbonate rock also marks the entire epi-karst and vadose zone. The surface is carved into subsoil stone forests (Figs. 1, 2), the surfaces of the karren are smaller and numerous hollow shafts are filled with fine-grained sediment. The outstanding characteristics of the karst surface are primarily the result of large surfaces of stone forests, which are difficult to detect prior to earthwork or geophysical research. Most of the surface is above the underground water level. The only exception is the motorway section at Hrastje, which was not fully uncovered due to the construction method and because lower road beds

[1]Karst Research Institute, ZRC SAZU, Titov trg 2, SI-6230 Postojna, Slovenia, e-mail: knez@zrc-sazu.si, slabe@zrc-sazu.si

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Fig. 1: Uncovering of subsoil stone forest.
Sl. 1: Razkrivanje podtalnega kamitega gozda.

Fig. 2: Subsoil shaped pillar of stone forest.
Sl. 2: Podtalno oblikovan steber kamnitega gozda.

were put upon a special grounding. For this reason we could only research the karst formations that had been shaped by water percolation through the karst surface. We did not find the characteristic subsoil karren as those discovered during the earthwork at Bič, which were also formed by the fluctuation of underground water (Knez *et al.*, 2004). Karst features discovered during construction work give us insight into the characteristics and manner of formation of the karst in the wider area of southern Slovenia; they thus unveil yet another characteristic of our karstic natural heritage that is hidden from view, but which also provides guidelines for planning activities on the surface.

THE MOTORWAY ROUTE AND THE MAIN CHARACTERISTICS OF THE LANDSCAPE

The north-eastern part of the motorway section starts in the vicinity of a swallow hole of the Igmanca stream near the villages of Hrastje, Dolenja vas and Šentjurij and pass the village of Selo along characteristic Dolenjska lowland. Lateral, changing and relatively thick beds of sediment and soil cover the land. The underground water is close to the surface of the predominant fluviokarst. Here we find individual karstic features, among them minor swallow holes, esatavellas and, to a lesser extent, an outcrop of carbonate rock. The terrain rises slightly towards the Strmec and Dobrava hills, where the road climbs more steeply and soon after the pass drops towards the Krka River. We have detected thinner sediment beds and frequent outcropping of karstified rock, which mostly disintegrates into small fragments. There is less surface water at that location since it flows into the subsoil relatively quickly due to the inclination of the terrain, the thin sediment beds and fragmentary cover of disintegrated rock. The stone forests and karren, which reach various depths, are composed of compact and also tectonically very crushed rock. Where the rock is not crushed and where compact blocks of limestone occur between the cracks, we noticed stone teeth on the surface. During the earthwork, these had in many cases revealed themselves as real stone pillars. Where the rock was tectonically cracked or crushed, we did not find karren on the surface; however, at some locations rudimentary stone teeth hidden beneath the soil immediately disintegrated during earthwork. Between the Brezovica and Lešnica hills we again find typical shallow Dolenjska karst with its underground level close to the surface, and its characteristic collapses and sinkholes. A rare network of streams is formed on the surface, but a substantial part of the source and side channels do not have permanent flows. Minor springs of underground water are frequent and flow along narrow, corroded cracks in the rock. Surface and subsoil karst features are rare. The surrounding valleys are dry for most of the year, and streams and floods only occur after downpours. Percolating water feeds small but permanent sources. Fluctuation of the flow from these sources is minimal and rarely more abundant, which reflects greater permeability and cavernosity. Underground water flow is close to the surface, for which reason karst formations such as this are called "shallow karst".

Thick beds of Plioquaternary sediments on carbonate rock, especially on a moist surface, are usually acid. It

is not yet fully understood whether these sediments are autochthonous or brought from the nearby dolomite surroundings (Gams 2004). After comparison with the circumstances in tropical karst, the opinion developed that in these valleys the thick layers of disintegrated material could have been preserved only because of the high underground water level and poor erosion, and thus developed into subsoil karst.

GEOLOGICAL CHARACTERISTICS OF THE AREA

The motorway route between Hrastje and Lešnica runs, for the most part, on Jurassic (Lower Malm) rock. In some cases it also crosses Plioquaternary sediment and alluvial river sediment. From the geo-tectonic aspect it belongs to the Outer Dinarids, characterised by its block structure and the Dinaric orientation of the faults and alignment of the folds. A covered fault runs along the western side of the road section. The anticline fold of the Upper Jurassic beds run in the Dinaric sense from Dolenja Nemška vas on the northwest to Novo mesto on the southeast. The road mostly runs along its northern flank. The dip of the beds changes, but the general direction is towards the northeast. We find various micro and macro fauna in the rock along the route as well as macro flora in its central part.

The Upper Jurassic beds to the north border on Upper Cretaceous brown and green marl, sandy marl, marly limestone and grey and red platy limestone with intrusions of breccia. To the south they border on Plioquaternary brown clay sediments. North of Prečna we find a minor area of upper Triassic stratified and un-stratified grey dolomite.

According to a geo-tectonic survey map (Pleničar & Premru 1977) the area of the motorway section lies on the Novo mesto block. Its northern part is a transition between the Sava folds and the Dolenjsko-Notranjska block. The oldest rock here is Middle and Upper Triassic dolomite over which Jurassic limestone had been discordantly deposited and over Cretaceous pelagic rock. The characteristics of the terrain are synclines and anticlines running in the Dinaric direction, which at places diverge from their characteristic orientation.

The Jurassic beds in the Novo mesto surroundings are generally composed of light grey limestone that lies on Cordevol Upper Triassic dolomite and forms the base for their discordantly deposited Upper Cretaceous pelagic sediments (Pleničar & Premru 1977).

The Lower Malm rocks are strongly varied along the motorway section north of Novo mesto (Pleničar *et al.*, 1976). In the northern biostratigraphic zone and southern biostratigraphic zone we find alternating white and grey limestone, oolitic limestone, reef limestone with hydrozoans and bedded limestone with chert.

The northern biostratigraphic zone can in a broader sense be found on the motorway section between Poljane and Mali Slatnik, east of Novo mesto (Pleničar & Premru 1977), which mostly runs north-east of this motorway section. Here light-grey, un-stratified reef limestone and large-grained reef breccia are predominant. Here and there we can find dark grey and almost un-stratified limestone between these beds. Rich hydrozoan fauna can be found in the un-stratified limestone. Occasionally we also found platy limestone with chert.

Along the south-eastern parts we are most probably following a middle biostratigraphic zone, which is lithologically similar to the northern biostratigraphic zone; hydrozoans are not as present in the rock. Oolitic limestone can also be found in the reef limestone (Pleničar & Premru 1977). Corals appear in some places. According to the geological map and it's commentary (Pleničar *et al.*, 1976; Pleničar & Premru 1977), southern biostratigraphic rock characterised by grey, dense and oolitic bedded limestone, does not exist along the route.

In the Plioquaternary sediments southwest of Mačkovec we find an outcrop of bentonite clay. The clay lies in the pockets of Triassic dolomite and in the Jurassic limestone. At places it is deposited in beds of a total thickness of up to 12 m.

KARREN SURFACE

Most of the surface of the higher-lying land is karren. The bottoms of dales are covered by sediment beds. Two types of karren can be clearly distinguished. Karren in their original meaning occur in areas that are not covered by sediment, but with thin layer of soil. They cover the major part of the surface. The carbonate rock is dissected along the cracks, and on the rock we can detect the traces of its former a) subsoil formation (Slabe 1999; Slabe &

Knez 2004) – these are relatively few, and b) indirectly transformed by precipitation, the surface was overgrown and c) finely shaped by bio-corrosive factors. The surface was mostly forested. Such karren existed on the surface of the cone in the dale at the beginning of the motorway section.

Especially in the area of the Strmec and Dobrava hills we observed well-expressed bio-corrosive activities on numerous karren outcrops of carbonate rock (Fig. 3). The rock was more diluted by bio-corrosion on the shadier sides. Moss mostly grows there while lichen can also be found on areas exposed to the sun. Bio-corrosive processes do not take place equally on the entire surface of the rock, but selectively. Most probably lithologically slightly different clasts in crushed and then cemented rock are diluted to various depths or else there are different organisms in the various neighbouring clasts. The contact areas between the various clasts are especially corroded, in some spots up to several mm deep.

The major part of the forest-covered surface was dissected mainly by individual rocks of various sizes with partially similar traces of formation to the karren described above. They are frequently defined by funnel-shaped mouths of larger subsoil channels. The rocks reach up to one to two metres in height, with a narrowing on top and with large areas of soil between them. The earthwork uncovered them as the tips of the larger areas of stone forests.

Fig. 3: Bio-corrosively etched surface of karren.
Sl. 3: Biokorozisko razjedena površina škrapelj.

SUBSOIL STONE FORESTS

Relatively large areas of subsoil stone forests illustrate the manner and long-lasting subsoil formation of this part of the karst surface, covered by fine-grained sediment and soil. The stone pillars are completely covered by the sediment and soil, or their tips protruding on the surface.

The configuration of the surface includes smaller or larger dolinas (Fig. 4). The largest have a diameter of several tens of metres. Some are filled with grey clay, the origins of which we are still investigating. Both are dissected by subsoil stone forests.

The subsoil stone forests are composed of a dense network of more or less thickset and pointed pillars, which reach up to 8, sometimes even 10 metres, although most are lower. The narrower pillars with a diameter of one to two metres have sharp or rounded spire (Fig. 5), while the thickest ones reaching up to ten metres (Fig. 6)

Fig. 4: Filling of dolina with gravel.
Sl. 4: Zapolnjevanje vrtače z gruščem.

Fig. 5: Pointed tops of narrower pillars.
Sl. 5: Kničasti vrhovi ožjih stebrov.

Fig. 6: Wider stone pillars.
Sl. 6: Obsežnejši podtalni stebri.

Fig. 7: Subsoil channels.
Sl. 7: Podtalni žlebovi.

in width have one or more spires or their tops are composed of more or less curved crests. Among them in most parts are funnel mouths of the perpendicular subsoil channels or horizontal subsoil channels.

Subsoil rock features predominate in the rock relief of the pillars (Slabe 1999; Slabe & Knez 2004), which indicates gravitational flow of water from the surface. These are mainly subsoil channels. The most typical are the vertical ones (Fig. 7) with diameters that can reach up to one metre, the largest of which, as we shall explain below, can also be called subsoil shafts, which at the top develop into funnel-shaped mouths. Surface water that flows from the soil along the rocks collects in them. In cross-section the funnel-shaped mouths can take various shapes. They can be open, semicircular or nearly round. Their shapes are often the result of the permeability of the rock and the sediment contact along which the water flows downwards. Long, drawn-out formations of the mouth at less permeable connections causes the rock features to erode deeper into the rock. The water found its way through the rock less frequently and veritable funnels were shaped. Smaller and curving channels are formed at less permeable connections or when minor quantities of water collect on the surface. This is characteristic for smaller pillars with tops that project out of the earth. Subsoil scallops are rare and generally indicate a well-permeable rock connection with the sediment that surrounds it, and moreover, we find elongated notches on the pillar walls, which are traces of water accumulation at the less permeable part of the connection and accelerated corrosion of the rock next to it.

Close below the surface where the rock is covered with soil the rock surface of the stone pillars is relatively smooth, while deeper, at the connection with the sediment that covers the surface, it is coarse and often has a configuration of rounded pendants. The rock there is weathered. The thickness of the weathered layer measures up to 1 cm. It is soft when moist, but as it dries out after being exposed on the surface for a longer period and the water evaporates from it, it hardens. The state of weathering of the top layer of the rock is the result of the connection with the sediment, which is moist most of the time. The connection is relatively less permeable, and the water that does permeate it only slowly washes the solution. The connection with more permeable soil is correspondingly also more permeable.

KARST HOLLOWS

Uncovered hollows are generally the result of vertical water percolation through the epi-karst and the vadose parts of the aquifer. The shafts can be classified as hollow and those filled with sediment. The latter are termed subsoil due to the similarity of their features with subsoil rock, mainly with vertical subsoil channels.

The fifteen shafts (Fig. 8), vertical and mostly simple with only one in level, the deepest measuring 24 m, three others deeper than 10 m, while the rest were less deep, with diameters reaching up to 5 metres, but in most cases less, indicate here and there, greater permeability, allowing dense vertical water percolation due to

Fig. 8: Discovering of shaft.
Sl. 8: Odkrivanje brezna.

their expressed vertical cracks and vertical rock strata (Figs. 9, 10). The shafts occur among the subsoil karren and forests. They do not reach the surface. Their walls are carved with larger or minor vertical channels and often covered with a thin layer of sediment, which causes their thiny dissection (Slabe & Knez 2004). The floors of

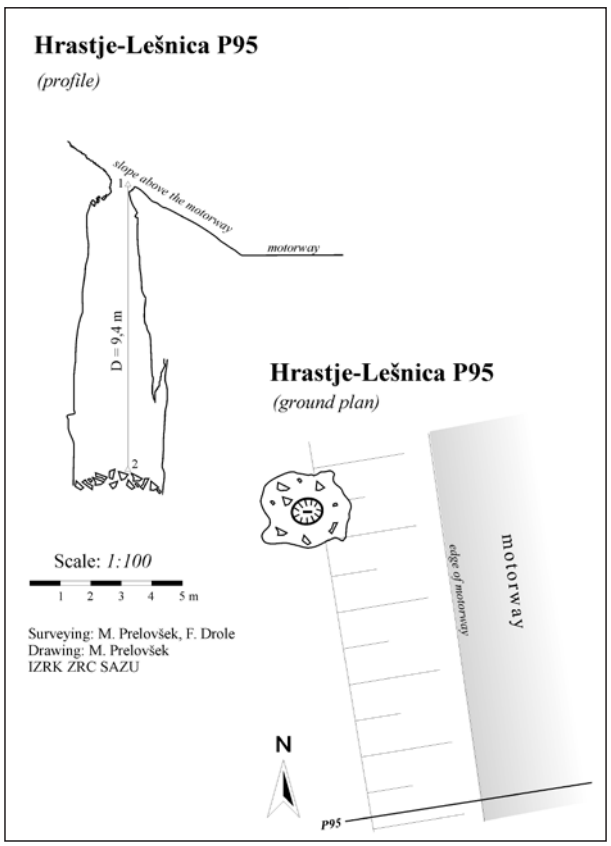

Fig. 9: Shaft on profile 95.
Sl. 9: Brezno na profile 95.

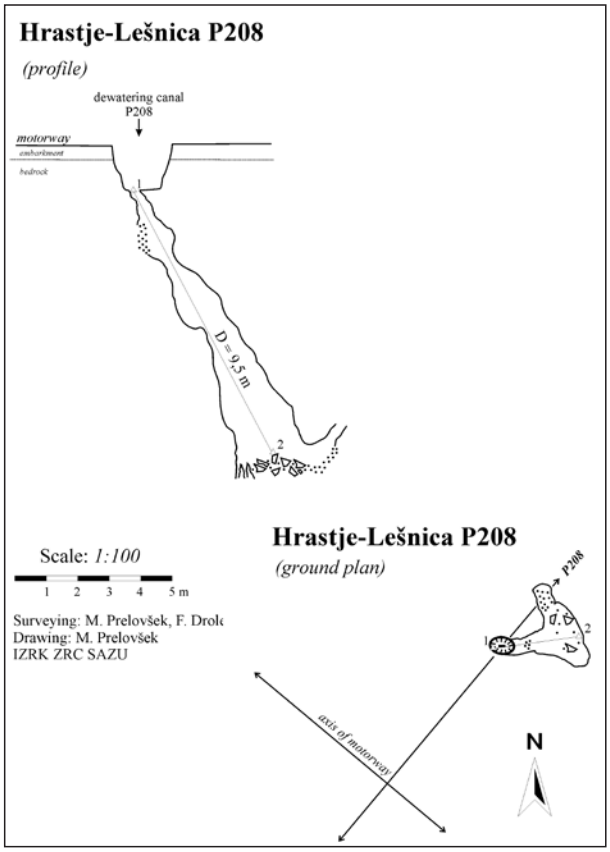

Fig. 10: Shaft on profile 208.
Sl. 10: Brezno na profilu 208.

the shafts are often covered by sediment or sediment fills their lower part.

Subsoil shafts are more or less vertical hollows, similar to ordinary shafts, through which water also percolates from the karst surface, but they are almost entirely filled with sediment, with only individual vertical sections

Fig. 11: Subsoil shaft along fault.
Sl. 11: Podtalno brezno vzdolž preloma.

hollow. The water that flows through them deposits the sediment that covers the surface. Their cross-sections are more or less round or extended at the cracks and bedding planes. Their diameters reach two metres. Sediment filling facilitates the shaping of their periphery, and notches appear at less permeable connections. Subsoil shafts are formed at local dense flow of larger quantities of water. They can develop from subsoil channels. Their walls are carved with along-sediment rock features, which are the traces of formation at the connection with fine-grained sediment. With greater permeability in the karst interior, the subsoil shafts can be emptied.

Above-sediment channels often occur on horizontal bedding planes and in cracks, or networks of anastomoses, the traces of paragenetic stratification. Thus, temporarily flooded areas occur locally and the water, which carries fine-grained sediment and deposits, cuts its way upwards.

CONCLUSION

More and more, the unique natural heritage and development of the Dolenjska karst reveal themselves. The importance of the participation of karst researchers in planning major activities in the environment and monitoring the work has been demonstrated once again. Cooperation with the road constructors has set an excellent example for many years.

This time we were given the opportunity to follow the water precipitating into the epi-karst and the upper part of the vadose zone, which were shaped under a relatively thick cover of sediment and soil and where stone forests, shafts and subsoil shafts have been formed over large areas.

The scarcity of stone forests and special geomorphological karst features characteristic of this part of the karst (Knez *et al*., 2003) demand that we prepare guidelines for further planning of activities in the karst landscape.

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GLACIAL DESTRUCTION OF CAVE SYSTEMS IN HIGH MOUNTAINS, WITH A SPECIAL REFERENCE TO THE ALADAGLAR MASSIF, CENTRAL TAURUS, TURKEY

LEDENIŠKO UNIČENJE VISOKOGORSKIH JAMSKIH SISTEMOV: PRIMER MASIVA ALADAGLAR, CENTRALNI TAURUS, TURČIJA

Aleksander KLIMCHOUK[1], Serdar BAYARI[2], Lütfi NAZIK[3] & Koray TÖRK[3]

Abstract UDC 551.331:551.44(560)

Aleksander Klimchouk, Serdar Bayari, Lütfi Nazik & Koray Törk: Glacial destruction of cave systems in high mountains, with a special reference to the Aladaglar massif, Central Taurus, Turkey

Erasure of karst features and dissection of karst are among the main destructive effects of glacial action upon karst (Ford, 1983). They lead to destruction of functional relationship between the relief and a karst system, and to glacial dissection of pre-glacial cave systems. Stripping of the epikarstic zone and upper parts of cave systems on sub-horizontal surfaces results in prevalence of *decapitated shafts* in high mountains affected by glaciations. Vertical dissection of a karst massif by glacial erosion creates cave openings in sub-vertical surfaces (cliffs), a well known feature. Observations of vertical shafts exposed by cliffs are less common. Such shafts, unwalled by surface geomorphic processes, are in a certain way an analogous to the "unroofed" caves, exposed by denudational lowering of sub-horizontal surfaces. The Aladaglar Massif (Central Taurus, Turkey) is an outstanding example of high mountain karst. The high-altitude part of the massif has been severely glaciated during Quaternary. Glacial erosion was the dominant factor in the overall surface morphology development, resulting in the formation of numerous glacial valleys, cirques, ridges and pyramidal (horn) peaks. The overall relief between the highest peaks and the lowest karst springs in Aladaglar is 3350 m. The local vertical magnitude of relief between bottoms of glacial valleys and surrounding ridges is up to 1700 m. Recent studies suggest that the most recent major glaciation occurred in the Aladaglar massif during the Holocene Cooling and terminated between 9,300 and 8,300 years BP. This paper describes *unwalled shafts* at subvertical surfaces, a feature which is common in Aladaglar but is not so common, or overlooked, in other high mountain areas. Exposure of such shafts is mainly due to intense gravitational processes induced by the combined effect of the removal of the ice support to cliffs and the glacial rebound.

Keywords: glaciations, karst, denuded caves, unwalled shafts, Aladaglar, Central Taurus, Turkey.

Izvleček UDK UDK 551.331:551.44(560)

Aleksander Klimchouk, Serdar Bayari, Lütfi Nazik & Koray Törk: Ledeniško uničenje visokogorskih jamskih sistemov: primer masiva Aladaglar, Centralni Taurus, Turčija

Erozija kraških površinskih oblik in zarezovanje v kras so najbolj uničujoče posledice ledeniškega delovanja na krasu (Ford, 1983). Rezultat je prekinjena funkcijska povezava med reljefom in kraškim sistemom ter razrez predglacialnih jamskih sistemov. Na površinah z majhnim naklonom, ledeniško delovanje prizadene predvsem epikras in vrhnje dele jamskih sistemov. Na takih površinah najdemo veliko brezen, ki jim je ledeniška erozija odstranila vrhnje dele (t.i. obglavljena brezna). Zaradi vertikalnega vrezovanja v kras, se v stenah masivov odpirajo jamski vhodi, redkeje pa naletimo na vzdolžno prerezana, izpostavljena brezna. Taka, »brezstenska« brezna, so na nek način analogija brezstropih jam, ki so nastale kot posledica denudacije sub-horizontalnih površin.

Masiv Aladaglar (Centralni Taurus, Turčija) je izreden primer visokogorskega krasa. Višji deli masiva to bili tekom kvartarja močno poledeneli, zato tam prevladuje tipična ledeniška morfologija v vseh pojavnih oblikah. Višinska razlika med najvišjimi vrhovi Aladaglarja in najnižjimi kraškimi izviri je 3350 metrov, lokalni vertikalni razpon med ledeniškimi dolinami in okoliškimi grebeni doseže 1700 m. Novejše raziskave kažejo, da je bila zadnja velika poledenitev v Aladaglarju med holocensko ohladitvijo, ki je trajala med 9300 do 8300 leti pred današnjostjo. V članku obravnavamo »brezstenska brezna«, ki so v stenah Aladaglarja pogosta. Takih brezen je v drugih visokogorskih masivih malo, ali pa so bila prezrta. Razkritje brezen je delo gravitacijskih procesov ob umiku ledenikov.

Ključne besede: poledenitev, kras, denudirane jame, brezstenska brezna, Aladaglar, Centralni Taurus, Turčija.

[1] Ukrainian Institute of Speleology and Karstology, Ministry of Education and Science, NASU, Ukraine; klim@speleogenesis.info
[2] Hydrogeological Engineering Section of Hacettepe University, Turkey; e-mail: serdar@geo.hacettepe.edu.tr
[3] General Directorate of Mineral Research and Exploration, Turkey

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INTRODUCTION

During the last decade considerable attention has been given by many researchers to so-called unroofed (denuded) caves. It was generally appreciated long ago that lowering of the karst surface due to ongoing denudation ultimately results in uncovering and destruction of caves. However, it was the work of Mihevc and his colleagues (Mihevc, 1996; Mihevc et.al., 1998) that drew specific attention to the topic. Subsequent publications by many scholars shed light on several aspects, to which the specific study of unroofed caves gave useful information. Unroofed caves were recognized as adistinctive sub-type of surface karst, a cave partially transformed by surface processes. More understanding arises about their roles in the formation of karst landscape and about the overall denudation progress in karst. Based on observations in tropical karst, Klimchouk (2005) revived the view that unroofing of caves can be a large-scale geomorphic process. The cosmogenic nuclide exposure dating (Gosse & Phillips, 2001) of rock surfaces exposed due to cave unroofing can give invaluable information on aging of unroofing events and relevant landforms – a sound possibility which is still to be tested and realized.

Most of studies of unroofed caves came from the areas of moderate to low relief karst topography, so that consequently they were focused on sub-horizontal passages that were unroofed by the sub-horizontal denudation surface. This is reflected by the very term "unroofed caves", which implies opening of sub-horizontal cave elements that had a roof. Works that investigate this topic in high mountain environment, are rare (see Mais, 1999 for an examples from Alps). In high mountains there is considerable vertical relief, which introduces more complexity into the conceptual representation and genetic consideration of the phenomena: as a consequence the term "unroofing" seems to be insufficient to describe various relations of caves with the surface.

Our recent karst and cave studies in the Aladaglar Massif, Central Taurus, Turkey, yielded a variety of instructive observations on different types of caves exposed to the surface by various geomorphological processes. In particular, this study revealed extraordinary examples of the exposure of vertical caves (shafts) by sub-vertical surfaces. In this article we present these observations, which inspired discussion of some general terminological and geomorphological aspects and gave insights to some problems of local geomorphological evolution.

GENERAL REMARKS ON TERMINOLOGY

The initial term "roofless caves" has been gradually replaced by the more correct "unroofed caves". A general definition is that unroofed caves are old caves that have been exposed due to the lowering of karst relief. This tacitly implies a sub-horizontal orientation of the lowering surface, hence – sub-horizontal caves are the most readily available for observations when truncated (unroofed) by such surface. Interestingly enough, vertical shafts cut by lowering of the sub-horizontal denudation surface are not considered as something of special interest in the context of "unroofing" as they retain the capacity of entrances to the underground space. Shafts retain their status as underground forms, and they are not going to be erased geologically as fast as sub-horizontal caves do when unroofed. Apparently, the term "unroofed caves" does not apply to vertical shafts.

Four types of shafts can be distinguished according to the mode of their exposure to the sub-horizontal surface. ***Ponor shafts*** are those developed in a direct genetic (hydrologic) relationship with the surface and still retaining this relationship, such as shafts swallowing streams formed on adjacent non-karstic rocks or catchments where dispersed infiltration is prevented by patches of a low-permeability cover. ***Epikarst shafts*** are those developed at the bottom of the epikarstic zone as epikarst-draining paths, and opened to the surface due to its gradual lowering and collapse (Klimchouk, 2004). ***Collapse shafts*** are those formed by collapsing of large underground rooms. ***Decapitated shafts*** are those exposed due to erasure of the upper part of a massif by some high energy agency, commonly by glacial stripping. The latter category is pertinent to the subject of this article.

In the high mountain karst steep to vertical surfaces such as cirque headwalls are common. They can be hundreds of meters in height, and sometimes more than 1500 m. Interception of sub-horizontal passages by sub-vertical surfaces creates open cave entrances, a common phenomenon. This article focuses on vertical shafts opened by such sub-vertical surfaces, a less known phenomenon. Their nature within the topography can differ because they can be created by fluvial incision or glacial erosion and/or gravity (rock detachment, fall and slide).

In general terms we are considering the intersection of 3D daylight surfaces with 3D systems of underground

caves. The daylight surface is polygenetic, and its intersection with a polygenetic 3D cave system will be guided by a number of geomorphic agents, as well as by the topology of both systems. The Table 1 clarifies the terminology for intersection features based on simple geometric considerations.

Tab. 1: Features resulting from intersection of the daylight surface and a 3D cave system

Components of a 3D cave system	**Geomorphic agencies dominating in creation of differently oriented surfaces that open caves in high mountains**	
	Sub-vertical faces	**Sub-horizontal surfaces**
	fluvial incision, glacial erosion, gravitational destruction (rock detachment and slide)	denudation due to dissolution, weathering mass wasting and areal erosion, glacial erosion by icecaps and at the bottoms of glaciers
Sub-horizontal cave elements (passages)	cave openings (entrances)	unroofed caves
Sub-vertical cave elements (shafts)	unwalled shafts	shaft openings (entrances)

Inclined cave components and inclined surfaces can produce a variety of features at their intersection. However, they can be assigned to one of the basic categories distinguished in the table and do not need specific terms. Cave and shaft openings (entrances) do not imply destruction of respective underground forms themselves. Unroofed caves and unwalled shafts are the two major types of disintegrating cavities, which can be collectively referred to as *denuded (or exposed)* caves.

The term "cave ruins" is also used to describe various kinds and states of cave disintegration (Mais, 1999). It could be used to describe fields of closely spaced disintegrating underground forms, when individual unroofed passages are barely recognizable.

THE ALADAGLAR KARST

Aladaglar is an outstanding karst massif located in the Central Taurus Range in the Adana-Kayseri-Niğde provinces of Turkey. It is situated between the regional Ecemis Fault to the west and the deeply incised Zamanti River valley to the east (Figs 1 and 2). The southeastern part of Turkey is an active plate boundary where the Arabian and the Eurasian plates are colliding along the Bitlis-Zagros suture. This determined the intensity of neotectonic processes and uplift since Late Oligocene, with the highest rates occurring in the Plio-Pleistocene. The Aladaglar Massif is composed chiefly by Triassic, Jurassic and Cretaceous limestones and rises up to 3750 m in elevation. The overall relief between the highest peaks and the lowest karst springs is 3350 m. The altitudinal distribution of the principal components of the surface geomorphology and the major known cave system is illustrated in Fig. 3.

The Zamanti River valley provides the general base level of erosion, towards which the karstic underground drainage is directed. The overall morphology is well illustrated by digital elevation models produced from the "Aladaglar Karst" GIS database developed during this study (Fig. 2). Morphologically, the northern (Black Aladag), central and southern (White Aladag) sectors can be distinguished, with the local relief increasing from north to south.

The high-altitude parts of the Aladaglar massif have been severely glaciated during Quaternary. Aladaglar belongs to the Pyrennean type of glacial landscape, i.e. glaciers there were confined to high areas but not occupied lower valleys where the outputs of a karst system occurred (Ford & Williams, 1989). Glacial erosion was the dominant factor in the overall surface morphology development, resulting in the formation of numerous glacial trough valleys, cirques, arêtes (narrow jagged ridges) and horn (or pyramidal) peaks. Our recent studies suggested that the magnitude and extension of Quaternary glaciations in Aladaglar was greater than previously thought (Bayari et. al, 2003; Zreda *et al*., 2005). Although the glacial landforms indicate there have been numerous episodes of glacial advance and retreat, evidences of the older glaciations are largely erased by the effects of the last, remarkably extensive, glaciation. Cosmogenic ^{36}Cl dating of morainic boulders in the Hacer Valley suggests that it terminated between 9,300 and 8,300 years BP there.

Glacial geomorphic processes acting on the karstified limestone substratum gave rise to the distinct pecu-

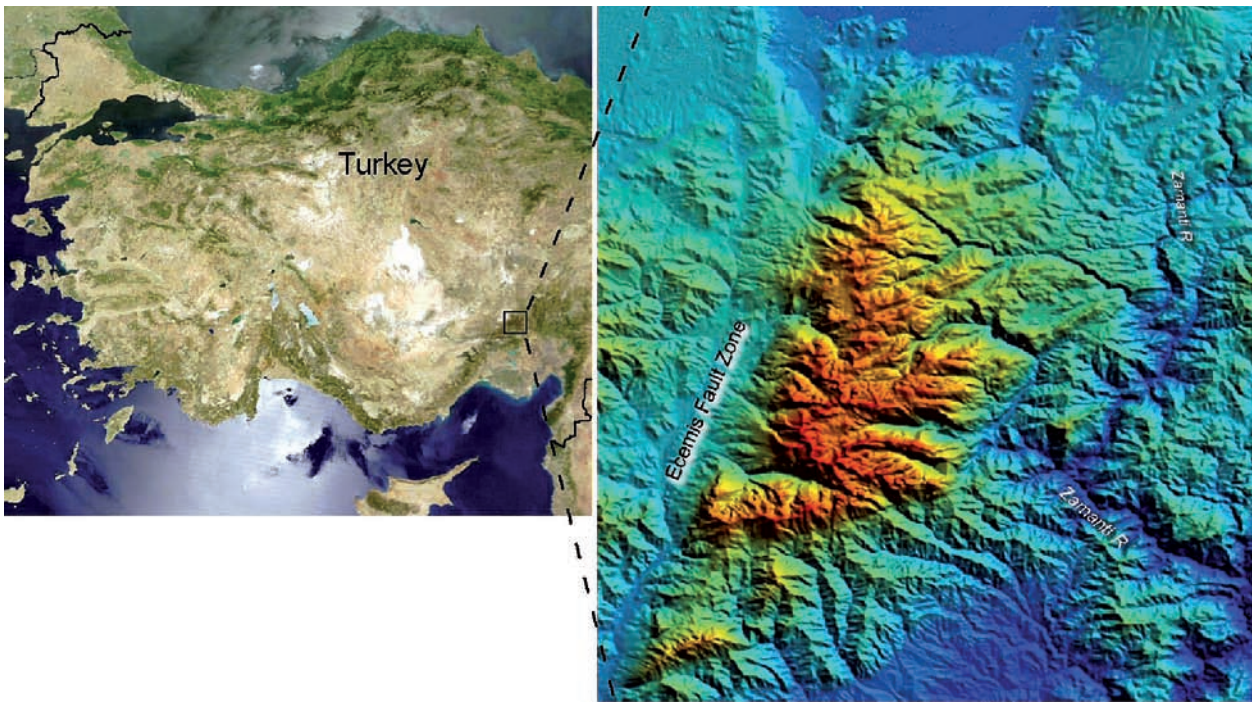

Fig. 1: Location of the Aladaglar massif (left) and its overview digital elevation model.

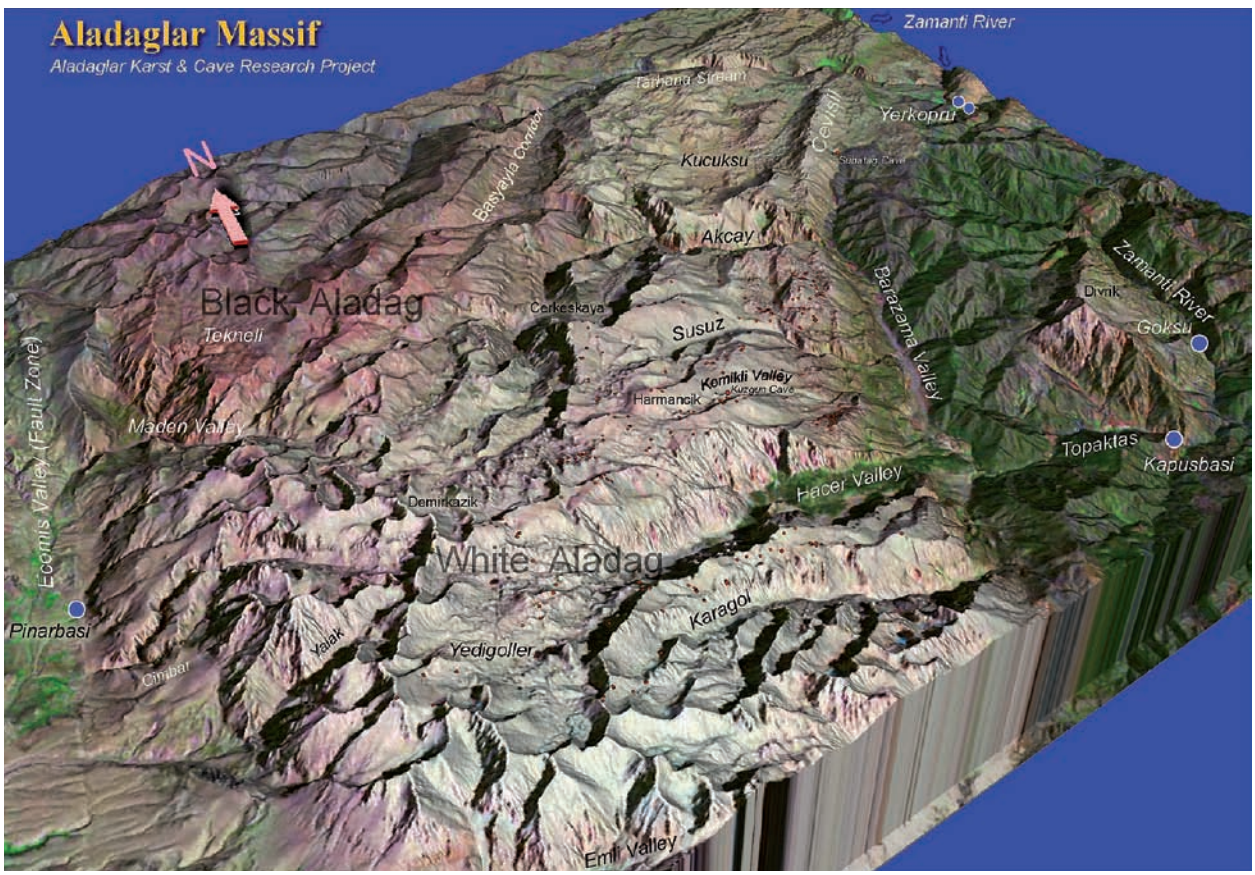

Fig. 2: Physiography of the Aladaglar Massif. The DEM is based on the 1:25,000 topographic map, overlain by a Landsat satellite image and data layers from the GIS "Aladaglar Karst and Caves". Distribution of explored caves is shown by small red dots and major springs are indicated by blue dots.

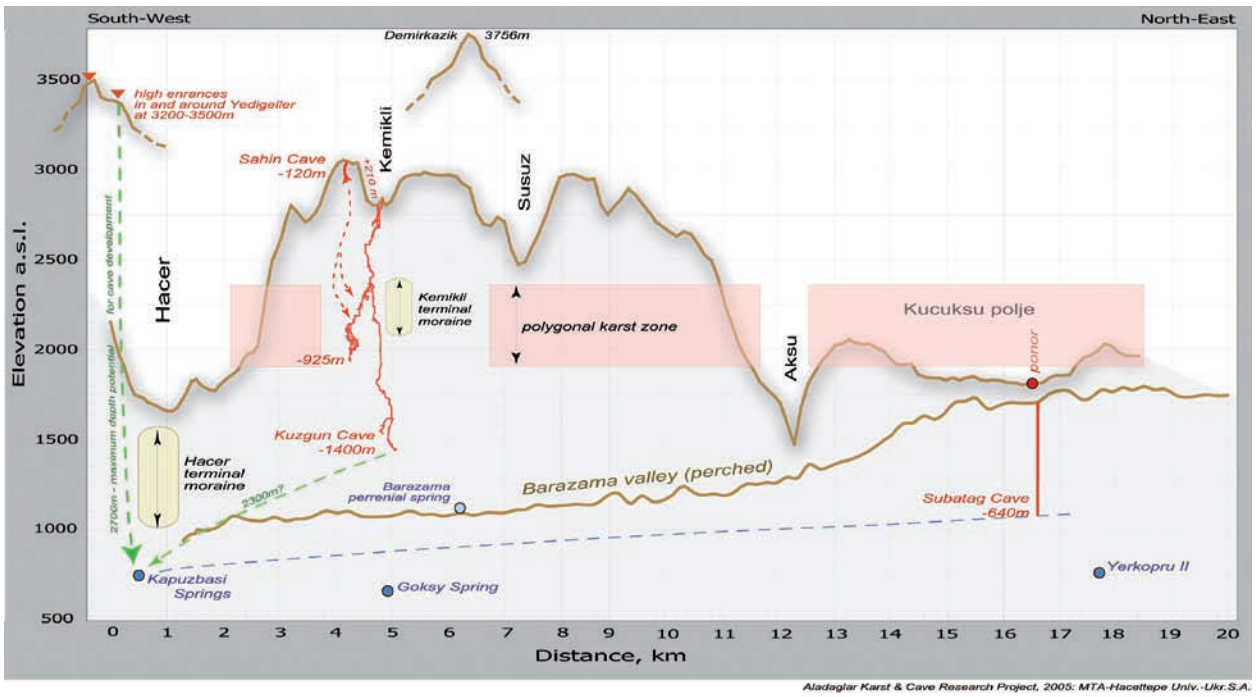

Fig. 3: Altitudinal distribution of principal denudation and erosion levels, springs and caves in the Aladaglar Massif, Central Taurus, Turkey. A composite profile SW-NE, sub-parallel to the Barazama Valley.

liar features known as glaciokarstic morphology. However, in local areas of moderate relief (glacial source areas and valley bottoms) recent glacial scouring of prominent mesoforms on the one hand, and filling of negative mesoforms by weathering (frost shatter) debris on the other hand, makes appearance of karstified surfaces generally smoother that it can be typically seen in lower-altitude Alpine karst massifs (Fig. 4).

Glacial valleys created during the Quaternary glaciations were entrenched into an already intensely karstified massif. Smaller glacial valleys extend from source areas at 3100-3300 m down to altitudes of about 1900-2300 m, while some large valleys (such as Hacer) incised as low as 1100 m asl. The local altitudinal ranges between ridges and

Fig. 4: Characteristic high altitude glaciokarstic landscape in Aladaglar. Glacial scouring in the recent past has made appearance of karstified surfaces generally smoother than can be typically seen in lower-altitude Alpine karst massifs, where the last glaciation terminated earlier. A = Yedigoller Plateau, a paleo-source area for the Hacer valley glacier at the altitudes of 3100-3400 m; B = Harmancik Plateau, a paleo-source area for the Kemikli valley glacier at the altitudes of 3100-3200 m. Photos by E. Medvedeva (A) and A. Kopchinsky (B).

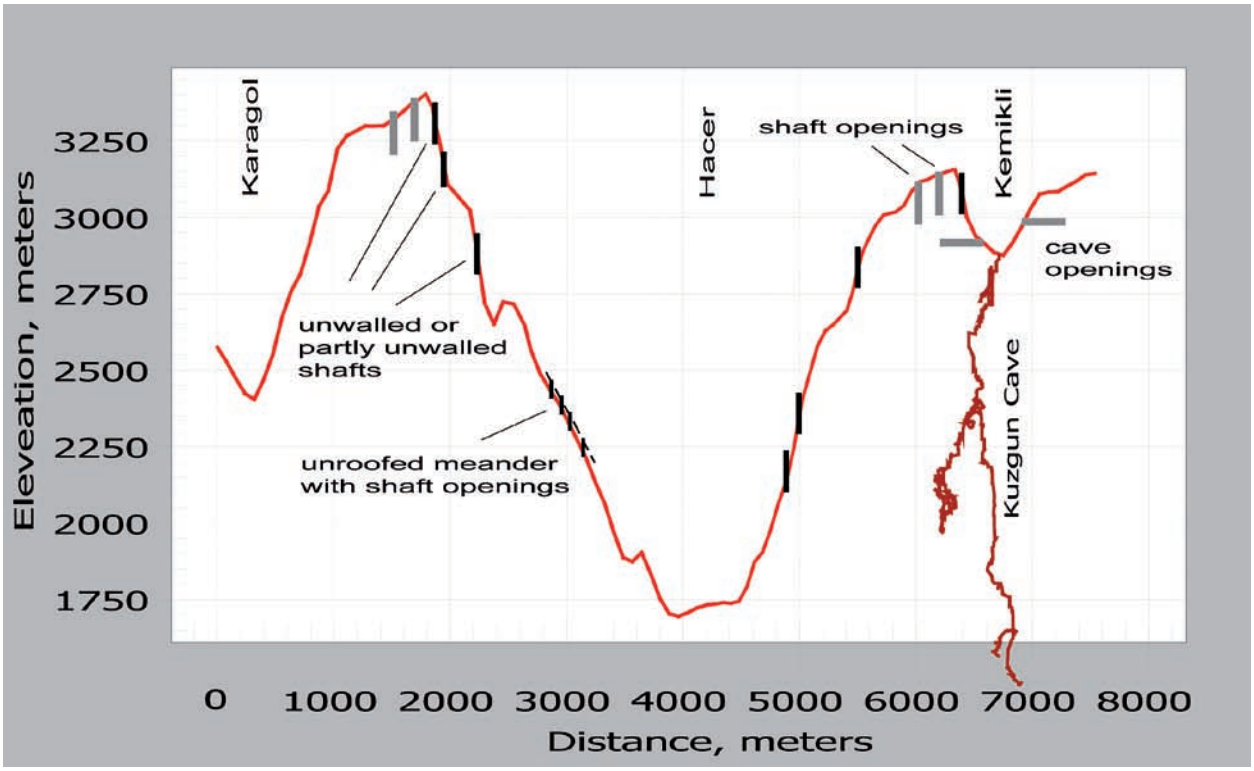

Fig. 5: Section across the Karagol, Hacer and Kemikli valleys, showing local elevation differences and the typical occurrence of caves and shafts intersected by variably oriented surfaces.

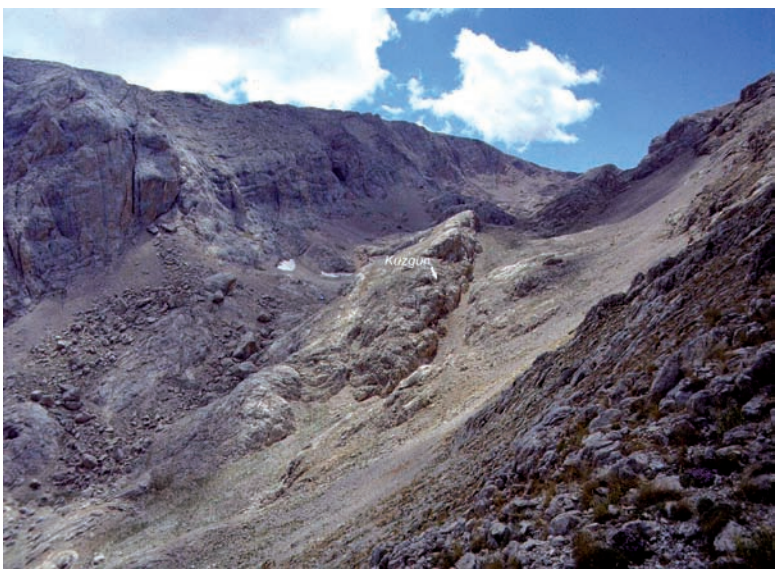

Fig. 6: Kemikli glacial valley. Note an unwalled shaft in the cliff on the left and a train of boulders on the scree apron and glacially stripped bedrock at the foot of the cliff. Photo by A.Klimchouk.

valley bottoms can be as great as 1700 m in large valleys, although in smaller valleys they are only of 200-700 m (Fig. 5 and 6). The steep valleys, with their many sub-vertical faces, are subject to intense gravitational processes.

The freshly glaciated rocky surfaces have many different orientations and thus expose numerous pre-glacial cavities (in the sense that they are older than at least the last major glaciation), creating all types of intersections outlined in Table 1: shaft openings and unroofed caves on sub-horizontal surfaces and cave openings and unwalled shafts on sub-vertical surfaces.

DECAPITATED SHAFTS

During 2001-2004 over 150 caves were explored in the Aladaglar Massif. They were mainly vertical, with an aggregate total depth of 6640 m. Of them 32 caves are deeper than 50 m, and 12 caves are in excess of 100 m. Fifty-seven caves are located above 3000m, the highest explored example being at 3410 m.

The great majority of shafts explored in the high karst zone are decapitated shafts that had been exposed due to erasure of the upper part of the massif by glacial stripping. Erasure of karst features by mechanical abrasion of bedrock at the base of ice is a known effect of glaciations on karst (Ford, 1983). Abundant evidence in Aladaglar suggests that this effect can be greater than was previously thought. Our observations suggest that the bedrock thicknesses up to several tens of meters, including the entire epikarstic zone and large dolines, can be stripped away by the glacier action.

Shafts entrances in valley bottoms and other low areas are blocked and obscured by debris, the result both of plugging by debris during glaciations and intense post-glacial physical weathering. Most shaft entrances that remain open are found at the crests of ridges or topographic eminences within valleys, such as roche mountonnées, – those places which were sites of intense glacial scour but have limited or no contemporary catchments to supply frost debris (Fig. 6). The smoothed tops of some ridges at altitudes of 3100-3300 m, along with the presence of polished surfaces and decapitated shafts, suggest that an icecap of some considerable thickness may have covered these ridges during the recent glaciation.

When decapitating shaft openings, glacial erosion stripped the upper portion of the rock together with the epikarstic zone and some upper sections of pre-glacial cave systems. Discovery of a decapitated shaft entrance on the surface and likenhood of finding an explorable cave beneath it depend on which particular component of a cave system was intersected and how the opening is situated in the relief (Fig. 7). If a large internal pit of

Fig. 7: Shafts decapitated by glacial erosion. Left panel – Aladaglar, right panel – Crowsnest Pass, Rocky Mountains, Canada. Photos by A. Klimchouk.

substantial diameter got exposed, it had little chance of remaining unplugged by frost shatter debris from weathering in the shaft mouth catchment. Hence, most shafts of this type are simple single pits blocked at the bottom. Some large shafts located in the tops of ridges are blocked with ice, which contains numerous bands of frost debris within it (e.g. there is about 100m in the Ice Cave). Complex and deep caves are commonly those which got exposed by stripping at the level of a narrow meander passage that continues to a next vertical pit.

UNWALLED SHAFTS

In the steep to vertical slopes of the Aladaglar glacial valleys, many unwalled or partially unwalled shafts are clearly displayed. We illustrate this with examples from the particularly deep Hacer glacial valley (Figs 8 and 9) and an example from the smaller and shallower Kemikli valley (Fig. 10).

Fig. 10 shows an unwalled shaft in the southern cliff of the Kemikli valley. Two other shafts, partly unwalled in the upper parts, are seen in the right background. The presence of a pile of boulders beneath this cluster of unwalled shafts (some of them with fragments of shaft solution morphology) indicates that the unwalling occurred as a rockfall, and that this event post-dated the last glaciation. See also Fig. 6, where a fall of boulder-sized blocks is well seen on the left, scattered on the scree apron at the foot of the cliff and on the glacially scoured rock surface below it. If the shaft unwalling had occurred before or during the last glaciation, boulders would have been be removed by the glacier.

Fig. 8: Exposed caves in the southern side (northern face) of the Hacer glacial valley. The vertical extent of the cliffs in the photographs is approx. 1000 m. Numbers indicate samples of: 1 = unwalled shafts, 2 = partly unwalled shafts, 3 = unroofed meanders with shaft openings. Many similar features, recognisable on photos, are not indicated in order to avoid clutter.

Fig. 8 shows the southern side of the central sector of the Hacer valley, where it has the maximum cross-sectional vertical extent of about 1700 m. Individual unwalled shafts more than 100 m in the vertical extent can be seen. Some shafts are partly unwalled, while others are open only at the upper or lower ends within inclined and hanging faces. On inclined faces some unroofed meandering passages, interspersed with shafts, can be traced for hundreds of meters.

Fig. 9 shows the cliff face in the upper Hacer valley, where there is a cave that is almost parallel to the external face. The wall that separates the shaft from the cliff is only a few to 20 m thick. It is apparent that this cave will become unwalled in the near geological future.

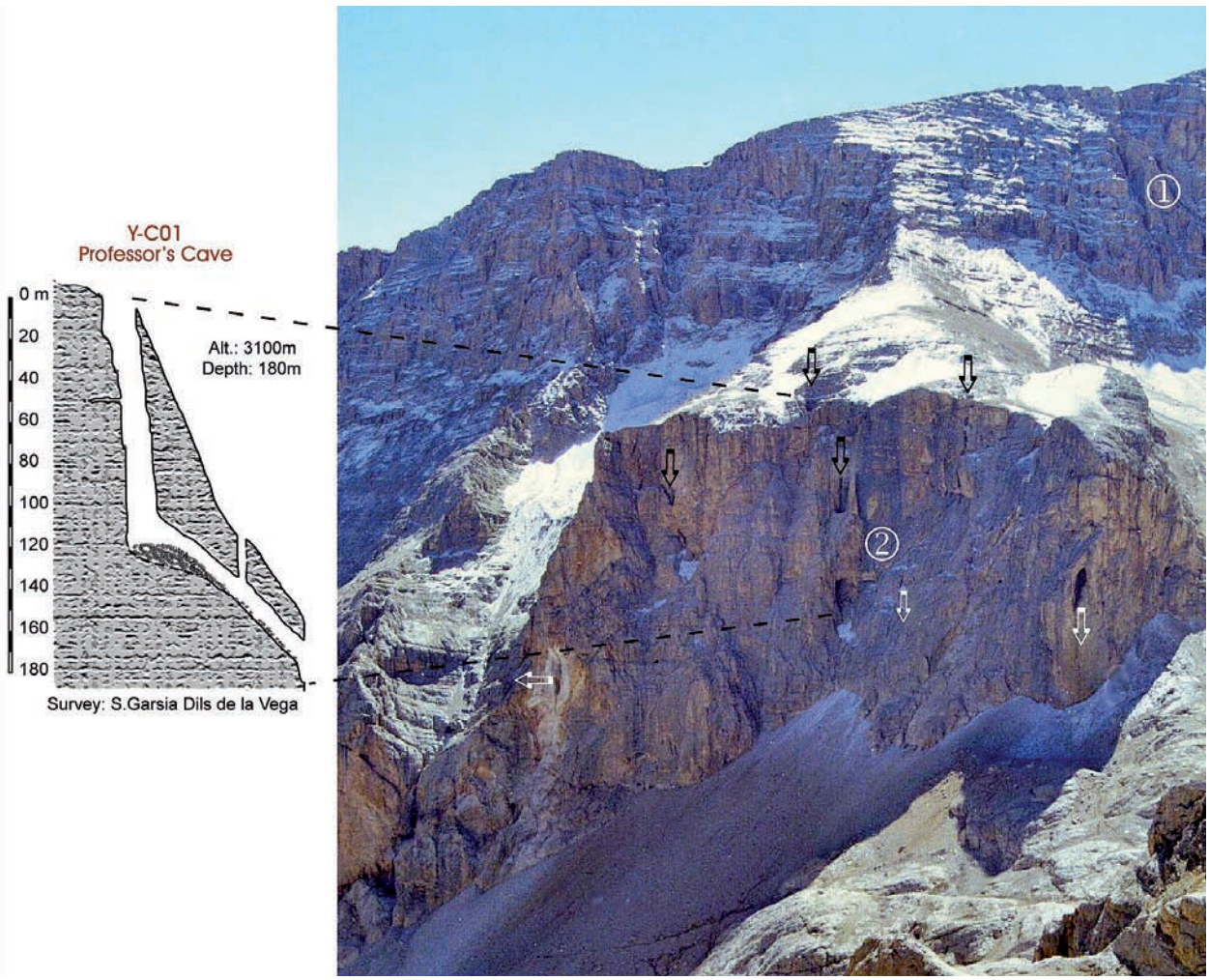

Fig. 9: Right: Exposed caves in the rock cliff in the upper part of Hacer glacial valley (northern facing). Numbers indicate: 1 = unwalled shafts, 2 = partly unwalled shafts. Black vertical arrows point to shaft openings, white vertical arrows indicate lower (downward-open) shaft outlets, a horizontal arrow indicates a cave opening. Left: The profile of the Professor's Cave, with the shaft entrance located some 10 m far from the drop and the lower outlet opened to the cliff. The wall between the shaft and the vertical rock face is 3-20 m wide.

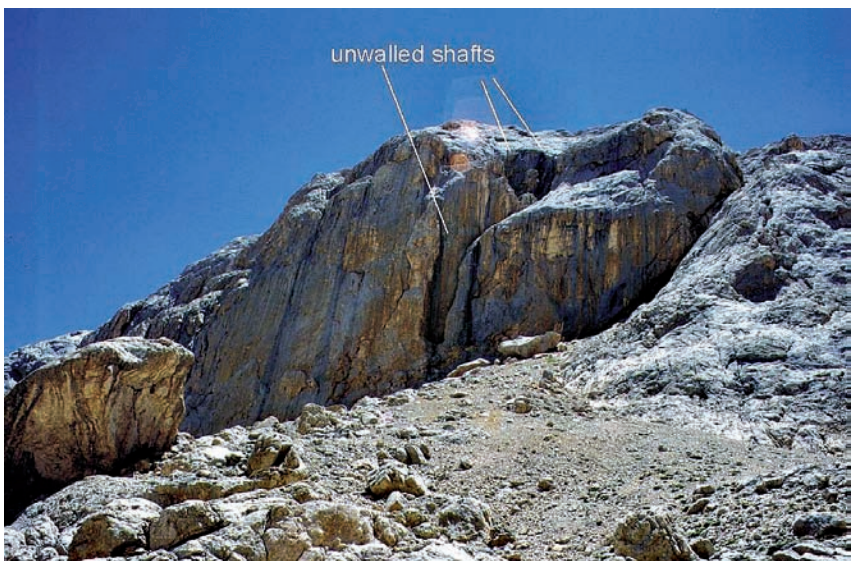

Fig. 10: Unwalled shafts in the Kemikli valley. Photo by A. Klimchouk.

DISCUSSION AND CONCLUSION

The creation of a considerable vertical component during the development of relief in highly energetic Mountain settings leads to the vertical dissection of previously formed cave systems. It is an important part of the cave disintegration process. Cave (passage) openings in sub-vertical surfaces (the holes-in-the-wall) are common and well-known features. Shafts unwalled in sub-vertical surfaces are the less acknowledged phenomena, but they are common and easily recognisable in the Aladaglar massif.

Although fluvial entrenchment can create very steep surfaces on valley sides, it usually cannot directly erode away any intercepted shafts to make them unwalled. Unless the stream is very large, it will be captured and channeled down the shaft, rather than dissecting it. Instead, by creating a steep relief, fluvial erosion may induce gravitational rock falls and slides, which then can expose the shafts, unwalling them on sub-vertical surfaces. More commonly, however, fluvial downcutting exposes cave openings by intersecting passages that are sub-horizontal.

Direct glacial erosion, applied to those parts of valley slopes that were in contact with ice, can be the shaft-unwalling agency. However, in Aladaglar unwalled shafts are also found on the higher sections of slopes that apparently were not in a direct contact with valley glaciers that produce the most of the lateral erosion (i.e. they are above the glacial trimlines). Gravitational processes, chiefly rock falls and slides, thus are the dominant processes in shaft unwalling.

Glacial erosion results in destabilization of sub-vertical slopes due to both additional downcutting and lateral undercutting in valleys. Both the glacial erosion and the glacial load cause considerable rearrangement of the strain field. When the ice recedes its support of the cliff face is removed. Glacial rebound and stress release after the ice removal further contribute to the cliff destabilization. As a result, a cliff may experience one major topple, fall or slide as a consequence of a particular glaciation. Those shafts that turned to be near sub-vertical external faces, were readily unwalled soon after the last glaciation. Subsequently there may be further falls, etc. but they are usually much lesser in scale.

Although the mechanism of the shaft unwalling is quite obvious, it remains unclear why unwalled shafts are more abundant in Aladaglar, as compared to most of Alpine karst massifs and many other formerly glaciated mountain karsts. One of the reasons could be the difference in the rates of the surface processes in different climatic settings and at different altitudes (2800-3700 m in Aladaglar versus 1800-2700 m in most of the typical Apline karsts). Unwalled shafts are not long-living surface features. Most likely, their morphology gets reworked fast by denudation agencies, giving rise to various kinds of grooves and small gorges in steep to sub-vertical slopes. Therefore, the difference in the amount of time since the ice receded in various regions could be another reason. The relatively large number of unwalled shafts in Aladaglar can probably be explained by the combination of both these reasons: very recent end of the last glaciation (Early Holocene) and slower rates of remodelling of the face morphologies since that due to the high altitudes. Other massifs of the comparable height and climate conditions may simply have a lower degree of pre-glacial karstification. And, eventually, the differences in the uplift rates between regions may also play a role.

Abundance of decapitated and unwalled shafts in Aladaglar clearly suggests that extensive and deep cave systems were already well developed there before major glaciations commenced.

The most pronounced and immense effect of mountain glaciations on karst is the destruction of functional relationship between the relief and the karst system and glacial dissection of the karst system (Ford, 1983). This is affected through erasure of the epikarstic zone and upper parts of cave systems on sub-horizontal surfaces (decapitation of shafts) and vertical dissection of cave systems by overdeepened valleys (unwalling of shafts).

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ELECTRON SPIN RESONANCE (ESR) DATING IN KARST ENVIRONMENTS

DOLOČANJE STAROSTI V KRASU S POMOČJO ELEKTRONSKE SPINSKE RESONANCE (ESR)

Bonnie A. B. BLACKWELL[1]

Abstract UDC 543.4:551.44, 902.035:551.44

Bonnie A. B. Blackwell: Electron Spin Resonance (ESR) Dating in Karst Environments

Electron spin resonance (ESR) dating has been developed for many materials, including hydroxyapatite in enamel, bone, and some fish scales, aragonite and calcite in travertine, molluscs, and calcrete, and quartz from ash, which have many potential applications in karst settings. Although the complexity of the signals in some materials has hampered routine application, research is solving these problems to make the method even more widely applicable. When tested against other dating techniques, age agreement has usually been excellent. Generally, the most reliable applications seem to be tooth enamel, some mollusc species, calcite deposits, and quartz minerals. ESR dating uses signals resulting from trapped charges created by radiation in crystalline solids. Ages are calculated by comparing the accumulated dose in the dating sample with the internal and external radiation dose rates produced by natural radiation in and around the sample. For fossils and authigenic minerals, no zeroing is necessary to obtain accurate ages. In sediment which contains reworked mineral clasts, ESR can be used to date the age of the mineral grain itself if it was not zeroed during erosion. For dating the sedimentation age, however, ESR signals must have been zeroed in order to give the correct age. High pressure, heating, and in some minerals, light exposure and grinding can zero an ESR signal, but some like hydroxyapatite have very high stability at surface temperatures. For materials that absorb uranium (U) during their burial history, such as teeth, bones, or mollusc shells, the age calculation considers their U uptake by cross calibrating with U series or U/Pb dating or by assuming different uptake models. Some difficulties in calculating the external dose rate can be overcome by applying the ESR isochron method, in which the sample acts as its own dosimeter. In open-air karst environments, changes in

Izvleček UDK 543.4:551.44, 902.035:551.44

Bonnie A. B. Blackwell: Določanje starosti v krasu s pomočjo elektronske spinske resonance (ESR)

Metoda ugotavljanja starosti s pomočjo elektronske spinske resonance (ESR), je bila razvita za najrazličnejše gradivo in snovi, vključno hidroksiapatit, emajl, kost, ribjo lusko, aragonit in kalcit v lehnjaku, školjčnih lupinah in kalcitnih skorjah, kremen v pepelu, kar vse nudi široke možnosti za uporabo v kraškem okolju. Čeprav pestrost signalov v nekaterem gradivu ovira vsestransko uporabnost, raziskave rešujejo te težavein tako je ta metoda še bolj vsestransko uporabna. Ob primerjanju z drugimi tehnikami datacije, je ujemanje v starosti običajno odlično. Na splošno je ta metoda najbolj zanesljiva, če se uporablja za zobno sklenino, nekatere vrste školjk, odkladnine kalcita in minerale kremena. ESR metoda izkorišča za datiranje signale, ki so posledica napetosti, ki jih ustvarja sevanje v kristalih. Starost se preračuna s pomočjo primerjave ohranjene količine sevanja v vzorcu za datiranje z deležem notranje in zunanje količine naravnega sevanja v vzorcu in okoli njega. Za fosile in avtigeno snov »ničenje« signalov za ugotavljanje prave starosti ni potrebno. Za sedimente, ki vsebujejo ponovno odložene mineralne skupke, se ESR lahko uporablja za določanje starosti samih mineralnih zrn, če tekom erozije niso bili signali »ničeni«. Za datiranje starosti sedimentacije pa morajo biti ESR signali »ničeni«, da dobimo pravilno starost. Visok pritisk, segrevanje in, v primeru nekaterih mineralov, izpostavljenost svetlobi ter drobljenje lahko »ničijo« signal ESR, medtem ko so nekateri drugi, npr. hidroksiapatit, pri površinski temperaturi zelo stabilni. Pri gradivu, ki v času, ko je pokopano v sedimentih, absorbira uran (U), kot so zobje, kosti, školjčne lupine, je treba pri ugotavljanju starosti upoštevati količino prejetega U s pomočjo križnega umerjanja U vrste ali datiranja s pomočjo U/Pb oziroma upoštevati ustrezne modele. Težave pri računanju prejetega zunanjega sevanja je mogoče premostiti s pomočjo ESR izohrone metode, kjer je vzorec tudi svoj lastni dozimeter. V primeru površinskega kraškega okolja

[1] Department of Chemistry, Williams College, Williamstown, MA, 01267, USA
e-mail: bonnie.a.b.blackwell@williams.edu

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the external dose rate due to altered sediment cover, and hence, changing cosmic dose rates, need to be modelled. For all karst environments, sedimentary water concentration and mineralogical variations with time also need to be considered. Many ESR applications are currently used in karst settings, but several more are also possible.
Key words: ESR (electron spin resonance) dating; ESR microscopy; cave geochronology; spring geochronology; teeth; mollusc shells; ratite eggshells; travertine; authigenic carbonates; authigenic salts; heated flint.

je potrebno modleirati spremembe v količini sprejetega zunanjega sevanja zaradi sprememb v sedimentnem pokrovu, torej zaradi sprememb deleža kozmičnega sevanja. V vseh kraških okoljih pa je treba upoštevati količino vode v sedimentu ter sčasoma nastale mineraloške spremembe. Danes je ESR metoda uporabljana v številnih primerih na krasu, a so možnosti njene uporabe še večje.
Ključne besede: ESR (elektronska spinska resonanca) datiranje, ESR mikroskopija, geokronologija jame, geokronologija izvira, zobje, školjčne lupine, lehnjak, avtigeni karbonati, avtigene soli, segrevan kremen.

INTRODUCTION

Electron spin resonance (ESR) dating can provide chronometric (absolute) dates over a substantial time range, from as young as 0.5 ka to about 5-10 Ma, currently with 2-10% precision. ESR, like its sister methods, thermo- (TL), optically stimulated (OSL), and radio- luminescence (RL), relies on detecting trapped charges induced by radiation in crystals. ESR can be used to date many materials that are commonly encountered at karst sites, as well as samples curated in museums, and new applications are constantly being added. ESR's importance in dating Quaternary and Pliocene sites has now been well demonstrated in archaeological contexts where it has dramatically changed our understanding of human origins and cultures (e.g., references in Blackwell, 2001). Many of these applications were in caves or abris, but could equally well be applied to open-air sites where the research questions are similar.

In karst settings, ESR provides several advantages over rival methods. For example, it can date fossils much older than the ^{14}C dating limit (~40-50 ka). ESR does not require a handy volcano to produce datable rocks like $^{39}Ar/^{40}Ar$ does, because ESR can also date fossils and sediment directly. Unlike the uranium (U) series methods, ESR can date most mollusc species accurately, as well as authigenic cements, some clays, and aeolian sediment. Unlike TL, OSL, and RL, ESR does not require that signals be completely zeroed for most applications and signals do not suffer anomalous fading. ESR's potential to date a wide variety of sample types will undoubtedly continue to make it an important research tool in late Cenozoic karst settings.

BRIEF HISTORY OF ESR DATING

In 1936, Gorter and colleagues delineated the basic principles of ESR spectroscopy. Early attempts to date many different materials were unsuccessful, despite ESR having been considered analogous to TL in its application. Finally, in 1975, Ikeya successfully dated a stalagmite from Akiyoshi Cave, Japan.

A flurry of research quickly followed in which geochronologists tried to date everything from fossils to dried blood, and quartz to engine oil, much of it led by Ikeya and other Japanese scientists. Important early applications included attempts to date fault gouge, burnt flint, teeth, and bones. Unfortunately, some early inaccurate applications to controversial archaeological sites, such as Caune de l'Arago, hampered its early acceptance by scientists. Currently, some 60 laboratories worldwide, 25 in Japan alone, research ESR dating and dosimetry, but only about 10 routinely perform dating. Its most common and reliable applications today include tooth enamel, molluscs, corals, and quartz from fault gouge, but research for food irradiation and retrospective dosimetry is producing numerous basic studies that may lead to new geological and paleontological uses. Developments in ESR imaging and microscopy promise many new mineralogical and paleontological applications.

PRINCIPLES OF ESR ANALYSIS

When minerals experience natural radiation, they gradually accumulate trapped unpaired electrons and positively charged "holes" (Figure 1a), which each produce characteristic ESR signals detectable with an ESR spectrometer. Several such signals result from defects in the crystalline structure associated with trace contaminants. If the ESR signal height (intensity) for a radiation-sensitive signal can be converted into an accumulated dose (Figure 1b)

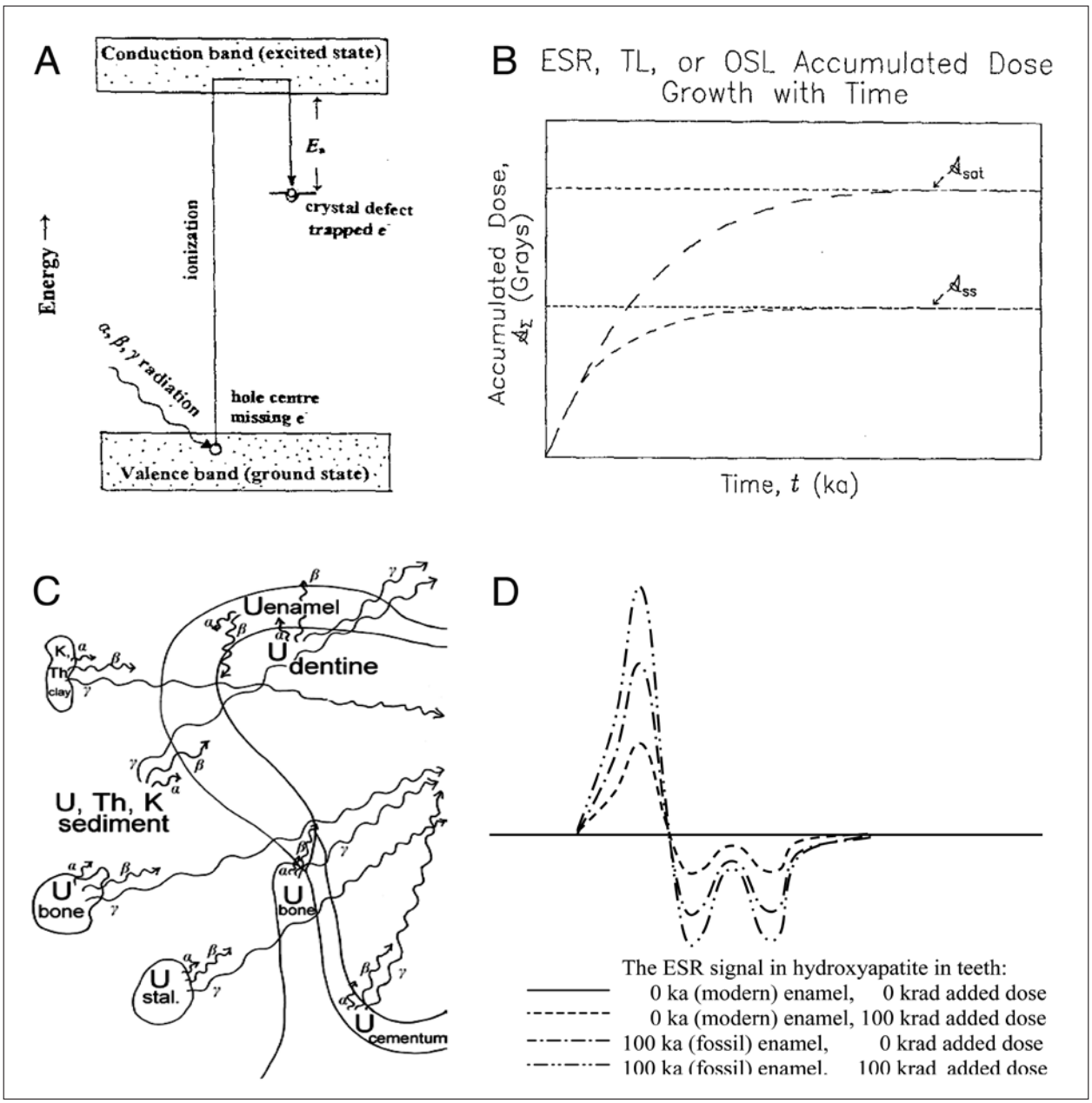

Fig. 1: ESR signal production.
With increased irradiation, the ESR signal's intensity grows, eventually reaching saturation:

a. After absorbing energy from incident radiation, excited electrons move through the conduction band. Although most return to the ground state, a few become trapped in charge site defect (traps, often at trace elements substituents in the crystal lattice) that each have specific energies above the ground state. ESR signals result from the magnetic fields generated by such unpaired electrons and the empty holes they have left behind. With irradiation, such trapped electrons and charged holes, which each produce characteristic signals, gradually accumulate in the materials.

b. With natural irradiation, the signal saturates at its maximum (saturated) accumulated dose, $A_{\Sigma, sat}$, or at a lesser dose, a steady state accumulated dose, $A_{\Sigma, ss}$, where signal fading loss equals signal production.

c. For any sample, many possible radiation sources may exist to produce the ESR signal. In addition to the U in the enamel itself, the dentine and other tissues in the tooth are emitting radiation, as are all the components in the sediment within 30 cm of the tooth.

d. In most fresh teeth, the hydroxyapatite signal has zero intensity. The exceptions are teeth that have experienced a nuclear accident. If a fresh tooth experiences irradiation, a measureable signal will appear after ~ 0.01 Grays exposure, making it a useful signal for monitoring dose exposure during nuclear accidents. In a fossil tooth, a measureable signal is present after ~ 1-20 ka, depending on the total dose rate that the tooth is experiencing. When any tooth experiences artificial irradiation, the signal will grow larger.

and the radiation dose rate experienced by the sample during its deposition is known or can be modelled (Figure 1c), a date can be calculated. ESR dates can be obtained using any material, which has a radiation-sensitive ESR signal (e.g., Figure 1d), provided it satisfies the following criteria,

1. At the time of interest, the mineral's ESR signal was initially, or was reset to, 0.0.

2. The signal lifetime, τ, exceeds the site age by at least two orders of magnitude.

3. The accumulated dose, A_{Σ}, is less than the saturation level in the material.

In karst contexts, tooth enamel, clean carbonates (speleothem, travertine, mollusc shells, calcareous cements, calcrete), and heated or bleached siliceous rock (flint or quartz) have several applications. Many salts may eventually produce valid dates, but the techniques have not been perfected yet. Sediment dates have been attempted, but problems related to incomplete zeroing must still be resolved. This discussion will focus on karst applications, illustrated where possible by karst examples. It omits other applications, although other recent reviews (e.g., Blackwell, 2001; Falguères, 2003) do discuss other applications.

A few technical terms become essential here. An ESR spectrometer uses a microwave signal to create resonance between the unpaired electrons in minerals and an externally applied strong magnetic field. Lande's factor, called the g value, is a dimensionless number that uniquely describes the ESR characteristics for any peak. Pulsed X-, K-, or Q-band ESR may ultimately improve our ability to separate interference signals (e.g., Grün *et al.*, 1997; Kinoshita *et al.*, 2004). Although other bands, such as Q- or L-band, are occasionally used to examine signals in more detail, for most ESR dating, spectra are analyzed in the X-band at 1-10 mW power using microwave frequencies near 8-10 GHz under a 100 kHz field modulation. Under these conditions, most geologically or archaeologically interesting ESR signals fall within 3 > g > 1.9 (Blackwell, 1995, Table 2).

Zeroing reduces an ESR signal's intensity to a level indistinguishable from background levels. Most newly formed minerals have no measurable ESR signals. In a mineral with an accumulated dose (i.e., a measurable signal; $A_{\Sigma} > 0$), several physical processes can also zero a signal. Strong heating to temperatures above 250-500°C, depending on the mineral, will also zero most ESR signals (Figure 2b). For some signals in a few minerals, exposure to intense sunlight can zero (bleach) the signal (Figure 2a). Luckily, for the radiation-sensitive signals in most minerals, sunlight causes little or no signal loss. High

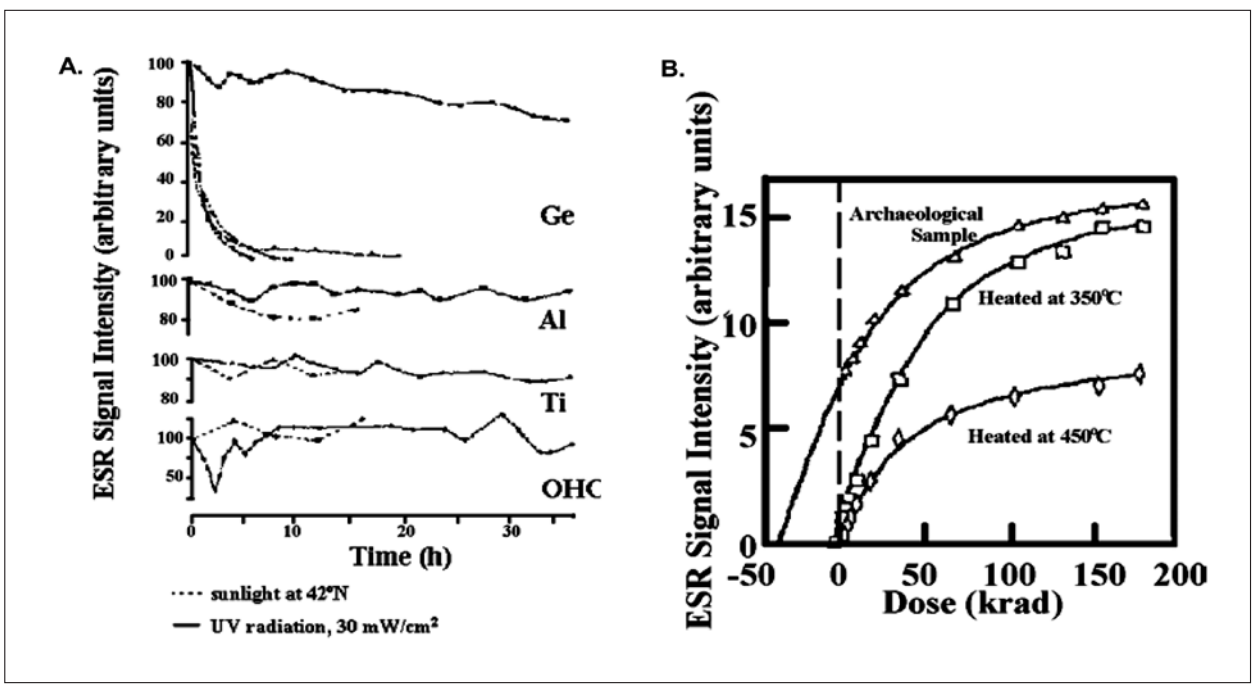

Fig. 2: Zeroing in quartz and chert. In quartz, several signals can be zeroed using different techniques:

a. Exposure to intense UV radiation and sunlight can completely bleach the Ge (germanium) signal and partially bleach the Al (aluminium), Ti (titanium), and OHC (oxygen hole) signals.

b. Heating archaeological chert to high temperature can zero the E' signal, reducing its accumulated dose, A_{Σ}, to 0. After zeroing, the signals can regrow if given more irradiation.

(adapted from Blackwell, 2001).

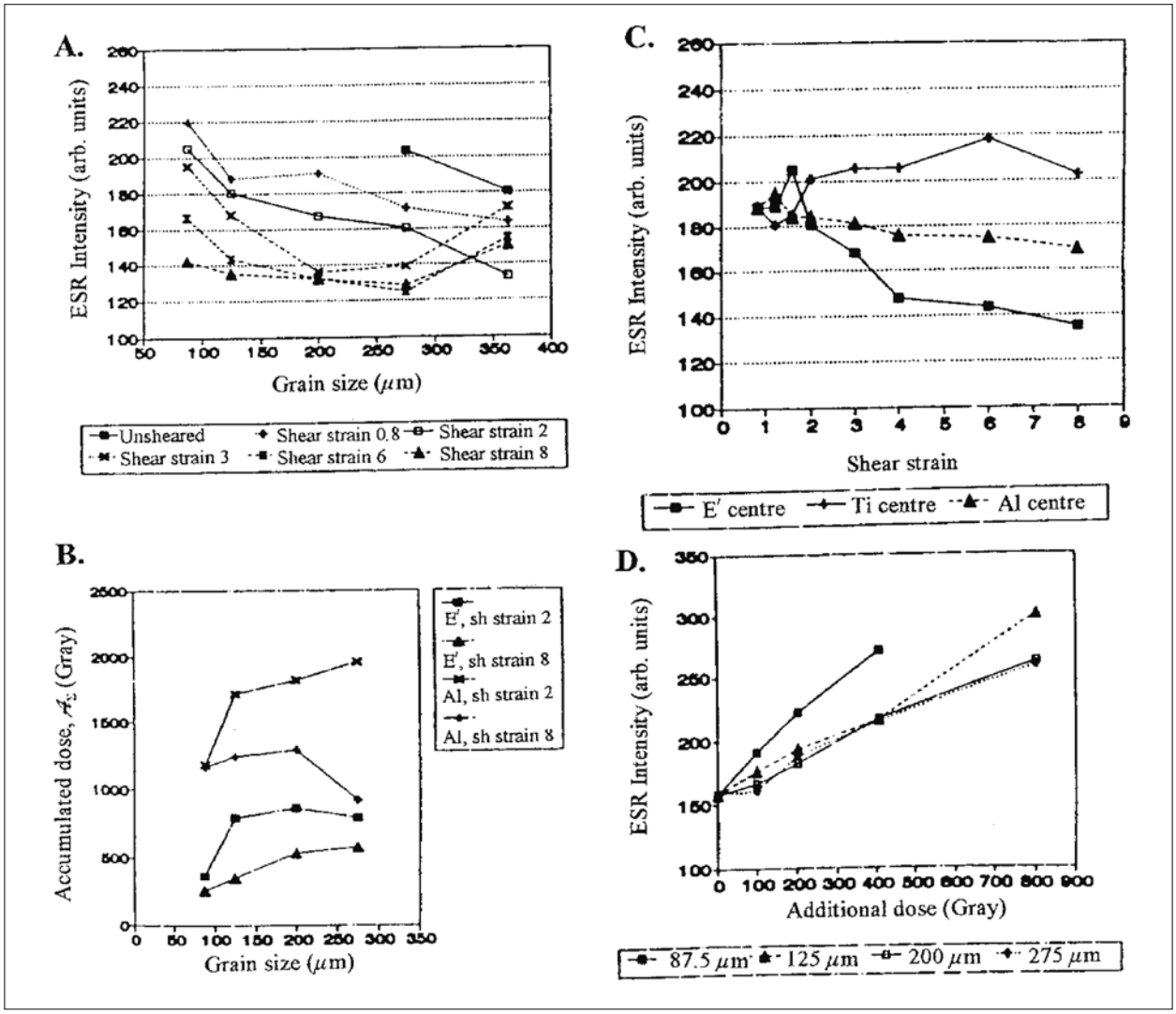

Fig. 3: Effects from shear strain on ESR signals in quartz. Shear strain will reset most ESR signals:

a. As strain increases, the differences in ESR intensity between different grain size fractions decreases.

b. At a normal stress of 10 MPa, the measured accumulated (equivalent) dose, A_Σ', decreases with decreasing grain size for both the E′ and Al signals, until at a small grain size the two signals give equal A_Σ, determinations.

c. While the E′ signal is the most easily reset, strain also affects the Al signal. The Ti signal appears unaffected.

d. During artificial irradiation for producing a growth curve, the smaller grain sizes show the greatest sensitivity and the most well behaved growth curves.

(modified from Lee & Schwarcz, 1993).

pressure or strain that builds up in faults can partially or fully reset some signals, as can the strain developed during comminution during an earthquake or grinding for sample preparation (Figure 3). Remineralization and diagenesis add new minerals whose radiation-sensitive signals will be zero at formation. Therefore, if the original and new minerals have signals with similar g values, the resultant complex signal may be impossible to resolve, adding inaccuracies to the age determination. If, however, the new signals do not interfere with the original signals, as is true for tooth enamel, only the dating signal's intensity is reduced, thereby reducing the discriminatory range and dating limits for the technique (Skinner *et al.*, 2000).

The method's reliability depends on the signal's thermal stability. Signals which zero easily at typical Earth surface temperatures have little value for dating, but may provide other information. The mean signal lifetime, τ,

must exceed the desired dating range by at least 2-3 orders of magnitude to ensure reliable ages. In tooth enamel, for example, $\tau \approx 10^{19}$ y (Skinner *et al.*, 2000), sufficiently long, in theory at least, to date anything within the history of the universe. Unlike TL, no datable ESR signal appears to suffer anomalous fading. In practice, however, most signals have a finite saturation limit, beyond which no new trapped electrons are formed. Many minerals also have a steady state level, somewhat lower than their saturation level, caused by electron loss and retrapping (Figure 1b). The mean signal lifetime and the steady state limit or saturation limit define the maximum datable age, while the ESR spectrometer's ability to discriminate between the dating signal and its surrounding background determines the minimum dating limit. Both limits differ depending on the mineral and its habit in the material to be dated. The radiation dose rates experienced by the sample determine how those limits are translated into an actual age. If samples experience high radiation dose rates, the minimum datable age will be relative low, but so will its maximum datable age, and conversely, low radiation dose rates mean higher minimum and maximum limits.

The ESR signal height (Figure 1d) is proportional to the number of trapped charges at that lattice site, and, therefore, to the total radiation dose, A_Σ, that the material has experienced. The ESR age, t1, the time that has elapsed since the mineral formed and began to accumulate charges then is calculated from Equation 1,

$$A_\Sigma = A_{int} + A_{ext} = \int_{to}^{t1} D_\Sigma(t)dt = \int_{to}^{t1} (D_{int}(t) + D_{ext}(t))dt \qquad (1)$$

where

A_Σ = the total accumulated dose in the sample,
A_{int} = the internally derived accumulated dose component,
A_{ext} = the externally derived accumulated dose component,
$D_\Sigma(t)$ = the total dose rate,
$D_{int}(t)$ = the total dose rate from internal sources: U, its daughters, and any other radioisotopes,
$D_{ext}(t)$ = the total dose rate from the external environment: sedimentary U, Th, and K, and cosmic dose,
t_1 = the sample's age,
t_0 = today.

For samples in which the total dose rate, $D_\Sigma(t)$, is constant, this reduces to

$$t_1 = \frac{A_\Sigma}{D_\Sigma(t)} \qquad (2)$$

SAMPLE COLLECTION

An ideal ESR sample should be as pristine as possible. To improve precision and accuracy, both the dating sample and any associated sediment samples should not experience the following treatments during or after excavation:

1. Glues, shellacs, and other preservatives can add contaminant U to the sample that reduces the accuracy of internal dose rate measurements, as well as organic compounds that might cause ESR signal interference.

2. Washing may remove U, datable mineral, and sediment. Sediment attached to the sample may offer the only chance to measure the external dose rates.

3. If used to remove samples from cemented sediment, acid dissolution can dissolve the sample and leach its U.

4. Removing attached bone from teeth reduces the accuracy of the external dose rate measurements.

5. Removing attached sediment from any sample reduces the accuracy of the external dose rate measurements.

6. Sample numbering uses inks and paints that can add contaminant organic compounds if applied to the sample.

7. Allowing clay samples to dry necessitates extensive grinding during preparation which can partially bleach some ESR signals.

8. Packing samples for transport with materials, such as old newspapers, dyed paper, etc., can cause trace elements or organic contamination if they contact the sample. The best packing is cheap unbleached, unperfumed toilet paper.

Although preservatives, if available, can be analyzed to correct for contamination effects, any resulting age will still have reduced precision. Fossils can be cast, providing that the casting resin and powder have been tested for contamination potential first.

For all dating samples except teeth, diagenesis or signal interference may cause some samples to be unsuitable (Table 1). Since fossils can be easily reworked into younger depositional units, any sampling program should collect at least 8-10 samples from each stratigraphic unit to increase the chance that the samples analyzed provide dates related to the event of interest. Although the required sample weight varies depending on the auxiliary analyses necessary (Table 1), the ESR analysis itself, and the associated NAA or geochemical analyses to measure the internal dose rate, require 1-2 g of pristine datable mineral per standard ESR subsample. For some materials, especially those prone to diagenesis, it is necessary to check for secondary mineralization and remineraliza-

tion, which affect ESR signal intensities (Table 1), thus requiring larger samples. For samples needing to be separated into discrete mineral phases, such as authigenic cements, caliche, calcrete, and gypcrete, the pristine mineral must be separated from the adjacent sediment, often necessitating much larger samples (usually, at least 15-20 g). For ESR dating sediment, pristine sample blocks of ~ 0.5 kg cut from thick or extensive units provide the best results, if available. For very small samples (100-200 mg), the ramping irradiation technique can be used in which several aliquots are reirradiated several times, but the special handling does lengthen the total analysis time significantly.

Most curated museum samples require isochron analysis (see below), because sediment has not usually been preserved. Salt samples need to be stabilized to prevent remineralization or recrystallization during transport, as can occur with some hydrated salts. For samples intended for isochron analysis, samples should be photographed before shipping to ensure that broken samples can be reconstructed to maximize the number of viable subsamples. Samples should be packed tightly with minimal air to reduce sample breakage and bag destruction.

SEDIMENT DOSIMETRY AND ASSOCIATED SEDIMENT SAMPLES

Many karst sites have sediment which is inhomogeneous (i.e., "lumpy"; Figure 1d, 4d) for radioactive dose generation. This is particularly true in caves where sedimentary inhomogeneity is the rule, rather than the exception. Whenever possible, the external dose rates should be assessed using at least two procedures from among isochron analysis, sediment geochemistry, i*n situ* γ or TL dosimetry. For TL or γ dosimetry, if dosimetry cannot be completed before collection, sampling locations need to be marked and preserved to permit future dosimetry. Effective TL dosimetry requires that the area within 3 m of the dosimeter insertion site be unaffected by further excavation or erosion for 6-12 months. In open-air sites, however, either γ dosimetry or sedimentary analysis is preferred over TL dosimetry, because TL dosimeters rarely survive undisturbed for the needed time. Isochron analysis is still experimental for many materials.

With sedimentary geochemistry, the external dose field can be mathematically modelled reasonably accurately. In sediment, β particles can penetrate about 2-3 mm, and γ radiation ~ 30 cm (Figure 4). The sediment immediately attached to, or surrounding, the dating sample usually provides the only direct measurement for calculating the β radiation dose rate. When using γ or TL dosimetry, this sediment must still be analyzed geochemically to provide the external β dose rate. Several sediment samples may be needed to represent the sphere influenced by γ radiation 30 cm in radius around the dating sample.

Sediment sampling protocols vary with the bed or unit thickness, its mineralogy, and its grain size (see Table 2; Figure 5). In many sedimentary contexts, the radioactive element concentrations can vary dramatically over short distances if the sediment contains large clasts of several different minerals ("lumpy"; Figure 4d). This requires collecting several samples from each unit or bed which might have contributed to the dating sample's external dose rate. If the sediment contains a homogeneous grain mixture of fine to medium grained clasts, ~ 5-10 g are sufficient for each associated sediment sample. For coarser sediment types, sediment samples should include representative portions of cobbles mixed with the matrix. Alternatively, separate matrix and cobble samples can be submitted, provided relative volume percentages of the various types are known. In units with fossils or artefacts, these must be considered as radioactive sources and analyzed also (Blackwell & Blickstein, 2000). Generally, the larger the grains, the larger the sediment mass that will be needed. In well cemented sedimentary units (e.g., "breccias", etc.), a block of sediment (20 cm on a side) showing all representative grains, matrix, and cements on the surfaces often provides the best sample.

If all the sediment samples preferred in the ideal circumstance are not available, sediment from the same or similar beds as close as possible to the dating sample can still be used to assess the radiation dose field's variability and estimate external dose rates. For museum samples, any samples from nearby outcrops may provide valuable clues. Accurately recording and photographing each sediment sample relative to the dating sample ensures accuracy in modelling the external dose field. All *in situ* sediment samples should be placed in clean, sealed jars or doubly bagged in new zip-lock bags immediately after collection to retain sediment moisture for water concentration analysis. For sections that have been exposed for a long time, or archived sediment, sediment moisture content is not analyzed.

Table 1: ESR Sample Types

Sample type	Minerals[1]	Zeroing req'd?	Isochrons possible?[1]	Species effects?[1]	Best type or species?	Minimum sample for standard ESR[2,3] (g/subsample)	Effects from diagenesis, secondary mineralization, or cementation			Incomplete zeroing?	Effects from grinding?
							Signal intensity	Interference?	Inaccurate ages?		
Enamel	HAP	no	yes	no	large teeth; no milk teeth	3-4	decreased	rarely	no	n/a	possibly
Dentine	HAP	no	yes	no	no milk teeth	5-10	decreased	rarely	no	n/a	possibly
Cementum	HAP	no	no	no	no milk teeth	0.1[4]	decreased	rarely	no	n/a	possibly
Bone	HAP	no	yes	no	cortical bone	10-20	decreased	possibly	possibly	n/a	possibly
Tusk, antler	HAP	no	yes	no	densest	10-20	decreased	possibly	possibly	n/a	possibly
Gar fish scales	HAP	no	no	unkn	only gar	2-5[4,5]	decreased	rarely	no	n/a	possibly
Molluscs	cct, argt	no	unkn	yes	large valved[6]	5-10[5]	may increase	likely	possibly	n/a	interference
Ratite egg shells	cct	no	theor	unkn	unkn	5-10[5]	may increase	likely	possibly	n/a	interference
Coral, echinoderms	argt	no	theor	yes	unkn	5-10[5]	may increase	likely	possibly	n/a	interference
Foraminifera, ostracodes	cct, argt	no	unkn	unkn	unkn	10-20[5]	may increase	likely	possibly	n/a	interference
Travertine, speleothem	cct, argt	no	yes	n/a	densest	50-100[7,8]	may increase	likely	possibly	n/a	interference
Calcrete, caliche, stromatolites	cct	no	unkn	n/a	densest	50-100[7,8]	may increase	likely	possibly	yes, if clasts CO_3 also	interference
Authigenic cement	cct, argt	no	unkn	n/a	densest	100 mg[4]	may increase	likely	possibly	n/a	interference
Phytoliths, diatoms, radiolarians	qtz	no	unkn	unkn	unkn	5-10[5] or 0.1[4,5]	may increase	possibly	possibly	n/a	reduced intens
Fault gouge, mylonite	qtz, fspar	yes	yes	n/a	qtz or fspar separates	50-100[7,8]	may increase	possibly	possibly	n/a	reduced intens
Ash/tuffs	qtz	yes	theor	n/a	thickest units	50-100[7,8]	may increase	likely	possibly	yes	reduced intens
Flint/chert (burnt)	qtz	yes	yes	n/a	avoid patina	5-10[8]	may increase	possibly	possibly	yes	reduced intens

Hearth sand	qtz	yes	unkn	n/a	closest to hearth	50-100[7,8]	may increase	possibly	possibly	yes	reduced intens
Silicrete, laterite	qtz	yes	unkn	n/a	qtz separates	50-100[7,8]	may increase	likely	possibly	yes, if clasts qtz also	reduced intens
Beach, fluvial sediment, loess	qtz, flint, chert	yes	unkn	n/a	qtz separates	50-100[7,8]	may increase	possibly	possibly	yes	reduced intens
Authigenic cement	qtz	no	unkn	n/a	densest	0.1[4]	may increase	likely	possibly	n/a	reduced intens
Dolomite (1°)	dmt	no	unkn	n/a	densest	50-100[7,8]	may increase	likely	possibly	n/a	unkn
Dolomite (2°)	dmt	no	unkn	n/a	dmt separates	0.1[4]	may increase	likely	possibly	n/a	unkn
Gypsum, gypcrete	gyp	no	unkn	n/a	gyp separates	50-100[7,8]	may increase	likely	possibly	n/a	unkn
Anhydrite	anhy	no	unkn	n/a	densest	50-100[7,8]	may increase	likely	possibly	n/a	unkn
Halite	hal	no	unkn	n/a	densest	50-100[7,8]	may increase	likely	possibly	n/a	unkn

[1] *Abbreviations:*

1°	=	*primary*	*2°*	=	*secondary*
HAP	=	*hydroxyapatite*	*qtz*	=	*quartz*
cct	=	*calcite*	*argt*	=	*aragonite*
dmt	=	*dolomite*	*gyp*	=	*gypsum*
anhy	=	*anhydrite*	*hal*	=	*halite*
CO_3	=	*carbonate*	*unkn*	=	*unknown*
intens	=	*intensity*	*theor*	=	*theoretically*

[2] *Sizes assume little or no diagenesis is present. For diagenetically altered samples, larger samples are needed.*

[3] *For isochron analysis, the sample size must be increased by a factor of 5-8.*

[4] *This uses a special ramped irradiation technique involves reirradiating some aliquots, but takes up to 2 years to complete.*

[5] *For species that have not been tested for ESR applicability, another 100-200 g is necessary.*

[6] *Smaller species may require special techniques or mixing multiple individuals into one subsample.*

[7] *Large sample sizes ensure sufficient pristine mineral for analysis after mineral separation and for XRD or petrographic analysis to check for recrystallization.*

[8] *For samples from new study sites or sample types not yet tested for ESR applicability, another 100-200 g may be necessary.*

Sedimentary Unit or Site[1]			Sediment Grains (Clasts)		1° Dosing Unit(s)[4] Thickness (cm)	Whole (Bulk) Sediment Samples			Samples of Clasts > 0.5 cm in Diameter[6]	Fig.
Character[1]	e.g. Fig.	Type[1]	Mineral Compositions[2]	Grain Size Range[3]		Mass[5] (g)	from 1° Dosing Unit(s)[4]	from 2° Dosing Units[4]		
"Smooth", thickly bedded sites	4c[7]	Thick smooth	Homogeneous	Uniform	> 65	5-10	4-6 orthogonally oriented	none	1-3 for gravel-sized matrix only	5a[7]
"Smooth", thinly bedded sites	4b[7]	Thin smooth	Homogeneous	Uniform	< 65	5-10	4-6 orthogonally oriented	3-5 for each unit ≤ 30 cm from dating sample	1-3 for gravel-sized matrix only	5b[7]
"Lumpy", thickly bedded sites	4d[7]	Thick lumpy 1	Homogeneous	Non-uniform	> 65	100-1000	4-6 orthogonally oriented	none	1-3 per unit	5a[7]
"Lumpy", thinly bedded sites	4d[7]	Thin lumpy 1	Homogeneous	Non-uniform	< 65	100-1000	4-6 orthogonally oriented	3-5 for each unit ≤ 30 cm from dating sample	1-3 per unit	5b[7]
"Lumpy", thickly bedded sites	4c[8]	Thick lumpy 2	Inhomogeneous	Uniform	> 65	50-100	4-6 orthogonally oriented	none	1-3 for gravel-sized matrix only	5a[8]
"Lumpy", thinly bedded sites	4b[8]	Thin lumpy 2	Inhomogeneous	Uniform	< 65	50-100	4-6 orthogonally oriented	3-5 for each unit ≤ 30 cm from dating sample	1-3 for gravel-sized matrix only	5b[8]
"Lumpy", thickly bedded sites	4d[8]	Thick lumpy 3	Inhomogeneous	Non-uniform	> 65	500-1000	4-6 orthogonally oriented	none	1-3 for each lump mineralogy per unit	5a[8]
"Lumpy", thinly bedded sites	4d[8]	Thin lumpy 3	Inhomogeneous	Non-uniform	< 65	500-1000	4-6 orthogonally oriented	3-5 for each unit ≤ 30 cm from dating sample	1-3 for each lump mineralogy per unit	5b[8]

Table 2. Sampling for Associated Sediment.

[1] Sampling strategy and site character definition is governed by the most inhomogenous unit present. If one "lumpy 3" bed occurs within 35 cm of the sample, the whole sedimentary package is treated as a lumpy 3 site.

[2] Mineral compositions in the units within 35 cm of the dating sample:
Homogeneous = all a single mineral, e.g., all calcite or all quartz
Inhomogenous = mixed sediment with several mineral or rock fragment types, e.g., mixed limestone and bone, till with quartz sand and gravel-sized granite clasts

[3] Clast (grain) sizes in the units within 35 cm of the dating sample:
Uniform = all one or two β size classes, e.g., all medium-coarse sand or all silt-fine sand
Non-uniform = several or a range of β size classes, e.g., diamicton, breccia, most fossiliferous units, till

[4] Dosing units are sedimentary units within the 30 cm γ sphere of influence (Figures 4, 5):
1o (primary) dosing unit(s) = the one or two unit(s) touching the dating sample that contribute both β and γ dose to the external dose rate affecting the sample.
2o (secondary) dosing units = all units ≤ 35 cm from the dating sample that contribute only γ dose to the external dose rate affecting the sample.

[5] assuming that sediment matrix is sand-sized or smaller; larger matrix grain size requires larger sample mass.

[6] assuming that the clasts are collected separately from the matrix.

[7] assuming that grains of only one mineral constitute all the components in the sedimentary unit(s).

[8] assuming that grains of several different minerals occur in the sedimentary unit(s)

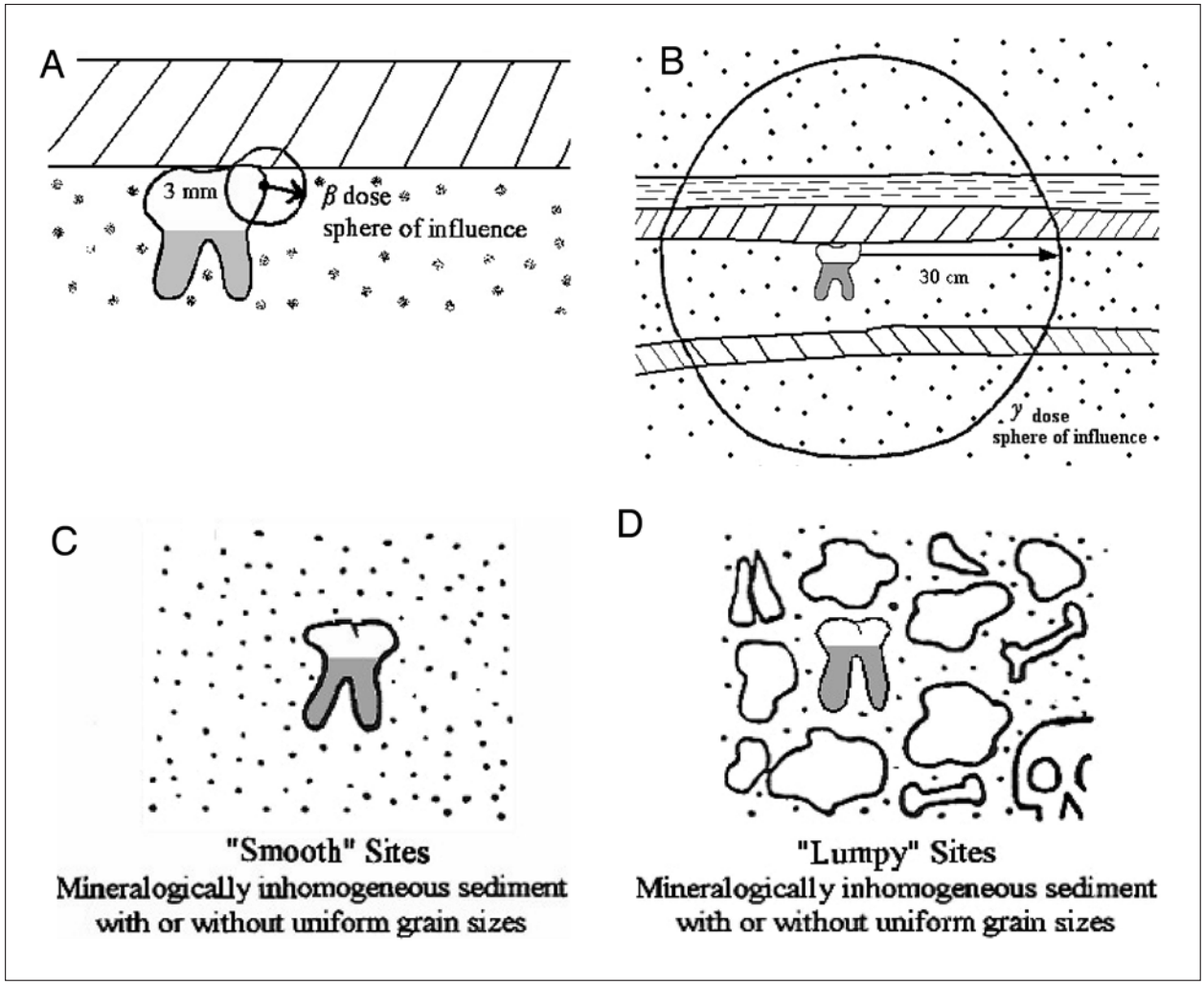

Fig. 4: Factors affecting the effective radiation dose field around dating samples.

Radiation can reach the dating sample from radioactive decay occurring within the sphere of influence for the particular radiation type:

a. *β particles deliver to a sample a significant, but variable, component in the total radiation dose, both externally and internally. Since the penetration range for a β particle averages 1-2 mm, comparable to the sample thicknesses, dose calculations must consider β attenuation within the sample. The sphere of influence for the contributions from β radiation will usually not include more than two or three sedimentary units.*

b. *Since γ irradiation can penetrate ~ 30 cm, the sphere of influence for the contributions from γ radiation can include several sedimentary units, which may produce very different dose rates.*

c. *In "smooth" sites with homogeneous sediment, the dose rate calculation is trivial.*

d. *In "lumpy" sites, different minerals or clasts within the sediment, which may contain different concentrations of radioactive elements, can contribute dose at very different rates.*

In all situations, the $D_{ext}(t)$ calculation must volumetrically average the dose rate from each source relative to its importance and location within the sphere of influence each stratigraphic unit or sediment type.

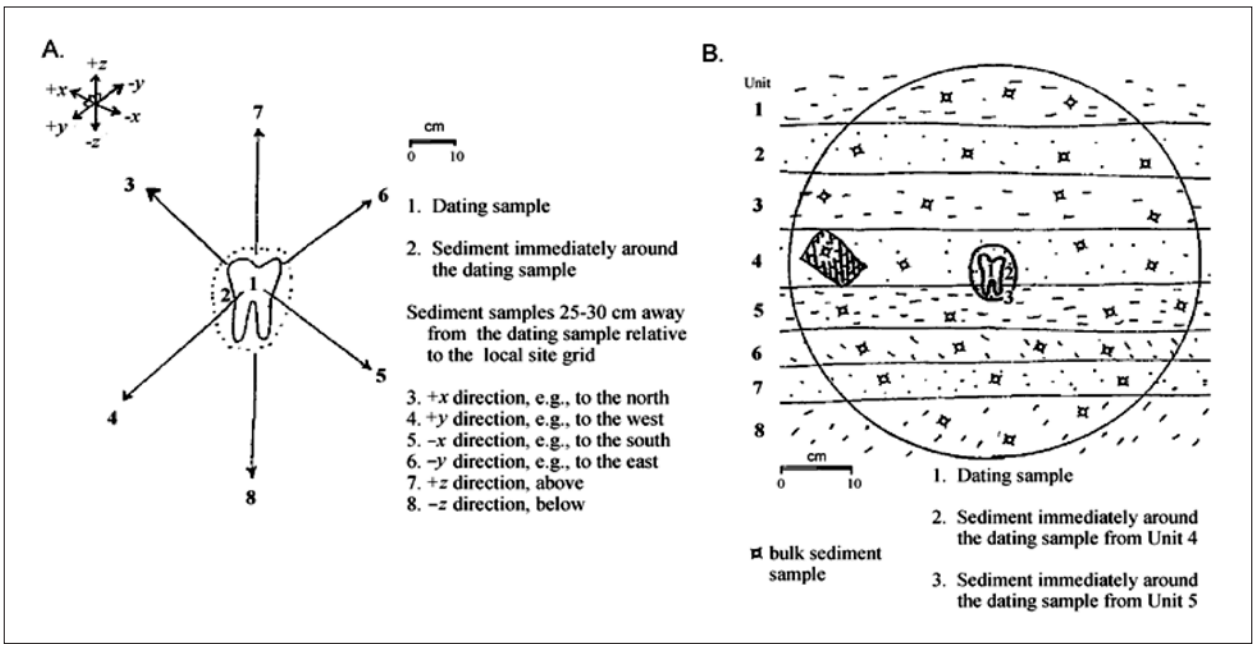

Fig. 5: Collecting protocols for associated sediment samples for ESR dating.

a. Thickly bedded homogeneous units ("Thick smooth" units, Table 2): Assuming that the dating sample lies at least 35 cm from the nearest sedimentary unit boundary, sediment should be collected from four to six of the six orthogonal positions. In pictured example, the associated sediments were collected from the six orthogonal positions that coincide with the site grid plan.

b. Thinly bedded or inhomogeneous units ("Thin smooth" units, Table 2): The sample for dating (1) sits within Units 4 and 5 (2, 3). In this circumstance, separate samples need to be collected from the two surrounding units. When sampling the surrounding sedimentary units, three to five sediment samples should be collected from each unit, distributing the samples throughout the unit as it falls within the γ sphere of influence. Ideally for each unit, a few should come from along the cut face, one from behind, and one from in front of the cut face in order to sample a somewhat even distribution for each bed.

ESR ANALYSIS

Calculating an ESR age requires considering some 30 different parameters, which affect the accumulated dose, the internal and external dose rates. Although improved spectrometers and ancillary equipment have sped the process and improved precision somewhat, the basic ESR dating protocols were established in the 1980's. Standard analytical protocols for all mineralogies require powdered samples. Although some ESR labs have developed "nondestructive" analyses for tooth enamel (e.g., Robertson & Grün, 2000; Miyake *et al*., 2000), even these cause some sample degradation.

DETERMINING THE ACCUMULATED DOSE, A_Σ

For each sample, the accumulated dose, A_Σ, is determined using the additive dose method (Figure 6a). This requires about 0.2-0.5 g of pristine prepared mineral sample (Table 1) in order to provide 10-15 aliquots of powdered, homogenized sample. Using fewer than 10 measurements causes significantly lower precision. Except for one, each aliquot is irradiated to a different precisely known artificial radiation dose, usually from a ^{60}Co γ source. The added doses used usually range from 0.1-10 Grays for the lowest added dose to 1-40 kGy for highest, depending on the sample's A_Σ. Older samples, those with higher A_Σ's, generally get higher doses. The selection of added doses does affect the curve fitting statistics, and hence, the precision for A_Σ for enamel (e.g., Lee *et al*., 1997), and presumably for other materials as well. In the ramping technique, only 3-4 aliquots are used, but one or two are used to calibrate the spectrometer with each set of measurements, and two or three are successively irradiated to ever higher added doses (Blackwell, 2001).

After measuring the ESR signal heights for both the natural and irradiated aliquots, the added dose is plotted *versus* the signal intensity to produce a growth curve (Figure 6a). Usually, the points are weighted inversely with intensity (peak height). In some materials, however, signal subtraction is necessary to isolate the dating signal from the interference to measure an accurate peak

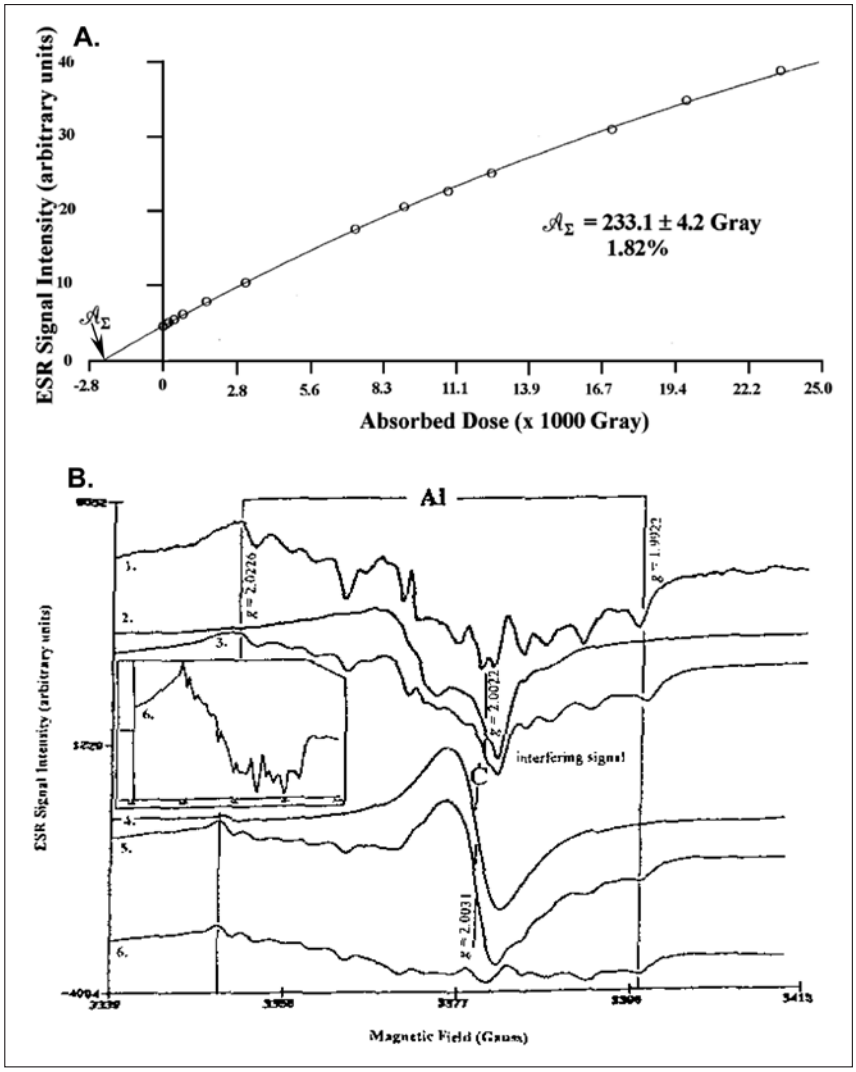

Fig. 6. Determining the accumulated dose, A_Σ.

The additive dose method is used to calculate the accumulated (or γ-equivalent) dose, A_Σ:

a. Under artificial irradiation during analysis, the HAP signal saturates at its maximum intensity, I_{max}. Plotting the signal intensity versus the added radiation dose produces a growth curve. The x-intercept for this curve gives A_Σ. This bovid tooth from Treugol'naya Cave, Russia, has a substantial accumulated dose, as expected for a Middle Pleistocene site dating to OIS 11 (Blackwell et al., 2005a).

b. For signals suffering interference, signal subtraction is used to remove the interference:

Curve 1. A pure Al signal is unaffected by interference signals.
Curve 2. An organic radical signal, Ċ, interferes with the Al signal.
Curve 3. Unidentified interference signals affect the Al signal.
Curve 4. The Al and Ċ signal in a natural archaeological sample.
Curve 5. The same sample as Curve 4 heated for 10 minutes at 320°C to zero the Al signal.
Curve 6. When Curve 5 is subtracted from Curve 4, the resulting signal shows the hyperfine splitting typical for the Al signal (see inset; modified from Blackwell, 2001).

height (Figure 6b). Despite controversies over measurement protocols, derivative spectra actually provide better resolution (Lyons & Tan, 2000). Most evidence also suggests that deconvolution is not necessary for many dating peaks (e.g., Skinner *et al.*, 2001a). The accumulated dose, A_Σ, required to produce the observed natural ESR signal intensity equals the x-intercept for the growth curve. Within some materials, such as travertine, calcrete, and caliche, crystals may vary greatly in their A_Σ. If some regions are at or near saturation, while others are younger,

and hence not saturated, age underestimation may also occur, because the dose response is nonlinear near saturation (Figure 1b). This is not a problem for tooth enamel where linear behaviour persists to large doses (Brennan, 2000). Generally, A_Σ can be measured with 0.8 to 5% precision depending on the spectrometer's calibration (Nagy, 2000), the radiation source calibration (Wieser *et al.*, 2005), the sample's age and diagenetic state (e.g., Blackwell *et al.*, 2005a).

DETERMINING THE INTERNAL DOSE RATE, $D_{int}(T)$

To calculate the internal dose rate, $D_{int}(t)$, the radiation sources (all U, Th, K, etc.) within the sample are measured (Figure 1d), usually using neutron activation analysis (NAA) or any geochemical technique able to measure elemental concentrations at the ppm-ppb range. Then, $D_{int}(t)$ is derived from theoretical calculations. For samples containing U or Th, those calculations must also consider the increased radioactivity due to ingrowth of the U or Th daughter isotopes (Figure 7a) over time using an iterative procedure. Dint(t) calculations also consider radiation attenuation by water within the sample, α and β dose attenuation due to mineral density, and radon (Rn) loss for U- or Th-rich samples (Figure 7b; e.g., Brennan *et al.*, 2000).

In samples, such as tooth enamel, bone, and fish scales, where the internal dose rate derives solely from U absorbed during its burial history, the calculated ESR age must account for U uptake: Either the sample must be dated by U-series or U/Pb analysis, which allows a unique uptake model to be selected, or a U uptake model must be assumed. Without calibrating dates, four models are commonly used (Figures 7c, 7d):

Early uptake (EU) assumes that the sample absorbed all its U soon after burial, providing the youngest age given the accumulated dose, A_Σ, and external dose rate, $D_{ext}(t)$.

Linear uptake (LU) assumes that the sample absorbs U at a constant rate throughout its burial history, giving a median age.

Recent uptake (RU) assumes U uptake very late in the sample's burial history, which reduces its internally generated dose, $A_{int,}$ to a minor contribution compared to A_Σ. This gives the maximum possible age.

Coupled uptake (CU) assumes that the enamel, dentine, cementum, and any attached bone in teeth absorb U by different models. Often, it assumes LU for the enamel and EU for the dentine, cementum, and any attached bone, yielding ages somewhat younger than strict LU, but older than strict EU, models.

Other models have also been suggested (e.g., Ikeya et al., 1997). CU only applies to materials like teeth where two different phases absorb U at different rates. In teeth, LU or CU ages often agree most closely with ages determined by other means for samples between than 80 ka and 500 ka, but, within a site, the uptake model can vary, since it depends strongly on microenvironmental conditions (e.g., Blackwell et al., 2001b). "For fossils and other materials that uptake U after deposition, TIMS or laser-ablation $^{230}Th/^{234}U$ analyses give coupled ESR-$^{230}Th/^{234}U$ calculations, which can constrain the U uptake history, as neither method can do independently (e.g., Eggins et al., 2003) For some older samples, it is still possible to use $^{230}Th/^{234}U$, providing the uptake has occured recently enough that the $^{230}Th/^{234}U$ ratios are not indistinguishable from secular equilibrium values. U/Pb can date some uraniferous samples older than 1-2 Ma, but it has not yet been applied to delineate an ESR uptake model. U leaching or secondary U uptake may also present problems for some samples, and hence, requiring complex models (Figure 7c; Blackwell *et al.*, 2005b; Hoffman & Mangini, 2003). Precisions for $D_{int}(t)$ depend strongly on the precision for U concentration measurement. Delayed neutron counting (DNC) neutron activation analysis (NAA) can routinely provide precisions and detection limits as low as ± 0.02 ppm, whereas instrumental NAA averages ± 0.2 ppm for precision and ± 1 ppm for detection limits, which makes dating young samples impossible. Any other technique able to measure the U at or below the ppb concentration level with better than ± 0.02 ppm precision provides sufficient discrimination to yield reliable ESR ages.

DETERMINING THE EXTERNAL DOSE RATE, $D_{EXT}(T)$

The external dose rate, $D_{ext}(t)$, strongly affects the calculated ESR ages (Figure 8a), especially for samples with low internal dose rates, $D_{int}(t)$, as is common for teeth from caves. Teeth from open-air sites tend to have larger internal dose rates, but the external dose rates, also can be more variable over the long term. Both types of sites need to be examined carefully to understand all the dynamic processes that affect the external dose rates.

To derive the total external dose rate, $D_{ext,\Sigma}(t)$, four methods can be used:

1. TL dosimeters placed in the site to measure the current external dose rate, $D_{ext,\gamma}(t_0)$ from sedimentary γ and cosmic sources over 0.5-2.0 years.

2. γ spectrometers measure the current dose rate, Dext, $\gamma(t_0)$ from sedimentary γ and cosmic sources over 0.5-2 hours.

3. Bulk geochemical analysis, often by NAA, using powdered sediment collected in conjunction with the sample measures the U, Th, K, and other significant radioisotope concentrations in any layers which may have

contributed to the sample's $D_{ext,\Sigma}(t)$ (Figures 4, 5). The radioisotopic concentrations are used to mathematically calculate the current dose rates, $D_{ext,\gamma}(t_0)$ and $D_{ext,\beta}(t_0)$ which include corrections for γ and β dose attenuation due to mineral density, and backscattering. Such $D_{ext,\Sigma}(t)$ calculations also require a measurement for, or assumptions about, $D_{cos}(t)$, the cosmic dose rate (Figures 8b, 8c) for samples buried less than 10 m and also the average sedimentary water concentration to correct for radiation attenuation by sedimentary water (Figure 8d). In sites with thinly layered deposits or inhomogeneous sediment, $D_{ext,\Sigma}(t)$ calculations ideally should consider each unit or sediment component individually by determining volumetrically averaged dose contributions (Figure 4b).

4. An isochron age for a large sample may obviate the need for a $D_{ext,\Sigma}(t)$ calculation, because it gives both the sample age, t1, and $\overline{D}_{ext,\Sigma}(t)$ the time-averaged external dose rate, simultaneously (Figure 9).

For adjacent U-rich or Th-rich layers or sediment components, the measurement or calculation is corrected for possible U uptake, U daughter isotope ingrowth, and potential Rn loss (e.g. Figure 7; Blackwell & Blickstein, 2000).

Assuming that $D_{ext}(t)$ has remained constant throughout the burial history, as many early studies did, can be naïve. Changing water or radioactive element concentrations in the sediment (Figure 8d; e.g., Olley *et al.*, 1997), increasing burial depth (Figure 8b), or variable $D_{cos}(t)$, among others, can all affect the $D_{ext,\Sigma}(t)$ experienced by the sample, requiring that $D_{ext,\beta}(t_0)$ and particularly $D_{ext,\gamma}(t_0)$ be corrected for any such significant variations. At sites where sedimentary water concentration variations can be significant, or where sediment accumulation or deflation can alter the depth of sediment cover, these considerations become significant, but not insurmountable.

In using geochemical analysis (e.g., NAA) at sites with very inhomogeneous sediment units ("lumpy" sites), the inhomogeneity in the dose field (Guibert et al., 1998) requires volumetric analysis in which the contribution from each component (Figure 1d, 8d) depends on its abundance in order to calculate the actual contribution to $De_{xt,\Sigma}(t)$ from different components or layers within the β and γ "spheres of influence". That still, however, does not consider the potential changes in $D_{ext,\Sigma}(t)$ due changes in radioisotopic concentrations within the sedimentary components. In lumpy sites, sedimentary components which may be able to absorb U (e.g., peat, teeth, bones, mollusc shells) can constitute a significant sedimentary fraction. If they can absorb U, $D_{ext,\Sigma}(t)$ will probably have changed with time, because,

1. Components such as teeth and bone only absorb U, not all its daughters which ingrow later (Figure 7a).

2. If the uptake occurred early in the sediment's history, its effect will be greater than if it occurred recently. This requires that U uptake into the sediment be modelled analogously to that into teeth (see $D_{int}(t)$ models above; Figure 7c).

3. U or other soluble daughters may have been leached, or Rn may have diffused (Figure 7b), from these components, requiring modelling to assess the effect on $D_{ext,\Sigma}(t)$ (e.g., Pike & Hedges, 2001; Figure 7c).

4. More than one discrete uptake or loss event may have affected these components (Figure 7c).

These sedimentary processes can produce significant differences in the calculated $D_{ext,\Sigma}(t)$ and ages. Therefore, the isochron method is preferred whenever possible, because the sample acts as its own dosimeter, theoretically compensating for inaccuracies due any change in $D_{ext,\Sigma}(t)$.

Precision in ESR dating depends on the method used to measure $D_{ext,\Sigma}(t)$ and the relative radioactive element concentrations. For γ and TL dosimetry, precision tends to average 3-10%, whereas for sedimentary analysis, uncertainties normally range from 5 to 15%. Precision for $\overline{D}_{ext,\Sigma}(t)$ in isochron analysis will exceed that associated with the isochron age, because $\overline{D}_{ext,\Sigma}(t)$ is derived from the age, rather than vice versa. The different measurement protocols do often yield somewhat different estimates for $D_{ext,\Sigma}(t)$ (Blackwell *et al.*, 2000).

THE ISOCHRON METHOD

Isochrons have been applied mainly to teeth (Figure 9), but also fault gouge minerals and stalagmites. With the isochron method, a sample that can yield at least five subsamples is analyzed by standard ESR analysis. If the accumulated doses, $A_{\Sigma,i}$, plotted against the time averaged internal dose rate, $\overline{D}_{int,i}(t)$ for each subsample, i, give a straight line, its slope equals the sample's age, t_1, while the y-intercept yields the accumulated dose due to external sources, Aext, from which can be derived the time-averaged external dose rate, $\overline{D}_{ext,\Sigma}(t)$ (Figure 9a).

In teeth, the method gives a family of lines which converge on Aext, but whose ages and $\overline{D}_{ext,\Sigma}(t)$ each depend upon the U uptake model used to calculate $\overline{D}_{int,i}(t)$ (Figures 9b, 9c). Tests have shown that, if the isochron has a high R^2 for the regression, the slope gives an age consistent with other dating methods (Blackwell *et al.,* 2002a). The isochron method is limited to samples whose internal dose rate, $D_{int}(t)$, constitutes a significant fraction of $D_{\Sigma}(t)$, effectively requiring the sample to contain ≥ 2 ppm U. If samples have lost U or gained U in more than one event, however, isochron analyses may give erroneous ages and/or $\overline{D}_{ext,\Sigma}(t)$ values (Figure 9d; Blackwell *et al.*, 2001a). Precisions for isochron ages and A_{ext} can range

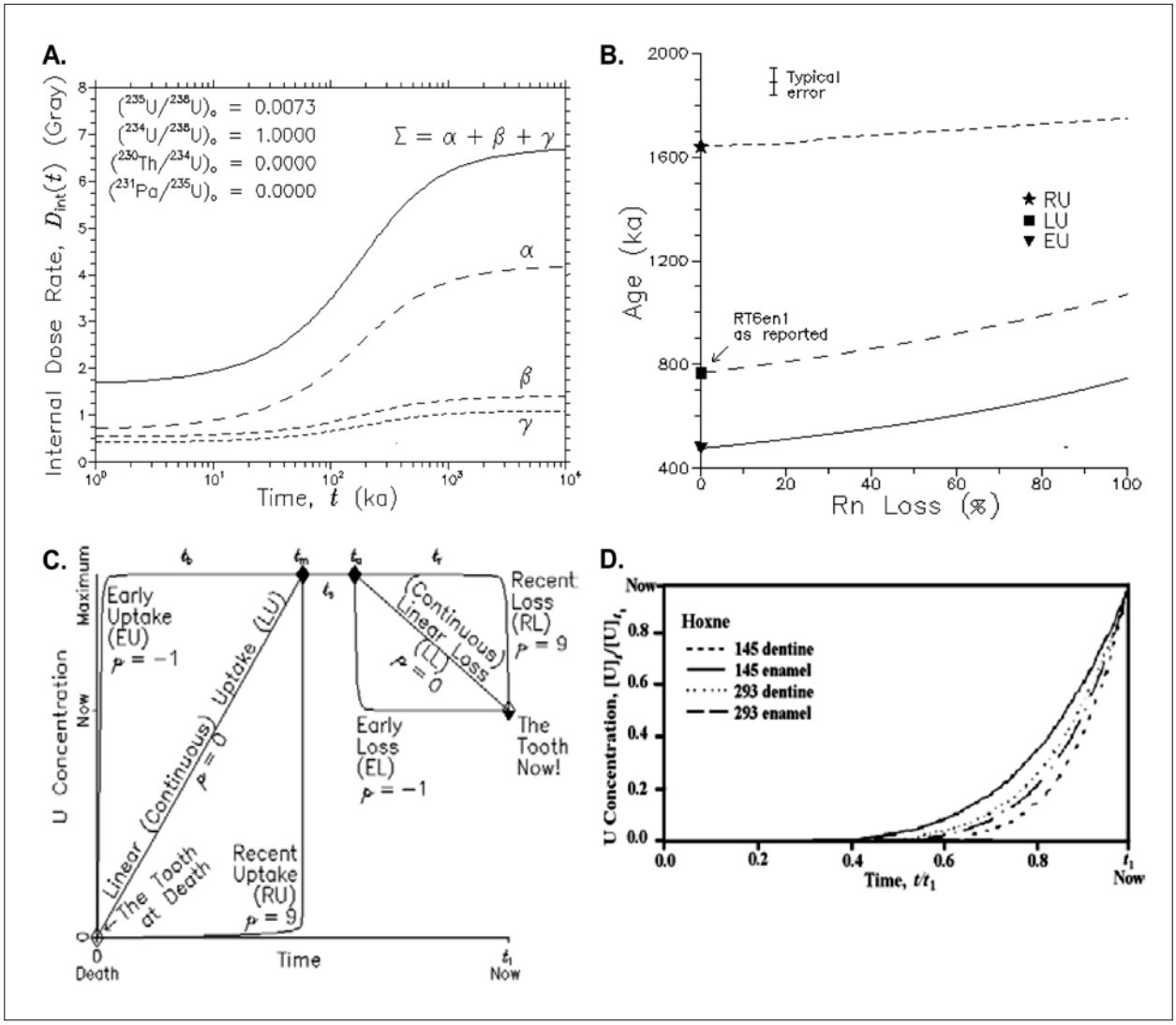

Fig. 7: Factors affecting the internal dose rate, $D_{int}(t)$.

For bones, teeth, molluscs, and other materials containing or capable of absorbing U, U uptake must be measured or modelled. For minerals or fossils capable of losing U or other U daughter products by leaching or degassing, these must also be modelled or measured:

a. $D_{int}(t)$ increases as the sample ages simply from ingrowth of the U daughter isotopes. This plot assumed an early uptake model U absorption of 10 ppm, with no initial Th or Pa.

b. Radon (Rn) gas, produced when U decays, can escape from samples during diagenesis and fossilization, causing $D_{int}(t)$ to decrease, and therefore, affecting the accuracy in the calculated ages. Assuming 0% Rn loss will not contribute significant errors to age calculation for most samples, except those with very high U concentrations. In this mammoth molar from a pond deposit in Hungary, the uptake model significantly affects the age calculation, because the dentine contains relatively high U concentrations, producing significant differences in the various calculated model ages.

c. A combined model for U uptake and leaching: The fossil absorbs all its U immediately after death in the early uptake (EU) model, but it absorbs almost no U until just before attaining its maximum U concentration in the recent uptake (RU) model. Under linear uptake, the fossil absorbs U continuously and constantly throughout the uptake time, and linear leaching assumes an analogous continuous, constant U loss through the leaching period. Under early leaching (EL), the fossil loses U in a geological instant some time before the fossil is discovered, whereas under recent leaching, the loss occurs just before discovery.

d. U uptake in teeth from Hoxne, England: Recent uptake models are applicable in some situations.

More complex models can be devised by combining several uptake and leaching events (adapted from Blackwell, 2001).

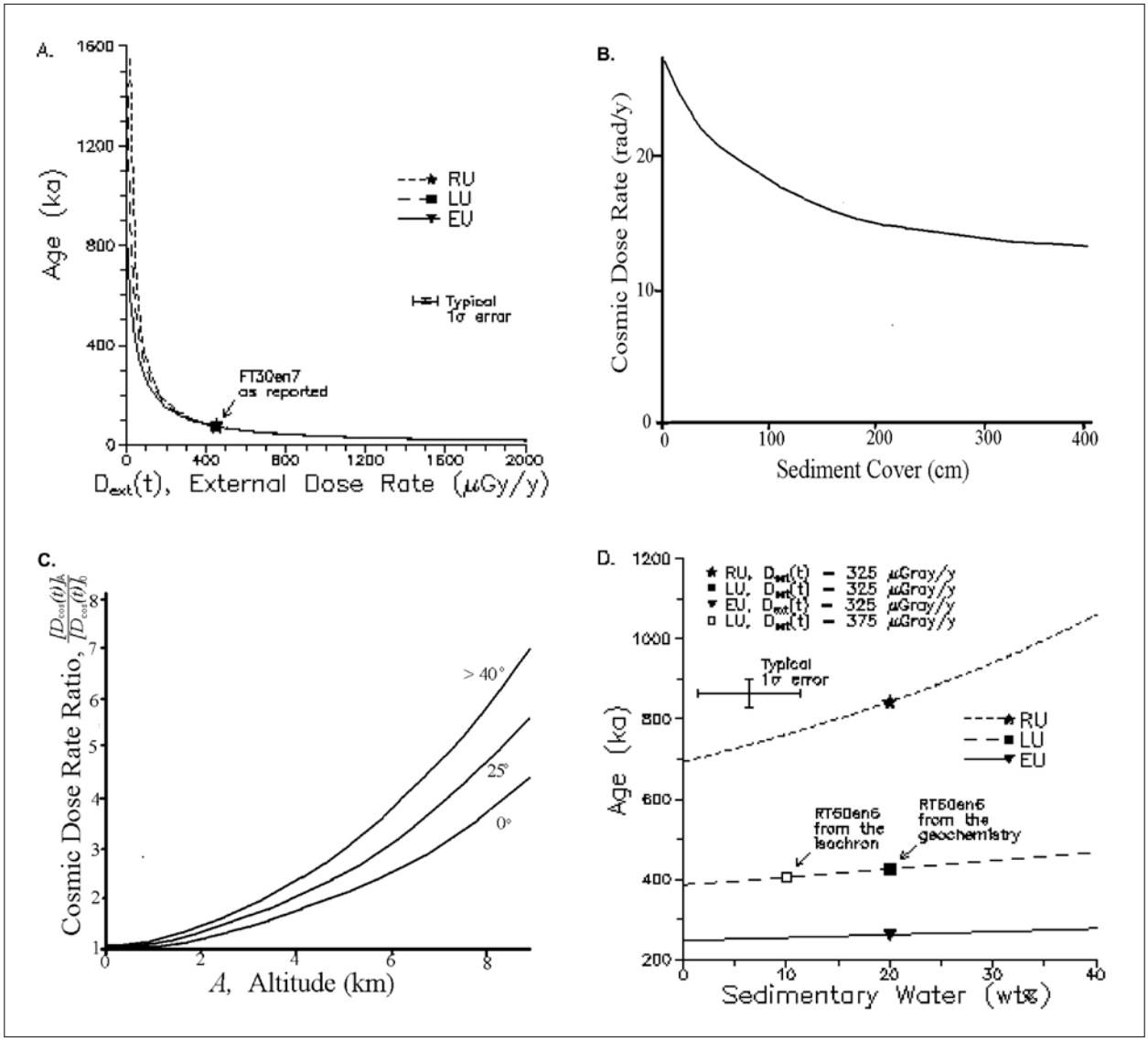

Fig. 8: The effect on ESR ages from the external dose rate, $D_{ext}(t)$.

Dext(t) is a function of many variables, including the water in the sediment and the cosmic dose impacting the sample:

a. *Miscalculated $D_{ext}(t)$'s can dramatically affect the calculated ages, especially for the RU ages. As the external dose rate increases, all the model ages decrease exponentially approaching 18 ka at 2.0 mGy/y. A 200 μGy/y (40%) decrease in the measured $D_{ext}(t)$ would reduce the calculated ages by approximately 13-15 ky (~25%), whereas a 200 μGy/y (40%) decrease would introduce a 26-32 ky (~50%) increase in the calculated ages. These are insignificant compared to the 2 σ uncertainties in the age calculation (Blackwell et al., unpublished data).*

b. *As sediment depth increases above a sample, the cosmic dose contributes less to the total external dose rate. For samples covered by 10 m of sediment, the cosmic dose is negligible.*

c. *At higher altitudes and higher latitudes, the cosmic dose increases.*

d. *Sedimentary water attenuates the external dose reaching the tooth. As the sedimentary water concentration increases, the external dose rate, $D_{ext}(t)$, decreases, but the calculated ESR age increases under all uptake models. Generally, changing the sedimentary water concentration by ±5-10 wt% does not significantly affect the calculated ages, especially for samples where $D_{ext}(t)$ represents a small percentage of the total dose rate, $D_{\Sigma}(t)$, as here. If, however, the sedimentary water concentration changes by > ±10 wt%, the model ages will exceed the reported values by more than the 2 σ uncertainty in many samples, especially under the RU model, as seen here. Using the water concentration suggested by the $D_{ext}(t)$ from the isochron analysis does not produce a significant change (after Blackwell et al., 2005a).*

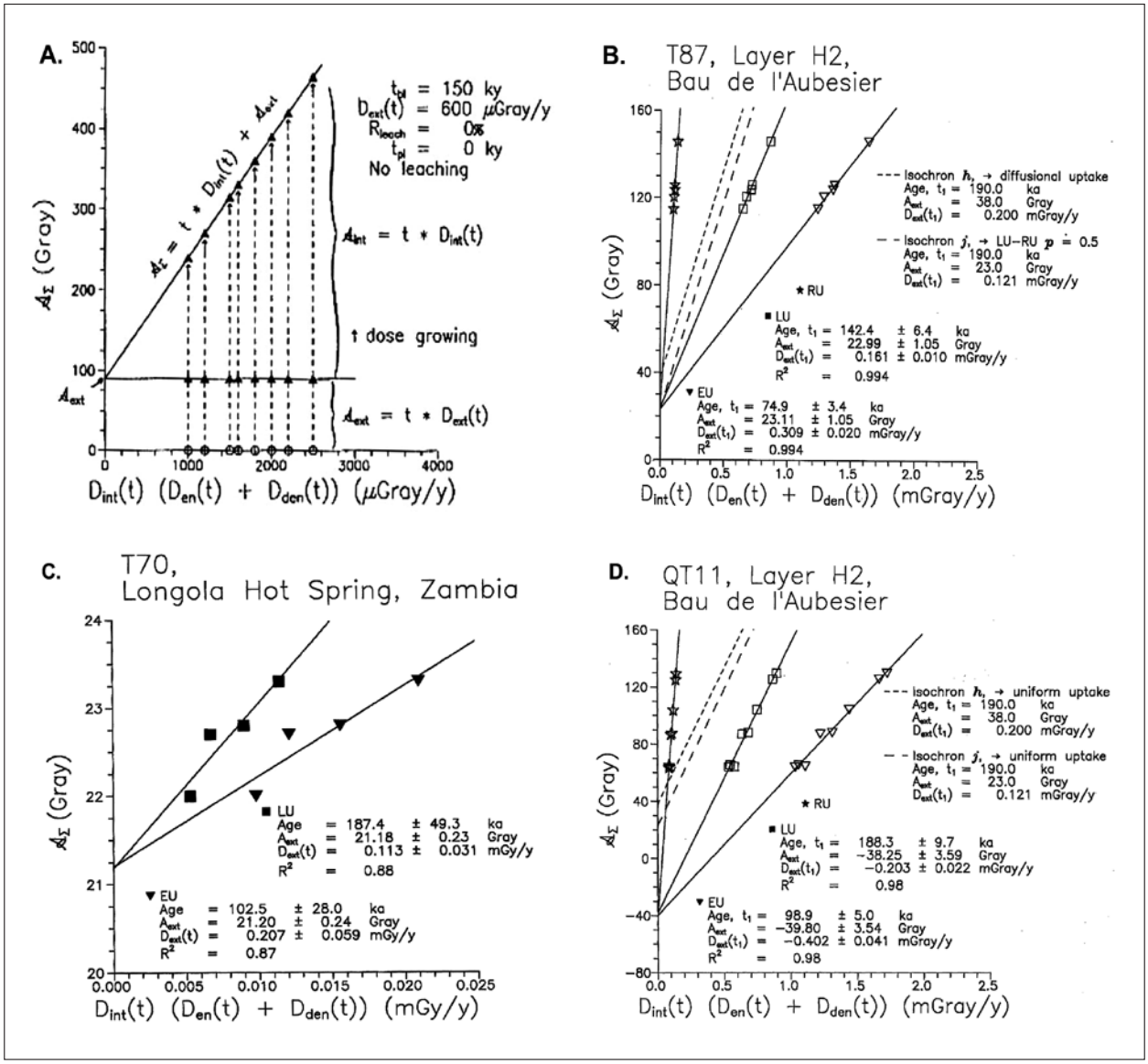

Fig. 9. ESR isochrons.

a. A theoretical plot: When the total accumulated dose, $A_{\Sigma,i}$, for each subsample, i, is plotted versus the time-averaged internal dose rate, $\bar{D}_{int,i}(t)$, the slope of the line gives the sample's age, t, while the y-intercept represents the external accumulated dose, A_{ext}.

b. A plot for a tooth from Bau de l'Aubesier, Provence: In practice, each uranium uptake model produces a line, which all converge on A_{ext}. Isochron analysis can yield ages with uncertainties as low as 4%.

c. An isochron for a tooth from tufa deposit associated with a thermal spring and lake at Longola, Zambia.

d. If a sample, such as this tooth, has experienced U leaching or a second uptake event, the isochron's intercept often becomes negative. In this example, the secondary uptake event must have occurred recently, because the isochron age agrees well with $^{230}Th/^{234}U$ age on adjacent stalagmitic horizons.

$\bar{D}_{int,i}(t)$, and A_{ext} all depend on the U uptake model selected after the first iteration of this technique (adapted from Blackwell et al., 2002a).

as low as 3-4%, but normally tend to be less precise than standard ESR analyses, while minimum uncertainties for $\bar{D}_{ext,\Sigma}(t)$ tend to be ~ 5-6%.

Because the isochron method averages $D_{ext,\Sigma}(t)$ over the entire burial history, isochron analysis automatically corrects for any changes in $D_{ext,\Sigma}(t)$ which may have occurred. By greatly reducing the need to measure $D_{ext,\Sigma}(t)$ in situ or to assume that it has remained constant, it can date samples from environments where $D_{ext,\Sigma}(t)$ are likely to have changed in response to complex sedimentological changes, such as open-air environments. Isochrons can also date samples from sites that have been destroyed or are otherwise inaccessible, especially samples in museum collections.

If an independent method (e.g., TL or γ dosimetry) can be used to measure $D_{ext,\Sigma}(t)$, and if $D_{ext,\Sigma}(t)$ can be shown to have been constant throughout time at the site by geological studies or an independent date, the isochron method can instead determine the U uptake history. Since the isochron calculation gives A_{ext}, which must equal the product of the age, t_1, with $De_{xt,\Sigma}(t)$ the isochron's slope that matches this age represents the "correct" isochron and uptake model for the sample.

ESR MICROSCOPY AND OTHER NEW TECHNIQUES

In ESR microscopy, an ESR spectrometer has been modified to scan across a solid mineral surface to measure the spin concentrations for a preset signal. With specialized analytical programs, 2D, 3D, and 4D ESR imaging is now possible, some of which are combined with other systems such as electrically stimulated luminescence (ESL), NMR and CT (e.g., Miki *et al.*, 1996; Mizuta *et al.*, 2002). ESR microscopy is still being explored to understand its full potential, but it shows great promise in studying fossil diagenesis, mapping crystal growth and defects, among other applications. Currently, it works best for materials with very strong ESR signals, such as tooth enamel (e.g., Oka *et al.*, 1997), bone (Schauer *et al.*, 1996), coral, gypsum, mollusc shells, aragonite, and barite.

Portable ESR dosimeters and spectrometers are used to assess nuclear radiation accidents on site (e.g., Oka *et al.*, 1996). Geoscientists can also use them in the field. In the field, such technology would help to recognize reworked fossils, to aid in selecting the best samples for dating, and to assess the effect of site inhomogeneity on the samples. Eventually, such technology may even allow preliminary age estimates while still in the field.

APPLICATIONS AND DATABLE MATERIALS IN KARST SETTINGS

Within karst settings, ESR can date materials that might provide valuable insight into a cave's or a karst system's history. Dating teeth, molluscs, ratite egg shells, authigenic carbonates or salts can delineate depositional histories and rates. Dates on authigenic cements may date diagenetic events or hydrological changes. Dating fossils, such as molluscs, teeth, and molluscs dates changes in biological diversity and groundwater chemistry. Dating burnt flints or hearth sands from archaeological sites or fossils from karst deposits can indicate the age for associated geomorphic surfaces and hint at paleoclimatic histories. Typical karst process, however, can cause all fossils, especially loose teeth, ratite egg shells, and molluscs, to be reworked (Figure 10).

MOLLUSCS, RATITE EGGS SHELLS, OSTRACODES, AND OTHER CARBONATE FOSSILS

In caves, open-air spring deposits, and karst fissure fills, dating mollusc shells found in the sediment (Table 2) can provide diverse information for Quaternary karst studies. Mollusc shells, however, act as open systems for U, although the moderate discordance between measured $^{230}Th/^{234}U$ and $^{231}Pa/^{235}U$ ratios suggests that most U uptake accompanies sedimentation.

Aragonitic mollusc shells normally show five ESR peaks (Figure 11), but calcitic molluscs have more complex spectra. For the calcitic peaks at g = 2.0018, 2.0007, and 1.9976, trap density is related to Mg/Ca ratios, which can change with diagenesis, secondary mineralization, and fossilization, making them unsuitable for dating some species. Generally, either the peaks at g = 2.0012 and 2.0007 in calcitic shells and the peak at g = 2.0007 in aragonitic shells are the most reliable, but that must be tested for each species individually, because complex peaks do occur and peaks other than that at g = 2.0007 may be light sensitive (Bartoll et al., 2000). Secondary mineralization can cause interference that affects A_Σ measurement and age calculation. Signal lifetimes vary significantly depending on the peak and species (e.g., Blackwell, 1995, Table 2). Some species show inflection points in their growth curves, making it difficult to select an appropriate set of added doses for measuring A_Σ (e.g., Shih *et al.*, 2002). Schellmann and Radtke (2001) advocated using a plateau technique with 40-60 irradiation steps to maximize accuracy in the growth curves.

Petrographic or geochemical analysis should accompany any ESR date to avoid remineralized and recrystallized samples. Contamination from Mn peaks often requires

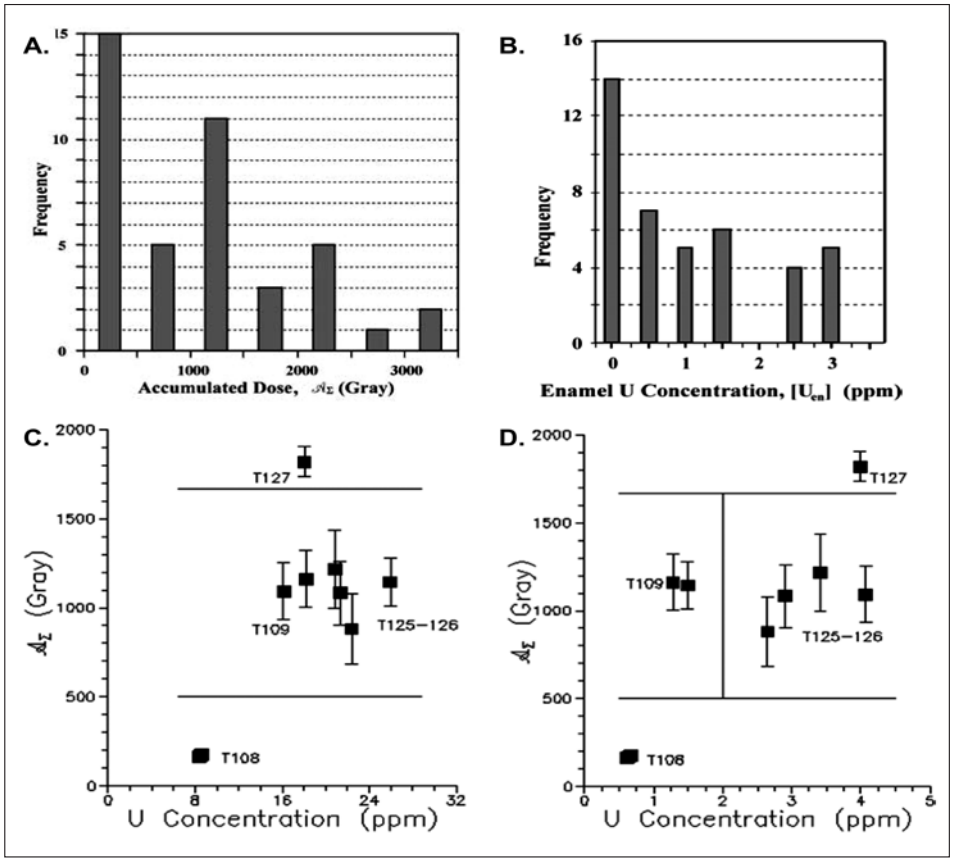

Fig. 10: Tests to check for reworked fossils.

For teeth from Swartkrans, South Africa:

a. The accumulated dose (A_Σ) histogram clearly reveals at least three different populations of teeth.

b. The enamel U concentration histogram shows at least two populations.

c. Plotting A_Σ vs. enamel U concentration reveals four distinct populations.

d. Plotting A_Σ vs. dentinal U concentration shows three different populations well separated from each other. Such plots delineate populations of teeth that have experienced different environmental conditions, one indication for reworking among samples from the same units (after Blackwell, 1994).

overmodulation to discriminate the dating peaks. Due to U uptake, modelling is required for samples that cannot be analyzed by coupled ESR-^{230}Th/^{234}U dating. In some fresh and hypersaline systems, the (^{234}U/^{238}U)o ratio may also need to be measured or modelled. For each species and signal, the β efficiency factor, κ_β, must be measured. Long-term signal fading may also need to be considered, depending on the peak and its thermal stability.

Specimens found in life position give the most reliable results, although that does not guarantee that reworking has not occurred. Larger species are preferred so that each subsample represents a single individual (Table 1), but several shells can be combined from a smaller species, assuming that none have been reworked. Fragmentary samples still need to be speciated. Since species effects do occur, submitting two or three different species from each unit can increase dating precision and accuracy. Good agreement between ESR, TL, ^{14}C, and AAR (amino acid racemization) ages has occurred in studies with *Hendersonia* and *Allogona* using g = 2.0007, in *Lymnaea baltica* and *Cerastoderma glaucum* using g = 2.0012. Thermal stabilities in *Monauha caucaicala* significantly exceeded those in marine molluscs. For untested species, ~ 100 g of pristine shell are needed to perform the necessary signal stability and calibration tests (Balckwell, 2001).

Applications in karst systems have been rare, but terrestrial and freshwater molluscs do give reasonable ESR ages. For example, Molod'kov (2001) reported ages of 393 ± 27 ka for Layer 5b, and 583 ± 25 ka for Layer 7a for terrestrial molluscs preserved in the Lower Paleolithic site at Treugol'naya Cave, Russia.

In ratite egg shells, two signals with good sensitivity exist. Although attempts have been made to date extinct birds, recent stability tests showed a very short signal lifetime, which would severely limit their application for sites older than 30 ka (Skinner *et al.,* unpublished data).

AUTHIGENIC CARBONATES, SPELEOTHEM, TRAVERTINE, CALCRETE, CALICHE

Speleothem and travertine from springs, as well as in swamps and shallow hypersaline lakes, contains calcite or aragonite with several strong signals. Unfortunately, many travertines and some speleothems also contain high organic concentrations that can add interference peaks. Nonetheless, ESR dating of speleothem, travertine, and other authigenic carbonates allow detailed paleoenvironmental determinations, and may document prehistoric human activities.

How post-sedimentary processes affect the ESR signals in authigenic carbonates (Blackwell, 1995, Table 2) is still not well understood. Although most travertine spectra (Figure 12) resemble those for speleothems, which have been extensively studied, other peaks do occur. The humic acid signal at g = 2.0040 does not appear accurate for dating. In Mn-rich samples, the peak at g = 2.0022 yielded reliable ages, but needs testing for annealing behaviour and replicability before general application. The most reliably measured peak occurs at g = 2.0007, while peaks other than that at g = 2.0036 may show light sensitivity (Bartoll *et al.,* 2000). Although many authigenic carbonates lack the peak at g = 2.0007, carefully sampling densely crystallized calcite can increase the success rate. Reliable ages have been found for some travertines, when compared against ^{14}C or U series ages. For some pisolites, calcrete, and caliche, contamination causes complex interference signals that affect accuracy, but preannealing samples before analysis may improve the results (Skinner, 2000).

Because most authigenic carbonates can experience remineralization, secondary mineralization or cementation, petrographic, SEM, XRD, or similar analyses should complement the ESR dating analysis to ensure viable geological conclusions. Otherwise, sample preparation is fast, requiring only powdering and a dilute acid leach to remove any transitory peaks induced by the grinding.

Relatively few ESR studies (e.g., Whitehead *et al.,* 2002) have systematically examined travertine or other authigenic carbonates after problems with the applications were found in the 1990's. Attempts to date the spring travertines from Vertésszőlős, Hungary, failed to reveal a datable signal without interference (Skinner et al., unpublished data). Modern signal subtraction and multiband studies might resolve some problems and improve the reliability for these applications (Kinoshita et al., 2004).

HYDROXYAPATITE (HAP), VERTEBRATE FOSSILS AND CRUSTACEAN CHITIN

ESR analysis can date hydroxyapatite (HAP), because a single radiation-sensitive ESR signal occurs at g = 2.0018 in fossil, but not modern enamel (Figure 1d; Tables 1, 2). Currently, most labs use placental mammal enamel, but marsupial and shark enamel also have datable signals (Blackwell et al., 2002b, 2004). Presumably, any vertebrate enamel should be datable, but this needs verification for each taxonomic order by extensive testing before general applicability can be assumed because tests with crocodile enamel showed Fe interference problems that hampered dating (Blackwell et al., unpublished data). Bones, dentine, some fish scales, and crustacean chitin also show the same signal (Figure 13) which grows similarly to that in tooth enamel. Rink et al. (2003) used the signal in authigenic apatite veins to date sequences in Tabun Cave, Israel, but non-organic apatites often lack radiation sensitive signals (Skinner et al., unpublished data). In tissues other than enamel, the signals do not fade, but their low sensitivity causes very low signal intensity unless the sample age approaches 0.8-1 Ma. Since diagenetic alteration in bone also complicates its use, bone dating has largely been abandoned in favour of enamel. Analyses for enameloid fish scales (e.g., gar, Lepisosteus) have been developed, but need further testing. In addition to interference problems, other fish scales do not appear to give sufficiently large signals for accurate dates. In HAP, ESR dates must consider U uptake and ingrowth by U daughters, as well as possible Rn loss and U leaching (Figure 7).

In HAP, the long ESR signal lifetime, $\tau \sim 10^{19}$ y (Skinner *et al.,* 2000), guarantees its utility. In mammals, its radiation-sensitivity does not depend on species, but does depend on the crystallinity which is affected by the animal's age and health (Skinner *et al.,* 2001a). In deciduous teeth (i.e., "milk" teeth), poorly crystallized HAP causes analytical problems. Although signal saturation depends on the sample's U concentration, saturation in enamel generally does not occur before the tooth is ~ 5 Ma. Teeth as old as 4.0 Ma have been dated successfully. Although some teeth as young as 8-10 ka have been dated, dosimetry experiments suggest that teeth with doses of ~ 0.05-0.1 Gray may be datable (Wieser *et al.,* 2005). Currently, few attempts have made to dates sites younger than ~ 25-30 ka (~ 2-5 Gray), because ^{14}C dating is usually used instead.

The standard ESR method (i.e., not isochrons) for tooth enamel has now been tested extensively against other dating methods for sites in the age range 30-300 ka (Blackwell, 2001, Table 1), but for teeth > 300-400 ka, relatively few calibration tests have been attempted. Archaeological applications have been extensive. Despite calls for much more complex measurement protocols

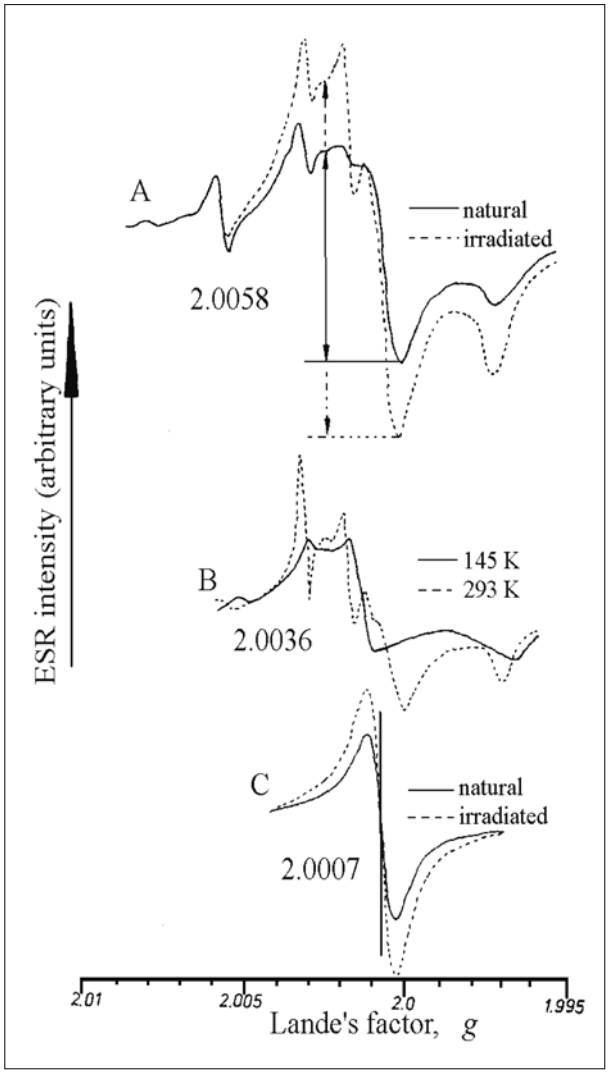

Fig. 11: ESR spectra in aragonitic mollusc shells.

Three signals commonly occur in aragonitic mollusc shells (adapted from Blackwell, 2001):

a. The signal at g = 2.0058 before and after irradiation measured at room temperature.

b. The signal at g = 2.0036 measured at room temperature (293°K) and at 145°K.

c. The signal at g = 2.0007 before and after irradiation measured at room temperature.

(e.g., Grün, 2002; Vanhaelewyn *et al.,* 2000), Q band tests indicate that, although the peak is complex, it grows uniformly and can be accurately measured by a simple peak height measurement without deconvolution (Skinner *et al.,* 2000). Human dosimetry experiments (Blackwell, 2001, Table 1) have hinted at possible problems with interference, temperature sensitivity, and signals induced by grinding and UV light exposure. Several researchers have suggested complex preparation techniques to compensate for these problems (e.g., Onori *et al.,* 2000), but their effect on teeth older than 10 ka must be minimal or the ESR ages would not agree with those from other dating methods. While standard ESR can still be improved methodologically, such as by fully understanding U uptake, this does not hamper its application, especially in many caves, where the dental U concentrations were so low that all the model ages are statistically identical (Figure 8a; e.g., Skinner *et al.,* 2005).

For the isochron method in enamel, calibration tests have been completed against $^{230}Th/^{234}U$, $^{40}Ar/^{39}Ar$, and standard ESR (e.g., Skinner *et al.,* 2001b). Disagreements between standard ESR and isochrons imply changes in $D_{ext}(t)$ or secondary U remobilization (Blackwell *et al.,* 2001a, 2001b).

For enamel dating, molars and premolars from large herbivores make the best specimens, because both isochron and standard ESR analyses can be completed. Very small teeth are analyzed with the ramped dosing technique, but the enamel must be separated from the dentine manually. For small teeth, several teeth from the same jaw can be attempted for isochron analysis. ESR dating does not require that mammal teeth be fully identified, but other vertebrate groups have not been tested sufficiently to preclude taxonomic identification. Fragmentary teeth are fine, providing enough enamel and dentine remains for analysis (Table 1). For example, one mammoth molar plate provides enough enamel for an isochron. New non-destructive techniques using smaller teeth are being developed, but are not yet routine.

For bones, dentine, ivory (mixed dentine and enamel), and antler, the method is more difficult to apply and has not been particularly successful. Their low signal sensitivity causes, if nothing else, a much higher minimum age limit. For dentine, tests suggest that sensitivity problems can be overcome by using it to date teeth > 1 Ma (Blackwell *et al.,* 2002c). Diagenetic minerals in dentine cause few problems, except further lowering sensitivity (Skinner *et al.,* 2000). In bone, tusk, and antler, contaminants and secondary mineralization can also complicate the signal measurement. Since all these tissues can absorb significant U, uptake modelling becomes even more essential in determining accurate dates. Crustacean shell chitin shows a typical HAP signal, but the method needs development to determine if it might be applicable to brine shrimp or other chitinous species.

In caves, the applications have been too numerous to detail them all, but open-air karst applications have been more limited (Blackwell, 2001, Table 1). Dating at human paleontological and archaeological sites has been the most common use (e.g., Falguères, 2003), but non-hominid faunal applications (e.g., Godfrey-Smith *et al.,* 2003) are becoming more common. ESR dates combined

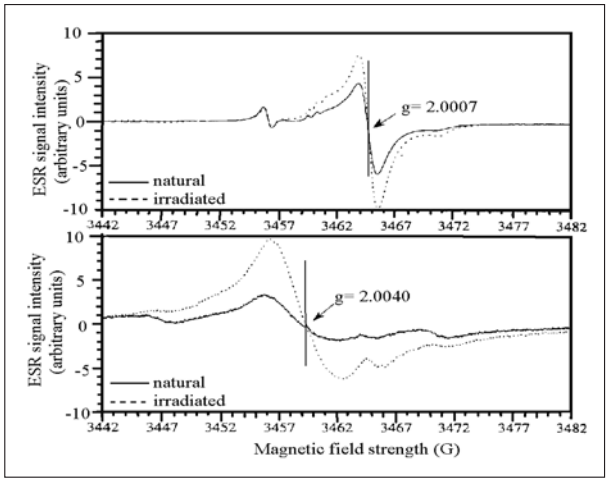

Fig. 12: ESR spectra in tufa and travertine.

In tufa and other slowly precipitated carbonates, the ESR spectra can vary dramatically, often due to interference signals from included organic matter, contaminant minerals, and trace elements (adapted from Blackwell, 2001).

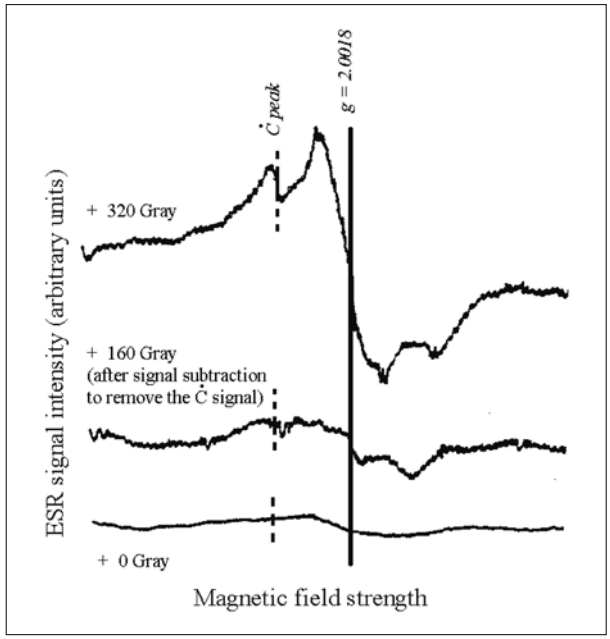

Fig. 13: The ESR hydroxyapatite signal in Lepisosteus platostomus (gar) scales.

In these scales from the Sangamonian lake at Hopwood Farm, IL, low signal intensity in the natural sample (lower) makes the signal difficult to discern, but artificial irradiation reveals the distinctive hydroxyapatite signal at g = 2.0018, along with a carbon radical signal that partially interferes with the dating signal.

with faunal, palynological, and geomorphological data at Treugol'naya Cave, in the Russian Caucasus, have begun to describe an extensive OIS 11 sequence (Doronichev *et al.,* 2004). Blackwell *et al.* (2001b) used ESR isochrons to assess U uptake and ages for the hominid site at Bau de l'Aubesier.

At Divje babe I, Slovenia, a flute made from cave bear bone was found associated with Mousterian artefacts. Initially, Lau *et al.* (1997) showed the flute to be > 43 ka. Altogether, more than 40 subsamples were dated from 16 *Ursus spelaeus* (cave bear) teeth found in Layers 8 through 20 to build a detailed and precise chronostratigraphic sequence (Figure 14a) which allowed other sedimentological analyses to be tied to an absolute time sequence (e.g., Figure 14b; Turk *et al.,* 2001). The resulting paleoclimatic interpretations were correlated with other global climatic events (e.g., Figure 14c; Turk *et al.,* 2002).

HEATED SILICA: VOLCANIC ASH, IGNEOUS ROCKS, BAKED SEDIMENT, BURNT FLINT AND CHERT

Cave and karst sediment may preserve volcanic ash, tektites, and baked sediment, but few ESR applications have been attempted. Heated chert and flint artefacts occur in archaeological sites associated with Late Pleistocene and Holocene karst.

Quartz and silica exhibit several radiation-sensitive ESR signals (Figure 15). Due to the Ti and Ge signals' low sensitivity, fast saturation, and propensity for bleaching (e.g., Woda *et al.,* 2001), most studies use the OHC, E', or Al signals. Some samples do require signal subtraction to remove trace contaminant interference signals (Figure 6b). Because quartz does not absorb U over time, its age calculations do not require modelling for U uptake like tooth enamel. To provide meaningful dates, any preexisting geological signals, however, must have been zeroed completely during the depositional event (Figure 2b). In some flint, an unbleachable component may survive typical heating (Skinner, 2000). Signal lifetimes of $\tau \leq 100$ y were measured for the E' and Al signals, but heated flints show much longer lifetimes, suggesting that the signals' kinetics may change on heating. A short-lived interference signal, E'_1, with $\tau = 40$ y, can interfere with E' signal measurement in some heated quartz samples (Toyoda, 2004), complicating dating for volcanic rocks and impact craters.

For burnt flint, chert, and quartz sand (Tables 1, 2), calibration tests against other methods and more basic studies are needed. The precision for A_Σ values from ESR compares well with those obtained from TL on the same materials. Flints and cherts as young as 10-20 ka may be datable, but the maximum dating limit, which depends on the flint type, has not yet been well established. Applications to dating burnt sand and volcanic ash are even less advanced, but theoretically feasible. Ulusoy (2003) and Beerten et al. (2003) have both been experimenting

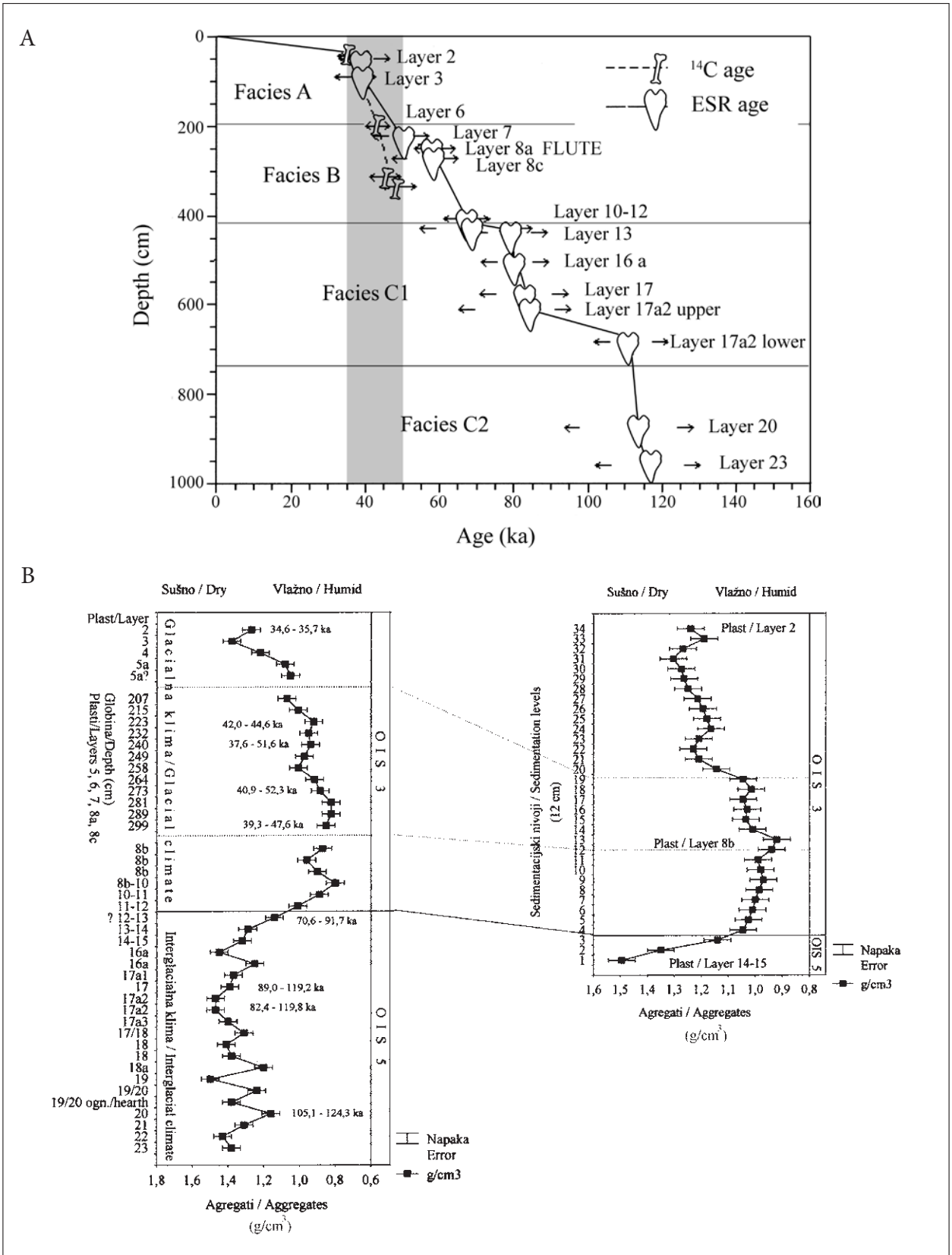

Figure 14: ESR dating at Divje babe I, Slovenia.

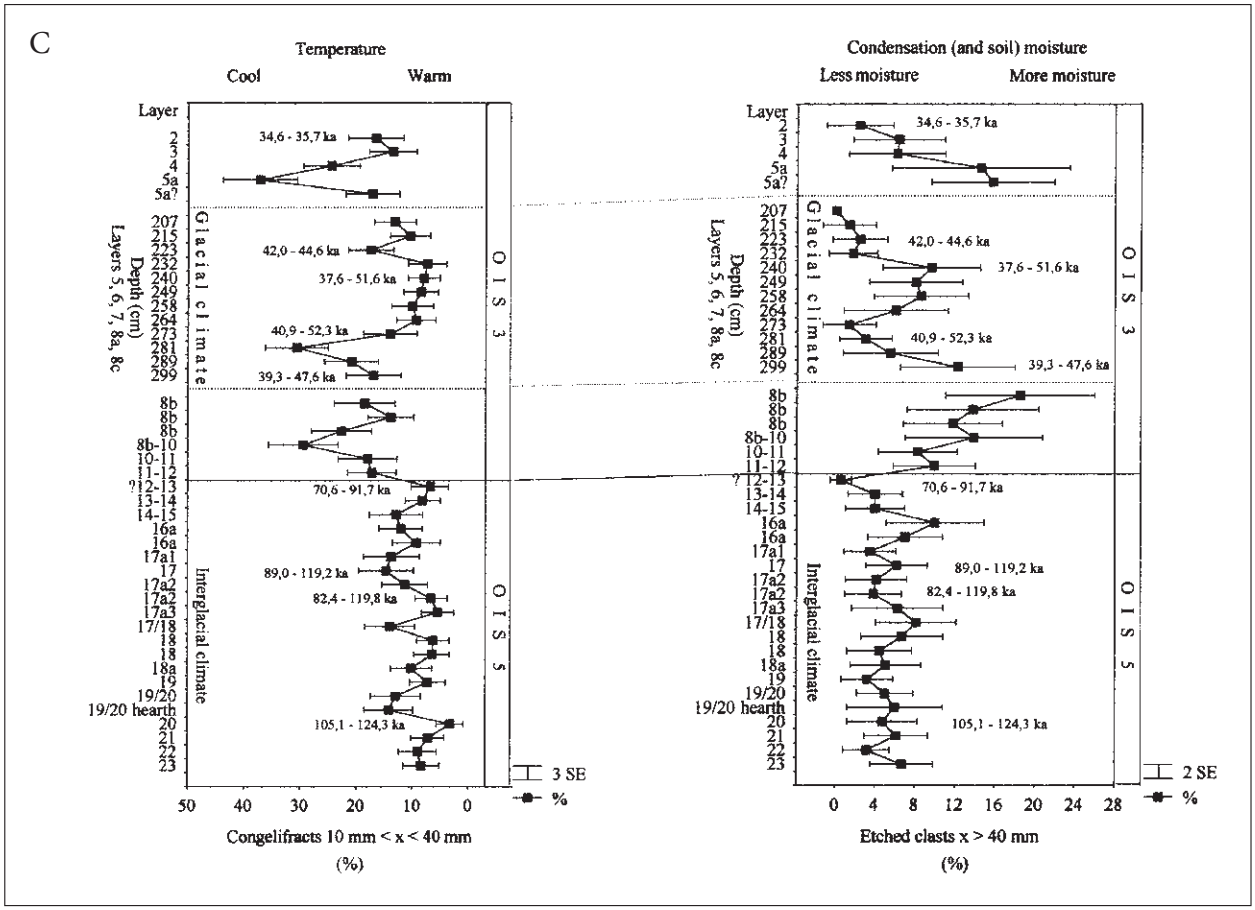

Fig. 14: ESR dating at Divje babe I, Slovenia.

Recently, a well dated sequence at Divje babe I cave, Slovenia, was coupled with detailed sedimentological analyses to develop detailed paleoclimatic interpretations and correlations with global climatic episodes:

A. The 16 teeth dated by ESR and four bones dated by ^{14}C show that the cave filled in episodically, with depositional hiati at approximately 420 and 590 cm below datum.

B. Given the dates for the layers, aggregate analyses from the fine sediment fraction can be correlated with the global OIS curve (Turk et al., 2001).

C. The ESR, aggregate, and other sedimentary analyses combine to indicate paleoclimatic variations for the area around Divje babe I during the late Pleistocene (Turk et al., 2002).

with single crystal techniques for dating quartz. Tani et al. (1998) examined the thermal history for a flint artefact based on its ESR signals.

STRAINED QUARTZ AND FELDSPAR, FAULT GOUGE, MYLONITE

In many karst systems, caves develop along faults. ESR can date the most recent, and sometimes several earlier, fault movements (Figure 16), allowing complex tectonic histories to be unravelled. In Japan, the technique has been widely applied to numerous faults (Blackwell, 2001, Table 1), but few directly associated with caves. Tatumi *et al.* (2004) reported potentially datable signals in feldspar, while Mittani *et al.* (2004) tried using the $[Pb\text{-}Pb]^{3+}$ center in amazonite.

In dating gouge, strain zeroes the signals in the gouge minerals (Figure 3). Several grain sizes must be tested to ensure that the signals have been completely reset. Most researchers use the *E′*, OHC, or Al signals in quartz (Figure 15) or occasionally feldspar, but the grains must be selected by hand after heavy mineral separation and HF leaching to ensure that only gouge minerals with no secondary overgrowths are used. Lee and Schwarcz (2001) advocate using at least two signals to ensure accuracy.

QUARTZ ZEROED BY LIGHT, BEACH SAND, LOESS, FLUVIAL SEDIMENT

If a radiation-sensitive ESR signal found in quartz can be completely zeroed by exposure to strong light, as can

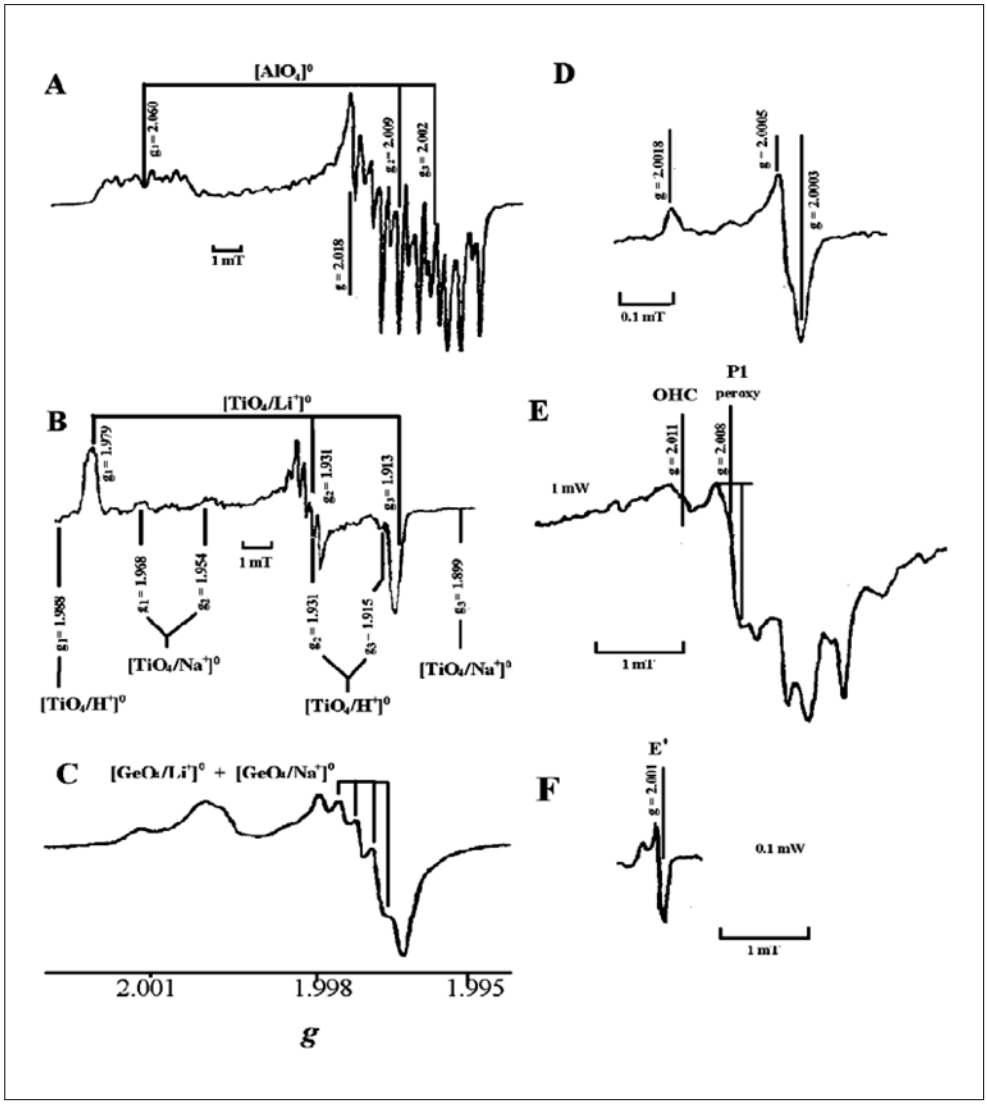

Fig. 15: ESR signals in quartz.

Several signals occur in quartz, flint, and fault gouge minerals (adapted from Blackwell, 2001):

a. The aluminum (Al) signal, often used for dating fault gouge, must be measured at 70°K. It is an $(AlO_4)^0$ defect.

b. The titanium (Ti) signal, which has not been used often for dating arises from $(TiO_4/H^+)^0$, $(TiO_4/Li^+)^0$, $(TiO_4/Na^+)^0$ defects.

c. Because the germanium (Ge) signal is more easily bleached than most other signals in many quartz samples, it is used for dating quartz sediment. This complex signal arises from overlapping $(GeO_4/Li^+)^0$ and $(GeO_4/Na^+)^0$ defects.

d. The E' signal at g = 2.0001 is easily measured at room temperature to date quartz, flint, and fault gouge.

e. The complex oxygen hole centre (OHC) signal and the P1 (peroxy) signal are also measured at room temperature. OHC has been used to date quartz, flint, and fault gouge.

the Ge signal (Figure 2a), then its deposition in a shallow subaerial environment can be dated. As yet, it remains controversial whether any signal is completely zeroed during natural deposition (e.g., Toyoda *et al.*, 2000; Voinchet *et al.*, 2003). If sediment does not bleach completely, then any ages become maximum ages. Since most applications attempted thus far have used dubious analytical techniques (e.g., Blackwell, 2001,), deciding if the results are fortuitous or genuine is difficult. Although these techniques await several basic theoretical studies, the recent successes with TL and OSL using similar sediment suggest that the potential exists here for many applications.

AUTHIGENIC QUARTZ: PHYTOLITHS, DIATOMS, CEMENT, LATERITE, AND SILCRETE

Both diatoms and phytoliths theoretically should be datable by ESR. Having a suitable signal, phytoliths need further investigation. Inherently, diatoms should also

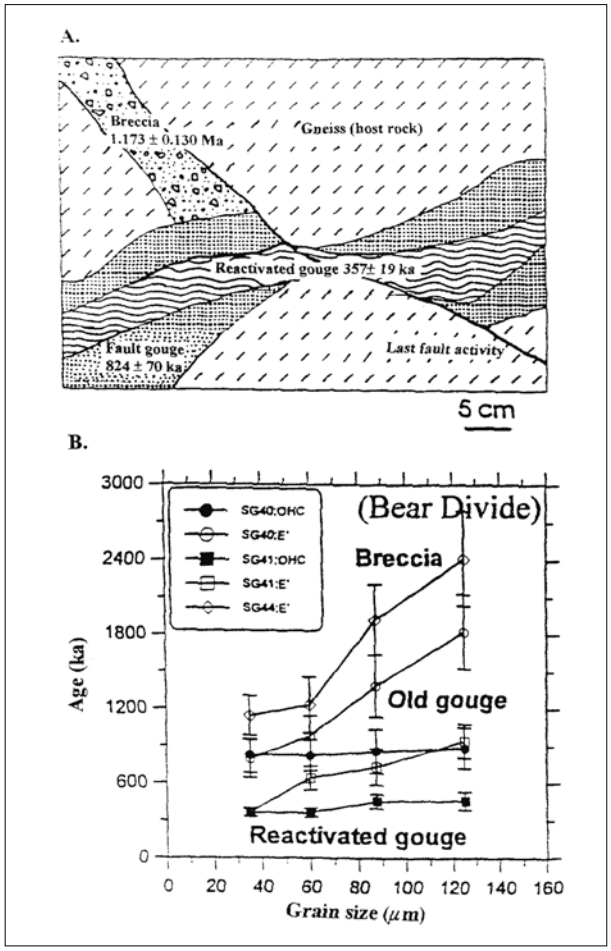

Fig. 16: Fault gouge dating.

In fault gouge from the Bear Divide, San Gabriel Fault, CA, the gouge records several periods of activity:

a. At least three earthquakes occurred in this outcrop at 357 ± 19, 824 ± 70, and 1173 ± 130 ka.

b. Plotting the ESR ages vs. grain size shows different plateaux in old and reactivated fault gouge.

(after Lee & Schwarcz, 1994).

have radiation sensitive signals similar to those in other quartz. In both, the ESR signals should be zero when the crystals form, thereby eliminating the problem of incomplete zeroing seen in other quartz applications.

Were one able to date laterite and silcrete, much geomorphic information might be discovered, but early attempts have not been systematically verified. Diagenetic alteration and secondary cementation may complicate these applications, creating complex curves. Nonetheless, all these have potential that should be developed further.

CLAY MINERALS

Several clay minerals have viable ESR signals. Both kaolinite and montmorillanite have an OHC signal associated with their silicate layers. In the latter, the stability, $\tau = 10^7$ years at surface temperatures, suggests that its applicability for dating should include at least the Middle and Late Quaternary. Montmorillanite also has a radiation-sensitive carbonate signal, but with even lower stability. Radionuclides in associated Fe-oxides cause the signals in kaolinite, which have been used to fingerprint and source the clays. Fukuchi (2001) has tried using the OHC signal in montmorillanite to date Japanese faults. Bensimon *et al.* (2000) examined signal stabilities in natural clay signals. All these methods still need much development before routine application will be possible.

OTHER SALTS: DOLOMITE, GYPSUM, GYPCRETE, HALITE, SULPHATES

Dating salts can provide detailed information about associated karst features. Since salts frequently experience diagenesis, remineralization, and cementation, they require petrographic or geochemical checks to ensure accurate ages.

Several salts have strong ESR signals (Blackwell, 1995, Table 2). Strong radiation-sensitive signals in other carbonates, sulphates, and phosphates all show potential to be developed into viable techniques. Useful signals may also exist in rare salts with analogous geochemical formulae, but few have been examined. Success may hinge on the salts' purity, since the organic radicals, especially from humic acids, common in some subaerially precipitated salts tend to interfere with dating signals (e.g., Debuyst *et al.,* 2000).

As yet, ESR dating has been attempted only for gypsum, anhydrite, halite, monohydrocalcite, dolomite, and barite, but not with unqualified success. Preliminary results on salt deposits indicate that signal intensities increase with sampling depth, but agreement with other dating methods has been poor. In gypsum, the g = 2.0082 signal gives the best results. Ulusoy (2004) studied gypsums from Turkey. Attempts to use gypcrete were hampered by the difficulties in obtaining sufficient sample for adequate growth curves to determine the β efficiency factor, k_β, which must be measured for each sample, due to differences in the precipitation history. Kohno *et al.* (1996) measured an accumulated dose in a barite desert rose. Once the idiosyncrasies in sample preparation have been standardized, these applications should provide interesting details about karst systems.

OTHER APPLICATIONS

Other applications include using ESR imaging systems to explore mineral (e.g., Gotze & Plotze, 1997) and fossil growth and diagenesis (e.g., Tsukamoto & Heikoop, 1996). Omura & Ikeya (1995) used ESR microscopy to

map gypsum crystal growth. Similar techniques could theoretically be applied to other salts. In a rather simplistic approach, Yugo *et al.* (1998) proposed a model for paleowind patterns based on the provenance of aeolian quartz dust as determined by the ESR intensity.

CONCLUSIONS

In caves, abris, and karst fissures, ESR dating has been particularly effective at dating teeth. While rare in caves, dating with molluscs, and other fossils also are easily applicable. Other methods have and are being developed that may prove extremely useful in future, including dating gypsum, dolomite, quartz, and other minerals.

In open-air karst settings, one must expect that changing sedimentary water concentrations, secondary leaching or addition of U or Th in the sediment, and changing cosmic dose rates in response to burial will affect the external dose rates. Therefore, accurate dates must consider these phenomena carefully. While this complicates the age calculations, ESR can still provide accurate dates for many materials found associated with open-air karst environments, including teeth, egg shells, mollusc shells, burnt flint, fault gouge, and possibly for foraminifera, phytoliths, diatoms, and ostracodes.

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THE HISTORY OF POSTOJNSKA JAMA: THE 1748 JOSEPH ANTON NAGEL INSCRIPTIONS IN JAMA NEAR PREDJAMA AND POSTOJNSKA JAMA

ZGODOVINA POSTOJNSKE JAME: NAGLOV NAPIS V JAMI PRI PREDJAMI IN POSTOJNSKI JAMI IZ 1748

Stephan KEMPE[1], Hans-Peter HUBRICH[2] & Klaus SUCKSTORFF[3]

Abstract UDC 551.44(497.4 Postojna)(091)

Stephan Kempe, Hans-Peter Hubrich & Klaus Suckstorff: The history of Postojnska Jama: The 1748 Joseph Anton Nagel inscriptions in Jama near Predjama and Postojnska Jama

Jama near Predjama and Postojnska Jama, Slovenia, are known for their rich body of historic inscriptions spanning over several centuries. Early explorers and visitors left names, dates and symbols. Here we present the inscriptions by the mathematician Josef Anton Nagel (1717-1794). Nagel and the painter and engineer Alois Schaffenrath (1794-1836) are the only ones that we can trace in both of the caves. Nagel visited the caves in July 1748 on order of Emperor Franz I. The inscription in Jama near Predjama is (for cave inscriptions) rather long and written in Latin, giving name, profession, cause and date of the visit, while the inscription in Postojnska Jama is rather short, giving only name and date of visit. Unfortunately the inscription in Jama near Predjama is already partly obliterated by an incautious visitor.

Key words: history of speleology, cave inscription, J. A. Nagel, Jama near Predjama, Postojnska jama, Slovenia.

Izvleček UDK 551.44(497.4 Postojna)(091)

Stephan Kempe, Hans-Peter Hubrich & Klaus Suckstorff: Zgodovina Postojnske jame: Naglov napis v Jami pri Predjami in Postojnski jami iz 1748

Jama pri Predjami in Postojnska jama sta znani po številnih zgodovinskih napisih, ki obsegajo čas več stoletij. Zgodnji raziskovalci so zapustili imena, datume in simbole. V prispevku so predstavljeni napisi matematika Jožefa Antona Nagla (1717 -1794). Le Nagla ter slikarja in inženirja Alojza Schaffenratha (1794-1836) je mogoče zaslediti v obeh jamah. Nagel je obiskal ti dve jami julija 1748, po ukazu cesarja Franca I. Napis v Jami pri Predjami, ki je za napise v jamah precej dolg, je v latinščini ter navaja ime, poklic, vzrok in datum obiska. Napis v Postojnski jami je precej kratek, le ime in datum obiska. Žal je nepazljiv obiskovalec del napisa v Jami precej poškodoval.

Ključne besede: zgodovina speleologije, napis v jami, J. A. Nagel, Jama pri Predjami, Postojnska jama, Slovenija.

INTRODUCTION

Inscriptions in caves are an important historic source. They inform about when cave visits began, when they peaked and who was visiting the caves. Specifically important are inscriptions of historically known persons. In this respect Postojnska jama is a speleohistoric treasure chest. This is, for example, completely different in case of the Baumann's Cave, Harz Mountains, which also contains hundreds of signatures, none of which so far was matched with a historically known person (for the early history of the Baumann's Cave see Kempe *et al*., 2004b).

[1] Prof. Dr. Stephan Kempe, Institute for Applied Geosciences, University of Technology Darmstadt, Schnittspahnstr. 9, D-64287 Darmstadt, Germany, e-mail: kempe@geo.tu-darmstadt.de;

[2] Dipl.-Ing. Hans-Peter Hubrich, Am Langenmarkstein 31, D-64686 Lautertal;

[3] Klaus Suckstorff, Rosenweg 42, D-21502 Geesthacht.

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Nevertheless, even in the Postojnska Jama inscriptions have not been researched extensively. An earlier paper on the pre-1818 inscriptions in the old cave (Kempe, 2003) focused mostly on the fact that these inscriptions have survived largely unaltered since they were first reported by Volpi (1821) and Hohenwart (1830, 1832a,b). Later (Kempe *et al.*, 2004a) dealt with the inscriptions in Pisani Rov (Erzherzog Johann Grotte), specifically with those of an inscription column, initiated by Alois Schaffenrath in 1825. Most recently Kempe (2005) discussed the "Tartarus Panel" that also was established by Schaffenrath in March 1825, but that also contains the signatures of the Fercher survey party of 1833. In addition to these signatures, letters were published for the first time, illustrating the background of the cooperation between the administration of the Adelsberger Grotte and the direction of the mercury mine at Idria during the survey.

One of the earliest historically known persons who left inscriptions in the investigated caves was Joseph Anton Nagel (1717-1800). He visited the caves of Carniola (Krain) in 1748 and left a hand-written manuscript about his visits. Here we give pictures of both his inscriptions in Jama near Predjama and Postojnska Jama, report on their conditions and give an overview of what he had to say about the two caves.

JOSEPH ANTON NAGEL

Joseph Anton Nagel was born in Rietberg (Rittberg), Westphalia on February 3rd, 1717, and received his training as a mathematician at the "Hohe Schule von Paderborn" (Wurzbach, 1869; Schönburg-Hartenstein, 1987; Killy & Vierhaus, s.a.). Possibly on recommendation by his country lord, Wenzel Anton Graf Kaunitz, (since 1764 Reichsfürst of Kaunitz-Rietberg) who held various offices at the court in Vienna since 1737, Nagel was able to continue his studies at the University of Vienna. After a short stay at Brünn and an administrative position at the Upper-Hungarian salt mine of Soowar, he found employment at the imperial-royal court where he worked in the administration, a position that did not challenge his profound mathematical talent.

Franz I (reigned 1745–65), the Emperor of the Holy Roman Empire of German Nation (not to be confused with Franz II, the last emperor of the Holy Roman Empire reigning 1792–1806 and who became Franz I, the Habsburgian Austrian Emperor, in which function he reigned 1804–1835) ordered Nagel to study natural curiosities, finally a task according to his talents that took him on travels throughout the Empire, first within Austria in 1747 and then to Carniola and Moravia in 1748. Nagel spent several weeks in Carniola (Slovenia) in summer of 1748. He duly delivered reports to the court (Nagel, 1748) that remain still largely unpublished (see Shaw, 1992). At around 1760 Nagel became a mathematician of the Habsburgian court and teacher of Erzherzog Karl Joseph and travelled abroad to France, England, the Netherlands, Hungary and Tyrol. On initiation by Maria Theresia he began to work on a map of the city of Vienna (1770 and 1779) and its suburbs (Ground plan of the Imperial-Royal Residence City Vienna, its suburbs and neighbouring towns) which was published as a copper etching in 1780/81. He also produced a map of the inner city of Vienna in 1774. Furthermore, he served as the director of the physical cabinet from 1770 until after 1790. In 1775 he was appointed director of the Philosophical Faculty of the University of Vienna, a position he held until his retirement at around 1790. Nagel died in Vienna on May 6th, 1794.

HIS REPORTS

The reports delivered by Nagel were hand-written in Current, the handwriting for official documents. The manuscripts about three of his early excursions were not published at the time (see Shaw, 1992). These are the descriptions of the Ötscher Mountain in 1747, about his travel to Crain and Moravia in 1748, and about his journey to Holic/Hungary. His account of the earthquake of 1768 was published in print.

During his Crain and Moravia excursion Nagel spent several weeks in Slovenia in summer of 1748. The manuscript related to his observations has 97 pages and 22 figures. It is kept at the Austrian National Library at Vienna (MS N. 7854). We have now transcribed it entirely, planning its publication in full length. It is baroquely titled:

Beschreibung
deren
Auf allerhöchsten Befehl
Ihro Röm: Kayl: und Königl:
Maytt: FRANCISCI I
untersuchten, in dem Herzogthum
Crain befindlichen Seltenheiten
der Natur

(Description of the curiosities of nature of the Herzogtum Crain studied by highest order of his Roman Emperial and Royal Majesty, Franz I.)

In this text we find many references to karst and caves, among them the "Lueger Höhle" (Jama near Predjama) and the "Adelsberger Grotte" (Postojnska Jama).

In the beginning of his report, Nagel clarifies some of the tales in VALVASOR's epic chronic (1689) that, as he explains, rest on wishful thinking, unproven hear-say and superstition but not on reality. In many cases he corrected doubtful passages by his own observations or by factual logic. He lists the following examples of distorted facts:

– catching crabs by whistling;
– hunting „Pilliche" (i.e. Bilche, Siebenschläfer, engl. dormouse, *Glis glis)* with boots and coats spread out on the ground;
– attracting leeches in Cerkniško jezero by singing;
– making „Heimchen" (i.e. the house cricket, *Acheta domestica)* appear by magic spells;
– cemeteries on the top of Beuscheza Mountain and on the Steiner Alps;
– the occurrence of eye- and featherless ducks after floods in Cerkniško jezero that can see and fly after two weeks again (which probably is a distorted early account of the endemic *Proteus anguinus);*
– that the condensed fog drifting from caves represents devilish smoke.

He reacted to such absurdities with the appeal that the authors should refrain from pleasing eulogies and distorting flourishes in „history books". Rather they should describe the reality and stick to truth.

Nagel deals with famous Cerkniško Jezero in a great detail. Among other facts he describes:

– Changing water levels – up to complete dryness – and their dependence on precipitation;
– the existence of numerous connections between the lake bottom and the conduits in the karst mountains;
– artesian bursts of water after torrential rains;
– water-level-limiting „swallow holes";

and he discusses thoughts about the connectivity of the water courses above and below ground.

The observed interdependencies and the conclusions drawn from them are finally packed together into a logical hydraulic model including abstracted inputs and outputs and water-level-depending discharges. Furthermore he postulates underground connections between caves and Cerkniško Jezero in the order: Cerkniško Jezero – Cave of St. Canzian (Rak valley, Zelške Jame) – Pivka – Adelsberger Grotte – Kleinhäusler Grotte – Untz.

He deals with the phenomenon of noisily flowing water masses in karst cavities as well as with the thunder of so called "weather holes" (Hexenlöcher, Coprniška Jama). He continues to describe his observations in the Karst, specifically about its caves, sketching their accessibility, spatial dimensions, length, divisions into compartments and remarkable flowstone formations.

Nagel reports about the cave at St. Canzian (Rak valley, Zelške Jame), the "Gotscheer" caves (Kočevje), the three weather holes at Ober-Gurck (Krka), the curious spring at Ober-Laibach (Vrhnika), the cave at Planina / Kleinhäusler Grotte as the source of river Untz (Unica) (Planinska Jama), the Adelsberger Höhlen (Postojnska Jama), the Magdalenen-Grotte (Črna Jama), the Lueger Höhle (Jama near Predjama), the cave at St. Servolo, the cave at Cornial (Vilenica), and the cave at Sloup in Moravia and the huge Macocha sinkhole.

These descriptions are flanked by reports about other natural curiosities, such as a special nut tree (i.e. a tree with an extremely short vegetation period), the *Dattili del Mare* (marine bivalves that can drill into limestone) and a waterfall at Freistritz in Ober-Crain.

NAGEL'S REPORT „VON DER LUEGER HÖLE"

Nagel did not find the Castle of Lueg, now a world-wide known tourist attraction, very attractive. He describes it as being built into the niche of the vertical wall above the cave entrance (Jama near Predjama). About 70 m behind the upper cave entrance a deep well is found that always contains good water. This cave served, according to legend, Erasmus Lueger, who was accused of having murdered Marshall von Pappenheim, of committing robbery and treason. This stronghold could not be conquered for a long time. It was provisioned through a four mile long secret passage from the Birnbaum Forest (Hrušica). Nagel did not find this passage and discredited it as a pure invention. The access to the main cave, across a bridge and 30 m below the castle, was walled up at the time of Nagel. Nagel was able to explore about 800 m of passages. He found several sections of different character: stretches

with a loamy floor without flowstone, low crawling passages, two white flowstone pyramids, and „rare" figures of flowstone on the wall reminding of trees and forests. He observed a strong air current, emanating from a hole at the end of the cave, and concluded that there must be more passages; and he saw the many inscriptions of names that people had left there prior to his visit.

NAGEL'S REPORT „VON DER ADELSPERGER HÖLEN"

In his paragraph about Postojnska jama Nagel states that the cave consists of four cavities. Into the lower, left one, the "Poyckfluß" (Pivka) sinks. Nagel makes the first map of the cave (one of the earliest ever made) and describes in the text the individual cave sections accessible at the time, noting length, situation, branches, special formations, flowstone figures etc.. 40 m behind the entrance there are remains of a wall from the time when the locals hid in the cave from raiding Turks. He cites the opinion and accedes with it that the Pivka reappears about 5 km further north from Planinska Jama as the "Untz" river (Unica). Again, just as in the preface to the manuscript, Nagel refutes VALVASOR, who related that a ghost haunts the first section of the underground water course and that it would turn the neck of any intruder, simply by stating that he himself and his party emerges from the cave with „straight necks". Nagel explains the occurrence of fishes in the cave streams with the changes in water level or discharge volume. For a 70 year old inscription Nagel calculates the flowstone growth rate (Pag. 46/2; see also Shaw, 1992). With this rate at hand, he estimates that the large columns in the Cave of Cornial (Vilenica) with six "Schuh" diameter must have taken 90,720 years to grow. But instead of casting doubt on the static Christian date of creation – calculated by Anglican Archbishop James USSHER (born 4th of January, 1581, in Dublin; died, 21st of March, 1656, in Reigate, Surrey) to have happened on 23rd of October 4004 BC – he shies away from the possible consequences and just states: *„Da aber seit der Sintflut nur 5696 Jahre verflossen seien, müssen sich Irregularitäten ereignet haben"* (But because 5,696 years passed since the deluge, there must have been (other) irregularities"). Here Nagel makes a mistake: Ussher actually dated the deluge to 2501 BC i.e. the year 1748 should have been 4249 after the deluge and not 5696. His date would (5696-4004-1748) place the deluge at 56 years after the creation of earth….

Nevertheless he questioned the accepted dogma in the following sentence (possibly with a twinkle in his eyes) by saying: *„Doch ist gewiß, daß sie (die Anwachsung des Tropfsteins) sehr lang zugehe (benötige), weil sonst die Höhlen in gar kurzer Zeit mit Tropfstein durchgehend angefüllet werden, folglich den Wässern zu ihrem Lauf kein Raum mehr übrig bleiben werde".* (But it is for sure that it (the growth of the stalagmite) takes a long time, because otherwise the caves would be filled completely in a short time and the waters would not have space for their passage). Nagel's report was written in 1748 and the time was ripe for some critical assessment on the age of the Earth. Only seven years later (1755) IMMANUEL KANT challenged the biblical view of the world in his book *„Allgemeine Naturgeschichte und Theorie des Himmels"* and in 1780 JAMES HUTTON laid the foundation in his „Theory of the Earth" to exchange the biblical dating for a more scientifically founded calculation of the age of Earth.

So far, not all of the pictures of Nagel have been republished, among others, Shaw (1992) reprinted a few of the pictures which accompany the reports including the first map of the old Adelsberger Grotte. It is an amazingly correct ground view of the frontal part of the cave, giving all at the time known passages in due proportions and directions.

NAGEL'S INSCRIPTION IN PREDJAMSKI JAMA

Probably the most important and certainly the longest inscription in Jama near Predjama yet documented was left by Nagel in Latin (Fig. 1). It is located on the right wall (looking in direction of the guided tour) in the "Name-Passage" (Imenski rov), about 1 m above the floor and just beyond the "Bear Hole" (Medvedja Luknja). We took a picture of it during a guided tour on 19th of July, 2005. It is a small inscription written with pencil. Because the common clay-graphite pencil had not yet been invented, the pencil used by Nagel was most probably either a metal pencil (silver, lead or tin) or a piece of sharpened mineral graphite. According to the German Jama near Predjama guide (Habe, 1981; p. 43) the inscription reads as follows:

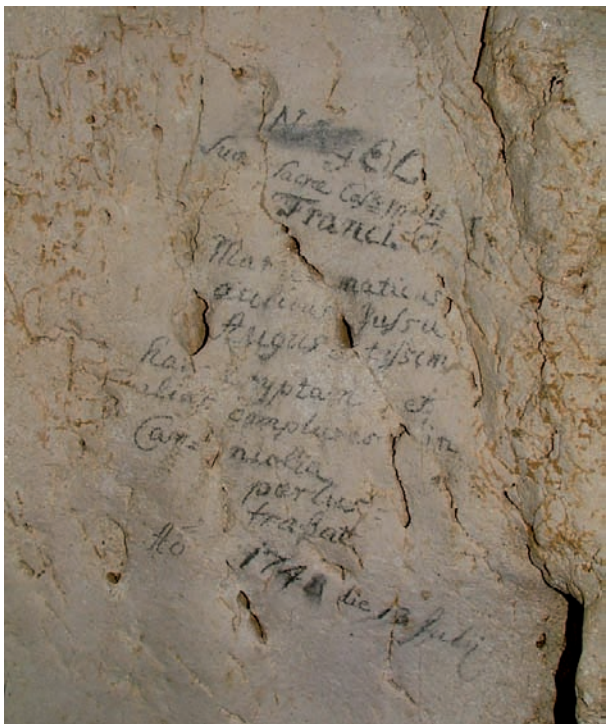

Fig. 1: Photograph of Nagel's inscription in Jama near Predjama (Photo by S. Kempe).

NAGEL
suae sacrae Caesareae Majestatis (abbreviated)
Franci. I
Mathematicus
aulicus Jussu
Augustissimi
hanc cryptem et
alias complures in
Car=niolia
perlus-
trabat
A//o 1748 die 13 Julii

That is translated:

His Holy Imperator and Majesty
Franz I
Mathematicus
on order of his
highest (lord)
(has) this crypt and
others many
in Carniola (Kärnten)
investigated
Anno 1748 day 13 July

Fig. 2: Situation of the Postojnska jama Nagel-Inscription (H.P. Hubrich for scale) (Photo by S. Kempe).

Habe (1981) reports that the inscription had first been identified by the Coleopterologist Egon Pretner. Habe (1981; Inset Plate 14) also published a color picture of the inscription. It is, however, too small to read details clearly. Comparing Habe's picture with our picture, it is clear that the inscription has been damaged in the meantime: The letters NAG from Nagels's name suffered a substantial smear. Also the "8" in "1748" appears somewhat blurred. Obviously someone touched the inscription accidentally while pointing at the lines. If it would have been an intentional damage, then the entire inscription could have been blurred with one palm stroke.

A few centimeters above Nagel's name there is another line with about five to six pencil-written letters, all illegible. If this line is connected with Nagel's inscription cannot be said with certainty.

NAGEL'S INSCRIPTION IN POSTOJNSKA JAMA

Nagel also left his name in Postojnska jama. Habe already mentioned this (1986, p.14) but fails to give its position. On July 21st, we visited the old gallery in Postojnska jama in search of Fercher survey team inscriptions (1833; see Kempe, 2005). We found Nagel's signature on the 45° sloping ceiling ca. 50 m from the access ladder (Fig. 2). It occurs – with a few other signatures (termed Old-Cave Panel 1) – at a place where there is no substantial speleothem growth. The signature is small and consists only of three lines (Fig. 3):

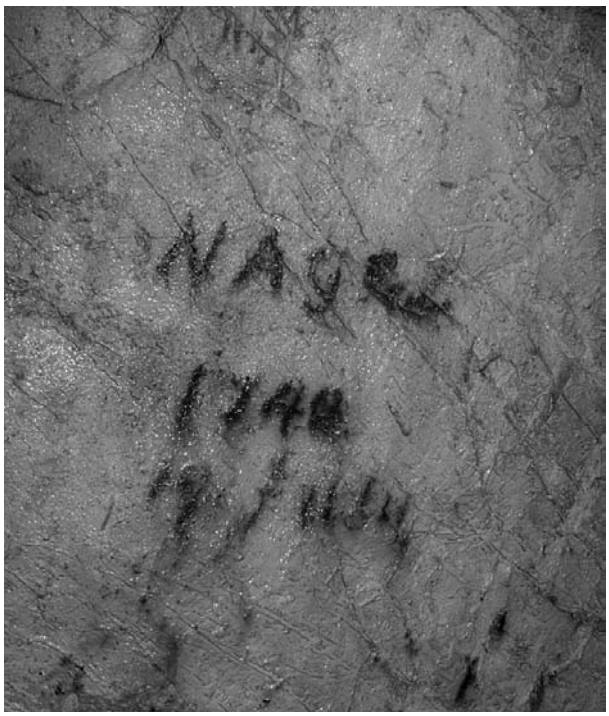

Fig. 3: Photograph of Nagel's inscription in Postojnska Jama (Photo by S. Kempe).

NAGEL
1748
19 Julii

In both inscriptions Nagel uses only his Family name, spelled in capitals (if one accepts the last three letters of the Postojna inscriptions as capitalia). In Postojna he also uses printed letters for the month, while in Jama near Predjama we find the month (as well as the other text) written in a fluent handwriting. Both times the name of the month is given in its Latin form. The Postojna inscription is, however, much more blurred than the Predjamski jama text. In Postojnska Jama probably the wall was not as dry as in Jama near Predjama and the "ink" apparently started to diffuse into the intergranulars of the underlying rock surface. Tiny white specs have overgrown the writing in addition and a thin transparent veneer of flowstone has covered them. The nature of the pen, with which was written cannot be assessed with certainty. In any case the reading of the inscription is much assisted by the knowledge of who made it and when it was made. The year and the name of the month can be identified clearly at least once one knows that Nagel visited the area in July 1748. The exact date of the month is, however, illegible. Habe (1986, p. 14) assumed it is the 13th, but that is highly unlikely. We rather suggest the 19th as being the correct reading. That it cannot be the 13th arises from the fact, that Nagel then should have visited both Postojna and Jama near Predjama on the same day. Even more so, he should have produced the quite accurate map of Postojnska jama and explored Jama near Predjama extensively. All this is not very likely to have happened in one day. Alternatively the second numeral in the day could be a "4" making it the 14th. In any case Nagel seems to have visited first Jama near Predjama, before he worked in the old Adelsberger Grotte.

CONCLUSIONS

The well dated Nagel inscriptions are part of a much larger body of inscriptions. The inscriptions tell us something about the frequency of visits. In Jama near Predjama there are many inscriptions dating from the 18th century. This is in striking contrast to the old cave of Postojna. There we only found two inscriptions out of ca. 250 documented by us as yet dating from the 18th century. Apart from Nagel, only one visitor signed during that century and that was much later, i.e. in the year 1795. The last date before Nagel's visit was 1699, making Nagel's date the only one within almost a hundred years!

Nagel's inscriptions are singular in that sense that they are the oldest of a person known for his speleological accomplishments. It is not the oldest of a historically known person because in Jama near Predjama we find signatures of the Cobenzl family, the owners of the Predjama Castle that probably predate Nagel's signature.

Nagel is also not the only person who left his name in both caves: Alois Schaffenrath (1794-1836), famous for his drawings of Postojnska jama (published by Hohenwart, 1830, 1832a,b, and in his guide to the cave, Schaffenrath, 1834) left his name also in both caves (Figs. 4 and 5)

Fig. 4: Photograph of Aloys Schaffenrath's signature in the old cave of Postojnska jama (Photo by S. Kempe).

Fig. 5: Photograph of Jacob Vidmar's and Aloys Schaffenrath's signatures in Jama near Predjama at the end of the historic passage (Photo by S. Kempe).

as we now discovered. Above Schaffenrath's signature the name "Jac. Vidmar" is found in the same handwriting. Jacob Widmar (spelled German) was one of the workers present, when Luka Čeč discovered the main passage in Postojnska jama and who left a written statement about the circumstances of this discovery. It was reproduced by Schmidl (1854) and is discussed in detail by Kempe *et al.*, (2004a). Obviously Vidmar and Schaffenrath visited Jama near Predjama together. Unfortunately they did not note the date of their visit.

Studying cave inscriptions yields new information about the history of the cave, its explorers and visitors. We are working now on a data bank documenting all of the inscriptions in the old cave of Postojna

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COBISS: 1.01

BALTAZAR HACQUET (1739/40-1815), THE PIONEER OF KARST GEOMORPHOLOGISTS

BALTAZAR HACQUET (1739/40-1815), PIONIR V GEOMORFOLOGIJI KRASA

Andrej KRANJC[1]

Abstract UDC 551.44 : 929 Hacquet B.

Andrej Kranjc: Baltazar Hacquet (1739/40-1815), the Pioneer of Karst Geomorphologists

Besides other sciences, B. Hacquet dedicated his research to geology and geomorphology (as we call them now). His most important work *"Oryctographia carniolica or Physical* (= geological) *description of Carniola..."* (1778–1789) contains descriptions of rocks, ores, fossils, as well as surface and underground features. In Carniola, karst is prevailing and therefore there is a lengthy description of karst geology and geomorphology included. His classification of mountains specially mentions *Montes secundarii* formed by grey limestone. Of surface features dolines, glacio-karstic dolines on high plateaus (with temperature and vegetation inversion), and karst poljes are mentioned. Hacquet presumed the evolution from flooded polje (seasonal lake) to a dry one. To explain the weathering and dissolution of limestone Hacquet took into account the differences between the rock, the exposition and its element content. That is the reason why Gams regarded him as a precursor of a climatic geomorphology and the "father" of corrosion theory. Hacquet has also found the difference between limestone and dolomite. His description of dolomite as *Lapis suillus* preceded the one of D. Dolomieu for 13 years. Hacquet's statements were not based on observation only, but on the experiment too. When looking upon Hacquet's explanations and results we must not forget that Hacquet's time was still time of parapathetic logic, of four elements and of the principle of burning - the *flogiston*.

Key words: history of geomorphology, karstology, Hacquet B., Carniola, Slovenia.

Izvleček UDK 551.44 : 929 Hacquet B.

Andrej Kranjc: Baltazar Hacquet (1739/40-1815), pionir v geomorfologiji krasa

Poleg drugih znanosti se je B. Hacquet posvečal tudi geologiji in geomorfologiji, kot ju imenujemo danes. Njegovo najpomembnejše delo *"Oryctographia carniolica* ali *Fizični* (= geološki) *opis Kranjske..."* (1778–1789) vsebuje opise kamnin, rudnin, fosilov kot tudi površinskih in podzemeljskih oblik. Na Kranjskem prevladuje kras in v svoje delo je vključil tudi dolg opis geologije in geomorfologije krasa. V razvrstitvi gora je posebej pozoren na *Montes secundarii* iz sivega apnenca. Od površinskih oblik omenja vrtače, na visokih planotah konte (z rastlinskim obratom) in kraška polja. Domneva, da so se kraška polja razvijala od poplavljenih (presihajočih jezer) do suhih polj. Da bi razložil preperevanje apnenca je Hacquet upošteval razlike v kamnini, osončenost in vsebnost elementov. Zaradi tega ga Gams šteje za začetnika klimatske geomorfologije in za »očeta« teorije korozije. Hacquet je odkril tudi razliko med apnencem in dolomitom. Njegov opis dolomita pod imenom *Lapis suillus* je izšel 13 let preden je objavil svojega D. Dolomieu. Hacquet ni sklepal le na podlagi opazovanj, ampak tudi na podlagi poizkusov. Ko gledamo na Hacquetove razlage in izsledke, ne smemo pozabiti, da je bila čas, v katerem je živel, še čas parapatetične logike, štirih elementov in principa gorenja - *flogistona*.

Ključne besede: zgodovina geomorfologije, krasoslovje, Hacquet B., Kranjska, Slovenija.

[1]Karst Research Institute ZRC SAZU, , Titov trg 2, Si-6230 Postojna, Slovenia, e-mail: kranjc@zrc-sazu.si

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INTRODUCTION

Baltazar (Balthazar, Belsazar) Hacquet was born in France 1739 or 1740 and died at Vienna in 1815. He spent the period from 1766 to 1787 in Carniola. During the first years he was a surgeon at Idrija mercury mine. During later years he hold different positions at Ljubljana, such as the secretary of the Agricultural Society and the professor of chemistry and obstetrics. Finally he left "bigoted and uncultured" Carniolians and took the offer of the University at Lvov (Lviv) to become professor of natural history and medicine there (Gauchon 1999) (Fig. 1).

Fig. 1. Baltazar Hacquet (Ilustrirani Slovenec 1927).

Besides medicine as his professional occupation, he was very interested in other sciences, mainly in chemistry, palaeontology with mineralogy, hydrology, and speleology, not to mention medicine, ethnography etc. In his works he often presented himself as being a chemist. He initiated new chemistry theories and introduced the methods of quantitative and qualitative chemical analyses to Carniola (Tišler 2003). He dedicated a great part of his free time to study and work in science. But travels attracted him the most, either walking around Idrija on a nice Sunday afternoon or travelling across Dinaric or Carpathians Mountains. Long distance travels, mostly through the mountains of Central, Southern and Eastern Europe took him two months per year in average. Not sport but scientific motives forced him to climb the mountains thus becoming very important person in the history of mountaineering. I must mention that he was a member of the second team who succeeded to reach Triglav (2864 m), the highest peak of Julian Alps. It is due to a bad weather that prevented him to be the first one (Lovšin 1946).

Hacquet published a lot, his bibliography contains 110 articles in scientific journals and about 30 books and extensive treatises as well (Valjo 1997). He wrote about the results of his observations and experimental work (even about an ice frost on his window panel) (Južnič 2003) as well as detailed accounts of his travels. To illustrate them he added maps drawn by himself. He published the first geological map of Carniola (a great part of present Slovenia). His principle to put on maps the names used by local population (in "local" language) is important for Slovenia – on his geological map there are Slovene names of places and not German ones as was the habit in Hacquet's time. It seems that Hacquet was the first to use the name "Dinaric Alps" roughly in the sense of nowadays Dinaric Mountains (Hacquet 1778 – 1789) (Fig. 2).

From the point of view of karstology his the most important work was *"Oryctographia carniolica oder Physikalische Erdbeschreibung..."* that is the "Physical Description of the Duchy of Carniola, Istria and part of neighbour countries", written in German language (Hacquet 1778 – 1789). It was published in four volumes, printed in Leipzig by J. G. I. Breitkopf between 1778 and 1789. The work has over 700 pages in total. In Hacquet's time physical description meant primarily geology and geomorphology, but a lot of work is dedicated to economy, mines and specially mining industry.

Fig. 2. Cutting out of the legend to Hacquet's Mappa Litho Hydrographica Nationis slavicae (Hacquet 1778 – 1789).

GEOMORPHOLOGY IN HACQUET'S TIME

"So little progress (in the field of geomorphology, note by the author) was made in Europe from the days of the first century A.D. until the opening of the sixteenth century that little need to be said about it " (Fenneman 1939). During the 15th, 16th, and 17th centuries land forms were explained largely in terms of the then-prevailing philosophy of catastrophism, according to which the features of the Earth were either specially created or were the result of violent cataclysms which produced sudden and marked changes on the surface of the Earth. As long as the Earth's age was measured in a few thousands years, there was not much chance for the importance of slow geologic processes to be appreciated (Thornbury 1969). Some of the Hacquet's ideas on geomorphology correspond to the general knowledge prevailing in the 18th century.

Hacquet's contemporaries were so called "pre-Huttonian" geomorphologists. The most important among them were Jean Étienne Guettard (1715 – 1786), Nicolas Desmarest (1725 – 1815) and Horace Benedict De Saussure (1740 – 1799). They, perhaps more than any others paved the way for Hutton (1726–1797) (Thornbury 1969). James Hutton himself lived at the same time as Hacquet. But his The Theory of the Earth was published too late (1785) to be possible for Hacquet to use it. Being a dense and borderline unreadable work it was not perceived by the science circles before the simplified version by Playfair (1802). Modern geomorphology started by Hutton's ideas and developed in the second part of the 19th century. It appears that the term "geomorphology" was used in its present sense by Keith as long ago as in 1894 (Thornbury 1969), while others stated that the term was first mentioned by Naumann in 1858 already (Herak & Stringfield).

In his *Oryctographia* Hacquet cited about 190 authors. Among them are well known old authors as Aristoteles, Democritus, Herodotus, Posidonius, Thales, and Plinius. He cited some works of his well known contemporaries, Beckmann (1776), Collini (1774), Gruber (1781), and Leroy (1776), just to mention some examples. Among the cited authors are well known authorities previous to Hacquet as Agricola, Buffon, Kircher, Leibnitz, and Linné. From the science of chemistry, mineralogy and geology Hacquet used the works of Boerhave, Born, Boyle, Delisle, Lavoisier, Sage, Scheele, and Wallerius among others less known nowadays. He was acquainted with the theories of his time about the Earth by the authors Bertrand, Burnet, Whiston and Woodwart. It is self-understanding that he knew the works treating the nature of Carniola and other nearby countries, for example Brown, Cluverus, Fortis, Gruber, Kircher, Schönleben, Scopoli, Steinberg and Valvasor.

Although Hacquet knew and used the works of his contemporaries, the scientists who founded a modern science, like Boyle and Lavoisier, his scientific knowledge corresponds to the knowledge of his time. Agricola's classification of minerals from 1556 was still in use. For example: mineral bodies were divided into inhomogeneous and homogenous bodies; the last containing simple minerals. And simple minerals were: earths, solified juices, stones, and metals. To explain different rates of solution of limestone and dolomite Hacquet helped himself by *flogiston* – the principle of burning.

In Oryctographia Hacquet cited and discussed Guettard's paper in "Mémoires de l'Academie Royale des Sciences" (1746–1764) on the types of "Tropfsteine" (speleothems). He appreciated very much DE Saussure's "Voyage dans les Alpes" (1777–1796). Regarding the fact that Hacquet only had the first two volumes of De Saussure's book and that the manuscript of the last volume of *Oryctographia* was completed in 1787, he could not be acquainted with De Saussure's views upon limestone Alps, which interested Hacquet the most: "...so hoffe ich auch, Herr von Saussure wird ... die grosse Kalkalpkette der Schweiz nicht übergehen..." (...so I hope that Mr. Von Saussure will not omit the great Alpine limestone range in Switzerland...).

HACQUET'S VIEW ON KARST MORPHOLOGY

Not only in "Oryctographia carniolica" the karst was mentioned but also in other Hacquet's books about his travels through Austrian and Turkish Illyrien, through Eastern Alps (from Triglav to Grossglockner), through Southern Alps (from Dinaric to Noric Alps) and through Carpathians.

In accordance with some other authors Hacquet classified the mountains into three types: Montes primarii - Hauptgebirge (the main range) of primary rocks; Montes secundarii - Mittelgebirge (middle mountains) of Lapis calcarius, the grey limestone; Montes tertiarii - Vorgebirge (fore mountains), product of weathering. But

Hacquet stressed that also limestone mountains can be of the same importance as the Montes primarii and that some middle mountains of limestone have the scree of limestone debris only, without marl (Fig. 3).

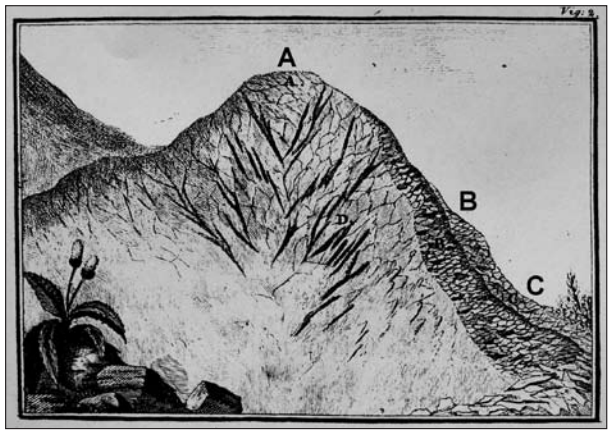

Fig. 3. Hacquet's illustration to Montes secundarii - Mittelgebirge of Lapis calcarius (Grey limestone). A - Grauer Kalkfels (Grey limestone rock), B - Schieferanlage (Shale complex), C - Kalktrümmeranlage (Limestone debris complex) (Hacquet 1778 - 1789).

Hutton's (1785) book on the evolution of the Earth and his famous statement "No vestige of a beginning - no prospect of an end" were not known by Hacquet as this book was published much later than "Oryctographia". In contrast to most of Hacquet's contemporaries, Hacquet clearly was not a "catastrophist". In nature, in landscape Hacquet saw a demonstration of slow relief evolution. For the illustration just few examples from "Oryctographia":

- Plateau Kras (Karst, Carso) was once a big lake or part of a sea, a bay of the Adriatic Sea. The ridges and summits of Dinaric Alps were a chain of islands, as are nowadays the islands along the coast, from Istria to Ragusa (Dubrovnik).

- The bottom (its features and the sediments) of the polje Dobrepolje proves that the polje was once a lake closed by limestone mountains, which drained and finally became dry.

- Levelled surfaces in the mountains, for example around the Snežnik Mountain, are due to the effect of rain.

- Terraces of the valley of Žejane (Istria) are the proof that once the valley bottom was higher than nowadays.

As for karst morphology Hacquet often mentioned bare rocky karst surface and its ability to absorb immediately all the meteoric water. He compared the region Kras (Karst) with the rocky Arabia petrea. Karst (closed) depressions specially attracted his attention, such as deep dolines and poljes. The first he calls Kessel (kettle) or Vertiefungen (deepening) and the second Kesselthal (kettle valley) or geschlossene Fläche (closed plain). He was specially impressed by great "Kessel" on high karst plateaus. In them Hacquet observed vegetation inversion. Today we call this form "konta" - a glacio-karstic doline. It is clear that he devoted a special attention to the polje of Cerknica or Cerkniško Jezero (lake) (Fig. 4).

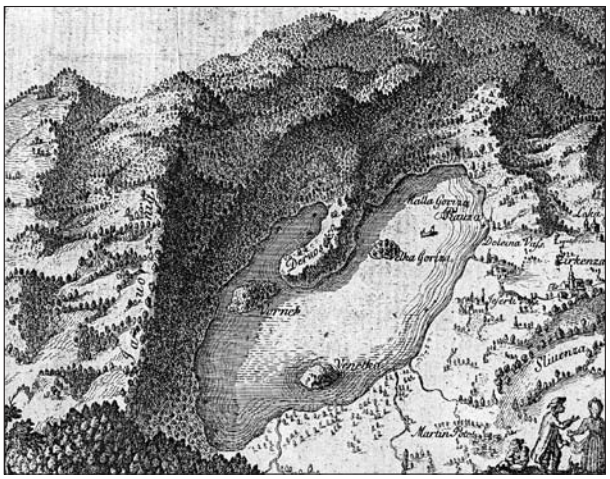

Fig. 4. Hacquet's panorama of Cerkniško Polje (Hacquet 1778 - 1789).

Hacquet paid a special attention to the weathering of limestone. He found out that the irregular weathering is due to unhomogeneity of limestone. He established this by a test by "mineral acid". He observed different intensity of weathering regarding the side of the slope: on the sunny side rocks are more weathered than on the shady side. He explained this by different intensity of calcination. In the heat the limestone calcinates stronger and the product, the calx is washed away by rain. Hacquet also knew that the limestone weathered first into clay-shale and finally into clay. The idea and the terms calx and calcination go back to Agricola. In modern terms they mean oxide and oxidation.

Maybe more than by the features which are a result of dissolution of limestone, Hacquet was interested in the process itself, in solution of limestone. By the general knowledge of the time the minerals and rocks contain the following components:

fixe Luft (fixed air) or Luftsäure (much later J. Black found out that "fixed air" is in fact CO2), Elementarerde (elementary earth), and fixe Feuer or Flogiston. According to Hacquet's ideas all bodies contain fixe Luft and fixe Feuer (Flogiston). Elementarerde which is never in pure form, is also in limestone. Regarding Flogiston, it was Lavoisier who proved that it does not exist.

Hacquet's views upon the dissolution of limestone can be resumed as follows:

- water dissolves limestone with the help of acid,
- dissolved limestone remains in water to be deposited later,
- water cannot dissolve dolomite because of the Flogiston.

The acid, which helps to dissolve limestone, is only one, Acidum universale, but it can exist in different forms. In the air there can be also other acids and alkalines, such as saline rain. Also calx may contain Acidum universale. And essential for the dissolution is Luftsäure/Elementarerde ratio. The process of dissolution has the following course: acid dissolves limestone by taking away essential parts of calx (fixe Luft or Luftsäure) and clay remains.

Opposite of dissolution is deposition, in this case deposition of calcite: water dissolves limestone, takes it into the cave and deposits it in the form of Tropfsteine (speleothems) or vielfältige Steinrinden or incrustationes (crust) (Kranjc 2003).

Hacquet is also important for geomorphology and geology because of his study of dolomite. In 1778 he described the dolomite for the first time as a rock different from limestone. It was 13 years before D. De Dolomieu (1791) published his basic paper "Sur un genre de pierre calcaires très peu effervescentes..." on the rock, which was later named after him. It has to be mentioned that Dolomieu visited Hacquet while travelling through Ljubljana. It was before the publication of the mentioned paper. Hacquet called dolomite Stinkstein (Lapis suillus), this is "stinking stone". He found out that water cannot dissolve a lot of dolomite - because of Flogiston. And therefore such water does not deposit flowstone or speleothems in caves. He observed such a situation in Podpeška Jama cave at the polje of Dobrepolje. The plan of this cave was already published by Valvasor in 1687.

The essential problem which has to be solved to explain the dissolution of limestone, or the process of corrosion as we say today, was according to Hacquet's opinion the following: Where does the acid which dissolves limestone come from? Does it come from the air (Vitriolsäure) or does it form from the Luftsäure which is one of substantial components of limestone itself?

CONCLUSION

For the conclusion I have to repeat the most important observations, ideas and revelations achieved by Baltazar Hacquet in the field of geomorfology and karstology:

– he explained the evolution of the relief by slow and continuous action of exogene forces instead of catastrophes;
– he tried to explain weathering of limestone;
– he discussed and tried to explain differential dissolution of limestone;
– he described the most important karst features (dolines, poljes, caves);
– he described the dolomite and drew the distinction between it and limestone (before De Dolomieu);
– he stressed the importance of limestone mountains.

ACKNOWLEDGMENT

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KAREL DEŽMAN IS NOT FORGOTTEN

When writing about Karel Dežman in the journal Acta carsologica 35/1, Stanislav Južnič[1] noted that Dežman's work was almost forgotten, even though he had been one of the leading nature historians of his time. In the abstract, Južnič underlined:

»His scientific works are not very well known because he did not follow the political line of the official Slovenian national representatives.«

In the summary, on the other hand, the author wrote:

»With the use of published works and manuscripts we can thus present, for the first time in greater detail, Dežman's great knowledge that extended even into mathematical and astronomical sciences.«

Karel Dežman, however, is and has not been forgotten, considering that much has been written about him in the last decade and that particularly his botanical activities have been covered relatively well.

This is what was written about Dežman's link with the botanist Valentin Plemel, his friend and grammar school classmate, by Nada Praprotnik[2] who presented his botanical activities at the symposium Flora of Slovenia 2000[3] and eventually published her supplemented and extended paper in the journal Argo[4]. About his work carried out at Ljubljansko barje, she wrote an article published in Narava Slovenije[5].

Karel Dežman worked during the botanical quietude in the period between Franc Hladnik and Alfonz Paulin. As a botanist, he began to engage in new spheres and soon surpassed, especially with his phytogeographical contributions, till then mostly floristic orientation of our nature scientists. He wrote much about the flora of Ljubljansko barje, was the first to call attention to the newly introduced (adventive) species in our country, and listed the lowest lying localities of the Alpine flora in Carniola. His herbarium collection is kept by the Slovene Museum of Natural History. At the beginning of his professional career, Dežman was engaged largely in botanical research, and it is his very botanical work that is presented fairly comprehensively and suitably evaluated.

In his life, Dežman was highly versatile, and as he was a leading personality in several spheres, it is difficult to present him in full. With his scientific criticalness he had a strong and favourable effect on domestic professional public and contributed a great deal primarily to the academic development of the Museum, for which he worked from 1852 till his death in 1889. Thanks to him, a new building was erected in 1888 for the Carniolan Provincial Museum, which is still home to two national institutions: the Slovene Museum of Natural History and the National Museum of Slovenia. Dežman's museal work has never been suppressed, as he is correctly cited in all historical surveys. It is true, however, that his museal merits have no doubt been insufficiently underlined!

As a member of the Ljubljana Street Naming Committee, Prof Dr Tone Wraber proposed (during his mandate from 1991 to1995) one of the streets (perhaps on the edge of Ljubljansko barje) to be named after Dežman and thus »to confirm the return of a lost son at the time when Slovenia acquired its independence«. Unfortunately, his endeavours proved unsuccessful.

Karel Dežman plays a discernible role also in the work by Dragan Matič[6] as »a herald of the Germans in Carniola« from 1861 onwards.

In Južnič's article, the portrait of Karl Dežman was published as well (with the painting's basic details missing). It was made by Filip Fröhlich around 1865 and is kept by the National Museum of Slovenia.

At the end, let us quote the following conciliatory words published by Bleiweis's Novice[7] after Dežman's death:

»If we are now to make a final estimate of Deschmann's work, it is difficult to judge whether his bantering made more harm than good for the mental development of the Slovenian nation. Deschmann's merits for the provincial museum have been acknowledged both by his followers and adversaries, and this is why we, too, are calling out at his grave: »Let him rest in peace!«

Nada Praprotnik

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THE 6th SINAGEO AND THE INSERTION OF THE KARST GEOMORPHOLOGY THEMATIC SESSION

Between September 6th and 10th, it took place in the city of Goiânia, Brazil, the 6th National Symposium of Geomorphology (VI SINAGEO), promoted by the Union of the Brazilian Geomorphology (UGB), simultaneously with the Regional Conference of Geomorphology, promoted by the International Association of Geomorphologists (IGA).

Such integrated event had as its objectives, to divulge and discuss the results of scientific studies, theories, models, methods and techniques, with emphasis in the tropical and subtropical environments. The studies were grouped in thematic sessions that synthetize the main currents of international trends and specialties of geomorphology.

Structuralized through the division of the subjects in 14 Thematic Sessions, the event counted on the presentation of about 550 works, between posters and oral communications, added by 18 lectures and 5 round table discussions, congregating more than 700 researchers, with greater importance given to the Thematic Session on Karst Geomorphology. For the first time, after six events of this kind, the Karst studies had its insertion due to the considerable number of papers in the formats of posters and oral communications.

The event was officially opened in September 7th with the lectures by professors Mike Thomas (Scotland) and Victor Baker (United States), both guided by the theme of the global climatic changes of the quaternary and its relation with geomorphology. Later on, in the same day, took place the round table on the subject "The Tropics: past, gift and future".

From September 8th to 10th the event was organized in lectures, oral communications and round tables according to the 14 existing thematic sessions. The biggest interest of the authors were the Thematic Session 5, related to Karst Geomorphology. This Session was presided by Andrej Kranjc of the Karst Research Institute (ZRC SAZU), together with the Heinz Charles Kohler, of the Post-Graduation Program in Geography of the PUC Minas, Brazil.

Under Kohler coordination, the karst studies started with the conference *"Kras - the Classic Karst (Slovenia-Italy)"*, given by Kranjc. His lecture was developed in a very interesting format, with the history behind the origin of the name Kras, as well a historical overview of the first studies initiated in the region.

According to Kranjc (2006), kras is a limestone plateau located northwest of Slovenia (45º45' N, 14º00' W) part of the Dinaric Mountains, being well detached in relation to the non-carbonatic adjacencies of the Triest Bay on the southwest, the alluvial plain of Friuli and the sedimentation valley of Vipava to the northwest. Such plateau is considered an anticlinorium of Cretaceous and Tertiary limestone, crossed by three main faults in "Dinaric" direction (NW - SE), with altitudes between 200 and 500 m covering an area of about 550 km^2.

When talking about the history behind the evolution of the studies of the Dinaric Karst or the "Classical Karst", the impressions of the authors were reinforced by considering the Karst as a vast field for human and physical studies.

By making an epistemological reflection on the origin of the term *Kras* until the currently used terminology, Kranjc catched our attention to the existence of brief descriptions of the karst in works from the 4th century B.C., as well the impressions left in the works of Strabo, Polibios, Plinius, Livius, and Vergilius, among others. Posidonius of Apameia (135 – 50 B.C.), for example, said that "the river Timavus springs in the mountain, flows into an abyss, reappears after the distance of 130 stadia, and flows into the sea", a clear description of a river sink and a resurgence.

At the Medieval Age, the "Tabula Peutingeriana" already showed indications of a karstic region with human settlements next to it. At the same Era, the tourism in caves initiated, more specifically in the Cave of Sveta jama (Sacred Cave), in 280 A.C., where masses and marriages started to be common. The caves of Landarska (888 A.C.), Postojnska (1213 A.C.) and Vilenica (1663) also called the attention of people living near by them.

By the end of the 17th century and the beginning of the 18th century, the region popularizes in consequence of descriptions made by geographers, topographers, scholars and travelers, and also by the fact of Trieste being turned into a "free trade" port in 1719. In this period, more systematic studies began to increase.

Thus, pioneers scholars dedicated to the study of the kras region, starting formally with a publication of Franc Jožef Hanibal HOHENWART (1830), where the term "karst" appears for the first time. Geographers and geologists of the 19th century started to use with more frequency the term *karst* and the works of Jovan Cvijić (1893) were considered to have given the scientific basis to the study of the "classical karst", followed by Grund (1805), Kraus (1894) and Martel (1894), for example.

After all this thoughts, Kranjc finished with the exemplification of its sayings with photos related to the karst geomorphology and human usage, since the use of

the endokarst for rituals, the exploitation of limestone in the region for house and terraces construction, the use of the exokarst for farming, water and ice catchment for food conservation, as well the inappropriate waste disposal in dolines.

Thus, all of those who went to the conference had the opportunity to have a general overview on the evolution of the Kras plateau, as well as understanding its complexity, management and need for preservation. In the afternoon the oral communications from the Thematic Session 5 took place under the coordination of K.H. Kohler.

Basically the papers presented had focused the geomorphology in sandstone and quartzite (pseudokarst) regions with the exposition of works that prioritized the deriving use of the concepts and definitions of the "classical karst" in regions where the development of caves took place silicateous rocks.

More important than the discussion on the terminology was the intention of the authors in proving its hypotheses through well structuralized and coherent works, fact that is appropriate to the academic discussion of the role of geochemistry as a key factor in the development of a karstic relief (classic) or not. The process of dissolution in detriment of the physical erosion was underlined, due to the premise that any rock is soluble, especially on tropical regions (water + heat).

On Saturday, the participants were able to attend the conference *"Brief considerations on the Brazilian Karstic Scenarios"* given by K.H. Kohler, under a. Kranjc coordination. As we all know, Prof. Kohler dedicated more than 30 years of his life in the study of the Brazilian tropical karsts, especially on the Lagoa Santa Karst, a widely studied region in the 19th century due to its karstological, paleontological, archaeological and speleological importance.

For him, the geomorphology contemplates the landscape in a spatial-time conception whose evolution (dynamic) in many ways is faster than the preventive intention of the man in conserve and preserve.

The origin of the Lagoa Santa´s endokarst retraces to the Jurassic/Cretacious, whereas the exokarst is shaped after the Rio das Velhas initiates the notch of the South American Plate in the Plio-Pleistocene, already in the outcrops of carbonatic rocks, remodeling the karstic scenario until present times.

An important anomaly in the current drainage system was also distinguished: the general drainage standard of the main river (Rio das Velhas) and its tributaries follows the N direction and, the Ribeirão da Mata is the only stream that flows in almost opposite direction, (SW). This anomaly suggests that the Rio das Velhas had already occupied the current course of the Ribeirão da Mata, flowing northwest, originating the Lagoa Santa Karst (KOHLER, 2006).

Through images and cartographic documents, the participants were able to observe this anomaly flow as well as understanding the genesis of the Lagoa Santa Karst plateau.

With the development of this Thematic Session, we could once more acknowledge the lack of researchers that are not necessarily speleologists that are interested on karst studies and its processes.

Even with the insertion, for the first time, of the thematic on Karst Geomorphology in an important national and international event, the number of papers submitted to us was still lower than the other papers sent to the other 13 Thematic Sessions.

Thus, we believe that a bigger integration between the scholars from the physical studies and human studies of karstic areas is necessary, because only doing this we´ll contribute for an optimum development of the Brazilian karstology.

It´s strongly recommended that, in the current stage of the karstological studies in Brazil, we started a systematic and detailed mapping of the Brazilian karstic areas, integrating those dedicated to the endokarst (speleologists) and those scientists of the exokarst (geomorphologists).

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Luiz Eduardo Panisset Travassos
Heinz Charles Kohler
Andrej Kranjc

THE LONGEST HISTORY OF AN ICE CAVE – UNDER URAL?

In the year **2005** an impressive book was published at **Jekaterinburg** by Mining Institute of Ural Branch of Russian Academy of Sciences at Perm – **Kungurskaja ledjanaja peščera: opit rezhimnih nabljudenij (Kungur Ice Cave: Monitoring Experience),** the first Russian monograph dedicated to the detailed scientific research of a cave, as is said in the introduction. It is nice hard bound book of 376 pages, ISBN 5–7691–1567–X.

The editor is well known Russian karstologist and speleologist **V. N. Dubljanskij** who co-ordinated the work of 16 authors. Beside Dubljanskij himself there are other specialists known in West too, O. I. Kadebskaja, V. N. Katajev, N. G. Maksimovič, and B. R. Mavljudov (see his paper in Acta carsologica 35/1), just to cite some examples. The book includes 76 tables, 189 maps, plans, pictures, graphs and photos, among them 18 colour photos and ends by 461 references; with the exception of 16, they are all in Russian language. To emphasize the title of my report - the oldest reference is going back to the year 1730.

The book consists of two parts, the first one presents the region where the cave is situated (northern part of the so called Ufa plateau, outside of the town of Kungur, on the bank of the Silva river, under the »Ice Mountain« hill) and the second part is dedicated exclusively to the cave itself. The entrance to this nearly 6 km long cave lies 115 m above the sea level, but the climate of the region is severe: average winter temperature is –6.3° C, with mean minimum of –40°. The average amount of precipitation is 500 mm (300 – 600) and evapotranspiration is 358 mm. It is self-understanding that the age of rocks of the Perm region is Permian, in this case Lower Permian with prevailing anhydrite and gypsum. The second part - Kungur Ice Cave - has 13 chapters: history of investigation, methodology of data processing, morphology, hydrogeology, hydrochemistry, microclimate, sediments, biology, experiments, changes and modifications, geological history, speleogenesis, and tourist display.

There are over 500 scientific papers and publications related to Kungur Ice Cave. The cave is known for more than 400 years, more than 100 years it is open for tourist visit, and in 2001 federal and local legislation proclaimed "Ice Mountain and Kungur Ice Cave" the "Historical and Natural Complex" extended over 106 ha. When famous Cossack's Hetman Yermak advanced to Siberia he and his men spent the winter of 1578/1579 in Kungur Ice Cave. The first survey dates to 1703, 45 years earlier of Postojnska jama, and during the 18th century the entrance part was gypsum quarry while further inside numerous crosses and icons were placed. In 1948, crystallisation of the ice ceased and that is why Moscow University set up there a field station. In 1949 there were already 30 monitoring points installed. In the period of 50 years the researchers gathered an enormous amount of different data and it is justifiable to talk of a real data bank.

In my opinion the most interesting results are related to the microclimate. The amplitude of the air temperature is between – 9.7° and + 5.1° C, at some points it is permanently under 0°. From 1974 to 1994 the mean temperature in the cave was rising and since that year it is little by little falling. The warm period prolonged from 1 to 8 month per year and the ice is melting more and more. Beside temperature researchers monitored humidity, air currents, air pressure, aerosols, composition of the air, condensation, and evaporation. In the cave different minerals were found and analysed such as gypsum, "gypsum rose", celestine, selenite, cryogene gypsum, mirabilite, calcite, and different crystallisation of ice. Gypsum is much more soluble than limestone and therefore the collapses on the Ice Mountain above the cave are frequent. Thank to great number of different data the scientists were even able to correlate collapsing and lunar phases.

Tourism which started very early, in 1840 there was a professional guide installed, also contributed to the general warming of the cave. In the 30-ies of the last century a new artificial entrance was made to facilitate tourist visits and during the decennials tunnels were dug connecting different parts of the cave. So the microclimate conditions, due mostly to changed aeration, deteriorate

a good deal. In 1957 an electric illumination reached far into the cave, to the Great Lake. In 2001 at the entrances iron grids were installed so that cold air can penetrate in the cave during the winter and helps to cool it.

When leafing through the book I got the impression that this is maybe not just the first book of such kind published in Russia, but that also elsewhere such books are very rare, treating a cave in such details and having so many data and so long observation period. This is not only the description of the Kungur Ice Cave and of the course of events in this ice cave. The book contains many data and conclusions particularly which illustrate and help to understand the evolution of other ice caves. Even more, such a long and detailed series of so many elements can be useful at evaluating long-term changes in the greater space - the global change.

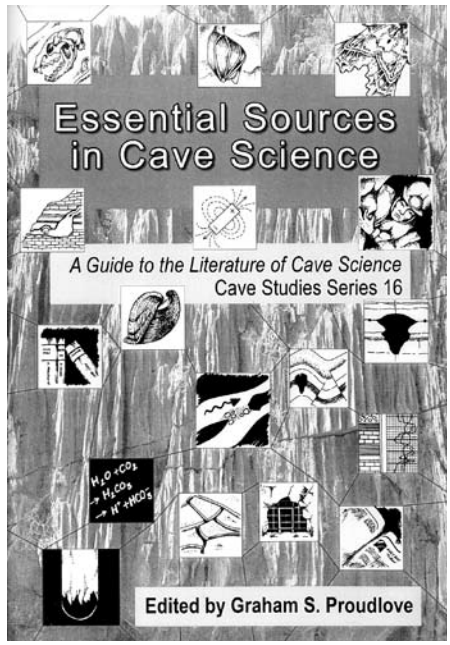
I cannot help to regret that the language barrier still exists (maybe even increases nowadays) and that such an important book has little chance to reach an international significance and wide response in international karstological spheres, as it should deserve. It would be a good opportunity to unite the forces of researchers of different nations, to combine the money of more publishing houses - and publish the book simultaneously in Russian and in English. I warmly recommend to everybody who knows the Russian "azbuka" to glance through the book, and to others interested in ice caves, to look the illustrations. But I cannot recommend buying it for the personal library – edition is limited to 300 copies only.

Andrej Kranjc

ESSENTIAL SOURCES IN CAVE SCIENCE

Graham S. Proudlove, Editor Essential Sources In Cave Science. A Guide to the Literature of Cave Science

Cave Studies Series 16, 56 pp, A4, BCRA 2006
ISBN: 0-900-265-31-0



In the time when all information are at the tip of our fingers, an issue like this seems to be unnecessary. On the other hand, even an experienced scientist will find problems looking for the relevant sources out of the Google hits. Not to mention a caver, interested to a science related to his/her free time activity. An issue, where people from the forefront of a scientific area guide the reader through the essential literature is most welcome. And this is exactly what this booklet does. The science related to caves is broken down into 13 areas covered by one or more authors as follows: **Geology** by Dave Lowe, **Geomorphology** by Tony Waltham, **Hydrology and Hydrogeology** by Chris Groves, **Chemistry** by Simon Bottrell, **Physics** by David Gibson, Clark Friend, Phil Murphy & Tony Waltham, **Speleogenesis** by Dave Lowe, **Minerals and Speleothems** by Charlie Self, **Paleoenvironments** by Andy Baker, **Biology** by Graham Proudlove, **Bats** by John Altringham, **Archeology and Paleontology** by Andrew Chamberlain, **Conservation and Management** by Graham Price, **Speleology** by Ric Hallivel.

Each area is introduced with a brief - half to one page - description of what it does, its history and the present state-of-the art. A list of selected printed references follows, which normally include several tens of entries. These are up-to-date, sources include journal articles, monographs, book chapters from edited books, conference proceedings etc. A few lines of description is added to each entry and a tag G or B is given, denoting whether the source is of general interest or related to Great Britain and Ireland. Three sources from the list are outlined to be most essential „for those seeking the quickest possible introduction".

The list of printed sources is (not always) followed by the list of web based resources, which has - for obvious reasons - no ambitions to be complete.

Last but not least is he list of periodicals publishing cave science.

From my own experience I know that many readers will miss some entries, particularly in the area where one is actively involved. Probably this is exactly the area which you shouldn't look for.

Franci Gabrovšek

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