THERMAL KARST SYSTEMS

TERMALNI KRAŠKI SISTEMI

PAOLO FORTI

Acta Carsologica, XXV (1996), 99-117, Ljubljana 1996

Izvleček UDK 551.44:551.23
556.368

Paolo Forti: Termalni kraški sistemi

Hidrotermalni kraški sistemi predstavljajo pomemben gospodarski vir, tako z vidika hidrologije kot tudi rudnih ležišč. V mednarodni literaturi skoraj ni sintetičnih del o tej temi, pač pa jih mnogo obravnava posamične aspekte termalnih kraških vodonosnikov in tudi hidrotermalnih rudnih nahajališč. Zato je koristno predstaviti klasifikacijo termalnih jam in funkcije njihovega genetskega mehanizma in posebnosti morfologije skupaj s kemijskimi sedimenti. Do danes še ni bila izdelana primerjava med morfologijo in kemijskimi sedimenti v različnih termalnih sistemih in speleogenetskimi mehanizmi. Nekatere reakcije lahko razložimo samo v povezavi z določenimi deli vodonosnika. Pričujoči članek prvič poskuša shematizirati obstoječe odnose med speleogenetskimi mehanizmi, deli vodonosnika in morfologijo razvitih sedimentov.

Ključne besede: termalni kras, klasifikacija, speleogeneza

Abstract UDC 551.44:551.23
556.368

Paolo Forti: Thermal karst systems

Thermal karst systems represent an important economic resource from the point of view of hydrogeology and ore deposits. A general study has never been performed to relate morphologies and chemical deposits of the thermal karst with the speleogenetic mechanisms which may be active in the different zones of the aquifer. In reality, due to the complexity and the variability of the thermal fluids, there are plenty of different chemical-physical reactions which are possibly active in such an environment: anyway some of them may be regarded as the most important, because they are active singly or combined with some others, at least in part of most of the hydrothermal caves.

Key words: thermal karst, classification, speleogenesis

Address - Naslov
Dr. Paolo Forti
Istituto Italiano di Speleologia
Via zamboni 67
I - 40 127 BOLOGNA
Italy

INTRODUCTION

Thermal karst systems may represent an important economic resource with regards to the hydrogeology and to the hosted ore deposits. In many countries there are many thermal establishments which make a direct, or indirect exploitation of the hydrothermal caves. Furthermore, the great sulfide ore deposits, such as those of the Iglesiente in Sardinia which have represented one of the most important mineral resources in Europe, can for the most part be considered Mississippi Valley type ore deposits (MVTOD) and therefore related to thermal karst systems.

Notwithstanding the evident economic interest, generally very little is known about hydrothermal karst systems and their hydrogeological and speleogenetic behaviour: in fact, even on an international level few papers give an overview on this topic (FORD & WILLIAMS, 1989), while many papers exist on special aspects, in particular the hydrothermal ore deposits (DZULINSKIY & SASS - GUSTKIEWICZ, 1989).

In the past when a cave showed strange morphologies or contained uncommon chemical deposits it was normally considered of hydrothermal origin. (HILL & FORTI, 1986). In reality, the further knowledge on the ever increasingly complex speleogenetic mechanisms demonstrates that several previously supposed hydrothermal karst systems have in fact developed in a normal environment.

This would explain why even recently the number of thermal karst systems, calculated at more than 10% (FORD, 1988) of the global karst phenomenon, was surely greatly overestimated.

THERMAL KARST SYSTEMS

In theory a cave may be regarded as hydrothermal in origin (or part origin) only if thermal fluids (normally hot water) flowed inside at least during a period of its development. Though this definition is apparently simple, in practice it is difficult to have objective proof of this origin.

In reality the origin of thermal waters can be absolutely different: juvenile (i.e. volcanic in origin) waters, connate (tapped sedimentary) waters, deeply circulating meteoric (normal karst) waters or even mixtures of these three waters in any proportions (see fig 1). Moreover shallow karst water can mix with these when they approach the surface, so it is practically impossible to define the contents of a typical thermal water in any clear way, though it can be affirmed that these waters are almost always characterised by a sufficiently high content of CO_2 and H_2S. The evolution of the karst systems is different in morphologies and above all in chemical deposits which should be deposited depending on which of these two gases prevails. The complexity of chemical-physical parameters of the thermal waters makes it even more complex to establish acceptable criteria of identification for the hydrothermal caves.

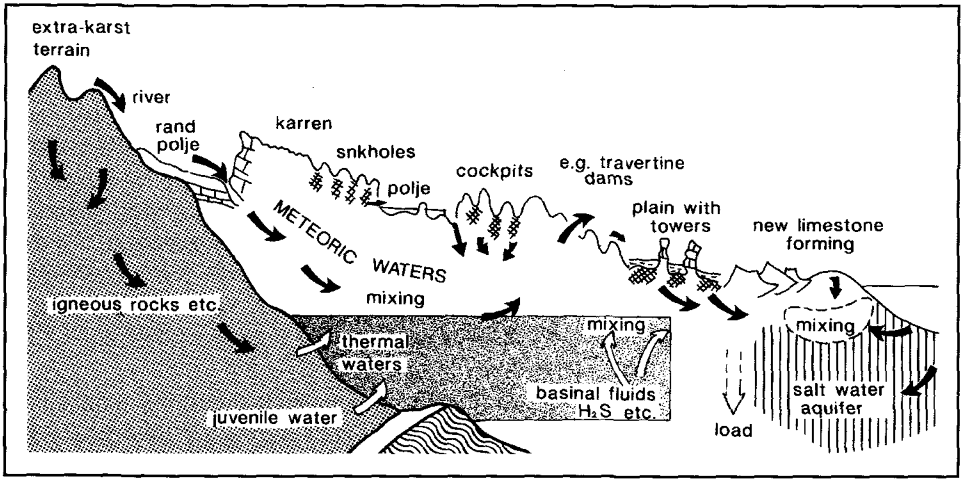

Fig. 1: The comprehensive karst system in which the area with possible active thermal phenomena is associated (FORD 1988, modified)

The identification critera may be divided in two categories: direct proof or indirect evidence (elements that suggest a former thermal activity).

There are essentially two kinds of certain proof; 1 - thermal waters flowing inside the karst system; 2 - stable isotope measurements of the chemical deposits in the system. Unfortunately it is not always possible to utilise either of these proofs.

In fact, it is unusual to find thermal waters in a cave due to the difficulty of entering inside a very hot system, therefore when we enter even a thermal cavity, the thermal flow has normally ceased long since. Moreover it does not always stand to reason that the presence of hot fluids automatically signifies a thermal evolution of the cavity: some cases are known where such fluids have penetrated a normal karst system (i.e. generated by meteoric waters), for example the Sciacca Cave, which has only recently become subject to the thermal effect and therefore at present the structure of the cavity has not been altered much by the hot fluids.

Thermal caves have often, though not always, internal chemical deposits (speleothems or cave minerals) which can be analysed to define their temperature of deposition (stable isotope analysis, fluids inclusion study, etc.). There are still problems in this case as these deposits are often found to be developed after the end of the thermal stage, or the geochemical system may result open and therefore altered in a more recent stage.

Therefore it is obvious that in the majority of cases we must use indirect evidence to define the thermal origin of a cave (either partial or total); these can be divided into two categories: the solution forms and the chemical deposits.

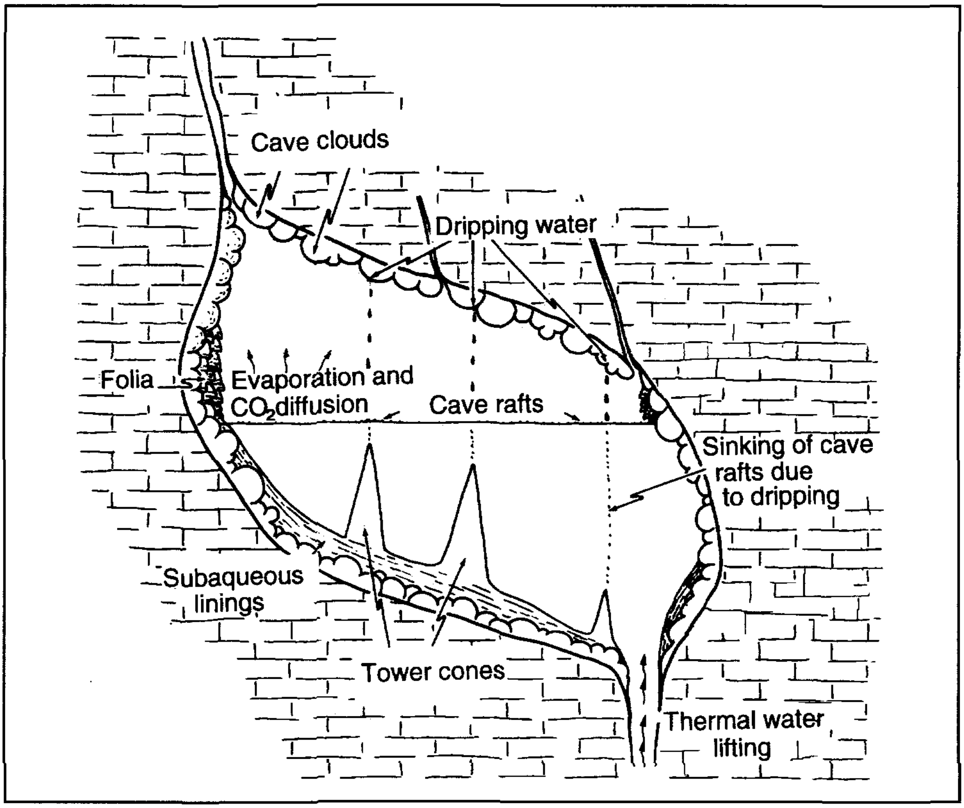

Fig. 2: Genetic scheme for the tower cones of the Giusti Cave (FORTI & UTILI, 1984): condensation water dripping from the ceiling causes the sinking of the cave rafts developing over the thermal water due to the CO_2 degassation. The underwater accumulation of the cave rafts allows the growth of cemented tight cones (tower cones)

Some solution forms are clear indicators of convective movements and therefore possible indicators of an upwelling of thermal waters. Among them the most characteristic are the rising structures of branching patterns of bell-shaped passages on top of a large basal chamber. Sometimes the presence of domed ceilings may also indicate thermal activity, though in most cases this morphology is evolved by completely different mechanisms (karst waters mixture, condensation corrosion etc.) The same can be said about the peculiar forms generated by gas bubbling in saturated environments, such as the bubble trials derived from gas diffusion from thermal waters in proximity to the piezometric surface (CHIESI & FORTI, 1987) but the same morphology can again derive from other phenomena, the principal one being biological oxidation of H_2S (FORTI, 1989).

The presence of a peculiar morphology is not the only indication of possible thermal water in a cave, but also the absence of other forms may be important as the lack of evidence for high to moderate water flow. The total absence of canyons and scallops or the lack of deposits of rounded cobble stones, are indirect proof of the water flow velocity from slow to very slow which is the normal hydrodynamic condition for hydrothermal fluids.

In the chemical deposit some speleothems tend, though not exclusively to be strictly confined to the hydrothermal environment: some to be remembered as thermal indicators are the Gaysermites from the Hungarian Czech and Slovak thermal caves (CHROMY, 1927; PANOŠ, 1960), the tower cones of the Monsummano cave (FORTI & UTILI, 1984: see Fig. 2) and the great development of cave clouds in the Carlsbad Cave (HILL, 1987).

Finally the presence of a large quantity and variety of cave minerals in a cave has always been attributed as proof of the "thermalness" (HILL & FORTI, 1986): in fact even if all of them may be found in a "normal" cave; what is distinctive in the hot water caves is their unusual abundance and their association together.

In conclusion we must always consider that even when all the indirect indicators of thermal origin are contemporaneously present in a cave, it is impossible to confirm for certain that hot fluids have gone through the cave; in fact, only direct proof can be conclusive.

MORPHO - GENETIC SUBDIVISION OF THE THERMAL KARST SYSTEM

The thermal karst systems can be morphologically divided in two principal categories:

1 - the thermal monogenic caves
2 - the maze caves

The subdivision remains consistent with the evolutive-genetic mechanisms which have developed the karst system into what we see today.

Monogenic caves: they are cavities created by the sole action of the hot water on the rock, hence the name monogenic: in effect the real "thermal caves" are quite rare also because it is unusual that the isolated action of hot water can produce wide karst voids. In fact an analysis of all the printed papers on this topic shows that the higher the development temperature, the fewer spaces generated (DUBLIANSKY, 1994).

A monogenic cave consists of a large basal chamber where the thermal waters accumulate (similar to the magmatic chambers in a volcano) from which a branching pattern of rising-bell shaped passages have grown; a typical "monogenic cave" is Statorkoputzka Cave in the Buda hills in Hungary (MULLER & SALVARY, 1977). These caves are generated by the dissolution and/or corrosion induced by the slow convective rising of thermal waters. The caves need a single point recharge at the base of the karst formation (where the basal chamber is formed) in order to develop. Though this condition is necessary it is not sufficient, because the karst rock needs to have a low fissure frequency and there must not be a point where the thermal waters have a direct discharge.

Only when all these "boundary conditions" are satisfied, thus allowing the establishing and subsequent maintenance of the upward convective motion of the hot water, then the evolution of the rising dendritical part that characterises these caves may develop. This is the reason the hydrothermal monogenic caves do not usually have a natural external outlet, and if they find one the development ceases, at least in this form.

It has been demonstrated (RUDNICKI J., 1978) that the form and dimensions of the bell-shaped passages forming the rising branches, as with the microforms eventually present on their surface, strictly depend on the convective motion installed in the bell itself. This in turn is controlled by the flow rate of the thermal water and by the temperature difference existing between this and the cave walls.

Thermal maze caves: the difference between a monogenic cave and this kind of cavity is that this is not a "pure" hydrothermal cave. More often than not its growth consists of different stages where not only thermal but also other different types of water take part in their evolution.

The possibility of evolution of these caves is where there is no defined input point and the recharge comes about in an aerial diffusion, moreover the karst rock must be heavily fractured and the discharge must be through one or more definite outlets (thermal springs).

The maze caves are subdivided in the following two categories;

2 - Dimensional maze caves
3 - Dimensional maze caves

which differentiate not only in structure but also in genetic mechanisms.

2-dimensional maze caves develop when hot rising water is tapped in the karst formation at a definite level. Thermal flow is then developed along horizontal lines thus creating a maze pattern of unclassed galleries. This always happens when the hydrothermal fluids are confined in the hosting carbonate formation by a watershed (fig. 3-A). But in reality, the biggest 2-D maze caves are observed in quite different conditions. In fact, even in this case the karst evolution still depends exclusively on the aggressive power of the thermal water and, as previously noted, it is not very strong.

There is another much more favourable condition that allows the evolution of the great 2-D maze caves: it is realised when a very stable thermal stratification is achieved inside the karst formation due to the presence of an overlying meteoric aquifer (fig. 3-B).

In these conditions the karst effect will be magnified by the cooling down effect (due to contact with a colder mass represented by the meteoric water) and above all by mixing corrosion (Bögli effect, Picknet effect, salt effect etc.) (FORTI, 1991).

In all cases, though the 2-D maze caves are more common than monogenic ones, they only represent a small minority in the range of hydrothermal caves, from being all points of view dominated by 3-D maze caves.

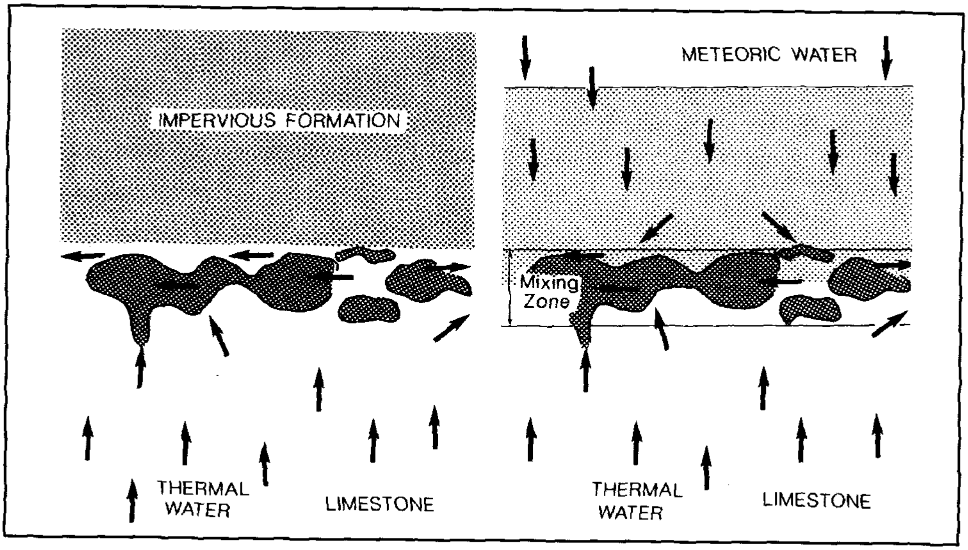

Fig. 3: Sketch for the evolution of 2-D maze caves; A - confined aquifer, B - unconfined aquifer with a very stable thermal - meteoric waters interface

3-D maze caves are by far the most common natural thermal karst phenomena, reaching over 100 km of passages (Jewel Cave in the USA, BAKALOWICS et al., 1987) and a depth of more than 600 m. (Stari Trg Mine in ex-Yugoslavia, PETROVIČ, 1969) This type of karst system can be generated by a homogeneous process when rapidly upwelling thermal fluids invade unconfined karst aquifers, even though this kind of genesis is not the most common. 3-D maze caves are more often the result of a heterogeneous process which corresponds to a progressive lowering of the thermal water and/or episodes of infiltration of meteoric seeping water at different levels inside the thermal aquifer with consequent successive mixing.

SPELEOGENETICAL EFFECT OF THE THERMAL FLUIDS

Due to the complexity and variability in the composition of the thermal fluids, there are plenty of chemical-physical reactions that succeed in the aquifer between the hot fluids and the hosted rock and they are always very complex and in many cases unstudied. For example the effective role has yet to be stabilised (certainly of great importance) biological reactions have evolved in this context (AA., 1994).

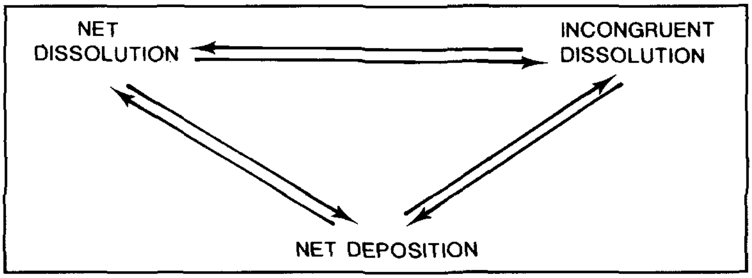

Fig. 4: Possible speleogenetic effects of the hydrothermal reactions: all three mechanisms may be active simultaneously in different zones of the same cave or the cave may be subjected to different effects at different periods

Generally, however, speleogenetic effects derived from these reactions can be put in three large groups (as schemed in fig. 4) practically corresponding to net dissolution which enlarge the voids, and to net deposition which corresponds to a reduction of the space available for the circulating water, but most of them are responsible for incongruent dissolution (deposition and dissolution in the mean time) (LOHMANN, 1987).

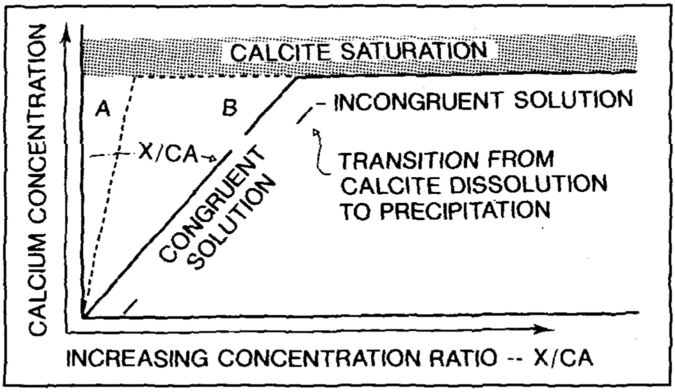

Fig. 5: The effect of solution of dolomite by water that already contained a certain amount of dissolved calcite. Initially the congruent solution of dolomites (net dissolution) is the active process and the resulting ions concentration is stochiometrically that obtained by the released ions from the solid stage. Once calcite saturation is achieved, whenever new dolomite is dissolved there will be a contemporaneous precipitation of calcium carbonate with a consequent variation of calcium/magnesium content (incongruent dissolution) (LOHMANN, 1987, modified).

It is possible to have all three of these effects simultaneously active in different places of the same karst system, or the same zone may alternatively undergo different effects in later stages of the cavity development.

Incongruent dissolution is the most common of the three speleogenetic effects inside the hydrothermal karst systems; moreover it is responsible for all the ore deposits of the Mississippi Valley Type (MVT). The karst effect of incongruent dissolution on a thermal system can however vary from case to case depending on the type of chemical reaction involved, which determines the relative importance of the depositing process in comparison to the dissolution one. Some karst cavities are found which developed themselves through incongruent dissolution and have few chemical deposits inside, as the Pfaff Cave in the Iglesiente (see Fig. 6) , or more frequently it is possible to observe an hydrothermal karst system completely fossilised by mineral deposits (see Fig 7).

A wide bibliography exists on the ore deposits related with thermal karst systems (MTVOD) (DZULYNSKY & SASS-GUSTKIEWICZ, 1989) it is possible to find descriptions that go from one extreme to the other, from cavities overflowing with deposits to those completely without. All things considered, it is almost impossible in the present stage of our knowledge to explain the evolution of a particular karst system as its final morphology may derive from successive stages where not necessarily one only of the three speleogenetic mechanisms, and not always the same one was active.

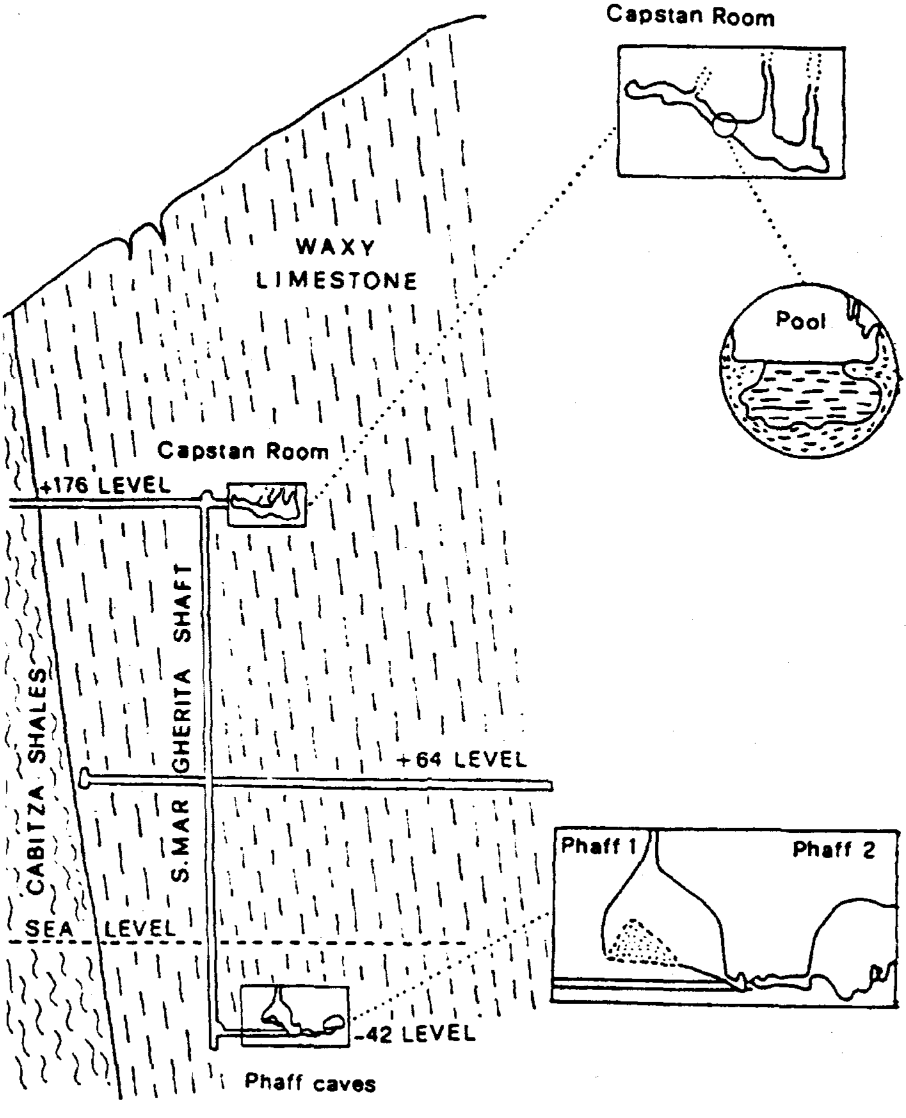

Fig. 6: Section on S.Margherita Shaft in the Masua Mine, where the position of the Pfaff Cave is in evidence, a large cavity partially thermal in origin, containing large thermal calcite crystals on the walls and a small quantity of Pb oxides and Zn sulphide (from DE VIVO et al., 1987, modified)

Even if this happened, the chemical reaction of the hot water or mixture can be greatly varied in time with consequent variation of the type of incongruent dissolution or the kind of deposition.

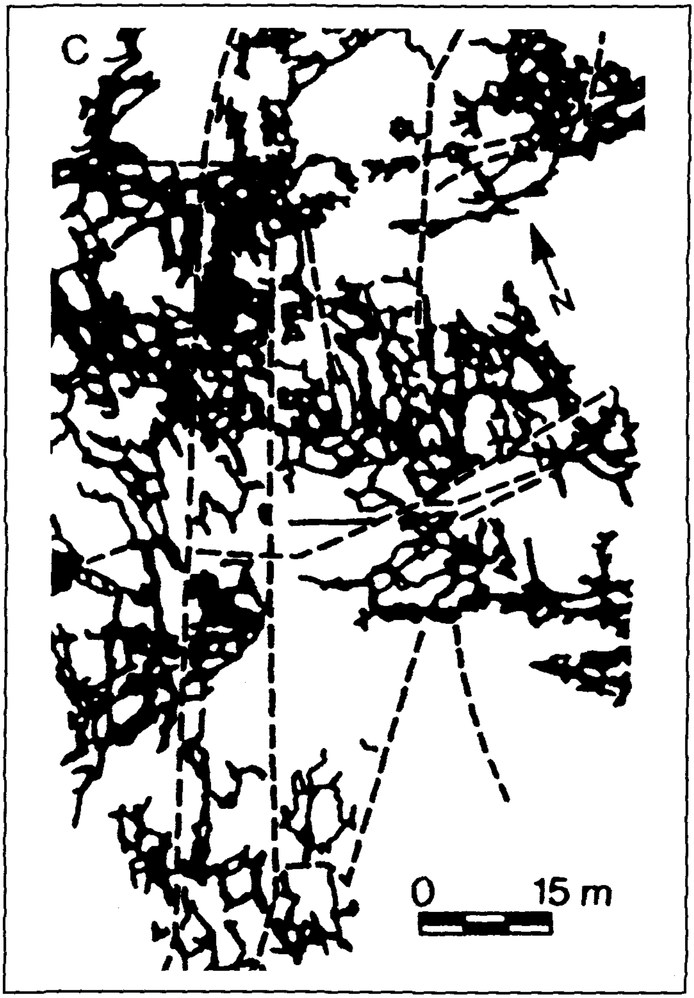

Fig. 7: Section of the Jefferson City Mine, Tennessee, where black is used to indicate galena deposits; it is evident how the mineralization has completely fossilised the 3-D maze karst system (from FORD & WILLIAMS, 1989, modified)

CHEMICAL DEPOSITS IN A THERMAL KARST SYSTEM

The ore deposits of MV type have been well documented and studied for their evident economical importance, but few specific papers have been written on particular hydrothermal karst deposits (HILL & FORTI, 1986)

The few existing papers reveal how the thermal caves are the shelter for peculiar concretions and a lot of cave minerals which are harder to find or totally absent in "normal" caves. In the paragraph dedicated to the thermal karst system we have already mentioned speleothems that can be directly referable to hydrothermal conditions (cave clouds, tower cones, gaysermites etc.) and therefore we will here only remark on the principal minerals which can be observed in thermal karst systems, as usual not taking into account those directly related to the ore deposit of MV type.

The secondary mineralization largely depends on the type of thermal fluid that circulates or has circulated in the cave: as it is not possible to list all the secondary minerals of thermal origin we will point out the more frequent, depending on the principal characteristics of the hot waters.

As previously said, thermal water always contains a great quantity of carbon dioxide and/or sulfidric acid; depending on the water chemistry, i.e. on the relative abundance of one or another of these two gases, the product of chemical deposition will vary enormously.

In the case when CO2 predominates, the most common deposit is calcite which is normally observed as an aggregate of large disphenoid crystals, often completely covering the cavity's walls and roof. Analysis has often indicated how these crystals have continued to develop from medium thermality up to meteoric waters, as in the Pfaff Cave in Sardinia (DE VIVO et al., 1987).

In the case when H2S predominates, gypsum is by far the most common deposit, under the form of more or less thick crusts of micro-crystals which may grow until reaching even total occlusion of great phreatic conduits; other much less common sulphates are barite, celestite etc.

Where H2S is dominant, a reasonably common deposit is sulphur which covers the walls of the aerate zone: its deposition is a direct consequence of the biological oxidation typical of the sulphur cycle in the vadose sections of the cave (FORTI, 1989).

Another common mineral in the hydrothermal caves is quartz: this mineral can be found in the systems characterised by dominating carbon dioxide and those with sulfidric acid even though it predominates in the last. It is generally observed under the form of great euhedral crystals: those deposited in the Jewel Cave in South Dakota (DEAL, 1962) are particularly famous. When, by chance, the thermal water temperature is not high enough, the silex is deposited as amorphous or cryptocrystalline speleothems, normally botryoidal opal.

Finally to give an example of the complexity of the thermal minerogenesis, we would like two small Italian cavities to be remembered which are united for the great interest in their secondary minerals: The Alum Cave at Volcano (Sicily) and the Cap Miseno Cave (Campania) (FORTI, 1992).

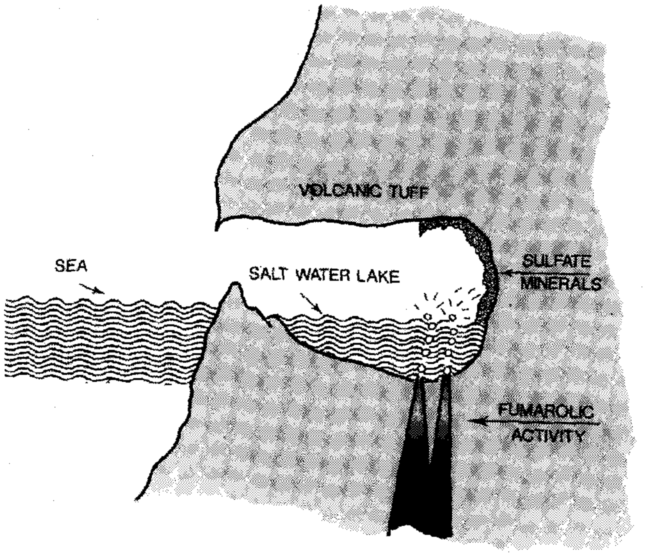

Fig. 8: The environmental conditions inside the Cap Miseno and Alum caves allow the mingling of sea water and thermal fluids and therefore cause the evolution of many rare secondary cave minerals (from FORTI, 1992)

They are two small tectonic cavities which open into volcanic tuff on sea level, therefore the saltwater in the cave comes in contact with fumarolic fluids, which react both with the salts in the sea water and with the tuff on the walls (see Fig. 8) giving place to an impressive series of minerals, some of which world-wide have only been observed inside these caves (see Tab. 1)

In the world, caves containing more than 4 or 5 different secondary minerals are extremely rare and merit absolute protection (HILL & FORTI, 1986), therefore it is understandable the exceptionality of these two small caves where the thermal fluids permit such an ample variety of peculiar deposits.

Table 1: The chemical deposits of Cap Miseno and the Alum Caves

MINERAL	Cave	Deposits morphological characteristics
Alunogen	M&A	small white to transparent crystals
Potash Alum	M	translucid lengthened fibres
Aragonite	A	coralloids
Coquimbite	A	small violet-pink hexagonal tablets
Hematite	M	translucent red - brown blades
Gypsum	A	acicular crystals
Halotrichite	M&A	white acicular fibres
Kalinite	A	acicular crystal tufts
Keramoalite	A	metallic silver coloured fibrous stalactite
Metavoltine	M&A	thin yellow hexagonal blades
Millosevichite	A	violet to green hygroscopic crusts
Misenite	M	pale grey soft fibre
Opal	A	small stalactite
Pickeringite	A	thin brilliant white crystals
Pisanite	A	green-blue crusts
Tamarugite	M	candid white elongated crystal figs
Voltaite	M&A	small pale green crusts
Sulphur	M	canary yellow crusts and single crystals

ACTIVE SPELEOGENETIC MECHANISMS AND THEIR MORPHOLOGIC AND DEPOSITIONAL EFFECT

At present, there are no general or specific papers in the international literature that relate morphologies and chemical deposits in thermal caves with the speleogenetic mechanisms which may be active in different zones of the aquifer.

Such analysis could be of extreme importance as it would permit, at least theoretically, recognition of the mechanisms which have affected the karst system maybe even in a remote age.

In fact, although there are at least ten different mechanisms which could make a thermal karst system evolve, each one has the possibility of being active only in a particular zone of the aquifer. The effect on the system varies from mechanism to mechanism and even internally of the same mechanism depending on the peculiar aquifer zone.

The biological oxidation of sulphur is an example: it can only be expressed in oxygen-rich zones, as in aerated places or at the most in the first meters down in the saturated area, but the results of such oxidation are far different. Gypsum flowers and elementary sulphur prevails in the aerate zones, while in the saturated one sulphur does not deposit and the gypsum is only of phreatic origin (thick deposits, undifferentiated or partially bladed, consisting of aggregates of micro crystals).

On the base of the few isolated and sporadic observations reported in the bibliography it was possible to schematise the existent relation between aquifer zones, the active speleogenetic mechanisms, the principal morphologies and/or evolved deposits (see Tab. 2).

This scheme is to be considered preliminary and essentially useful as a discussion base to reach a detailed relationship on the exististing relations between boundary conditions and evolved morphologies in a thermal karst system.

Table 2: Existent relations between aquifer zones, potentially active speleogenetic mechanisms, morphologies and/or chemical deposits developed in a hydrothermal karst system (modified from FORTI, 1994).

Zone	Mechanism	Morphologic or depositional effects
AE	Diffusion of CO_2 & H_2S	deposition of cave rafts, folia, tower cones, gaysermites
RE	Organic oxidation of H_2S	depositions of sulphur speleothems and crystals, large deposits of gypsum, opal crusts
ATE	Condensation corrosion	domed ceilings, accentuated forms of corrosion, gypsum deposits
INTER	Diffusion of CO_2 & H_2S	Megascallops, domed ceiling, bubble trials
FACE	Organic oxidation of H_2S	deposition of phreatic gypsum
S	Net dissolution	normal phreatic morphologies
A	Corrosion	normal phreatic morphologies
T	Mixing corrosion	domed shaped, branched, cavities via convective motions
U	Incongruent dissolution	large maze cave, deposit of MV type
R	Net disposition	large scalenoedric crystals of calcite
A	Pressure drop	deposition of large druse of calcite
T E	Temperature drop	deposition of various minerals in druses of large crystals

FINAL REMARKS

At the end of this short review on hydrothermal karst we can affirm that although the phenomenon is common in many parts of the globe it has been up to now certainly overestimated. This happened because our knowledge of the speleogenetic mechanisms was not sufficient to justify the evolution of complex morphologies and the great variability of chemical deposits in a normal karst environment, developed by meteoric seeping waters.

Apart from this, however, the hydrothermal karst systems maintain a great importance in the world and above all for the economic implications (mineral deposits of primary importance but not forgetting the hydrothermal exploitation). Notwithstanding this the thermal karst system is surely little known and less studied; the reason for this can be found in the complexity of the chemical-physical reactions which develop internally and which are often catalysed by living organisms (bacteria, nanobacteria, algae etc.), as recently demonstrated (AA. 1994).

Therefore an interdisciplinary approach is necessary fully to understand the thermal karst, in which scientists in hydrogeology, geology, karst and microbiology co-operate. It is auspicious that in the near future we are able to activate such multi-disciplinary research on this topic, maybe in Italy, a land especially rich in karst thermal phenomena.

REFERENCES

AA.VV., 1994 *Breakthroughs in karst geomicrobiology and redox geochemistry* Abs. of Papers, Karst Water Inst. Spec. Publ. 1, p.1-112

BAKALOWICZ M.J, FORD D.C., MILLER T.E., PALMER A.N., PALMER M.V., 1987 *Thermal genesis of solution caves in the Black Hills, South Dakota.* Bull. Soc. Geol. Am., 99, 729-738

CHIESI M., FORTI P., 1987 *Studio morfologico di due nuove cavita' carsiche dell'Iglesiente (Sardegna Sud Occidentale)* Ipoantropo, 1986(4), p.40-45

CHROMY J., 1927 *Zbrazovske' krapnikove' jeskyne'* Hranice, p.11-19

DEAL D.E., 1962 *Geology of Jewel Cave National Monument, Custer County, South Dakota with special reference to cavern formation in the Black Hills* M.S. Thesis , Univ. of Wyoming

DE VIVO B., MAIORANI A., PERNA G., TURI B., 1987 *"Fluidi inclusion and stable isotope studies of Calcite, Quartzand Barite from karstic caves in the Masua mine, Southwest Sardinia, Italy"* Cem. Erde 46, p.259-273

DUBLIANSKY Y., 1994 *Transitional karst* in press

DUBLIANSKY V. N., 1980 *Hydrothermal karst in the alpine folded belt of southern part of the U.S.S.R.*. Kras i Spel. 3(13), p.18-36

DZULYNSKY S., SASS-GUSTKIEWICZ M., 1989 *Pb-Zn ores* in BOSAK P. ed. *"Paleokarst"*, Academia, Praga, p.377-398

FORD D., 1988 *Characteristics of dissolutional cave systems in carbonate rocks* in JAMES N.P. & CHOQUETTE P.W. *Paleokarst*, Spring & Verlag, New York, p.25-57

FORD D., WILLIAMS P., 1989 *Karst geomorphology and hydrology,* Unwin Hyman, London, p. 282-293

FORTI P., 1989 *The role of sulfide-sulfate reactions in speleogenesis* Proc. X Int. Congr. Spel., Budapest, 1, p.71-73

FORTI P., 1991 *Processi ipercarsici e speleogenesi* Speleologia 24, p.42-46; 26, p.11-15

FORTI P., 1992 *Cave minerals in volcanic caves* Act. Int. Symp. Vulcanospeleology, Terceira, in press

FORTI P., 1994 *Thermal karst systems* Abst. of Paper "Breakthroughs in karst geomicrobiology and redox geochemistry, Colorado spring, p.23-24

FORTI P., UTILI F., 1984 *Le concrezioni della Grotta Giusti* Speleo,7(2), p.17-25

HILL C.A., FORTI P. 1986, *Cave Minerals of the World,* Nat.Speleol. Soc., USA, p.1-238

LOHMANN K., 1987 *Geochemical patterns of meteoric diagenetic systems and their application to study of paleokarst* in JAMES N.P. & CHOQUETTE P. W. *Paleokarst*, Springer Verlag, New York, p.58-80

MÜLLER P., SALVARY I., 1977 *Some aspect of the developments in Hungarian speleology theories during the last 10 years.* Karszt-és-Barlang, p.53-59

PANOŠ V., 1960 *Nalez gejzirovych stalagmitu v termomineralnich jeskynich v okoli Budapesti* Geogr. Časopis, 12(3), p.198-205

PETROVIĆ J., 1969 *Pojava Dubinske karstifikacije u južnom delu starog massiva Kopaonika.* Zb. prir. Nauke Matice sprske 36, p.97-108

RUDNICKI J., 1978 *Role of convection in shaping subterranean karst forms* Kras i spel. 11(2), p.92-101

TERMALNI KRAŠKI SISTEMI

Povzetek

Termalni kraški sistemi so lahko pomemben hidrogeološki vir ali pomembna nahajališča rud. Kljub temu so zadevni prispevki zelo redki v mednarodni literaturi, v italijanski pa jih sploh ni.

V preteklosti se je za vsako jamo, ki je bila nenavadnih oblik ali je bila zapolnjena z eksotičnimi odkladninami, kot so nenavadni spelotemi ali različni minerali običajno menilo, da je nastala v hidrotermalnih razmerah.

V zadnjih desetih letih, ko se je naše znanje o različnih in od časa do časa bolj zamotanih speleogenetskih mehanizmih izboljšalo, se je večkrat pokazalo, da so številni, domnevno hidrotermalni kraški sistemi, nastali v normalnih okoliščinah.

Teoretično je neka jama hidrotermalnega nastanka (ali deloma takega) takrat, če so termalne tekočine (običajno vroča voda) tekle skoznjo (ali skozi njen del) vsaj v času njenega nastajanja.

Četudi je ta definicija zelo preprosta, so kriteriji, ki uvrščajo jamo med termalne relativno zamotani in često po njih ni mogoče napraviti zaključkov: najbolj gotov (čeprav najbolj redek) je tok vroče vode skozi jamo.

Iz literature poznamo več prispevkov, ki govore o posebnih termalnih sistemih, vendar zelo redki podajajo pregled preko te snovi (Ford & Williams 1989).

Večina raziskav se ukvarja z morfologijo takih jam. S tega vidika lahko hidrotermalne jame razdelimo v dve skupini (Müller & Salvary 1977); v monogene hidrotermalne jame, sestavljene iz velike osnovne votline, iz katere se širi navzgor razvejana mreža rovov v obliki zvonov; drugo skupino sestavljajo jame v obliki 2D in 3D labirintov. Možnosti za razvoj različnih tipov hidrotermalnih jam so dane z razpokanostjo kamnine, s prisotnostjo neprepustnih krovnih kamnin, z načinom napajanja in pretokom ter z drugimi dejavniki (Müller & Salvary 1977; Dubliansky 1980; Bakalowicz et al. 1987).

Le malo prispevkov govori o nenavadnih speleotemih iz hidrotermalnih jam in nobeden izmed njih s splošnega vidika (Hill & Forti 1986). Nasprotno pa je obilo literature o rudnih nahajališčih (tipa doline Mississippija) povezanih s termalnimi kraškimi sistemi (Dzulynsky & Sass-Gustkiewicz 1989).

Ni še bilo splošne raziskave, ki bi primerjala morfologijo in kemijske sedimente termalnega krasa s speleogenetskimi mehanizmi, ki lahko delujejo v raznih delih vodonosnika.

V resnici je, glede na kompleksnost in spremenljivost termalnih tekočin, mnogo raznih kemično-fizičnih reakcij, ki lahko delujejo v takem okolju. Vseeno pa lahko nekatere med njimi štejemo za najpomembnejše, glede na to, da same ali v kombinaciji z drugimi potekajo vsaj v delih večine izmed hidrotermalnih jam.

Nekatere od teh reakcij povzročajo ali samo raztapljanje ali samo odlaganje, toda večina med njimi povzroča "inkongruentno raztapljanje" (sočasno odlaganje in raztapljanje). Običajno ti mehanizmi lahko delujejo le v določenem delu vodonosnika in zato njihovi učinki kažejo na okolje, v katerem se je jama razvijala.

Zato bi bilo zelo pomembno, če bi lahko določili medsebojna razmerja med speleogenetskimi mehanizmi, deli vodonosnika in ustrezno morfologijo in/ali kemičnimi usedlinami. Ta prispevek daje v razpravo prvi poizkus take klasifikacije.