PONORNE ZONE I NJIHOVI PRIRODNI NASTAVCI U VAPNENAČKIM NASLAGAMA

Mr. Šrečko BOŽICEVIĆ, Geološki zavod Zagreb

Šrečko BOŽICEVIĆ, M. Sc., Institute of Geology — Zagreb

SAŽETAK

U radu se prikazuju rezultati istraživanja danas aktivnih ponora u koje se zbog znatnog nanosa naplavljenog materijala obično ne može dalje prodijeti. Pri izvođenju građevinskih radova na zapadnom rubu Buškog Blata istražnim su bušenjima ustanovljeni nastavci postojećih ponora. Nabušene šupljine ponora Proždrikoza, te sistem Sinjskog ponora u zoni Sinjske jaruge postali su nakon detaljnog speleološkog istraživanja indikatori za pronalazak podzemne odvodnje akumuliranih voda u Buškom jezeru. Ova su otkrića upozorila na činjenicu, da se ovakvim pojavama može postići određena pažnja pri sličnim situacijama u ostalim područjima Dinarskog krša.

UVOD


INTRODUCTION

The report reviews the investigation results of the currently active swallow holes which are usually inaccessible in their remote sections due to considerable flood material deposits. During civil engineering works on the western border of Buško Blato, the extensions of the existing swallow holes were discovered by investigation drillings. After detailed speleological investigations, the drilled spaces of the swallow hole of Proždrikoza, the system of Sinjski ponor in the zone of Sinjska jaruga became indicators for investigation of underground drainage of the water stored in Buško jezero (lake). These discoveries pointed to the fact that such occurrences should be paid attention to in similar situations that may be encountered in other parts of the Dinaric karst.
merous swallow holes and sinkhole systems. Slower or faster draining in all these swallow holes depends on the quantities of top water and on permeability, i. e. the seeping speed through underground channels. The whole drainage system is also influenced by the depth of limestone deposit karstification at certain areas, lithologic rock characteristics and hydrogeological character in relation to their permeability or impermeability characteristics. Stronger or weaker faulted zones; i. e. the existence of tectonically formed fissures in carbonate sediments also promote faster water draining into the karstified underground.

Very strong, whirling and sinking accompanied by the deafening noise of waterfalls are often noticed in swallow holes giving an impression that kilometres and kilometres of underground channels are behind the opening, but unfortunately, this is not so. In a detailed investigation of any speleological karst phenomenon — cave, pit or swallow hole, man — the researcher only has access to those parts to which he can get personally by means of simple technical facilities. Narrow cracks, impassable for man, prevent detailed investigations. Up to recently, it has been the same situation with symphonic water reservoirs. Nowadays, however, siphonic reservoirs are passable by the help of individual divers, while the access to narrow cracks has been enabled by mining or by civil engineering works — i. e. by drilling and the enlargement of channels up to the entrance to larger underground spaces.

When investigating swallow holes, particularly the active ones, the obstacles most often encountered are accumulated and deposited material. To prevent or reduce such depositing, the entrances of some swallow holes in the region of the Dinaric karst are protected by steel gratings, while in some more important swallow holes the dis-
charge channels are occasionally cleaned. Such measures have been undertaken in many large fields which are important to the economic development of the nearby population.

Thus in the region of Buško Blato, which is the lowest part of Livanjsko polje, all the active and larger swallow holes have protected entrances, while in some of them even underpinning and clearing were carried out fifty years ago in the main channels so as to promote drainage (Božičević and Malez, 1967). During their investigations, the author of this report found out that deposited material considerably fills in the channels of the most active swallow holes. Stara Minica, Liškovača, Šinjski ponor and Proždrkoza swallow hole, and estavelles near Kurtovina and Kazagecinac.

Branches and other material are transported by water into drainage channels and after flooding they get covered by gravel, sand and mud from the field. All this reduces the permeability of the fissure systems and drainage capacity of the swallow holes. Irregular cleaning of swallow holes resulted in increasingly larger quantities of deposited material which prevented the investigation of speleological structures being carried out to the end. It was assumed that the length of these swallow holes would be great in relation to the great quantities of flood water, but the lengths, that were accessible to man in this underground area ranging from 129 to 389 metres. The ends of the swallow holes had very narrow passages filled in with subsided blocks or by branches brought in during flooding, thus making any further movement impossible. Comparing the lengths of these swallow holes with the channel lengths in other swallow holes of the Dinaric karst region (e.g. swallow holes in Popovo polje), a great difference can be seen in the lengths of channels.
The conclusion was that the swallow holes in Buško Blato probably continue in depth through impassable channels and spaces which are impossible to reach without certain civil engineering works.

Even 10 m high man-made walls in some swallow holes could not provide their constant permeability in the case where regular cleanings were left out.

Civil engineering works in swallow hole zones

During the construction of the man-made reservoir Buško Blato within the Orlovac water system, it was necessary to seal the fissures in the hinterland of the Proždrkoza, swallow hole and Sinjski ponor. The designed grou-

Lociranje: nabušenih kavernoznih prostora izvršeno je prema istražnim bušotinama kao i bušotinama iz trase same zavjese. Kôd utvrđivanja većeg apron was made in their hinterland so that a gross number of boreholes were drilled in cavernous spaces, the result being larger or smaller co-

Sl. 1. Glavni otvor ponora Proždrkoza ispod niskog uzvišenja Matkovače s krom jaruga kroz koji su doticale vode iz polja.

Fig. 1: Main entrance of the Proždrkoza swallow hole below a low elevation called Matkovače with the ravine bed through which water came from the field.
nabušenog prostora odlučeno je da se u njega i stvarno uđe uz pomoć građevinskog zahvata izradom rudarskih potkopa ili »stolnih« dužine od 10—100 m, te vertikalnih »šahtova« dužine od 12 do 40 metara.

Uz zapadni rub Buškog Blata, radi građevinskih zahvata, otvorili su međusobno udaljeni oko 900 metara. U vrijeme manjih poplava u polju-vođa je otvor dolazila uređenim kanalima ali jarugama dubokim nekoliko metara.

Zona poruna Proždrkova nalazi se najsjevernije i osim glavnog otvora imala je niž vidljivih poniranja u pukotinama na kontaktu kvartara—naslage vapnenaca mezozojske starosti (Sl. 2). Ako registriramo činjenicu da je ovaj poror u hipsometrijskom odnosu na najvišoj koti u Buškom Blatu i da je dubina nekada prirodne naplavne vode kod njega bila relativno mala, tada je i za očekivati da je nanašen materijal u njemu polagano taložen i da će naslaga tog materijala biti znatna. Prva naša istraživanja poruna (godine 1960) pokazala su, da se ovdje radi o relativno uskom i niskom sistem jednog kanala dužine svega 129 m. Dno kanala bilo je prekriveno u najvećoj mjeri kamenim valučicama i kršjem dok nanosa zemlje i blata nismo našli mnogo. Završetak poruna bio je među obrušenim blokovima s nešto blata i nanešenog granja.

U sjeverozapadnom zaleđu iza od prije, poznatog kanala ponora Proždrkova nabušena je, i djelomično omeđena velika kaverna. Za ulaz u nju, izvedeno je bušenje vertikalnog šahta promjera 70 cm. Pošto je nadlož naotkrivenom kavernom bio relativno malen, — svega 12 m. probijanje, je izvedeno relativno brzo, pa nam je omoćeno detaljno speleološko istraživanje. (1970, g) — vidi Sl. 3.

The swallow hole of Proždrkova zone is furthest to the north. Besides the main opening it also had a number of visible sinkings in fissures at the contact point of the Quaternary limestone deposits of the Mozozoic age (Phot. 1). If one takes into consideration the fact that this swallow hole is in hypsometric terms at the highest elevation point in Buško Blato and that the depth of its natural flood water used to be relatively small, then one can also expect that flood brought material was being slowly deposited in it and that these deposits are quite considerable now.

In the first investigation of the swallow hole (in 1960) the author found out that it was a relatively narrow and low system of a channel hardly 129 m in length. The bottom of the channels was covered mostly with rounded stones, pebbles, and debris, the deposits of earth and mud being rather poor. The
Ovdje je otkriven podzemni prostor dug 135 m s dvoranom širokom 50 m i dugom oko 55 m. Visina od poda do stropa u novootkriženom dijelu varira od 1 do 10 m. Otkriveni podzemni sistem nastavljao se jednim sve nižim kanalom koji se pružao prema za vrijetku od prije poznatog sistema poñora Proždrikoza (sa debelim nanosom raskvašenog blata od dna do stropa).

end of the swallow hole was among subsided blocks with some mud and branches. In the northwestern hinterland, behind the already known channel of the swallow hole of Proždrikoza, a great cavern was drilled and partly bordered. In order to make the entrance to it, a vertical shaft of 70 cm in diameter was drilled. Since the layer above the discovered cavern was re-
Iz proučenih morfoloških detalja bilo je očito, da se na kraju prije poznatog prostora ponora Proždrikoza nalazi kameni 'čep', kroz koji je prolazila samo voda i najfinije čestice kvartarnog nanosa, koji je u novootkivenoj dvorani formirao nakupinu pečinske ilovačke blata. Iskazali su pretpostavku, da pravac odvodnje vode iz polja nije bio samo privilegiranim namom poznatim putem već jednim složenim sistemom pokotina koje se počivaju na terenu sjevernije od postojećeg otvora ponora Proždrikoza (područje Matkovače). Izrazna oblikovanost nabušenog prostora ponora Proždrikoza ukazuje na veći erozional i korozionalni dio voda u nabušenom dijelu podzemlja, za razliku od prije požnjitog ulaznog kanala ponora: relativno maši — only 12 m, drilling was rather fast thus enabling detailed speleological investigation (1970). See Phot. 3.

An underground space was discovered there, 135 m long with a hall 50 m in width and 55 m in length. The height from floor to ceiling in the newly discovered part ranged from 1 to 10 m. By an increasingly lower channel with thick deposits of soft mud which filled the channel from bottom to top, the new underground system was extended towards the already known system of the swallow hole of Proždrikoza.

Morphological studies revealed that there was a rock 'plug' in front of the previously known space of the swallow hole of Proždrikoza, through which only water and the finest particles of
Morfologija ponora Proždrikoza karakterizirana je relativno uskim i niskim ulaznim dijelom (vidi Sl. 3) koji je, izgleda, imao manju funkciju gutanja vode, nego bočno položeni kanali (nedorostupni za speleoška istraživanja). Otkriće nabušenog dijela sa velikom dvoranom upućuje na postojanje niza kanala koji su se sastajali na ovom mjestu i gdje su vrložne struje ponornih voda oblikovale postojeću veliku šupljinu. »Pukotinski ponor« u površinskom dijelu dovodnog kanala samog polja usmjeren je prema »Zarušenoj jami«, a ova prema nabušenim šupljinama uz sjeverni rub velike blatne dvorane (Sl. 5).

Velika blatna dvorana u umjetno nabušenom prostoru široka je oko 50 m, dok joj visina od poda do stropa varira od 2 do 15 m. Naplavljena zemlja i glina koja prekriva velike urušene bloke ve došla je iz polja kroz ulazni i sada nedostupni dio ponora, nataloživši se u prostoru u kom nije bilo jakog protjecanja vode.

the Quaternary deposit passed, making thus in the newly discovered hall the deposit of cave clay and mud over 10 m in height. (Phot. 4). The adjoining channels in this system proved the assumption that the direction of drainage from the fields did not go only along the privileged ways known to us, but through a complex system of fissures which can be noticed in the terrane north of the existing opening of the swallow hole of Proždrikoza (the region of Matkovača). Very pronounced forms of the drilled part of the swallow hole of Proždrikoza point to strong erosional and corrosional water effects in the drilled part of the underground, which is not the case in the previously known entrance channel to the swallow hole.

The morphology of the swallow hole of Proždrikoza is characterized by a relatively narrow and low entrance part (Phot. 3), which absorbed less water than the lateral channels (inaccessi-
Št. 5. Južni dio velike dvorane ponora Proždrikoza s početkom vodenog kanala koji je vodio u smjeru polja.

Fig. 5. The southern part of the great hall of the swallow hole of Proždrikoza with the beginning of the water channel that ran in the field direction.

Vrlo polagano spuštanje tla ponora od ulaza do velike dvorane registrirano je na svega 3 metra, dok se u prostoru ponora iza nakupljene barijere u ljevkastim ponorima tlo spušta preko deset metara ispod razine polja. Zbog nakupina injekciono mase, spuštanje u eventualno niže dijelove nije bilo moguće. Ukupna dužina istraženog dijela ponora koji je umjetno nabušen iznosi 135 m.

Urušeni blokovi na kraju istraženog dijela ponora ukazuju na stadij sniža-

ble for speleological investigation). The discovery of the drilled part with the large hall points to the existence of a number of channels that used to meet at this place and where whirlpools of swallow hole water created the existing large cavity. »Fissure swallow hole« in the surface of the field gully stretches towards the »fallen-in pit« and this one towards the drilled cavities along the northern border of the great mud hall (Phot. 55.)
vanja nivoa podzemne vode, koja u ovom dijelu otječe sada nešto niže.

Odsutnost sigastih nakupina stalagmita upućuje na činjenicu, da je postojeće prokopljivanje sa strapa padalo u raskvašen blatni materijal koji je povremeno odnašan naplavnim vodama. To znači da je i u posljednjim poplavama (prije građevinskog zahvata za akumulaciju) veći dio ponora bio zahvaćen vodom koja se postepeno gubila među urušenim blokovama i ljevkastim udubljenjima. Polagano otjecanje rezultiralo je taloženjem disperziranih čestica gline i humusnog materijala.

Za čovjeka nedostupni ili neistraženi dio između sada poznatog i nabušenog dijela ponora Proždrikoza iznosi 80 m, a sveukupna dužina danas poznatog ponornog sistema Proždrikoza iznosi oko 320 metara.

Zona Sinjskog ponora sažtoj se od dijela prirodnog nastavka samog ponora (u koji se ušlo uz pomoć potkopa!) i od niza nabušenih kaverni, koje se protežu uz Sinjsku jarugu u smjeru Liskovače.

Od ranije poznati Sinjski ponor (sadašnji »ulazni dio«) imao je dosta prostrane kanale, a naročito završnu dvoranu s visokim nanosom naplavljenog materijala. Najudaljenija istražena točka ovog ponora bila je 160 m od ulaza, a najniža točka svega nekoliko metara ispod razine polja (vidi sl. 6).

U zoni Sinjskog ponora nepoznat podzemni prostor nabušen je jugozapadno od poznatog završetka ponora s propadanjima većim od deset metara. Prema odluci projektanta izrađen je potkop u pravcu tzv. »osmog sektora«. Nakon 28 m bušenja otvorio se ulaz u veliku kavernu s vodenim tokom, na njezinu dnu u odvodnom kanalu. Radi izvođenja daljnjih istraživanja u ovom prostoru, izbušen je još 22 m dugi potkop za ulazak u kavernu »sedmom sektoru« kao i 20 m dugi potkop za otkrivanje kavernoznog prostora u jugo-

The great mud hall in the man-made drilled space is about 50 m wide, its height from floor to ceiling ranging from 2 to 15 m. Earth and clay that cover great subsided blocks were brought from the field through the entrance part of the swallow hole which is now inaccessible and were deposited in the space where the water flow was not very strong.

The inclination of the swallow hole soil from the entrance to the great hall is very low, i.e. only 3 m, while in the space of the swallow hole behind the deposited barrier, in funnel-shaped swallow holes, the slope of the soil is above 10 m below the field elevation. Due to grout mixture depositing, it was impossible to reach some lower parts. The total length of the investigated part of the swallow hole that was artificially drilled is 135 m. Subsided blocks at the end of the investigated part of the swallow hole reveal the lowering of the groundwater level which in this part flows somewhat lower.

The absence of travertine deposits, i.e. stalagmites points to the fact that the existing dripping from the ceiling fell into softened mud which was occasionally taken away by flood water. That means that during the latest floodings, the greater part of the swallow hole was filled with water which gradually drained away through subsided blocks and funnel-shaped recesses. Gradual drainage resulted in deposits of dispersion particles of clay and humus material.

The part of the swallow hole of Proždrikoza which is between the now familiar and drilled part is 80 m long and is inaccessible to man and has not yet been investigated.

The total length of the presently known swallow hole system of Proždrikoza amounts to up to about 320 m.

The zone of Sinjski ponor consists of a part of a natural continu-
SINJSKI PONOR
I. NJEGOV OTKREVEN NASTAVAK

Fig. 6.

Sl. 6.

zadnjom dijelu pri dnu velike dvorane. Nakon izrade betonskog čepa na dnu dvorane do njega je sa stražnje strane izbušen dodatni potkop dug preko stotinu metara.

Radi dolaženja u ostale nabušene prostore Sinjske zone potkopi su još izrađeni na 24-torn, 27-torn i 31-torn sektoru, dok je za ulazak u nabušenu kavernu 17-tog sektora izbušen 40 m dug vertikalni “šaht” promjera 70 cm.

Direktnim ulaženjem čovjeka u nabušene prostore omogućeno je sagledavanje morfološke postojićih kanala, praćenje hidrogeoloških pojava u samom podzemlju, te donošenje pravilnih odluka za što bolje rješavanje potrebnog građevinskog zahvata.

Promatramo li površinski prostor oko otvora Sinjskog ponora (sl. 7), tada primjećujemo uvučeni dio jaruge sjeverno od njegovog ulaza, ali i južno u obliku kanala Sinjske jaruge. (sl. 8).

ation of the swallow hole (which was reached by means of a heading) and a number of drilled caverns which go along the ravine of Sinj in the direction of Liskovača.

Sinjski ponor as known in the past and which nowadays is the “entrance part”, used to have rather large channels, particularly the final hall with a high deposit of flood material. The farthest investigated point in this swallow hole was 160 m away from the entrance, the lowest point being only a few metres below the field level (Phot. -6).

In the zone of Sinjski ponor, an unknown underground space has been drilled to the southwest of the known ending of the swallow hole which had subsidences higher than 10 m. According to the desision of the designer, a heading was made going in the direction of the so called “eighth sector”. 
Prostor na kom je otvor ponora izdignut je poput grebena s izraženim punkotinskim sistemima. Jugozapadno od današnjeg otvora na kotama višim od razine polja ističe se kružno udubljenje fosilnog ponora kao i velika vratača na koti od 705 do 710 m. Sve ove pojave upućivale su na određena zbivanja u unutrašnjosti vapnenčkih naslaga uz ponor i u njegovoj neposrednoj okolini.

Vrlo složena morfološka kanala izrađena je već poznatog prostora Sinjskog ponora kao i nalaz vodenog toka u najdijelovima dijelom na vrlo naglo snižavanje gradijenta ili nivoa podzemne vode uz rub polja. To naglo snižavanje uz konstataciju velikih kolичina vode u polju (u periodu diluvijalnog oblija obrina) rezultat je velike

After 28 m of drilling an entrance appeared leading to a large cavern with a water flow at the bottom of it and a drainage channel. For the purposes of further investigation of this space, another heading in the length of 22 m was drilled to enable the entrance to the cavern of the »seventh sector«, as well as a 20 m long heading which provided access to cavernous space in the southwestern part, at the end of the great hall. Having made a concrete plug at the end of the hall, an additional heading over a hundred of metres long was drilled at the back of it.

To enable the access to other drilled spaces of the zone of Sinj, headings were made in the 24th, 27th and 31st

Si. 7. Otvor Sinjskog ponora sa visokom ulaznom stijenom snimljen prije pregrađivanja i zatvaranja betonskim čepom.

Fig. 7. The opening of Sinjski ponor with high entrance rock, photographed prior to partition and closing by a concrete plug.
Sl. 8. Pogled na dio Sinjske jaruge od ulaza u potkop »osmog« sektora. Strelice označuju kaverne na 17-om i 24-om sektoru.

Fig. 8. A view of the part of Sinjska jaruga going from the entrance into the heading of the »eighth« sector. The arrows denote the caverns in the 17th and 24th sectors.

Erozionalne snage razaranja pukotinskih sistema i labilnih partijs važnjenjačkih naslaga. Erozioni oblikovani prostor naknadno se proširuje korozionim djelovanjem u kom se nastavlja period kalcitnog izlučivanja i vezivanja urušenih blokova (sl. 9).

Velika dvorana »osmog« sektora je duga 48 m, sa širinom prostora od 14 m na početku (pri ulazu iz potkopa) do 11 m u sredini i 18 m na svom kraju. Dvorana se isporna postepeno, a kasnije vrlo naglo spušta (ΔA = 1.8m) i to od ruba polja. Visina od poda do stropacนา dnu velike dvorane iznosi 22 m što je vrlo mnogo za podzemne šupljine u našem kršu. Desni bočni kanal uspinje se pod kutom od 35° i svojim stropom sector, while the entrance to the drilled cavern of the 17-th sector was provided by a 40 m long vertical »shaft« with 70 cm in diameter.

Having made the drilled spaces directly accessible to man, it was possible to get acquainted with the existing channels morphology, to follow hydrogeological phenomena in the underground and to make the best decision regarding the necessary civil engineering works.

In the surface area round the Sinjski ponor opening (Phot. 7), one can notice a recessed part of the ravine in the north of its entrance, but also in the south, in form of a channel of the
prelazi kotu stropa velike dvorane. Tio
i bokovi ovog kanala u potpunosti su
prekriveni kalcitnim prevlakama znat-
ne debljine. Voden kanal dug je 90 m,
spušta se 7 m i izraži je primjer ero-
zionog odvodnog kanala duž vertikalno
položenih vapnjenjačkih naslaga (sl. 10). Variranje visine od 2 m na ulazu do
11 m u središnjem dijelu ispunjenom
Sinjska jaruga (ravine) (Phot. 8). The
space of the opening of the swallow
hole is raised as a reef with pronounced
fissure systems. In the southwest of
the present swallow hole opening, at
elevations higher than the field level,
there is a round shaped recess of a
fossil swallow hole and a great funnel
shaped depression at the elevation of

Sl. 9. Ogoromni urušeni blokovi u nabušenom dijelu velike dvorane »osmog« sektori Sinj-
skog porora. Srimu i visinu dvorane usporedite s tijekom.

Fig. 9. Large subsided blocks in the drilled part of the great hall of the »eighth« sector in
Sinjski ponor. The width and the heigh of the hall can be seen by comparing to
the size of man.
Fig. 10. The drainage canal of the Sinjski ponor in the drilled part is formed along almost vertically placed layers along which rocks used to fall out and form underground spaces.

blokovima, te uski i relativno niski za-
vršni dio upućuje na činjenicu, da je
njegovo formiranje završilo vrlo da-
vno. Naime, ocjeđivanjem vode iz ka-
nalna našlo se na njegovom dnu na si-
gaste nakupine — stalagmaste, znatne
debljine koji nisu mogli nastati u vodi.
Radiokarbonskom analizom utvrđena je
starost sigastih nakupina, a i starost
705 to 710 m. All these things point to
 certain occurrences that must have
happened inside the limestone deposits
very close to the swallow hole or in
its direct vicinity.

Very complex morphology of the
channels behind the already known
space of the Sinjski ponor and the dis-
ccovery of the water course in the lo-
urušavanja pojedinih blokova u ovom kanalu kao i u velikoj dvoran. Sigaste nakupine nađene su i u ostalim nabušenim vodenim kanalima jugozapadno od velike dvorane a sige — stalaktiti i stalagmiti viđeni u dubokoj vodi upućuju na zaključak, da je sve ovo u ne-
đavnoj geološkoj prošlosti bio suh prostor, u kome je došlo do formiranja kalцитних nakupina.

Nabušena kaverna »sedmog« sektora istražena je u dužini od oko 80 m. Najnija kota koja je promatrana bila je razina vodenog bazena, dok je visina gornjih šupljina dosizela 28 m, približujući se velikoj vrtići na površini terena. Na rubu bazena u ovoj kaverni registrirani su oko 1 m debeli stalak-
titi, koji su svakako samo ostatak ne-
ked velikog podzemnog prostora ispu-
njenog s većim brojem tih nakupina.

Nivo podzemne vode registriran u trenutku istraživanja u kaverni »sed-
mog« sektora iznosi je 15 m, a u ka-
vern »osmog« sektora 28 m ispod raz-
ine polja.

Promatramo li sve uočene šupljine ovog prostora u zadevu nekad poznatog dijela Sinjskog ponora, moramo konstra-
tirati, ukazuju na znatnu morfološku složenost te i međusobnu povezanost, ali se na žalost nije moglo proći kroz sve te šupljine zbog zabeleženja injekcijom masom. Ukupna dužina svih iz-
mjerenih dijelova zaleđa Sinjskog po-
ora sada iznosi 280 m. Razlika između uzadnje točke u ulaznom dijelu ponora do ruba vodenog bazena u »sedmom« sektoru je 30 m.

Naknadno istraženi dijelovi kanala uz nove potkope povećavaju tu dužinu za navedenih 30 metara.

Otkriće podzemnog toka u nabušenim kavernama »sedmog« i »osmog« sektora, te dokazivanje veze bo između otvora Sinjskog ponora i vodenog toka u spomenutim kavernama, potvrdilo je činjenicu, da se podzemni odvodni sistem nekog ponora u našem kršu ne završava na mjestu koji je čo-
west parts of the swallow hole, point to a very sudden drop of groundwater level directly along the border of the field. Such sudden drop, and, on the other hand, great quantities of water in the field (in the period of high di-
luvial precipitation) are the result of the great erosional strength which in-
fluenced the decaying of fissure sys-
tems and less stable limestone depos-
sits. Space shaped by erosion was la-
ter on enlarged by corrosion processes which go together with calcite secre-
tion and linking of subsided blocks (Phot. 9).

The great hall of the »eighth« sector is 48 m long, its width being 14 m at the begin-
ning (at the entrance from head-
ing), 11 m in its middle part and 18 m at its end. The hall slopes down birst gradually and later on very quickly. The height from floor to ceiling at the end of the great hall is 22 m which is very much for underground cavities in our karst regions. The right lateral channel goes upwards at the angle of 35° and its ceiling exceeds the eleva-
tion of the great hall ceiling. The floor and side walls of this channel are com-
pletely covered with calcite layer of considerable thickness.

The water channel is 90 m long, it slopes down for 7 m and is a typical example of erosional discharge chan-
nel along the vertically placed lime-
stone deposits (Phot. 10). Differences in height, ranging from 2 m at the en-
trance to 11 m in the middle part which is filled-in with rock blocks, narrow and relatively low ending part of it show that its formation had been com-
pleted long ago. Having drained water from the channel, travertine deposits were found at its bottom — stalag-
mites of considerable thickness which could not have been formed in water. Radiocarbon analyses revealed the age of travertine sediments, as well as sub-
sidence of some rock blocks both in this channel and in the great hall. Tra-
vjeku lagano dostupan, već da se na-
stawlja i iza više puta i prirodno for-
mirane barijere.

Detaljnim istraživanjem dostupnih
prostora nabušenih šupljina, te pove-
zivanje s već poznatim prostorom Sinjs-
skog ponora uočeno je da se radi o
jednom cjeolovitom sistemu s naknadno
pregrađenim prostorima u kontinuiran-
om kanalnom toku poniruće vode.

Tragovi fosilih ponora i velika uru-
šena vrtača na kotama višim od današnji-
njeg nivoa polja u neposrednoj blizini
ulaza Sinjskog ponora, te sistem pod-
zemnih šupljina u njegovom nastavku
ukazuju na jednu cjelinu, a uz to i na
postupnost stvaranja kavernoznog pro-
stora s vodenim tokom. Prema svemu
do sada ispitano, iza nekada poznatog
160 m dugog Sinjskog ponora nalazi
se još 340 metara podzemnog spiljskog
prostora, odnosno sve zajedno 500 m
kanala.

Zona Sinjske jaruge

Uz rub Sinjske jaruge, odnosno na
kontaktu kvartara i vapnenjačkih na-
slaga proučene su još četiri podzemne
spiljske pojavce, ali tih je pojava bilo i
više. Brojne sufoxije uz rub polja kao
i veće pukotine s naplavljenim granjem
dokazuju jače poniranje vode u vapi-
nečke naslage.

Na lokalitetu 17-og sektora is-
tražena je podzemna kaverna dužine
oko 250 m nakon izbijanja vertikalnog
šahta, (sl. 11). Pratnica voda konstati-
rana je 46 m ispod razine polja. Nadšo-
loj nad nabušenom kavernom iznosu u
ulaznom dijelu oko 40 m, u središnjem
također oko 40 m, dok na mjestu po-
java protok vode i dostupnog kraja
kaverna i preko 100 m. Najviša točka u
ovoj kaverni dolazila je na razinu
današnjeg polja. U »nedavnoj« geološkoj
prošlosti voda iz polja ponirala je
na tom mjestu, a snižavanjem razine
nivoa podzemne vode ovaj je otvor za-
verteine deposits were found in other
drilled water channels in the south-
wester of the great hall- and stalactites
and stalagmites seen in deep water
point to the fact that in the recent
geologic past it had been a dry space
in which calcite deposits were formed.

The drilled cavern of the »seventh« sector has been investigated in the
length of about 80 metres. The lowest
level investigated was the water basin level, while the height of the
upper cavities was about 28 m apro-
aching the great funnelshaped depre-
sion at the surface of the terrane. Sta-
lactites, about 1 m thick were found at
the border of the basin in this cavern,
being certainly the remains of a for-
mer large underground space filled
with a large number of such deposits.

The ground water level recorded du-
ring investigations in the cavern of the
»seventh« sector was 13 m and in the
cavern of the »eighth« sector 28 m be-
low the field level. All cavities
discovered in the space of hinterland
of the once well known part of Sinjski
ponor display considerable morpholo-
gical complexity and connectivity; un-
fortunately, all the cavities were not
accessible because they were blocked
by grout mixture. Total length of all
the measured parts of the Sinjski po-
nor hinterland amounts up to 280 m.
Distance from the last measured point
at the entrance part of the swallow
hole to the border of the water basin
in the seventh sector is 30 m.

New investigated parts of the chan-
nel, together with new headings in-
crease that length for the above men-
tioned 30 m.

The discovery of the underground
flow in the drilled caverns of the »se-
venth« and »eighth« sectors, as well
as the connection between the opening
of Sinjski ponor and water flow in those
caverns, which was proved by dy-
ing, confirm the fact that under-
ground discharge system id a swallow
rušen i pregrađen obrašenim stijenama i nanosom iz polja. Veličina podzemnog prostora te hidrološke promjene prikazane su na sl. 12, 13 i 14. U nabušenom prostoru 24-og sektora ušlo se u relativno mali podzemni spiljski sistem, jer je najveći njegov dio bio ispunjen injekcionom masom.

U području 27-og sektora nabušene šupljine bile su ispod razine tla, a podkopom od svega 15 m nakon 20 metara ušlo se u njih. Podzemni prostor na tom mjestu istražen je u dužini od skoro 80 m. Vjisinska razlika najniže i najviše točke u ovom sistemu bila je 22 m. Zbog spuštenog nivoa podzemne vode najveći dio ove šupljine ispunjen je dubelim naslagama kalcitičnih formi (sl. 15).

Razvijeni sistem u ovom podzemnom prostoru upućuje na činjenicu, da je starost njegovih dijelova vrlo velika, a da su najdonji prostori šada u fazi hole in our karst regions does not end at places easily accessible to man, but continues behind sometimes naturally made barriers.

Detailed investigations of both the accessible parts of drilled spaces and the already known space of Sinjski ponor revealed that it is one complex system in whose continual channel of sinking water flow we can come across some blocked spaces formed in the course of time. Traces of fossil swallow holes and a large subsided funnel shaped depression at elevations higher than the present field level in the vicinity of the Sinjski ponor entrance, and the system of underground cavities in its further part point to one unit, and also to gradual formation of the cavernous space with water course in it.

According to all the investigations carried out up to now, there are 340
Sl. 12. Dvije snimke nabušene kaverne 17-og sektora snimljene na istom mjestu — gornja za vrijeme povlaštenja nivoa podzemne vode, a donja u vrijeme niskih podzemnih voda.

Fig. 12. Two photographs of the drilled cavern of the 17th sector, taken at the same place — the upper during the increased ground — water level, the bottom one during the low groundwater level.
Fig. 13. The lowest part of the drilled cavern of the 17th sector which is 46 metres below the field elevation. Below the sloped layers, all the subsided 'blocks' are covered with mud deposit. When this photograph was taken, the groundwater level was about 2 m below the block level.

The zone of Sinjska jaruga (ravine)

Along the border of the Sinjska jaruga, i.e. at the contact of the Quaternary and limestone deposits, further underground cave phenomena were investigated, although their number
U smjeru Liskovače registrirano je postojanje još nekoliko podzemnih šupljina, ali se u njima nije moglo ući.

Promatrajući razvoj podzemnih šupljina uz rub Sinjske jaruge uočavamo činjenicu postojanja privilegiranih pu-
was much higher. Numerous suffusions along the border of the field and large fissures with flood brought branches point to the pronounced water sinking into limestone deposits.

![Image of a cave](image)


*Fig. 14. The final hall of the drilled cavern of the 17th sector, formed as the result of great water quantities sinking. The hall well reflects the process of calcite deposits formation. The size of the space can be compared with the size of the speleologists.*

*Photographs taken by: Srečko BOŽIČEVIĆ*
Having made a vertical shaft, an underground cavern about 250 m long was discovered and investigated in the 17th sector (Figure 11). Seepage water was found at 46 m below the field elevation. The layer over the drilled cavern is about 40 m in the entrance part, about 40 m in the middle part, while at the place of water seepage occurrence and the accessible part of the cavern it exceeds 100 m. The highest point in this cavern is at the present field level. In the "recent" geological past, water from the field used to sink at this place, but lowering of the groundwater gradient resulted in falling-in of this opening and in its blockage by subsided rocks and deposit from the field. The size of this underground space and

![Diagram](image)
Na žalost, potpuno upoznavanje podzemne morfologije kavernoznih prostora na ovom dijelu Buškog Blata spriječili su izvedeni zaptivni radovi.

**Formiranje podzemnih prostora i odvodnja površinskih voda**

Nabušene šupljine ponora Proždrikoza, Sinjskog ponora u široj zoni Sinjske jaruge i zaleđa Liskovača indikatori za promatranje podzemne odvodnje naplavljenih voda Buškog Blata.

Nakon zadnje orogenetske faze, tj. nakon formiranja pukotina i rasjeda u karbonatnim naslagama na zapadnom obodu Buškog Blata u periodu diluvijalnog obilja površinskih voda ovo se podzemlje formira i proširuje u zonama međuslojnih pukotina, u prostorima ispunjenim laporovitim materijalom ili vertikalnim pukotinama zapunjenim razlomljenim kršjem i crvenicom.

Erozijski i korozioni rad vode u horizontalnom i vertikalnom smislu rezultira oblikovanjem podzemnih šupljina, urušavanjem labilnih partiij stijena u vodene tokove i odmazanjem istih u jednom drugom vremenskom periodu. Privilegirani pravci rasjeda i izrazitih pukotina utječu na smjer otjecanja vode i na postepeno snižavanje zonе okrušavanja. Nivo podzemnih voda se snižuje, gradijent u neposrednoj blizini polja postaje sve veći, a u isto vrijeme u stvorenim šupljinama urušavanje je završeno i počinje period izlučivanja kalcitnih naslaga.

Radiokarbonске analize učinjene na nekim primjerima sige iz ovog podzemlja, pokazale su, da je najstarija na-kupina u kaverni jednog sektora stara od 20 do 30.000 godina, a da dokazi za urušavanje blokova u kaverni drugog sektora datiraju od prije 1400—2800 godina pa sve do recentnog urušavanja od prije 300 godina.

Hydrological changes are presented in Figures 12, 13 and 14.

In the drilled space of the 24th sector, it was possible to enter only a relatively small underground cavernous system, because its largest part was filled-in with grouting mixture.

In the region of the 27th sector, the drilled caverns were 20 m below the field elevation, and they were accessible by means of a heading of only 15 m in length. The underground space at this spot was investigated in the length of 80 m. The height range in this system was 22 m. Due to lowered groundwater gradient, the largest part of this cave is filled with thick deposits of calcite forms (Figure 15).

The well developed system in this underground space points to the fact that the age of its parts is great and that the lowest spaces are now in the phase of subsiding and settlement over the existing eroded cavern.

The underground space of the 31st sector was entered by another sloping heading behind which there was about 200 m long space. The lowest point in this system is 15 metres below the field elevation. This space is characterized by clay deposits several metres thick with a thin layer of calcite over them. Very narrow fissures in the final part of the system prevented further movement.

Some other underground caverns were traced in the direction of Lisko-vača, but they could not have been entered.

The observations of the underground cavities development along the border of Sinjska jaruga revealed the existence of the privileged courses of groundwater flow and its discharge in the direction of the pronounced fault of Lisko-vača. The length and accessibiltity of these spaces were determined at a few places only. The remaining part are still unknown.
By means of civil engineering measures it was possible to get an insight into the cavernous space almost 900 m long which runs along the border of the Sinjska jaruga behind the previously discovered space of Sinjski ponor, 160 m long. The occurrence of underground cavities can be noted at various elevations in relation to the present field elevation. Each cavity represents a part of a certain hydrological situation in limestone deposits and of a relationship of water infiltration from the field into the underground.

Unfortunately, the complete knowledge of the underground morphology of cavernous spaces in this part of Buško Blato was hindered by certain sealing works.

Underground spaces formation and surface water discharge

The drilled cavities of the swallow hole of Proždrikoza, Sinjski ponor in the lager area of the Sinjska jaruga and the hinterland of Liskovača could serve as indicators for the investigations of underground discharge of the flood water from Buško Blato.

After the last orogenic phase, i.e. after — the formation of fissures and faults in carbonate deposits on the western border of Buško Blato in the period of abundant diluvial surface waters, this underground space continues to be formed and enlarged in the zones of interlayer fissures, in spaces filled-in with marlaceous material or in vertical fissures filled-in with crushed debris and terra rossa.

Erosional and corrosional water activity in both horizontal and vertical direction is the result of underground cavities formation, subsidence of unstable rock mass into water flows and its transport over a long period of time. Privileged strikes of the faults and lar-
koji nam nisu lako dostupni. Obradeći primjer upućuje i upozorava na potrebu kontinuiranog čišćenja i zaštivanja ponora od prijevremenog začepljenja.


ge-fissures influence the discharge direction and the gradual lowering of the karstification zone. Groundwater level gets lower, the gradient in the vicinity of the field rises; at the same time, subsidence in the cavities gets completed and the period of calcite depositing is started.

Radiocarbon analyses of some samples of travertine from this underground have shown that the oldest deposit in the cavern of a sector is 20 to 30,000 years old, while the proofs of rock block subsidence in the cavern of another sector date from 1400–2800 years ago up to recent subsidence of 300 years ago.

All the data when compared to samples from other parts of the Dinaric karst show that it was the Pleistocene karstification phase starting from the periods of the Würm glacial and interglacial in which intensive cold climate periods were succeeded by very warm climate.

The formation of all the underground water ways had been most probably completed in the Postglacial period, while in the Holocene period, the temporary floodings and drainings of the field resulted in clogging of the swallow hole entrance and in the continual water flow under higher pressure in the lower parts of the karstified rock mass.

The existence of the very evident and those less evident groundwater flow channels is the result of the very complex karstification process of carbonate deposits in this region of the Dinaric karst system. All this requires a complex approach to inter-relations of lithostratigraphic members, tectonic deposit damages and combined erosional and corrosional activity of the water from the natural storage of Buško Blato.

The speleological investigations carried out in the larger area of the swallow hole zone of Buško Blato, from
the swallow hole of Proždrikoza, to Sinjski ponor revealed the existence of the drainage channels and underground spaces of active swallow holes, unknown up to know. The conclusion is, that special attention should be paid to similar occurrences in, other parts of the Dinarič karst region. Our knowledge of the occurrences inside the karst would be better and more comprehensive if the man could enter the intact parts of the underground space. For the time being, however, similar occurrences of caverns can be expected behind the already known drainage channels of the swallow hole or in the spaces that are not easily accessible. This assumption is made on the basis of the lithological composition of limestone deposits, on their tectonic fractures, on duration and intensity of waters that used to sink at a certain part of our karst. The example treated in this work points to the need to continually clean and protect the swallow hole against the early clogging.

REFERENCES


Božičević, S., 1970; Speleological investigations of the swallow hole of Proždrikoza, Buško Blato, Files of the Institute of Geological Researches, Zagreb.


Božičević, S., 1982; Applied speleological investigations, Naše jame, No. 13, Ljubljana.


Raljević, B., 1987; Geological and hydrogeological relations in the larger area of Buško Blato, Geološki vjesnik, No. 20, Zagreb.
