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LJUBIĆEVA PEĆINA: LASERSKO SKENIRANJE I GEOFIZIKALNA MJERENJA U SEZONI 2019.

LJUBIĆEVA PEĆINA: LASER SCANNING AND GEOPHYSICAL WORK IN THE 2019 SEASON

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Rad donosi rezultate terenskog istraživanja u Ljubićevoj pećini kod Marčane u Istri, provedenog u 2019. godini. Tijekom terenskog rada provedeno je lasersko skeniranje dijela lokaliteta te geofizikalna mjerenja gornje etaže pećine. Navedena mjerenja poslužit će u svrhu kvalitetnijeg planiranja budućih sustavnih arheoloških istraživanja navedenog lokaliteta.

KLJUČNE RIJEČI: *prapovijest; geofizika; LIDAR; Istra; Hrvatska*

The paper presents the results of fieldwork at Ljubićeva pećina near Marčana in Istria conducted in 2019. During fieldwork, laser scanning of a part of the site, as well as geophysical work in the upper part of the cave, was conducted. This work will provide a better basis for the planning of future systematic archaeological excavations of the site.

KEY WORDS: *Prehistory; geophysics; LIDAR; Istria; Croatia*

UVOD

U razdoblju od 29. srpnja do 2. kolovoza 2019. provedena su terenska istraživanja lokaliteta Ljubićeva pećina pokraj Marčane u Istri. Pećina je nastala u krednom vapnencu kao rezultat djelovanja vode, a njezin ulaz posljedica je rušenja krova. Ulaz u pećinu smješten je na dnu velike kraške vrtače, a ulazni otvor visok je oko 20 i širok oko 15 metara (sl. 1). Pećina je prilično prostrana i relativno složene morfologije. Sastoji se od dviju etaža (gornje i donje) koje su povezane vertikalama. Prva (gornja) etaža sastoji se od veće, centralne dvorane i manje dvorane smještene lijevo od ulaza. Tijekom ovogodišnjih istaživanja uočeno je i više mogućih kanala koji su danas ispunjeni sedimentom.

Iako se špilja prvi put spominje u pisanim dokumentima 1926. godine i njezin položaj omogućuje relativno jednostavan pristup, prva sustavna iskopavanja započela su 2008. godine, kao zajednički projekt Hrvatskog restauratorskog zavoda i Museé d'Anthropologie préhistorique de Monaco (Percan et al. 2008). Tijekom četiri sezone iskopane su četiri sonde, jedna u središnjoj dvorani i jedna u manjoj dvorani gornje etaže (sonda

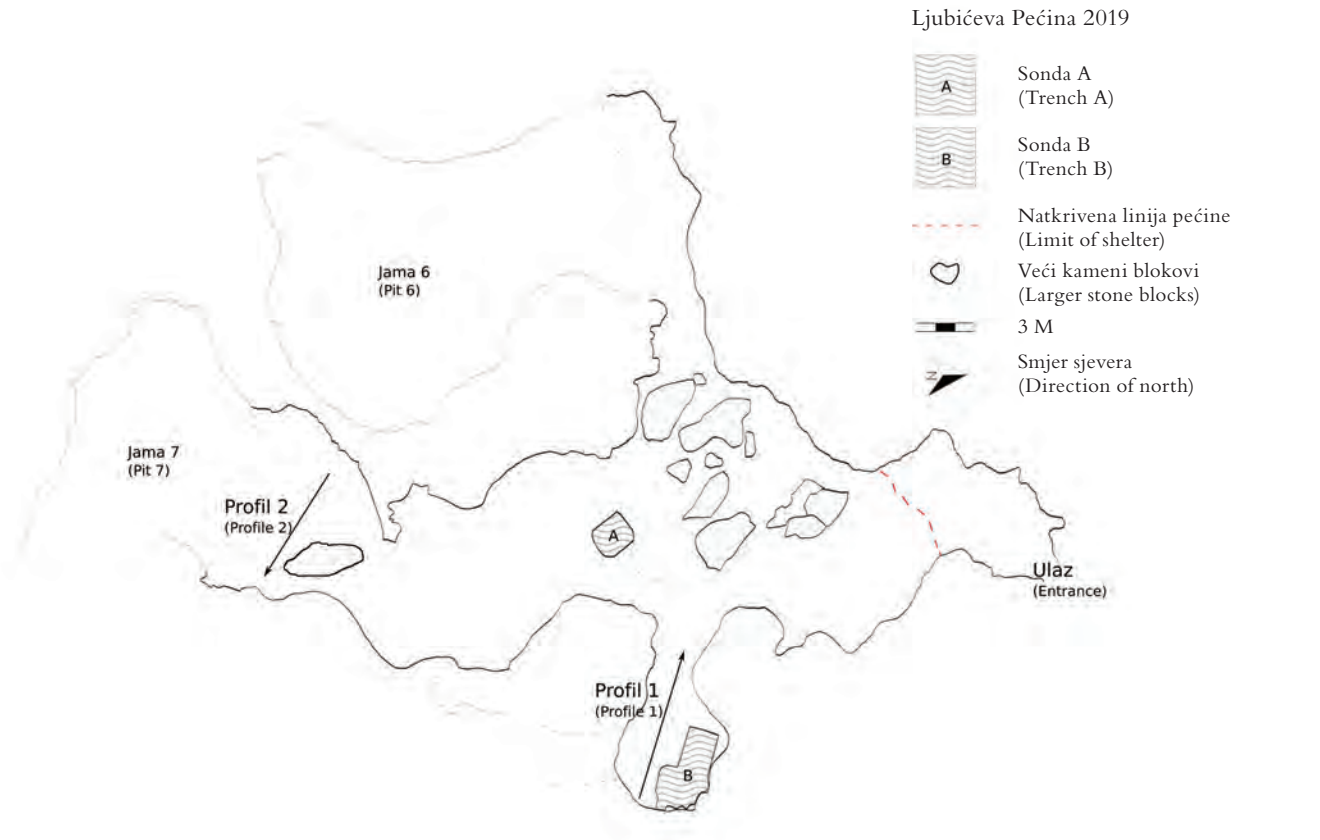
Sl. 1 Ulaz u Ljubićevu pećinu (fotografija: I. Janković).
Fig. 1 Entrance to Ljubićeva pećina (photo by: I. Janković).

INTRODUCTION

Between 29th of July and 2nd of August 2019, fieldwork was conducted at the site of Ljubićeva pećina near Marčana in Istria. The site was formed in Cretaceous limestones as a result of water activity and the entrance to the cave opened as a result of a partial roof collapse. The entrance to the site is located at the bottom of a large karstic sinkhole. It measures approximately 20 meters in height and 15 meters in width (Fig. 1). The cave is spacious and relatively complex in morphology. It consists of two levels (the upper and lower) connected with vertical parts. The first (upper) level has two chambers, a central (larger) one and a smaller side chamber located left of the cave entrance. During this year's fieldwork we noted several possible channels that are today completely filled with sediments.

The first mention of the cave is found in documents dating to 1926 and although the location allows easy access to the site, the first systematic excavations only began in 2008 as a joint Project of the Croatian Conservation Institute and Museé d'Anthropologie préhistorique de Monaco (Percan et al. 2008). During four excavation seasons, two trenches were excavated in the upper level, one in the central chamber and one in the smaller side chamber (Sonda A and Sonda B on Fig. 2) and two trenches were excavated in the large chamber on the lower level of the site (Percan et al. 2008; Percan 2009; 2010; 2011). Most of the material was collected in the trench in the side chamber and dates from the Late Upper Palaeolithic, Neolithic, and Bronze Age. Of particular interest to us is the material from layers dated to between 11300 ± 50 and 12230 ± 70 BP (Percan et al. 2008) that includes various lithic types (blades and bladelets, backed bladelets and so on), several bone tools, faunal remains, snails, traces of ocher and other archaeological remains (Percan et al. 2008; Percan 2009; 2010; 2011). In addition, a human tooth and finger phalange were discovered in the same sequence. Most of the collected material was only preliminarily studied (e.g. Simonet, 2013), and detailed anthropological, technological, typological, raw material, faunal and other specific studies are in progress.

As the continuation of the systematic excavations of the site is planned, this year's preparatory work at the site included laser scanning of a part of the site (the whole upper level and a part of the first vertical section) and geophysical research of the upper level.



Sl. 2 Tloris prve (gornje) etaže Ljubićeve pećine (J. C. M. Ahern).
Fig. 2 Ground plan of the first (upper) level of Ljubićeva pećina (J. C. M. Ahern).

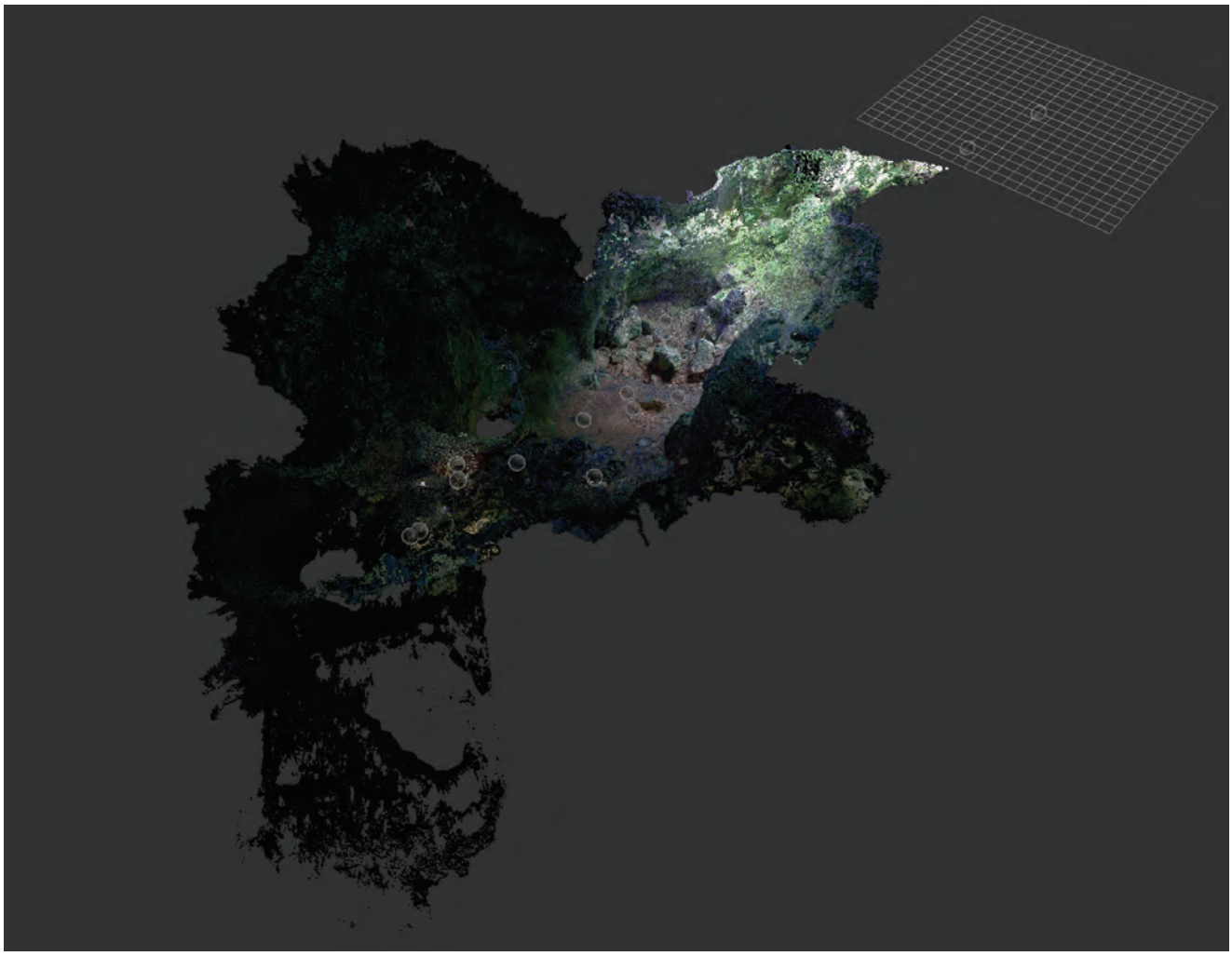
A i sonda B na sl. 2), a dvije na donjoj etaži nalazišta (Percan et al. 2008; Percan 2009; 2010; 2011). Za vrijeme istraživanja prikupljen je materijal iz vremena kasnog gornjeg paleolitika, neolitika i brončanog doba. Od posebnog je interesa nastanjivanje lokaliteta tijekom kasnog gornjeg paleolitika, što potvrđuju litički nalazi iz slojeva datiranih u 11300 ± 50 odnosno 12230 ± 70 prije sadašnjosti (Percan et al. 2008). Tijekom istraživanja otkriveni su litički nalazi (sječiva i pločice, pločice s hrptom itd.), nekoliko koštanih alata, faunalni ostaci, puževi, tragovi okera te drugi arheološki ostaci (Percan et al. 2008; Percan 2009; 2010; 2011). Osim toga, u slojevima gornjeg paleolitika otkriven je i ljudski zub te kost prsta. Većina pronađenog materijala samo je preliminarno analizirana (npr. Simonet 2013), a u tijeku su i detaljnije studije kao što su antropološka, tehnološka, tipološka, petrografska/sirovinska, faunalna i druge specifične analize.

Budući da je u planu nastavak sustavnih terenskih istraživanja lokaliteta, ove su godine provedene pripremne radnje u svrhu boljeg planiranja budućih arheoloških iskopavanja. To je uključivalo lasersko skeniranje dijela

LASER SCANNING

In order to prepare for anticipated continuation of excavations at Ljubićeva pećina, high resolution laser scanning of a part of the cave was conducted during 2019 fieldwork (Fig. 3). A total of twenty-seven individual scans

Sl. 3 Lasersko skeniranje lokaliteta (fotografija: I. Janković).
Fig. 3 Laser scanning of the site (photo by: I. Janković).



Sl. 4 Model 3D oblaka točaka sakupljenih laserskim skeniranjem Ljubićeve pećine. Krugovi označavaju mjesta skeniranja (3D model J. C. M. Ahern). Fig. 4 Image of the 3D point cloud generated from laser scanning of Ljubićeva pećina. The orbs indicate the locations of the individual scans (3D model by: J. C. M. Ahern).

lokaliteta (čitava gornja etaža i dio prve vertikale) te geofizikalna mjerenja gornje etaže pećine.

LASERSKO SKENIRANJE

Kao priprema za predviđeni nastavak iskopavanja u Ljubićevoj pećini, tijekom 2019. godine na terenu je provedeno lasersko skeniranje dijela špilje u visokoj rezoluciji (sl. 3). Ukupno je napravljeno dvadeset i sedam pojedinačnih skeniranja (sl. 4) uz pomoć prijenosnog LIDAR i panoramskog sustava Leica BLK360 (https://leica-geosystems.com/products/laser-scanners/scanners/blk360). BLK360 bilježi podatke u obliku oblaka 3D točaka u kombinaciji s prekrivenom HDR panoramskom fotografijom. S brzinom od 360 000 mjerenja snimljenih u sekundi, BLK360 prikuplja podatke oblaka točnosti od 6 mm na 10 mm i 8 mm na 20 metara. Raspon rada BLK360 je između 60 cm i 60 m.

(Fig. 4) were taken using a Leica BLK360 portable LIDAR and panoramic imaging system (https://leica-geosystems.com/products/laser-scanners/scanners/blk360). The BLK360 captures 3D point cloud data combined with overlaid HDR panoramic dome photography. At a rate of 360,000 measurements taken per second, the BLK360 collects point cloud accuracy of 6 mm at 10 mm and 8 mm at 20 meters. The working range of the BLK360 is between 60 cm and 60 meters.

Using Autodesk's Recap Pro application for the iPad Pro (https://www.autodesk.com/products/recap/overview), the individual scans were registered with one another in three-dimensional space to create a single point cloud scan of most of the Ljubićeva pećina site. Only the lowest level (Jama 6) and connecting passageways (Jama 7) were not captured (see Fig. 2). The end result is a high-fidelity 3D model that can be used for precise measurements of the site, including the creation of high

Nakon prikupljanja, podaci su registrirani u trodimenzionalan prostor putem Autodesk Recap Pro aplikacije za iPad Pro (https://www.autodesk.com/products/recap/overview) kako bi se stvorio jedinstven oblak za čitav lokalitet. Tijekom ovogodišnjeg rada nisu prikupljeni podaci za donju etažu (jama 6) niti za jamu 7 (vidi sl. 2). Krajnji rezultat je 3D model visoke rezolucije koji se može koristiti za precizna mjerenja, uključujući izradu karata visoke razlučivosti. Nadalje, podaci oblaka točaka mogu se registrirati s EDM 3D koordinatnim podacima, tako da će svi EDM podaci uzeti tijekom iskopa biti povezani s točnom topografijom špilje.

GEOFIZIKALNA MJERENJA

Geoelektrična rezistentna tomografija (Earth resistance tomography, ERT) je geofizikalna tehnika kojom je moguće sakupiti podatke profila u dvije dimenzije. Takvi podaci mogu pružiti uvid u dubinu sedimenta i položaj matične stijene, što je od velike pomoći u planiranju budućih arheoloških istraživanja u Ljubićevoj pećini (Aspinall & Gaffney 2001; Clark 1997; Dahlin 1996; Noel & Xu 1991; Papadopoulos, Tsourlos, Tsokas & Sarris 2006; Samouëlian, Cousin, Tabbagh, Bruand & Richard 2005). Ova tehnika također je korištena za procjenu dubine sedimenata u Velikoj pećini u Kličevici, kao i za detekciju pozicija sondi iz ranijih iskopavanja u Pećini kod Rovinjskog Sela 1 (Becker, Janković, Komšo, Ahern, Gerometta & Weinstock 2017; Becker, Karavanić & Vukosavljević 2018). Iz tog razloga, tijekom istraživanja postavljena su dva profila. Profil 1 smješten je u manjoj dvorani na gornjoj etaži (sl. 5). Profil je dug 8 metara i postavljen je pored sonde iz ranijih istraživanja od 2008. do 2011. godine. Profil 2 dug je 6,5 metara i nalazi se pri kraju veće dvorane, između velike stijene i vertikalnog dijela koji spaja gornju i donju etažu lokaliteta.

Podaci za svaki profil sakupljeni su uz pomoć GeoScan RM85 uređaja mjerenjem pol-pol niza, u smjeru označenom na slici 2. Podaci su prikupljeni svakih 0,1 m duž linije profila s maksimalnim razmakom od 5 m. Za preuzimanje podataka s RM85 korišten je TerraSurveyor softver. Res2DINV program olakšava postupak modeliranja inverzije. Za modeliranje ovih podataka koristi se regularizacija L1 norma za optimizaciju najmanjih kvadrata pri 0,05 faktora ograničenja podataka. Učinak visokog površinskog otpora poboljšava se korištenjem snažnog ograničenja inverzije modela pri 0,005 graničnom faktoru.

Granica konvergencije od 1% početne pogreške korijena (RMS) kroz dvije iteracije koristi se za optimizaciju dok se

resolution maps. Furthermore, the point cloud data can be registered with EDM 3D coordinate data so that all EDM data taken during excavation will be relatable to the exact topography of the cave.

GEOPHYSICAL WORK

Earth resistance tomography (ERT) is a geophysical technique that produces 2D depth profiles. These profiles can be used to estimate sediment depth to bedrock, as well as for detecting archaeological features (Aspinall & Gaffney 2001; Clark 1997; Dahlin 1996; Noel & Xu 1991; Papadopoulos, Tsourlos, Tsokas & Sarris 2006; Samouëlian, Cousin, Tabbagh, Bruand, & Richard 2005). Having estimates for sediment depths in various locations within the cave system is useful in planning future excavations within Ljubićeva pećina. This technique was also applied for estimating sediment depths in Velika pećina in Kličevica and for identifying a previous excavation trench location at the Cave in Rovinjsko Selo 1 (Becker, Janković, Komšo, Ahern, Gerometta & Weinstock 2017; Becker, Karavanić & Vukosavljević 2018). Therefore, during fieldwork in Ljubićeva pećina, two resistance profiles were established at the site. Profile 1 is located in the smaller chamber on the first level of the site (Fig. 5). This profile is 8 m long and runs alongside an earlier excavation trench from the 2008-2011 excavations. Profile 2 is 6.5 m long and is located in the back of the main chamber between a large bolder and vertical part of the site that connects the two levels of the site.

The data from each profile were collected using a GeoScan RM85 arranged in a pole-pole array. Each profile line proceeded in the forward direction as indicated on Fig. 2. Data were collected every 0.1 m along the profile line with a maximum probe spacing of 5 m.

Sl. 5 Geofizikalna mjerenja u Ljubićevoj pećini (fotografija: I. Janković). Fig. 5 Geophysical work at Ljubićeva pećina (photo by: I. Janković).

broj iteracija i srednja apsolutna pogreška (aps.) prikazana u svakom Res2DInv izlazu razlikuju u skupu podataka. Za svaki skup podataka javljaju se velike vrijednosti na stranama modela jer se iteracije približavaju konvergenciji od 1%, pa se u softveru Res2DInv koristi tzv. "smanjenje efekta bočnih blokova" (Loke 2017; Loke et al. 2003). Prikaz razmjera za ohm-m u svakom profilu inverzije normaliziran je za konzistentnu vizualnu prezentaciju preko profila minimalne vrijednosti konture od 5 i čimbenika povećanja konture 2. Povišenja su prikupljena uz pomoć totalne stanice za svaki položaj sonde duž oba profila. Podaci o nadmorskoj visini uključeni su u postupak modeliranja i prikazani su s rezultatima, da bi se dobio uvid u topografije površine tla duž svake linije profila.

Do trenutka pisanja ovog teksta podaci sakupljeni tijekom ovogodišnjeg terenskog rada u Ljubićevoj pećini još se obrađuju. Međutim, obrada podataka bit će završena početkom jeseni 2019. godine što će omogućiti da se rezultati analize upotrijebe za buduća iskopavanja u špilji.

ZAKLJUČNA RAZMATRANJA

Terenski rad u Ljubićevoj pećini u 2019. godini bio je usmjeren na prikupljanje geofizikalnih podataka i 3D skeniranje. Prikupljeni podaci omogućit će kvalitetnije planiranje nastavka terenskih arheoloških istraživanja i sondažnih iskopavanja koja se planiraju provesti u budućnosti. Iako je u ovom trenutku obrada podataka te izrada preciznog 3D modela još u tijeku, rezultati će omogućiti uvid u detaljnu morfologiju pećine, dubinu sedimenta i druge podatke važne za izradu kvalitetnijeg radnog plana.

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TerraSurveyor software was used to download data from the RM85. Res2DINV software facilitates the inversion modeling process. The L1 Norm regularization for the least squares optimization at a 0.05 data constraint factor is utilized for modeling these data. The effect of high surface resistivity is improved with the use of a robust model inversion constraint at a 0.005 cutoff factor. A convergence limit of 1% Root Mean Square Error (RMS) across two iterations is used for the optimization while the number of iterations and Mean Absolute Error (Abs.) displayed in each Res2DInv output varies by data set. For each data set, very high values appear at the sides of the model as the iterations approach the 1% convergence and thus the so called "reduce effect of side blocks" function in the Res2DInv software is used (Loke 2017; Loke et al. 2003). The scale display for ohm-m in each inversion profile is normalized for a consistent visual presentation across the profiles at a minimum contour value of 5 and a contour increase factor of 2. Elevations were collected using a total station for each probe position along both profiles. These elevation data are included in the modeling process and are displayed with the results to provide a sense of the ground surface topography along each profile line.

As of the time of this writing, the data from the 2019 ERT survey at Ljubićeva pećina are still being processed. However, the data processing will be completed in early fall of 2019, allowing the results of the analysis to be used in future excavations in the cave.

CONCLUSIONS

Fieldwork at Ljubićeva pećina in 2019 has been focused on geophysical data collection and 3D scanning. The collected data will enable a better planning of the continuation of the field archaeological research and future excavations. Although data processing and the development of an accurate 3D model are currently underway, the results will provide insight into the detailed cave morphology, sediment depth, and other data important for developing a better work plan.

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