INTEGRATION OF POINT CLOUDS FROM UAV PHOTOGRAMMETRY AND LASERSCAN SURVEY FOR THE ASSESSMENT OF THE RISK OF COLLAPSE OF THE VAULT OF AN UNDERGROUND CAVITY

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ABSTRACT

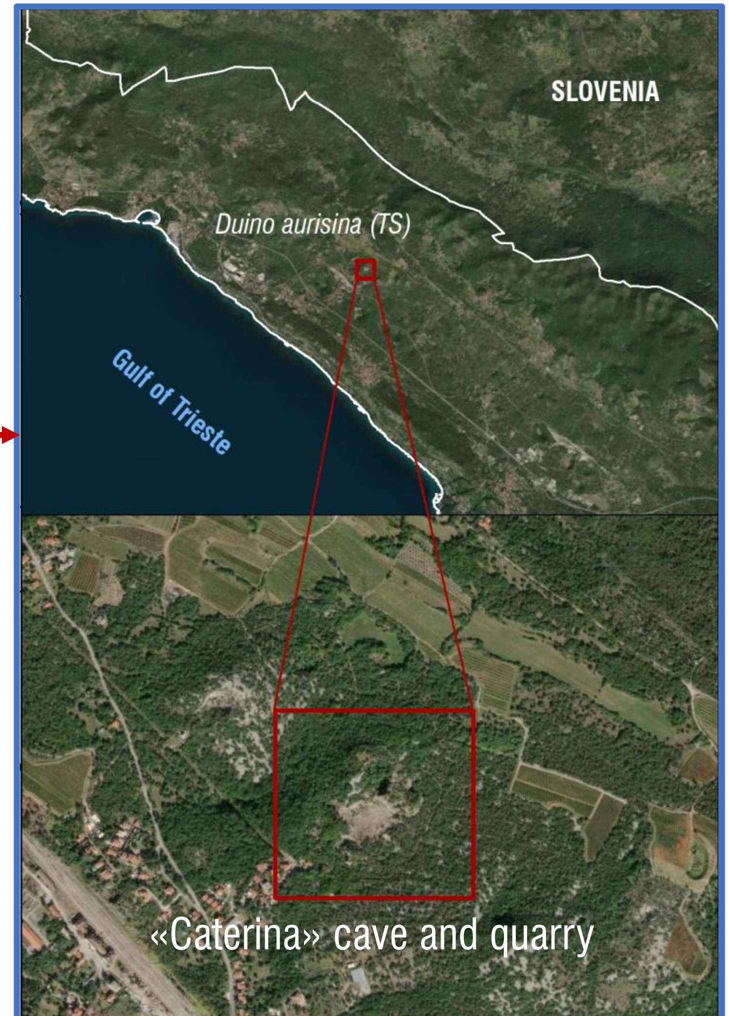
Photogrammetric surveys from UAV and LiDAR surveys are two techniques that allows the generation of very high resolution point clouds.
The use of these techniques can provide a detailed reconstruction of difficult-to-access environments such as underground cavities.
A rigorous georeferencing of the acquired data allows the comparison of the hypogean development of the cave and the overlying territory.
This study presents a case of integration between these two techniques, applied to the risk assessment of the collapse of the vaults in a natural cavity in the Trieste Karst (north east Italy).
This site is particularly delicate given that on the slope above the cave there is an abandoned stone quarry.
In order to survey the quarry above the cave, a flight was performed with UAV, while the cave was surveyed with Laser Scan from the ground. The flight was made using a UAV DJI Phantom RTK, which carried a 20 Mpixel 1“ sensor camera. 8 ha of terrain was surveyed, capturing about 733 high resolution images and surveying 22 GCPs (Ground Control Point) with a GNSS RTK receiver. It was possible to reduce the number of GCPs, since the drone recorded the shooting positions very accurately with the on-board GPS RTK. Data were analyzed using Agisoft Metashape Professional to produce an orthophoto and a DSM (Digital Surface Model) with a ground resolution of 0.02 m and 0.04 m respectively. The point cloud has a density of 586 points/m^2.
The LiDaR survey was carried out using an ILRIS 3D ER laser scanner from Optech. The point cloud has a density of approximately 2500 points/m2 and 5 stations were needed to cover the underground development of the cavity. The georeferencing of the data was carried out by roto-translation on geo-referenced benchmarks, surveyed with GPS RTK and total station. The point cloud was processed using Terrascan software (Terrasolid).
The two point clouds were aligned, geo-referenced and combined using Polyworks software (Innovmetric), in order to evaluate the thicknesses of the material present above the vault of the cave. The integration of epigean and hypogean data made it possible to identify some critical points related to a vault thickness of approximately 2 meters, located at the quarry square.
This work allowed to highlight critical issues difficult to detect without the integrated approach of these different survey methodologies.

KEY POINTS

- Caves are difficult-to-access environments
- The hypogean development of a cave may present risks to the above activities due to the possibility of collapse
- Trieste Karst (north east Italy) is a territory with high presence of caves (more than 2700)
- A precise and efficient method of **integration between different techniques** is necessary to survey and relate the hypogean and epigean morphology of an area
- These techniques are:
  - **High resolution and accuracy UAV (*Unmanned Aerial Vehicle*)** for epigean morphology
  - **TLS (*Terretrial Laser Scanner*)** for hypogean cave development

GEOGRAPHICAL SETTING:

- Italy - Friuli Venezia Giulia region
- Trieste Karst (classic Karst)
- Duino Aurisina county
- «Caterina» cave (cod.146/239VG) and the above abandoned stone quarry

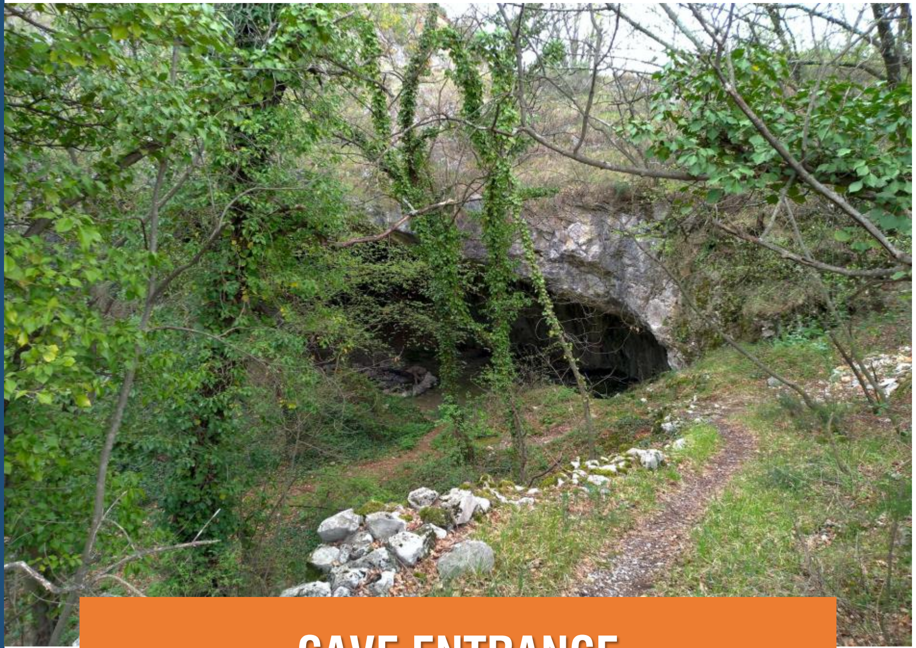


«CATERINA» CAVE AND THE ABOVE ABANDONED STONE QUARRY

STUDY AREA

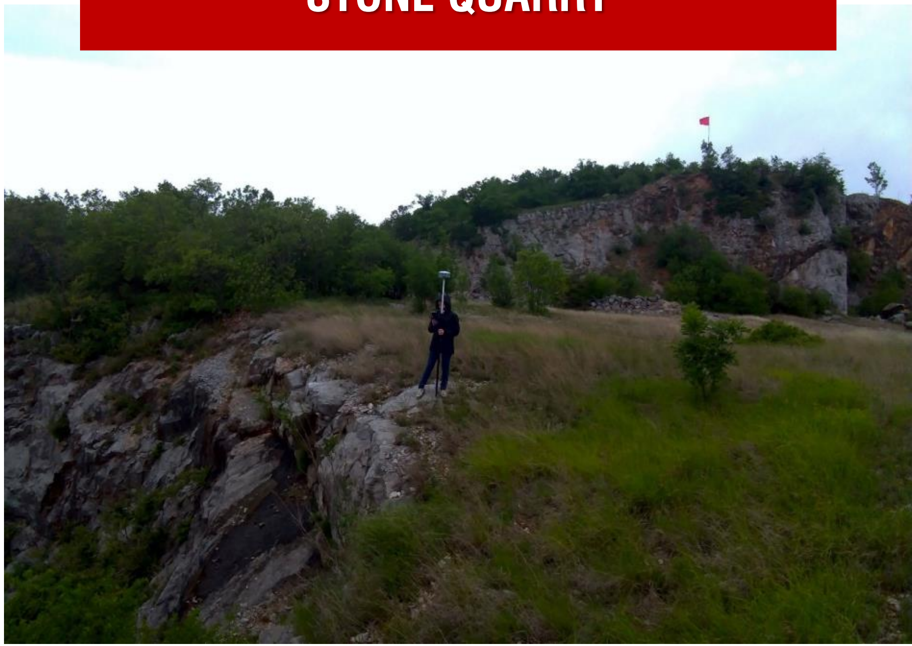
«CATERINA» CAVE AND THE ABOVE ABANDONED STONE QUARRY

STUDY AREA



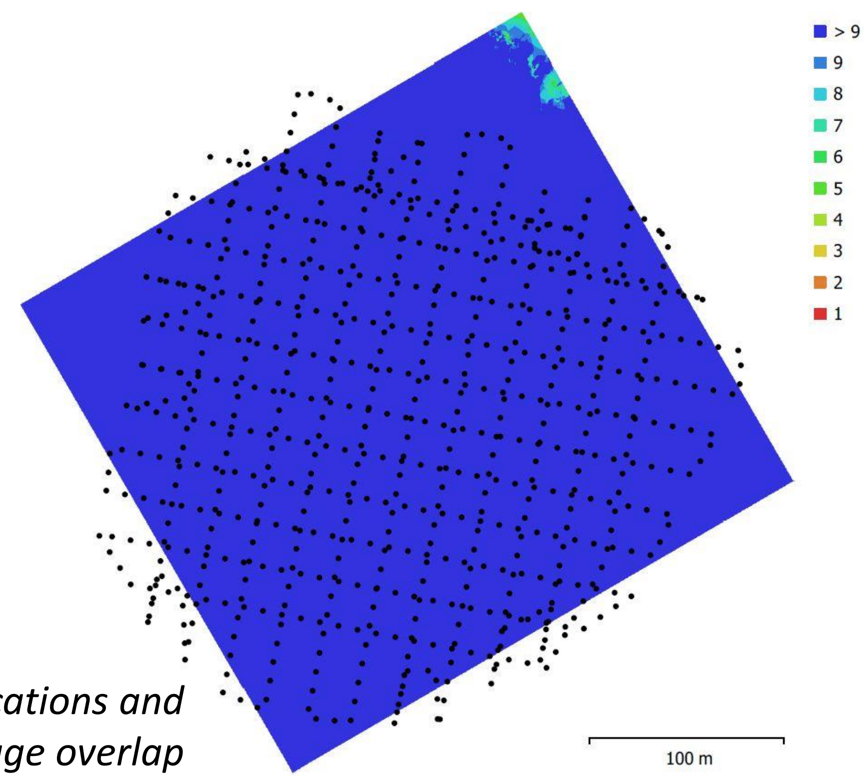
CAVE ENTRANCE

STONE QUARRY



UAV (*Unmanned Aerial Vehicle*) SURVEY

- The UAV survey was carried out using a **DJI® Phantom RTK**, connected to HxGN Smartnet reference stations network for real time GNSS correction
- Flight plans planned with **80%** sidelap and overlap in 3D mode with **camera tilted at 60°**
- **8 ha** of terrain surveyed
- **733** high resolution images captured



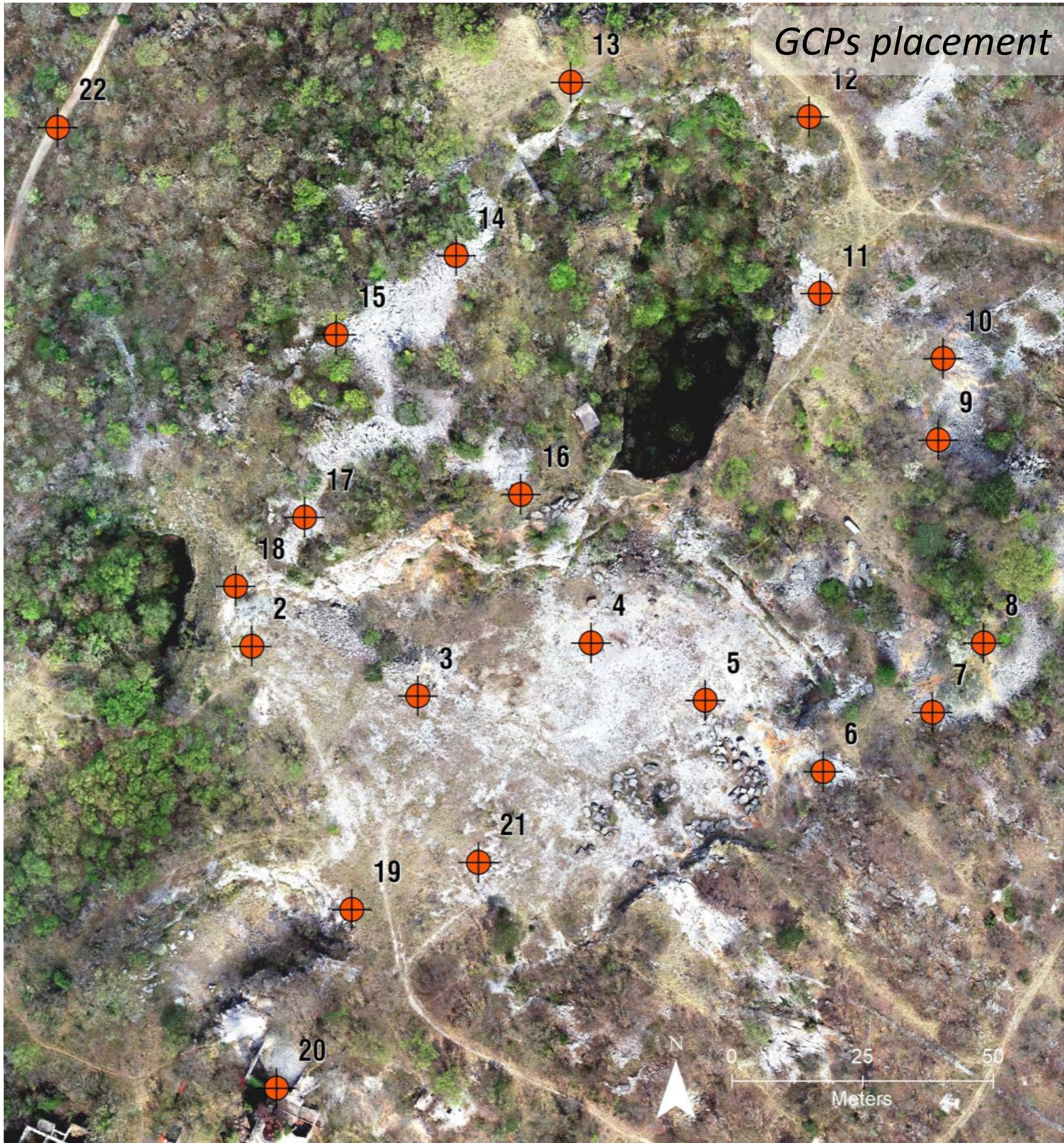
Camera locations and image overlap

UAV SURVEY

UAV GCP (*Ground Control Points*)

- **22 GCPs** (⊕) surveyed with a GNSS **STONEX® S9 III** NRTK receiver (connected to HxGN Smartnet) to achieve high accuracy in georefencing photogrammetrical model
- ~ **0.05 m** total RMSE

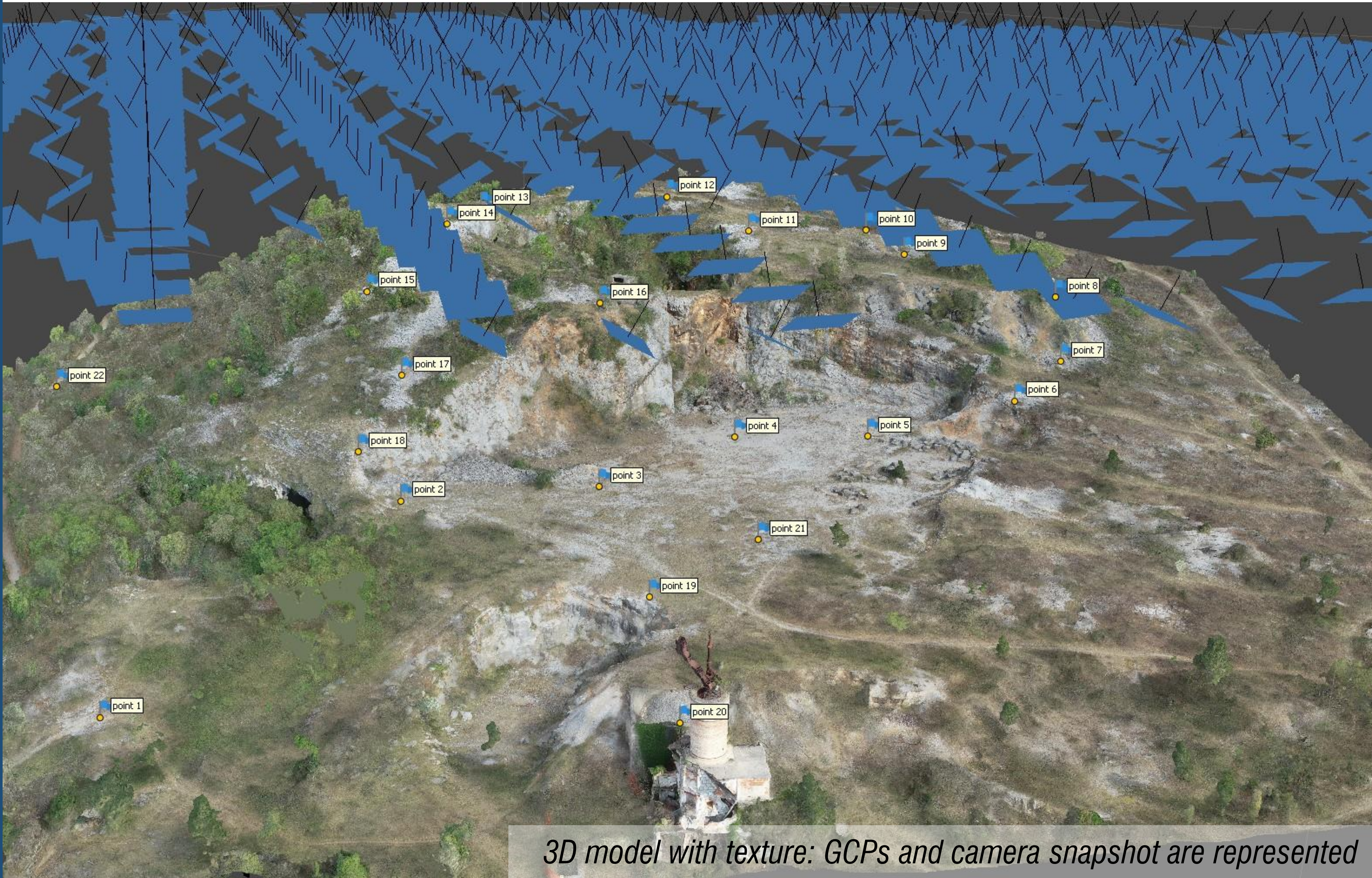
Fieldwork: GCP survey



GCPs placement

PHOTOGRAMMETRIC 3D MODEL

Data were analyzed using **Agisoft Metashape Professional** to produce a 3D model with high accuracy and resolution



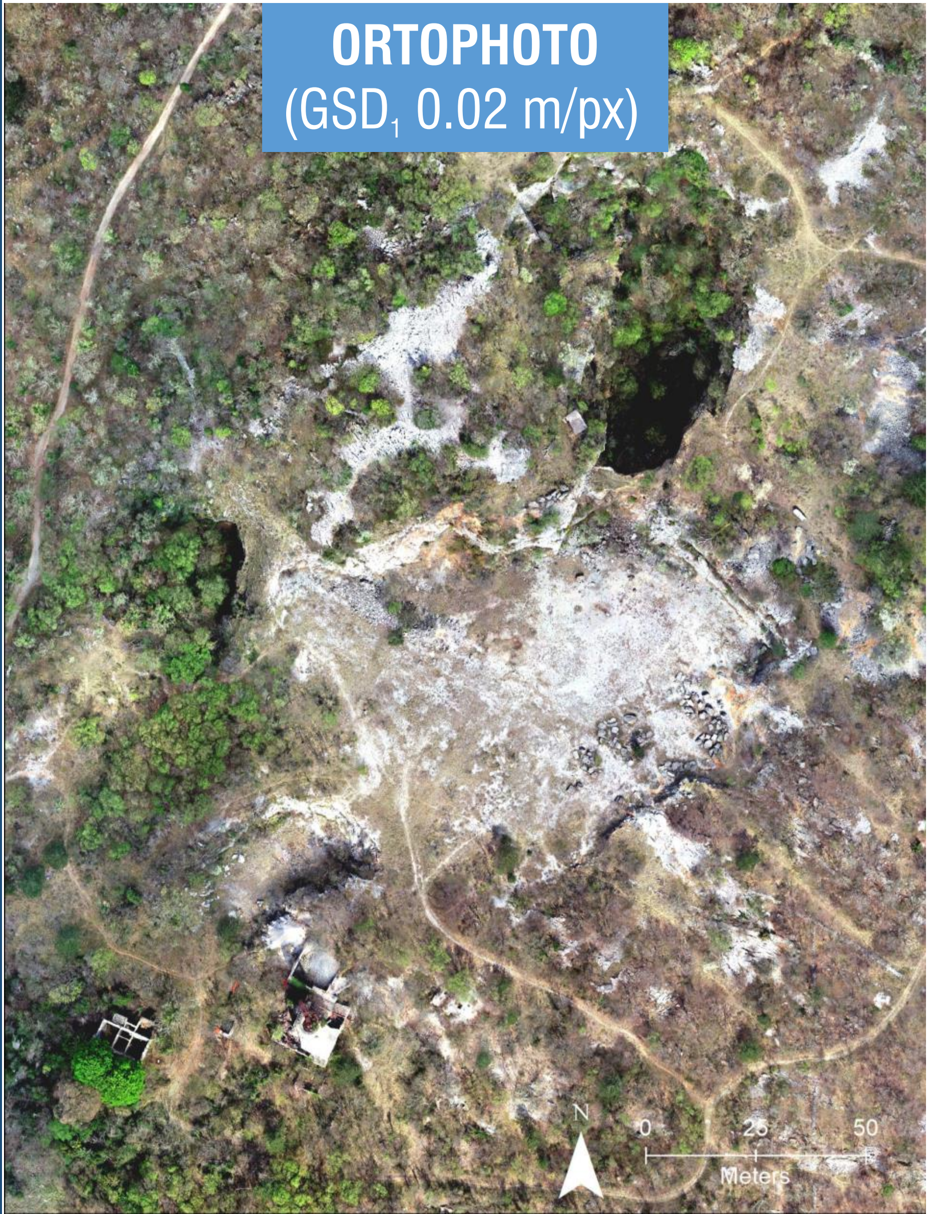
3D model with texture: GCPs and camera snapshot are represented

DATA-PROCESSING

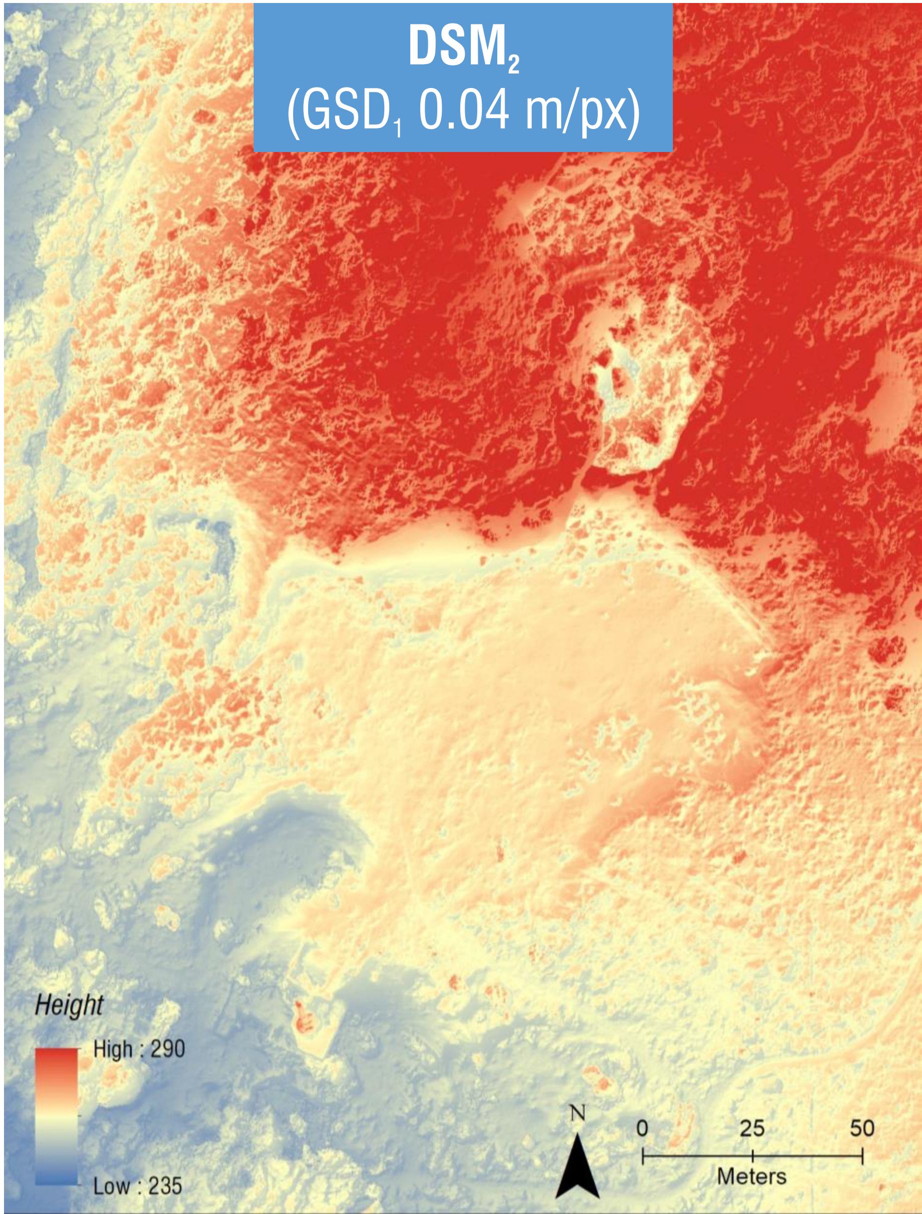
From 3D model we generated:

1 *Ground Sampling Distance;* 2 *Digital Surface Model*

ORTOPHOTO
(GSD_1 0.02 m/px)



DSM_2
(GSD_1 0.04 m/px)



From 3D model we generated:

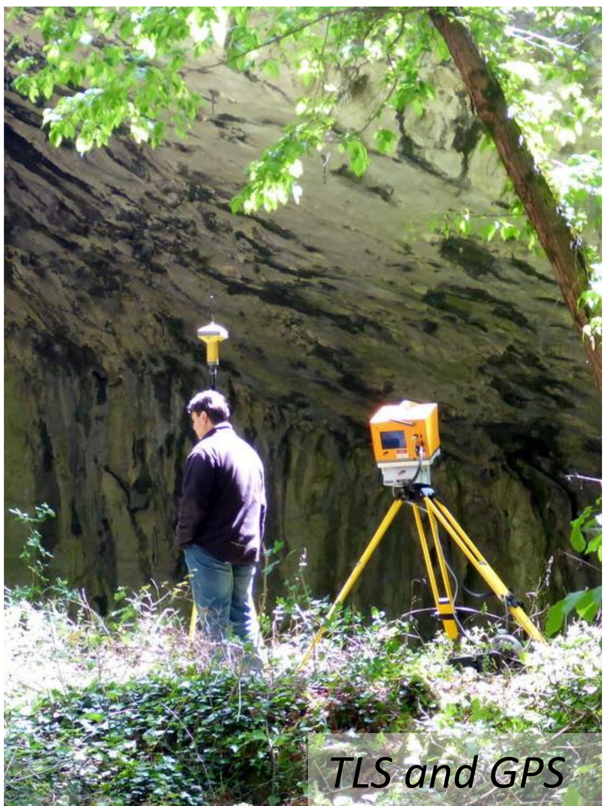
POINT CLOUD (586 points/m^2 density)

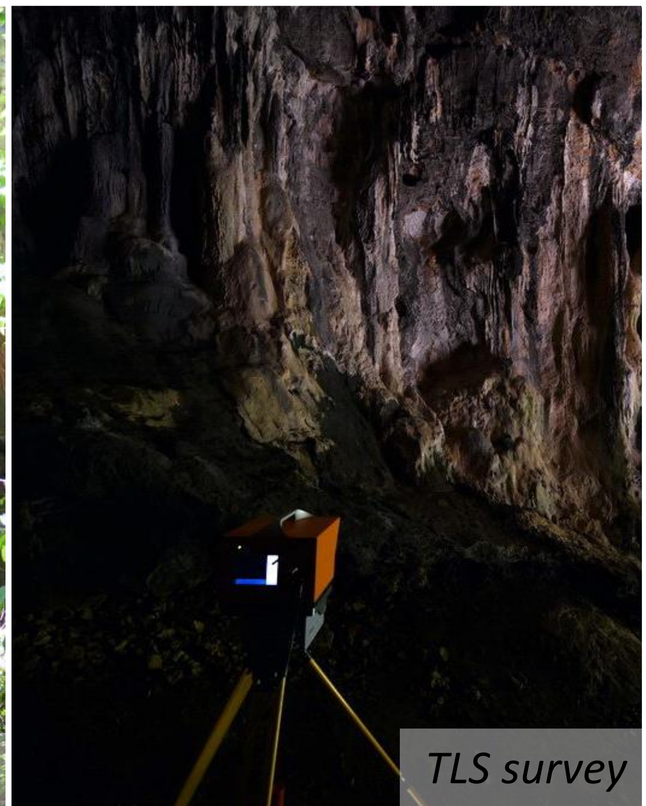
DATA-PROCESSING

TLS (*Terrestrial Laser Scanner*) SURVEY

- The LiDaR survey was carried out using an **Optech® ILRIS 3D ER** laser scanner.
- **5** stations were needed to cover the underground development of the cavity.


Fieldwork


TLS and GPS

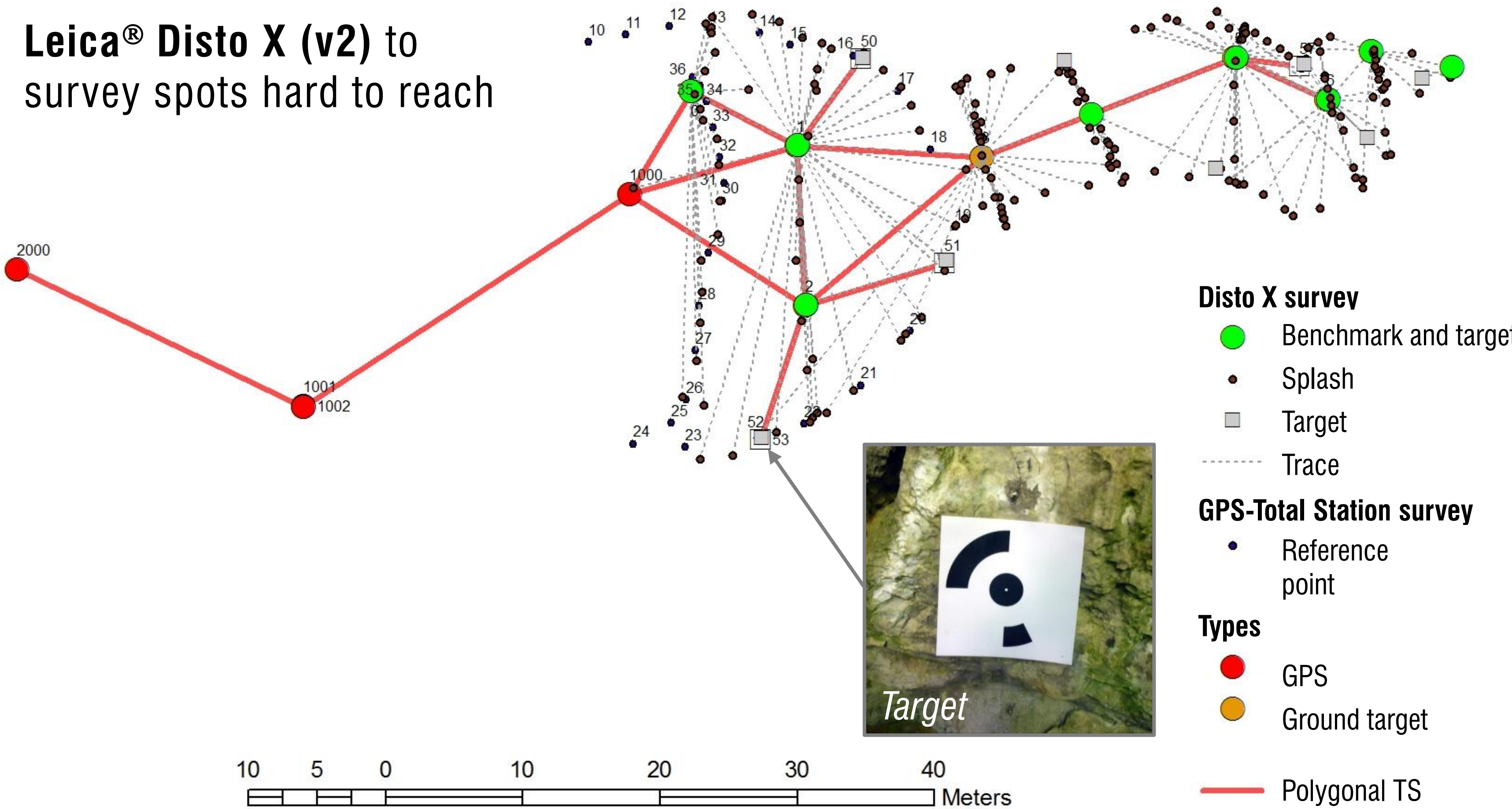

TLS survey


Total Station survey

TLS BENCHMARKS

Data georeferencing was carried out by roto-translation on geo-referenced benchmarks, surveyed with:

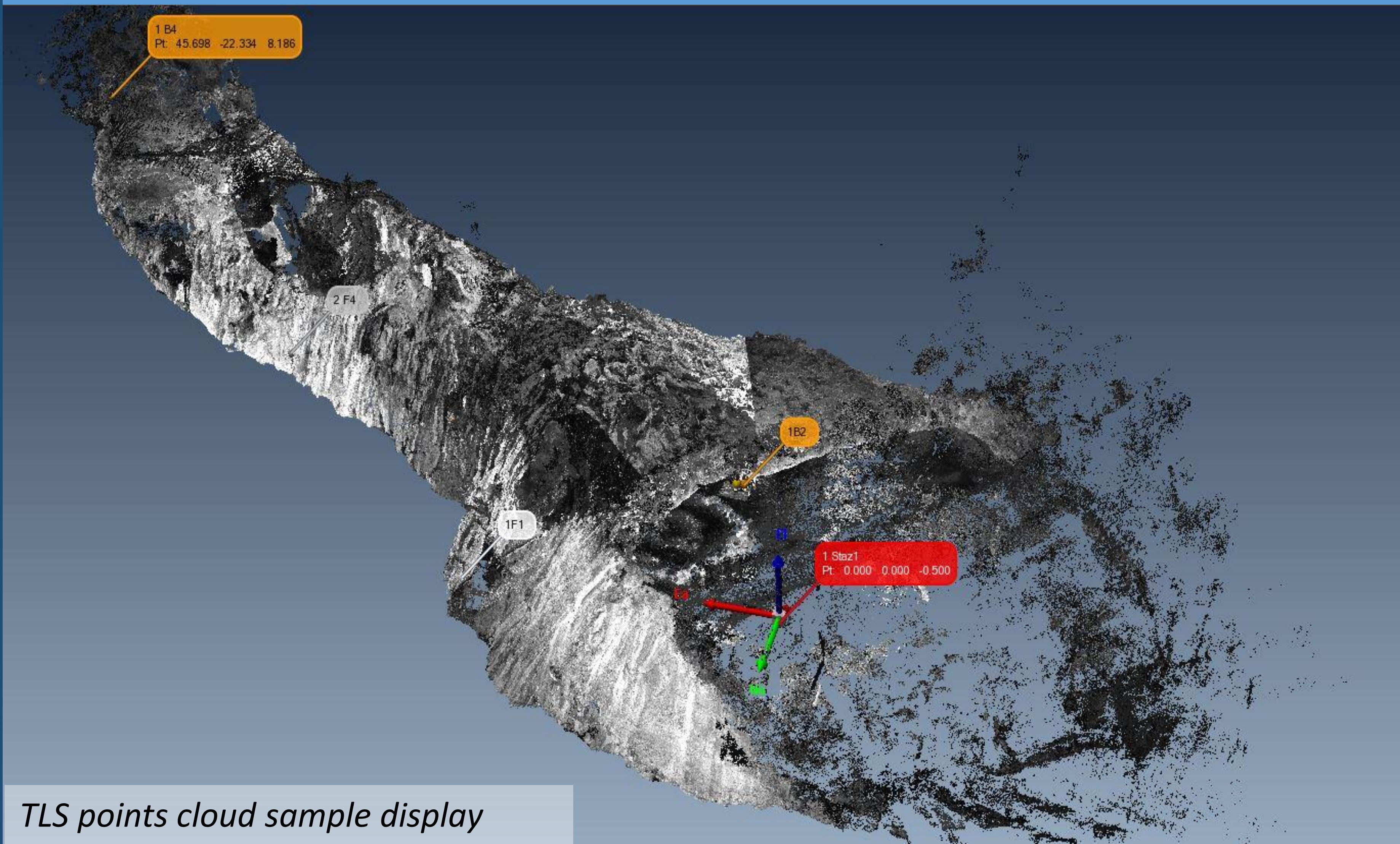
- GNSS **Topcon® GR5** NRTK
- **Leica® TPS 1200** total station
- **Leica® Disto X (v2)** to survey spots hard to reach



TLS DATA-PROCESSING

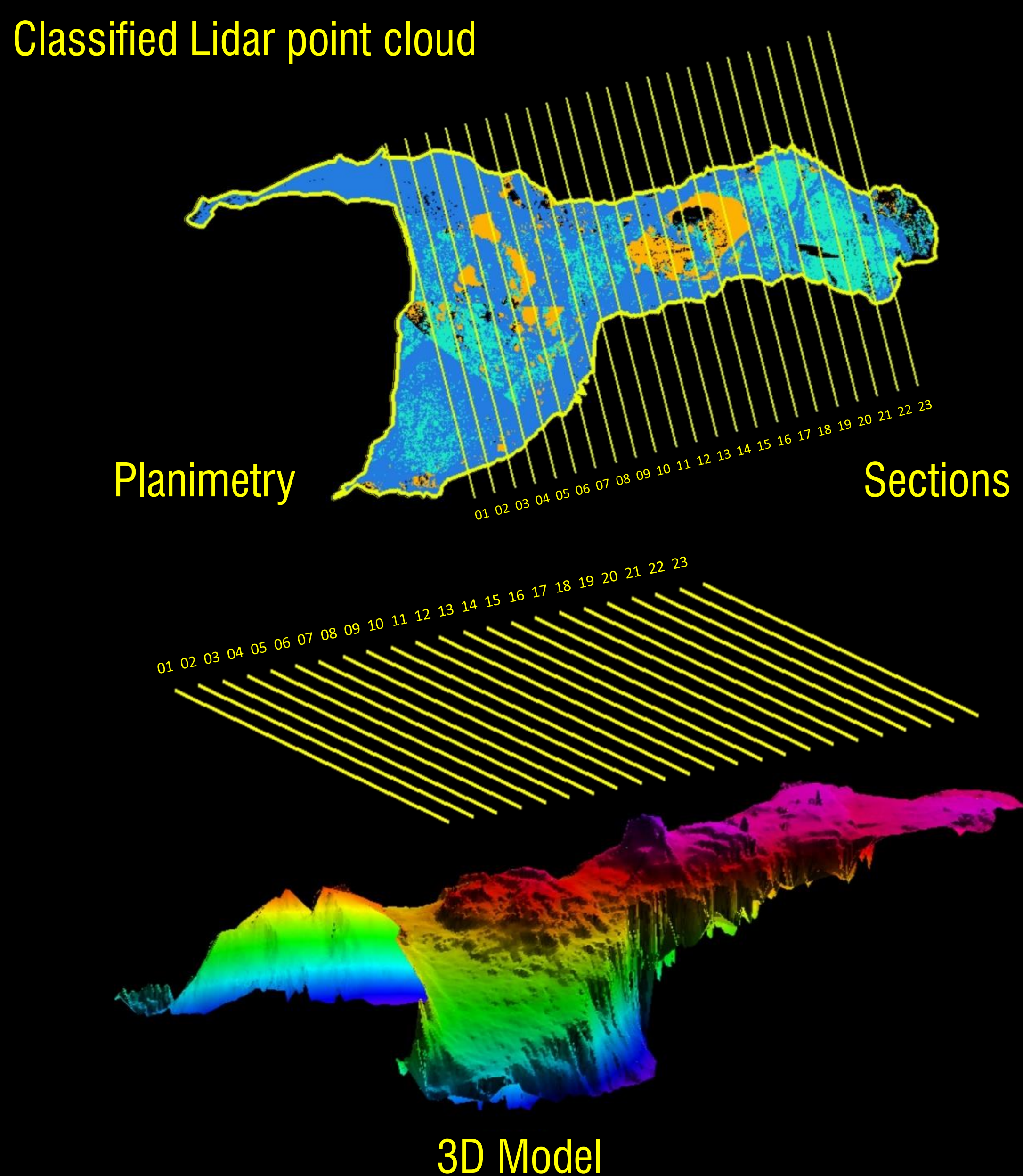
The TLS point cloud was processed using **Terrascan** software (Terrasolid).

POINT CLOUD (2500 points/m^2 density)



TLS points cloud sample display

TLS point clouds **classification** and **volume** calculation through sections

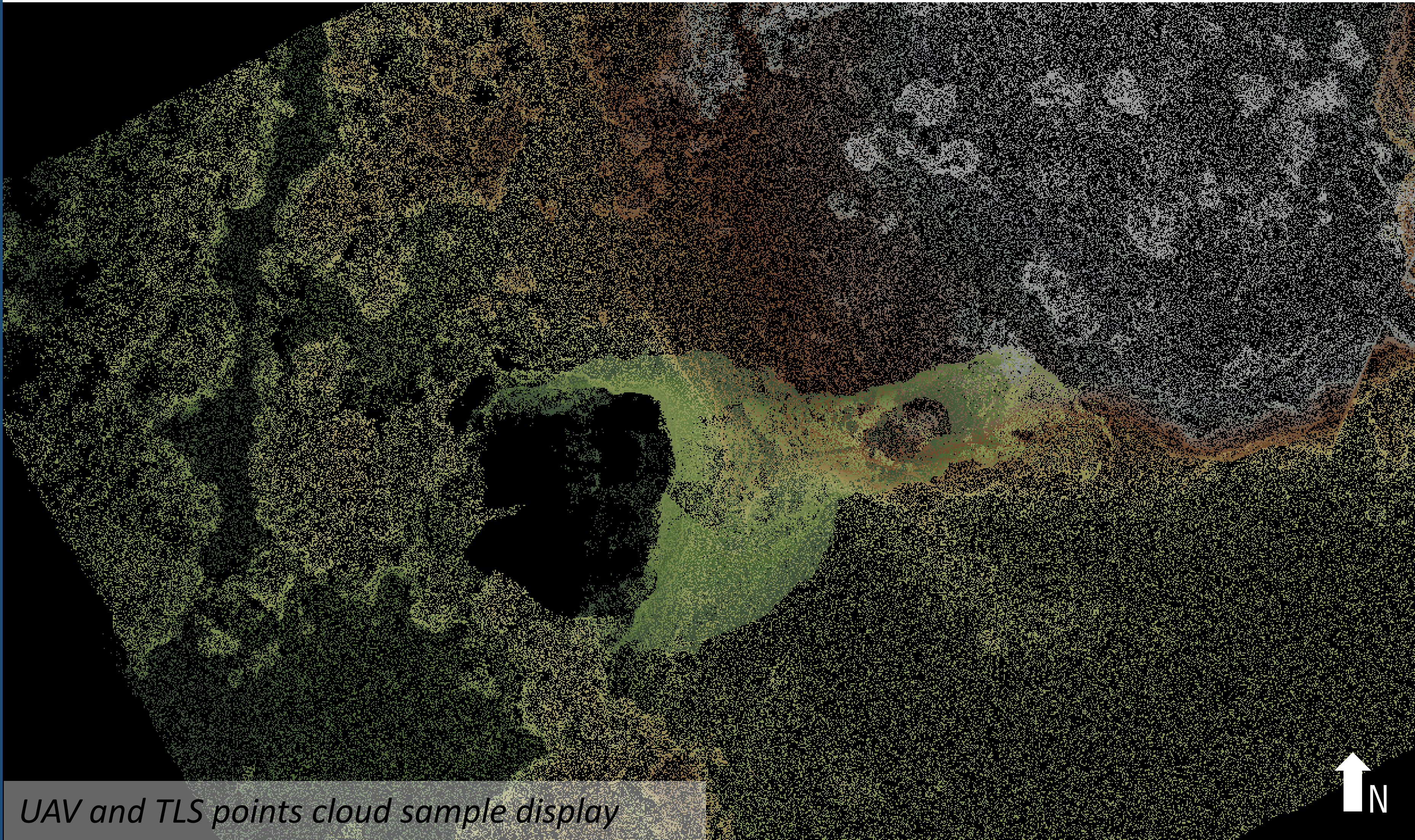


Volume Calculation

Section #	Area [m2]	Distance [m]	Max Vol. [m3]	Min Vol. [m3]	Average Vol. [m3]
1	245,20	0			
2	242,98	2	490,40	485,96	488,18
3	240,35	4	485,96	480,70	483,33
4	231,43	6	480,70	462,86	471,78
5	216,66	8	462,86	433,32	448,09
6	200,76	10	433,32	401,52	417,42
7	166,92	12	401,52	333,84	367,68
8	130,66	14	333,84	261,32	297,58
9	103,67	16	261,32	207,34	234,33
10	89,38	18	207,34	178,76	193,05
11	98,38	20	178,76	196,76	187,76
12	84,43	22	196,76	168,86	182,81
13	78,43	24	168,86	156,86	162,86
14	75,26	26	156,86	150,52	153,69
15	67,88	28	150,52	135,76	143,14
16	66,01	30	135,76	132,02	133,89
17	68,22	32	132,02	136,44	134,23
18	59,95	34	136,44	119,90	128,17
19	57,43	36	119,90	114,86	117,38
20	44,85	38	114,86	89,70	102,28
21	35,21	40	89,70	70,42	80,06
22	29,42	42	70,42	58,84	64,63
23	17,09	44	58,84	34,18	46,51
			5.266,96	4.810,74	**5.038,85**

TLS AND UAV POINT CLOUDS MERGE

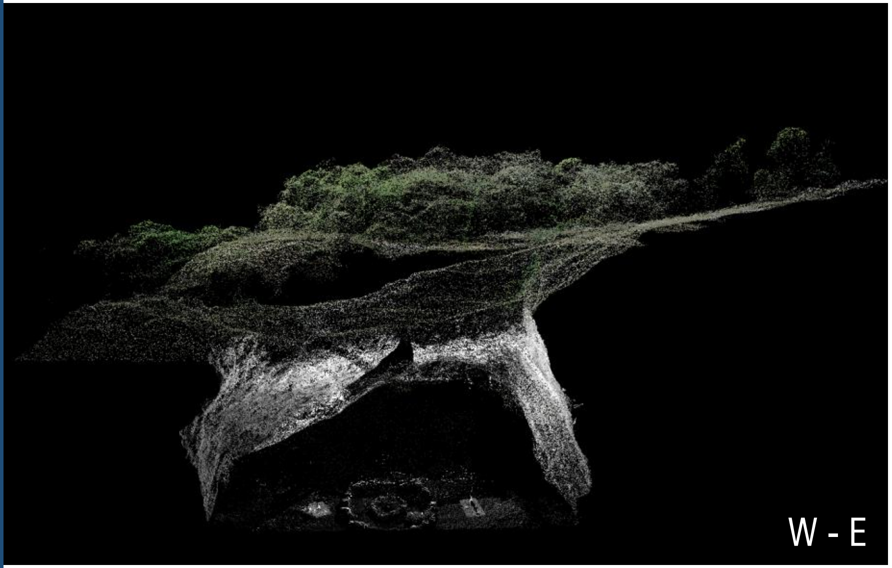
The two point clouds were aligned, geo-referenced and combined using **Polyworks** software (Innovmetric), in order to obtain an epigean and hypogean data model and check the thickness of the material placed above the vault of the cave.

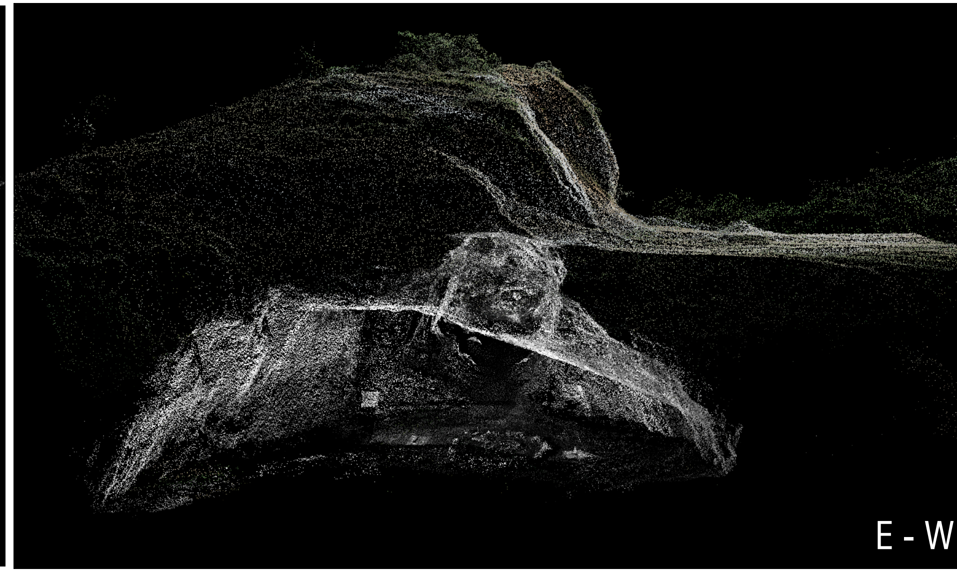


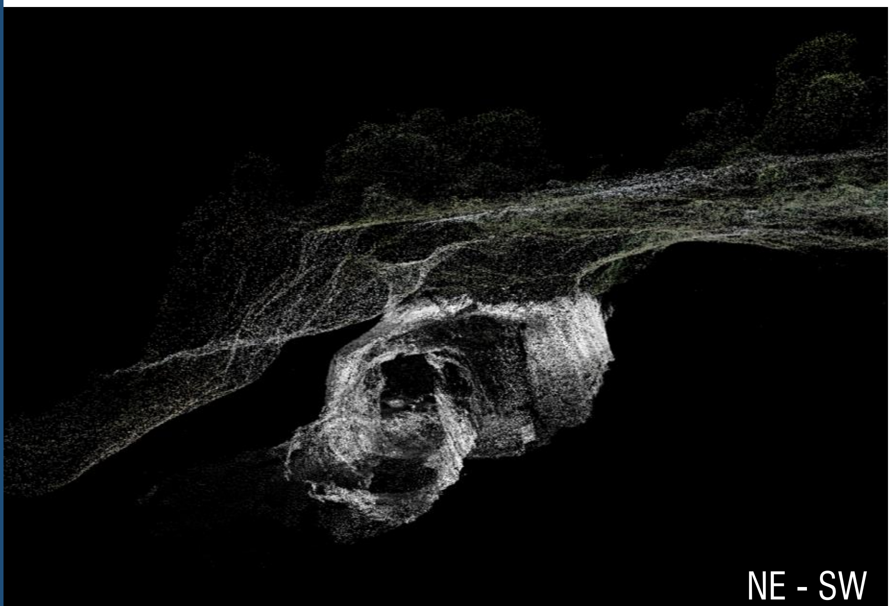
UAV and TLS points cloud sample display

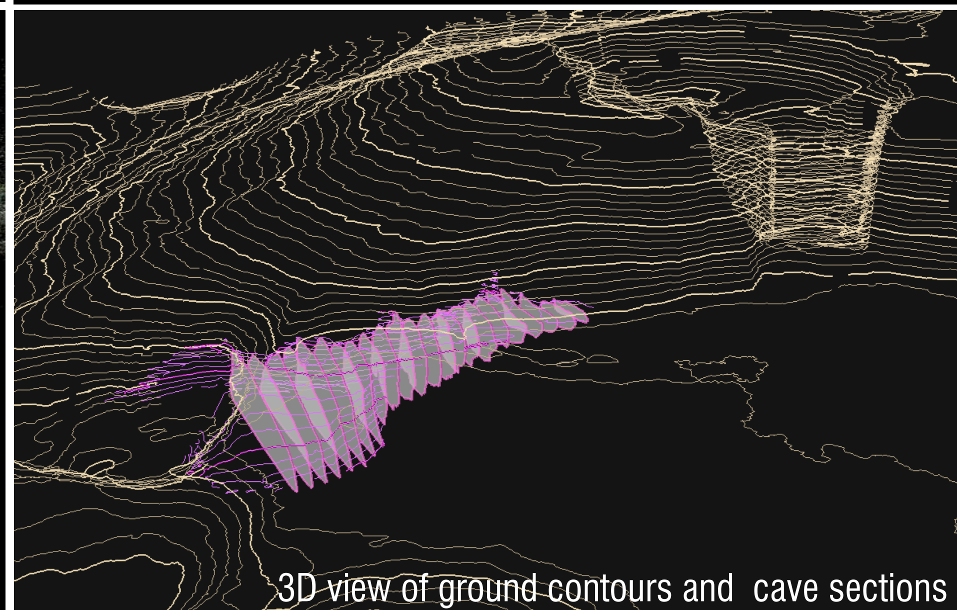
TLS AND UAV POINT CLOUDS MERGE: VIEWS

POINT CLOUDS MERGE

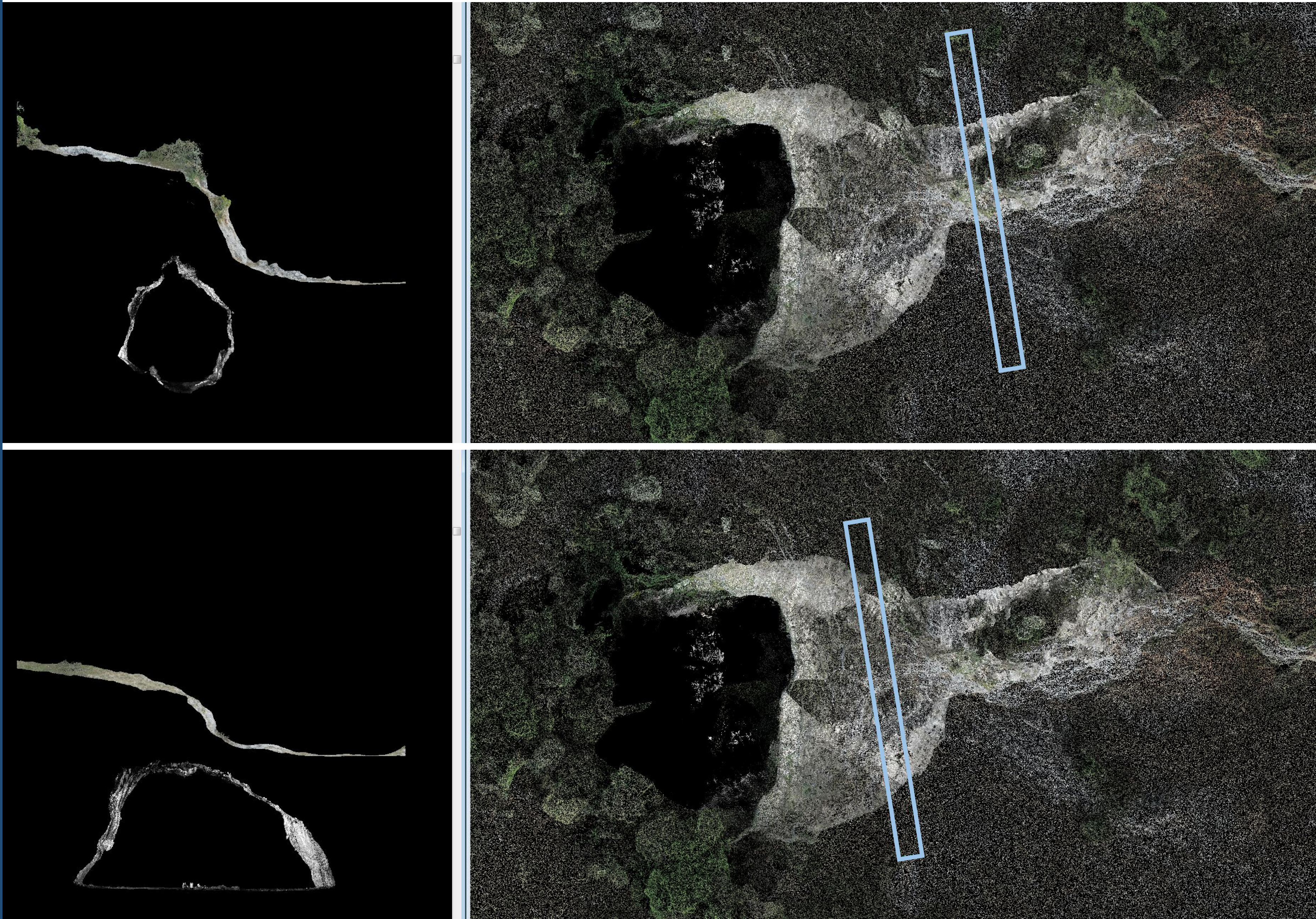








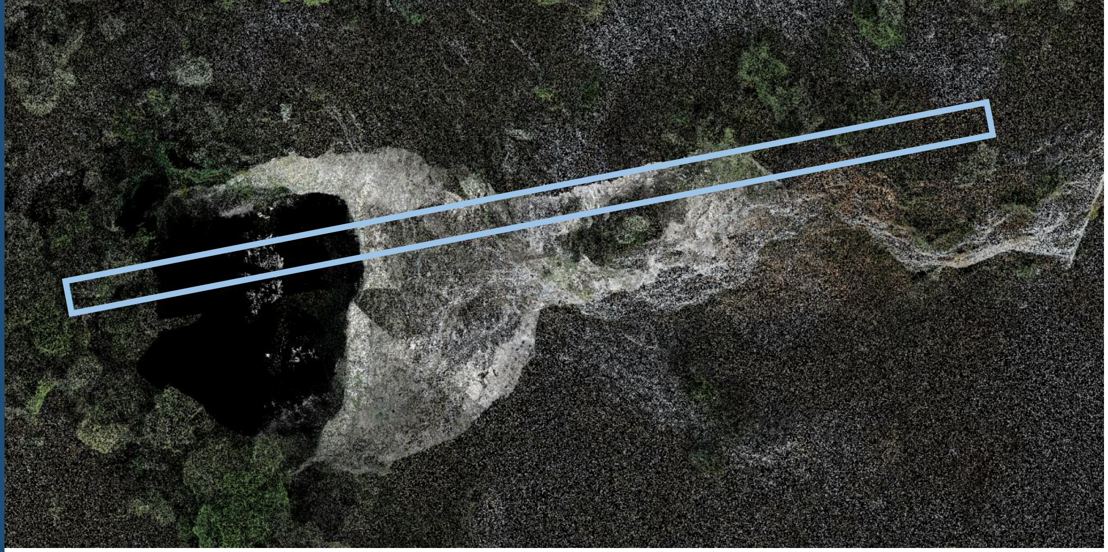
TLS AND UAV POINT CLOUDS MERGE: SECTIONS

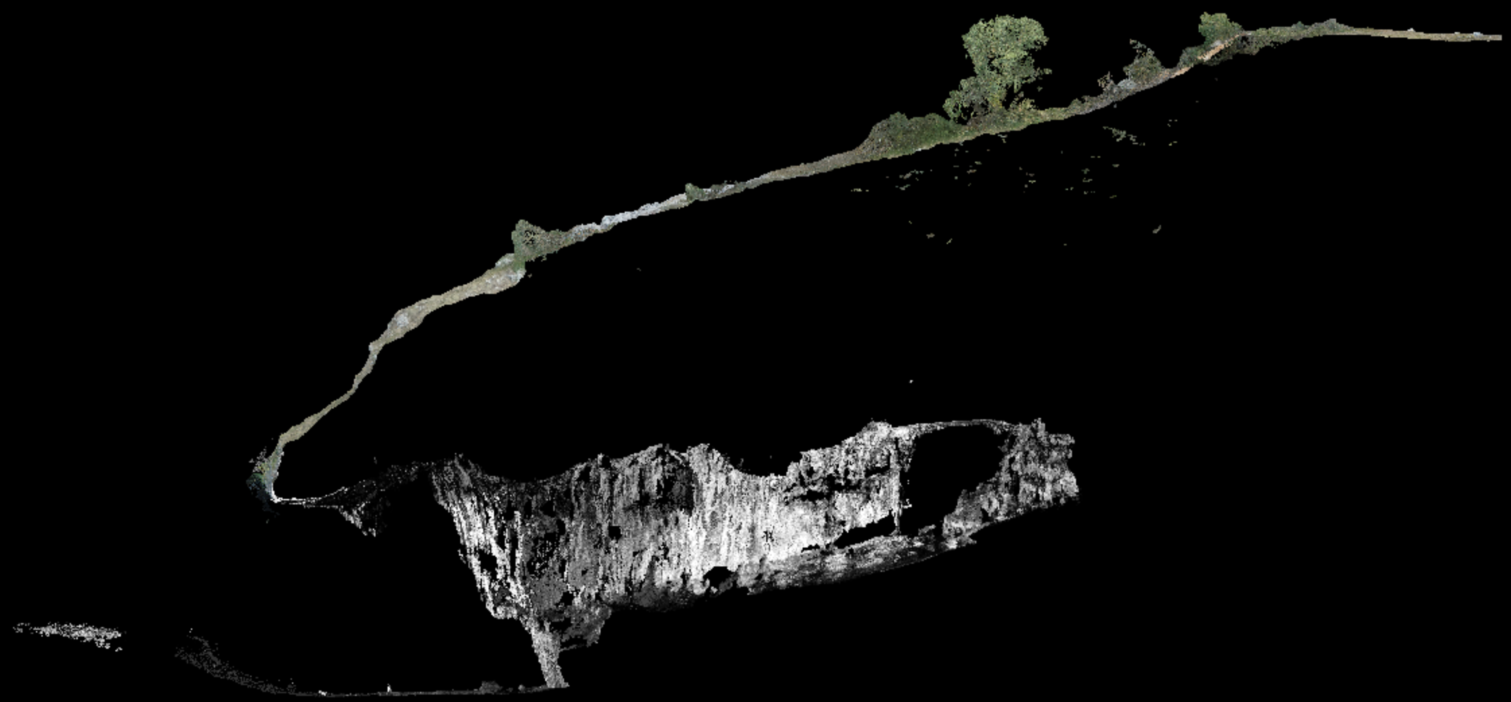


POINT CLOUDS MERGE

POINT CLOUDS MERGE

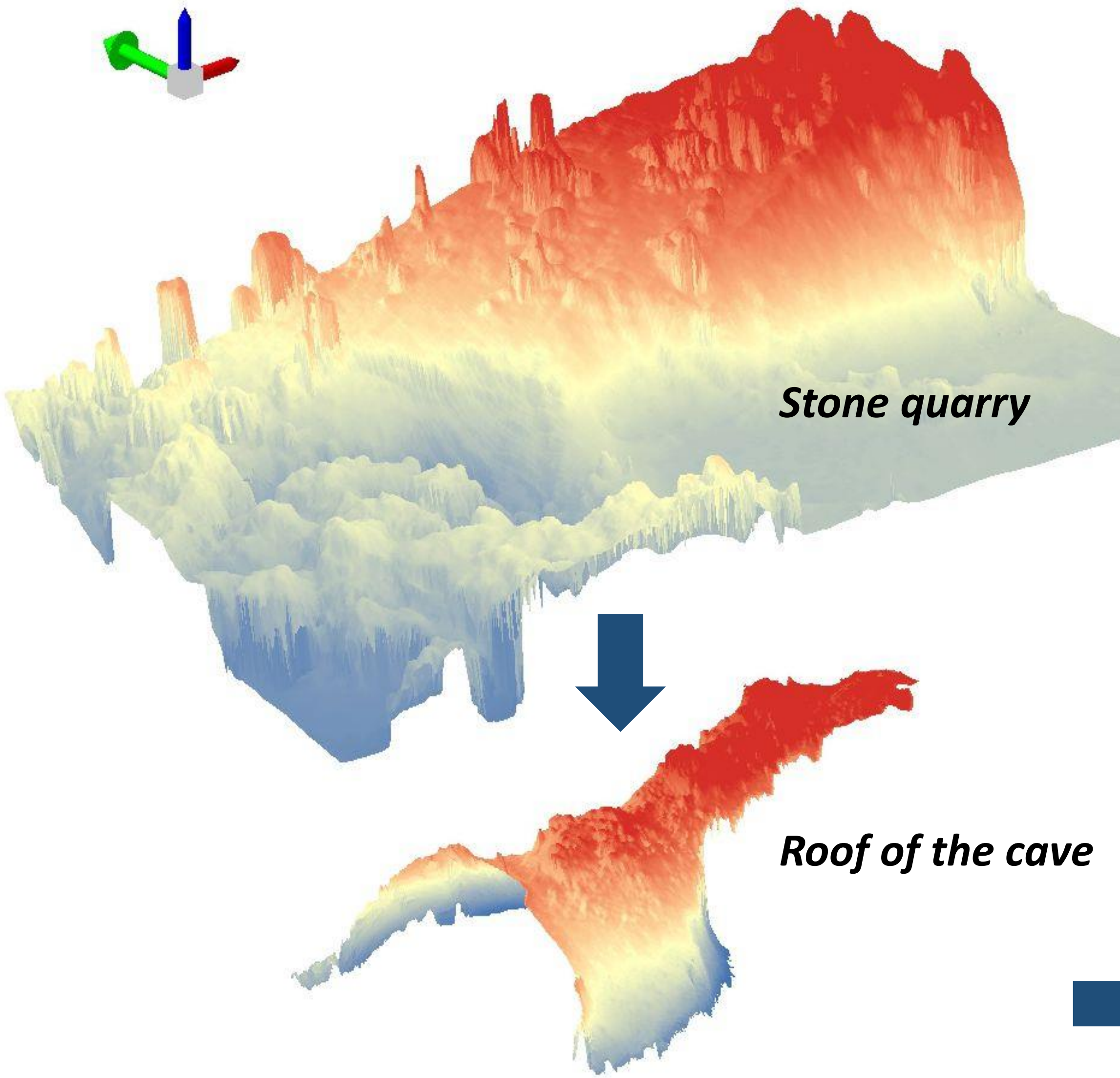
TLS AND UAV POINT CLOUDS MERGE: SECTIONS



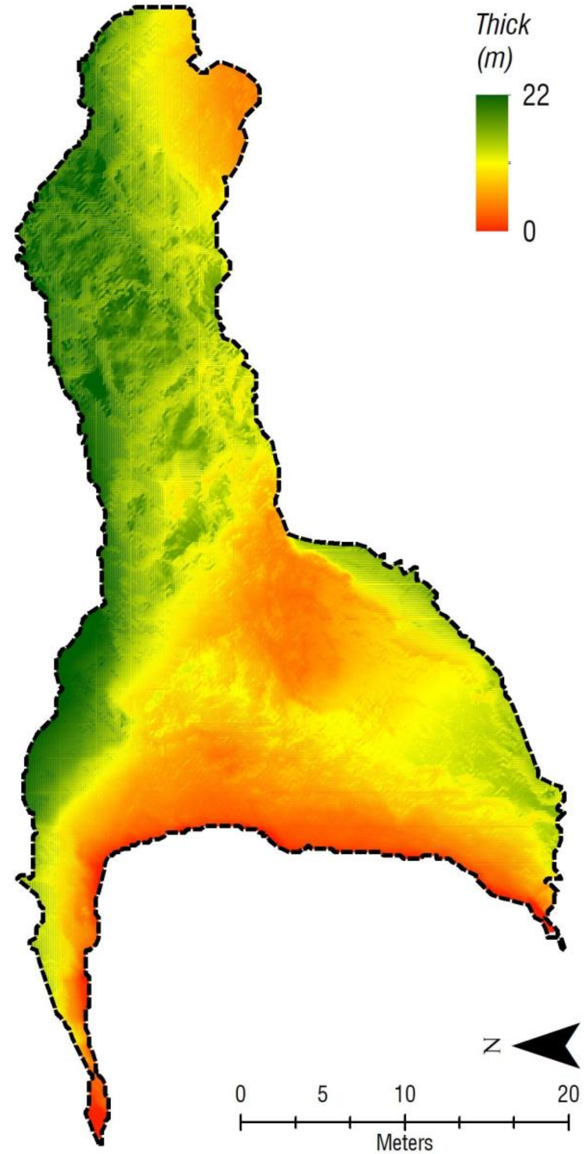


Integration of DTMs derived from UAV and TLS survey

DTMs SUBTRACTION



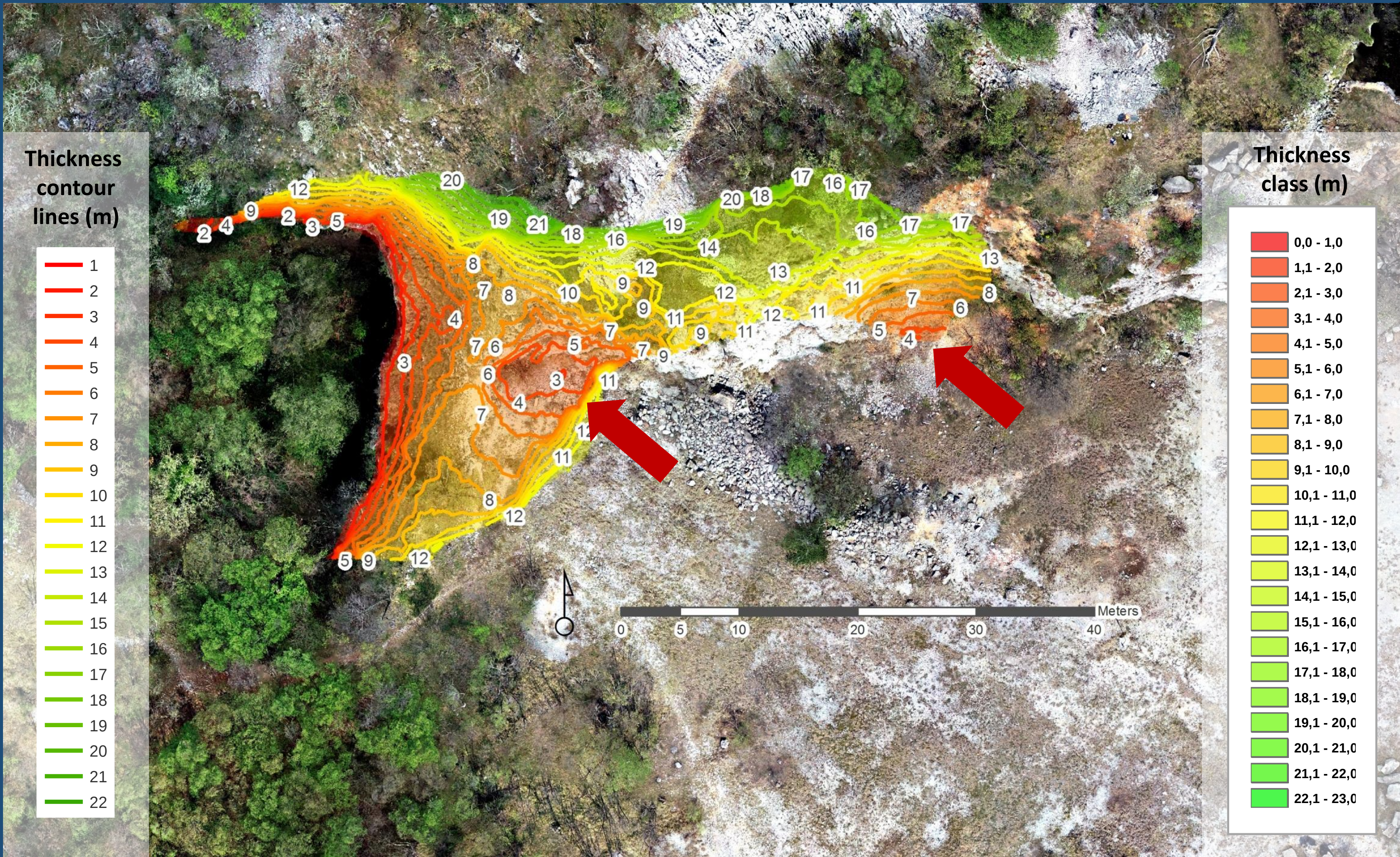
VAULT THICKNESS



Analysis of **critical areas** due to **vault thickness**

VAULT THICKNESS

Rock thickness between the vault of the cave and the outer surface



CRITICAL POINTS

CONCLUSION

- High resolution **UAV** and **TLS** surveys were successfully **integrated** thanks to an **accurate georeferencing** of the data acquired

- The integration of **epigean** and **hypogean data** made it possible to **identify** with high accuracy some **critical areas** related to a **vault thickness**, located at the border of the quarry's square

- The **integration** of UAV and TLS **dense cloud** made it possible to create a real and complete **3D model** of the cave and the quarry

- The **methodology** can be useful for vulnerability assessment in similar context and for improvement of karst phenomena research

THANKS FOR YOUR ATTENTION

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