COST Action TU1208

Civil Engineering Applications of Ground Penetrating Radar

This lecture is part of the TU1208 Education Pack

Applications of GPR in Karst

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Main applications of GPR in karst

Detection and non-destructive investigation of:

- Caves/caverns, cave galleries
- Sinkholes
- Surface subsidence hazards
- Collapsed dolines
- Karst aquifers
- Tectonic features related to karstification
- Karst dolines
- Epikarst

Five case studies are presented in this lecture.

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Detection of caves/caverns

- Detection and investigation of caves and caverns is a customary application of GPR in karst. In particular, GPR allows to:
  - assess geotechnical hazards related to sudden collapse of a cavity;
  - detect cavities along the profile of a planned tunnel;
  - support speleological investigations by detecting unknown galleries;
  - detect underground chambers having archaeological value.

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Detection of caves/caverns

- Depth range of investigations:
  - Most frequently, the GPR detection of shallow cavities (depth <10 m or even <5 m) is described in the literature, because such cavities pose significant hazards for surface constructions.
  - GPR systems with 200 – 500 MHz antennas were applied by various teams, in various projects such as in tunnel construction.
  - GPR systems with 25 – 100 MHz antennas are applied for seeing deeper, although the resolution is worse.
  - Rigid low-frequency antennas are large and difficult to apply in rough terrains. Special rough-terrain antennas exist.

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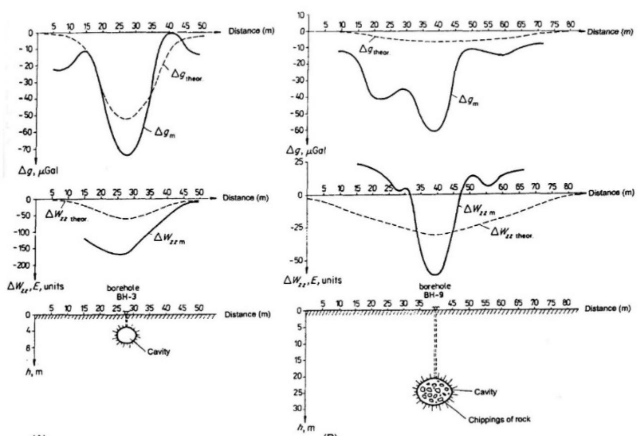
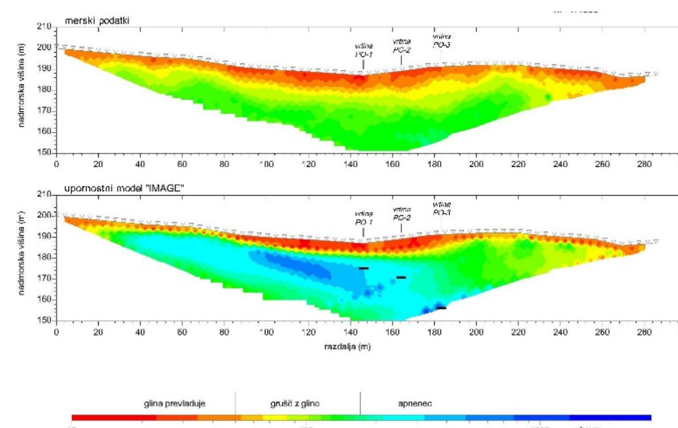
Detection of caves/caverns

- Complementary geophysical methods, applied in addition to GPR:
  - Electric tomography (ERT)
  - Micro-gravity measurements (MG)
  - Seismic refraction (SRefr)
  - Seismic reflection (Srefl)
  - Magnetic method (Mag)
  - Electromagnetic methods (EM)
  - Self potential (SP)
  - Induced polarisation (IP)

Electric Tomography (ERT)



Micro Gravity Measurements (MG)



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GPR equipment – low frequency

- Rough Terrain Antenna (RTA) - 50 MHz (unshielded)
  - rugged surface, dense vegetation – typical for karst areas
  - sufficient depth penetration
  - reasonable resolution

250MHZ shielded antenna

- Vertical and horizontal resolution of 50 MHz acquisition system in limestone:
  - Centre frequency: 50 MHz
  - Wavelength (λ) in air: 6 m
  - Dielectric constant (ε) in limestone: 7
  - EM velocity in limestone: 11.3 cm/ns
  - Wavelength in limestone: 2.3 m

Depth (m)	Vertical res. (m)	Horizontal res. (m)
10	1.1	4.1
20	1.1	7.6
30	1.1	11.2
40	1.1	14.7

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Case Study 1 (CS1): Looking for a buried cave entrance

Mt. Kanin, S-19 cave

The S-19 cave, with its explored depth of 177 m, was one of the most important caves of the Mt. Kanin massif. After its discovery in 1974, a huge snow avalanche protection dyke (see picture) was constructed across the cave entrance. Recently, it was decided to excavate the buried cave. Hence, the accurate location of the cave had to be determined.

A GPR with special 50 MHz antennas for rough terrain was selected as the best geophysical method for the given conditions, with thick debris overlaying a rugged limestone surface.

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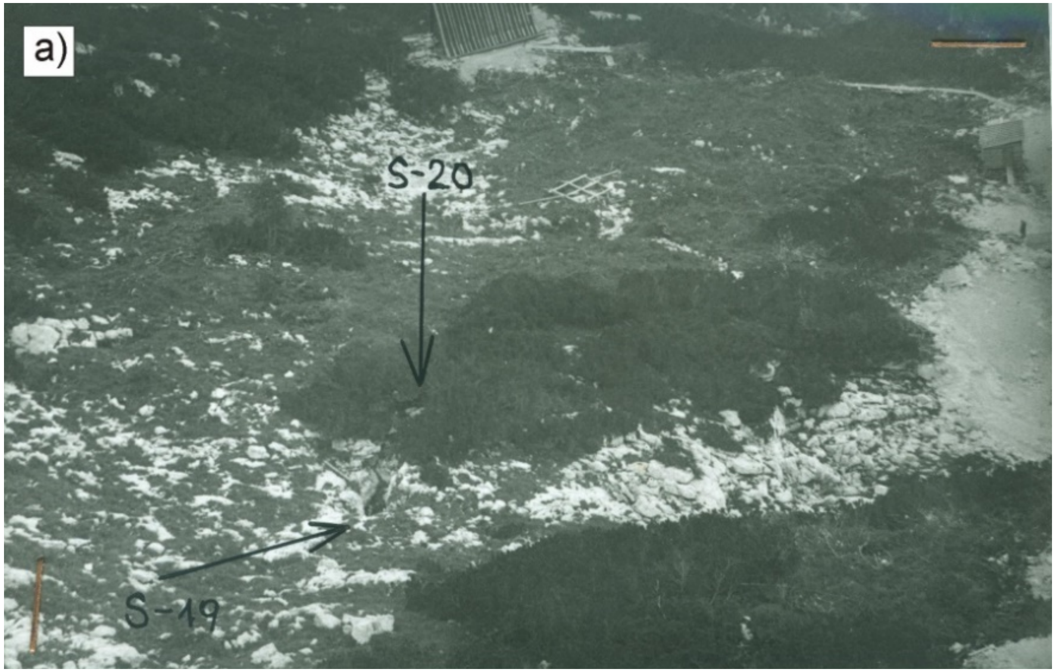
CS1: Looking for a buried cave entrance

After a first survey, it was not possible to directly detect the relatively narrow cave entrance, due to data resolution limits. A historical photo of the area showed that the cave entrance was located in a local depression (see picture). This represented the main target of the next GPR survey.



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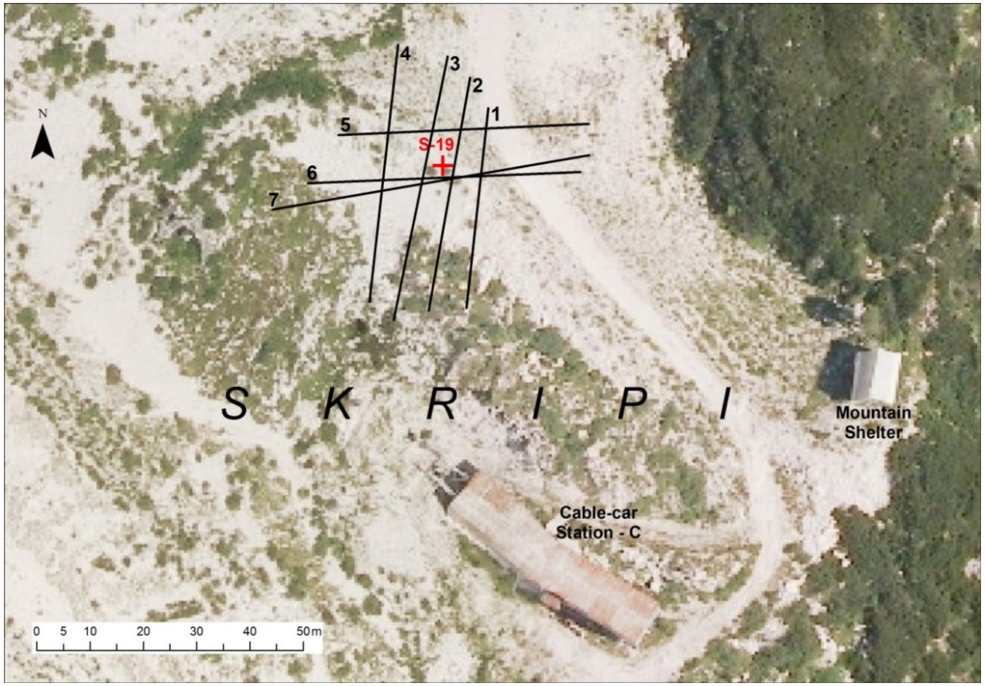
CS1: Looking for a buried cave entrance

Seven GPR profiles were measured across the rough and steep surface; it was difficult to access the area with sensitive research equipment.



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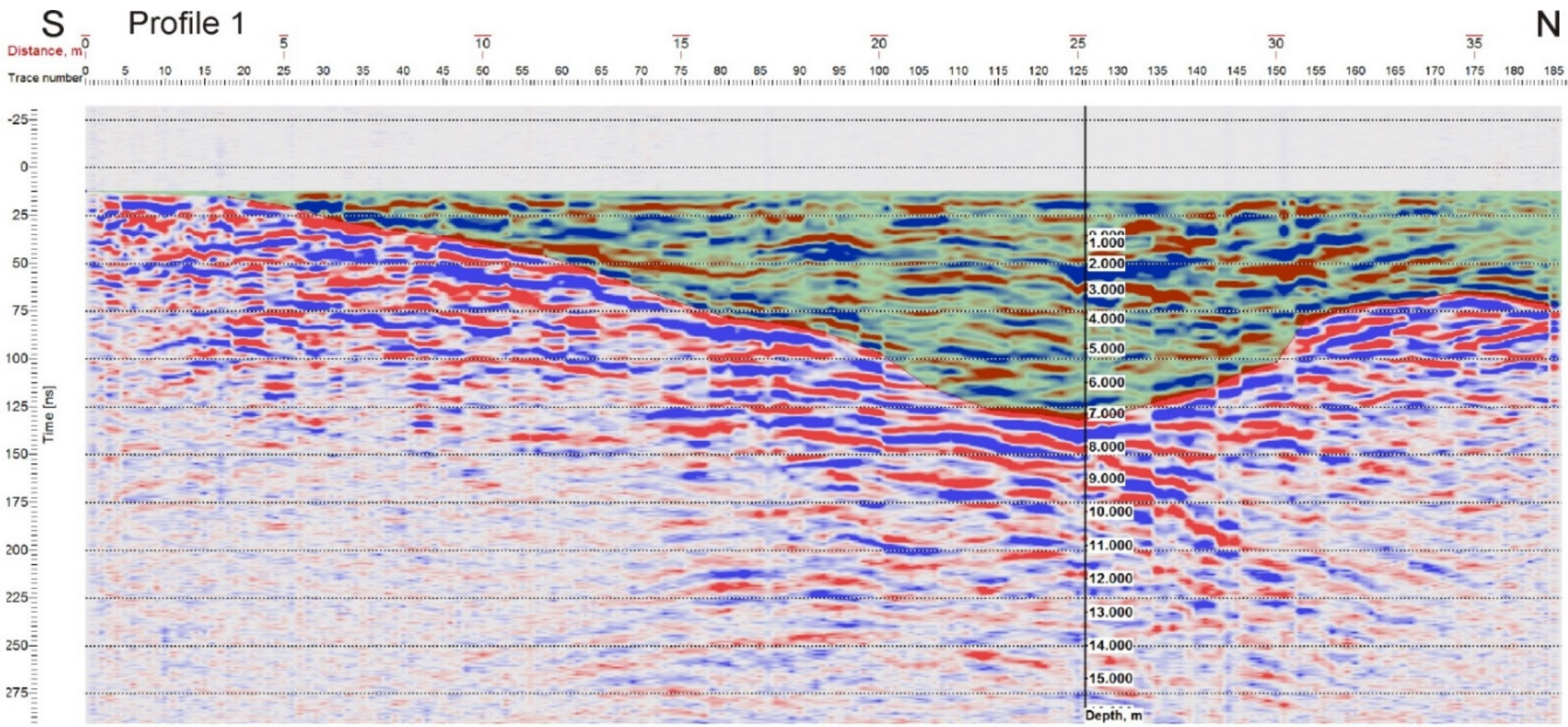
CS1: Looking for a buried cave entrance

In all the recorded radargrams a small depression was imaged under debris (marked green in radargrams) and recognized as a topographic feature related to the cave entrance.



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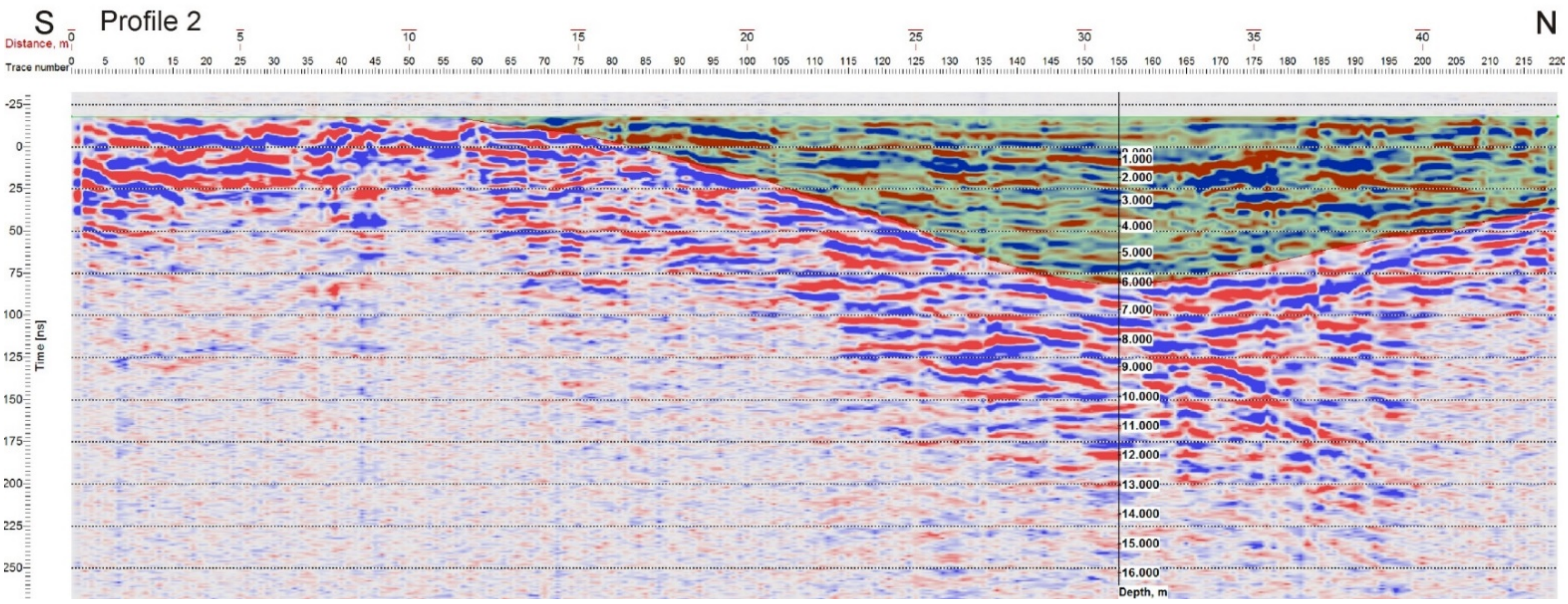
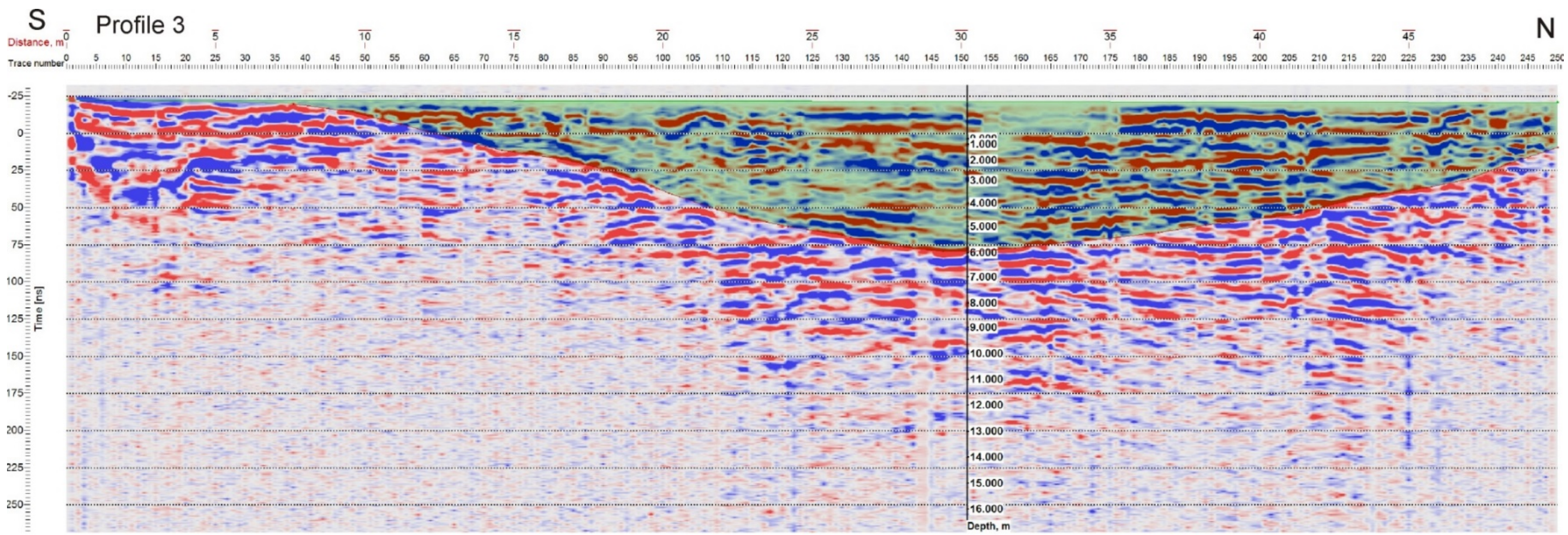
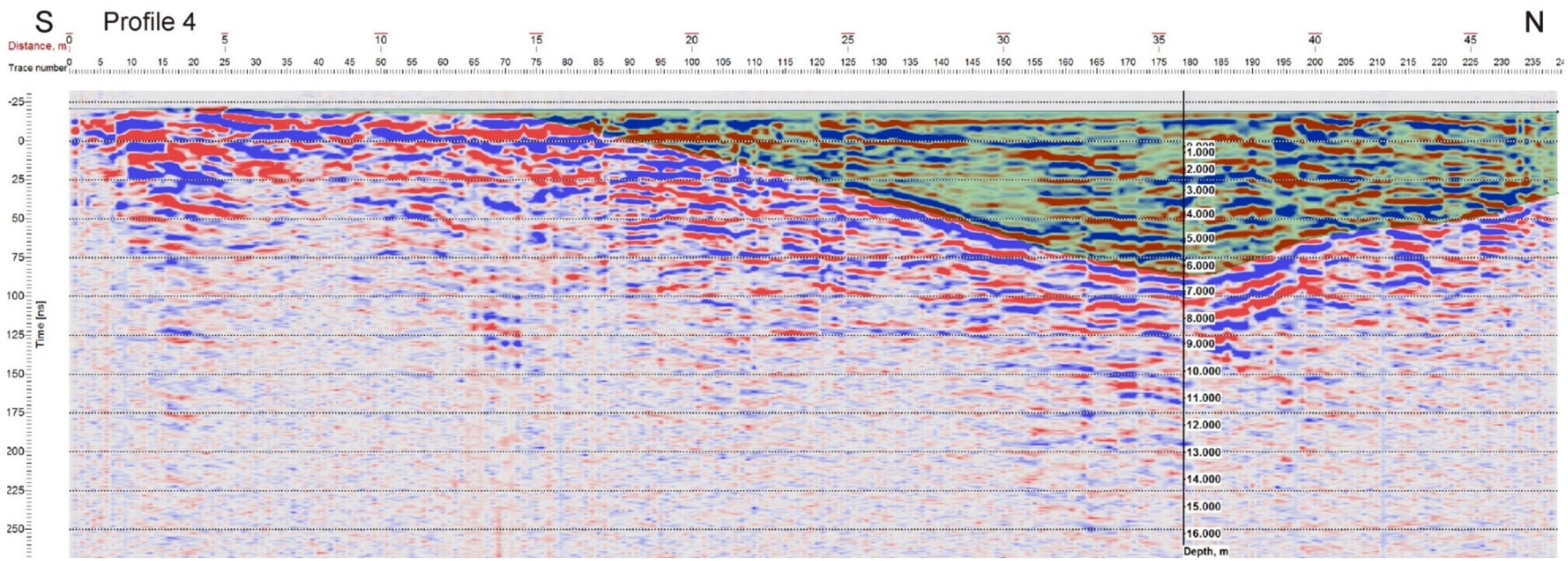
CS1: Looking for a buried cave entrance

The same depression here is imaged on a different profile.



And here the same depression is imaged on two more profiles!





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CS1: Looking for a buried cave entrance

Based on the GPR data interpretation, the exact location for digging was determined and the thickness of debris was assessed as 6.5 – 7 m.

A massive excavation by a dredger resulted in a successful opening of the cave entrance, confirming the GPR-determined location and depth.

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Case Study 2 (CS2): Investigating unknown cave galleries

Divača cave (Slovenia)

High frequency GPR is usually applied for cavity detection in a shallow subsurface of karst areas, to prevent geotechnical hazards. For specific projects, such as tunnel construction, it is important to detect also larger voids at medium depth range. However, the size of classical rigid low frequency GPR antennas seriously limit their applicability in a rough terrain with dense vegetation, as is commonly encountered in a karst.

In this example, special 50 MHz rough-terrain antennas were used to detect a cave gallery at a depth of 12 – 60 m: the Divača cave. This cave was selected because of the wide range of depths under the surface, the possibility of unknown galleries in the vicinity, and the presence of a rough terrain surface.

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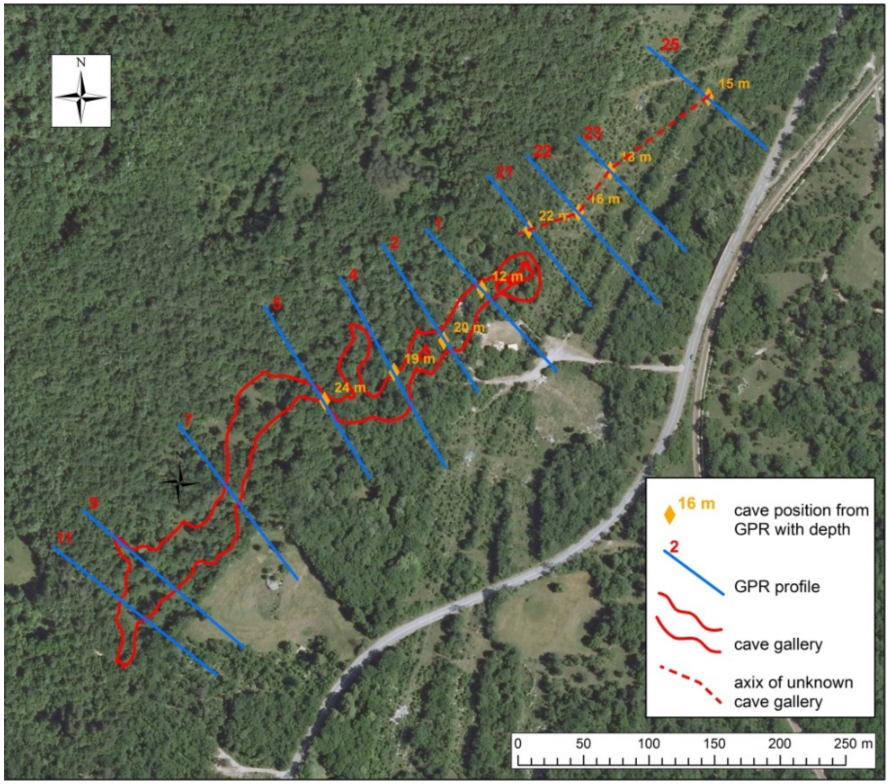
CS2: Investigating unknown cave galleries

Seven GPR profiles were measured across the main gallery of the cave and additional four profiles were measured north-east of the cave entrance, where no galleries were known.



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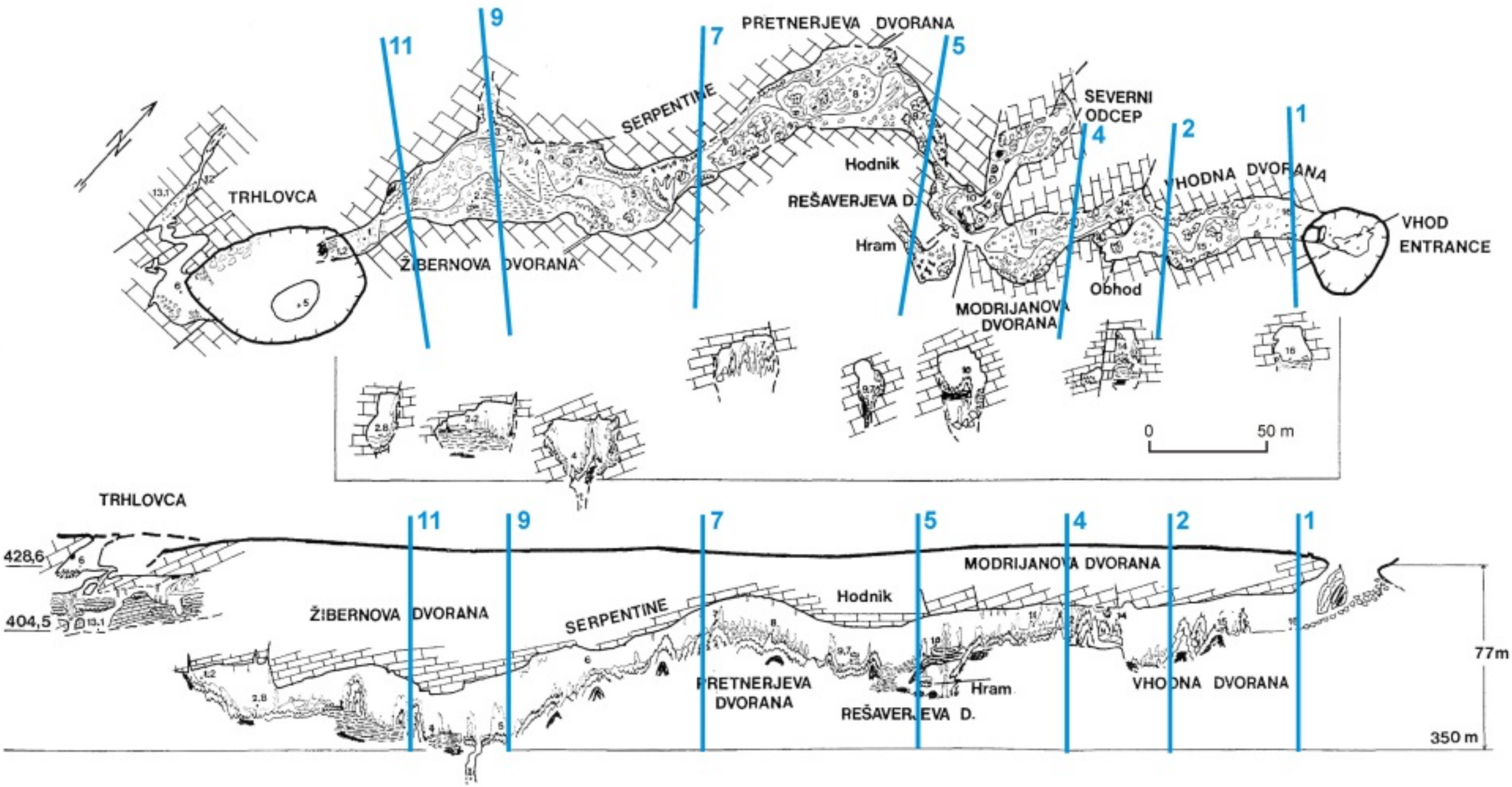
CS2: Investigating unknown cave galleries

These drawings show the seven GPR profiles measured across the main gallery of the cave.



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CS2: Investigating unknown cave galleries

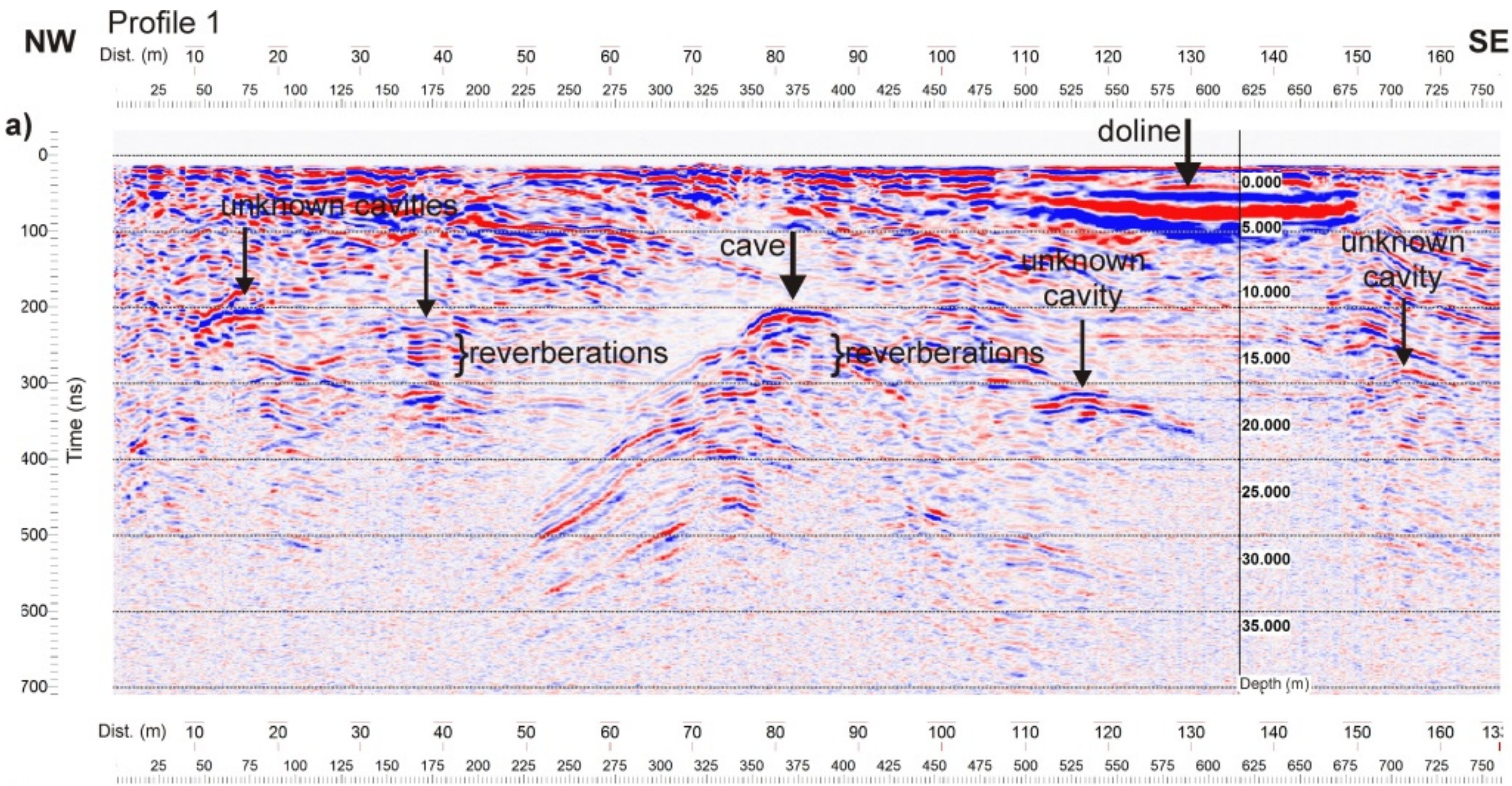
Different acquisition and processing settings were considered, along with data resolution issues.

The main gallery of the cave was clearly imaged in the section where the roof of the gallery is located at a depth of 10 m to 30 m. The width of the open space, in this section, is around 10 m.

The adopted GPR system was not able to detect the gallery in the part where the roof of the gallery is located deeper than 40 m, however several shallower cavities were discovered which were unknown before.

CS2: Investigating unknown cave galleries

Let us now look at radargrams and interpret meaningful signatures in them!



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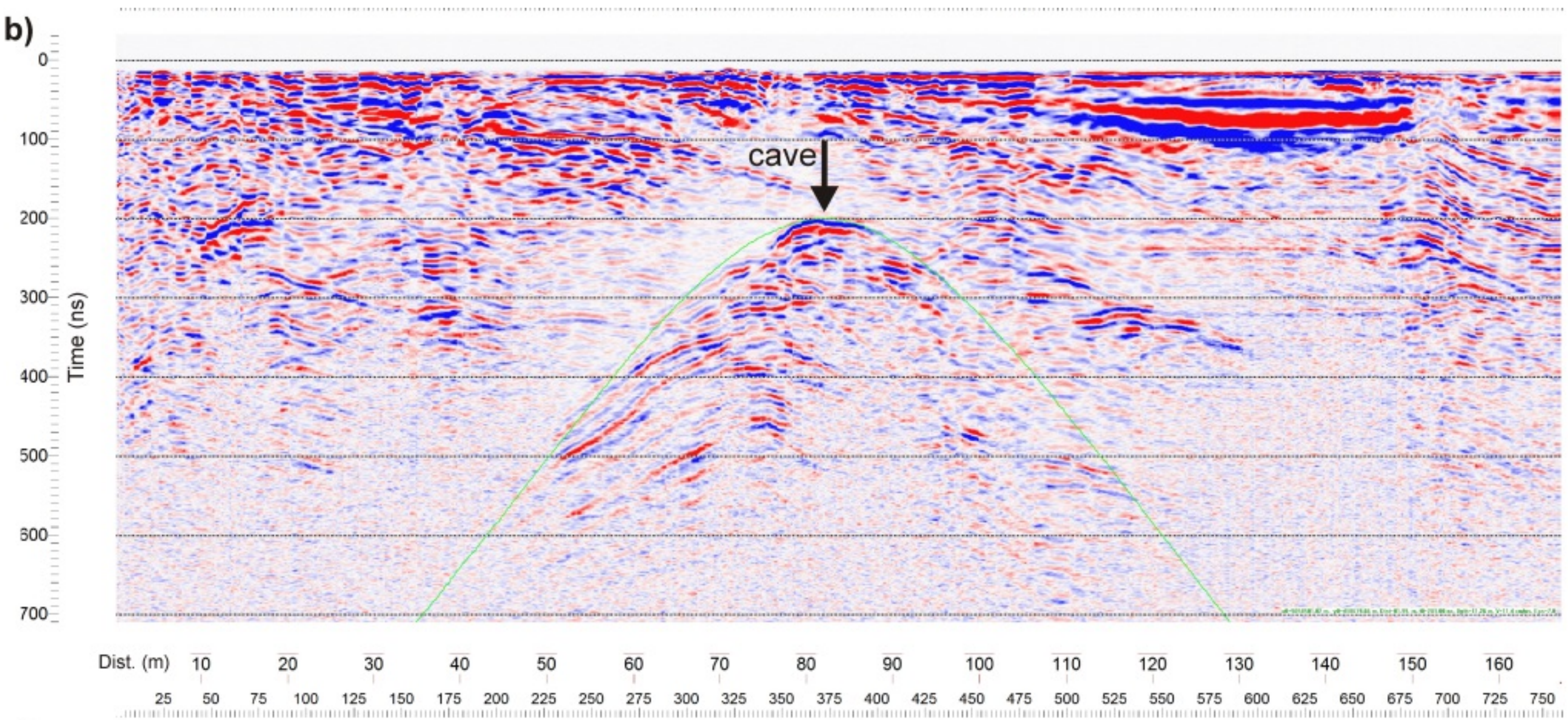
CS2: Investigating unknown cave galleries



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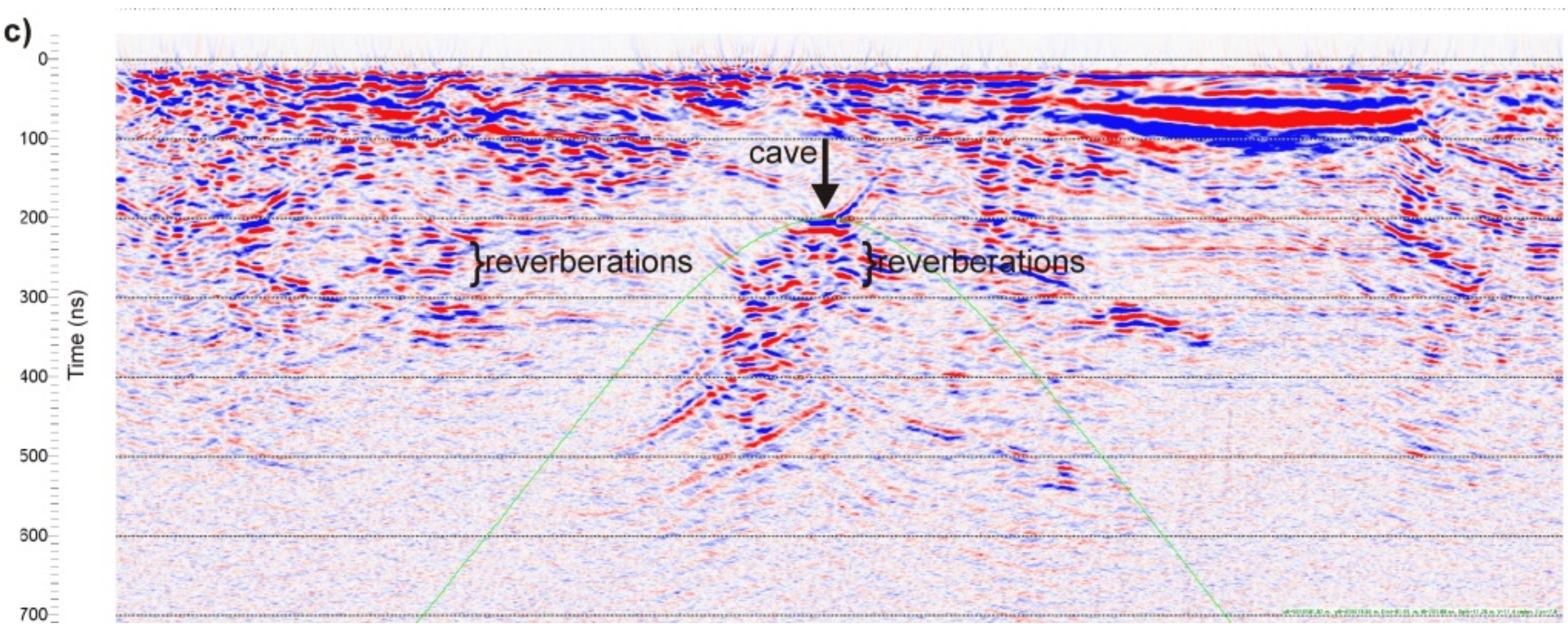
CS2: Investigating unknown cave galleries



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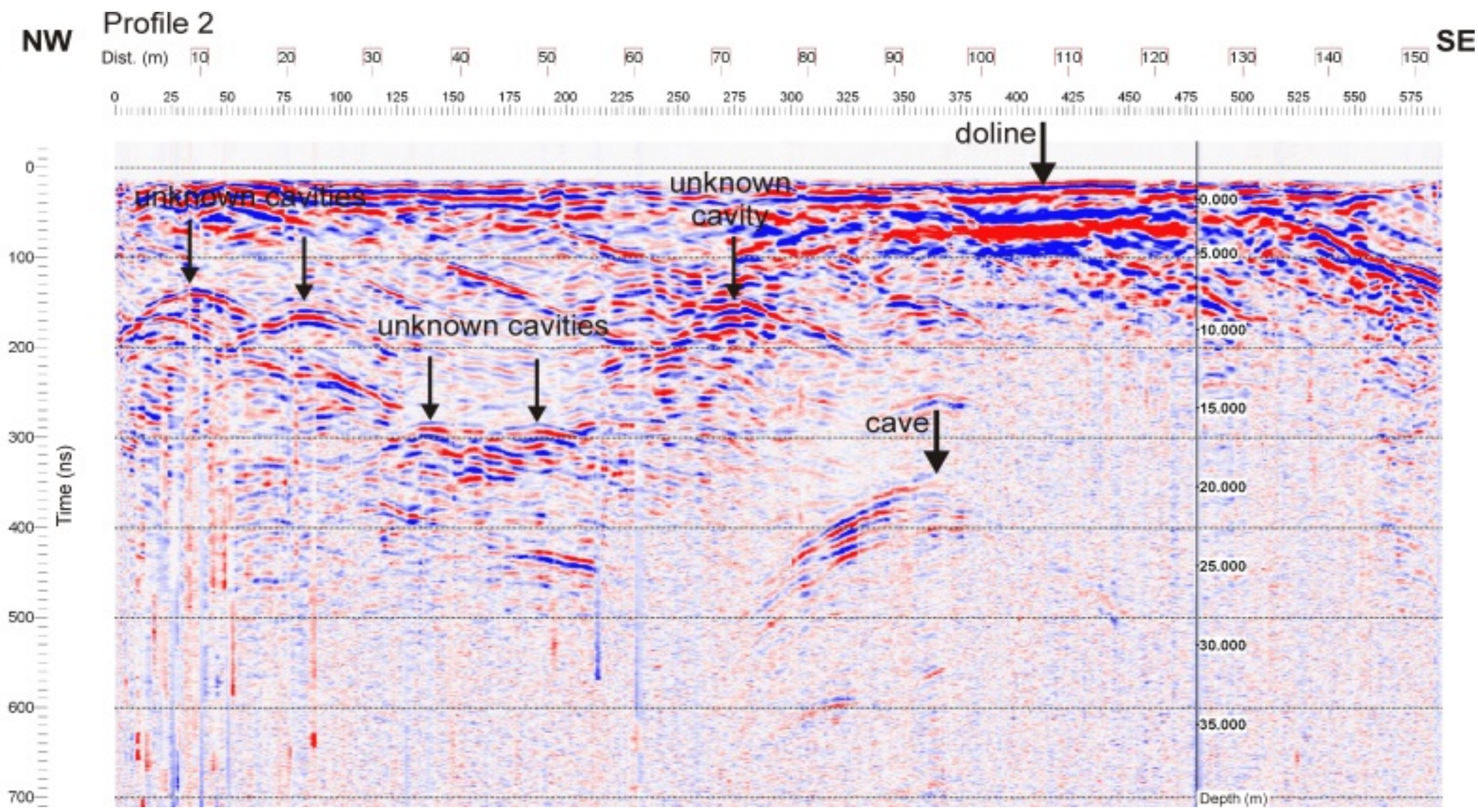
CS2: Investigating unknown cave galleries

The most important result is that profiles acquired north-east of the cave entrance revealed very clearly the existence of an unknown gallery, which is located at a depth of 15 m to 22 m and represents the continuation of the Divača cave. The access to this gallery is blocked by sediments filling the entrance shaft of the cave.

The results of this study are important also for future infrastructure projects, which may involve construction of tunnels through karstified limestone, as well as for speleological investigations where GPR results can be useful to properly direct research efforts.

CS2: Investigating unknown cave galleries

Let us look at a few more radargrams.



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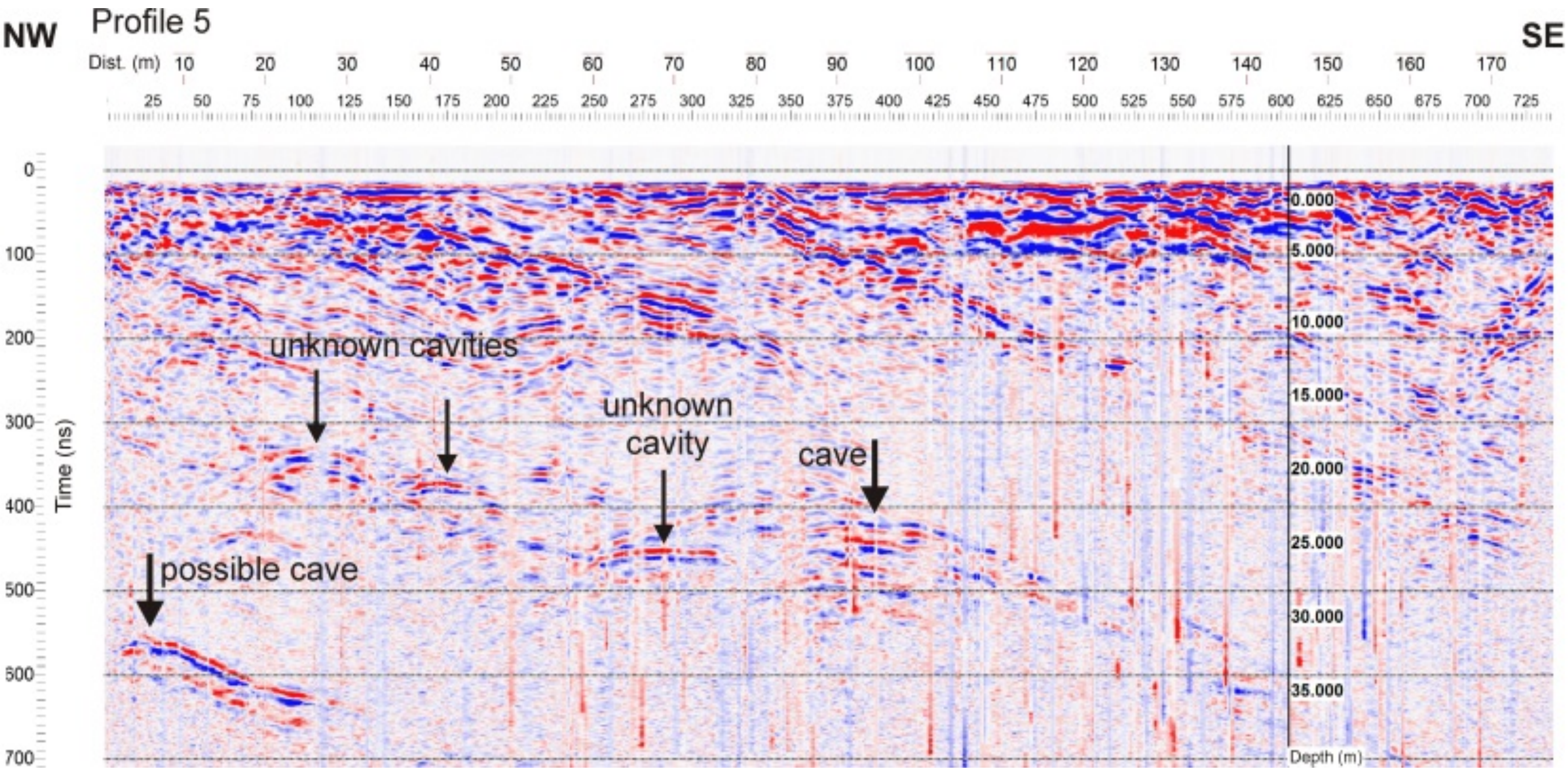
CS2: Investigating unknown cave galleries



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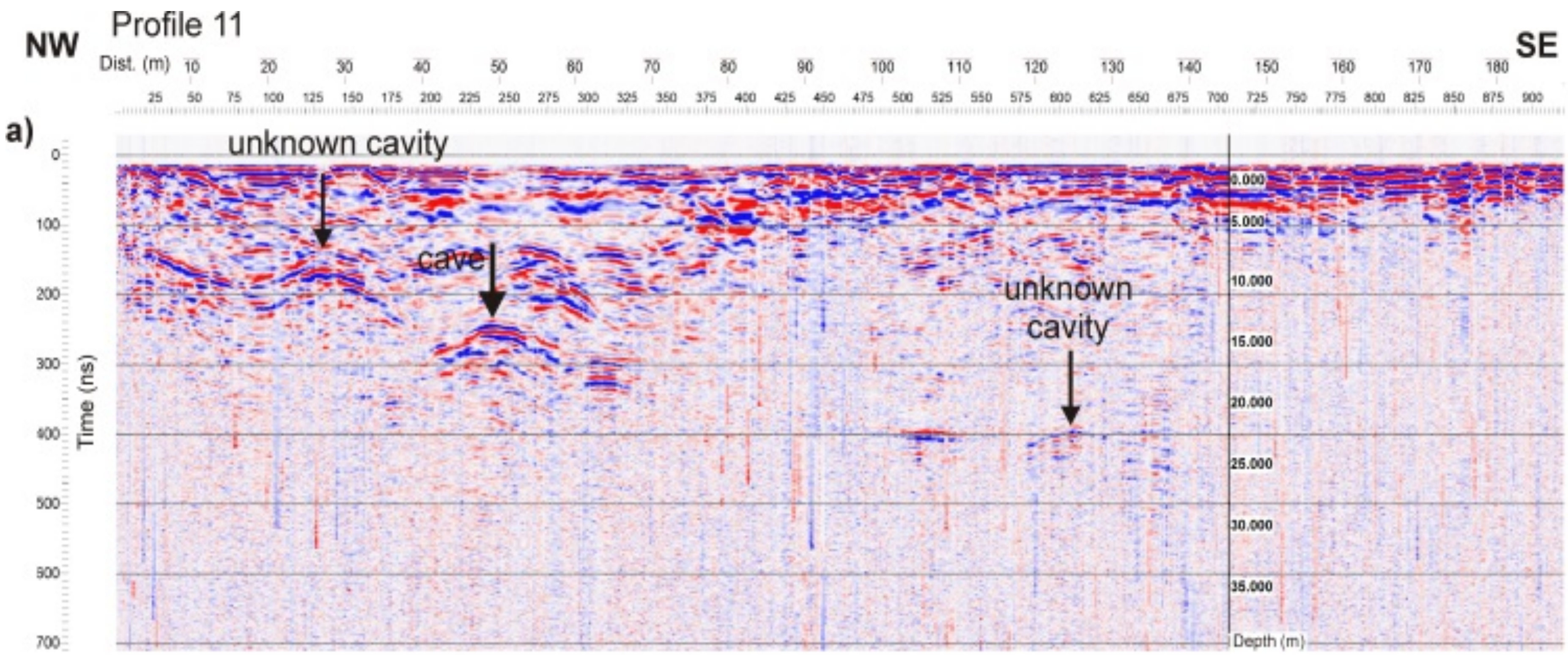
CS2: Investigating unknown cave galleries



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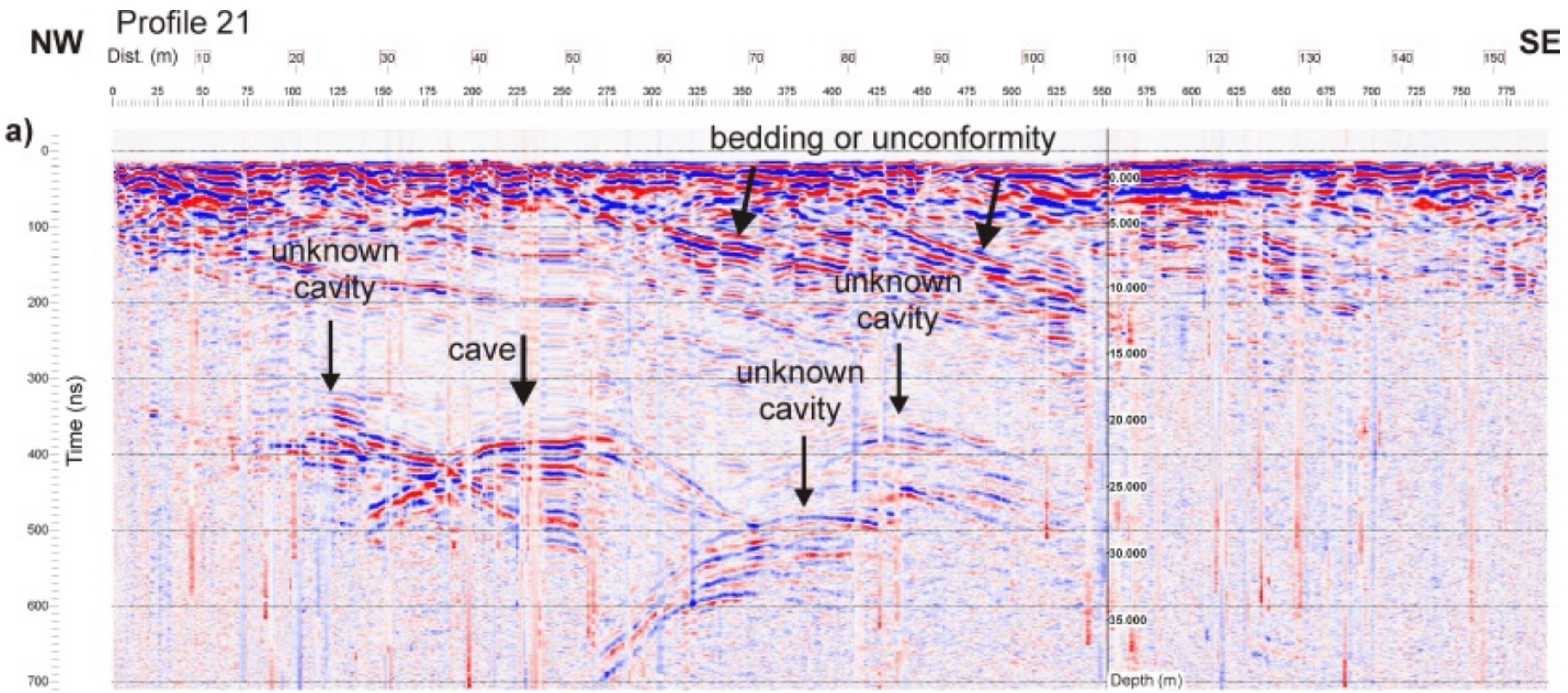
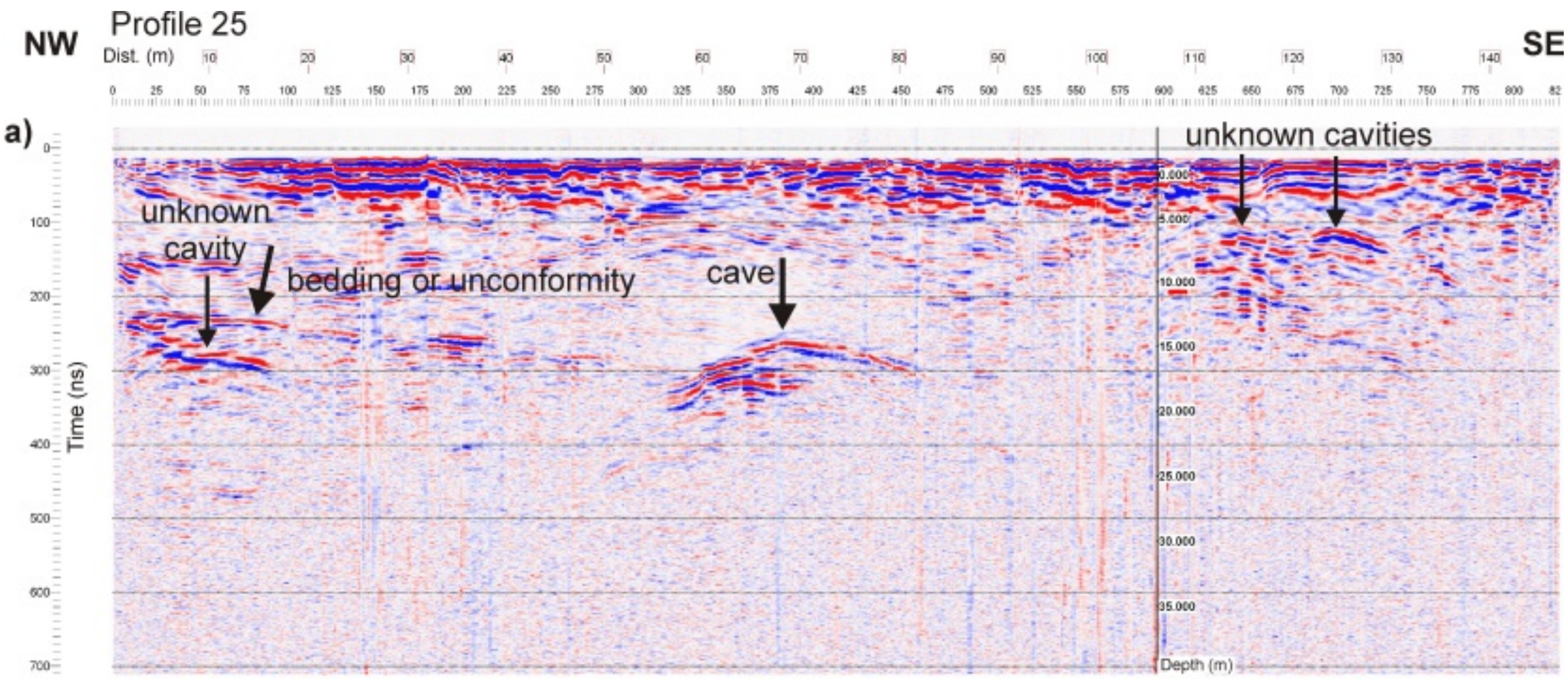
CS2: Investigating unknown cave galleries



CS2: Investigating unknown cave galleries



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Case Study 3 (CS3): Geological hazards for exploitation

Rodež Quarry (Slovenia)

During the exploitation of flyschoid rocks in quarries, the presence of karst features, such as cavities and phreatic channels in carbonate units, can be extremely hazardous. Some case studies demonstrated that GPR is a suitable method for detecting such features.

We evaluated its use in detecting karst cavities and discontinuities that may form potential landslide surfaces in the flyschoid rocks of the Rodež quarry in Anhovo.

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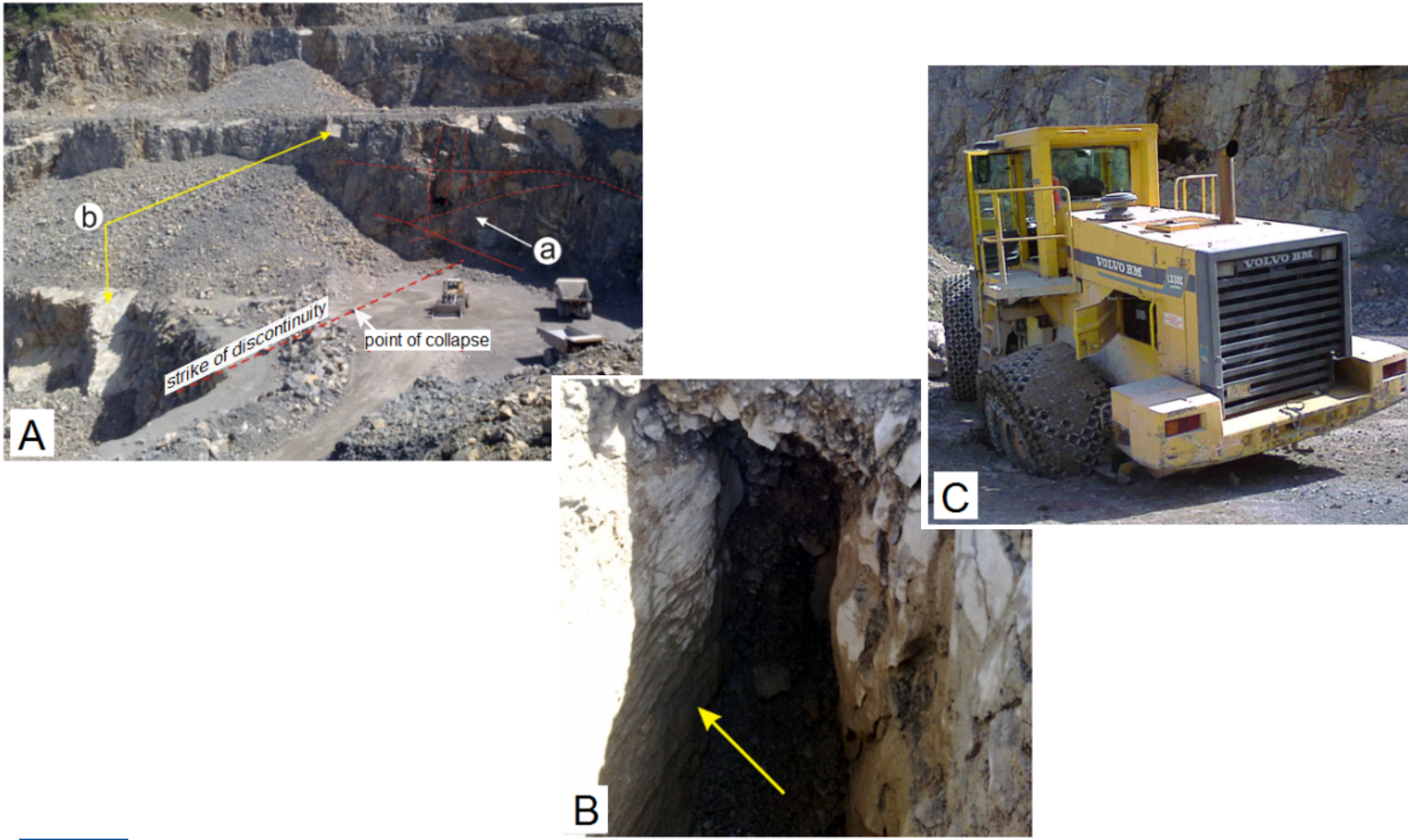
CS3: Geological hazards for exploitation



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CS3: Geological hazards for exploitation

We recorded 21 GPR profiles in 3 consecutive benches, with unshielded 50 MHz rough-terrain antennas. We correlated the acquired data with the results of a detailed structural and lithological mapping of the area.

By processing and interpreting the measured GPR profiles, we were able to locate several karst cavities and confirm the presence of discontinuities.

The complexity of the intersections of structural discontinuities and the mechanical properties of rocks contribute to the formation of sliding surfaces and to the development of karst features.

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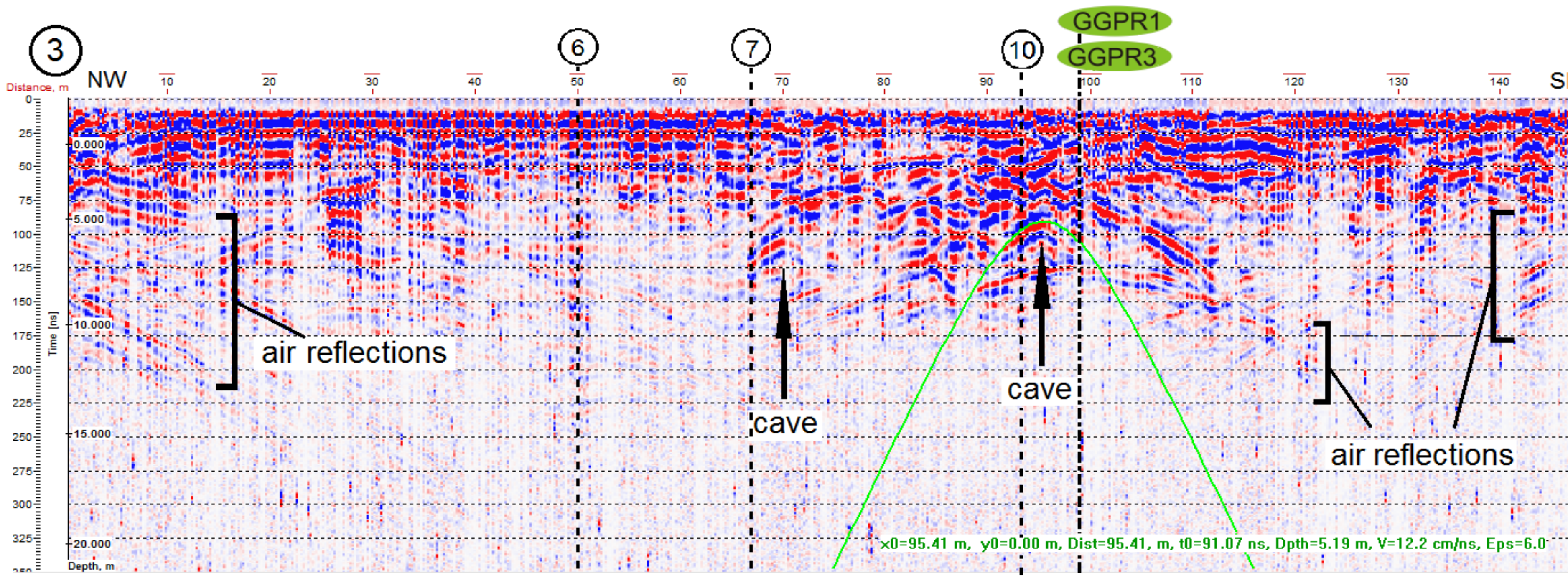
CS3: Geological hazards for exploitation

Let us now look at radargrams and interpret meaningful signatures in them!

Longitudinal profile



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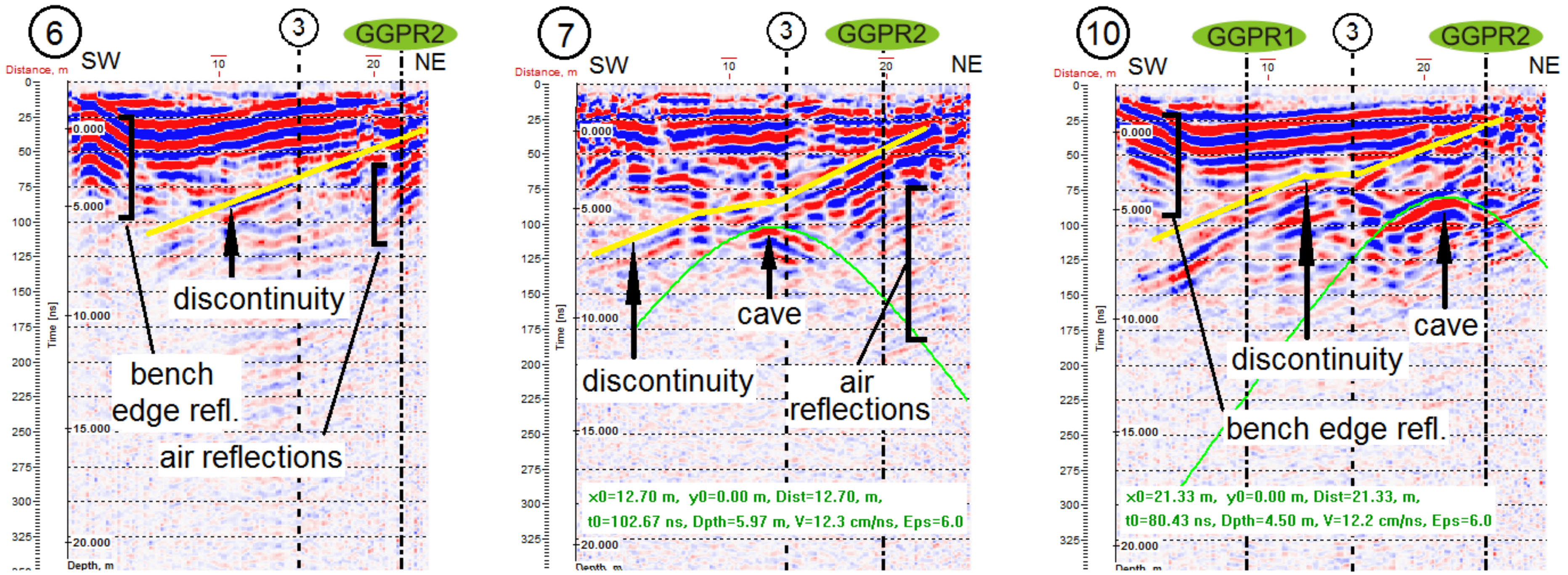
CS3: Geological hazards for exploitation

Transverse profiles



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Case Study 4 (CS4): Investigation of limestone-flysch trust-fault contact

Črnotiče Quarry (Slovenia)

A pronounced geomorphologic step formed by an important thrust-fault represented a major obstacle for the realization of a planned new railway route. Understanding the geotechnical and structural properties of the area, as well as the geometry of the thrust-fault planes, was of great importance.

Geological mapping cannot give information about the subsurface and cannot reveal buried complex 3D structures. The numerous boreholes needed to destructively investigate the area were deemed too expensive and time consuming. Hence, the application of GPR was decided.

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CS4: Investigation of limestone-flysch trust-fault contact

A low frequency GPR system with 50 MHz rough terrain antenna was used and 13 GPR profiles along three floors of the quarry were recorded. The profiles were positioned across some existing boreholes.

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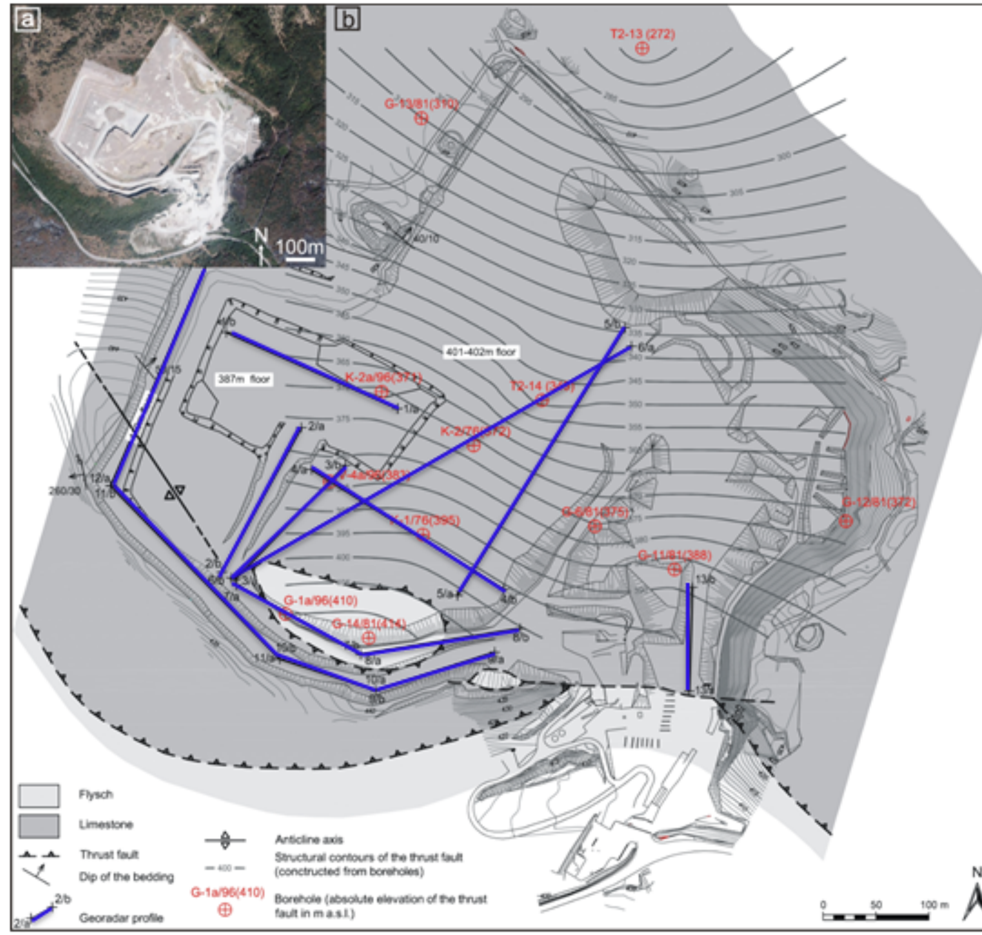
CS4: Investigation of limestone-flysch trust-fault contact

The GPR results were correlated with borehole data as well as geological mapping results.

comparison of GPR depths and borehole data

good correspondence



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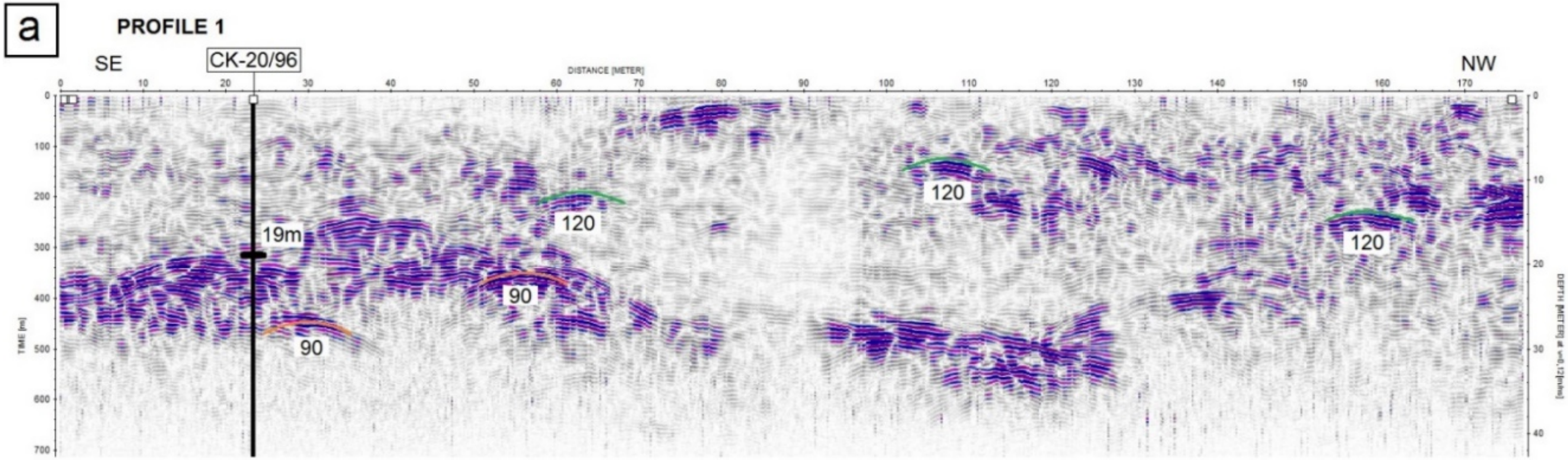
CS4: Investigation of limestone-flysch trust-fault contact

The GPR provided precise information on the geometry of the thrust-fault. Moreover, it was very useful for establishing the position of some known as well as several potential cavities, both air- or sediment-filled.



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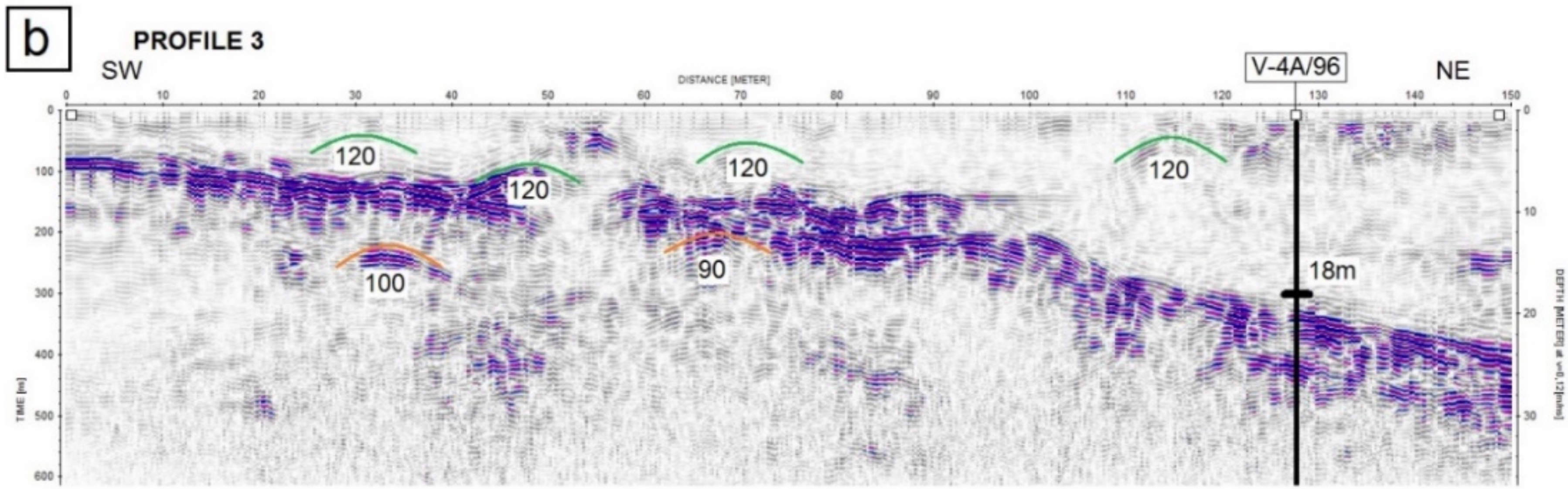
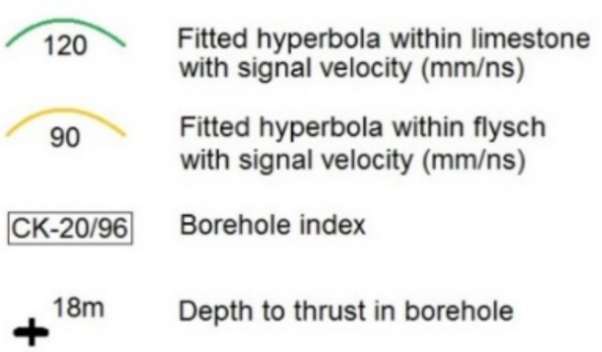
CS4: Investigation of limestone-flysch trust-fault contact





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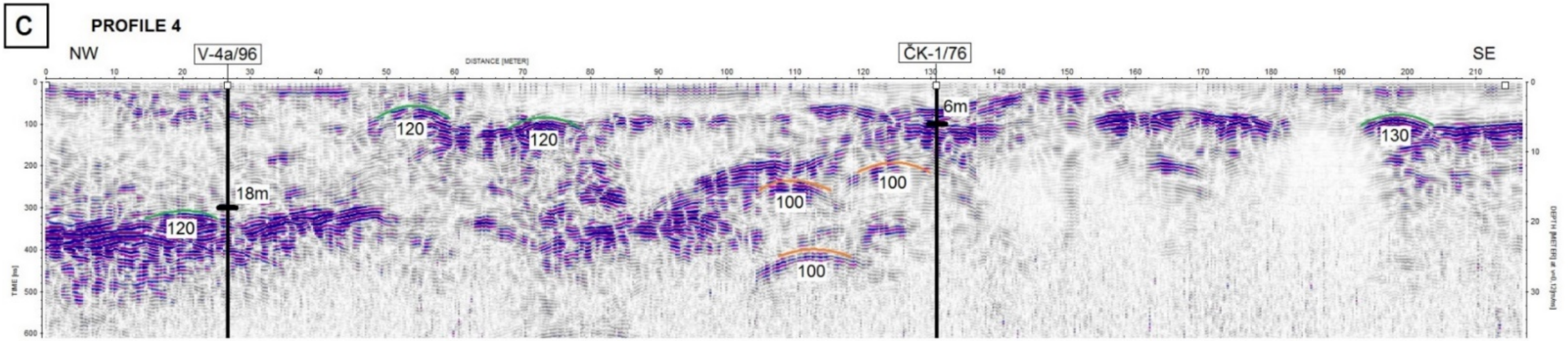
CS4: Investigation of limestone-flysch trust-fault contact



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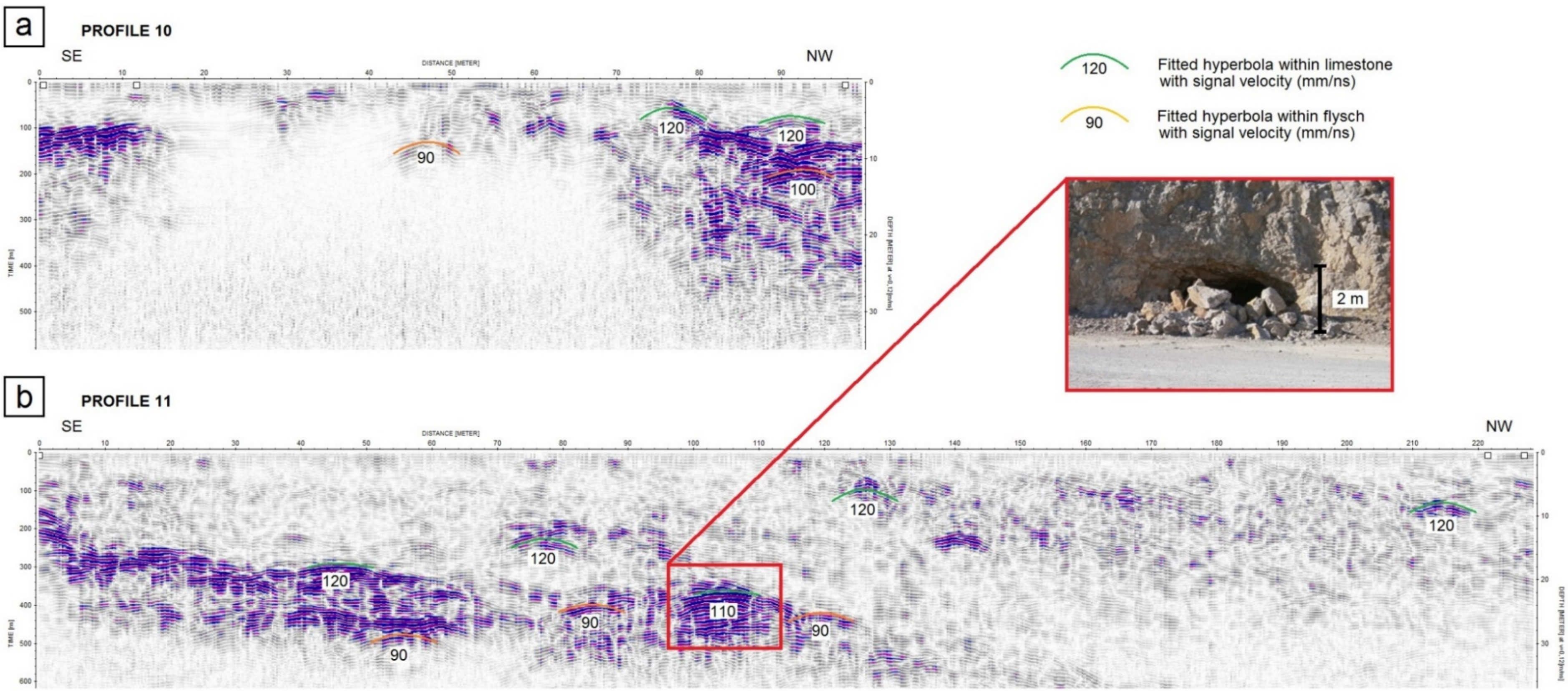
CS4: Investigation of limestone-flysch trust-fault contact

a: Note the filled cavities. b: Note the thrust, the cavity in bench wall, and bedding!



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CS4: Investigation of limestone-flysch trust-fault contact

a: filled cavities

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Case Study 5 (CS5): Investigating surface karst features

Krk island (Croatia)

Valley-like depressions and other sediment-filled irregular features on a karst surface, which are presumably not classical karst dolines, were noticed on the Krk island.

Their origin could not be interpreted by performing only geomorphological field observations and aerial images analysis. In particular, it was unclear which processes (surface and/or underground) prevailed during the formation of these features.

Therefore, it was decided to employ the GPR method to further study the various features and discover their interconnections.

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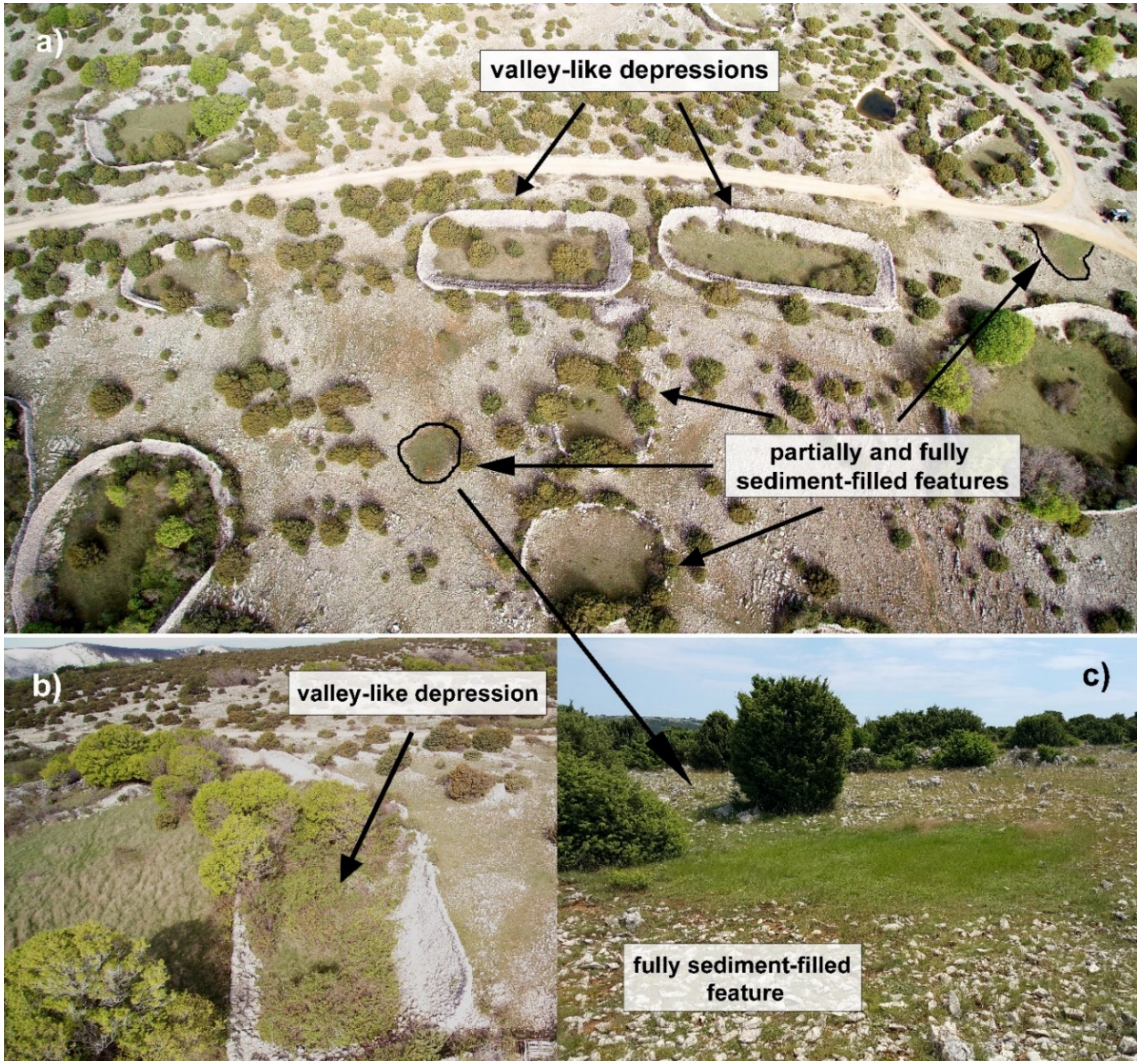
CS5: Investigating surface karst features



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CS5: Investigating surface karst features

To test the applicability of the GPR method to this kind of scenario, two different antennas were used: a 250 MHz shielded antenna and a 50 MHz unshielded rough terrain antenna.

The main conclusions of GPR investigations are:
1) the increased thickness of sediments was detected, within all the investi-gated features;
2) in the areas between different features, attenuated zones in the radargrams were noticed and thus the feature interconnections were revelead;
3) links between the surface and underground features were characterized by the transition zone in GPR data;
4) the underground continuous surface depression, detected by the GPR, proves the speleogenetic origin of the features.

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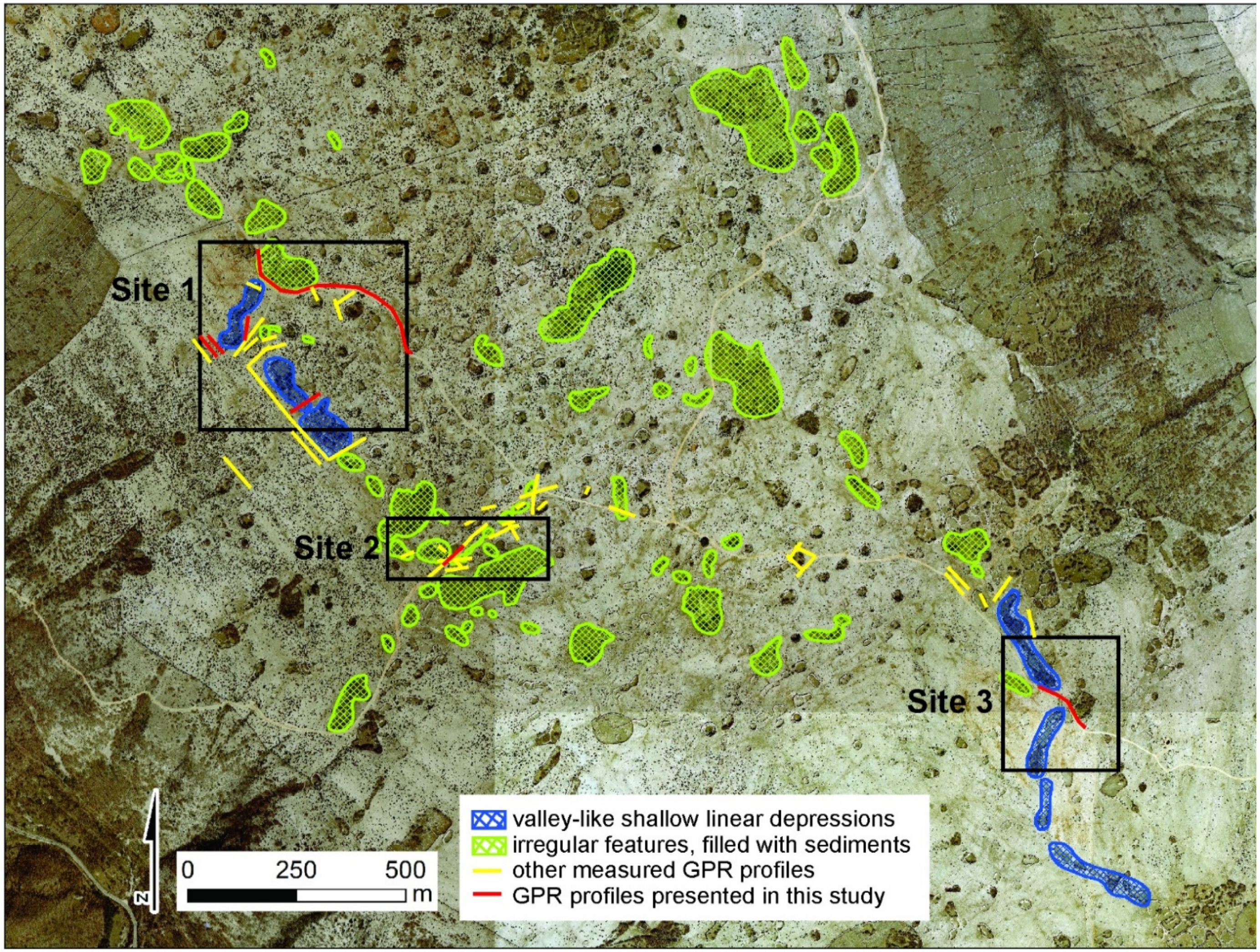
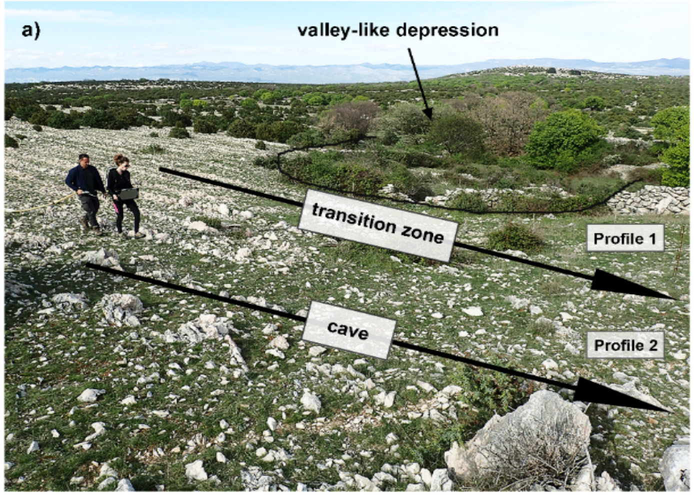
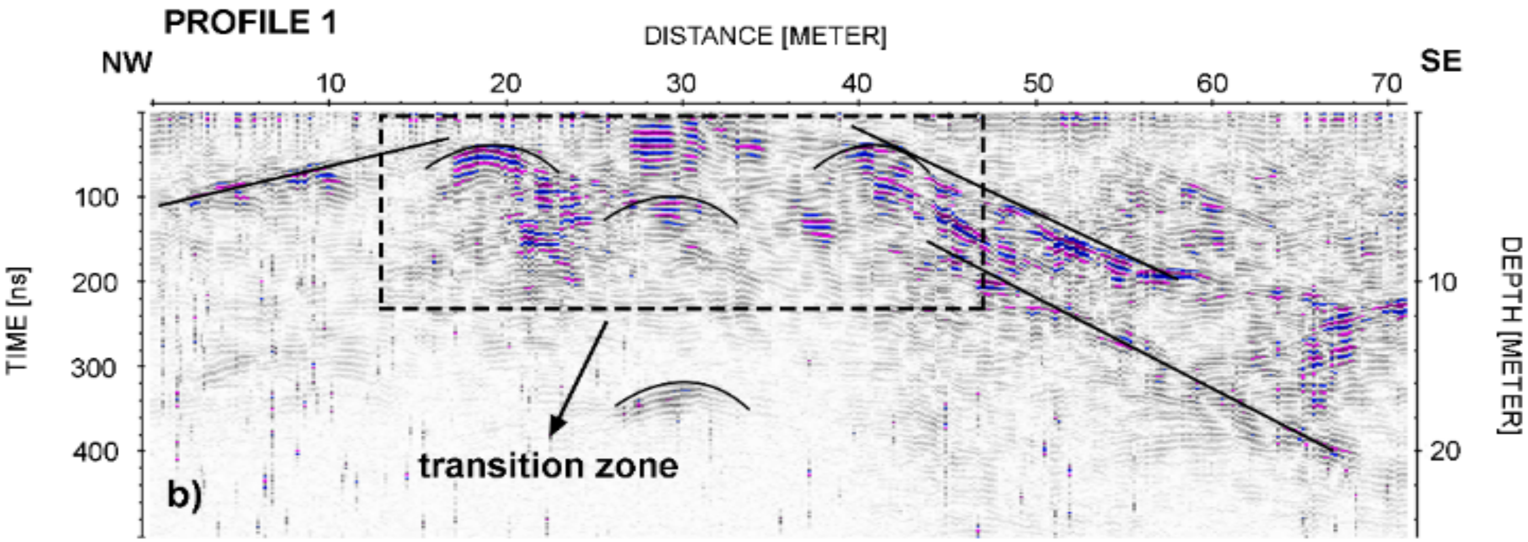
CS5: Investigating surface karst features



CS5: Investigating surface karst features





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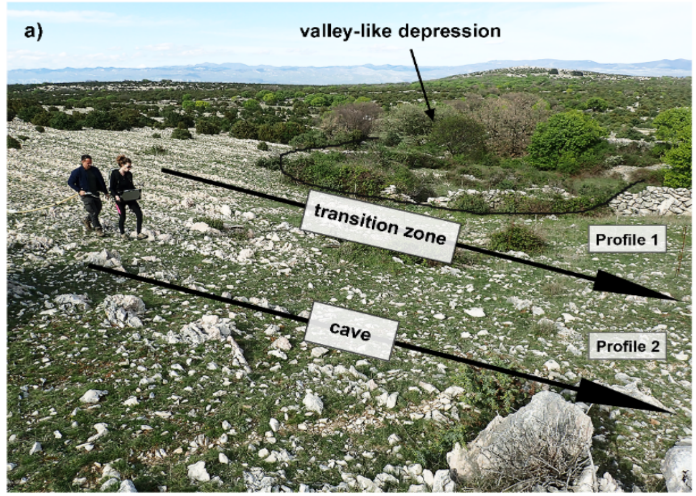
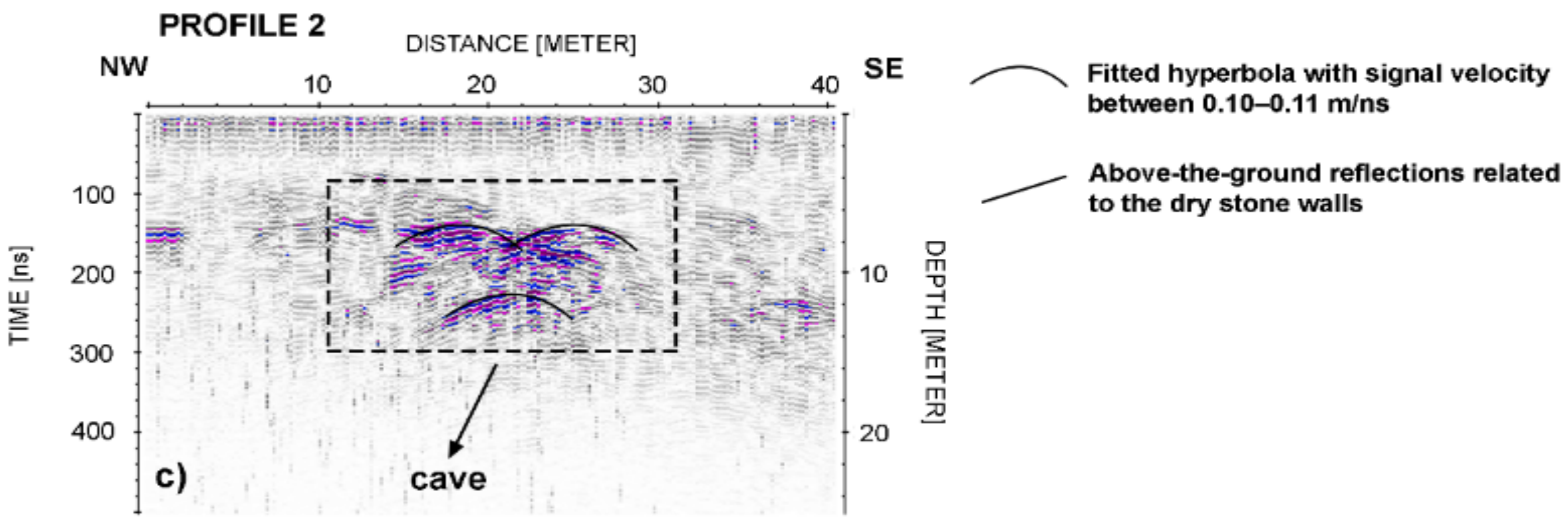
CS5: Investigating surface karst features





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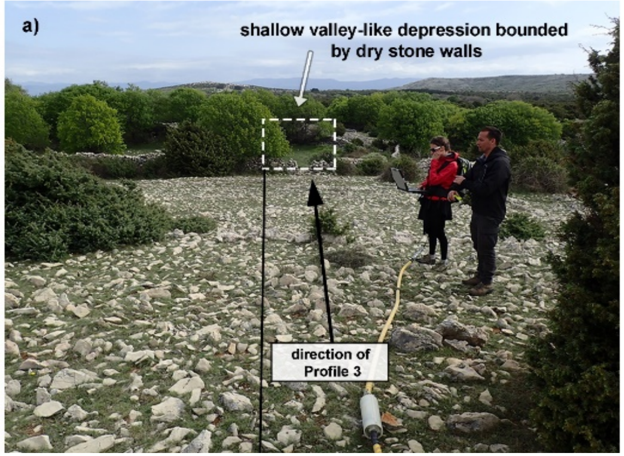
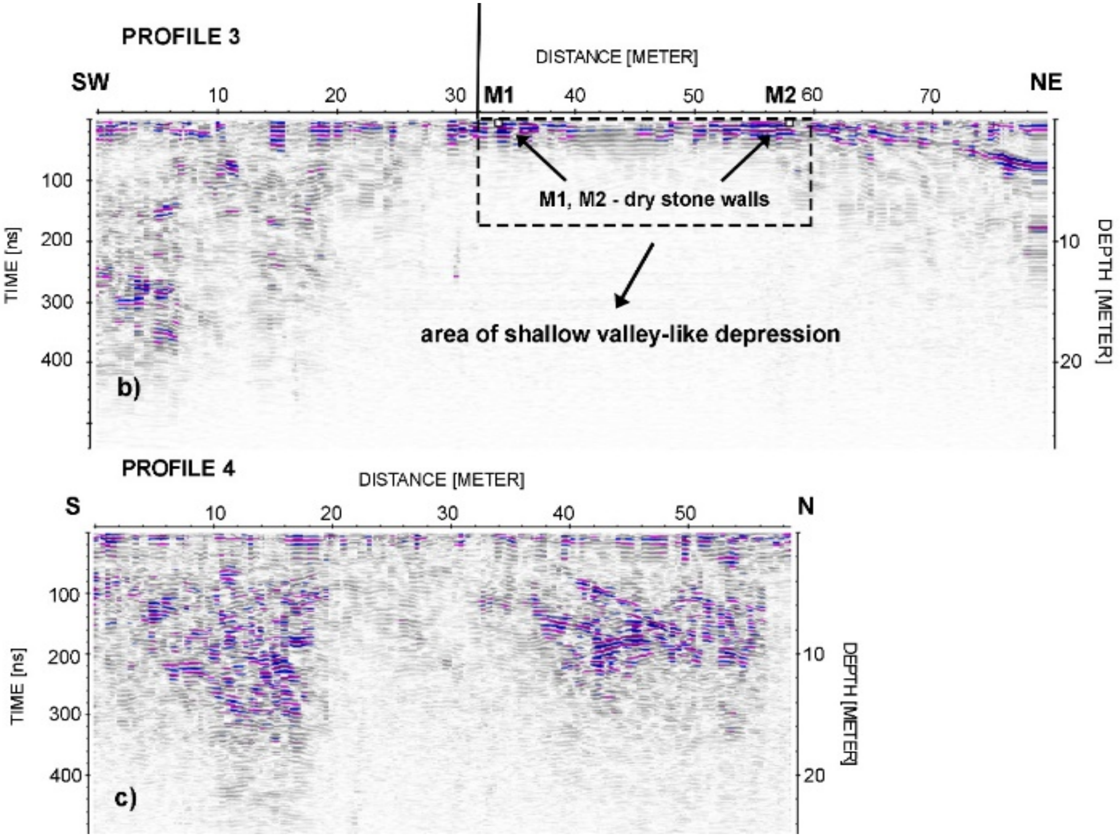
CS5: Investigating surface karst features





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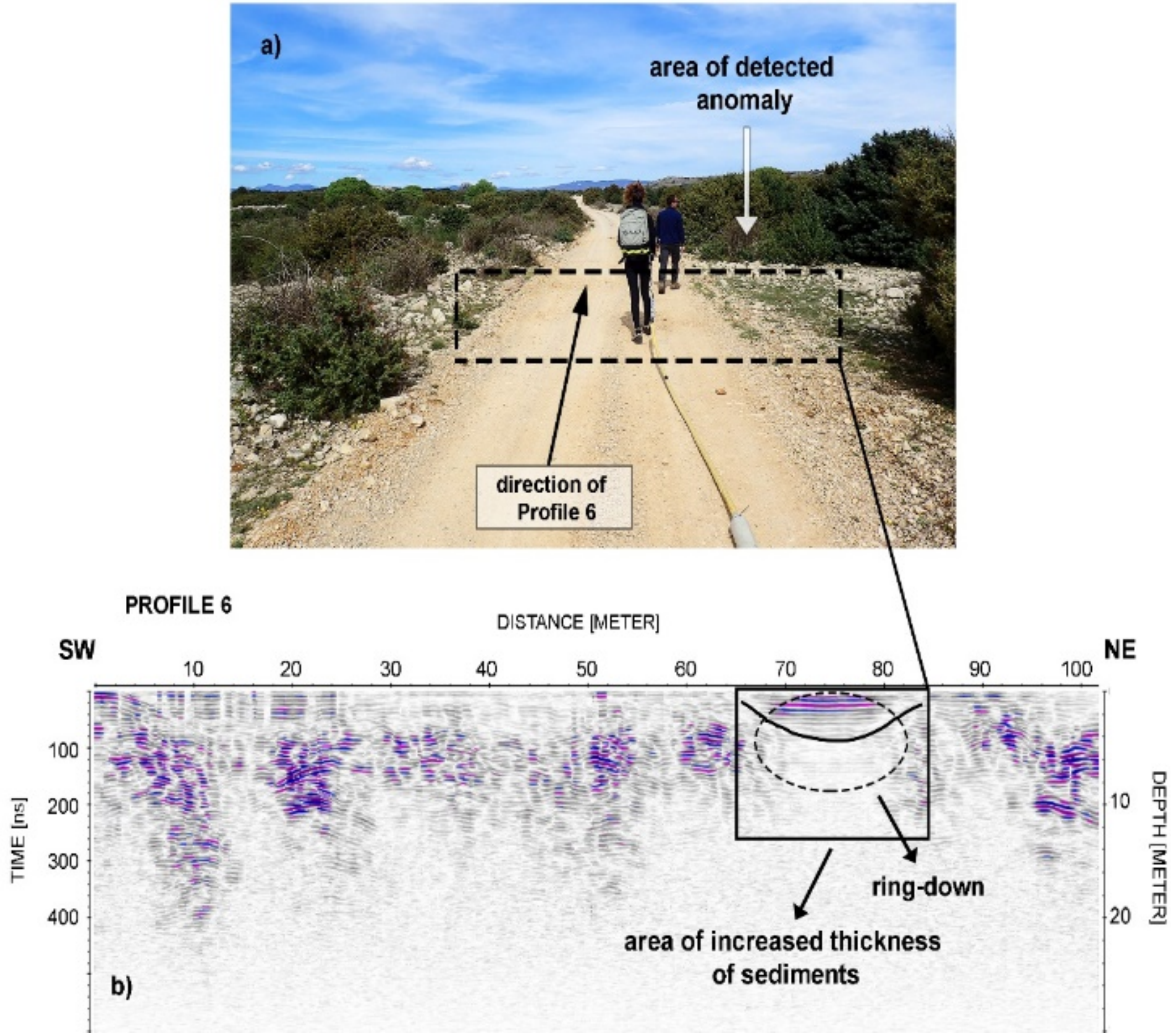
CS5: Investigating surface karst features



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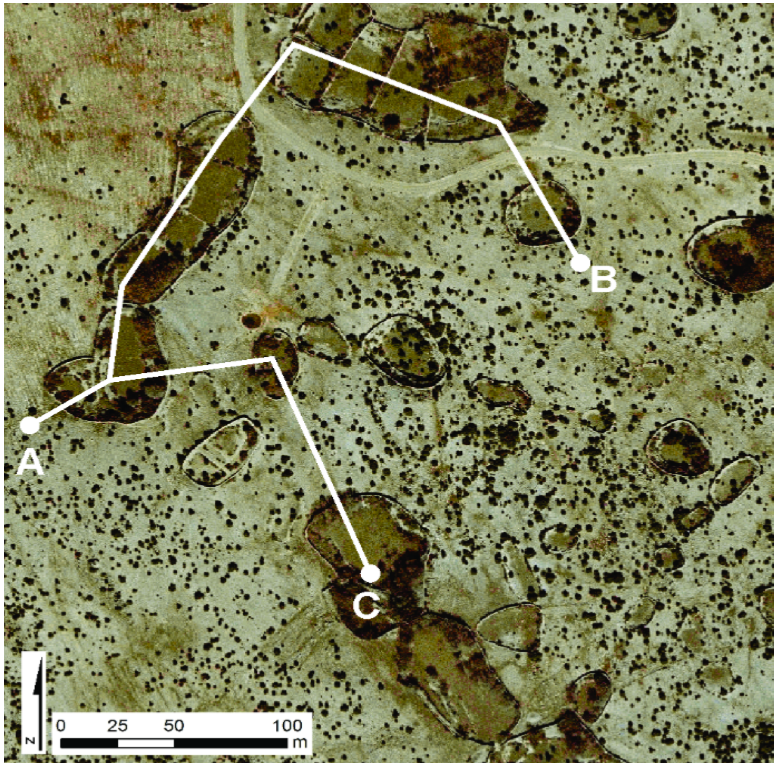
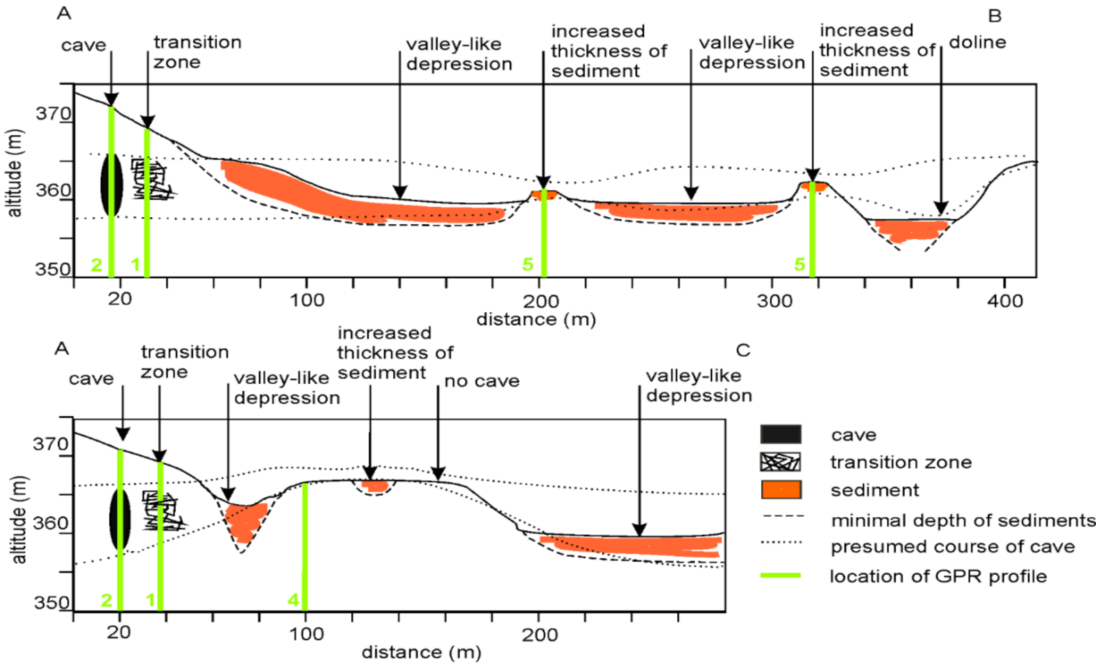
CS5: Investigating surface karst features

Results of our GPR study indicate that the investigated sediment-filled surface features, having different shape and size, belong to one former underground cave system ("unroofed cave"), which is now exposed on the surface as a result of denudation.





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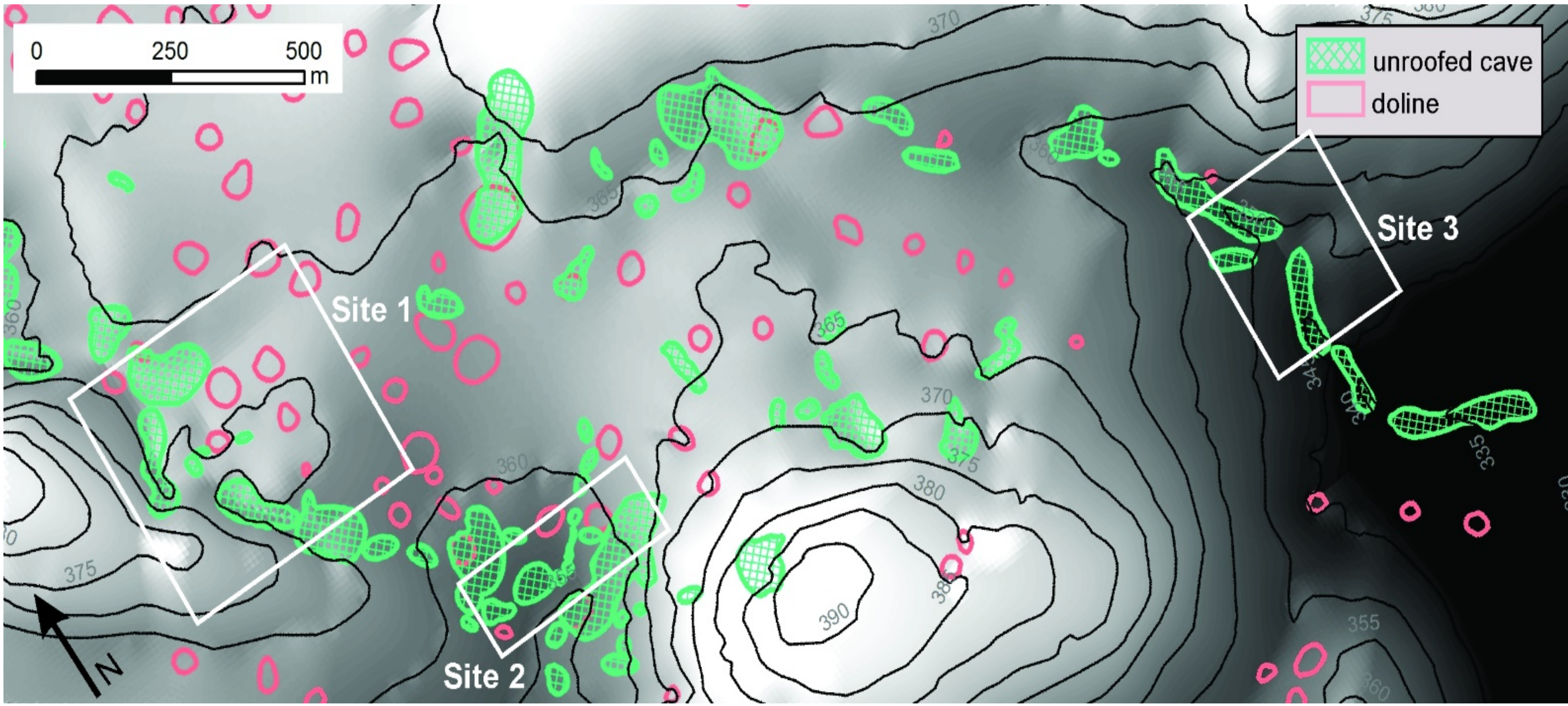
CS5: Investigating surface karst features

Most sediment-filled surface features belong to a large former underground cave system, which is now exposed on the surface as an "unroofed cave". Other features are classical karst dolines.



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References

[1] Gosar, A. 2012: Analysis of the capabilities of low frequency ground penetrating radar for cavities detection in rough terrain conditions : the case of Divača cave, Slovenia. Acta Carsologica, 41/1, 77-88.

Research paper on analysis of the capabilities of 50 MHz RTA system for cavity detection. An unknown cave gallery was discovered.

[2] Gosar, A., Čeru T. 2016: Search for an artificially buried karst cave entrance using Ground Penetrating Radar: a successful case of locating the S-19 cave in the Mt. Kanin massif (NW Slovenia). International Journal of Speleology, 45/2, 135-147.

Research paper on the use of low-frequency GPR to locate the entrance of a deep cave buried under a big avalanche protection dyke, in very rough terrain conditions. Excavation confirmed GPR-determined location and depth.

References

[3] Zajc, M., Pogačnik, Ž., Gosar, A. 2014: Ground penetrating radar and structural geological mapping investigation of karst and tectonic features in flyschoid rocks as geological hazard for exploitation. International journal of rock mechanics and mining sciences, Vol. 67, 78-87.

Research paper on the detection of cavities and discontinuities that can represent geotechnical hazard for exploitation in an open pit mine. GPR was successful in locating several karst cavities and sliding surfaces.

[4] Zajc, M., Celarc, B., Gosar, A. 2015: Structural geological and karst features investigations of the limestone – flysch thrust-fault contact using low frequency ground penetrating radar (Adria – Dinarides thrust zone, SW Slovenia). Environmental Earth Sciences, vol. 73, 1-13.

Research paper on 3D mapping of an important thrust-fault contact using low-frequency GPR. In addition several karst cavities were discovered.

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[5] Čeru, T., Gosar, A., Šegina, E. 2017: Application of ground penetrating radar for investigating sediment-filled surface karst features (Krk Island, Croatia). IWAGPR Proceedings, 1-6, Edinburgh.

Conference paper on GPR study of sediment-filled valley-like surface karst features. They were interpreted as a former underground cave system.

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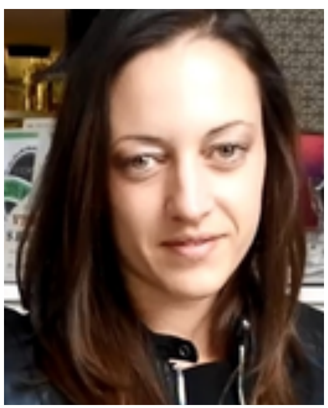

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Thank you

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