Fondazione Museo Civico Rovereto
6-7 dicembre 2018
Geologia e Geofisica
applicate ai beni culturali

# Rilievi georadar e sismici nel sito archeologico della Prima Guerra Mondiale di Punta Linke (3629 m slm, Gruppo Ortles-Cevedale, Comune di Pejo, Trento).

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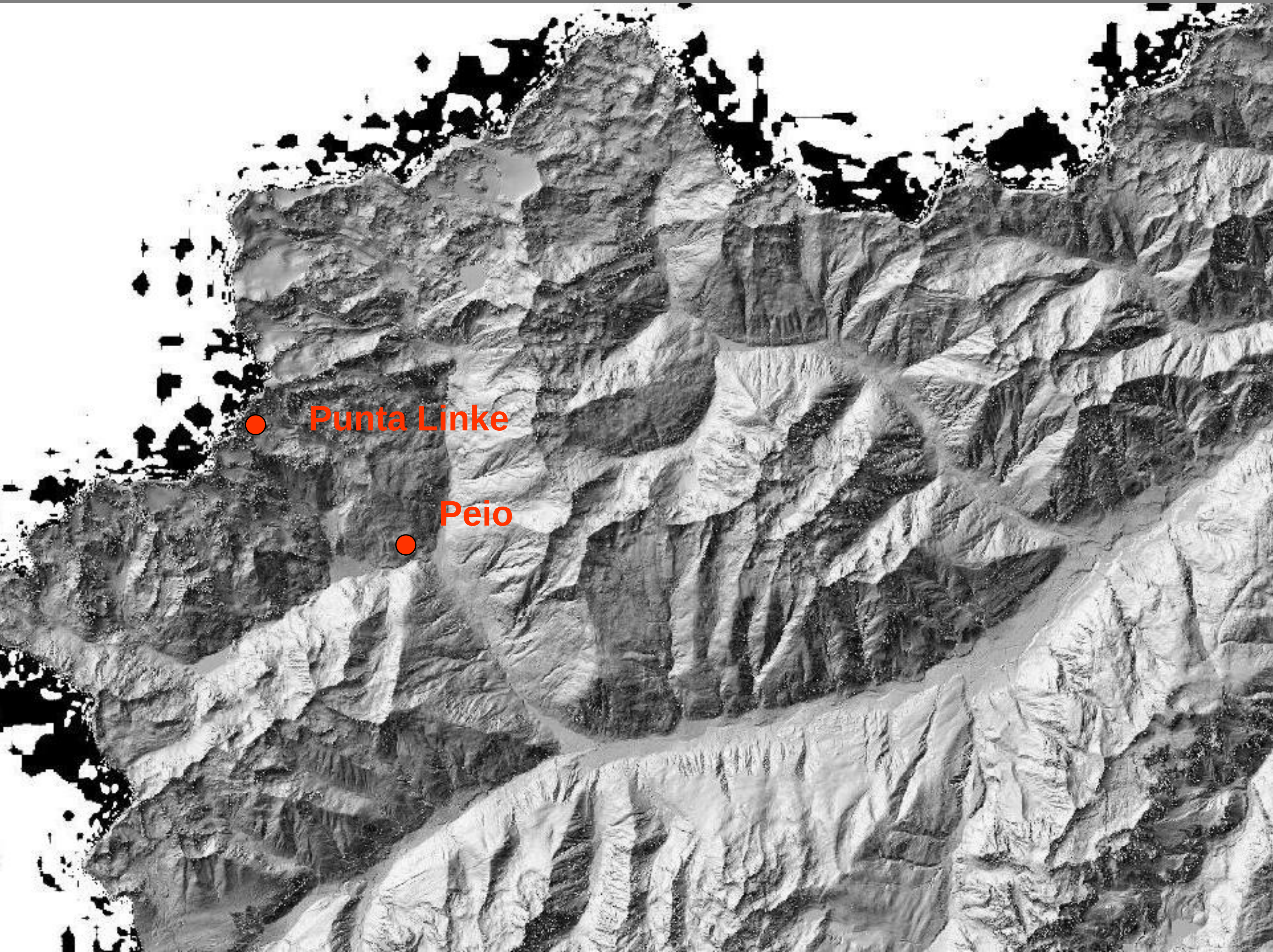

Punta Linke
Peio


Monte Vioz (3644 m asl)


Punta Linke (3632 m asl)


0 5 cm10

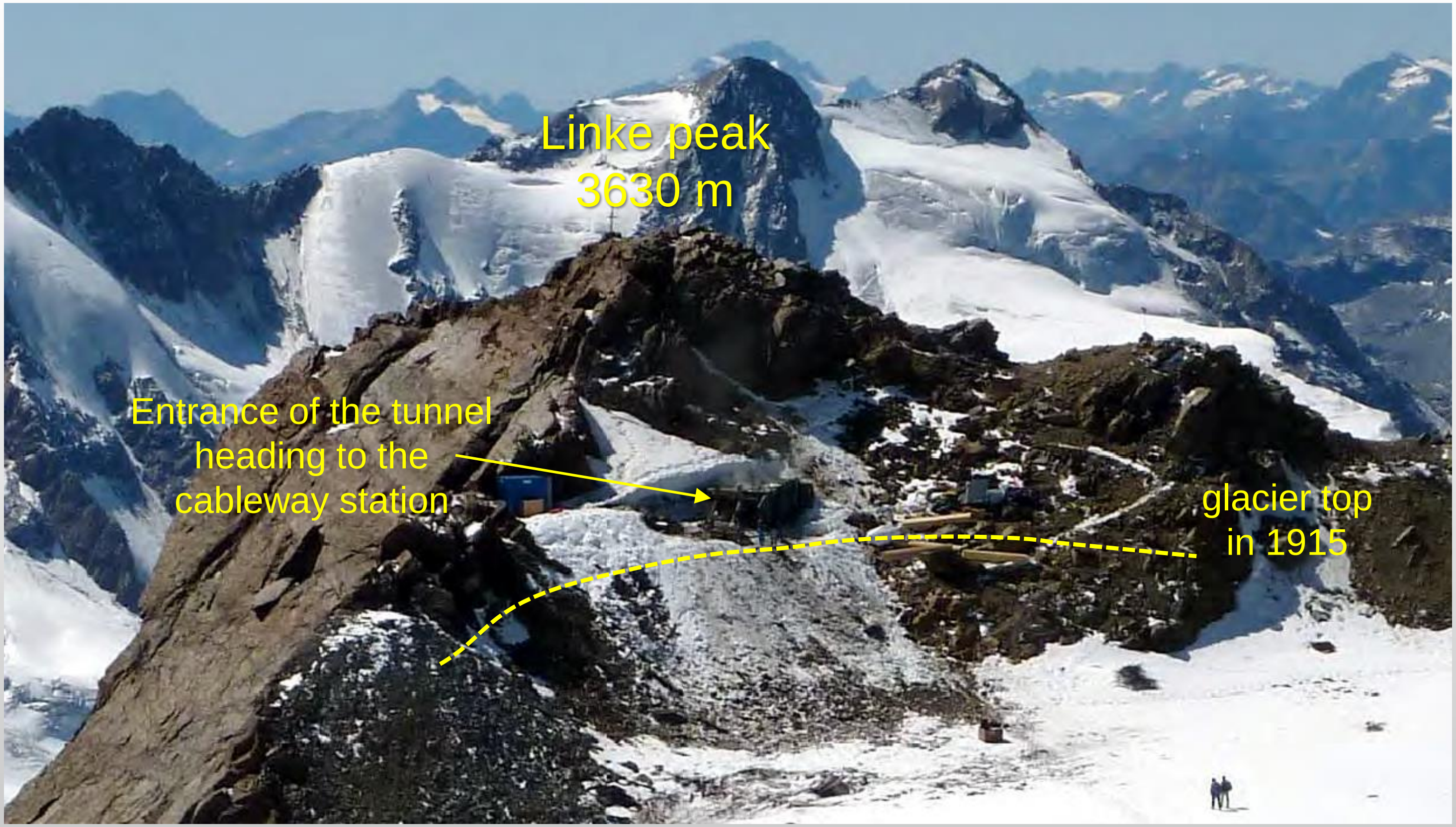

TN PUNTA
32


NUMS
ZIGARETTEN-HÜLSEN
ANTINIKOTIN
2/75


TN LINKE '12
GALLERIA
OVEST

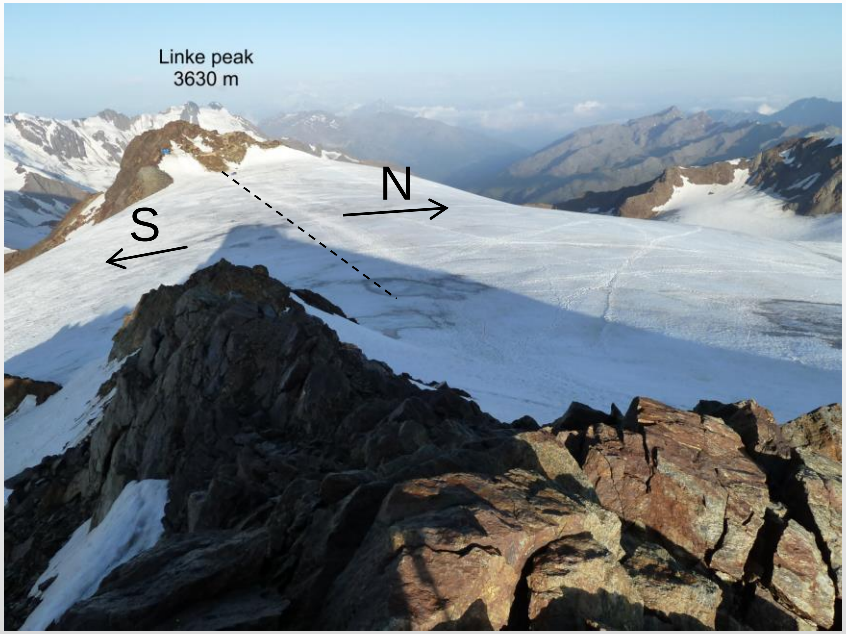

TN 2011
PUNTA LINKE
GALLERIA
RR224

# Introduction and motivations

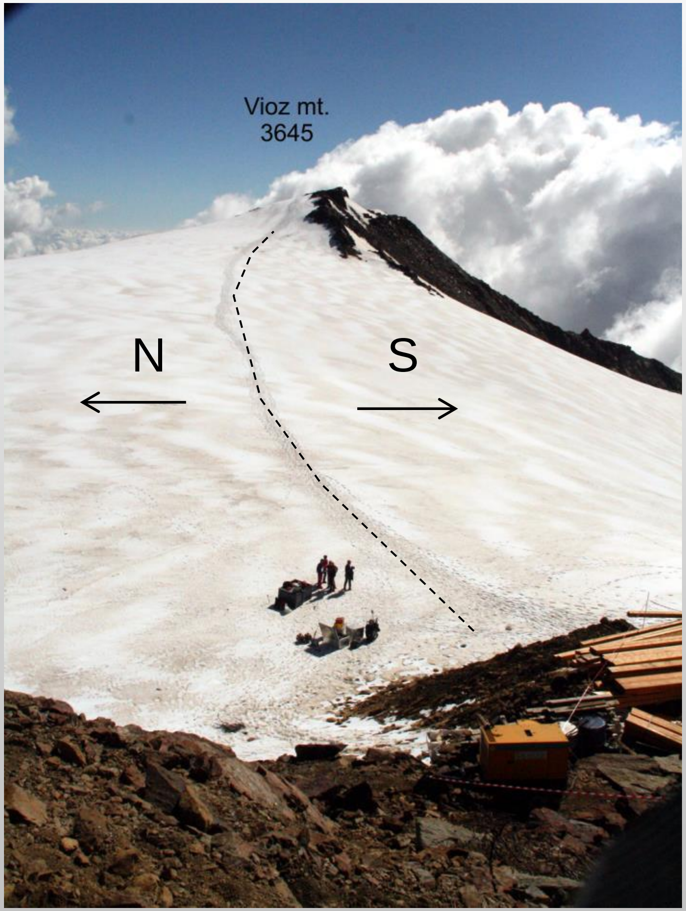



Geophysical investigation was part of this project. GPR and seismic surveying were carried out in the saddle between Mt. Vioz (3645 m) and the Linke peak (3630 m). The objective was two fold: provide glaciological information and map buried remains (if any).

# General settings (site morphology)



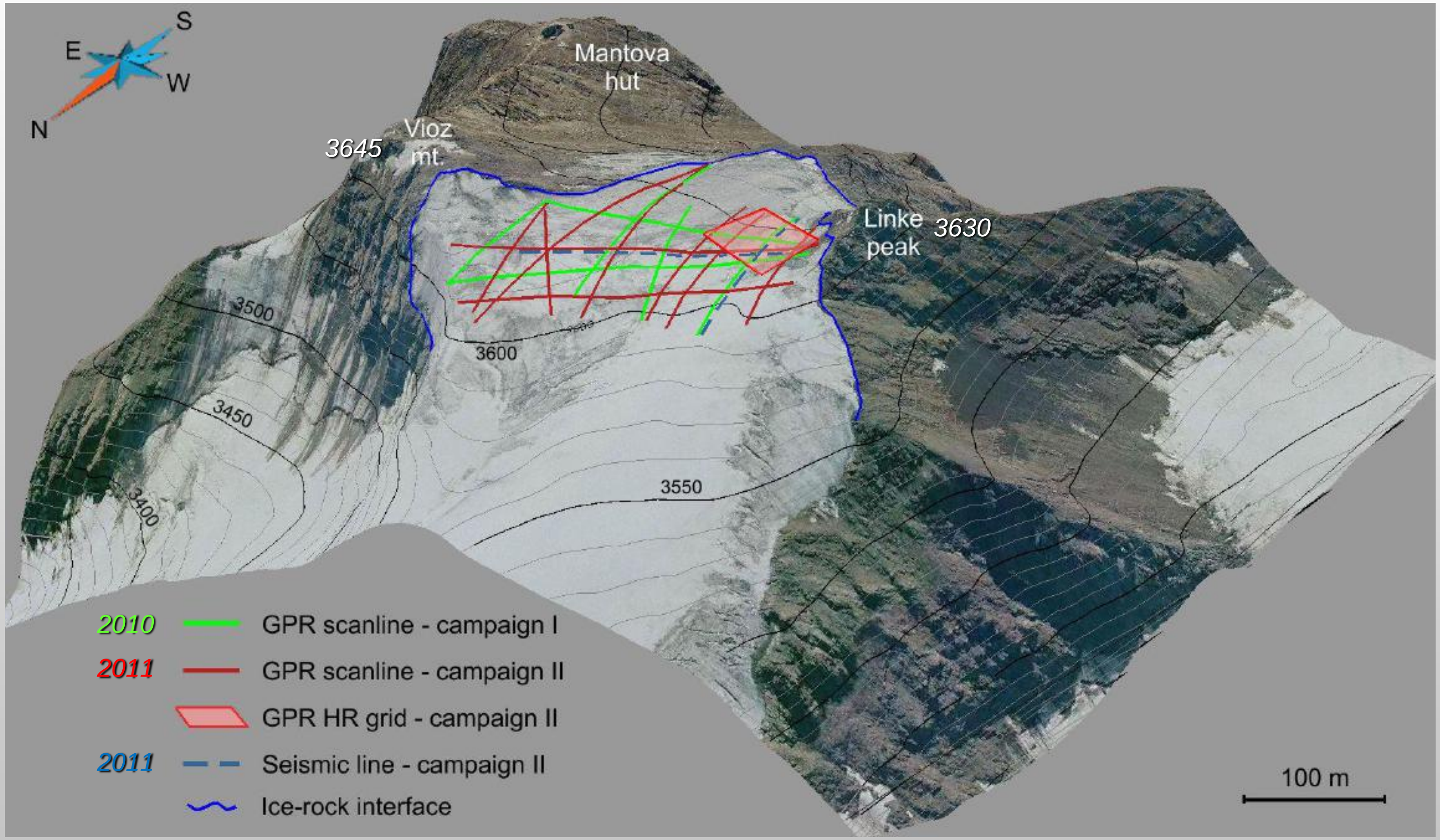

The elevation of the top of the Linke-Vioz saddle is 3605 m a.s.l.




The saddle is gently dipping Northwards and Southwards for about 120 m and 50 m respectively.

# Data acquisition and processing

The survey was split in two campaigns conducted during the late summer of the years 2010 and 2011.




The 2011 campaign targeted some anomalies from the 2010 survey.

# Data acquisition and processing (survey parameters)

2010 campaign:

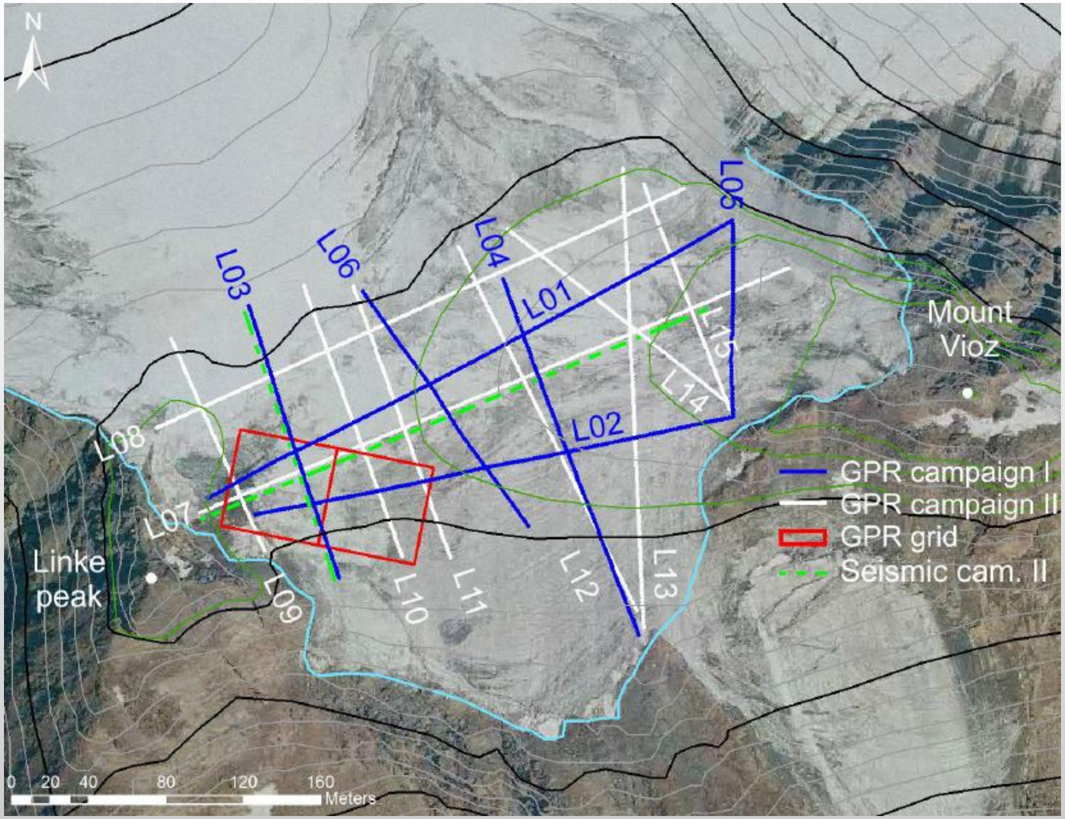
7 GPR profiles, ~ 1200 m,
- 75 MHz antenna,
- 200 MHz antenna;

2011 campaign:

9 GPR profiles, ~ 1800 m
- 75 MHz antenna;

GPR grid, 51m x 102m
53 L&T profiles, 3m spacing
- 200 MHz antenna;

2 Seismic profiles, ~ 500 m
24 channels seismograph,
4.5 Hz geophones,
Isotta gun.




Geo-referencing of the different spreads was achieved surveying several reference points by means of a geodetic GPS in differential configuration. The elevation was computed surveying a benchmark point located in the vicinity of the Mount Vioz summit.

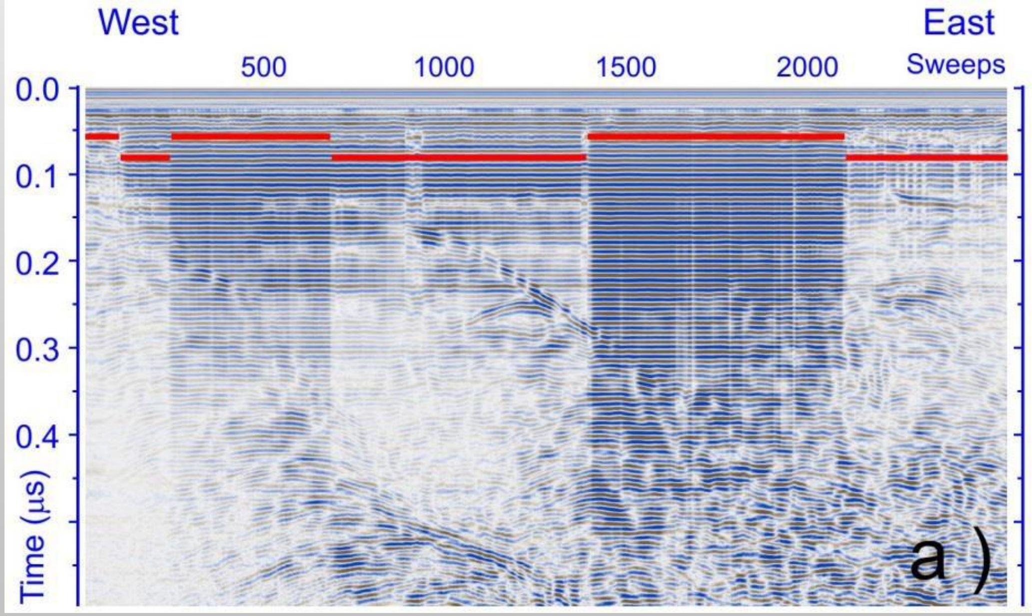
# Data acquisition and processing (processing)

GPR and Seismic processing was performed entirely in the open-source environment of the Seismic Unix package.

GPR data processing was somewhat complicated because of the random nature of the ringing occurring in the 75 MHz dataset. This was probably due to sudden changes in the coupling (presence of melting water).

The base processing flow included zero time correction, frequency filtering and background removal.

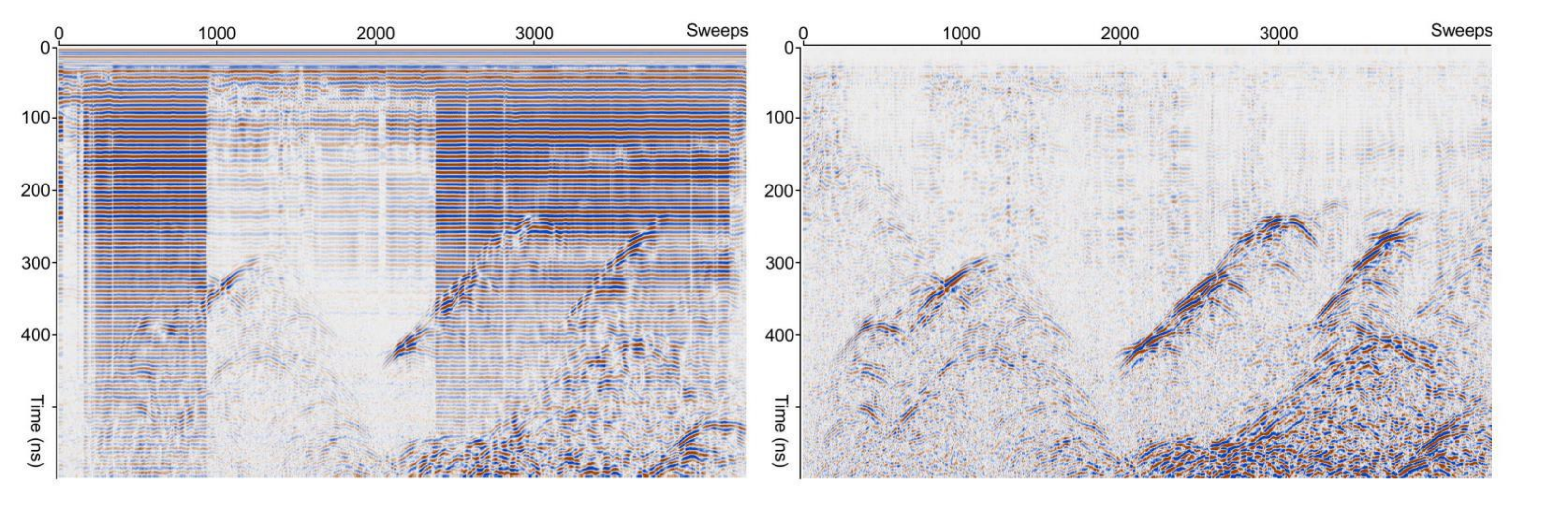
The common running average filter, often used to attenuate the ringing, was effective only using narrow trace window causing the low-angle reflectors to be also attenuated.



# Data acquisition and processing (processing)

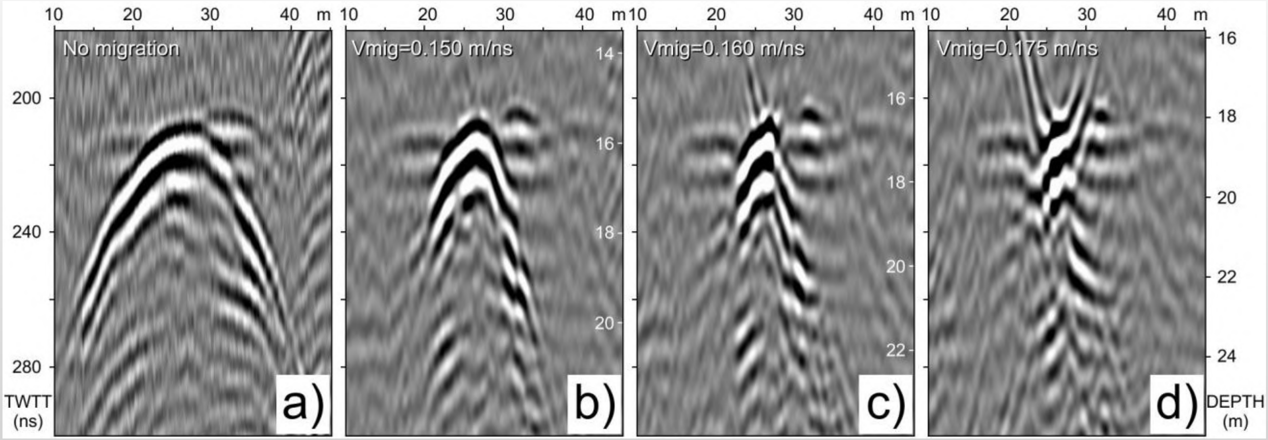
A specific routine was then coded and used to attenuated this variable ringing.

The routine was capable of extracting segments of the profile with an homogeneous ringing, computing and removing the mean trace and then recombine the data



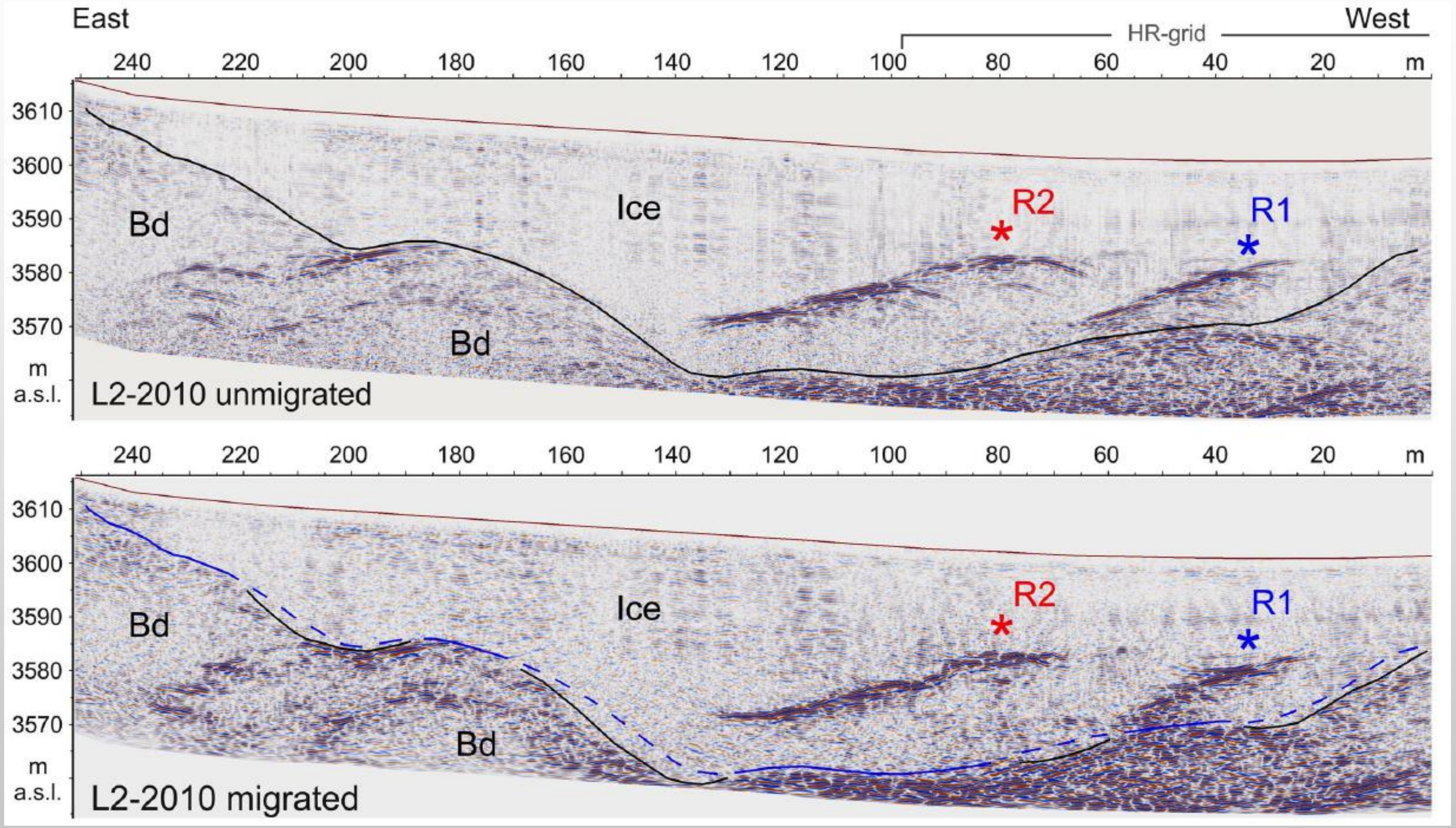

Some additional referencing modules were finally coded to correct for the topography and convert the data from time to depth domain. The radar wave velocity in ice was estimated analyzing the curvature of some diffraction hyperbolas. EM wave velocity ranges in the interval 15.5-16.5 cm/ns.

## Velocity analysis and migration



# Data acquisition and processing (processing)





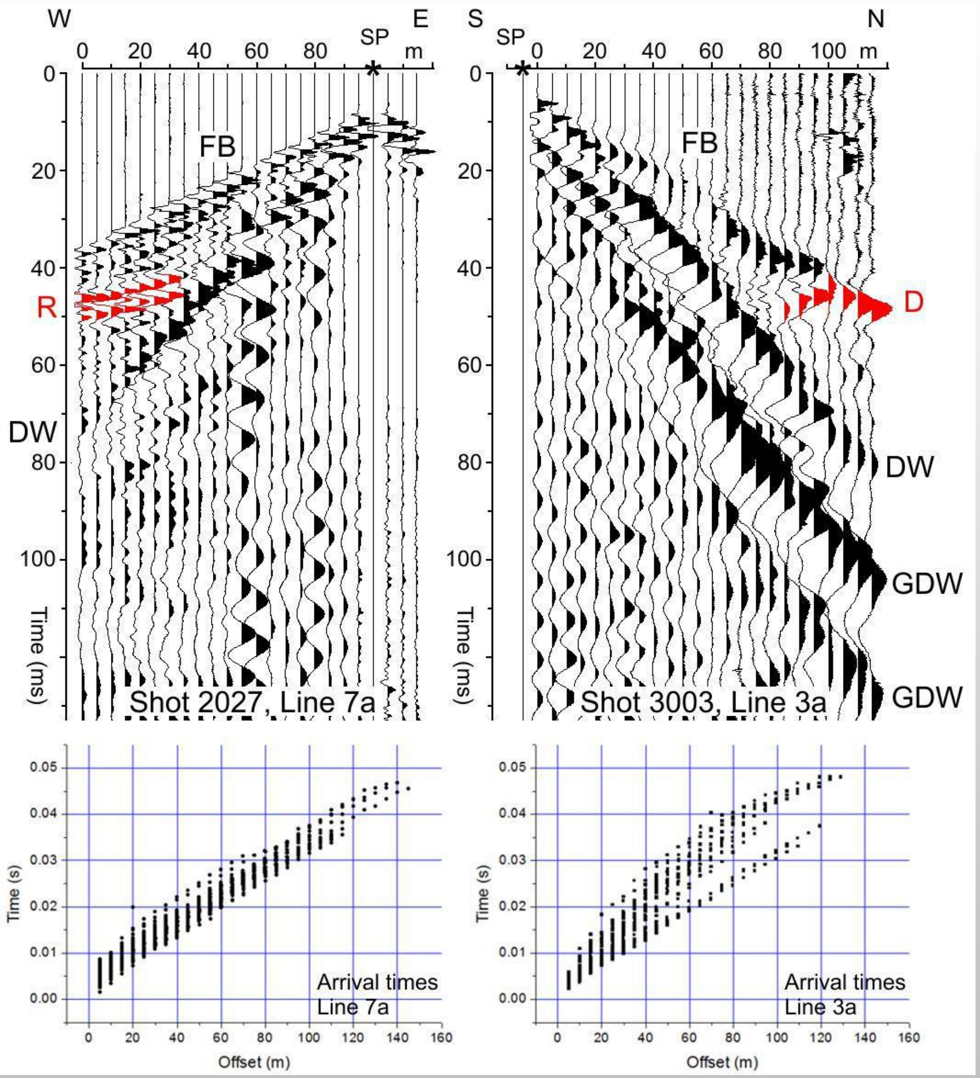

maxE ≅ 5%Z

# Data acquisition and processing (processing)

Seismic processing was mostly focused on mapping the P-wave velocity in the uppermost snow-firn layer.

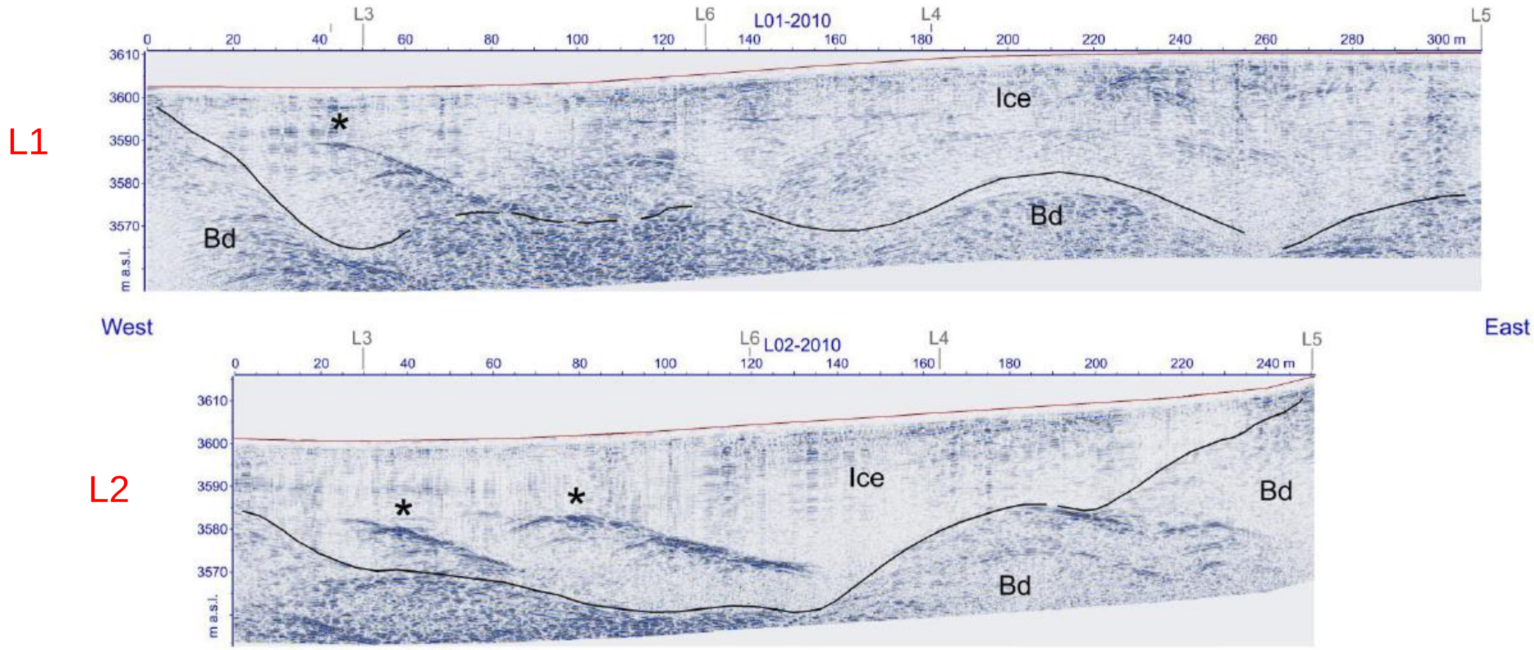
Data were overwhelmed by powerful source-generated noise.

The flow chart was straightforward and included geometry assignment, frequency filtering and 2D dip filtering to remove linear noisy events from the records.



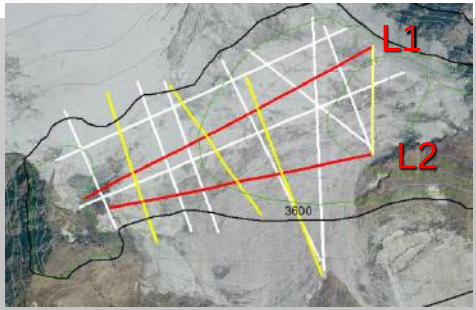
# Results and discussion

TRANSVERSAL PROFILES L1 & L2 (2010) – 75 MHz antenna




The radar wave propagated down to a depth greater than 50 m from the glacier surface and several reflecting horizons, with distinct signatures, have been outlined in this interval. The signal partially penetrated also in the underlying sediments and into the granite bedrock. The bedrock geometry is clearly undulated with a prominent mound.

Some anomalous reflections (*) are also visible (will be discussed later).

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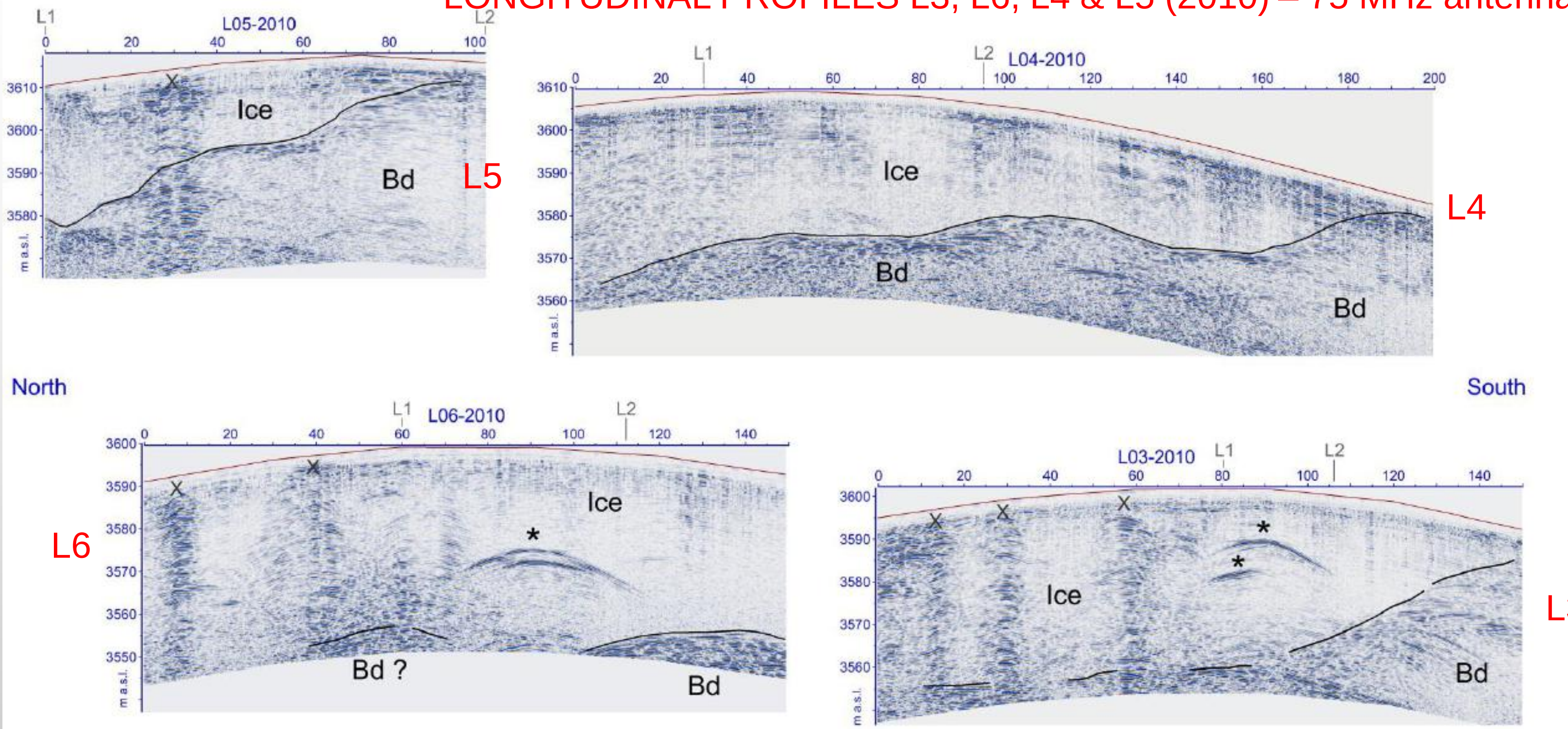
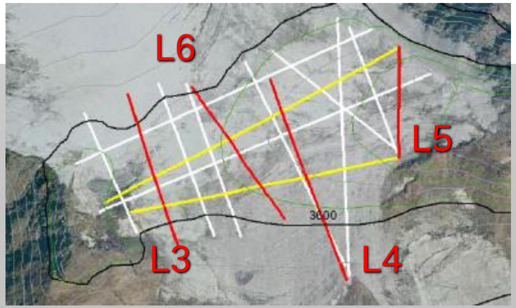
# Results and discussion

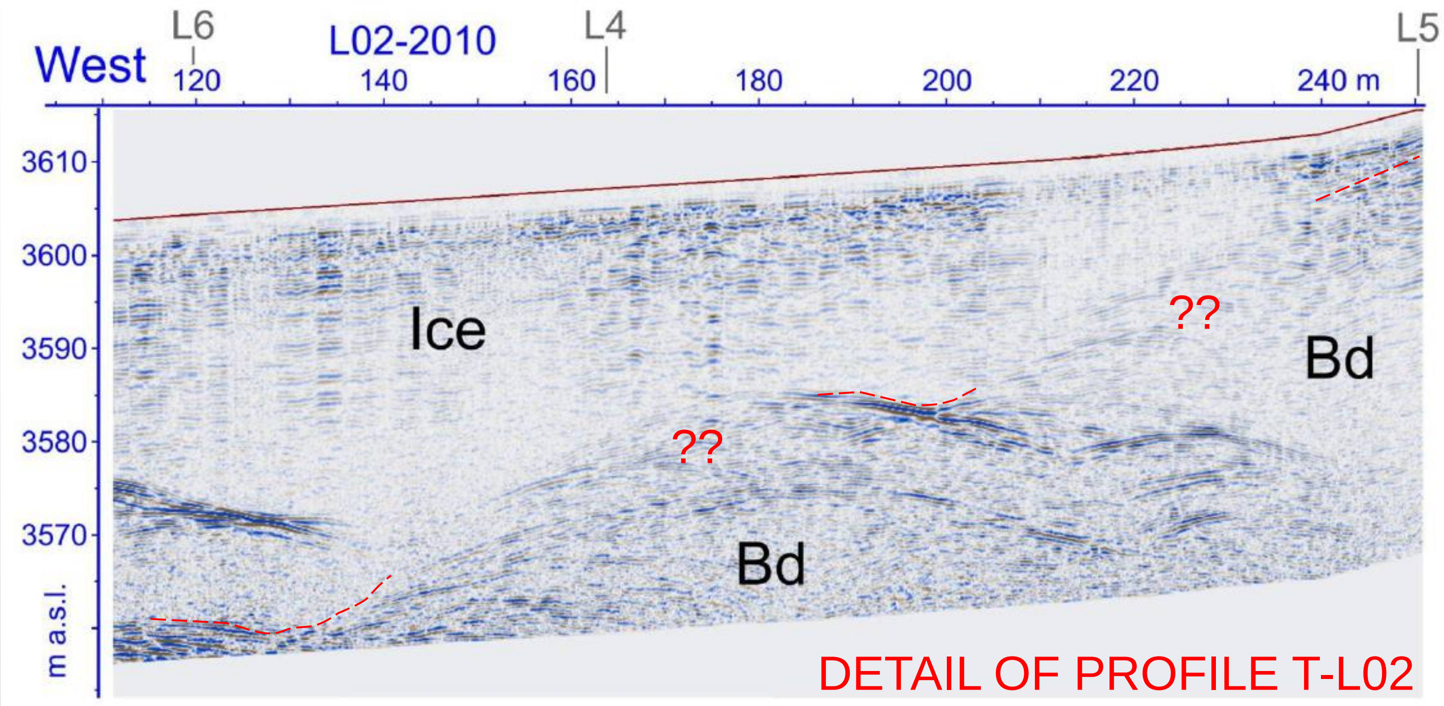
LONGITUDINAL PROFILES L3, L6, L4 & L5 (2010) – 75 MHz antenna




In the longitudinal profiles the bedrock sinks Northwards with less prominent undulations. The reflectivity of the interface in the L profiles is slightly higher compared to the T scans. This is somewhat caused by the different polarization of the radar antenna.



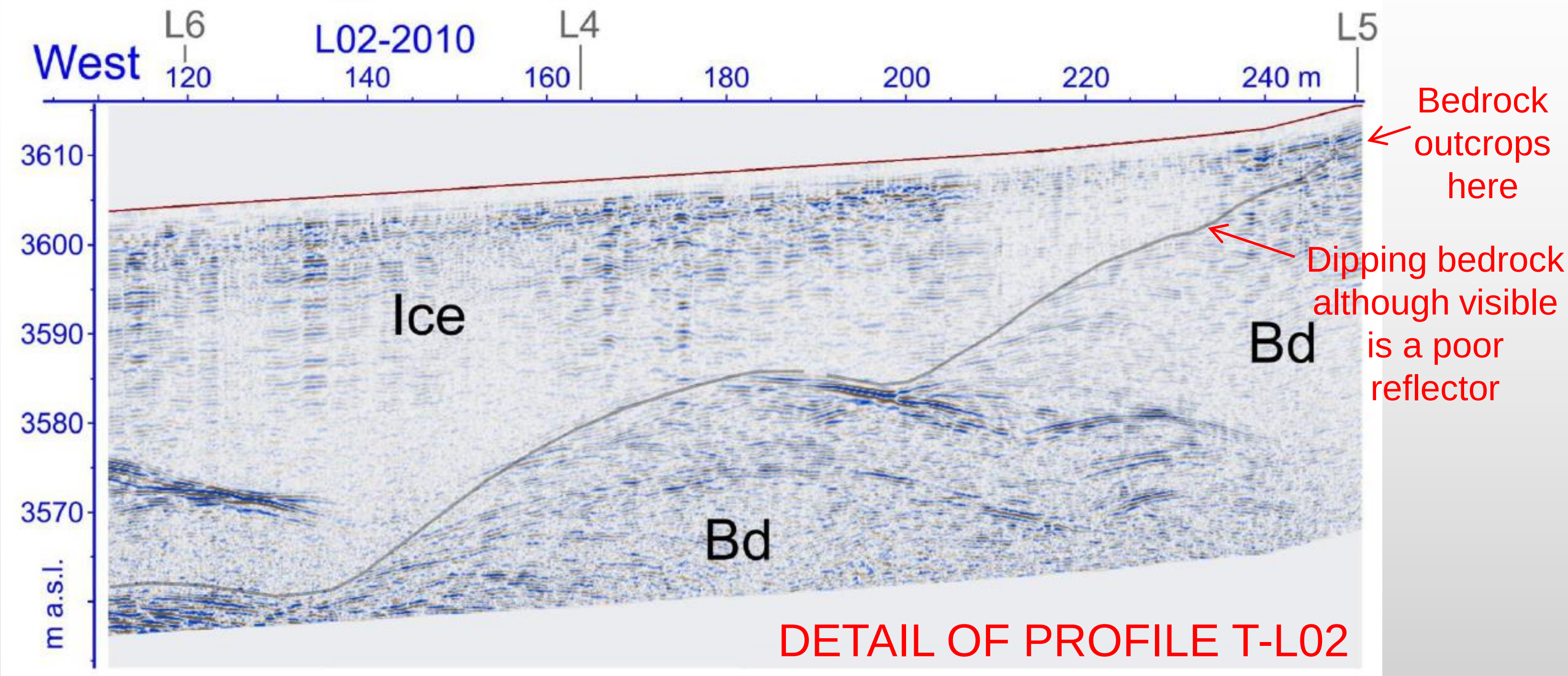
# Results and discussion






The bedrock signature in the T scans is less clear than expected and the reflected amplitude appears to be strongly dependent on the dip of this interface and probably also on the relative abundance of water and sediments above the bedrock (Carturan et al., 2013).

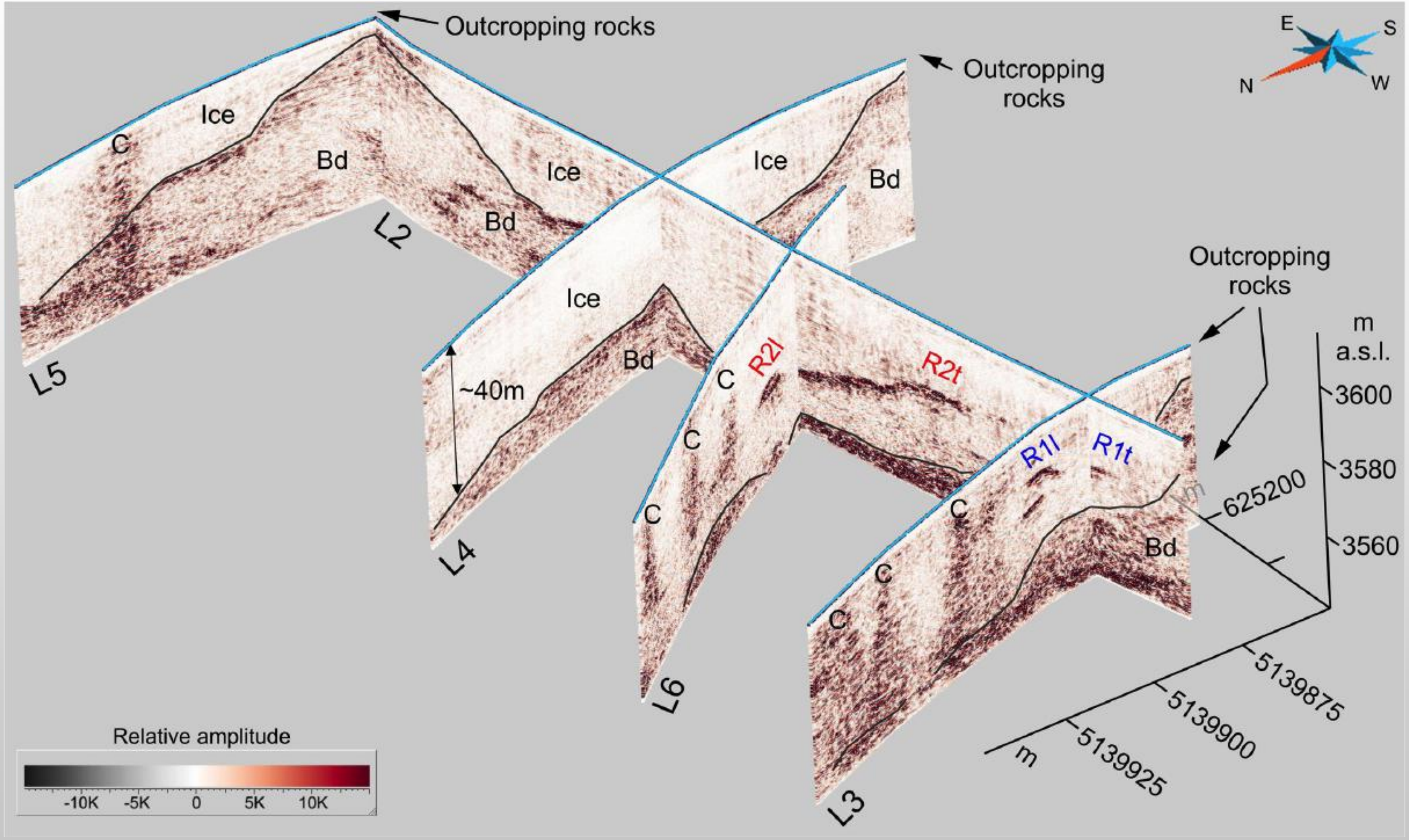
# Results and discussion





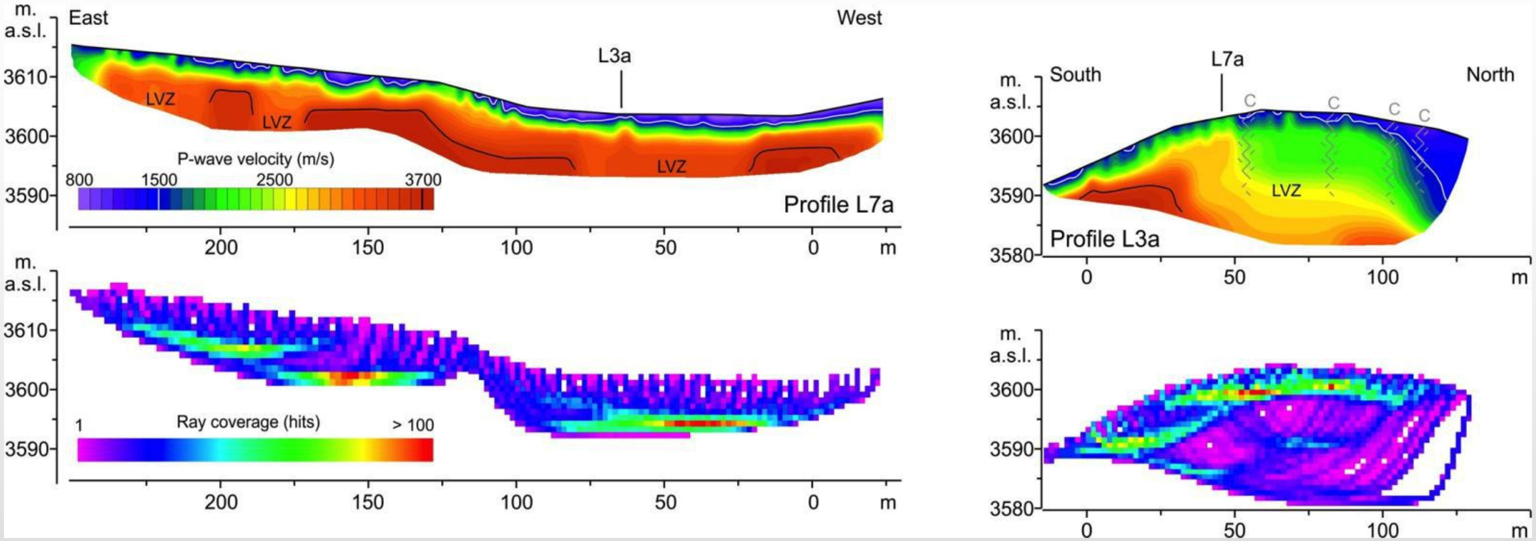

The bedrock signature was then recognized using all the available surface constraints (bedrock outcrops) and jointly interpreting the various profiles.

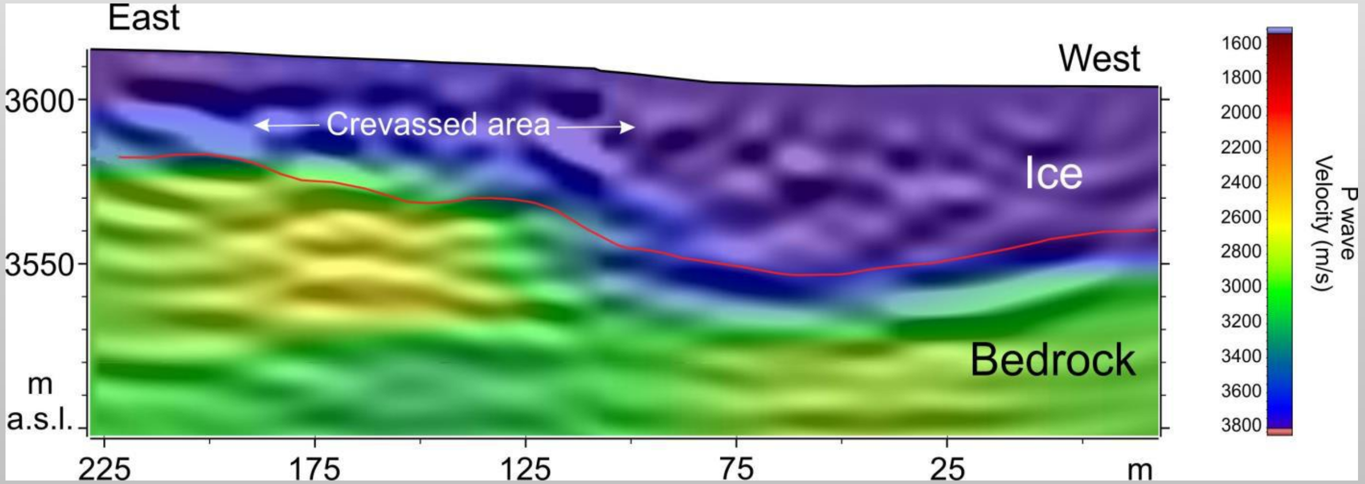
# Results and discussion



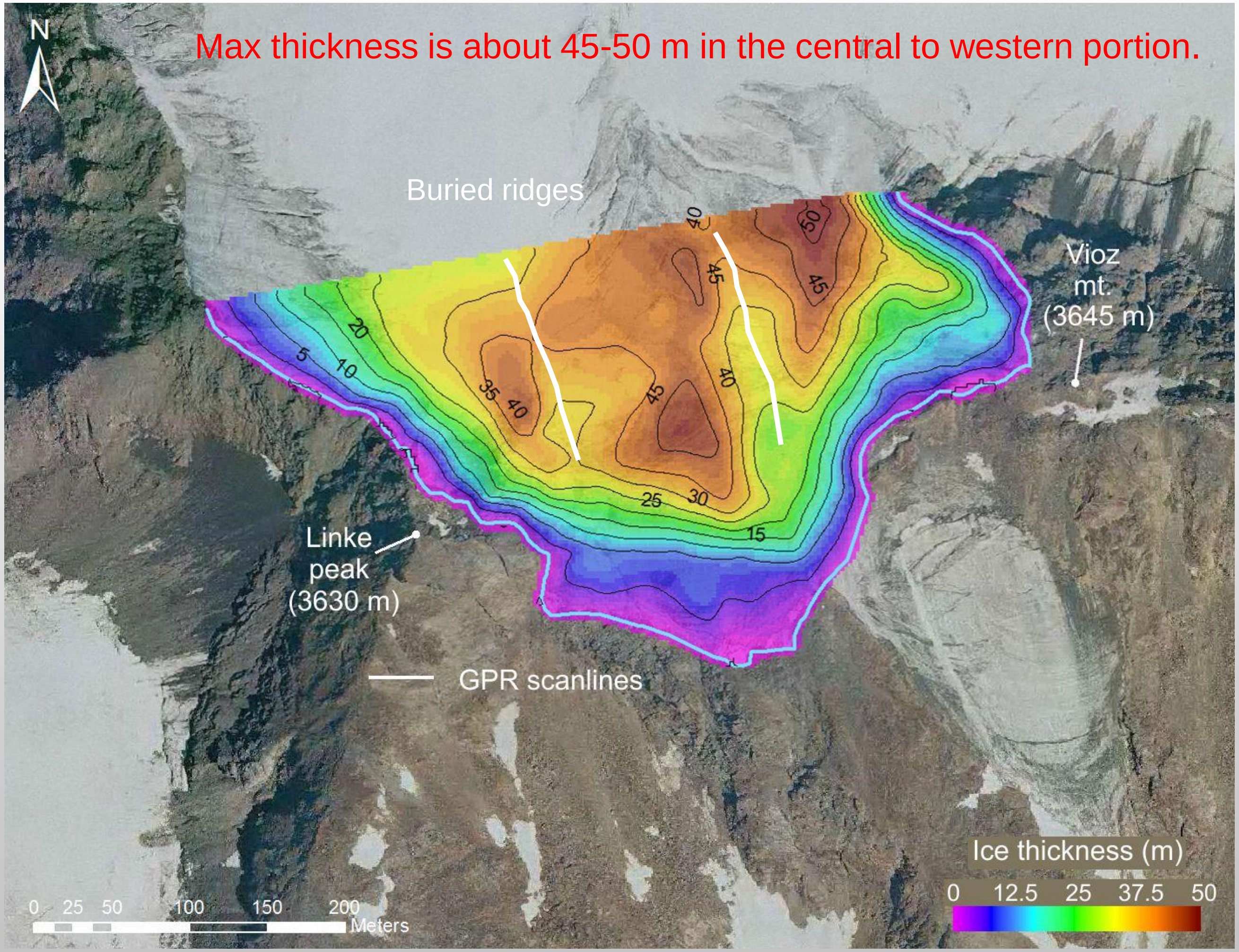

Correlation of the bedrock signature across the different profiles

# Results and discussion



# Results and discussion

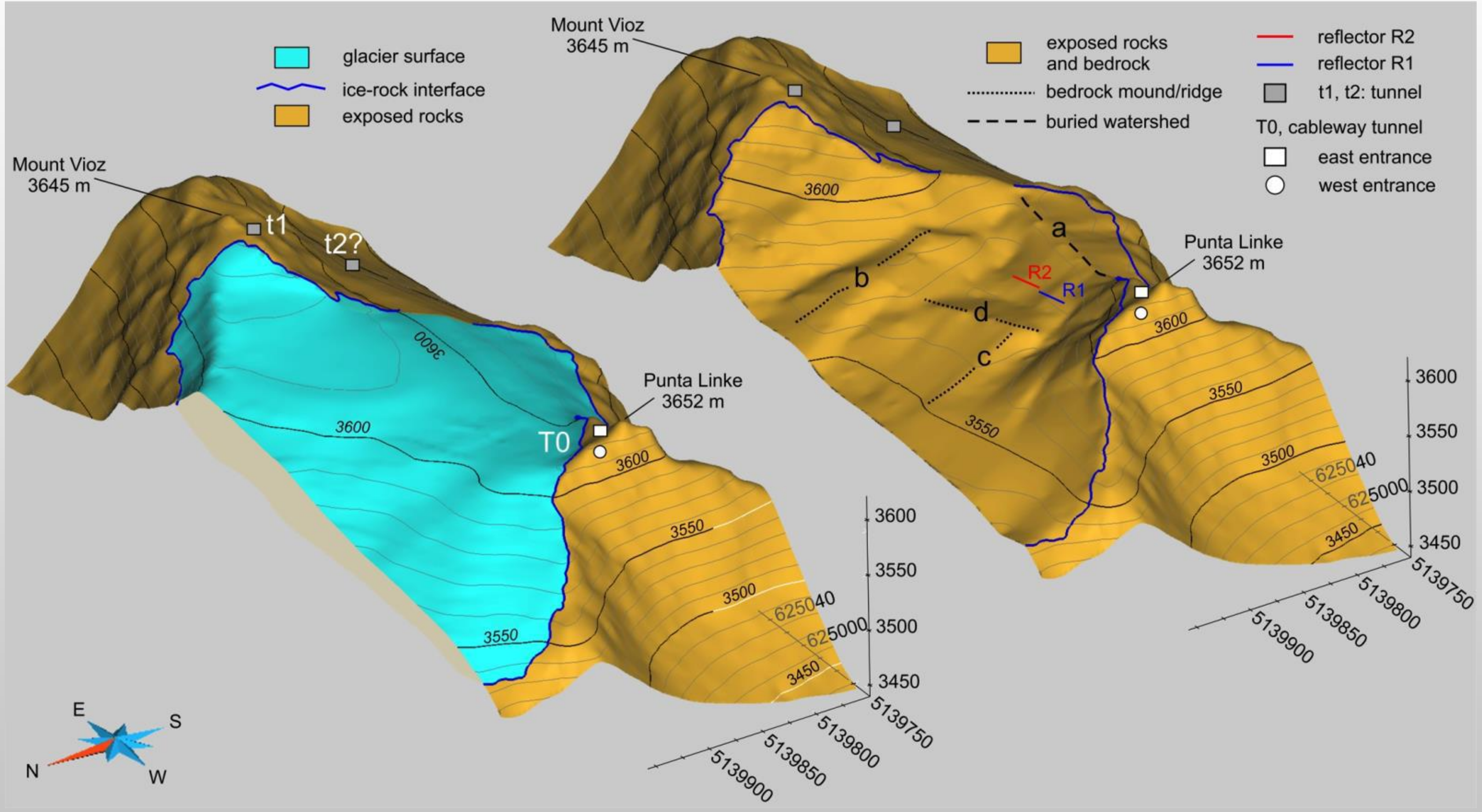



The density of radar profiles allowed for a tri-dimensional reconstruction of the glacier body over the entire saddle.

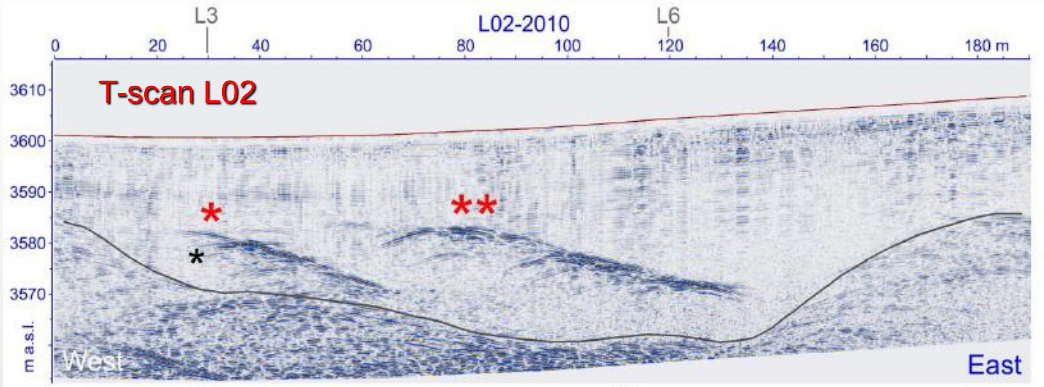
Bedrock morphology Is rather complicated with two longitudinal ridges with a crest width of about 25 m.

The ridges probably developed because of the locally larger stiffness of the granite rocks.

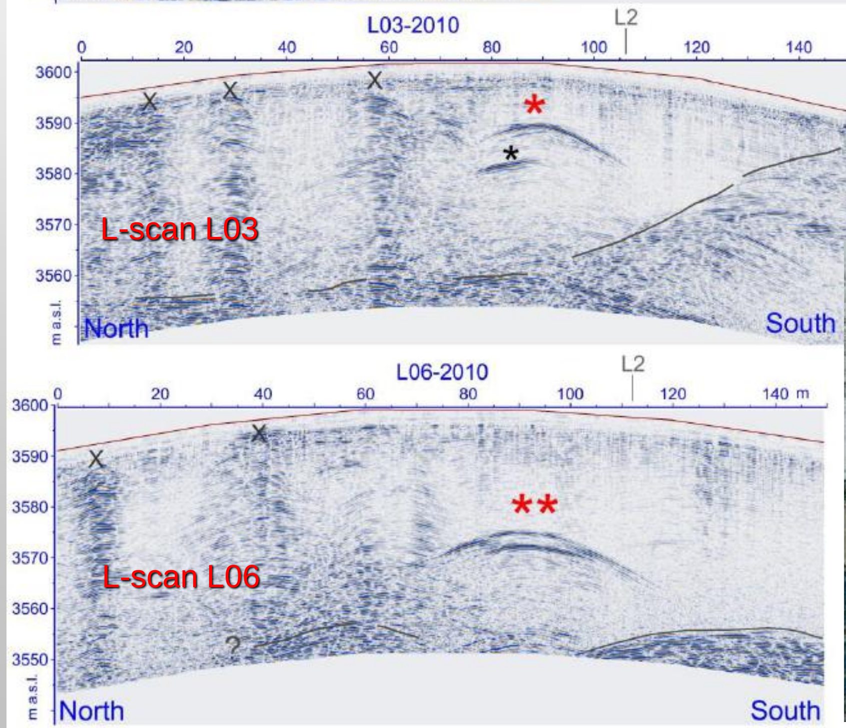
# Results and discussion



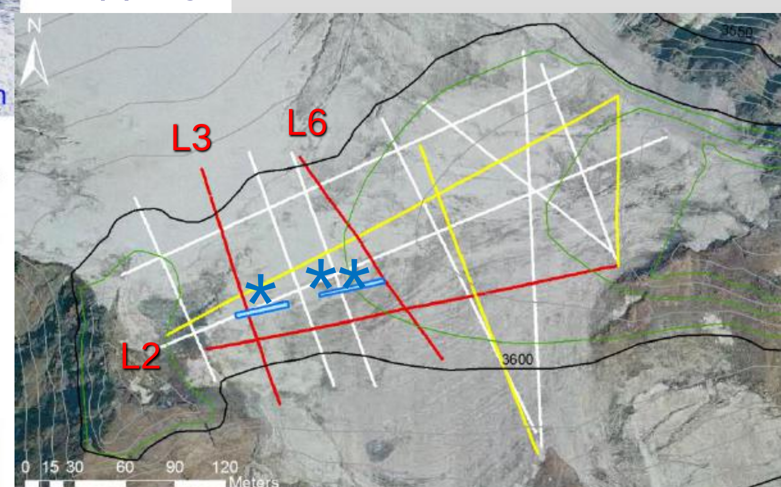
# Results and discussion (geo-archaeology)




Mapping of the bedrock was the key to analyze the anomalous reflectors embedded in the ice body.




The response in the L-scan is very similar to the one of a buried pipe while in the T-scan we observe a dipping feature.

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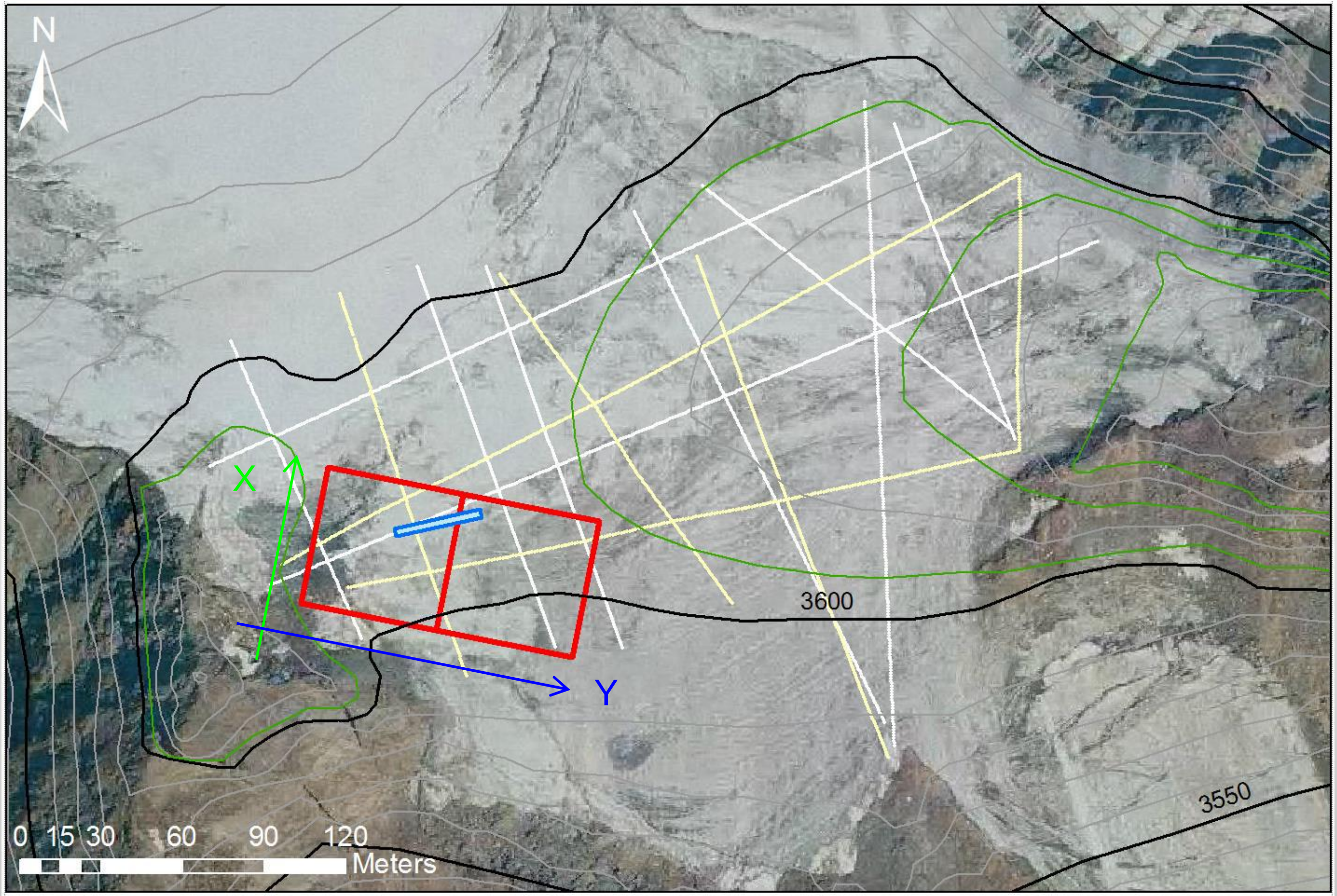
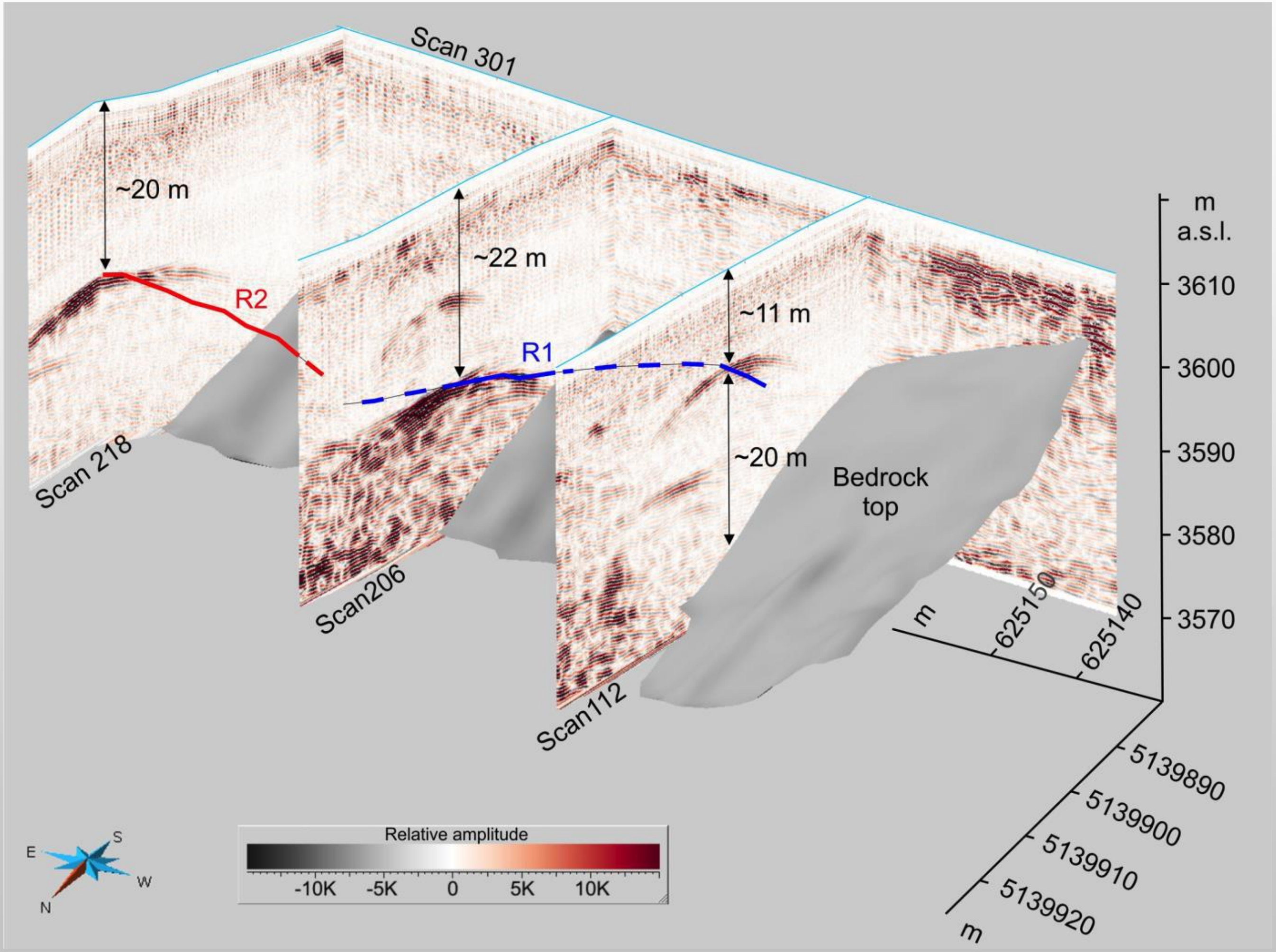
# Results and discussion (geo-archaeology)



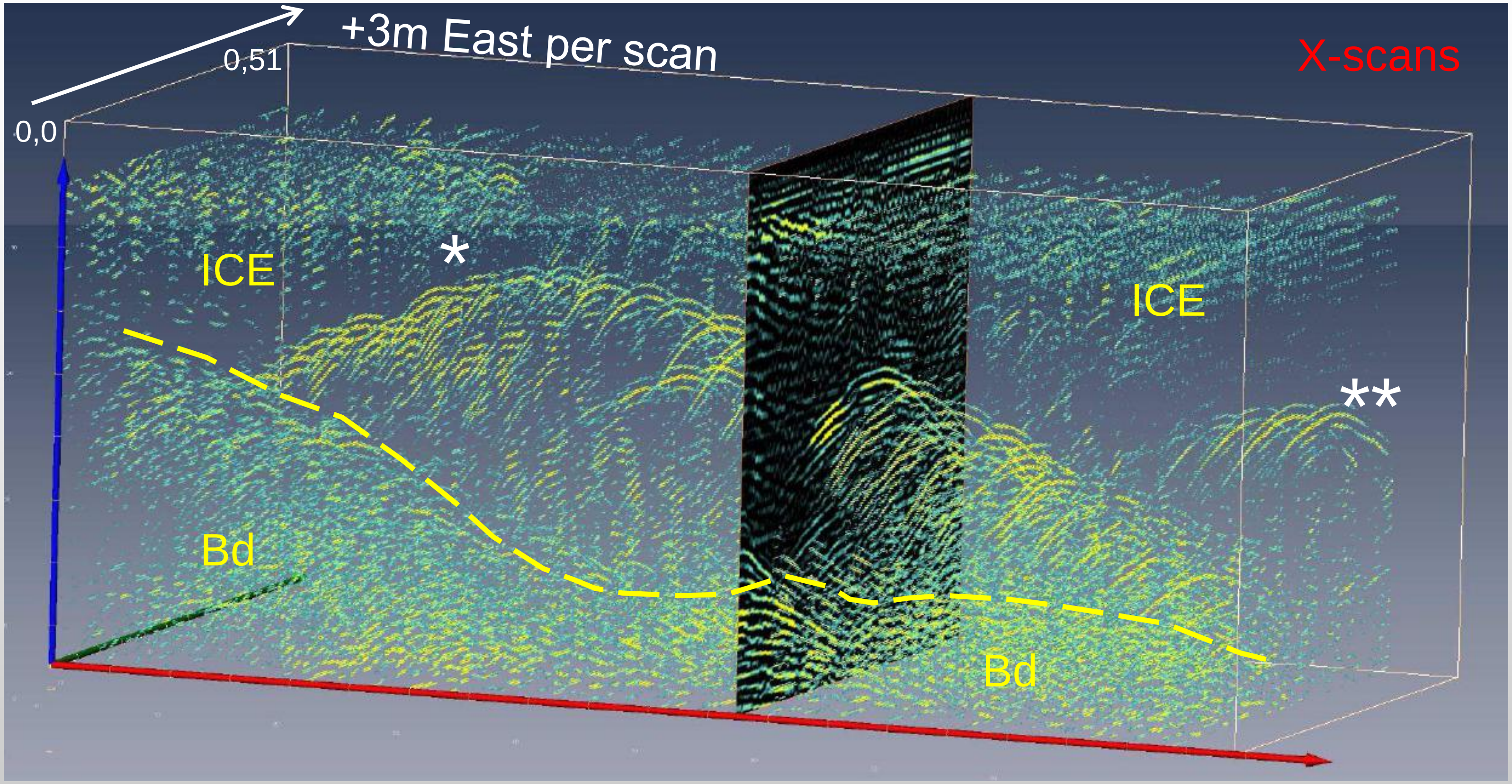



Anomaly (*) was targeted scanning the subsurface along the two axes of a HR grid. The grid was slightly shifted southwards to gain full control on the bedrock reflection and avoid pitfalls.

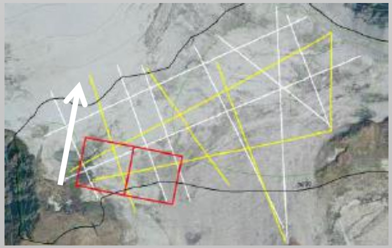
# Results and discussion (geo-archaeology)



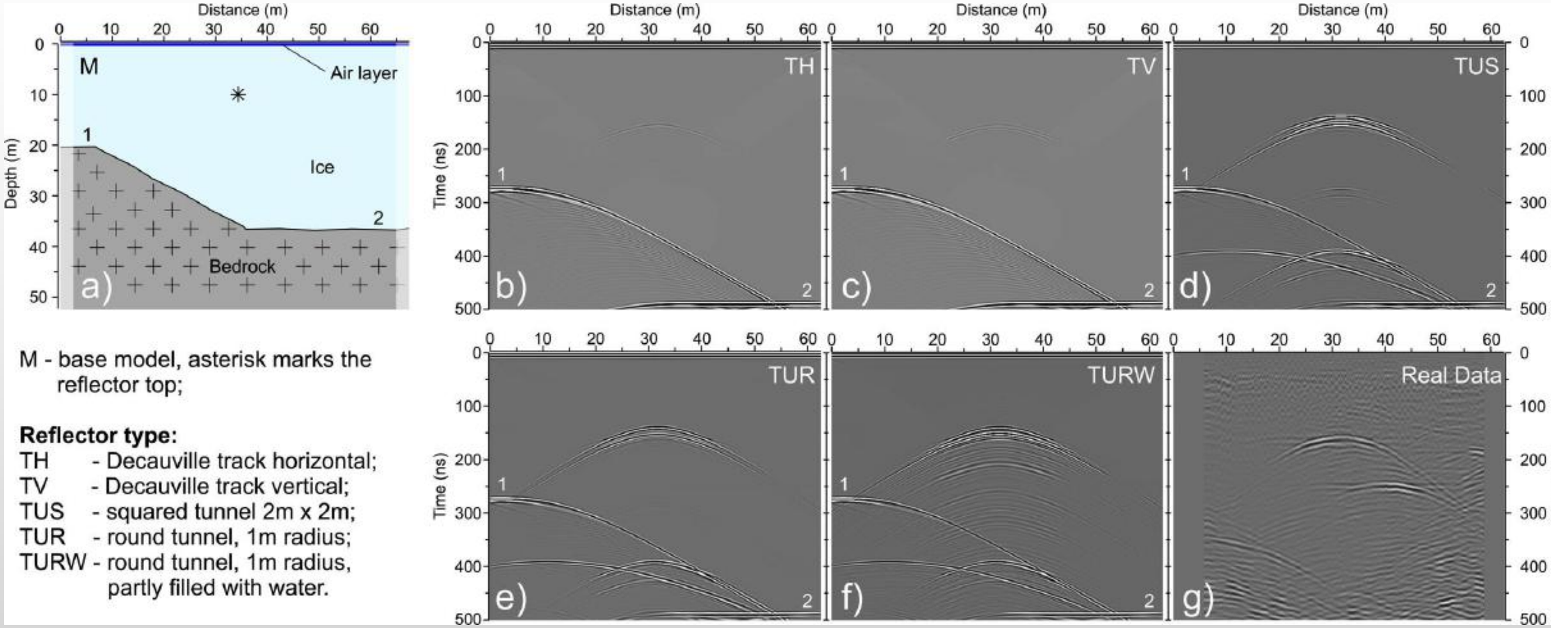
# Results and discussion (geo-archaeology)




Reflector (*) is the most prominent and its signature is always sharp and symmetric suggesting an artificial origin. In the X-scans its response is even sharper.



# Results and discussion (geo-archaeology)




## Numerical Modeling

**Electromagnetic properties**

| Medium | Permittivity $\varepsilon$ $(\varepsilon_0)$ | Conductivity $\sigma$ (S/m) | Velocity (m/ns) |
|---|---|---|---|
| Air | 1 | 0 | 0.30 |
| Ice | 4 | 0 | 0.15 |
| Bedrock | 15 | 0.01 | 0.08 |
| Metal | 1 | 0.1 | --- |
| Water | 80 | 0 | 0.03 |

Permittivity of free space: $\varepsilon_0 = 8.854 \cdot 10^{-12}$ F/m

**Table 2. Electromagnetic properties**

# Results and discussion (geo-archaeology)

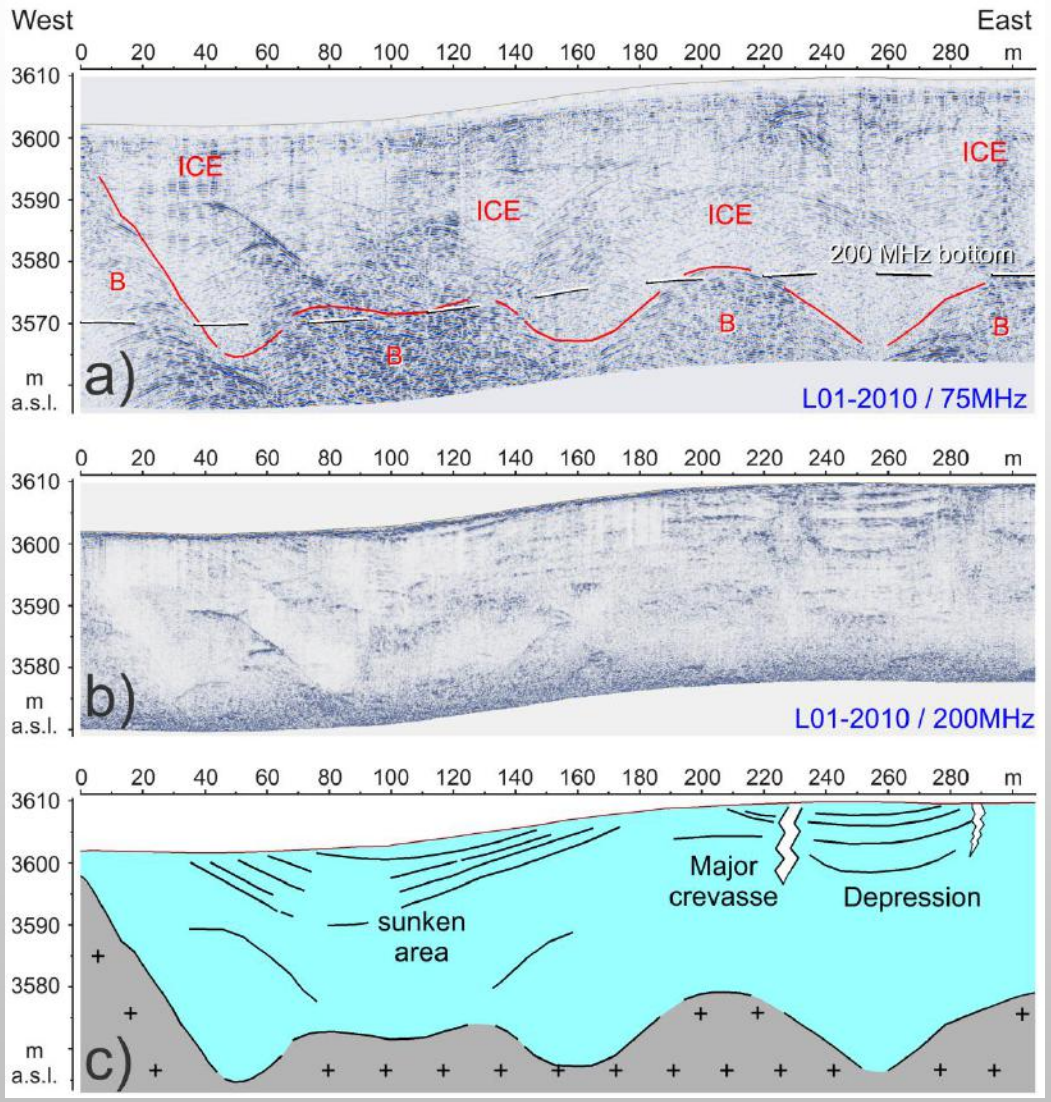
Elementi a favore dell'ipotesi tunnel WWI:

Direzione, congruenza con strutture, firma spettrale

Come mai si è preservato ?
Sella, movimenti modesti (detriti), buried divide

E' un condotto endoglaciale ?

# Results and discussion (geo-archaeology)




Further evidences of the presence of anomalous buried structures were provided by the T-scan L01, collected with the 200 MHz antenna (b).

Two groups of curved reflectors are visible within the ice body. These reflectors are barely observable in the 75 MHz profile (a).

Particularly the structure on the west side of the profile is really anomalous and appears to be a sort of infill after a collapse occurred just above the bedrock.

# Conclusions

- The survey conducted on the Linke-Vioz saddle provided a relevant insight both in the glaciological and in the archaeological perspectives;

- Results were encouraging although the abundant presence of melting water was the cause of radar wave dispersion and powerful coherent noise generation during the second campaign;

- The bedrock was reconstructed in details down to a depth larger than 45-50 m. The ice-bedrock interface exhibits a rather variable signature depending on dip and on the relative presence of water and fine sediments;

# Conclusions

- The detailed reconstruction of this interface allowed for a better interpretation of some anomalous reflectors embedded in the ice. The signature of this reflectors is peculiar and slightly different from other reflectors commonly visible in the Alpine glaciers;

- Although the nature of these reflectors is still under investigation the most convincing hypothesis is the presence of the remains of a tunnel in the ice similar to other tunnels that soldiers dug into several Alpine glacier during the military events of WWI.

Buona giornata !

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