GEOPHYSIAL METHODS FOR DETAILD MAPPING OF ZONES WITH CLAY IN BERGGRUNN.

Jan Steinar Rønning, **Guri Venvik Ganerød** & Odleiv Olesen

NORGES GEOLOGISKE UNDERSØKELSE
- NGU -

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This is not an option for our tunnels

The Hanekleiv tunnel Spring 2007.

Content

- **Model of deep weathering**
- **Geophysical methods**
  - Seismic, VLF-EM, 2D Resistivity
- **Resistivity**
  - Possibilities and restrictions (Modelling)
  - Opposed model of interpretation based on results from the Lunner tunnel
- **Examples from tunnel projects**
  - Hanekleiv, Ravneheia, Holmestrand
- **Summary**

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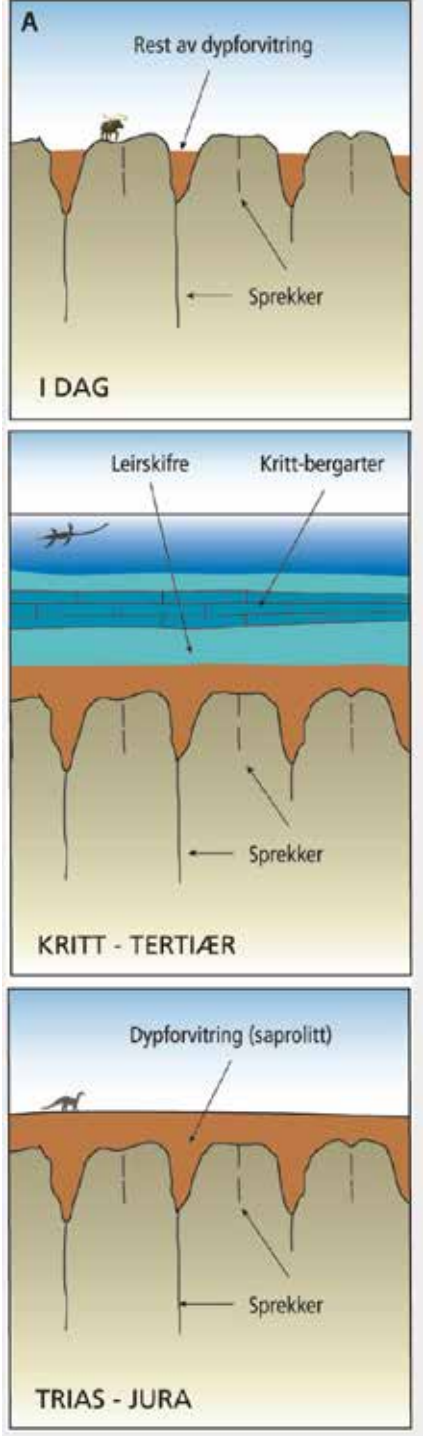
Deep weathering in Norway.



AMAGER-method.

Deep weathering from Trias and Jura.

Signature:
Silicate minerals altered to clay minerals, magnetite to less magnetic minerals.

Effect: Low terrain and low magnetic field.

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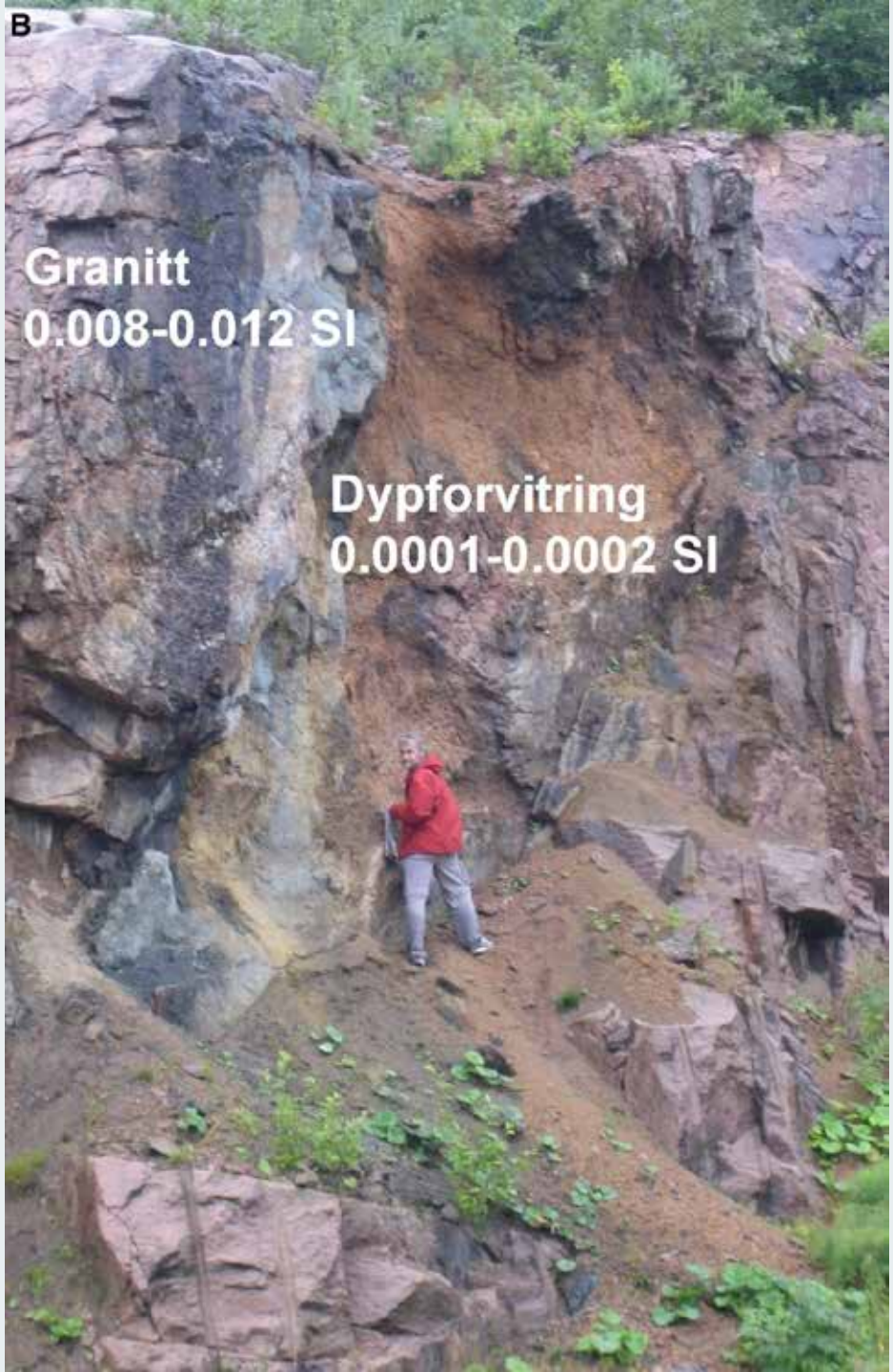
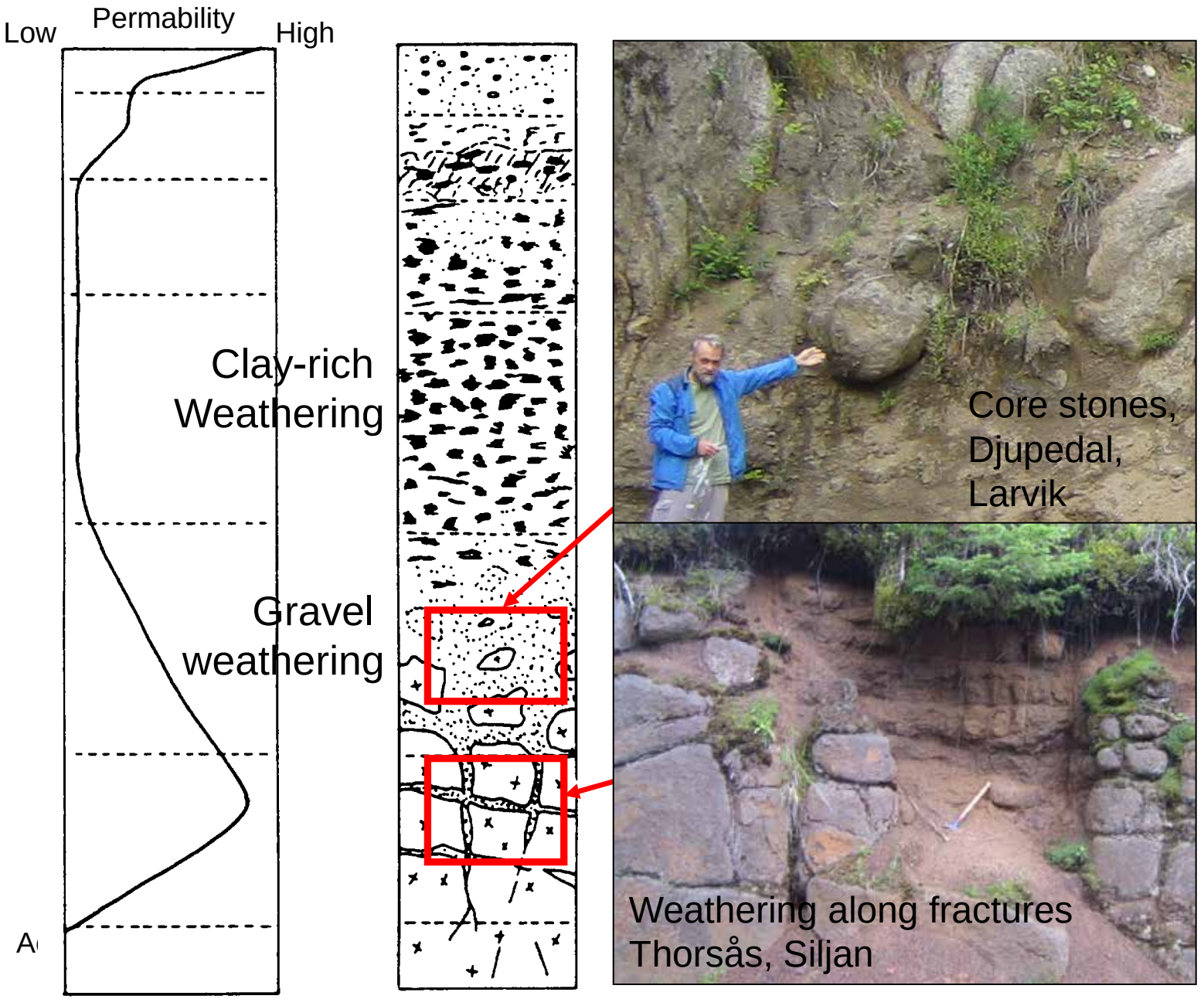
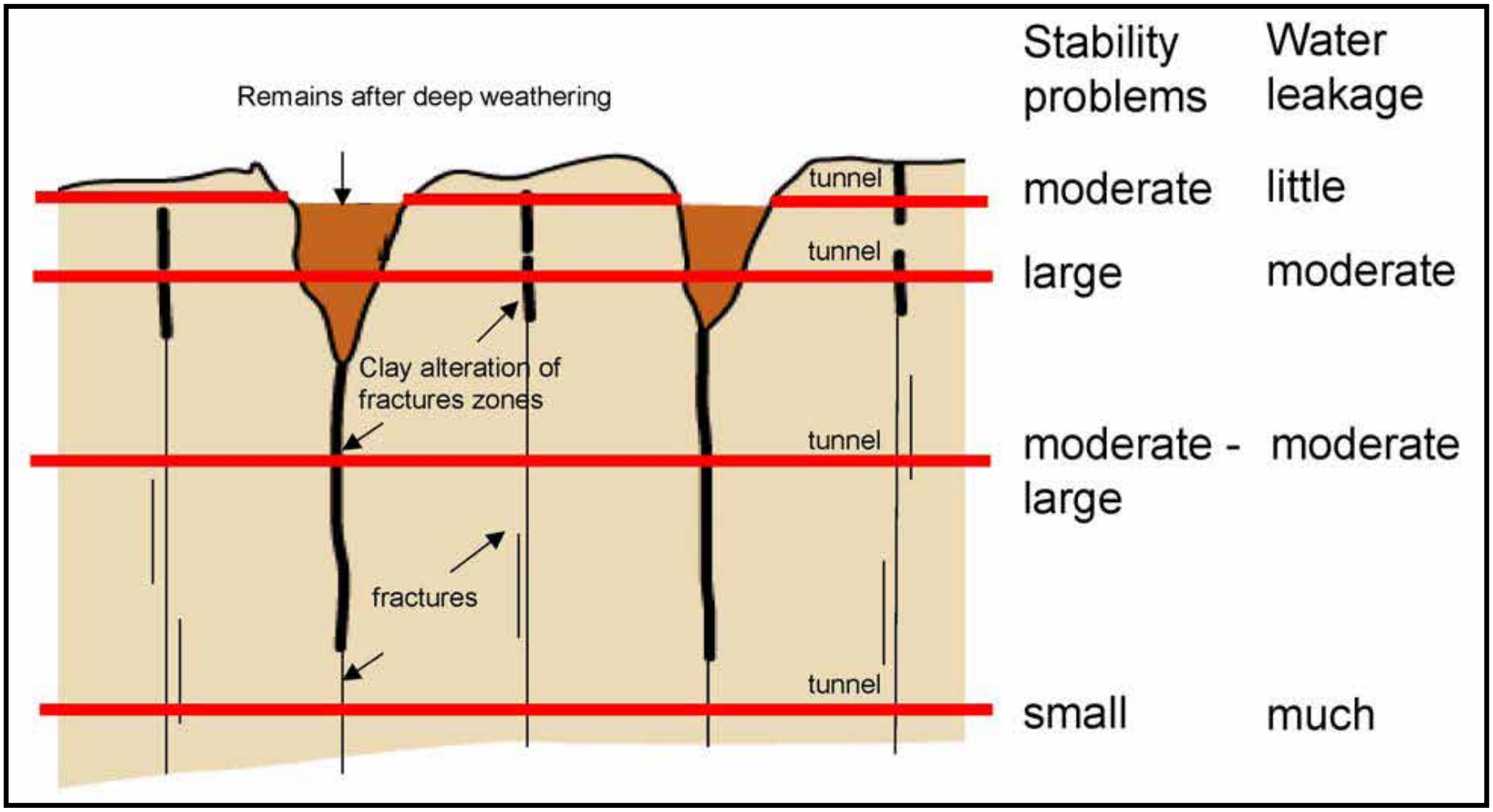


Eksample from Røyken

Weathering profile – tropical climate



Different problems at different levels



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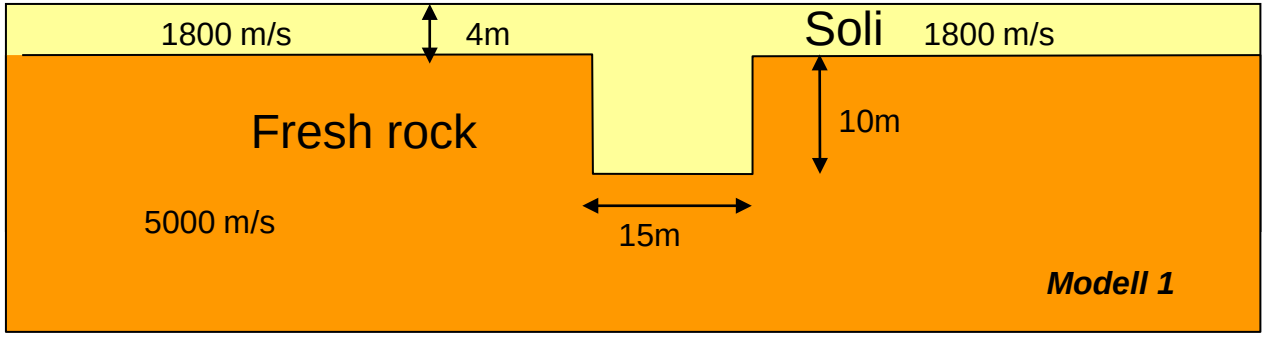
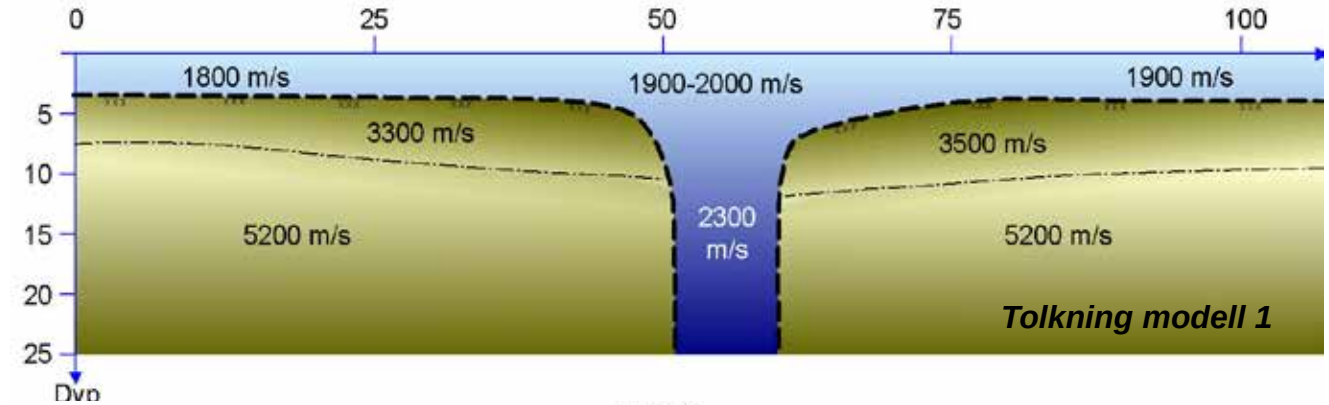
Refraction seismic, Blind test.

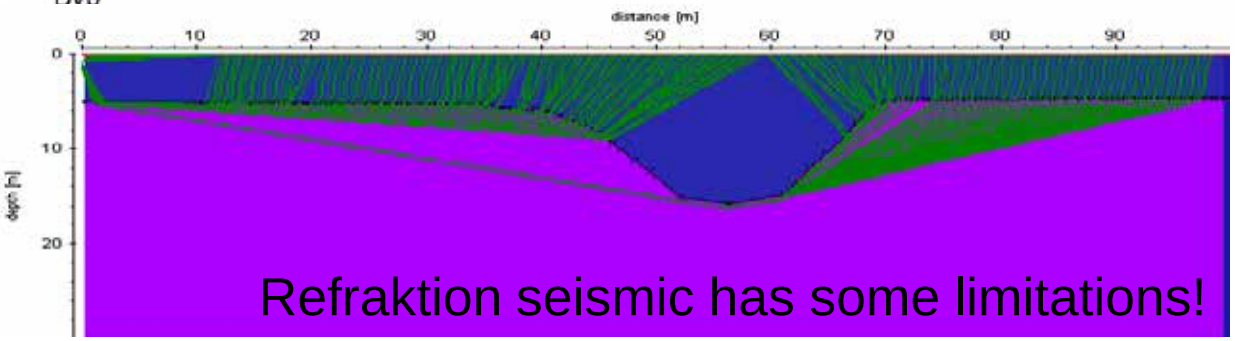
Traditional interpretation of synthetic data (Westerdal 2003).



Syntetic data generated from this model.



Interpretation from the expert.
Weak zone open towards the depth.
General weathering (Vp = 3300 – 3500 m/s).



Ray tracing. A shot at the surface to the left will not give information from the lower part of the trench.

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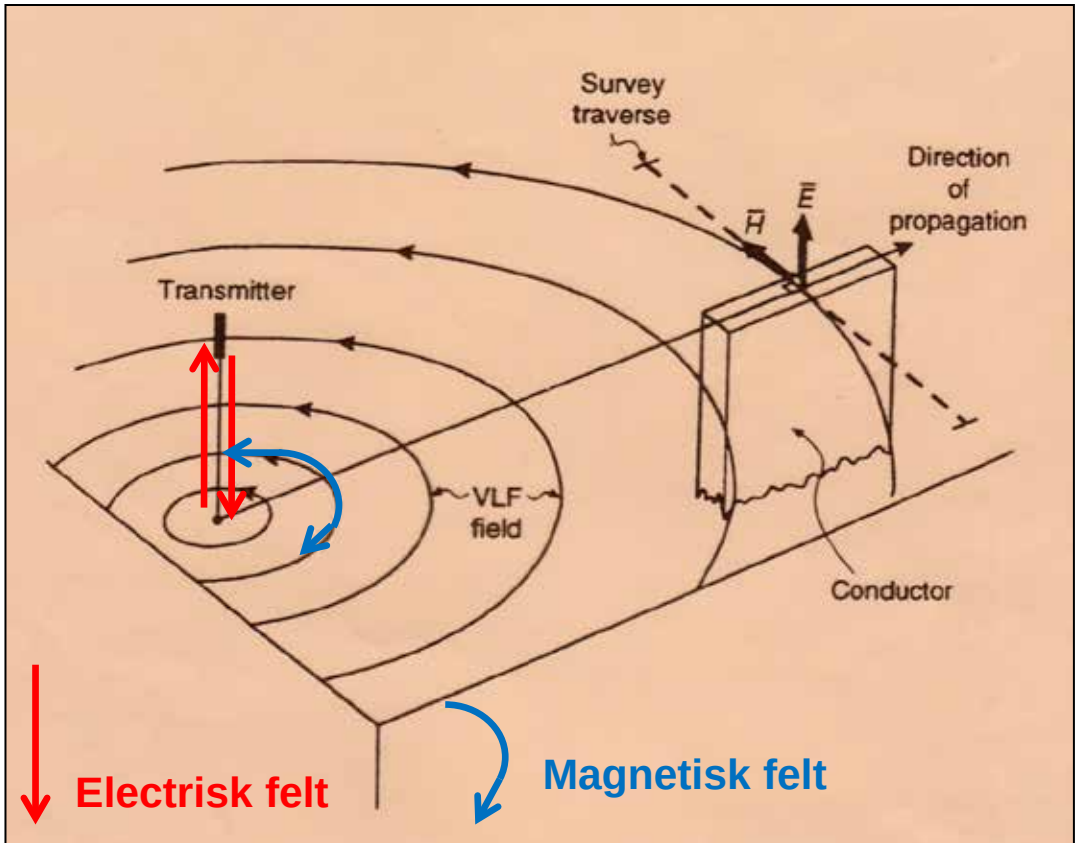
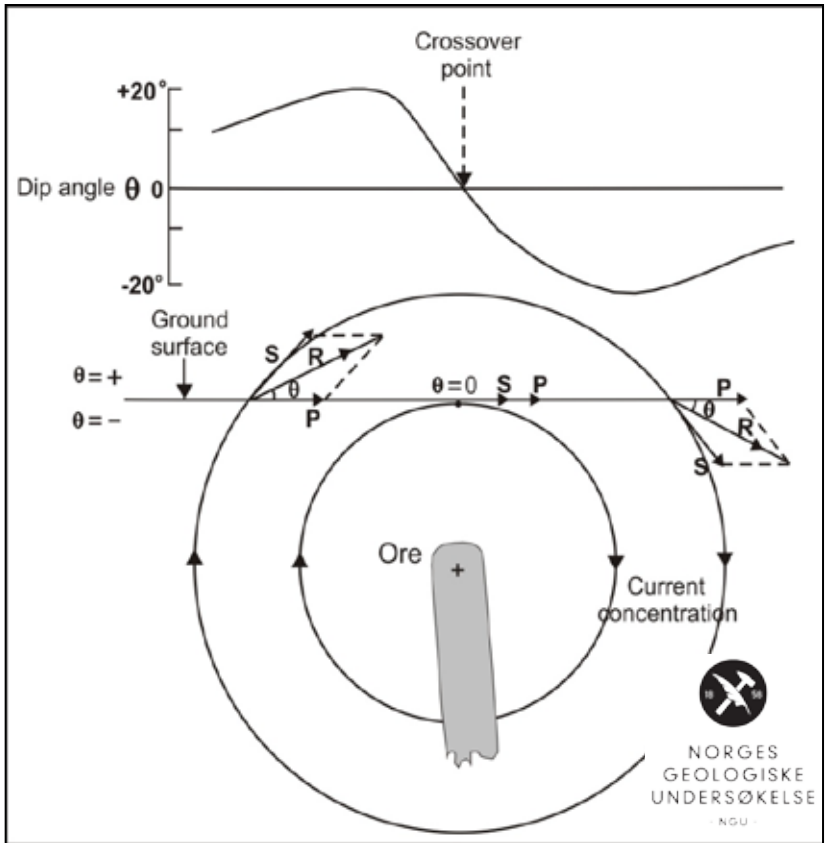
VLF-EM,
Very Low Frequency ElectroMagnetic.

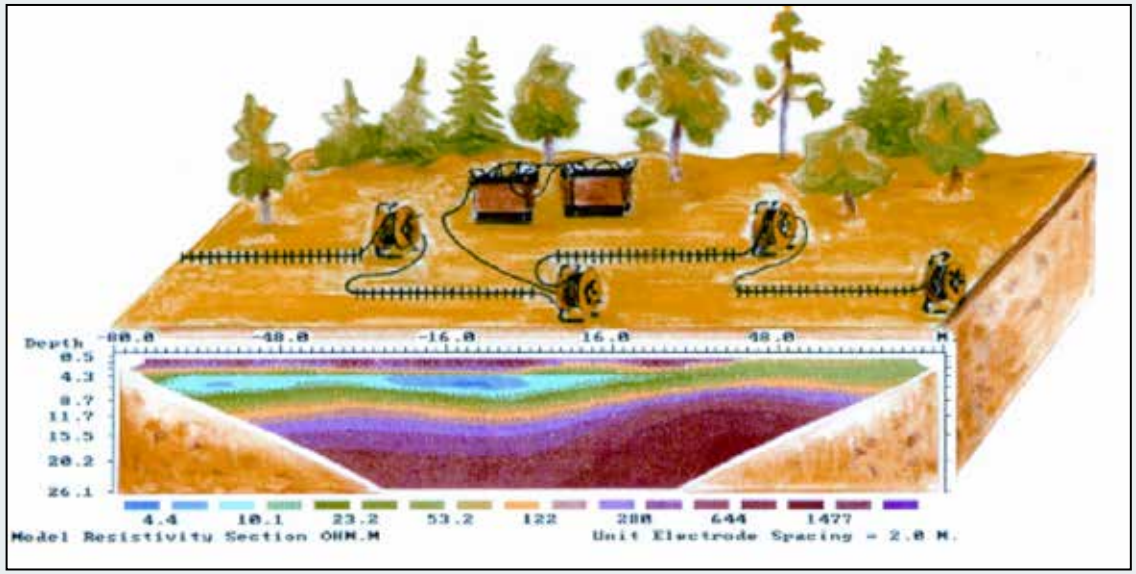
The method uses military radio transmitters as energy source.
Can locate conducting structures in the ground.





2D Resistivity.

- **Cable system on the ground, electrodes connected.**
- **Automatic measuring procedure.**
- **Lund-system, 4 cables, total length 160, 400 or 800 m**
- **Electrode spacing 2, 5 or 10 m**
- **Multi gradient electrode configuration**
- **ABEM Terrameter 4000 or ES**
- **Inversion, Calculation of ”true resistivity”: Res2DInv (Loke 2014)**
  - ”Standard” inversion / Robust inversion
  - Preferences to vertical structures if wanted (V/H = 2)



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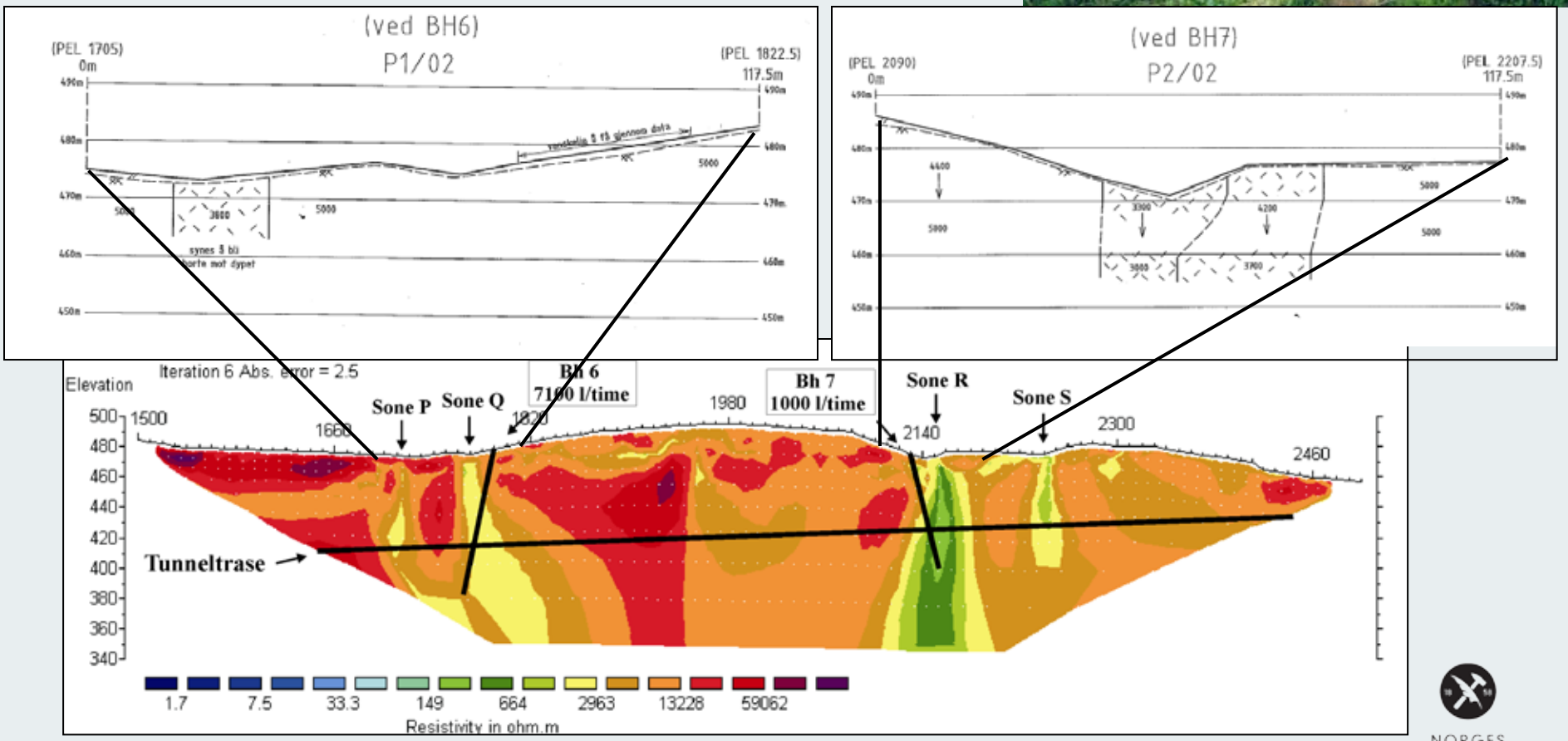
Fracture zones in bedrock

Refraction seismics and 2D resistivity, eastern part of the Lunner tunnel



Seismic from Geomap as.

Miljø- og samfunnstjenlige TUNNELER

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At the Lunner tunnel

- Three borehols with resistivity < 500 ohmm, all collapsed, and there were serious tunnel construction problems

- Three zones with resistivity from 1000 to 3000 ohmm, all with water problems during tunnel construction

Rønning et al. 2013

Rønning et al. 2013

Resistivity values (NGU colour scale)	Resistivity values	Characterisation
	> 3000 Ωm	Good rock quality
	3000-500 Ωm	Fractured rock and water leakage
	< 500 Ωm	Instable rock mass with clay and water leakage

In addition: Modelling has proven that it is possible to geometrical caracterisation of fracture zones: Depth extend, dip and thickness.

Model confirmed at least 10 other problem zones in other areas.

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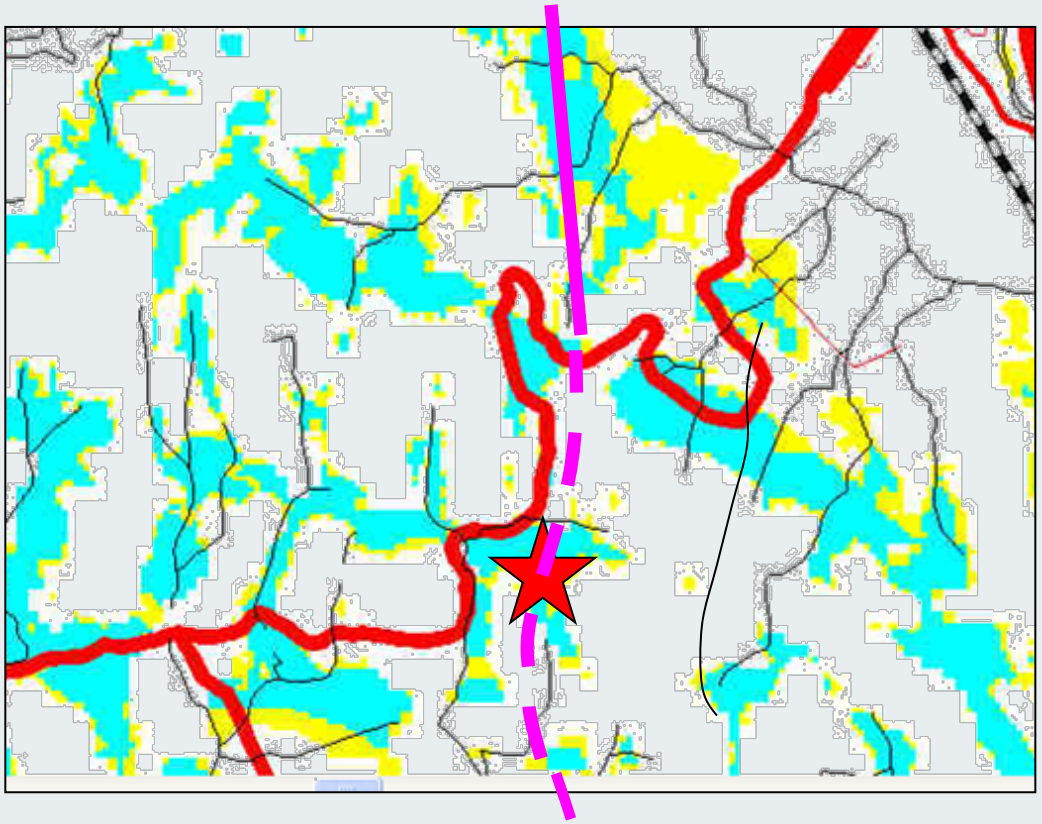
Hanekleivtunnelen,

Problem zone indicated by the AMAGER-method.

– AeroMagnetic And GEomorphological Relations

22.11.2006: First version of weathering map presented for ”Vegdirektoratet”

25.12.2006: Rockfall in the southbound line in ”Hanekleivtunnelen”.



Probable deep weathering

Possible deep weathering

Rønning et al. 2013

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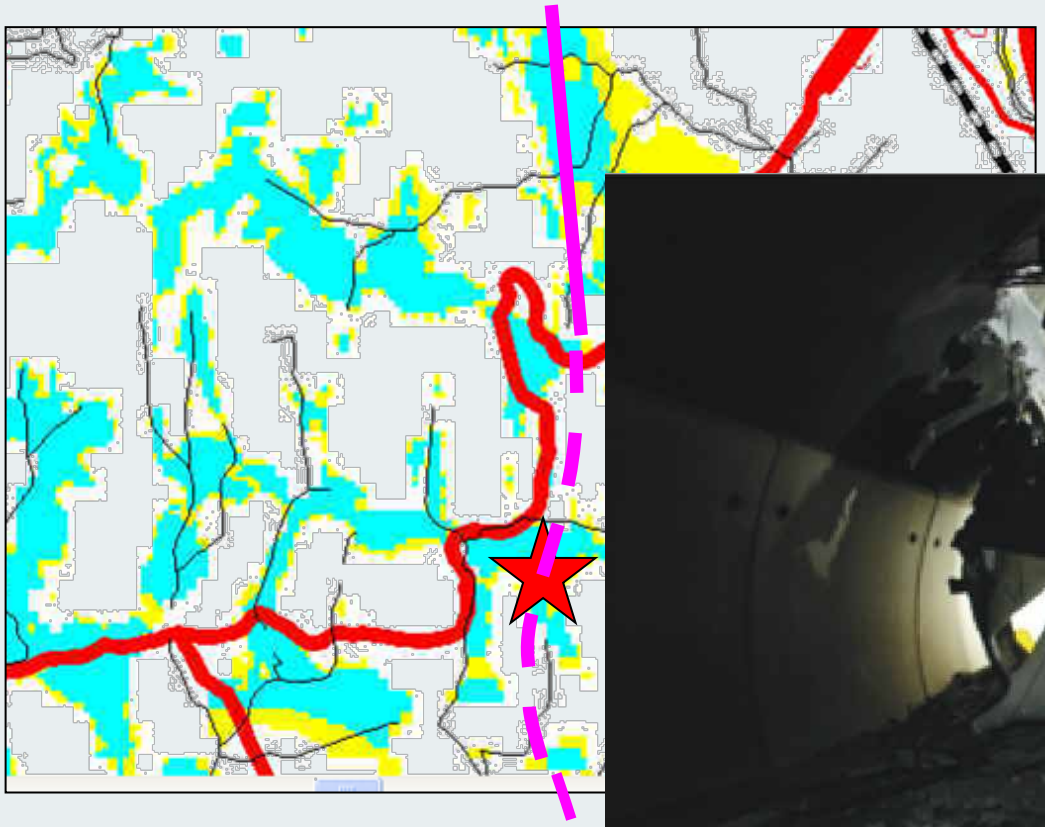
Hanekleivtunnelen,

Problem zone indicated by the AMAGER-method.



Probable deep weathering
Possible deep weathering

Deep weathering, hydrothermal alteration and sand/gravel refill of eroded zones have the same effect - weaker magnetic field

Rønning et al. 2013

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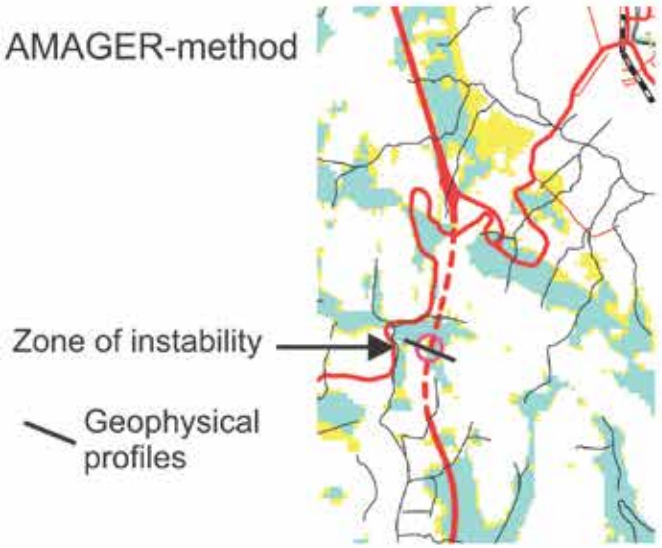
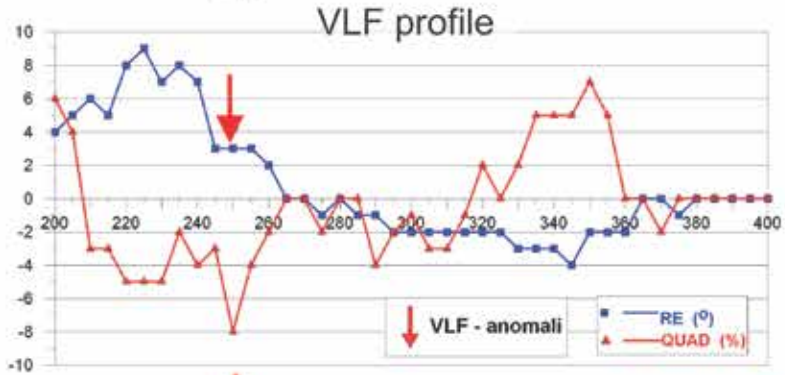
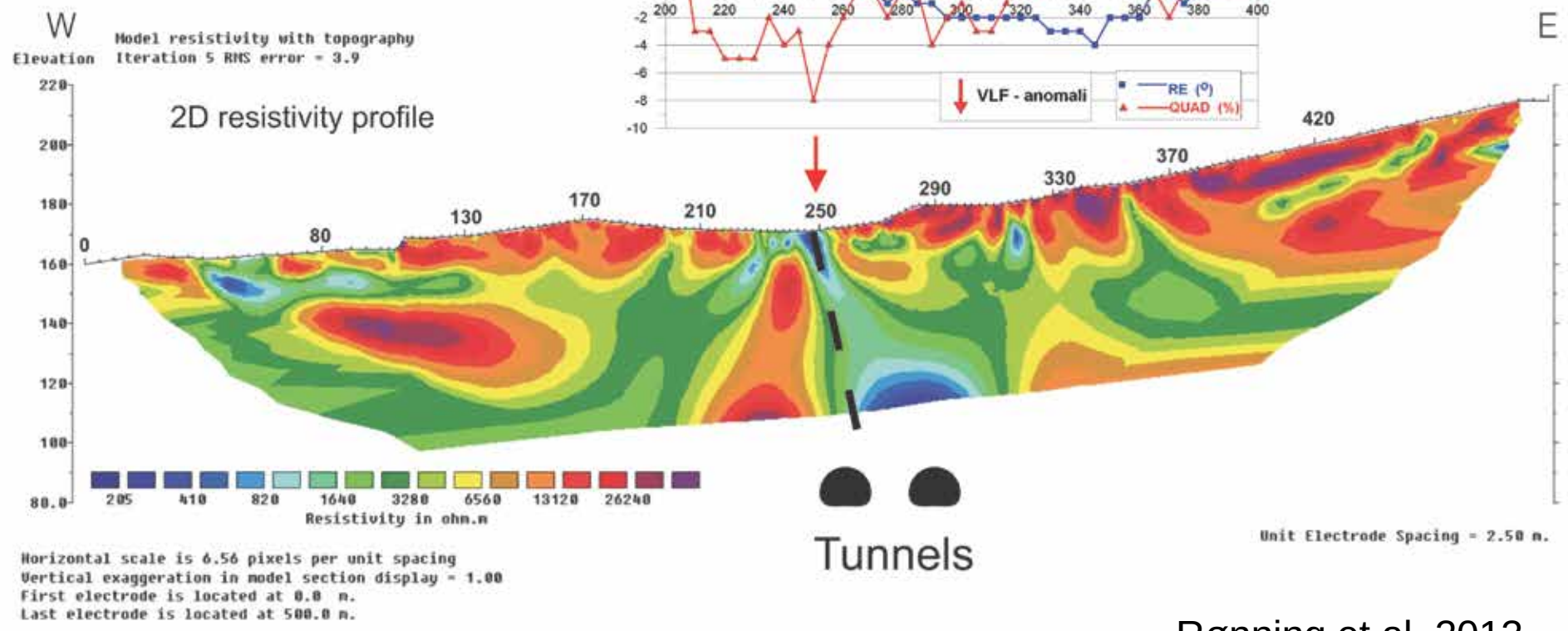
Hanekleivtunnelen
Refraktion seismic, VLF-EM and 2D Resistivity

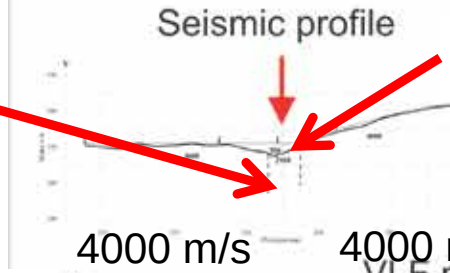




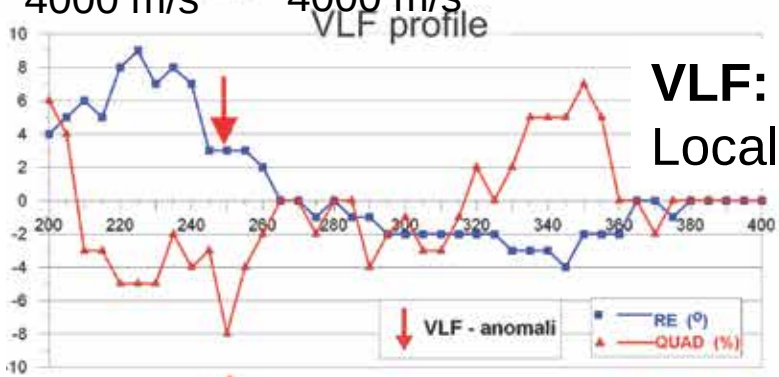


Rønning et al. 2013

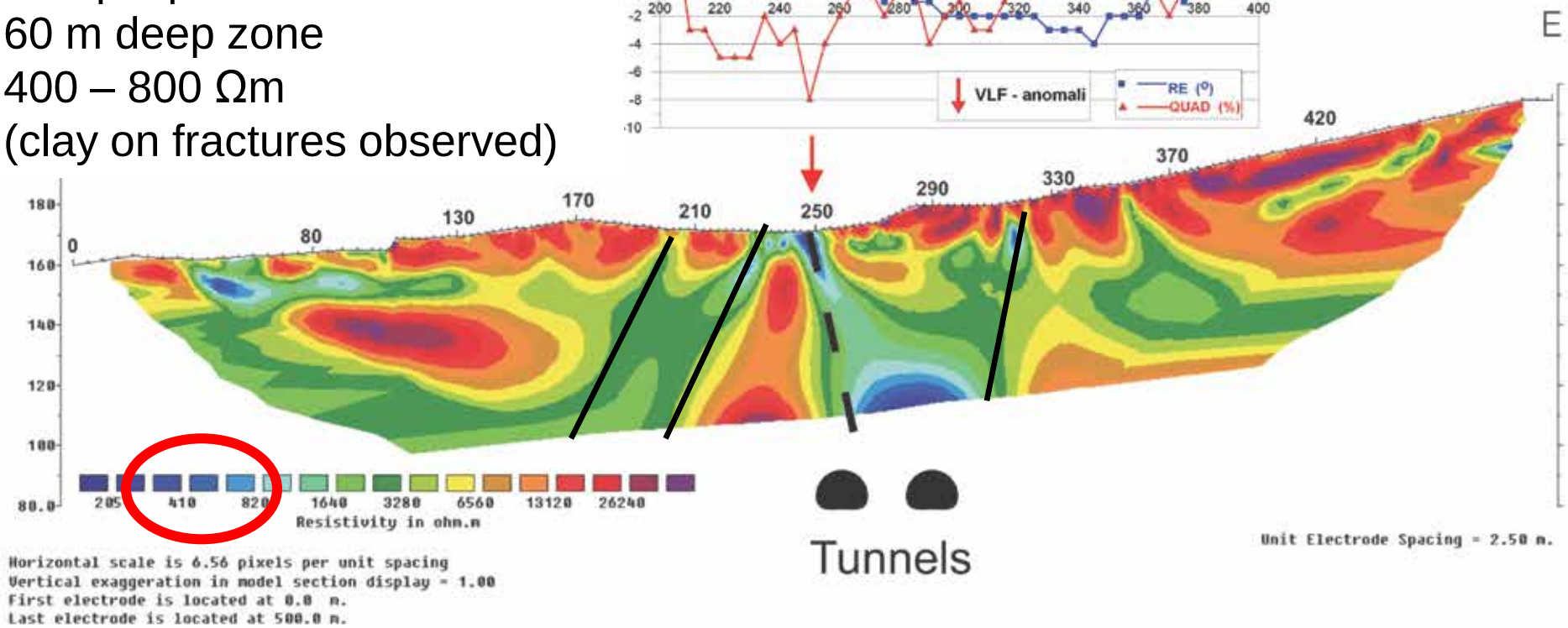
Seimic:
Zone: V= 2900 m/s
Ca. 10 m thick



Resistivity:
Ca. 10 m at surface
Steep dip towards east
60 m deep zone
400 – 800 Ωm
(clay on fractures observed)

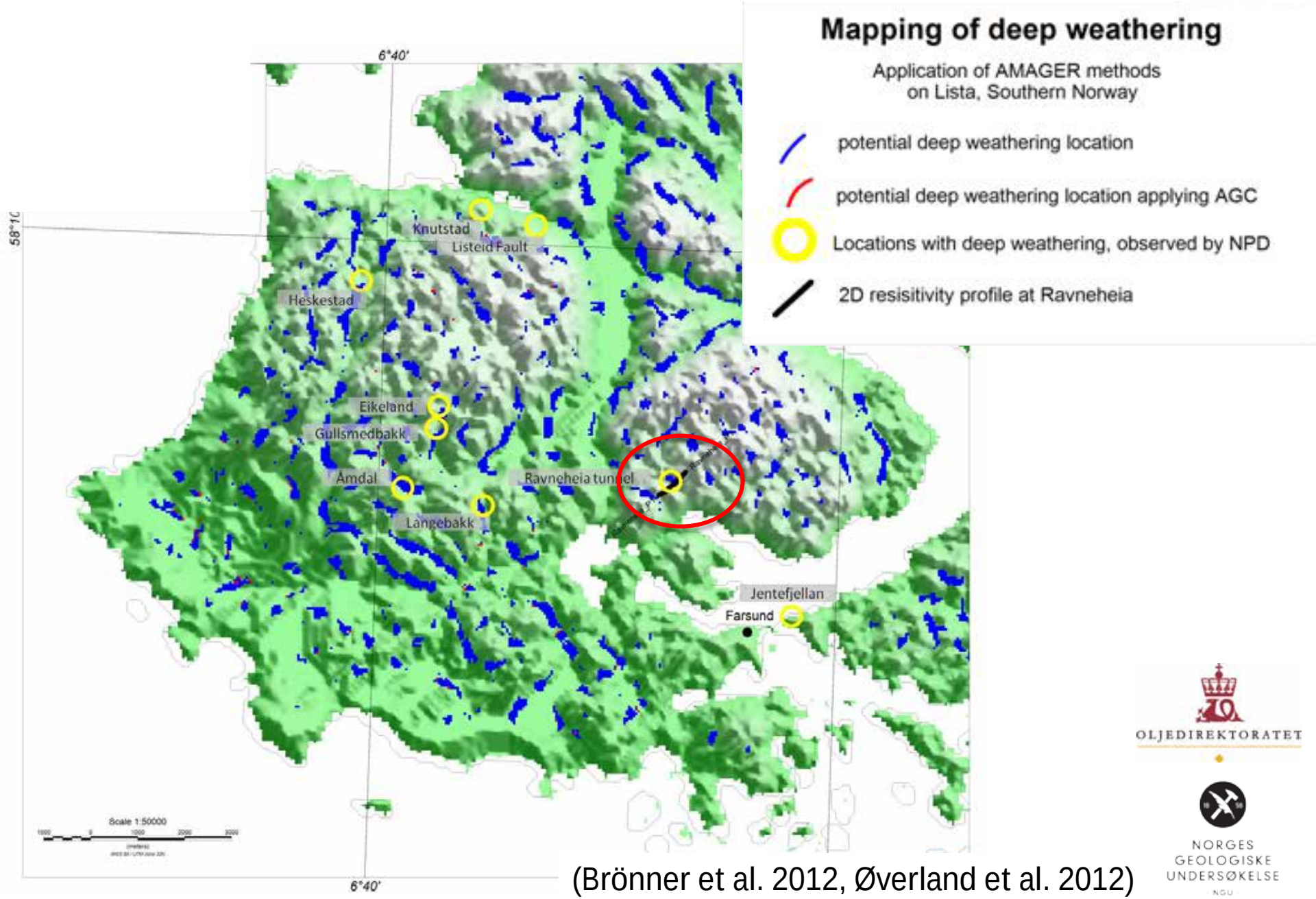


VLF:
Localising zone



Rønning et al. 2013

Interpreted and observed deep weathering at Lista



(Brönner et al. 2012, Øverland et al. 2012)

OLJEDIREKTORATET

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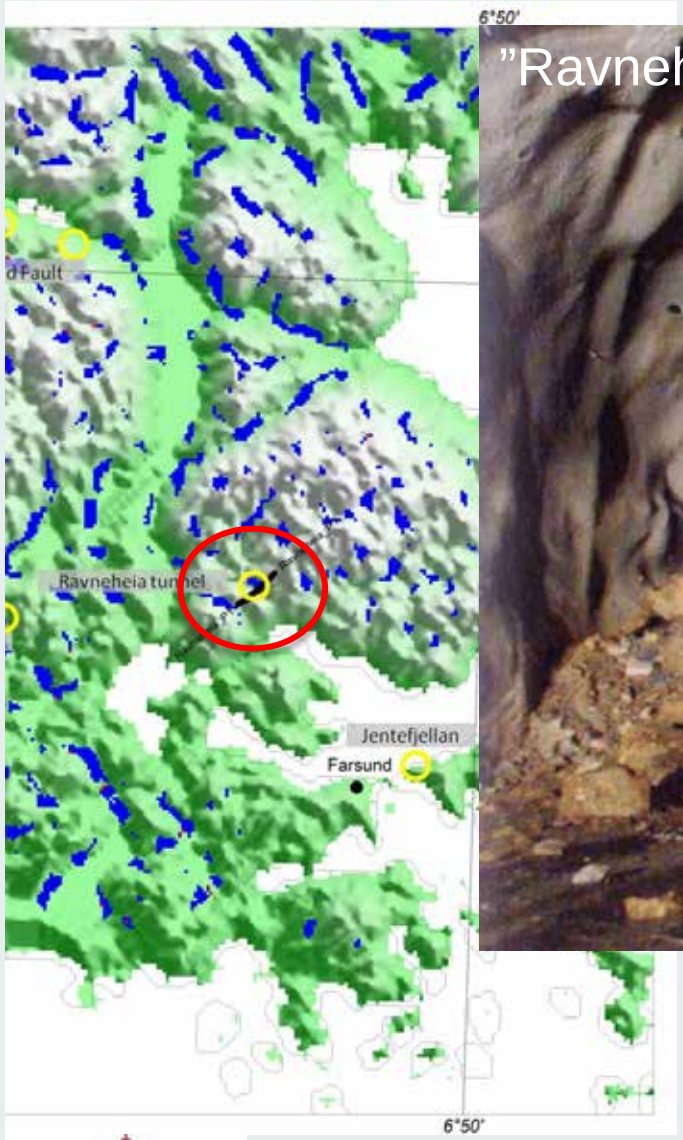
Interpreted and observed deep weathering at Lista



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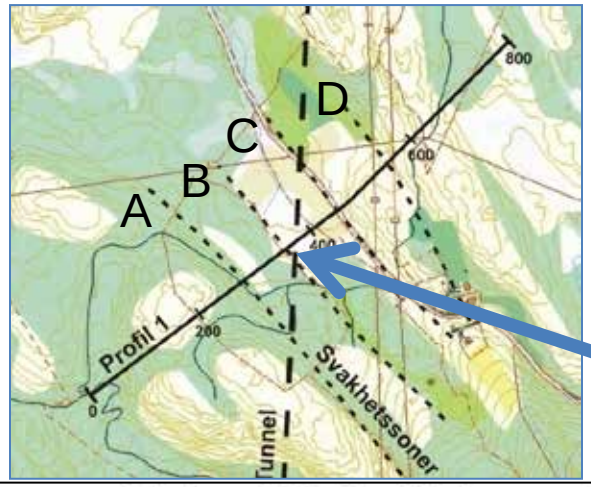
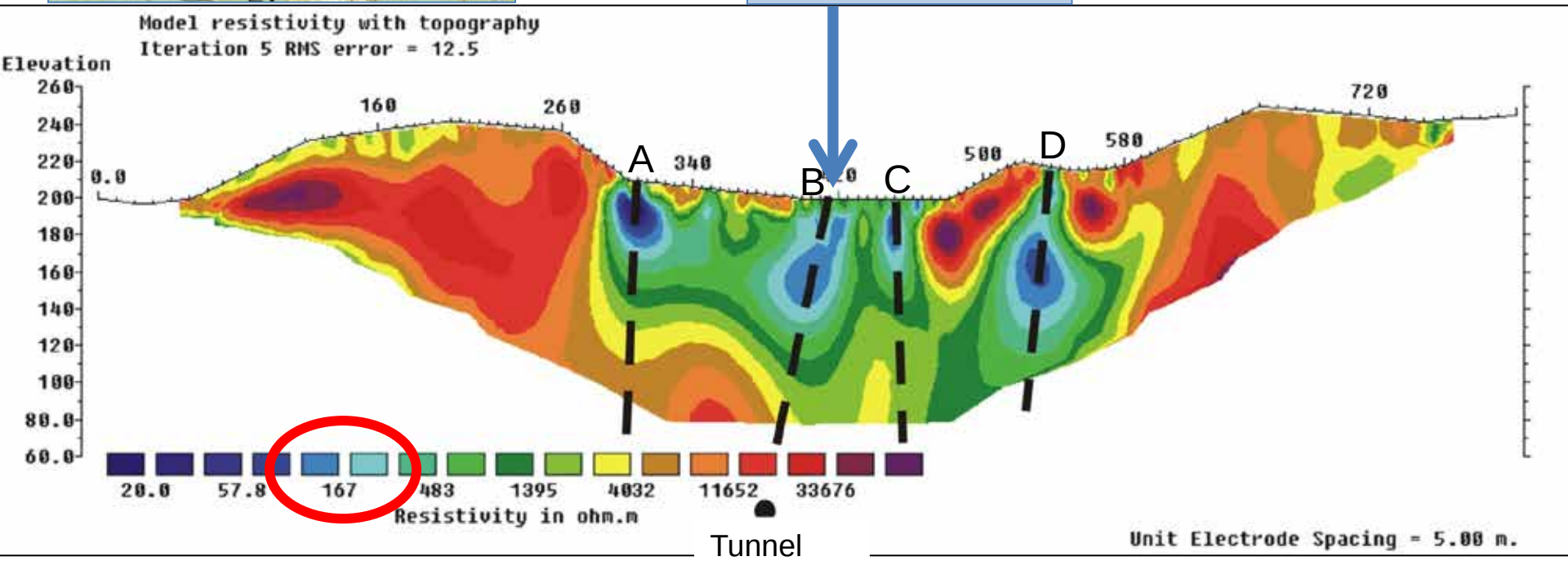
Resistivity Ravneheia



Tunnel collapse



Observation in the tunnel:

Crushed and weathered rock with **swelling clay**

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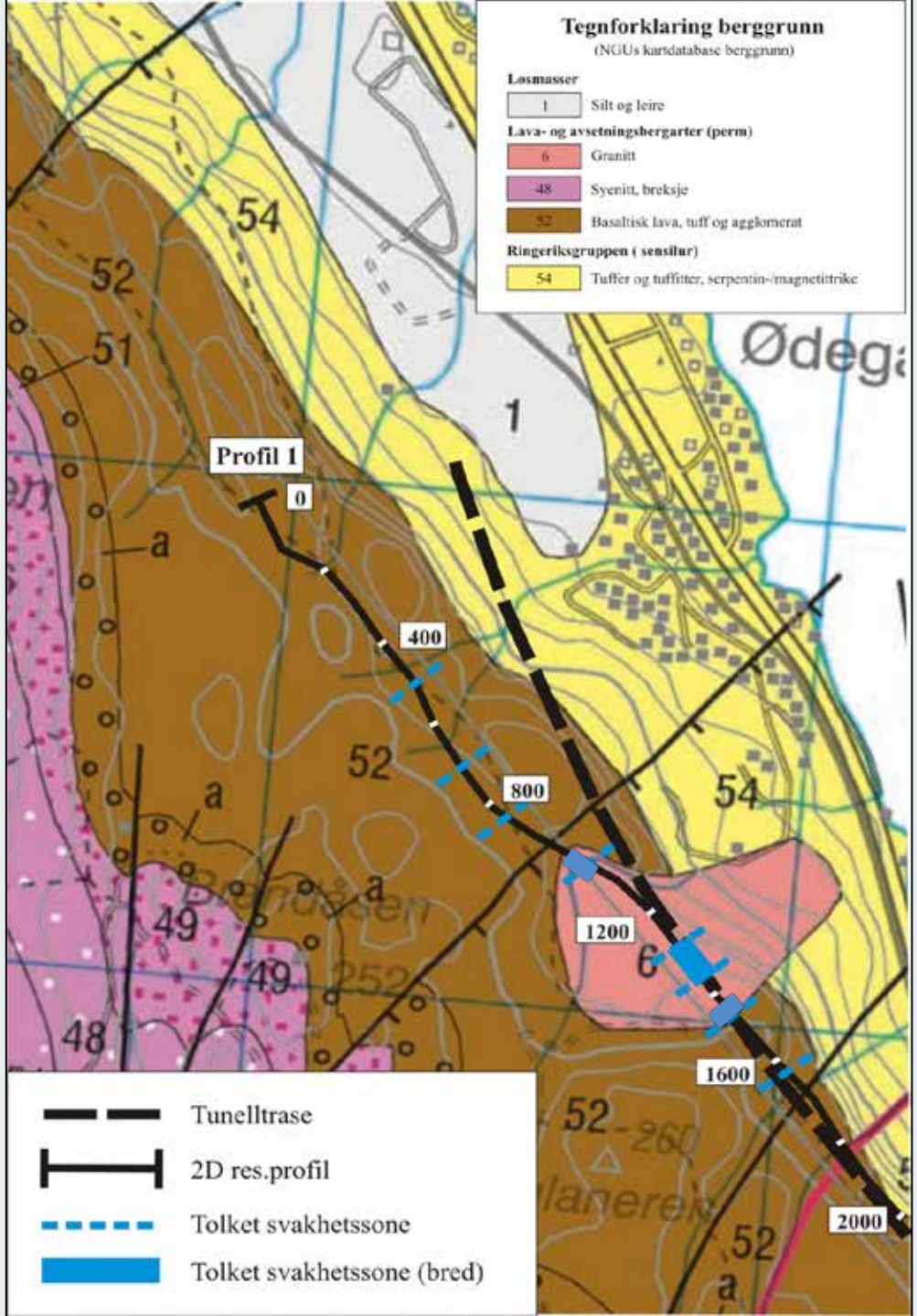
The Holm tunnel at Holmestrand



Resistivity profile do not follow tunnel from the start.

From resistivity, weak zone central in the granite and at the contacts

Rønning m. fl.
Bergmekanikkdagen 2015.

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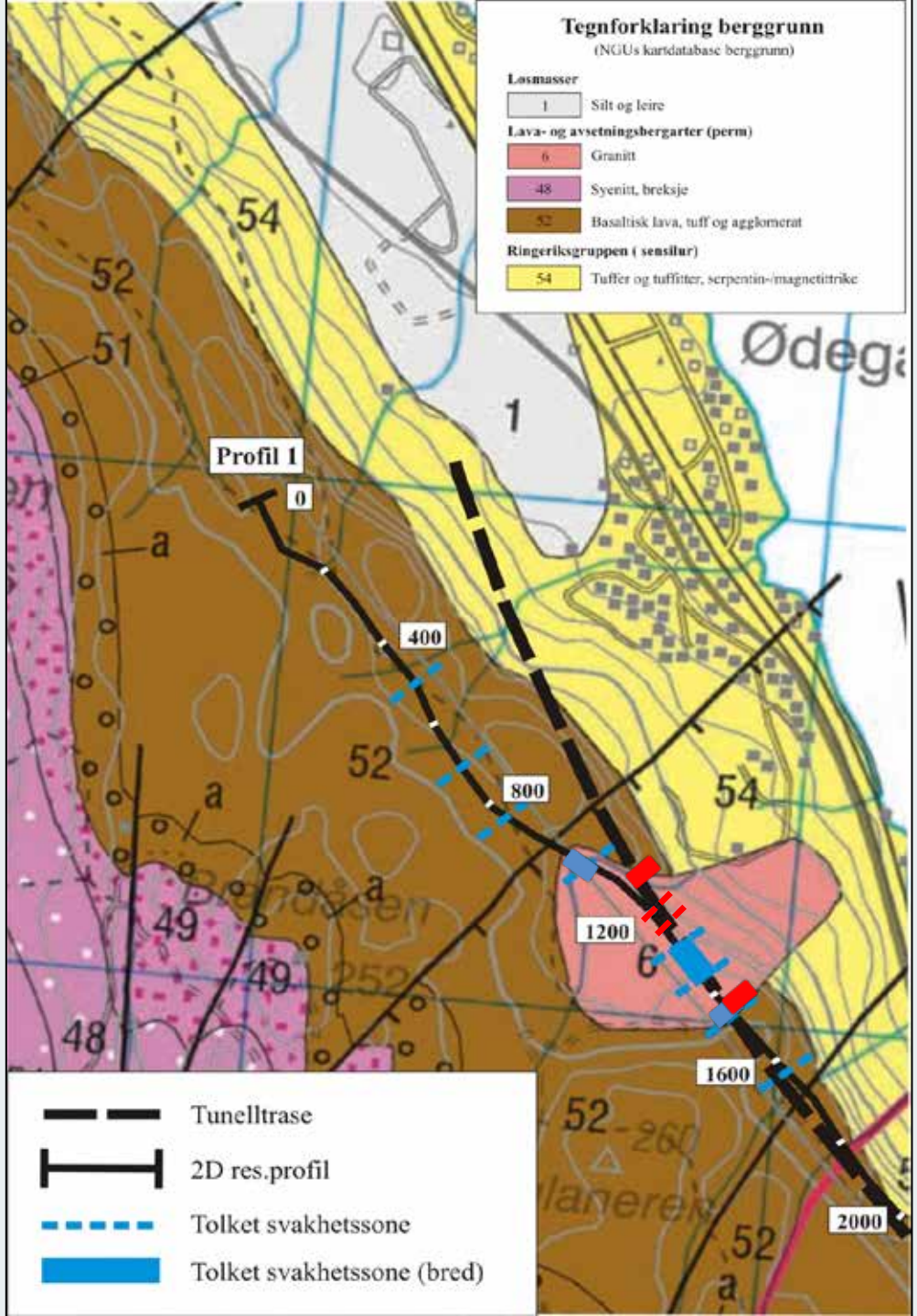

The Holm tunnel at Holmestrand

During constructions – large water inflow at bedrock contact

Weak zone in the central part gave no signature during tunnel work

Problem zones during tunnel work

Rønning m. fl.
Bergmekanikkdagen 2015.

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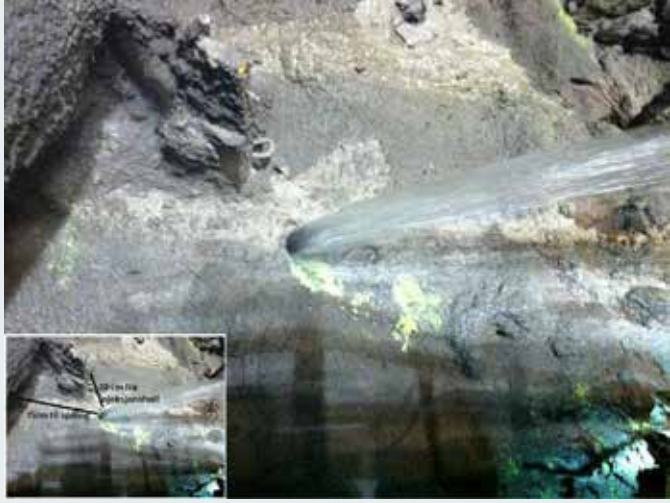
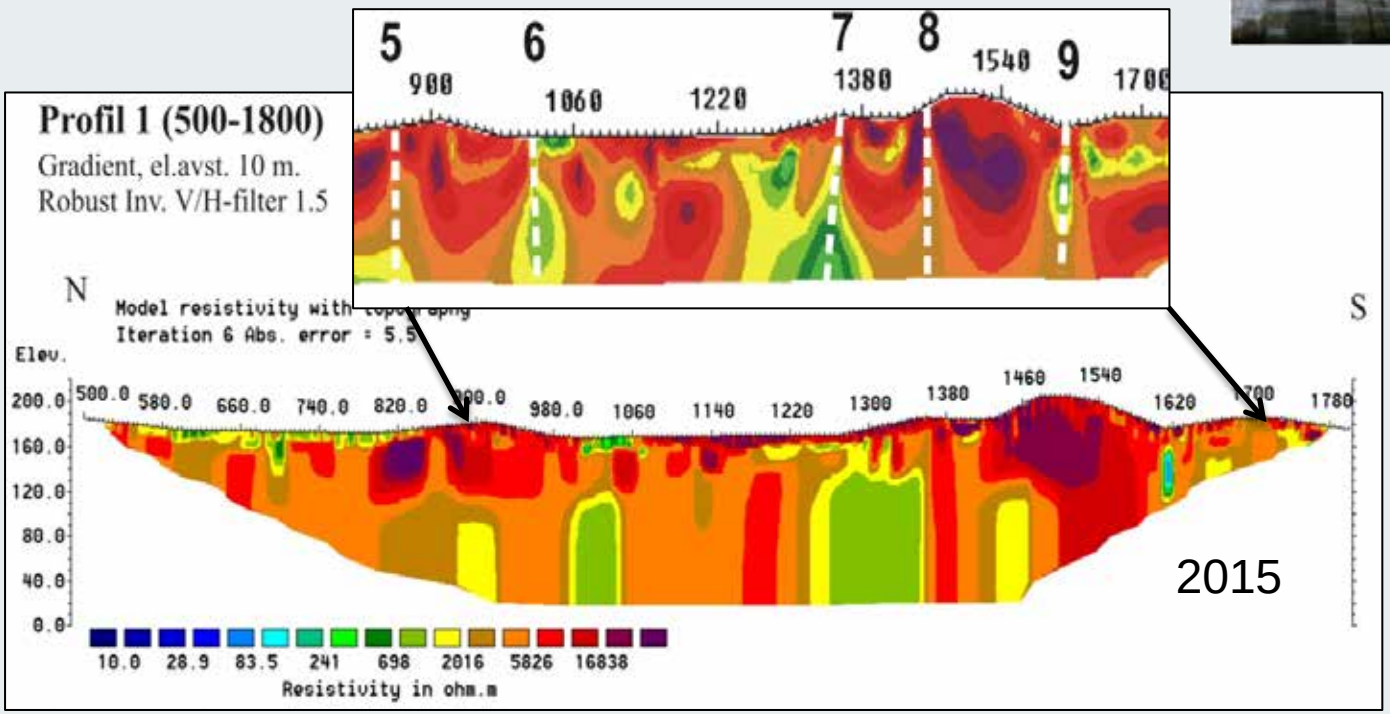
Water leakage in Granite at Holm the Holmestrand tunnel



2009



Standard vs. Robust inversion

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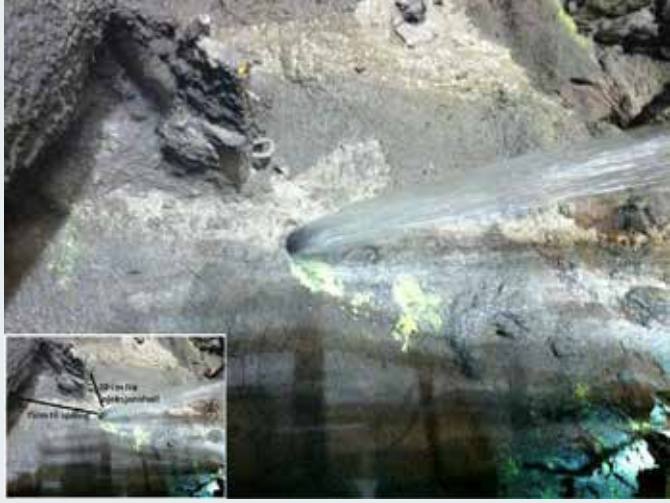
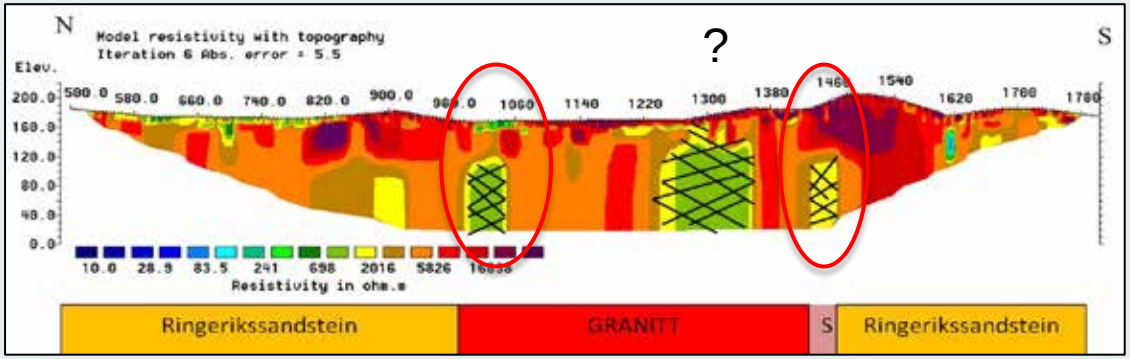
Water leakage in Granite at Holm the Holmestrand tunnel





Position	Length (m)	Average Q-value	Comment
79200 - 79350	150	0,8	Deep weathered granite with huge amount of water
79445 – 79485	40	0,5	Crushed zone in contact between granite and syenite

Two structures at contact zone of the granite, one central in granite

Poor rock quality (Q < 1) and much water (500 l/min in single borehole)

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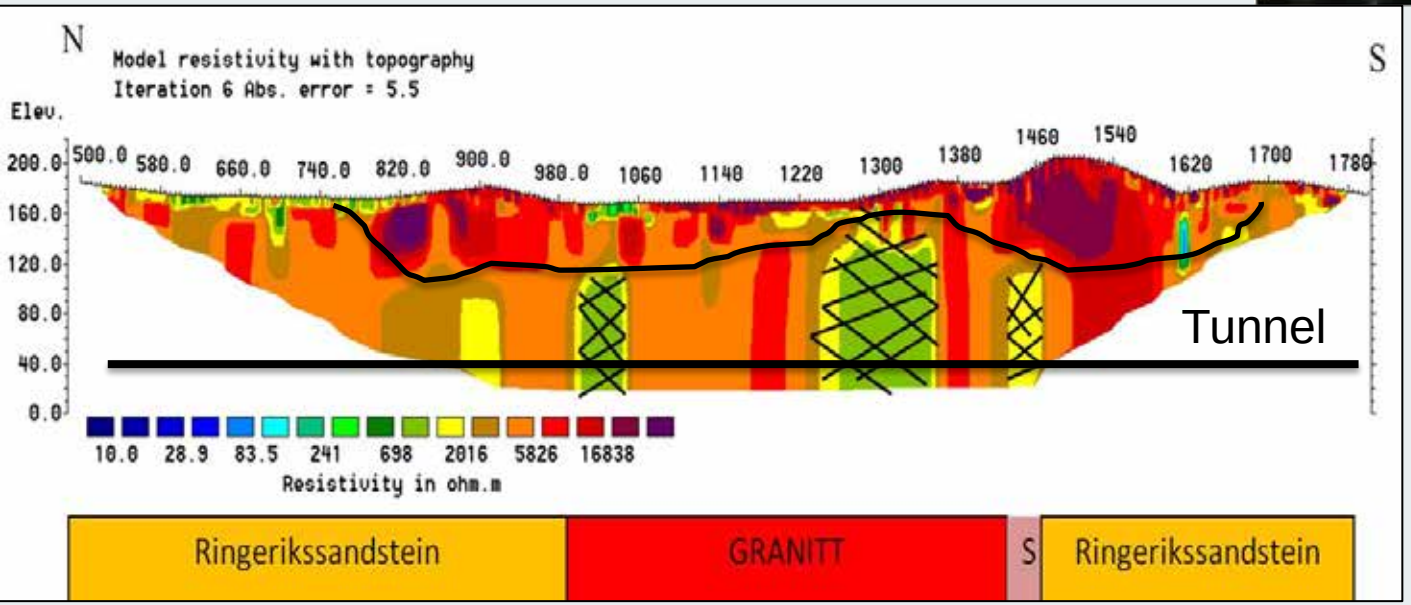

Structures do not reach the surface

Structures seems to reach tunnel level

According to model, Resistivity indicate water problems (700 to 2000 Ωm)

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Summary geophysical methods

Geophysical method	Location of zone	Location below clay	Thickness of zone	Dip of zone	Depth extent	Clay minerals
AMAGER	+	+	-	-	-	+
VLF-EM	+	-	-	-	-	-
SEISMIC	+	+	+	-	-	+ (?)
RESISTIVITY	+	-	+	+	+	+

We have methods for **location** and **characterization** of fracture zones in bedrock.

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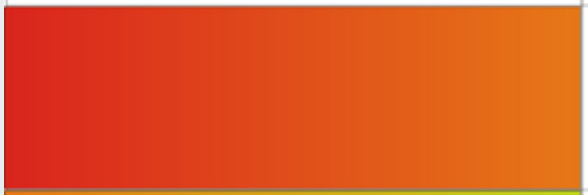
Summary geophysical methods

Resistivity values (NGU colour scale)	Resistivity values	Characterisation
	> 3000 Ωm	Good rock quality
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Method indicate possibility for geometrical caracterisation of fracture zones

Depth extend

Dip direction

Thickness

Rønning et al. 2013

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References (se Conference Proceedings):

- Rønning, J.S., Ganerød, G.V., Dalsegg, E. & Reiser, F. 2013: Resistivity mapping as a tool for identification and characterization of weakness zones in bedrock - definition and testing of an interpretational model. Bull. Eng. Geol. Environment Volume 73, Issue 4 (2014), Page 1225-1244.
- Rønning, J.S., Dalsegg, E., Drageset, L., Ganerød, G.V. & Wiig, Hanne Sagen 2015: Resistivitetsmålinger langs jernbanetunnel Holm – Nykirke. Hva kan vi lære? Fjellspregningsteknikk/Bergmekanikk/Geoteknikk 2015, artikkel 31. (15 sider).

Takk for oppmerksomheten!

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