Kairausten ja in situ geofysiikan integroinnista

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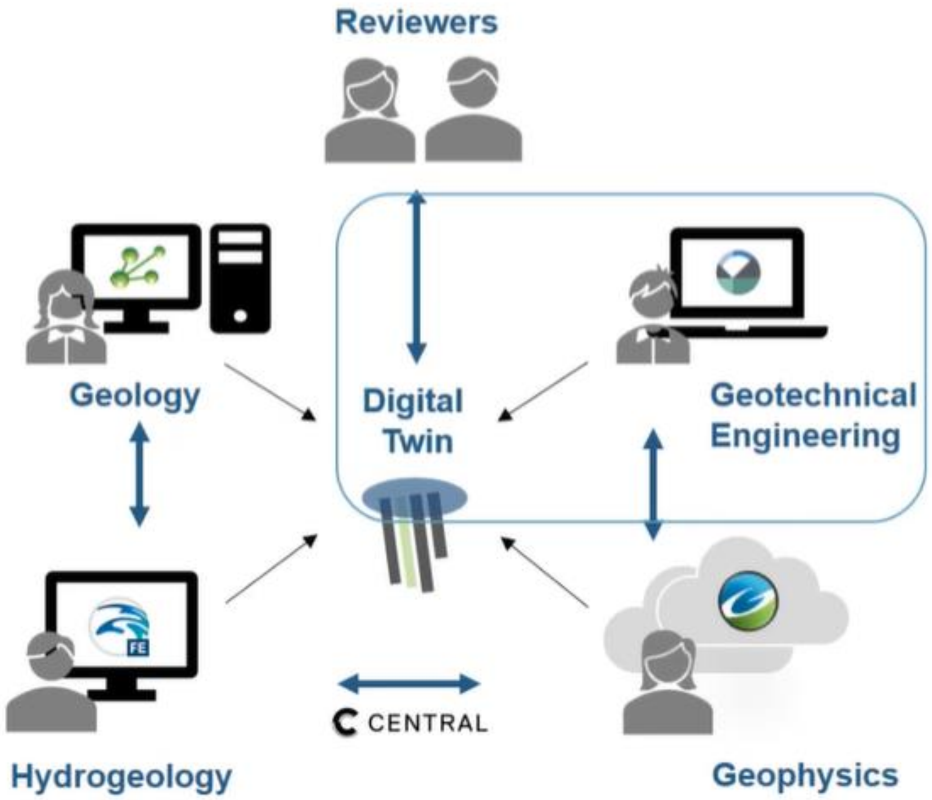
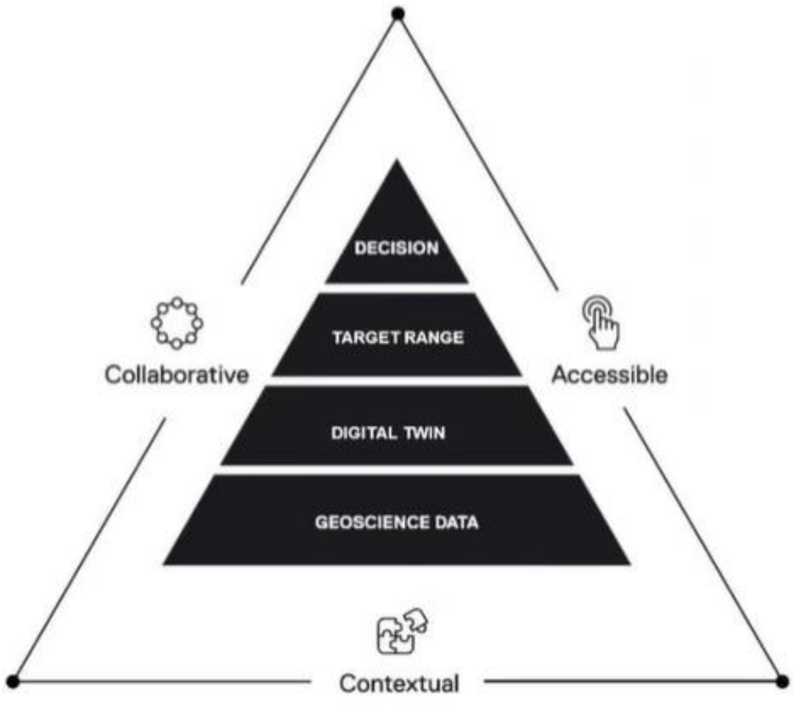
Bentley Systems-Seequent (2020) Infrastructure Digital Twins – Connect the Physical and Virtual World, Synchronize work, gain greater visibility, and make sense of the right data at the right time across the lifecycle of assets

"When working in a global multi-disciplinary team, **transparent flow of information** and **uninhibited communication** are key factors to comprehensive digital twin modelling."





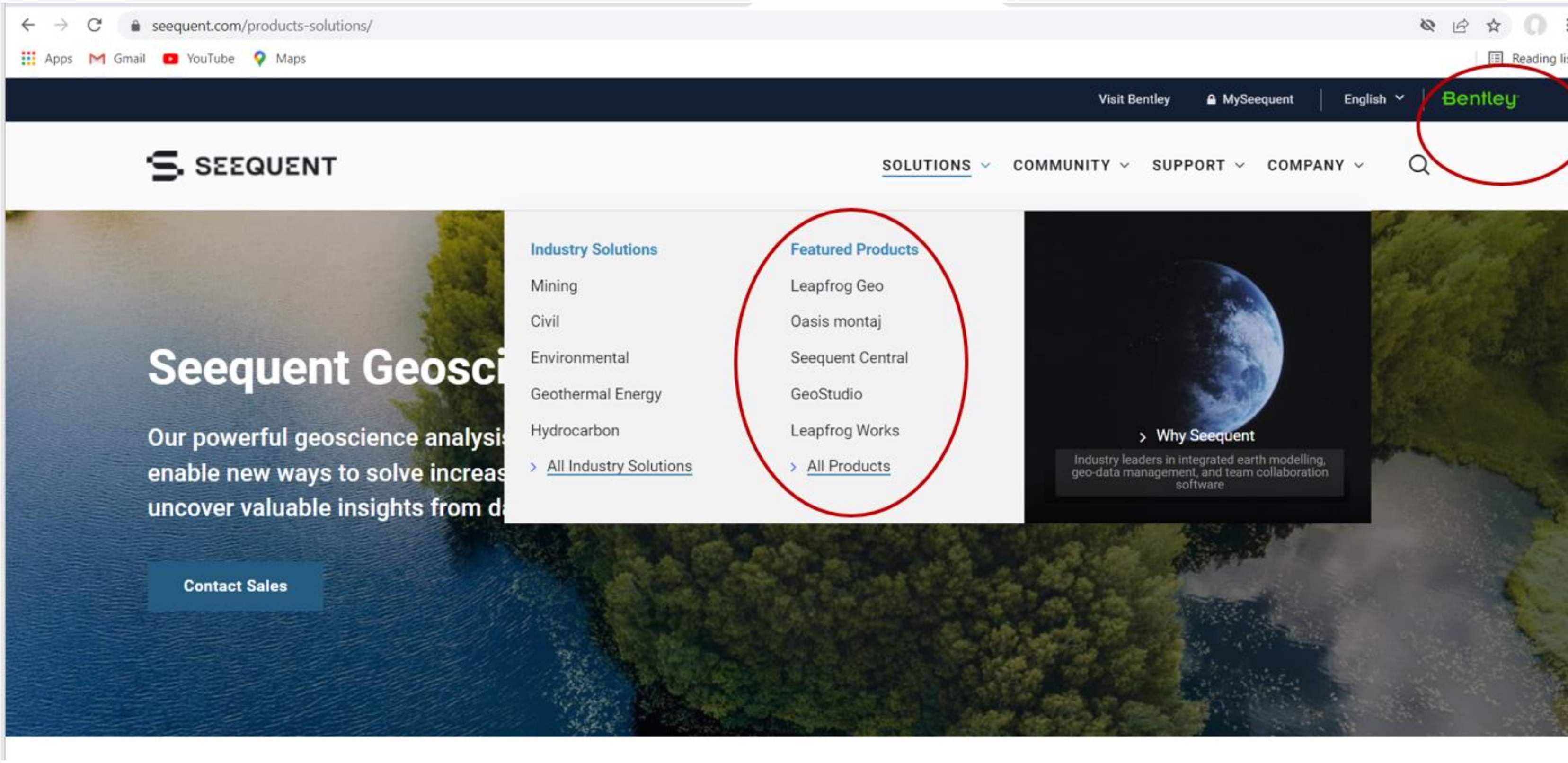
Bentley Systems Leapfrogs into 3D Geological Modeling with Billion Dollar Acquisition

Seequent will help Bentley rule infrastructure with above-ground and below-ground modeling.

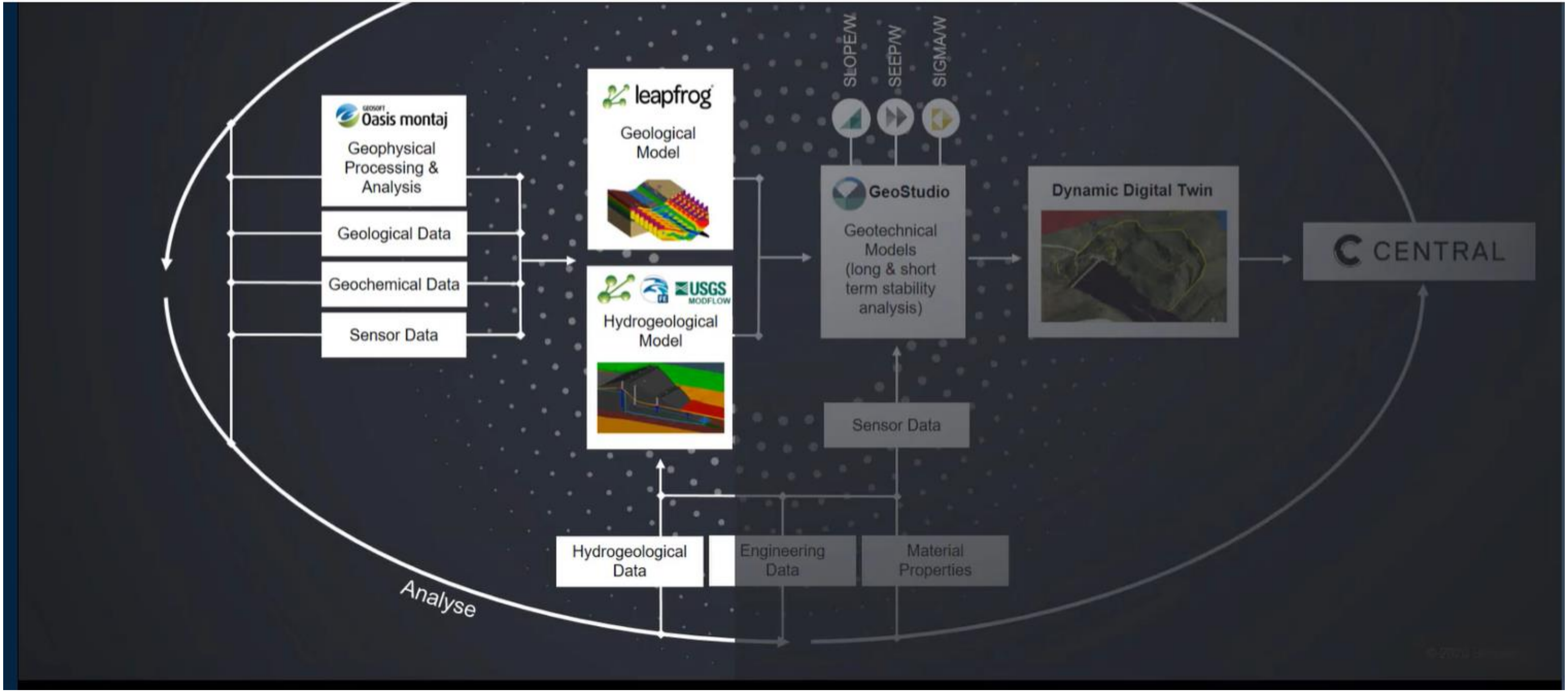
WRITTEN BY Rita Stange | PUBLISHED Mar 23, 2021 | READING TIME ~9 mins | LISTEN TO STORY

A natural fit. Bentley, a leader in modeling infrastructure above the ground, is to acquire Seequent, a leader in belowground modeling.

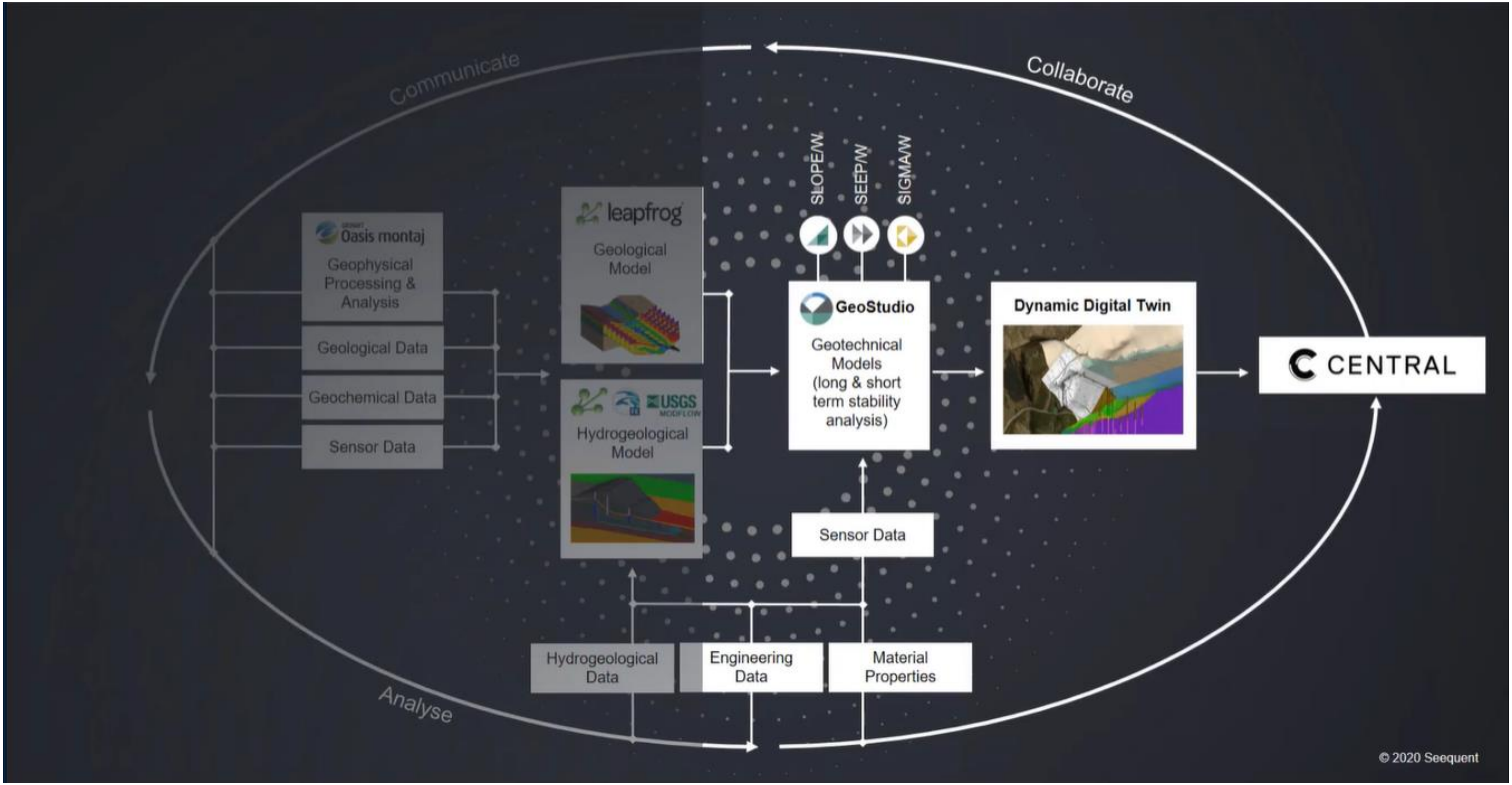
"Data/information is only valuable if it is interpreted in the context of the digital twin"



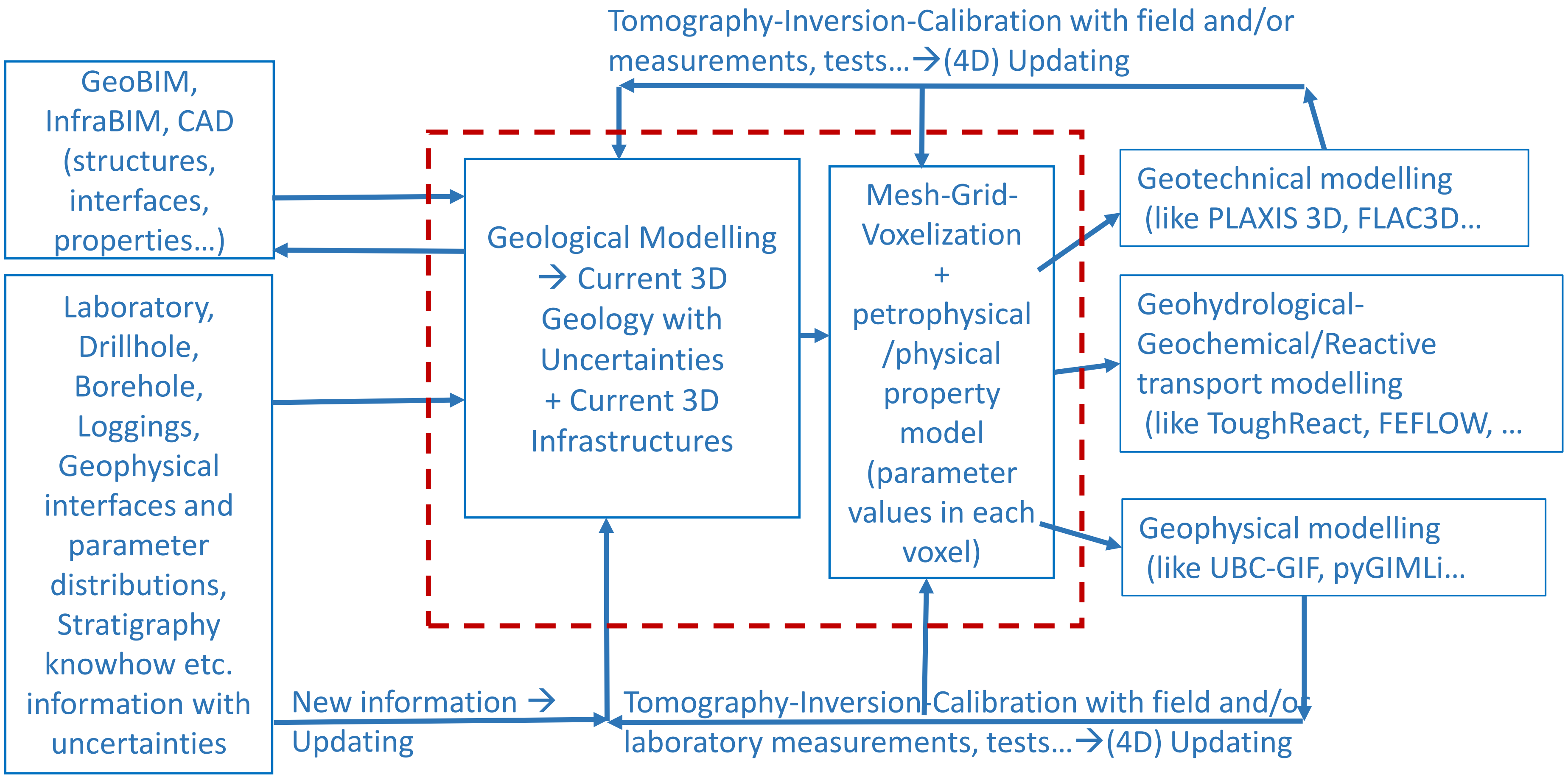
Bentley Systems – Dynamic Digital Twin approach



Bentley Systems – Dynamic Digital Twin approach

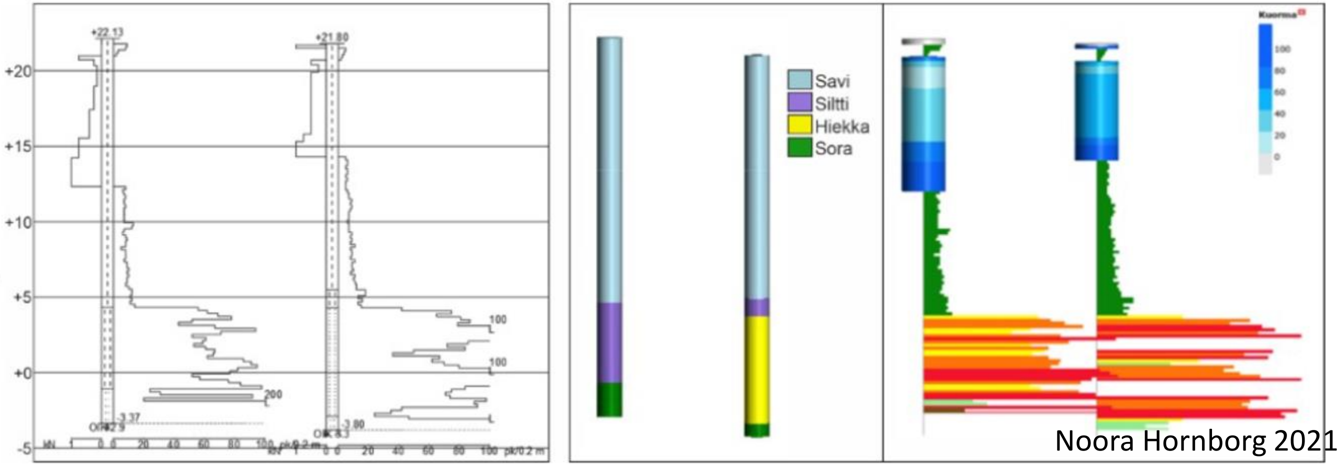


Juhanin "Digital Twin" kaavio (2018; BIM goes underground esitelmä): 3D underground modelling to civil engineering industries – 3D geological modelling, dynamic model updating and behaviour modelling

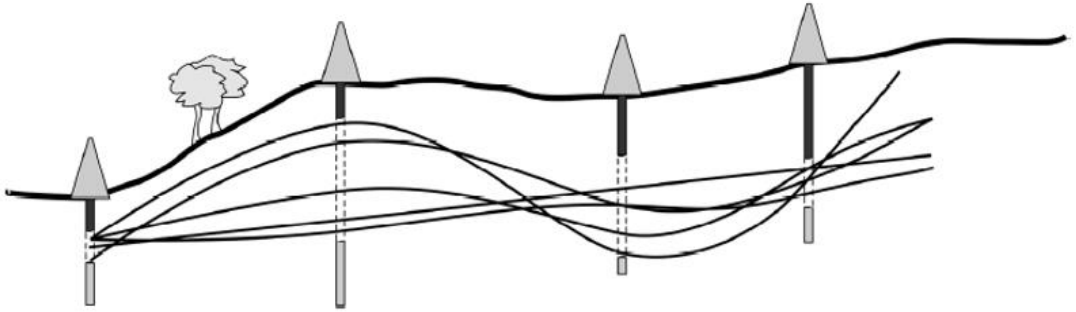


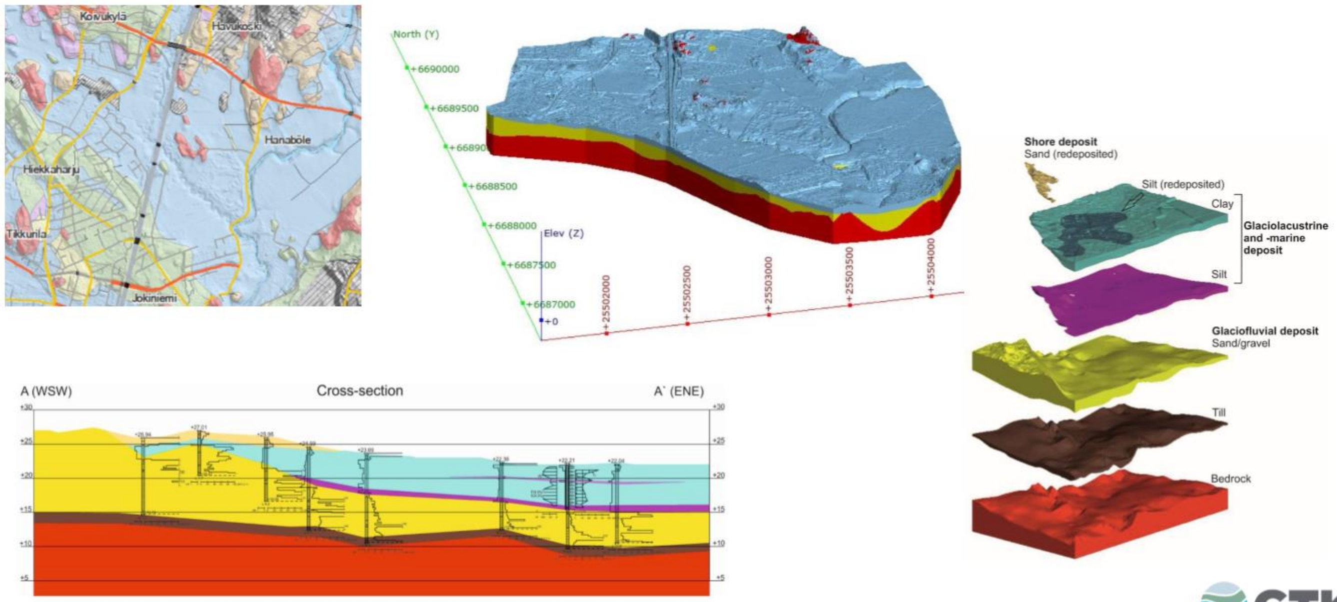
Implicit modelling - Leapfrog 3D

- Less control from the modeller
- The model is created based on the internal algorithms of the software
- The model is directly connected to the database
- Automatic update of the model
- Optimal approach for large borehole data sets

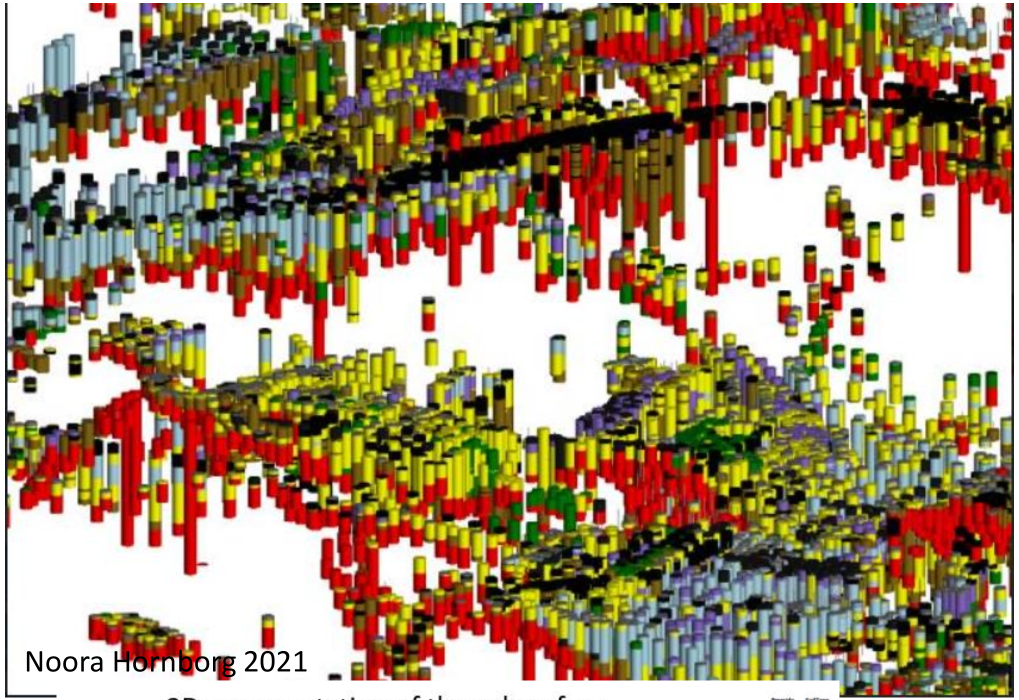


VANTAA, HIEKKAHARJU: ESIMERKKI SAVEN JA SAVENALAISTEN HIEKKOJEN TUTKIMUKSESTA JA MALLINNUKSESTA

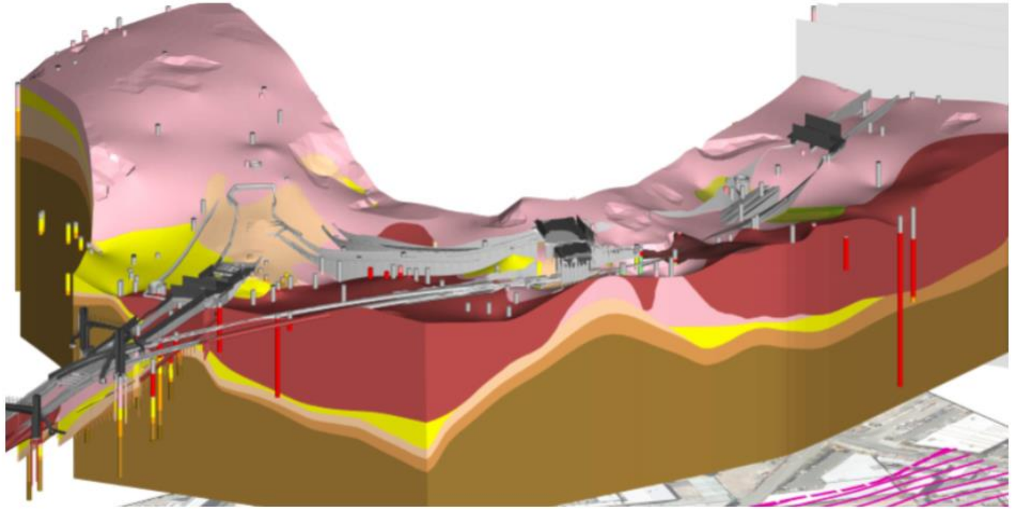




Gtk: Noora Kähkölä & Emilia Kosonen 2019

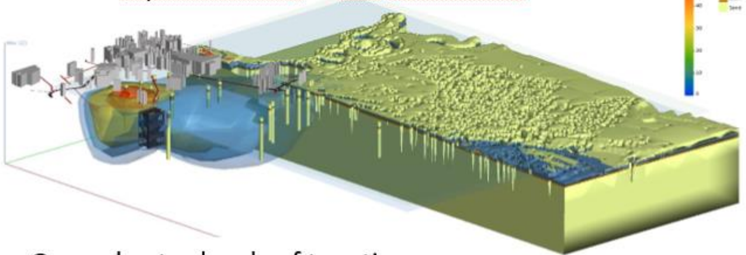


Noora Hornborg 2021

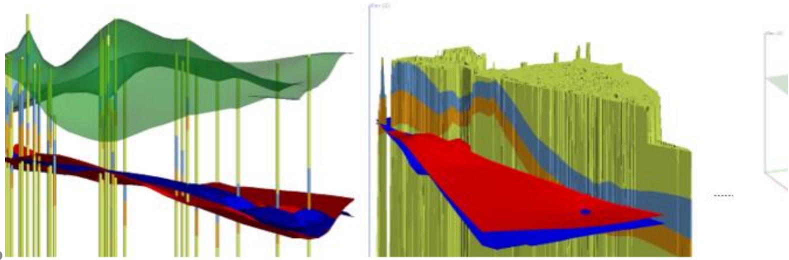


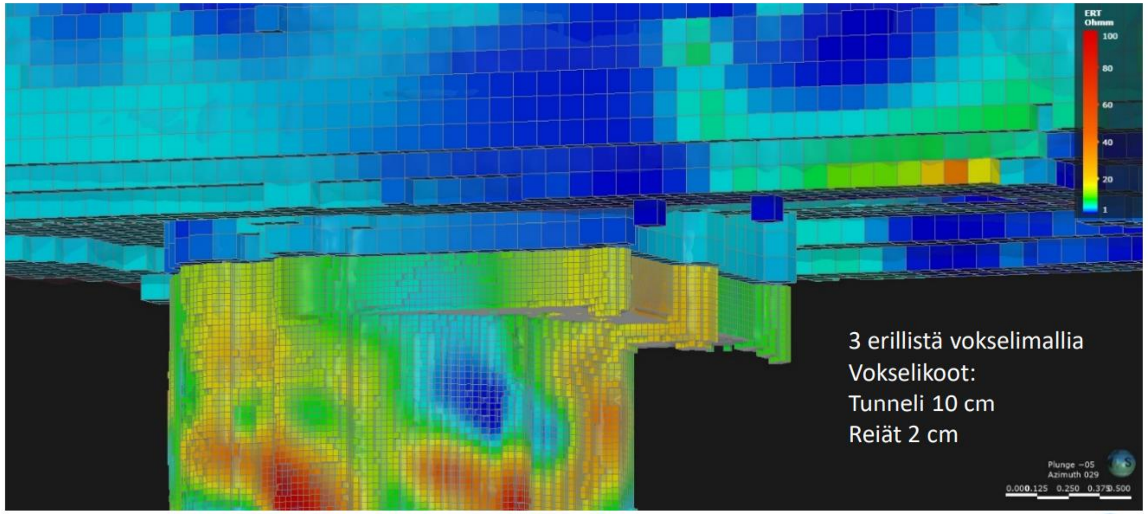
Seequent/Leapfrog 2019; TunnelTalk.com)

3D representation of the subsurface

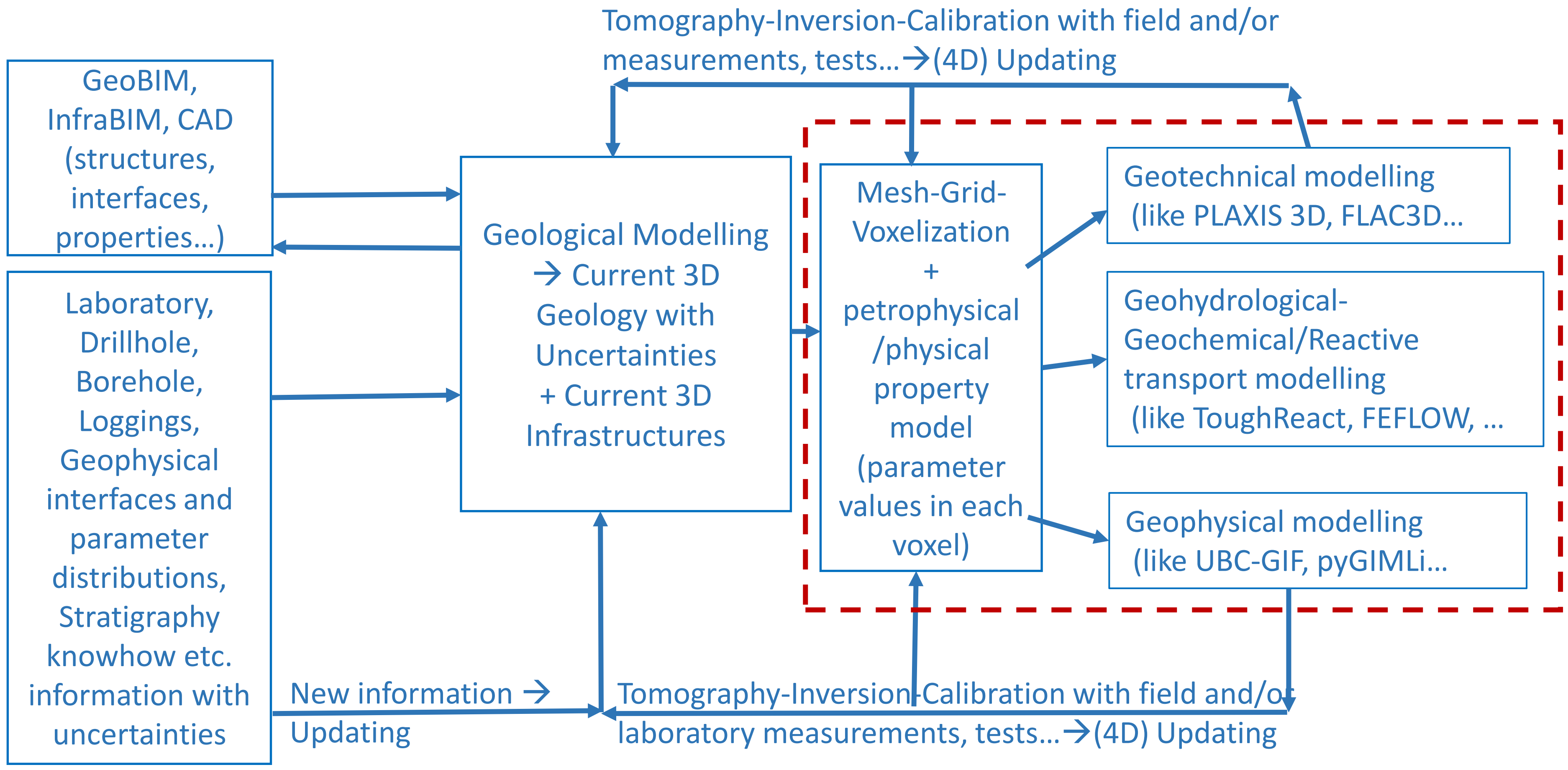


Groundwater levels of two time periods; groundwater relative to lithology

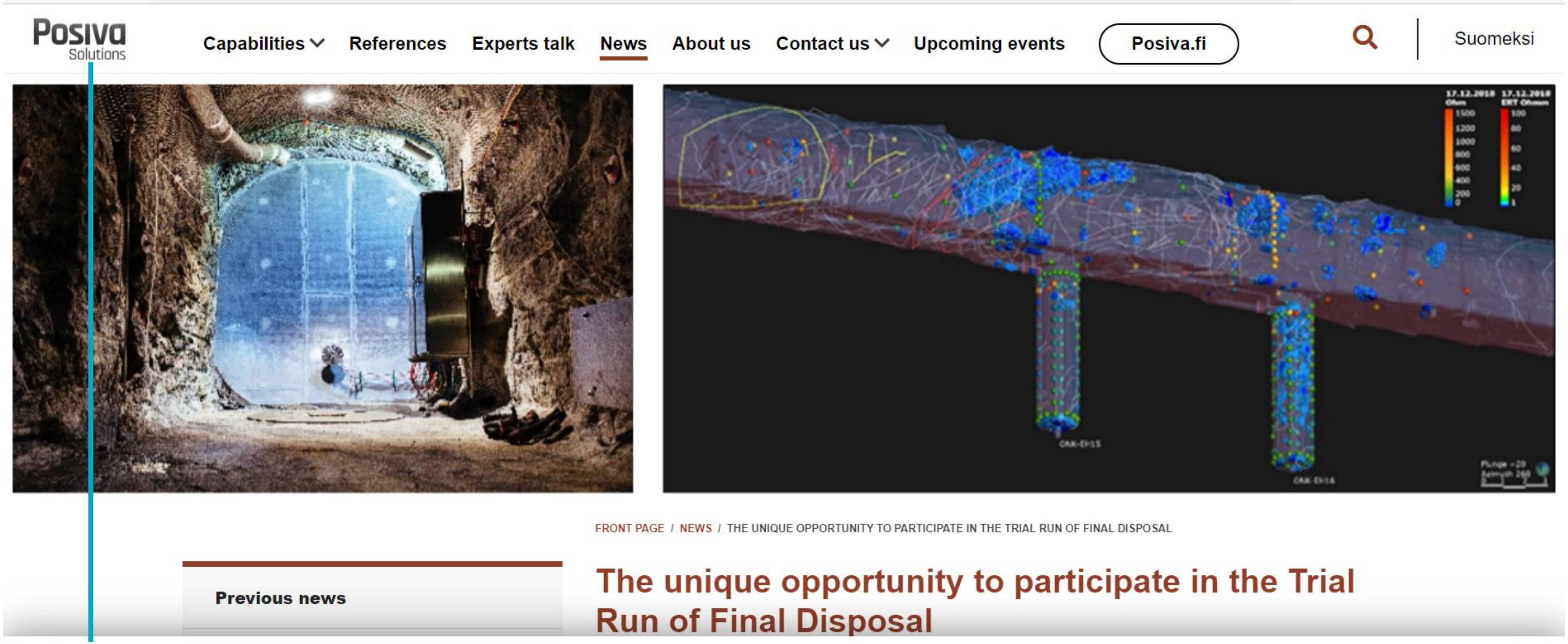




3D underground modelling to civil engineering industries – 3D geological modelling, dynamic model updating and behaviour modelling



[Posiva Solutions - The unique opportunity to participate in the Trial Run of Final Disposal]



Phases of the inversion process

Input
- electrode locations x, y, z
- All measured resistances and electrode numbers linked to each individual resistance measurement
- mesh generation

→

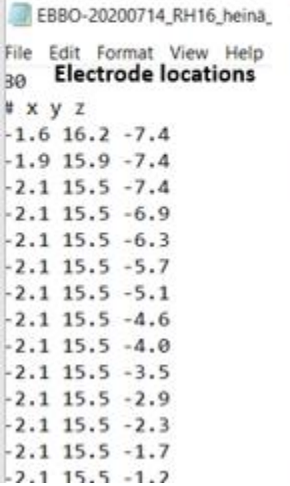
3D inversion
-separately for two buffers and tunnel volume
-starting models, reference models as well as possible model constraints

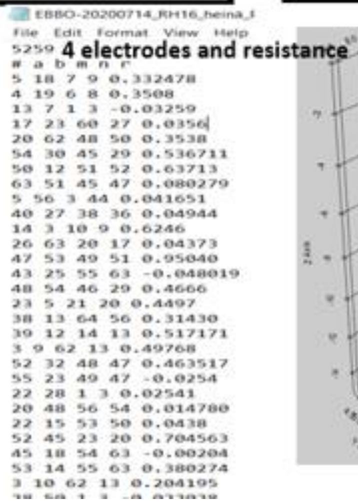
→

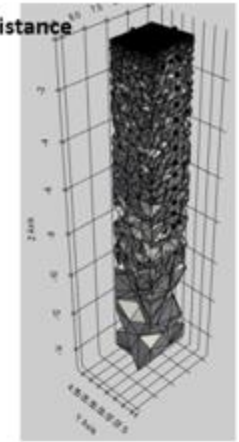
Results
-resistivity value for each element in the 3D finite element mesh

→

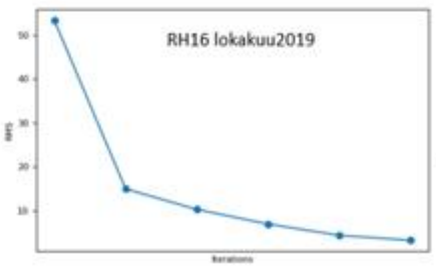
Visualization/ analyzes
-Leapfrog Geo

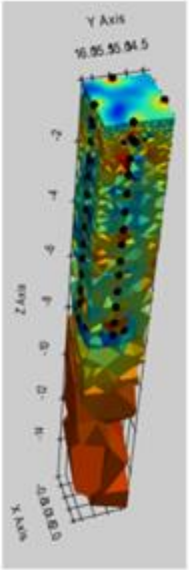


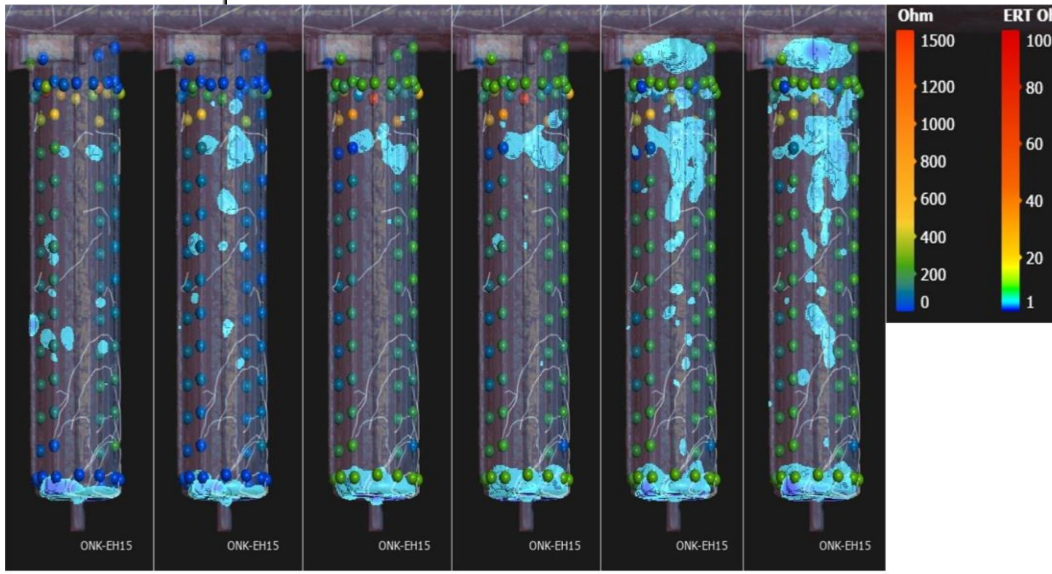




Normal regularization

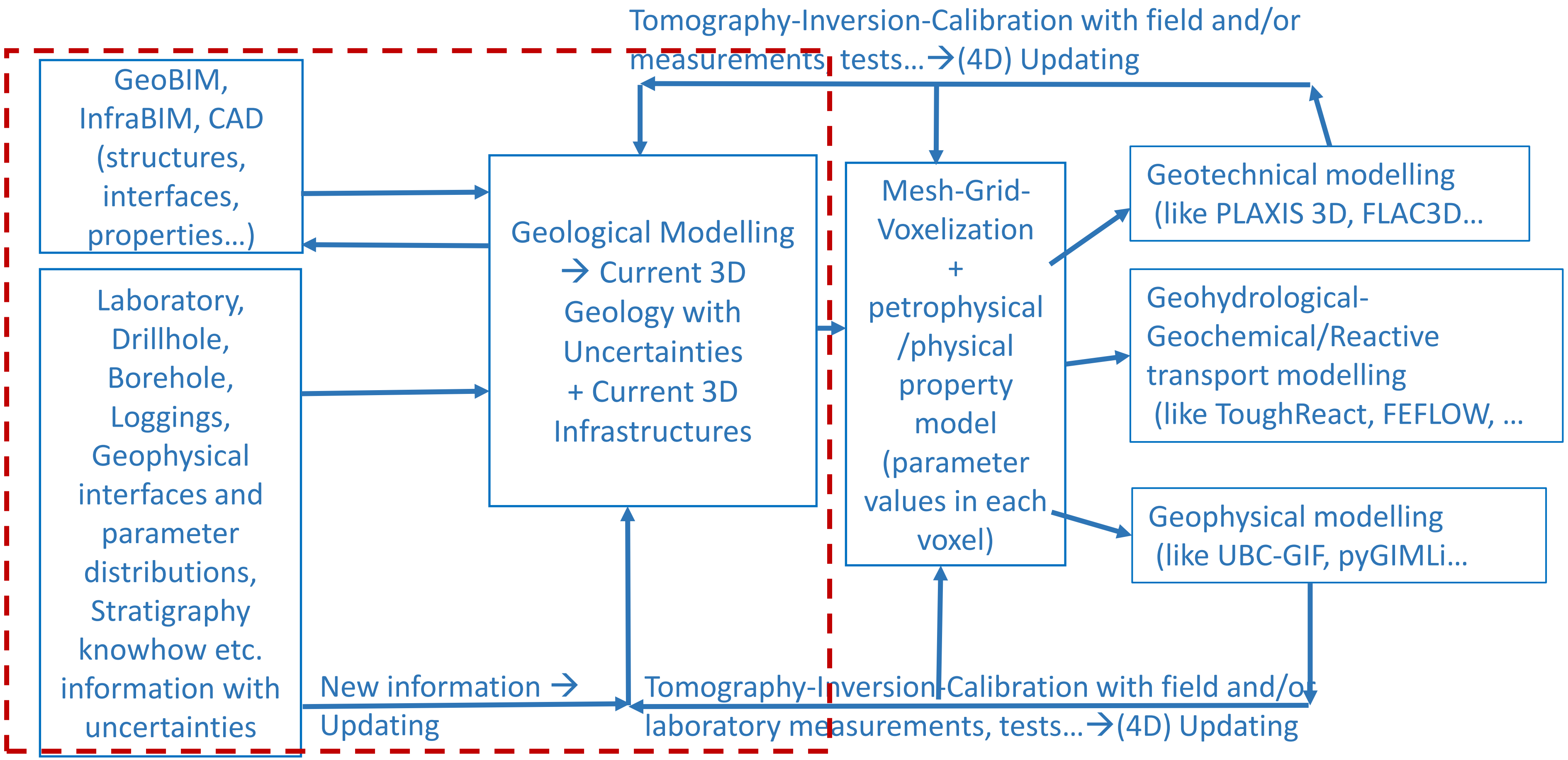






28.8.2018 | 30.10.2018 | 17.12.2018 | 15.1.2019 | 26.2.2019 | 26.3.2019

3D underground modelling to civil engineering industries – 3D geological modelling, dynamic model updating and behaviour modelling

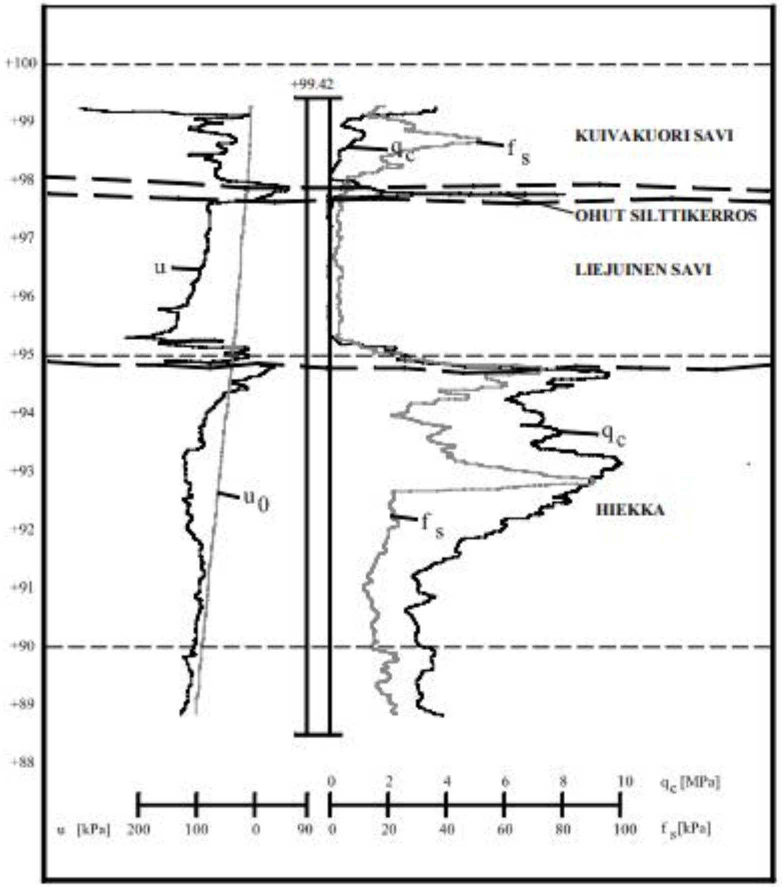


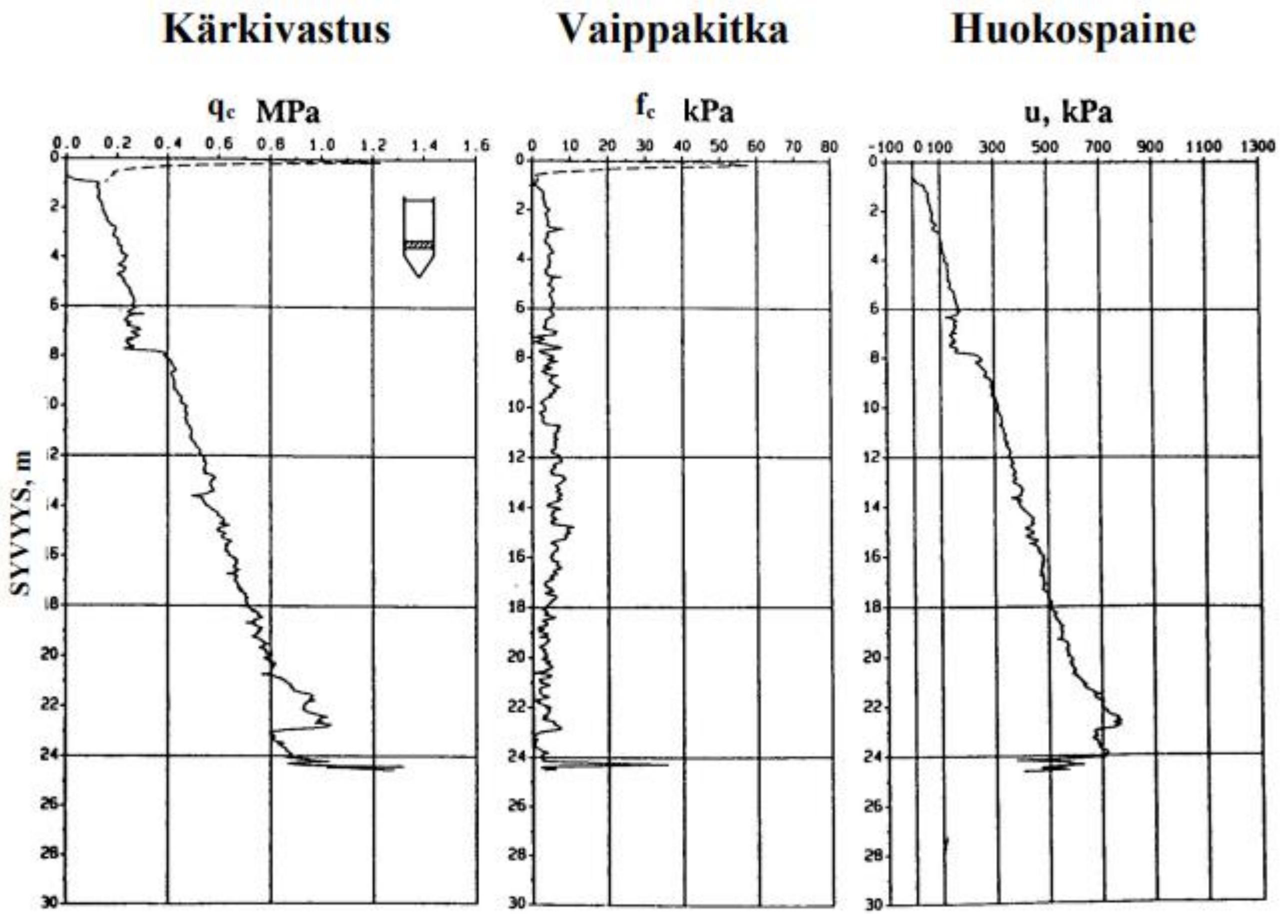
Interpretable machine learning and automated interpretation of CPT and Weight Sounding data (adapted partly from Nynke ter Heide (2019); Interpretable machine learning for geotechnical profiles)

- Normalisation of input parameters; selection of soil types related to each geotechnical measurement (like qc combined with this fs is equal to soil type x)
- Unsupervised algorithm – Clustering (like KMeans, DBSCAN)
- Supervised algorithm – SGDClassifier (This estimator implements regularized linear models with stochastic gradient descent (**SGD**) learning)
- SGDClassifier: we can add new input parameters like depth information, geological knowhow as well as geophysical loggings…

Esimerkki input aineistosta: CPTU kairaus

- Vettä läpäisevien kerrosten tunnistaminen
- Maan kokoonpuristuvuusominaisuudet
- Vedenläpäisevyyden määrittäminen
- Pohjamaan moduulin määritys





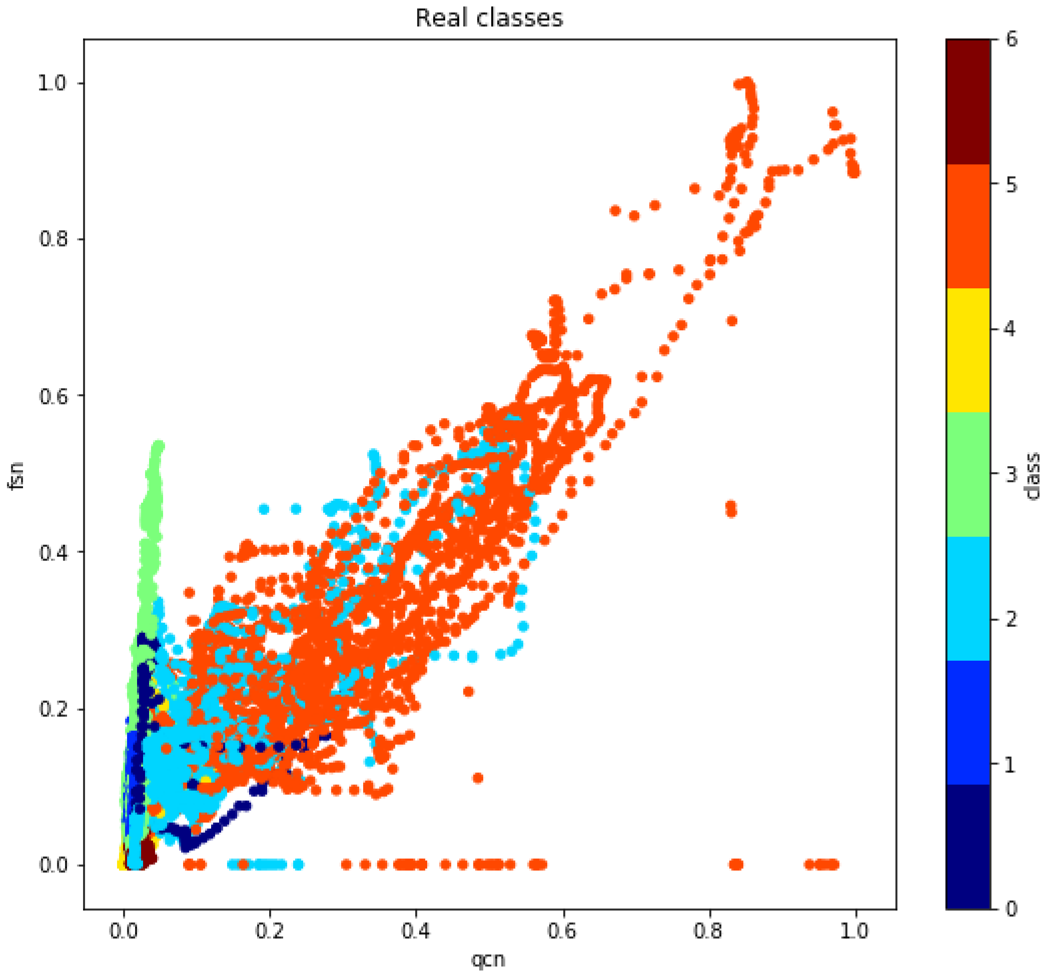
Kuva 1. CPTU-kairauksen mittaustuloksia.

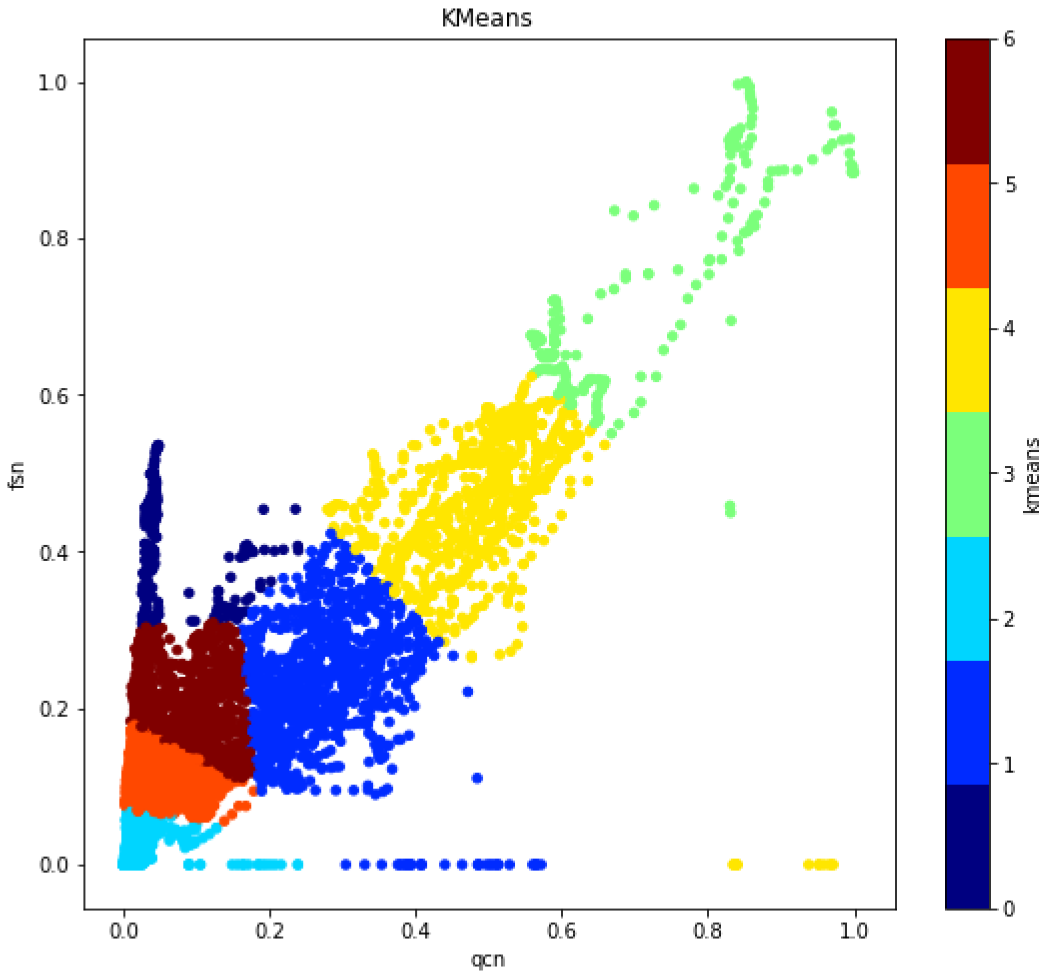
Törnqvist (2001; TPPT)

The data is actually stored in GEF files (a way to exchange this kind of data) which look like this;

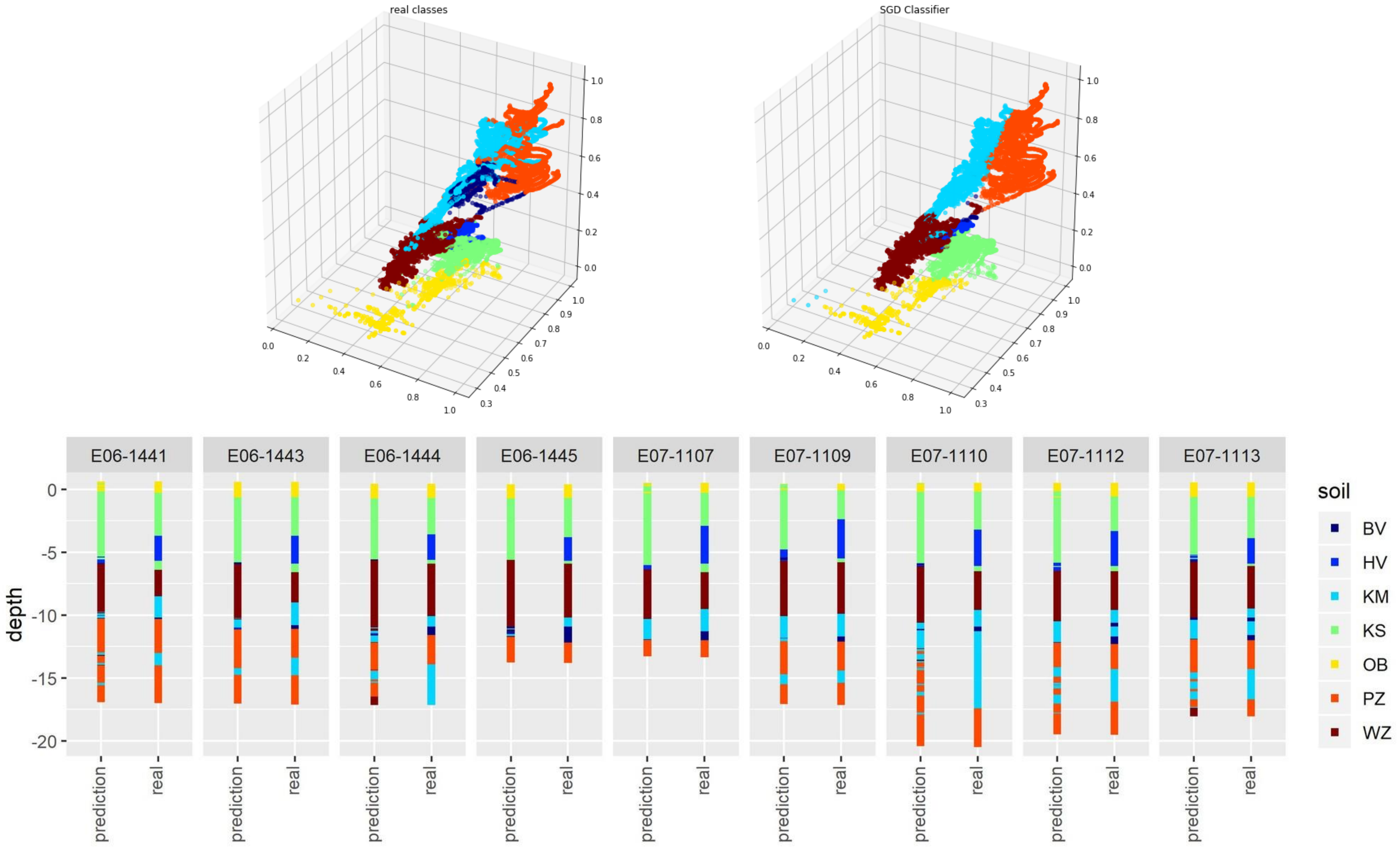
```
    0.0000e+000 2.2240e-001 0.0000e+000 7.7970e-001 5.1130e-001 1.0000e+001 9.3240e-0
    1.0000e-002 2.2650e-001 0.0000e+000 4.0940e-001 7.8660e-001 1.0910e+001 8.8680e-0
    2.0000e-002 3.8760e-001 0.0000e+000 9.7470e-001 5.3100e-001 1.1410e+001 1.1099e+0
    3.0000e-002 3.8760e-001 0.0000e+000 9.7470e-001 5.3100e-001 1.1830e+001 1.1099e+0
    ...
```

```
soils = {
     'E06-1441':'99,OB,-0.6,KS,-4.0,HV,-6.0,KS,-6.7,WZ, -8.8,KM,-10.5,BV,-10.6,PZ,
     'E06-1443':'99,OB,-0.9,KS,-4.0,HV,-6.2,KS,-6.9,WZ, -9.3,KM,-11.1,BV,-11.4,PZ,
     'E06-1444':'99,OB,-1.0,KS,-3.9,HV,-5.9,KS,-6.2,WZ,-10.4,KM,-11.2,BV,-11.9,PZ,
     'E06-1445':'99,OB,-1.0,KS,-4.1,HV,-6.0,KS,-6.2,WZ,-10.5,KM,-11.2,BV,-12.5,PZ,
     'E07-1107':'99,OB,-0.6,KS,-3.2,HV,-6.2,KS,-6.9,WZ, -9.8,KM,-11.6,BV,-12.3,PZ,
     'E07-1109':'99,OB,-0.4,KS,-2.7,HV,-5.8,KS,-6.1,WZ,-10.2,KM,-12.0,BV,-12.4,PZ,
     'E07-1110':'99,OB,-0.5,KS,-3.5,HV,-6.4,KS,-6.8,WZ, -9.9,KM,-11.2,BV,-11.6,KM,
     'E07-1112':'99,OB,-0.9,KS,-3.6,HV,-6.4,KS,-6.8,WZ, -9.9,KM,-10.9,BV,-11.2,KM,
     'E07-1113':'99,OB,-0.9,KS,-4.2,HV,-6.2,KS,-6.4,WZ, -9.8,KM,-10.5,BV,-10.8,KM,
}
```



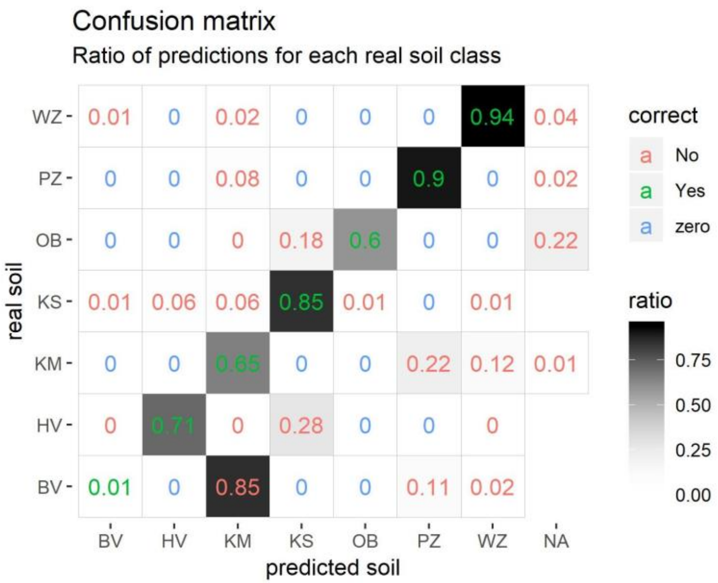


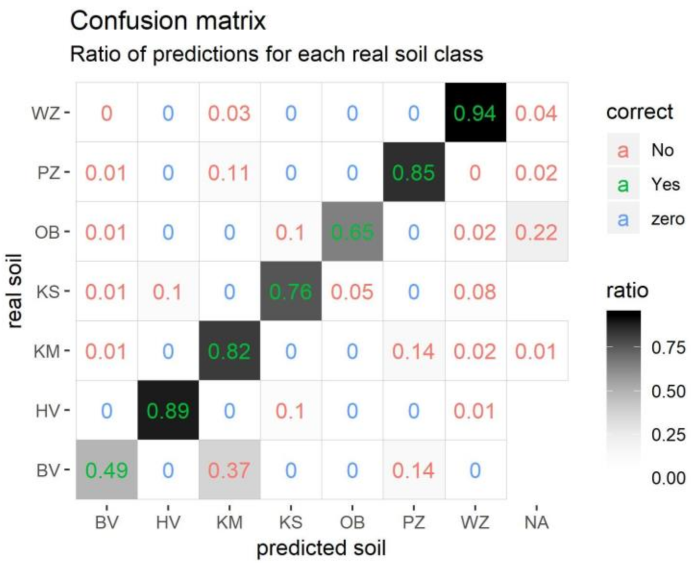
Also, depth information and geological knowhow…



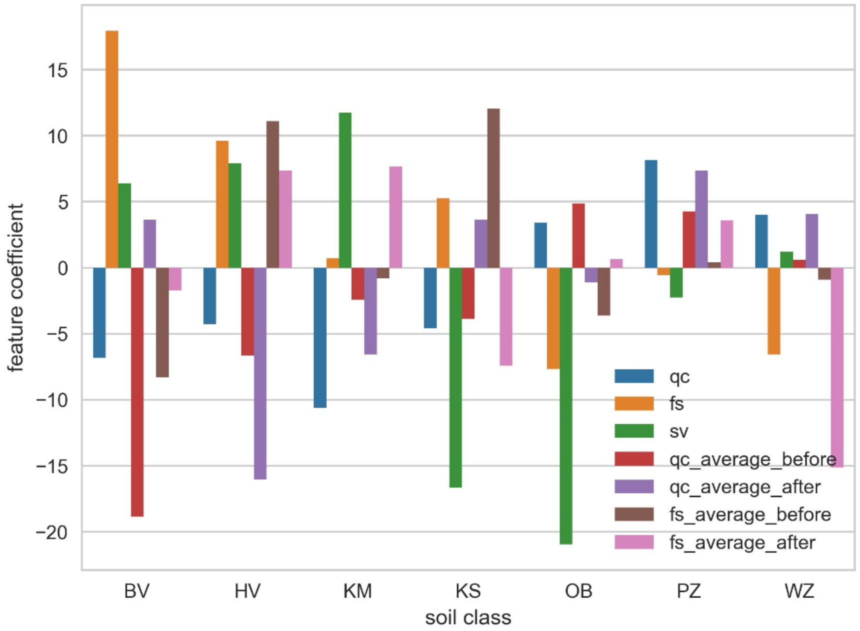
Interpretable machine learning…

Esim. Nähdään, että jos todellinen maaperäluokka on “WZ”, tämä on ennustettu oikein sen hetkisellä mallilla 94% (suhde 0.94). Tämä on ennustettu väärin “KM” 3% ja 1% väärin “BV”. Lopuista 4% ei ole ennustetta.





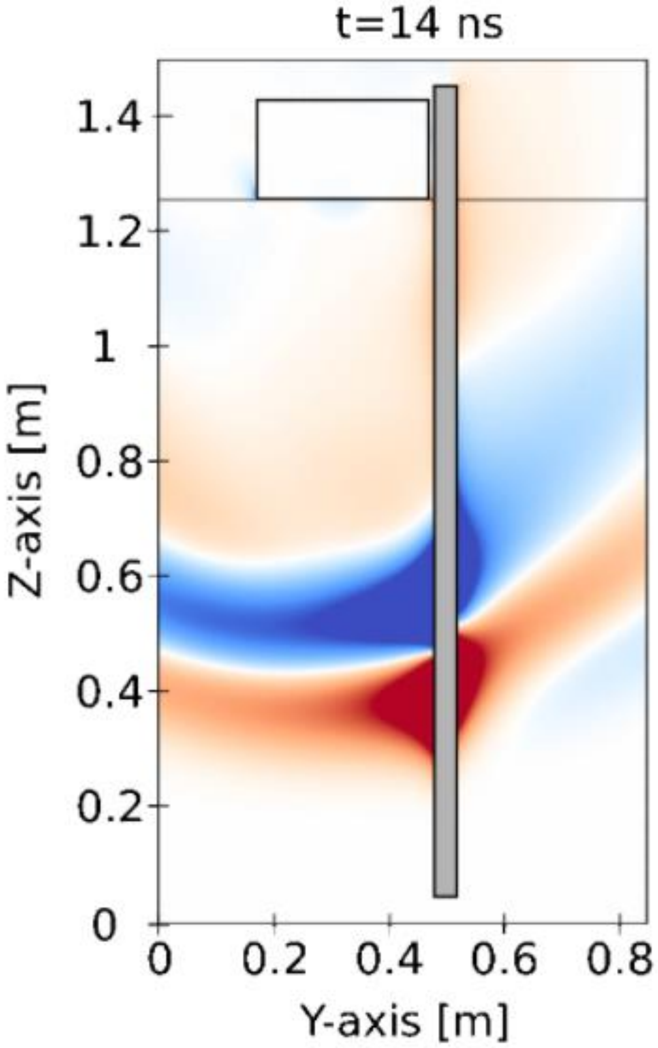
CPT-vasteiden “cone pressure (qcn)” , “friction (fsn)” ja “soil pressure (svn)” painotukset opetetussa mallissa kullekin maaperäluokalle



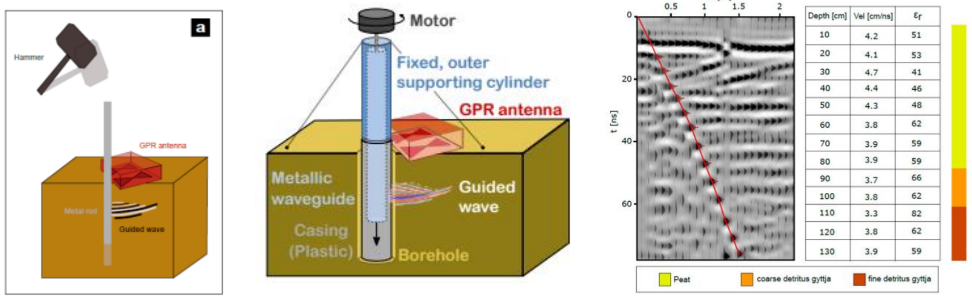
Pystymmekö liittämään kairausprosessiin uusia mittauksia, uutta teknologiaa…?

- Sulautetut järjestelmät (mikrokontrollerit, mikroprosessorit; Arduino, Raspberry Pi…)
- Älykkäät sensorit (mm. MEMS mikromoduulit ja Smart)
- Avoimen lähdekoodin ohjelmistot (esim. Python kirjastot)
- Integroimaan geofysikaalisia mittausjärjestelmiä osaksi kairauksia
- Hyviä kaupallisia esimerkkejä: CPTU, CPTR, RCPTU, Seismic CPT…
- Entä sitten "Guided GPR waves, Resistivity & Induced Polarization (Resistivity as a function of frequency) & Current in Transmission" –mittaukset ?!

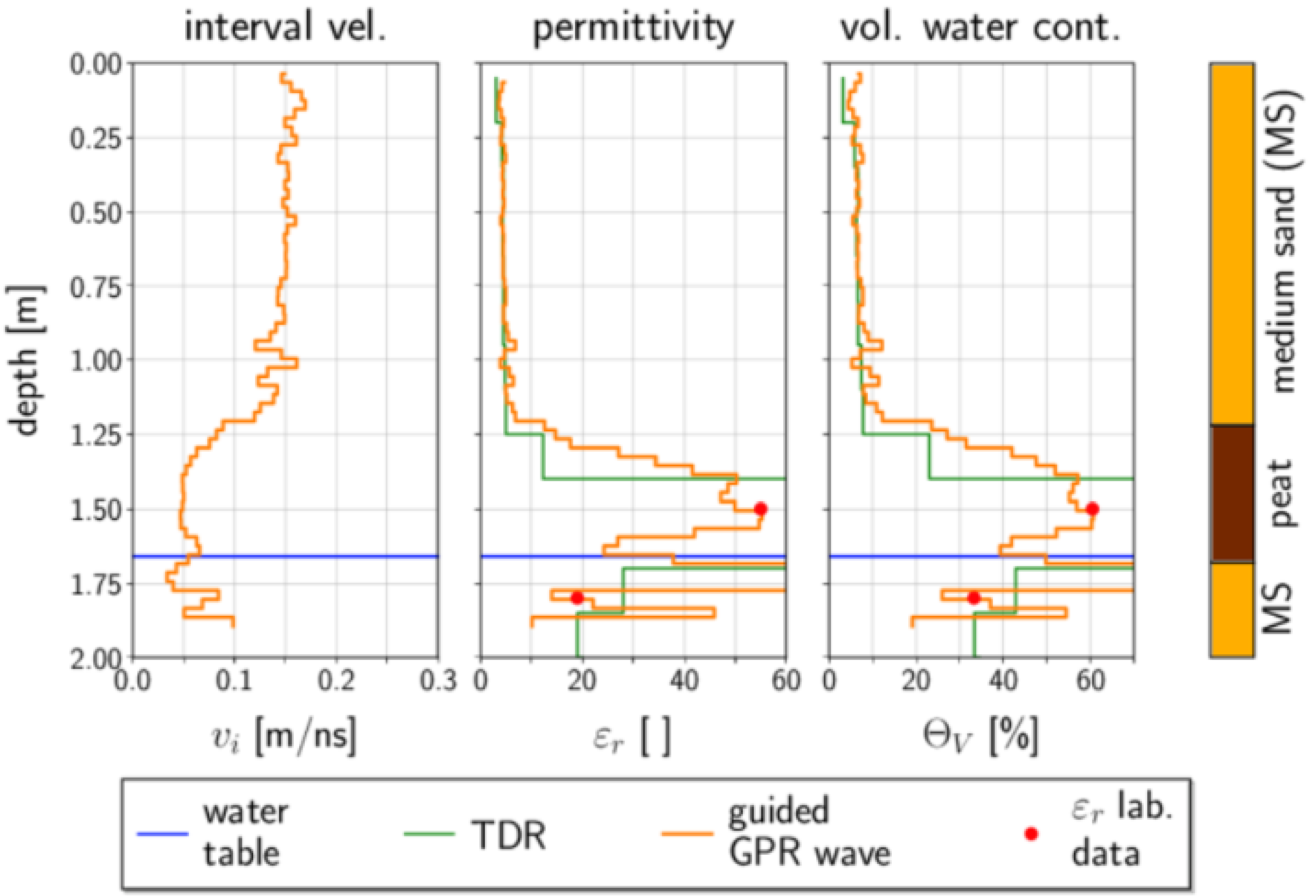
Guided GPR waves



Vertical 2D cut through a 3D model. Shown is the simulation result in form of the E-field distribution (radial component) of the guided wave.elle.



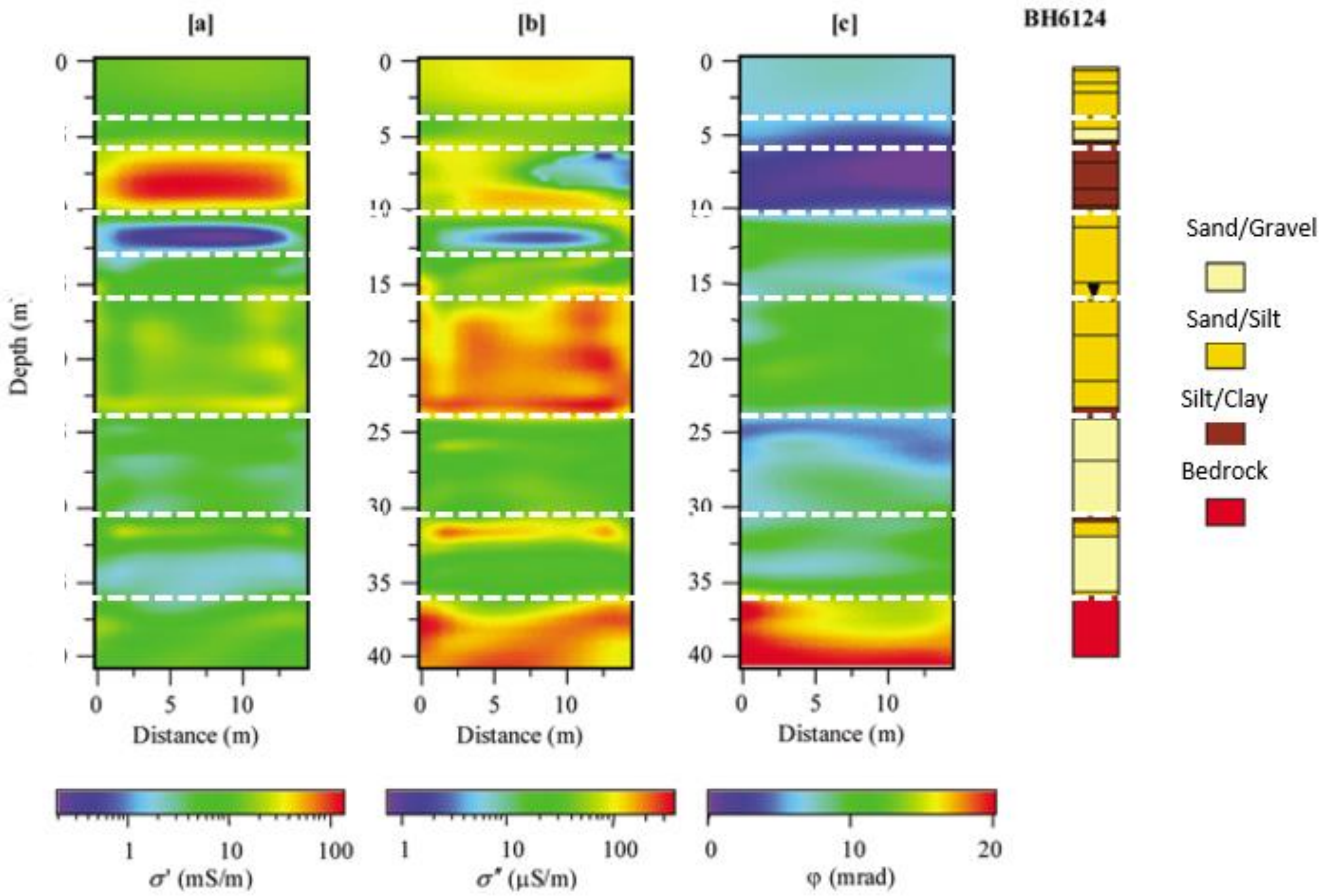
Depth [cm]	Vel [cm/ns]	ε_r
10	4.2	51
20	4.1	53
30	4.7	41
40	4.4	46
50	4.3	48
60	3.8	62
70	3.9	59
80	3.9	59
90	3.7	66
100	3.8	62
110	3.3	82
120	3.8	62
130	3.9	59



Stadler & Igel (2018)

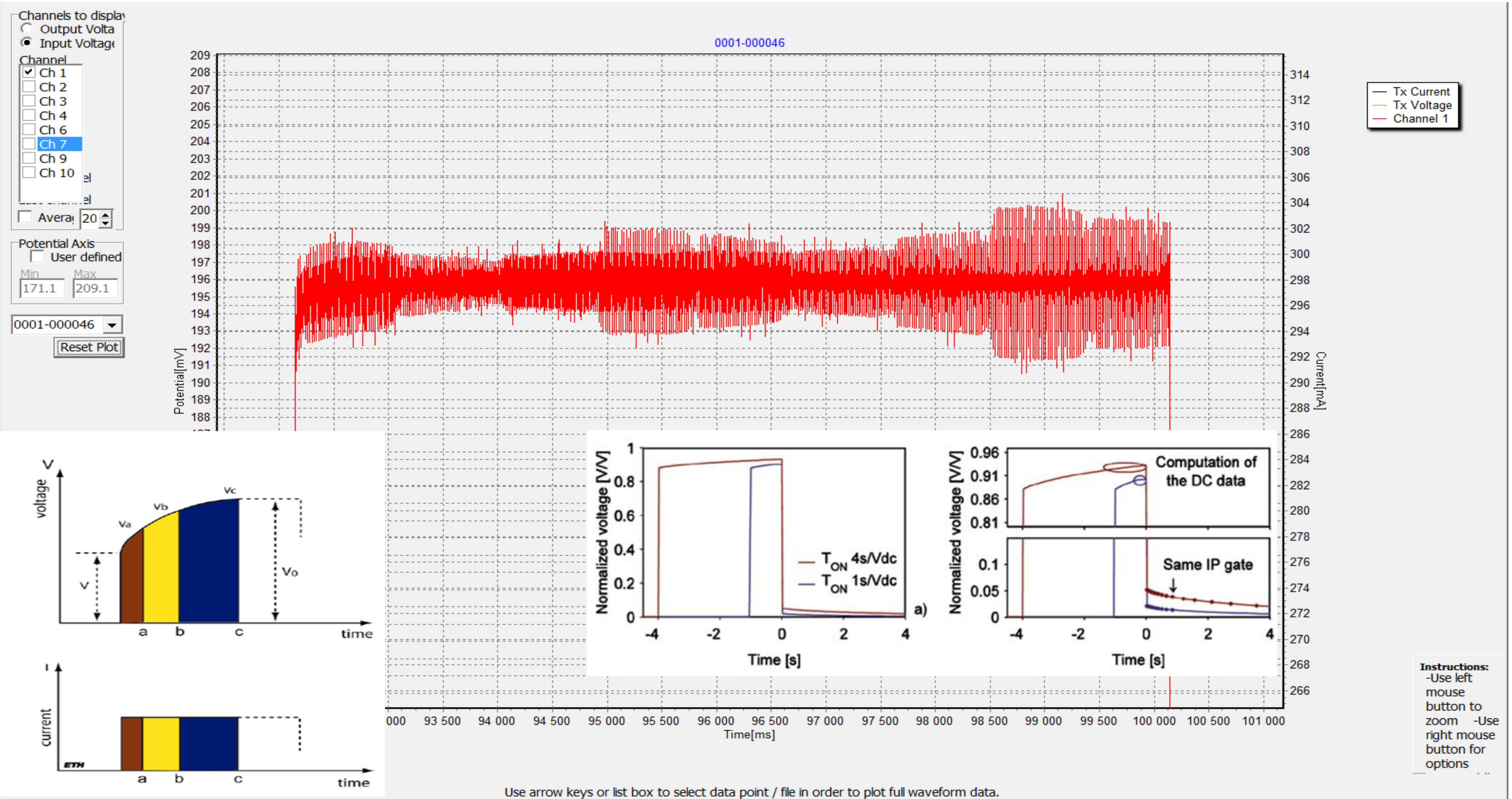
ta

ERT/IP (resistiivisyys taajuuden funktiona) – mittaukset osana kairauksia… Normalisoidut IP-vasteet suoraan verrannollisia kationin vahtokykyyn (CEC) ja raekokoon – elektrodit voidaan irrottaa in situ ja jättää maaperään



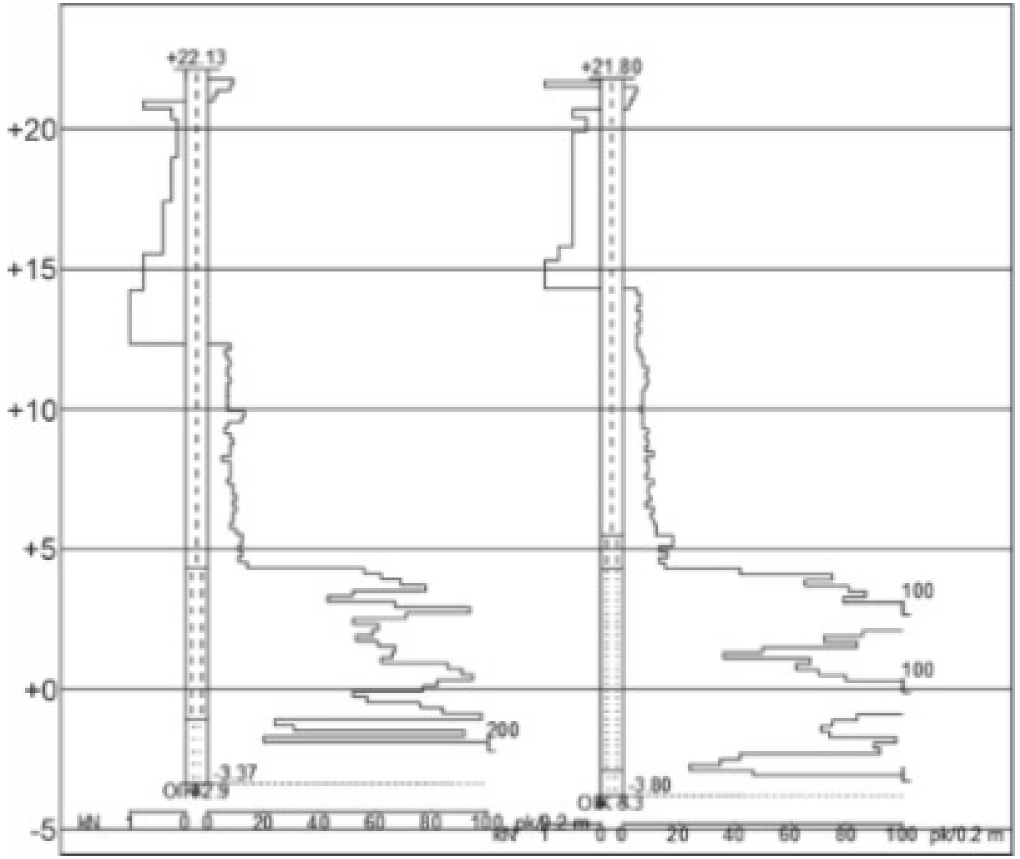
Uutta mikrokontrolleritekniikkaa pitkäaikaiseen monitorointiin

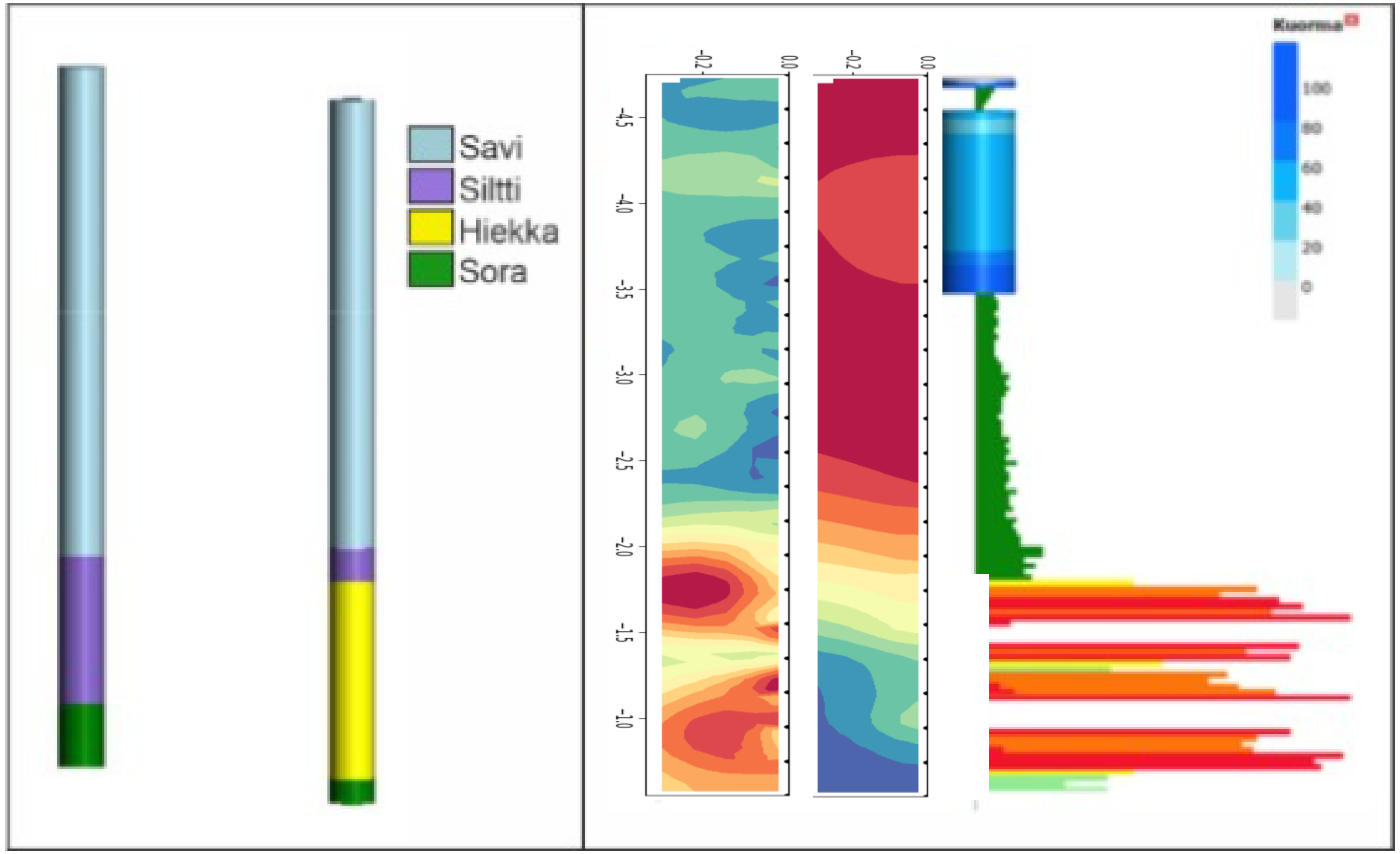
Normalisoidut IP-vasteet suoraan verrannollisia kationin vahtokykyyn (CEC) ja raekokoon
- EU/Modern2020 → The measurement of the IP response in the frequency domain using the time-domain signals when current is ON



Parametric Design → Integrated in situ geotechnics and geophysics

Resistivity &
normalized IP-response





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Approach tested with Olkiluoto overburden data

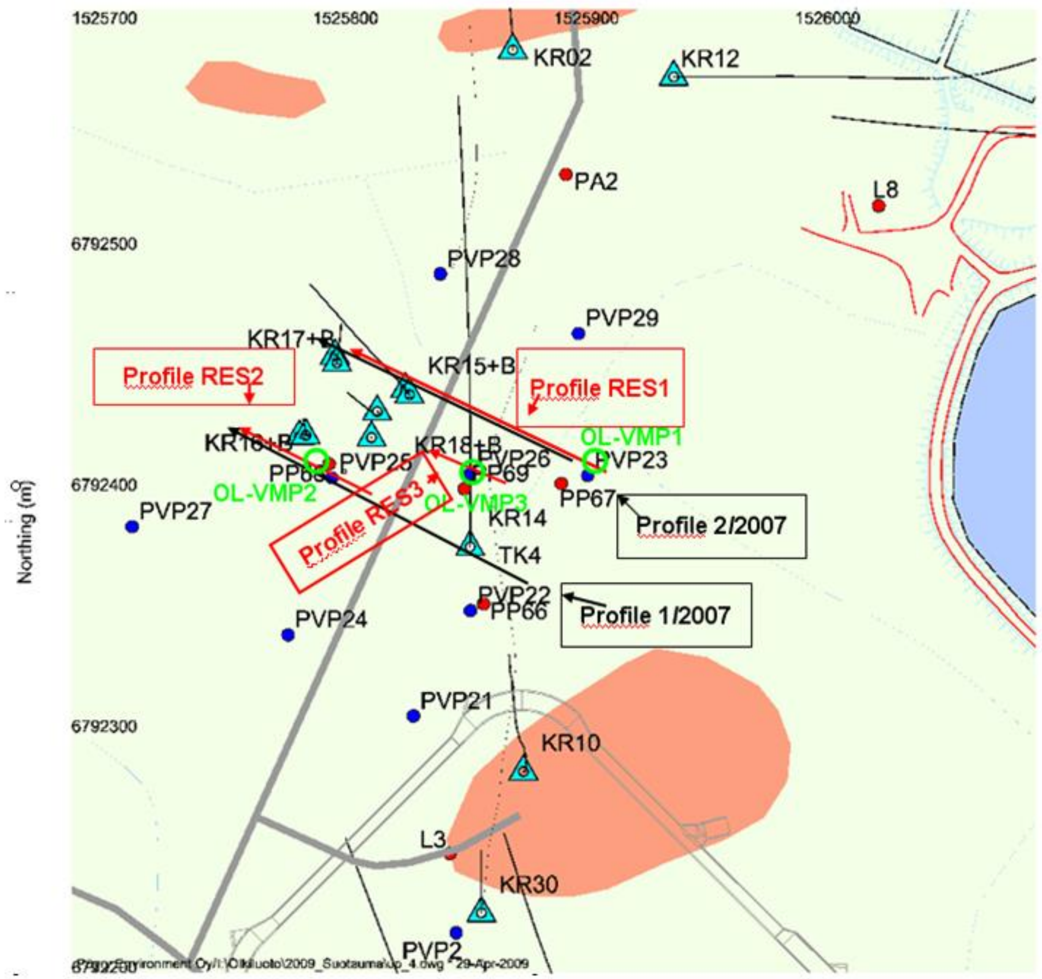
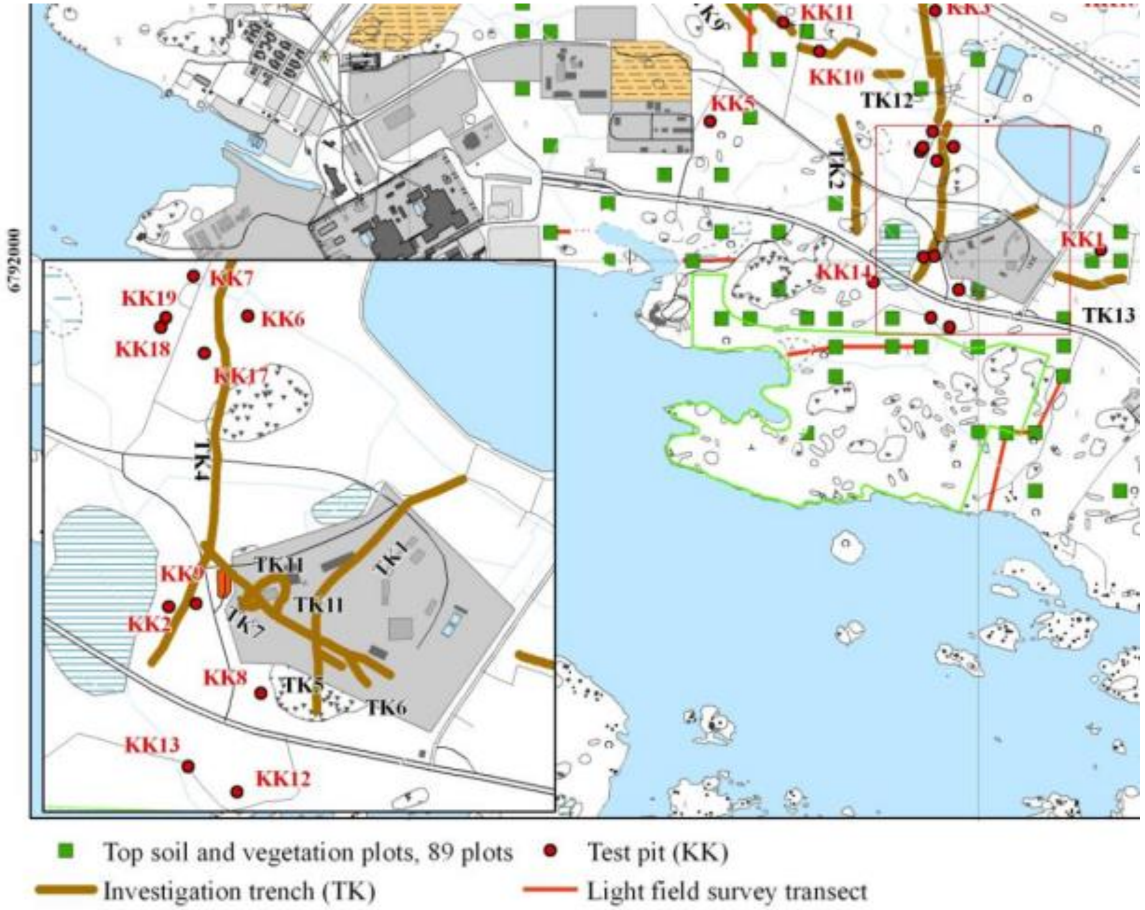


Figure 1-1. Resistivity profiles (RES1, RES and RES3) during 2008-baseline and 26-28.5.2009 and 8-10.12.2009 monitoring phases (red lines) at the infiltration experiment site. Vertical resistivity measurement tubes (OL-VMP1 – OL-VMP3) are also measured during all measurement events.



Pitkänen, P., Korkealaakso, J., Löfman, J., Keto, V., Lehtinen, A., Lindgren, S., Ikonen, A., Aaltonen, I., Koskinen, L., Ahokas, H., Ahokas, T. & Karvonen, T. 2008. Investigation Plan for Infiltration Experiment in Olkiluoto. Olkiluoto, Finland: Posiva Oy. Working Report 2008-53. 38 p.

WSP_Soil_Classes_Posiva_Olkiluoto_WR_2017-27_web.pdf

Table 2-1. *Classification of the soil and sediment types in the biosphere assessment and their linkage to the key sources of data; abbreviations or codes used in the classification system are in parenthesis. The ISO classification (ISO 14688-1:2002) is included for international context. (Posiva 2012).*

Soil/sediment type	ISO classification	GEO classification [a]	Soil map [b]	Forest surveys [c]	Sea sediments [d]
Rocky soil [e]	boulder (Bo, LBo), cobble (Co)	bedrock; pebble, cobble deposit (Ki), boulder deposit (Lo)	rock soil [f] (19)	exposed bedrock (40), stone field (50)	bedrock[-dominated sediment] [g] (1)
Coarse-grained mineral soil	gravel (Gr)	gravel (Sr); gravelly till (SrMr)	gravel (15); earth fill [h] (6)	gravelly till (11), gravel (21), coarse sand (22)	sand and gravel [i] (3)
Medium-grained mineral soil	sand (Sa)	sand (Hk); sandy till (HkMr)	sand (14); till [j] (16)	sandy till (12), coarse fine sand (23)	till [j] (2), washed sand layer (4)
Fine-grained mineral soil	silt (Si)	silt (Si); silty till (SiMr)	coarse fine sand (12), fine sand (18), very fine sand (13); fine-textured till (20)	fine-textured till (13), fine sand (24), silt (25)	mixed [glacio-aquatic] sediment (5)
Clay	clay (Cl)	clay (Sa)	clay (17)	clay (26)	glacial clay (6), Litorina clay (10), Ancylus clay (7)
Gyttja	–	gyttja, (Lj), mud (Mu)	gyttja/mud (22)	–	recent gyttja clay (8); gaseous sediment [k] (11)
Peat	–	peat (Tv)	sedge peat (21), Sphagnum peat (11); peat production area (5)	sedge peat (31), Sphagnum peat (32)	–

a The soil classification system (Rantamäki *et al.* 1979, Jääskeläinen 2009) most commonly used in Finland.

b Soil map of the Geological Survey of Finland (Haavisto 1983, Haavisto-Hyvärinen & Kutvonen 2007).

c Rautio *et al.* 2004.

d Rantataro 2001, 2002; Rantataro & Kaskela 2009.

e Rock outcrops and thin soils (<30 cm) regardless of the soil type of the deposit; *i.e.* Leptosols (Lilja *et al.* 2006, tables 3 and 8; Tamminen *et al.* 2007, p. 9).

f In the soil map classification of the Geological Survey of Finland, rock soils means < 1m soil deposits; this category includes, but is not limited to, bare rocks or outcrops (Haavisto-Hyvärinen & Kutvonen 2007, ch. 12). This class is often mislabelled as 'bedrock'.

g Although the class was originally labelled as 'bedrock', it was confirmed from the authors of the interpretation of the sediment sounding that the class is characterised similarly to the 'rock soil' in the terrestrial areas (see footnote *f* to this table).

h By assessment decision; most of earth fills (usually containing a varying amount of rubbles) are more similar to gravel than to finer grain sizes especially regarding the nutrients status, stoniness and degree of compaction.

i The combined class of sand and gravel has been considered coarse-grained mineral soils (emphasis on gravel), whereas washed sands are classified here as medium-grained mineral soils.

j This denotes a generic class of tills. Sandy tills cover about 75 % of the till soils in Finland (Haavisto-Hyvärinen & Kutvonen 2007, p. 41).

k 'Gaseous' and gyttja sediments are classified into the same group. Both these sediments are high-organic clays (Rantataro & Kaskela, 2009, p.15)

Code	Soil layer
0	Peat
1	Gyttja
2	Clay
3	Fine mineral soil (FMS)
4	Medium-grained mineral soil (MMS)
5	Coarse mineral soil (CMS)
6	Rocky soil

The soil pit OL-KK19 is situated about 10 m north from OL-KK18. The humus layer was about as thick (20 cm). The mineral soil down to 200 cm was clayey till with stones up to 0.5-1 m in diameter also here. At the depth of 200-235 cm there was grey and tight clay layer. The gravitation plate lysimeters were installed at the depth of 220 cm. The bedrock was not reached. The soil profile of the excavator pit OL-KK19 is presented in Figures 14 and 15. The vegetation is mixed forest.

Lahdenperä, A-M, 2009. Summary of the Overburden Studies of the Soil Pits OL-KK14, OL-KK15, OL-KK16, OL-KK17, OL-KK18 and OL-KK19 at Olkiluoto, Eurajoki in 2008. Posiva WR-2009-109

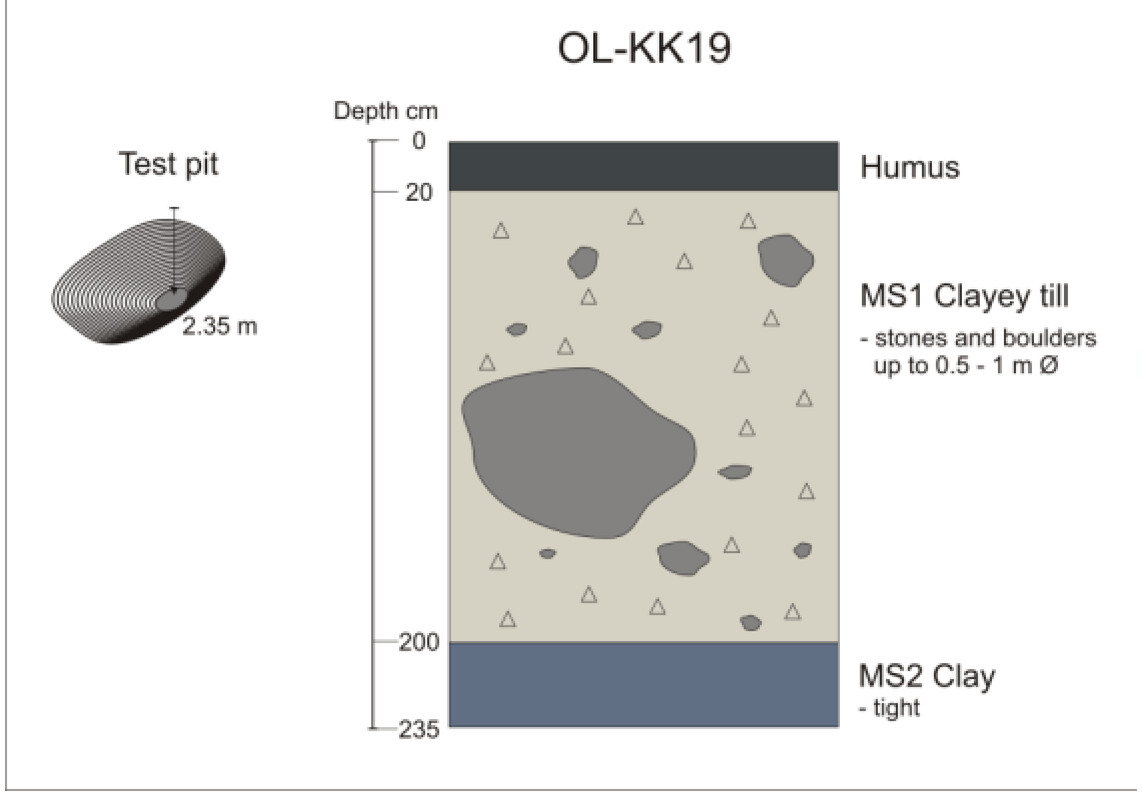


Figure 14. The soil profile of OL-KK19 (graphics Teea Penttinen/Pöyry Environment Oy).

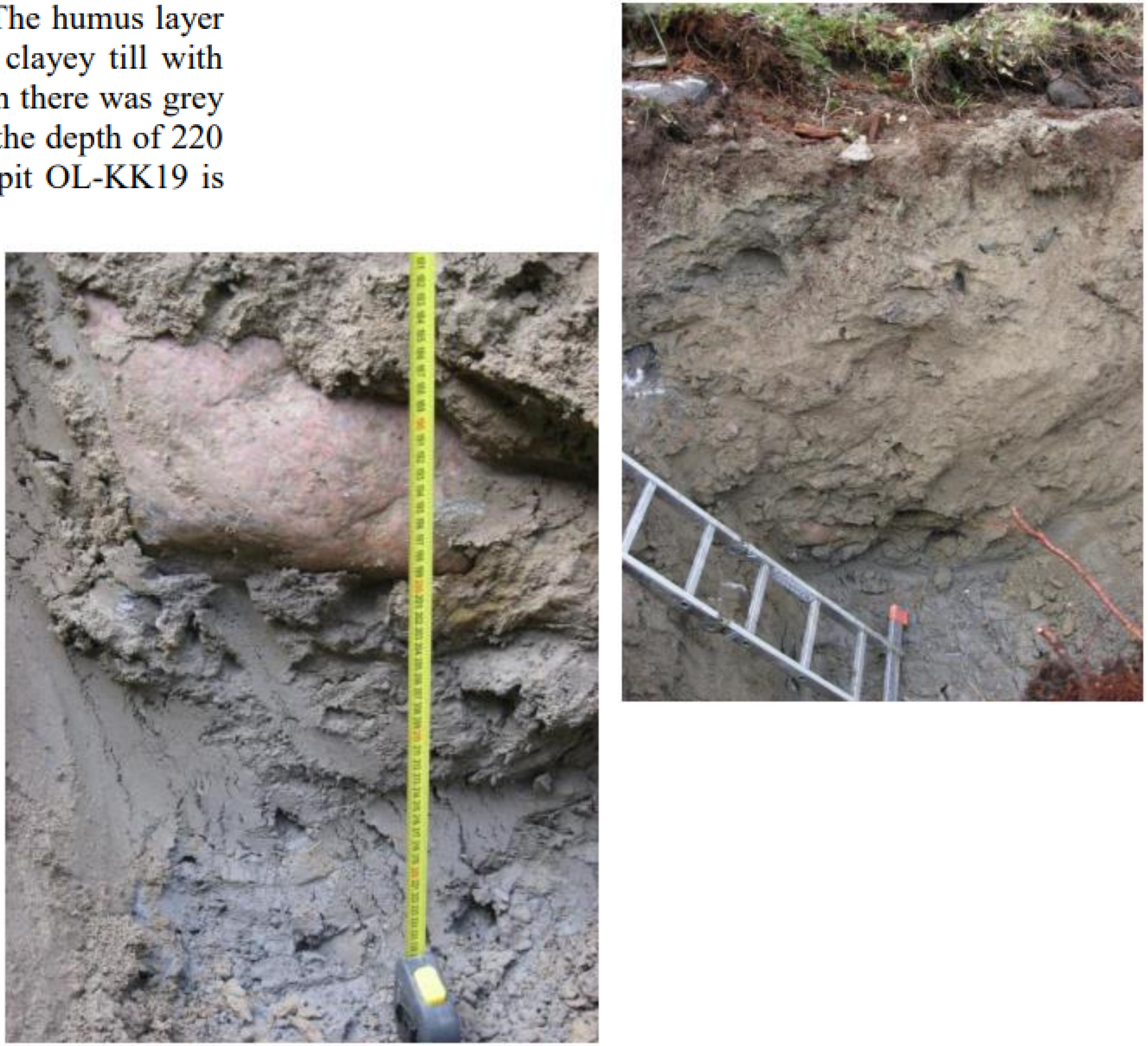
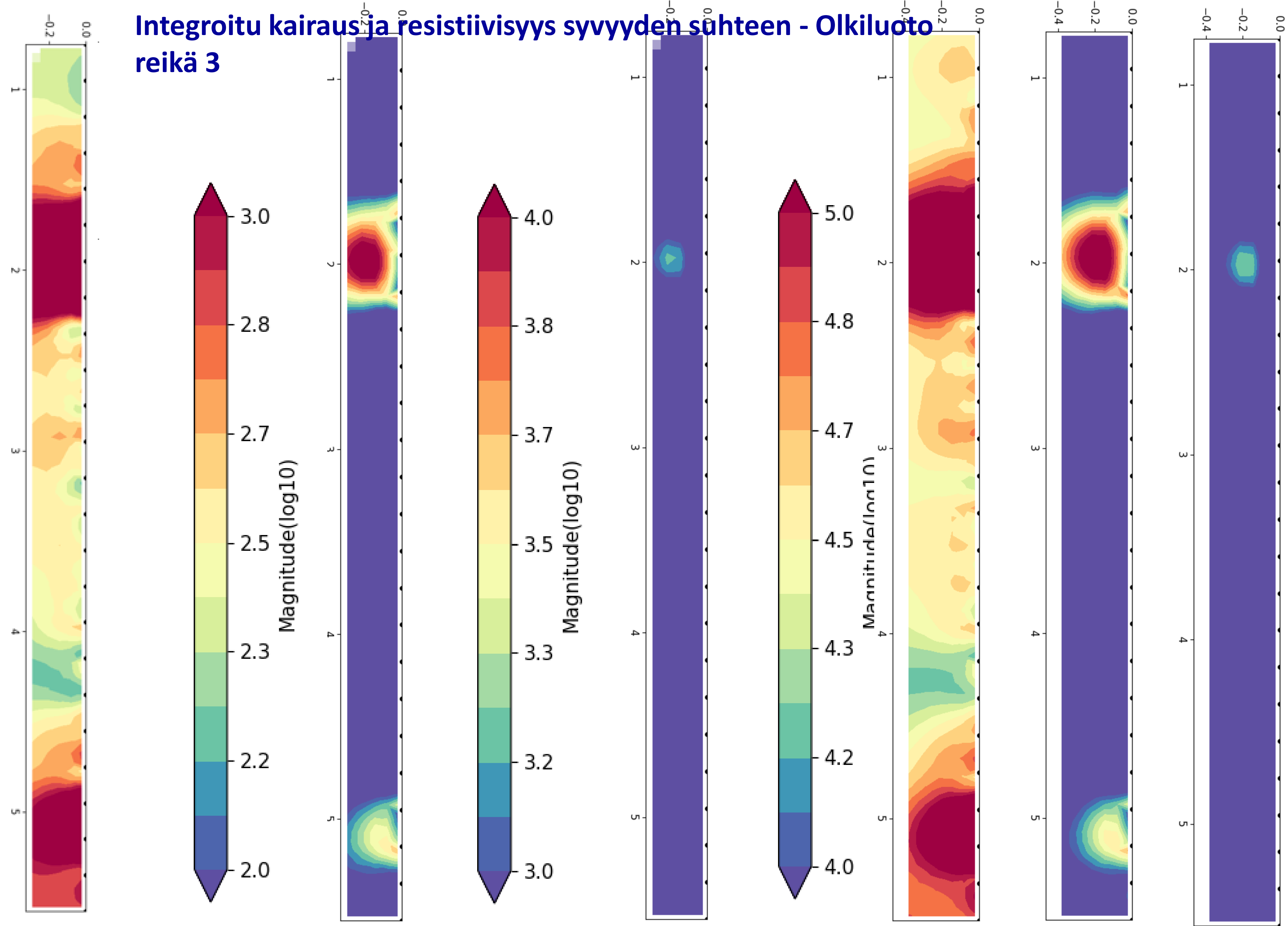


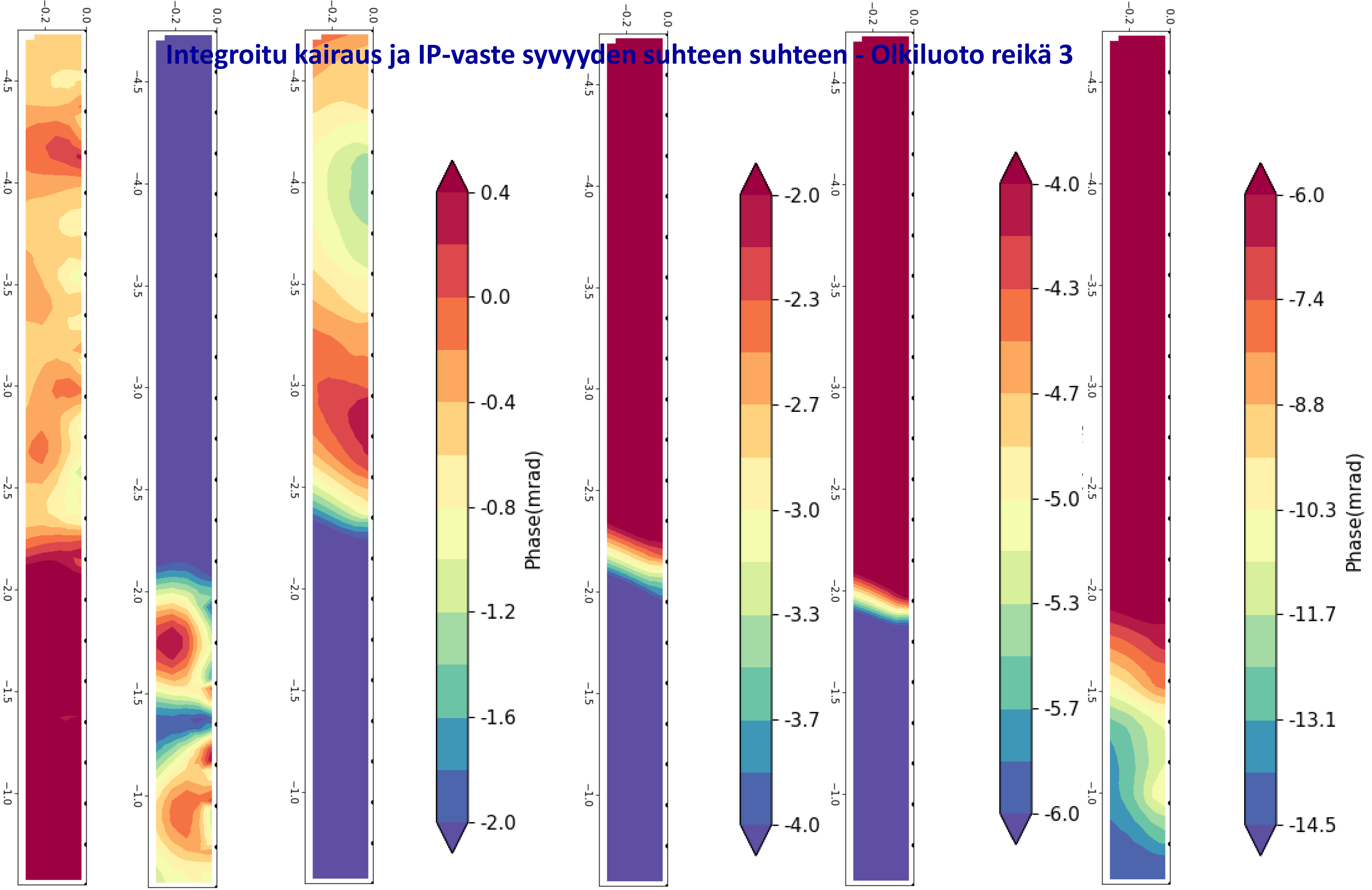
Figure 15. The soil profile of the excavator pit OL-KK19 (top) and a part of the profile with a big stone at the depth of 185-200 cm (bottom) (photo by Susanna Lindgren/Posiva Oy).

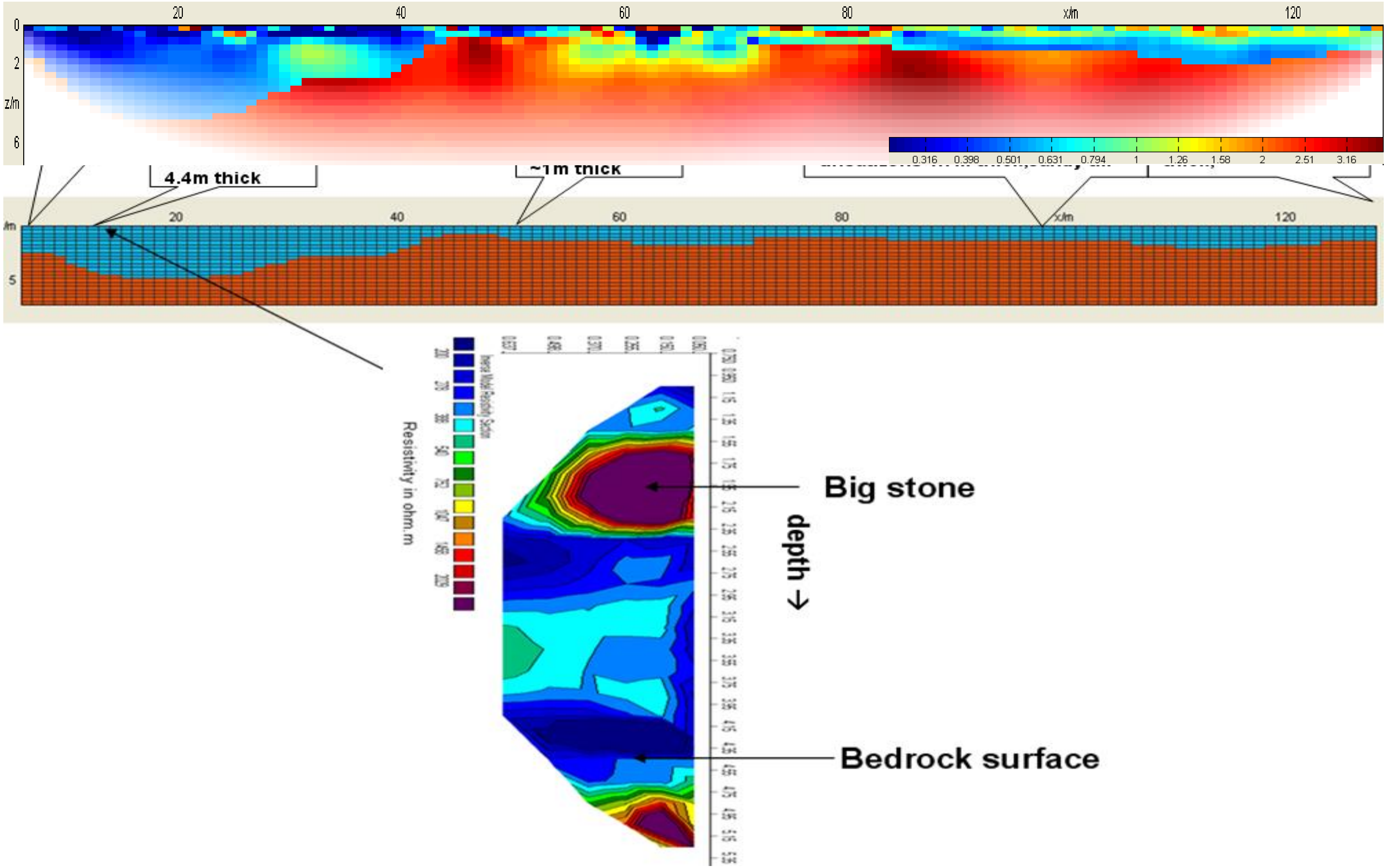
Integroitu kairaus ja resistiivisyys syvyyden suhteen - Olkiluoto reikä 3

Hole32009 ja Hole3new2021



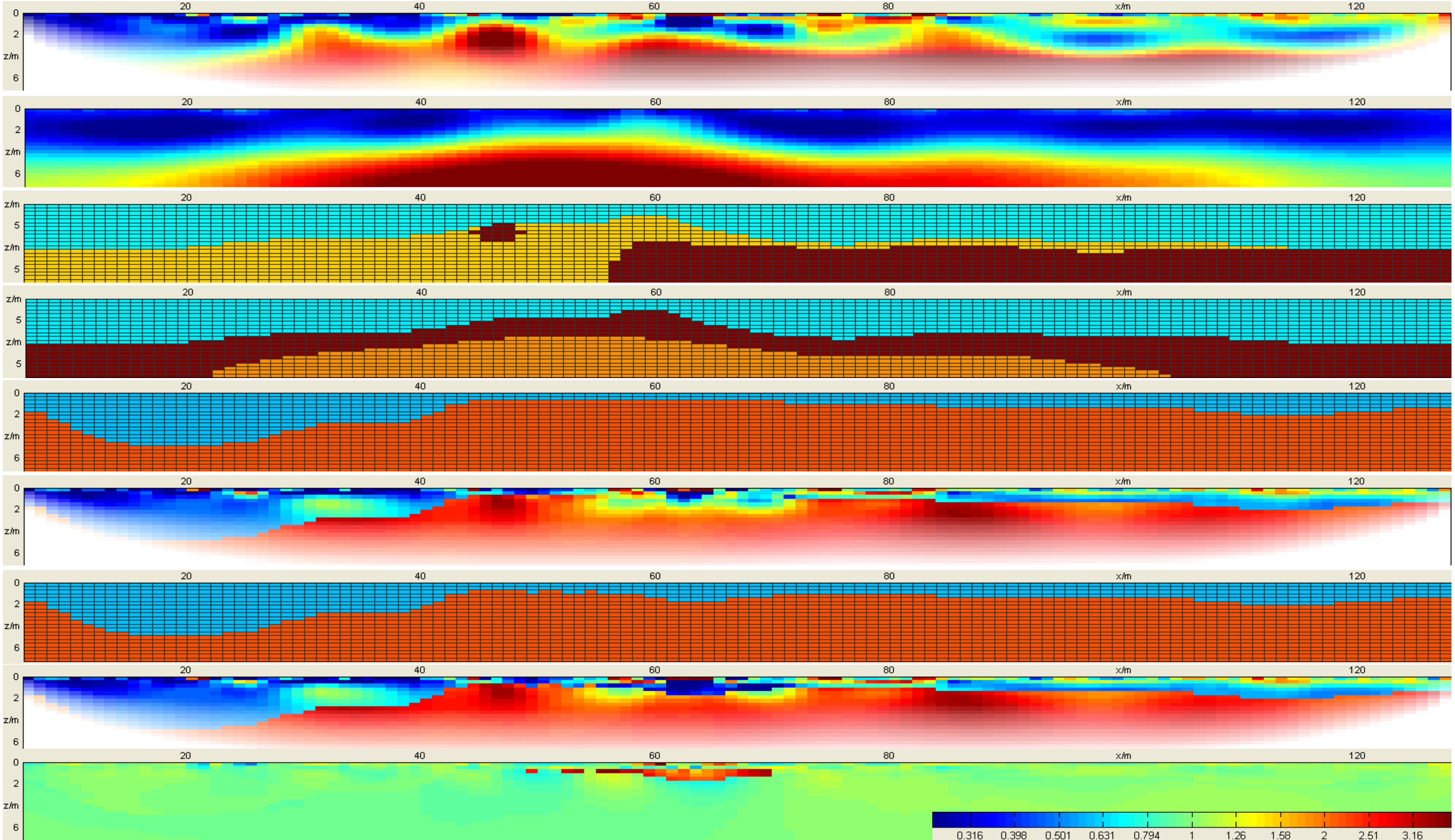
Integroitu kairaus ja IP-vaste syvyyden suhteen suhteen - Olkiluoto reikä 3



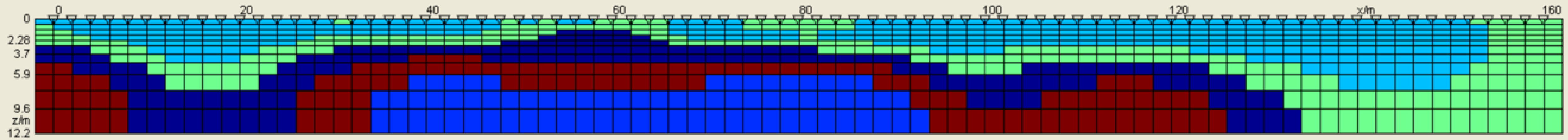


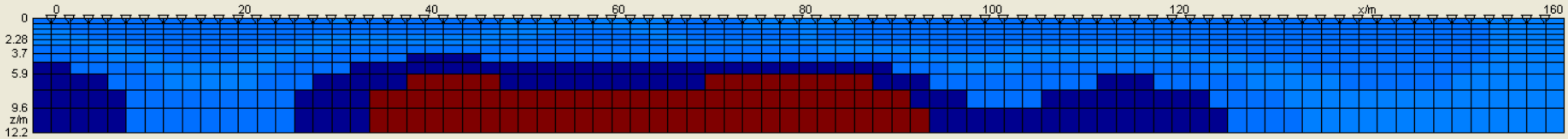
Geological, average resistivity model for an assumed overburden and upper bedrock structure (i.e. reference model) for the profile RES1

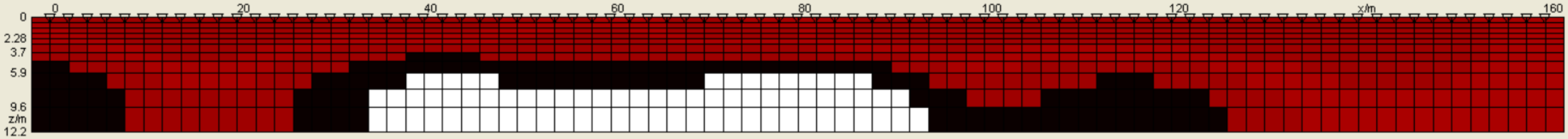
From Mathematically Constrained to Geologically Constrained Inversion – Olkiluoto RES1 Test Line



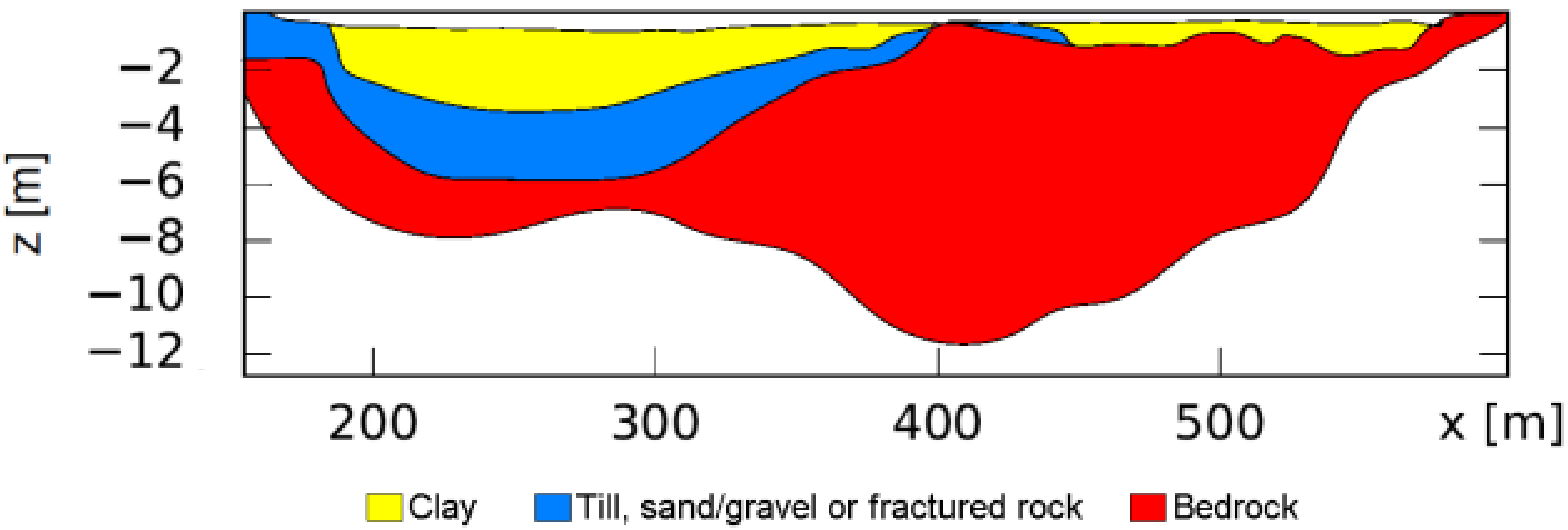
Maaperän luokittelu RES1 profiili (paras klusteriden määrä yhtyy eroteltavien maalajiluokkien määrään







Esimerkki klusteroinnin ja koneopetetun prosessin lopputulemasta, joka siirtyy sitten numeerisen (geologisen/Leapfrog) malliin eli sen rakentamiseen/päivittämiseen



Kiitos !