A Collaborative Platform for Large-Scale 3D Geological Modeling

- Experiences from Denmark

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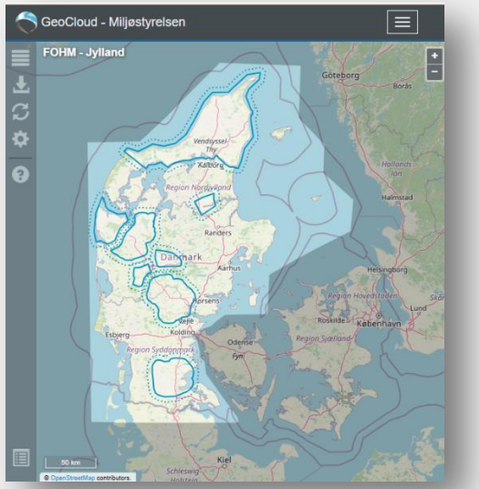
Groundwater mapping in Denmark



25 years, groundwater mapping campaign in Denmark.

Large amounts of data has been collected: borehole information, **geophysics** etc.

Databases containing borehole information and geophysics

All data and knowledge are compiled into a confined national 3D hydrogeological model

– a 300 mio € model!

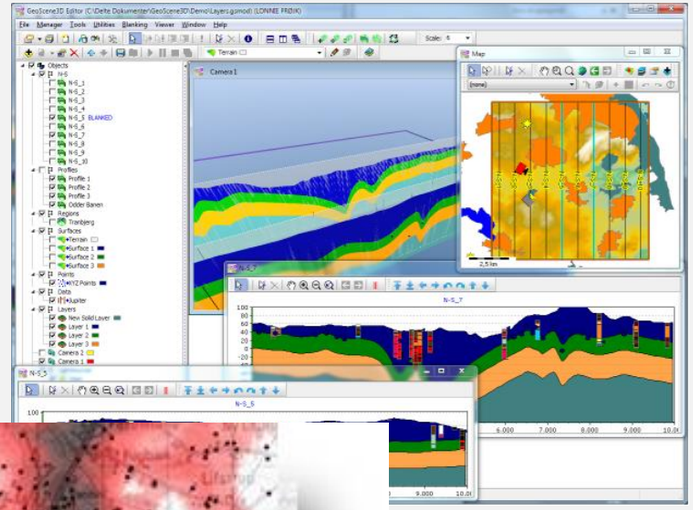
- go through needs, process and result

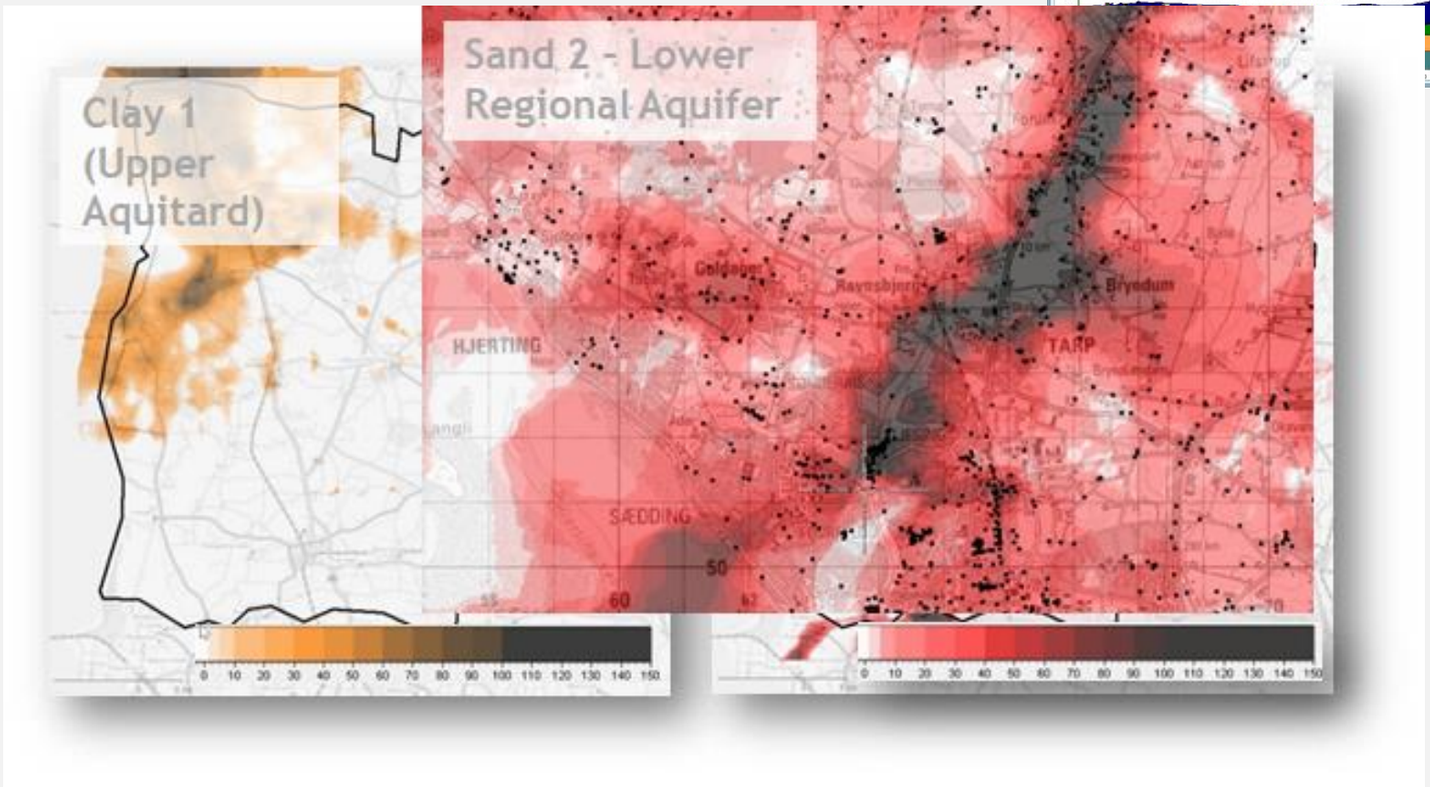
3D hydrogeological as base for groundwater management and planning

The model defines:
- Geology/Hydrogelogy
- Basins
- Aquifers/aquitards
- Interconnections

Answer questions:
- Recharge
- Volumes
- Potential threats
- Etc…

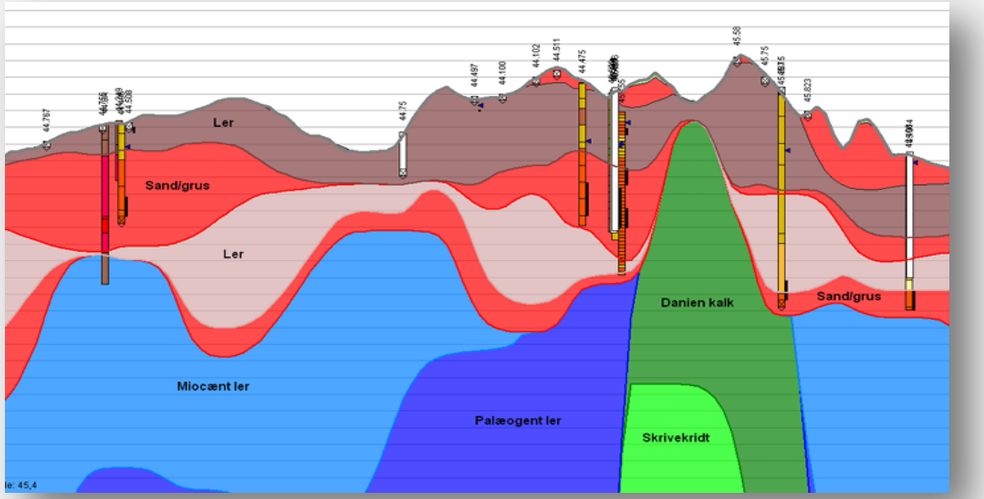
Delineate:
- Further knowledge needed?



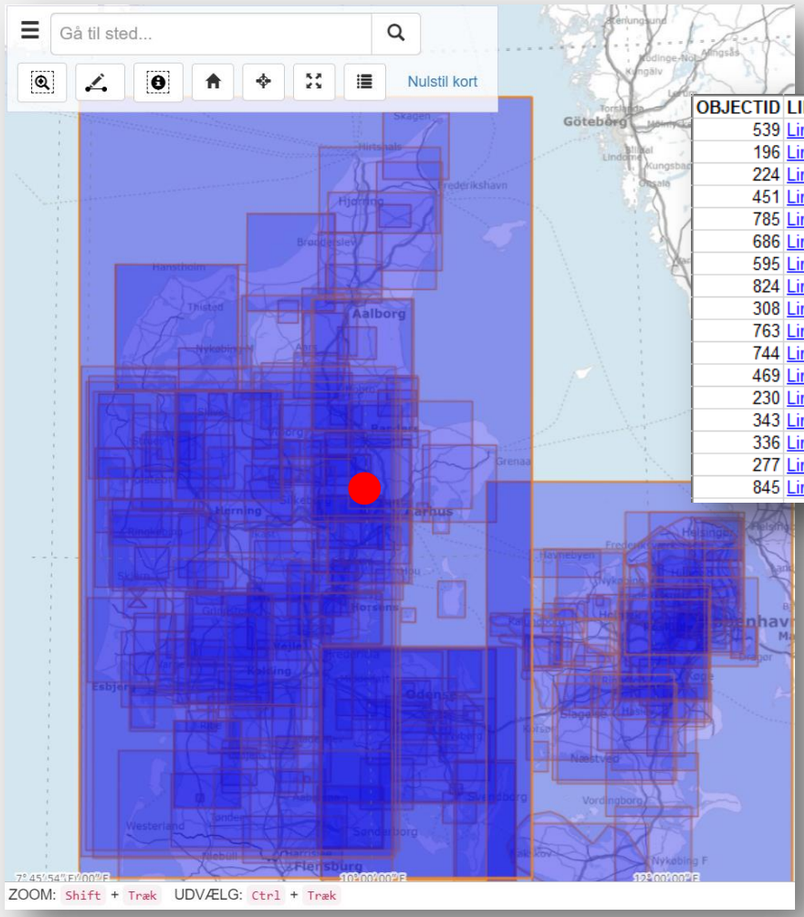


(Hydro)geological modeling in Denmark

- Conceptual hydro stratigraphic layered modeling approach
  (manual, cognitive approach)
- Different geo-modeling software's until 2006 – no standards
  (after 2006, GeoScene3D defined as the standard tool)
- No well-defined modeling concepts before 2008 (GW mapping campaign started back in 1999)
  (after 2008 guidelines were defined by GEUS and partners)



The Danish Model Database (250+ models) – A mixed box of candy



Model Database @ GEUS

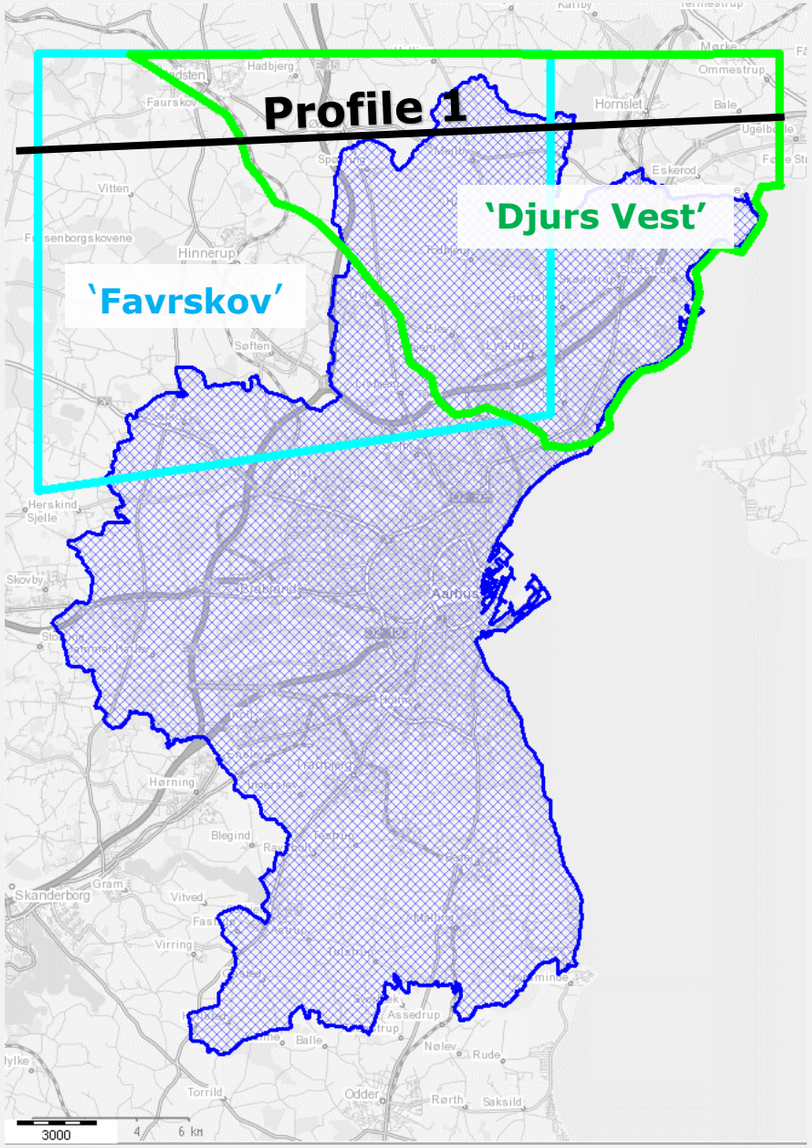
Table: List of models at the red dot

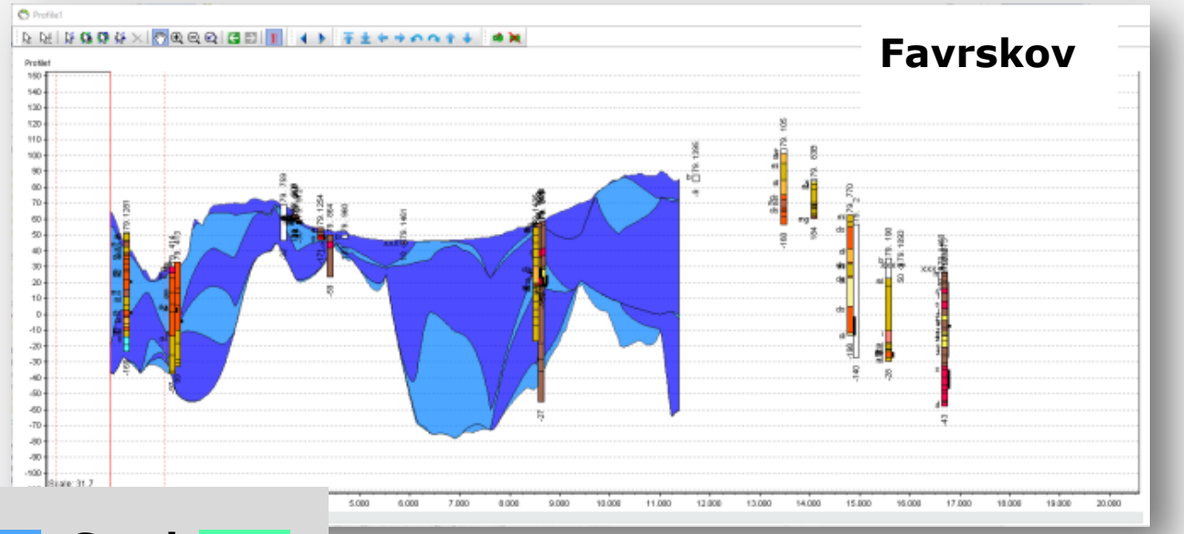
OBJECTID	LINK	DOWNLOAD	MODELNAVN	OMRAADETYPE	KONSULENT	EJER	MODELBESKRIVELSE
539	Link	Link	Hammel hydrologiske model	Udbredelsesområde	Rambøll	Naturstyrelsen	Grundvandsmodel for Hammel kortlægningsområde
196	Link	Link	Rumlig geologisk model Århus Vest	Udbredelsesområde	ALECTIA A/S	Miljøcenter Århus	Rumlig geologisk model
224	Link	Link	Hydrostratigrafisk Model for Aarhus Vest	Udbredelsesområde	Miljøcenter Aarhus	Miljøcenter Aarhus	
451	Link	Link	Hydrostratigrafisk model for Hammel	Udbredelsesområde	Rambøll	NST Aalborg	Hydrostr.grafisk model for kortlægningsomr. Hammel
785	Link	Link	Hammel Model Opdatering2017	Udbredelsesområde	Rambøll	Miljøstyrelsen	Hammel hydrostratigrafiske og hydrologiske model
686	Link	Link	Skanderborg Kommune hydrostratigrafisk model	Udbredelsesområde	Rambøll	Skanderborg Kommune	hydrostratigrafisk model for Skanderborg Kommune
595	Link	Link	Silkeborg Nord Hydrostratigrafisk model 2015	Udbredelsesområde	Rambøll	NST Aalborg	Hydrostr. model for kortlægningsomr. Silkeborg N
824	Link	Link	Langaa2019	Udbredelsesområde	Rambøll	Miljøstyrelsen	Hydrostratigrafisk model for Langå
308	Link	Link	Hydrogeologisk model. Favrskov Kommune	Udbredelsesområde	Rambøll Danmark A/S	Favrskov Kommune	Opdatering af Hadsten modellen
763	Link	Link	GeoFavrskov2015 hydrostratigrafisk model	Udbredelsesområde	Orbicon A/S	Favrskov Kommune	Hydrostratigrafisk model
744	Link	Link	Miocæn 3D opdateret 2015	Udbredelsesområde	GEUS	NST	Rumlig geologisk model
469	Link	Link	Miocæn 3D opdateret 2014	Udbredelsesområde	GEUS	Naturstyrelsen Aalborg	Rumlig geologisk model
230	Link	Link	Miocæn 3D	Udbredelsesområde	GEUS	GEUS	Rumlig Geologisk model baseret på punkttolkninger
343	Link	Link	dkmj_gvf_102013	Udbredelsesområde	geus	hydro	indlagt ifm grundvandsforekomst revision 2013
336	Link	Link	dkmj_gvf_092013	Udbredelsesområde	geus	geus	indlagt ifm grundvandsforekomst revision 2013
277	Link	Link	DKmodel2009Jylland	Udbredelsesområde	GEUS	GEUS	DKmodel2009f release
845	Link	Link	DK-model2019 (dk4-6)	Udbredelsesområde	GEUS	GEUS	Kun numerisk/hydrologisk model og model rapport

# of models at the red dot (17)

- Which one to choose?
- Which one/ones are used by the authorities?
- (Includes models from the last 25+ years).

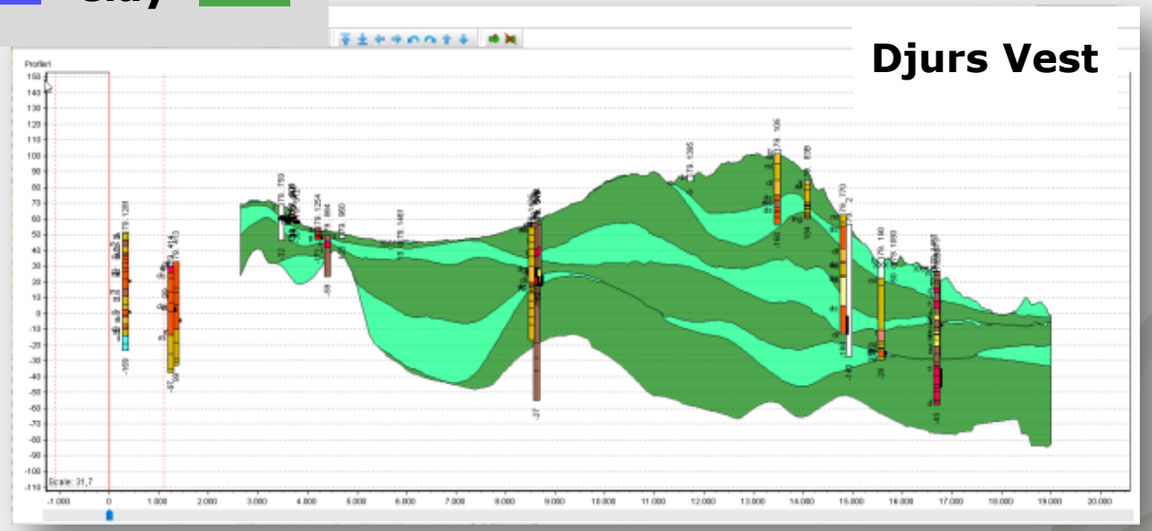
Challenges – an example





Sand

Clay



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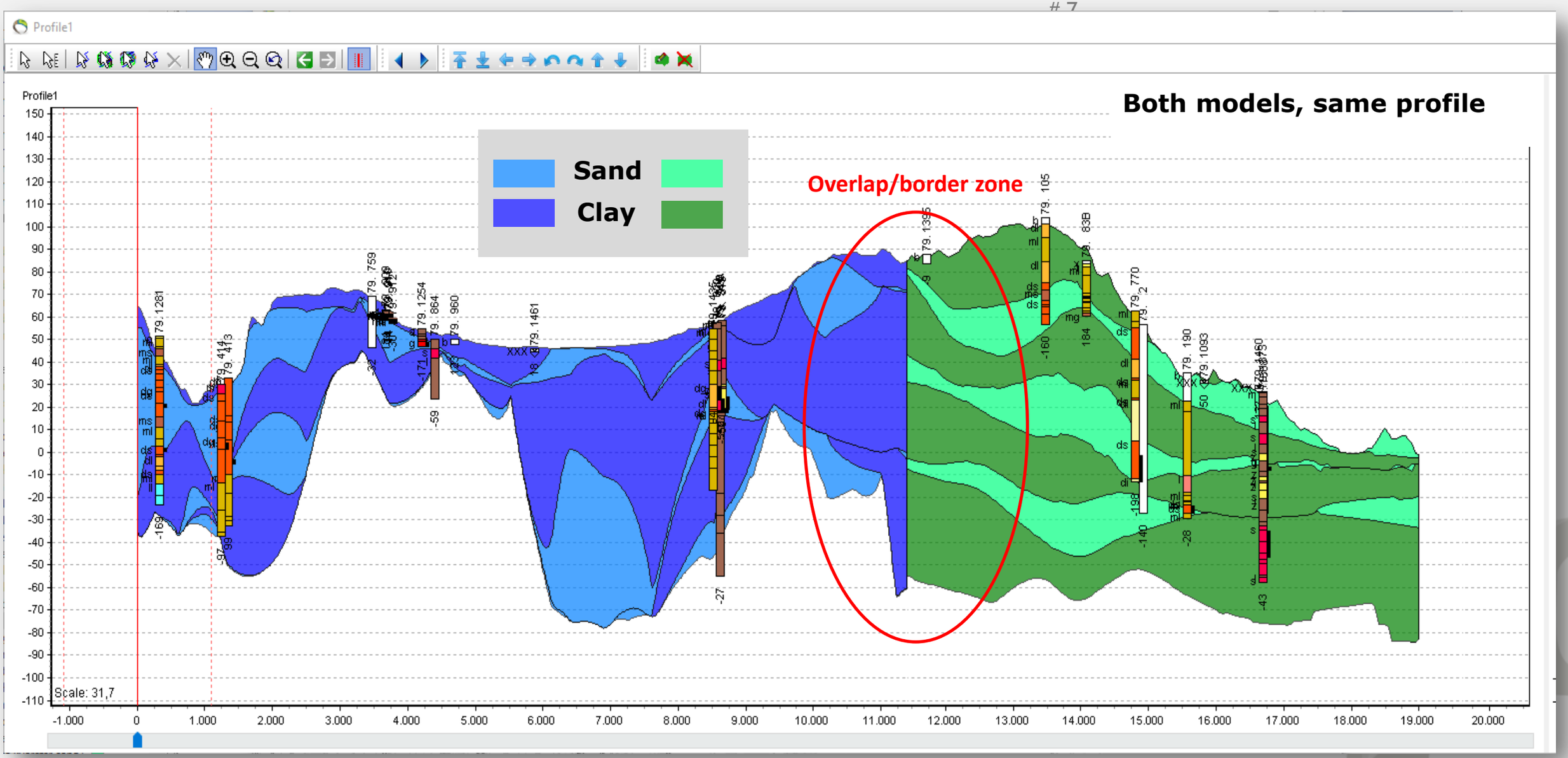
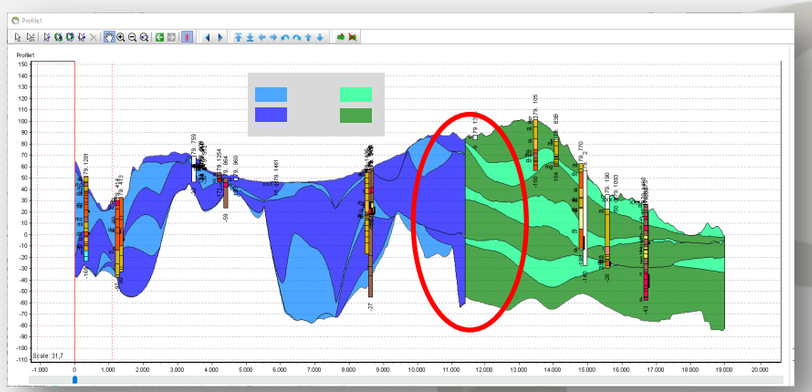
Challenges - an example



Reasons to these model differences

Why these differences?

- Different models, different premises/scope
- Economy and time (Quick & Dirty, State of the Art?)
- Skills and experience
- Development in mapping methods over time
- More data and knowledge over time
- Better modeling and visualization tools over time



In 2018

The Danish EPA wanted to combine the best of all models into one single hydrostratigraphic model – the *FOHM model*

"Common Public Hydrogeologic Model"

Budget:	1,2 mio. €. In 2018 – no sooner, no later!
Goal:	A layer-based model incl. interpretation points and hydrostratigraphic units Based on existing work – no new interpretations Modeling tool: GeoScene3D
Timeline:	8 month in total!
Partners:	EPA, GEUS, I•GIS, Private consultants

FOHM - maximum stratigraphy

The model framework / the reference model
– *the maximum stratigraphy;*
45 hydrostratigraphic layers.

Quaternary layers

- Surface near, local units
- Regional plateau units
- Buried valleys

Miocene layers

- Regional stratigraphic units from national model
- Mostly defined in central Jutland

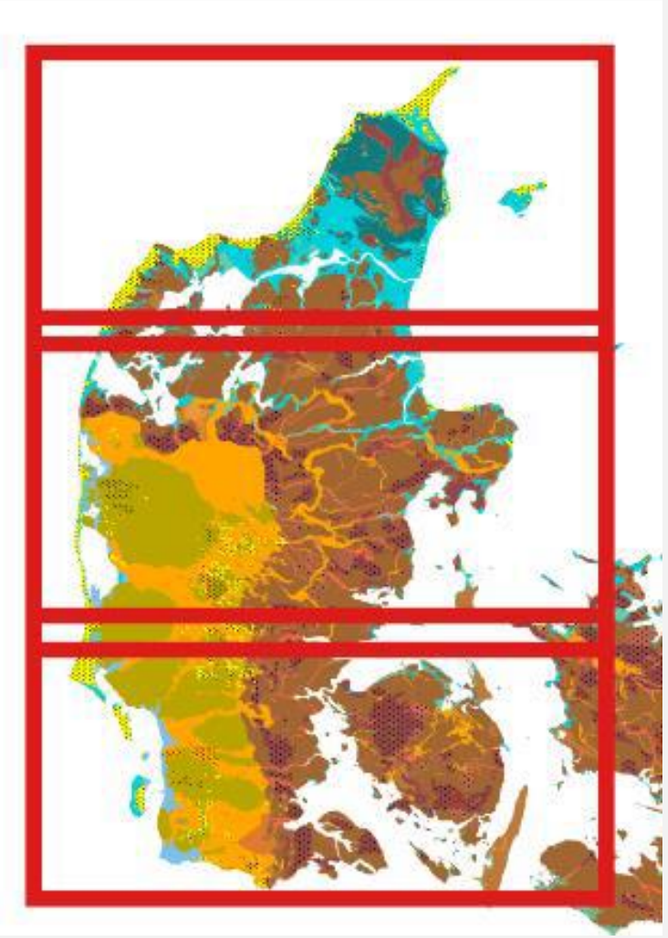
Pre Miocene

- Chalk
- Salt

	FOHM Tolkningsdatabase	Maksimal Stratigrafi
Quaternary		
Terrænnær	100_Postglacial_toerv	Organisk Lag
	200_Kvartaer_sand_bund	Sand
	300_Kvartaer_ler_bund	Ler
	400_Kvartaer_sand_bund	Sand
Plateau	1100_Kvartaer_ler_bund	Ler
	1200_Kvartaer_sand_bund	Sand
	1300_Kvartaer_ler_bund	Ler
	1400_Kvartaer_sand_bund	Sand
	1500_Kvartaer_ler_bund	Ler
Begravet dal	2100_Kvartaer_sand_bund	Sand
	2200_Kvartaer_ler_bund	Ler
	2300_Kvartaer_sand_bund	Sand
	2400_Kvartaer_ler_bund	Ler
Miocene		
Prækvartær lagserie	5100_Maadegruppen_Gram_og_Hodde_Bund	Ler
	5200_Oevre_Odderup_ODS3_bund	Sand
	5300_Oevre_Arnum_ARL3_bund	Ler
	5400_Nedre_Odderup_ODS2_bund	Sand
	5500_Nedre_Arnum_ARL2_bund	Ler
	5600_Bastrup_BADS6_bund	Sand
	5700_Klintinghoved_KRL6_bund	Ler
	5800_Bastrup_BADS5_bund	Sand
	5900_Klintinghoved_KRL5_bund	Ler
	6000_Bastrup_BADS4_bund	Sand
	6100_Klintinghoved_KRL4_bund	Ler
	6200_Bastrup_BADS3_bund	Sand
	6300_Klintinghoved_KRL3_bund	Ler
	6400_Bastrup_BADS2_bund	Sand
	6500_Klintinghoved_KRL2_bund	Ler
	6600_Bastrup_BADS1_bund	Sand
	6700_Klintinghoved_KRL1_Vejle_Fjord_Bund	Ler
	6800_Billund_BDS6_BDS9_Bund	Sand
	6900_Vejle_Fjord_VFL6_Bund	Ler
	7000_Billund_BDS4_BDS5_Bund	Sand
	7100_Vejle_Fjord_VFL4_Bund	Ler
	7200_Billund_BDS3_Bund	Sand
	7300_Vejle_Fjord_VFL3_Bund	Ler
	7400_Billund_BDS2_Bund	Sand
	7500_Vejle_Fjord_VFL2_Bund	Ler
	7600_Billund_BDS1_Bund	Sand
	7700_Vejle_Fjord_VFL1_Bund	Ler
	7800_Billund_BDS0_Bund	Sand
Pre-Miocene	8000_Palæogen ler_Bund	Ler
	8500_Danien Kalk_Bund	Kalk
	9000_Skrivekridt_Bund	Kalk
	9500_Stensalt_Bund	Stensalt

Modeling areas

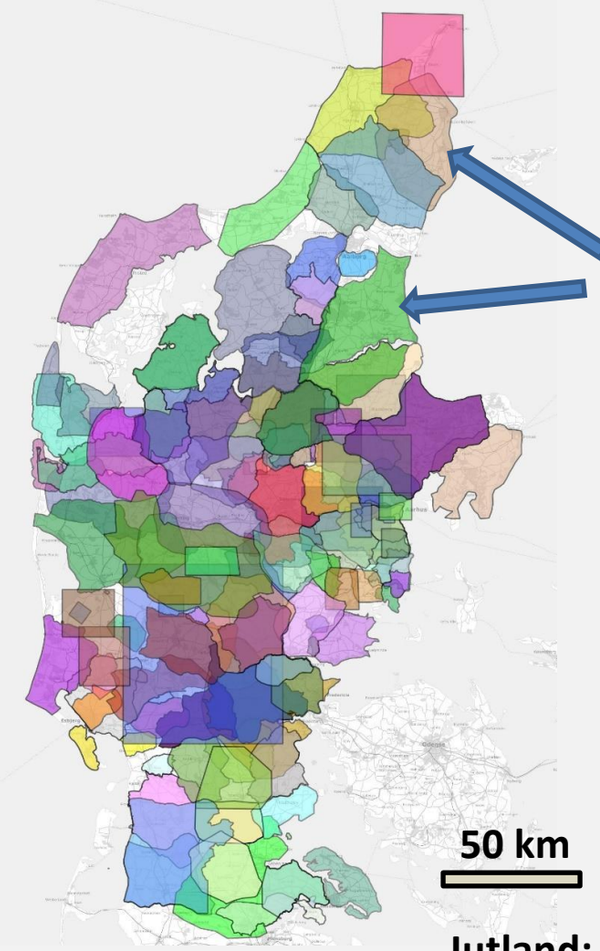
…distributed taking consultants local references into account



Consultant 1
(consortium of 2 companies)

Consultant 2

Consultant 3



Individual models

More than 150 models in total. Typical 6-12 layers and size of 400-1200 km^2.

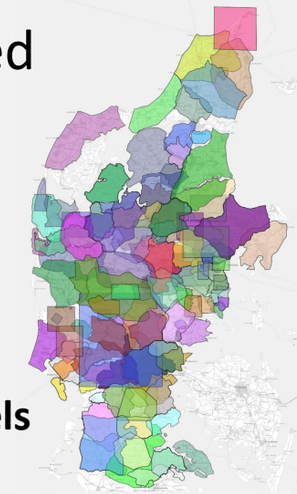
Jutland: ≈ 30.000 km^2

Model selection and quality categories

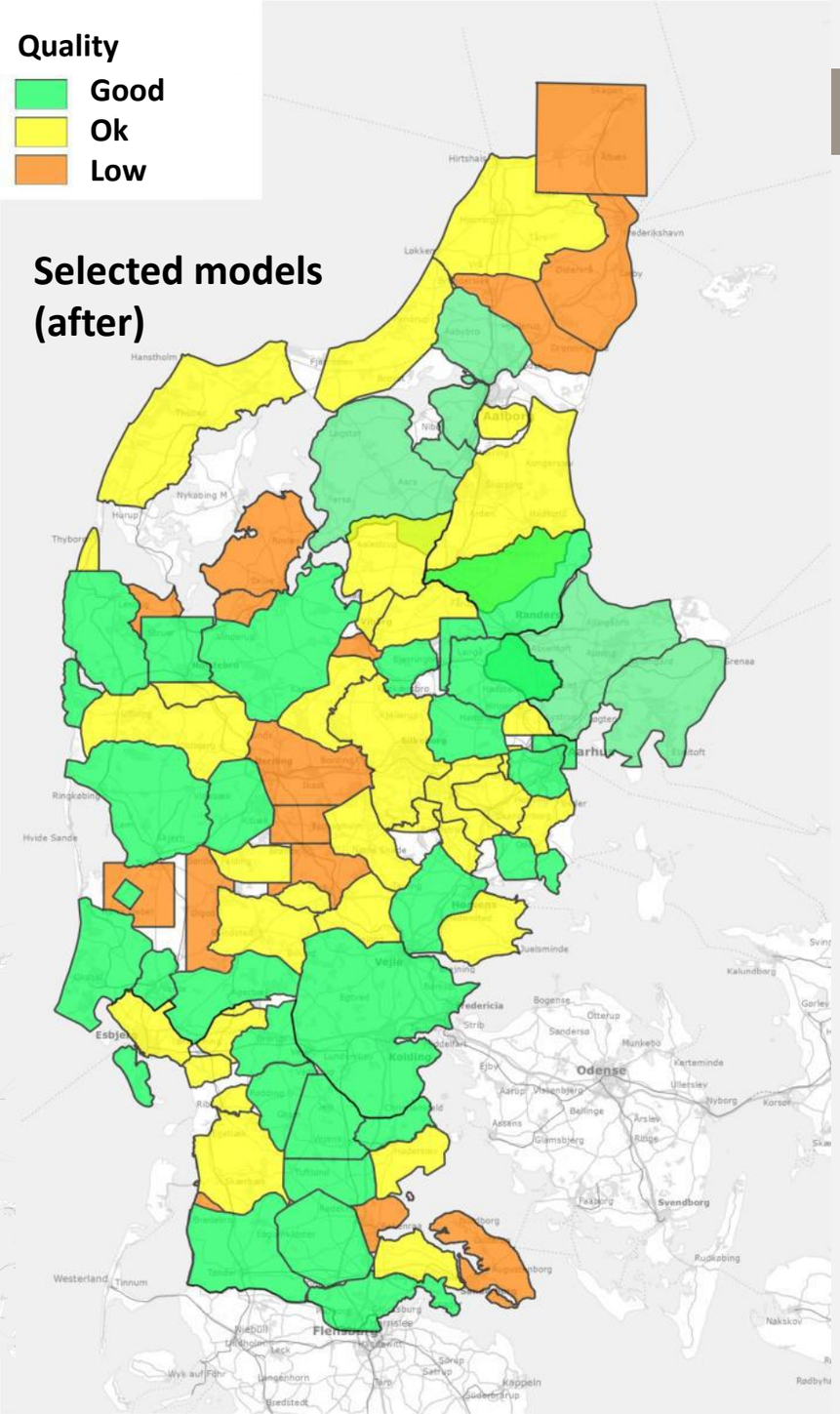
- “Good”
- “Ok”
- “Low”
- “Not to be used”

87 hydrostratigraphic models were selected

More than one “good” model in an area: Prioritized list was made as well.



All models (before)



Selected models (after)

FOHM workflow

One model:

Cell size 100x100m

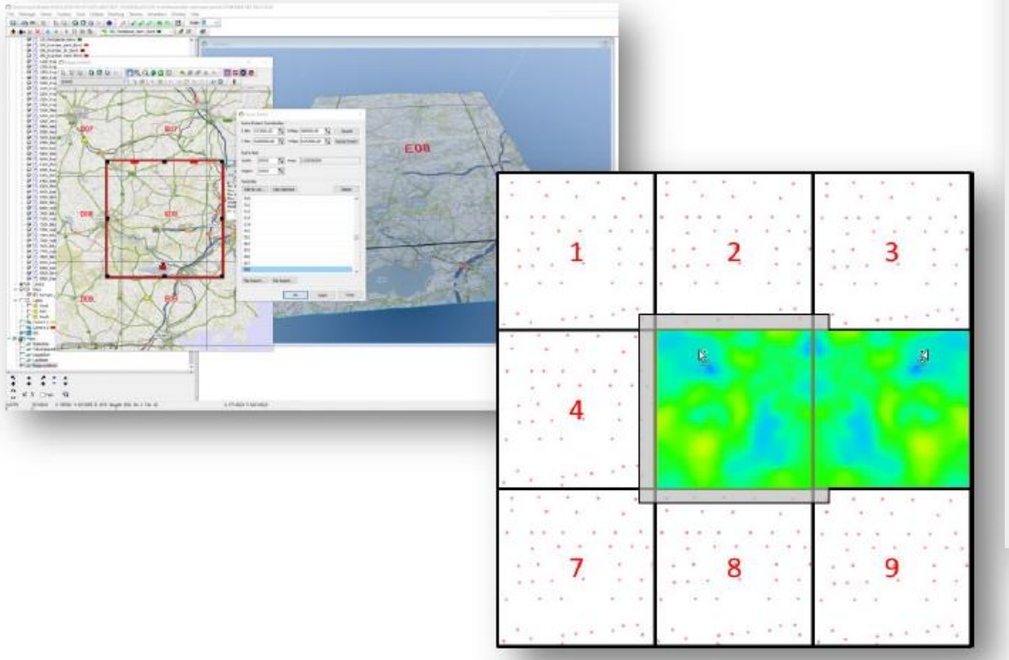
Outline: 400x200km

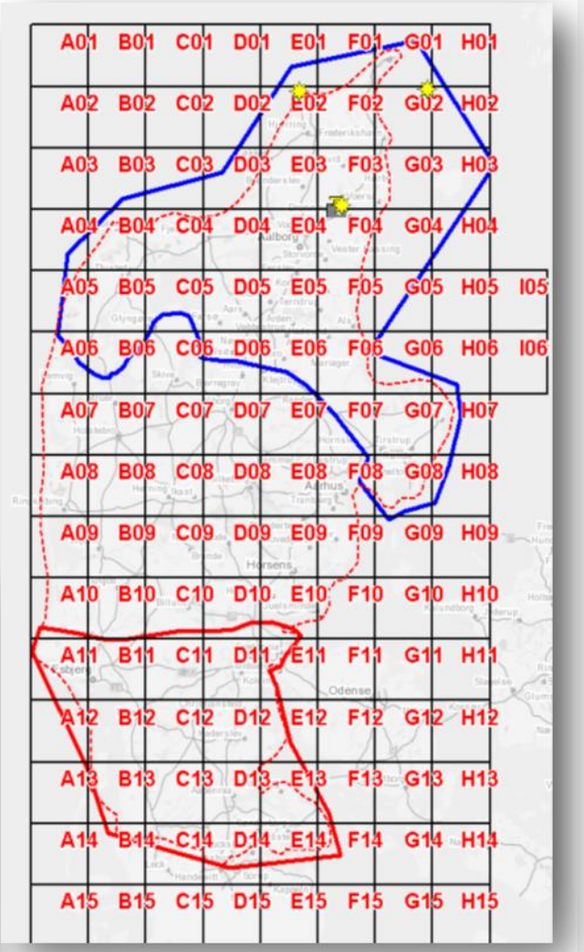
GeoScene3D software:

Scene Extent concept

Scene Extents og Tiles

- Scene Extents: 35 x 35 km (1225 km^2)
- 82 tiles. Tile = Scene Extent + 5 km buffer
- Modeling done within scene extent





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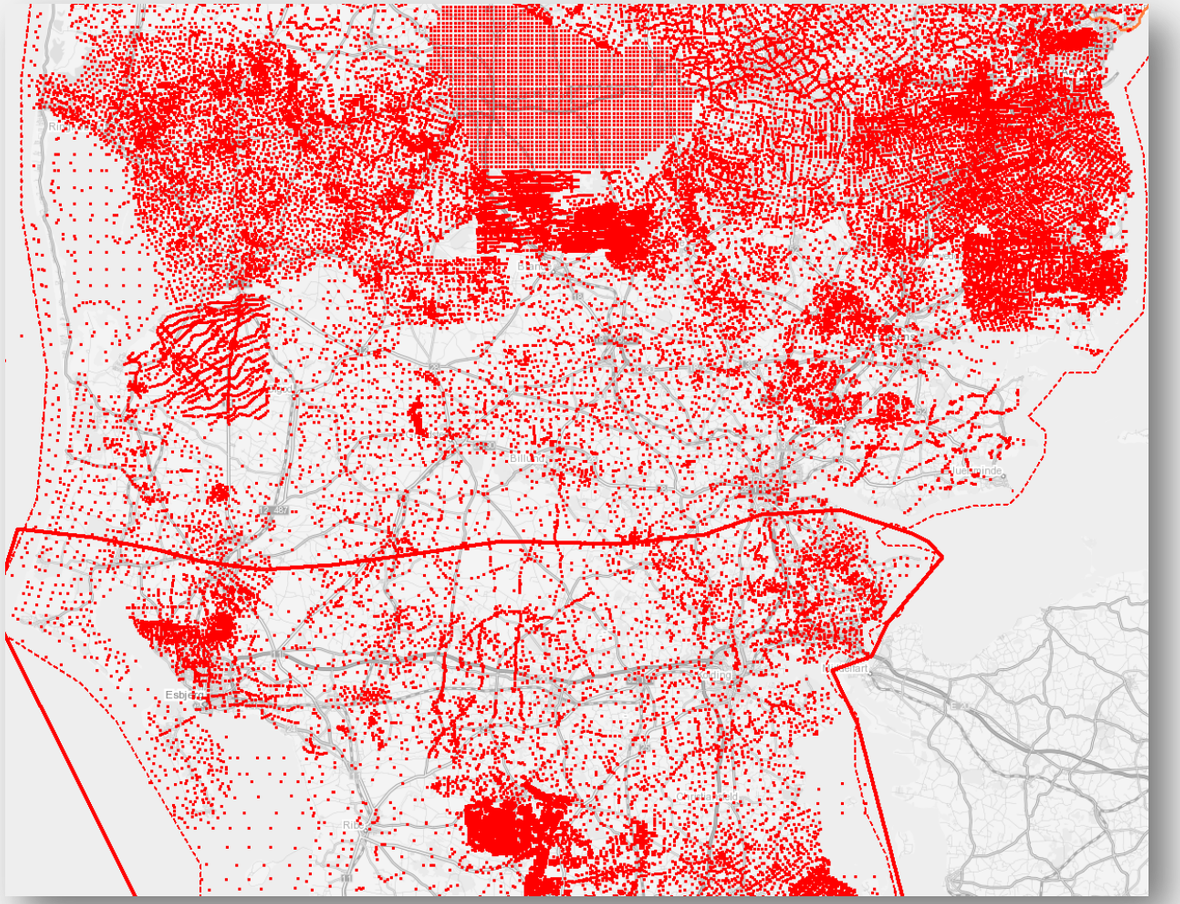
FOHM workflow



Point density within one layer

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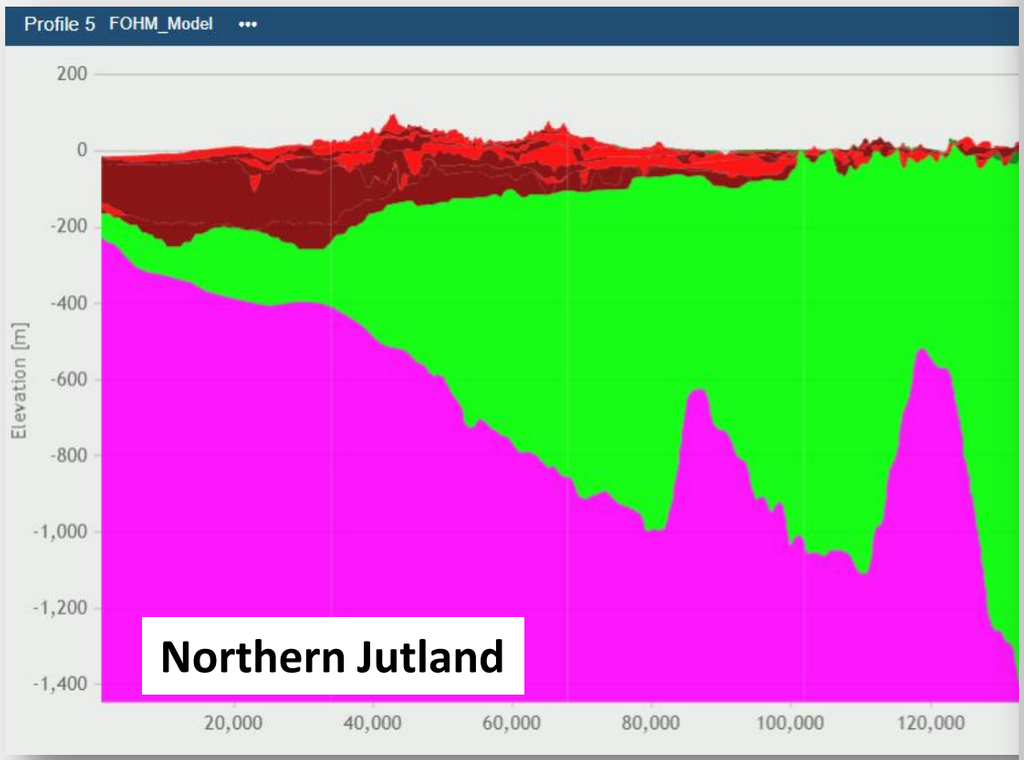
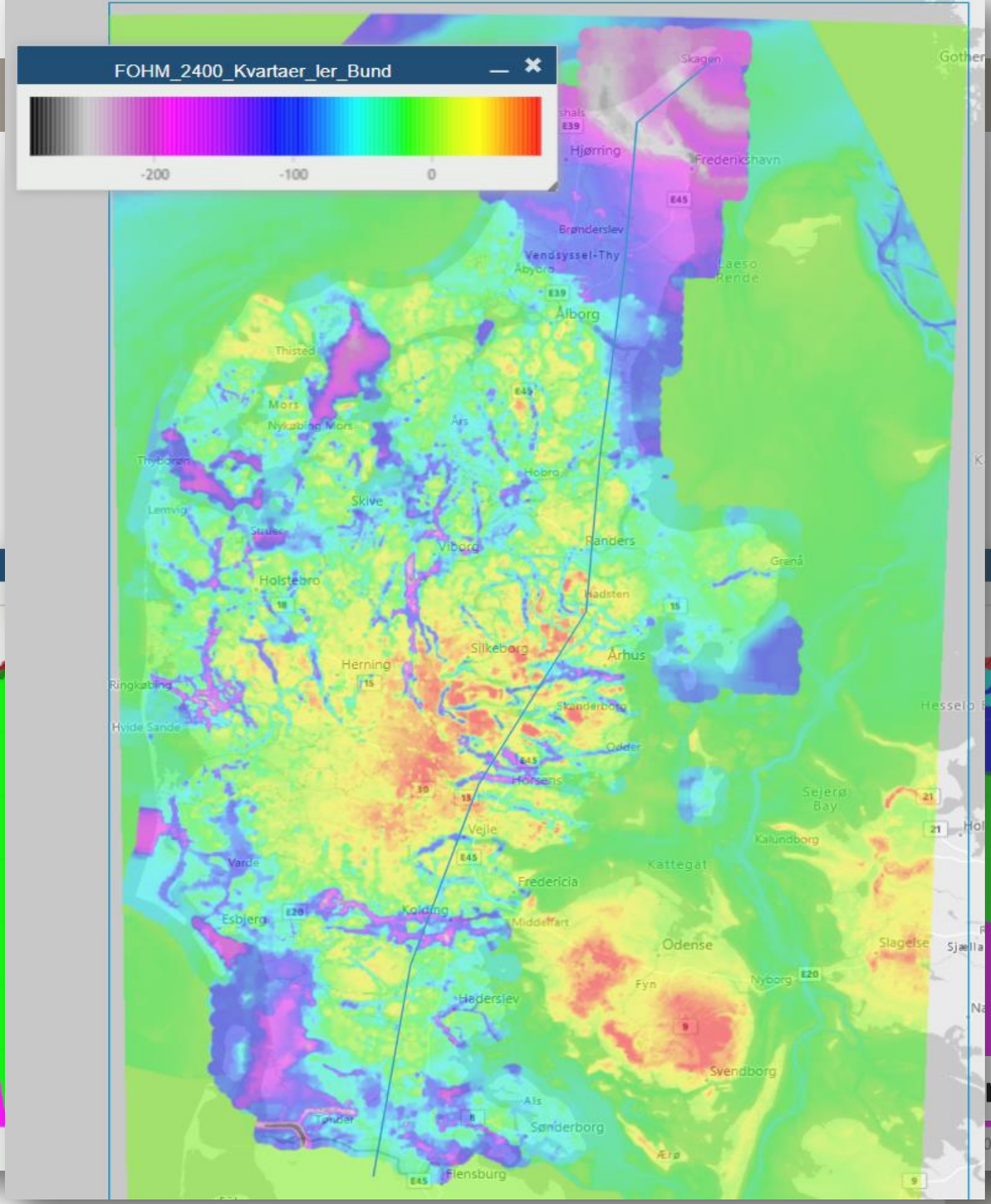
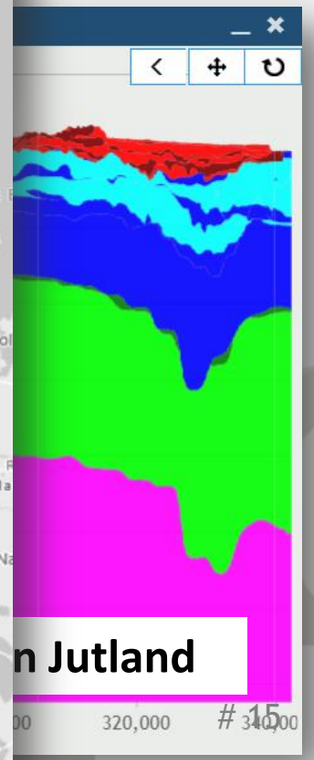
We succeeded
– output examples
Cross sections (user defined).

(Profile below: 345 km)



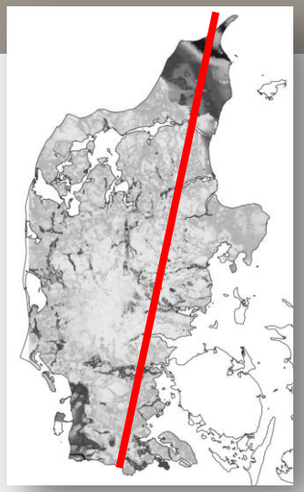


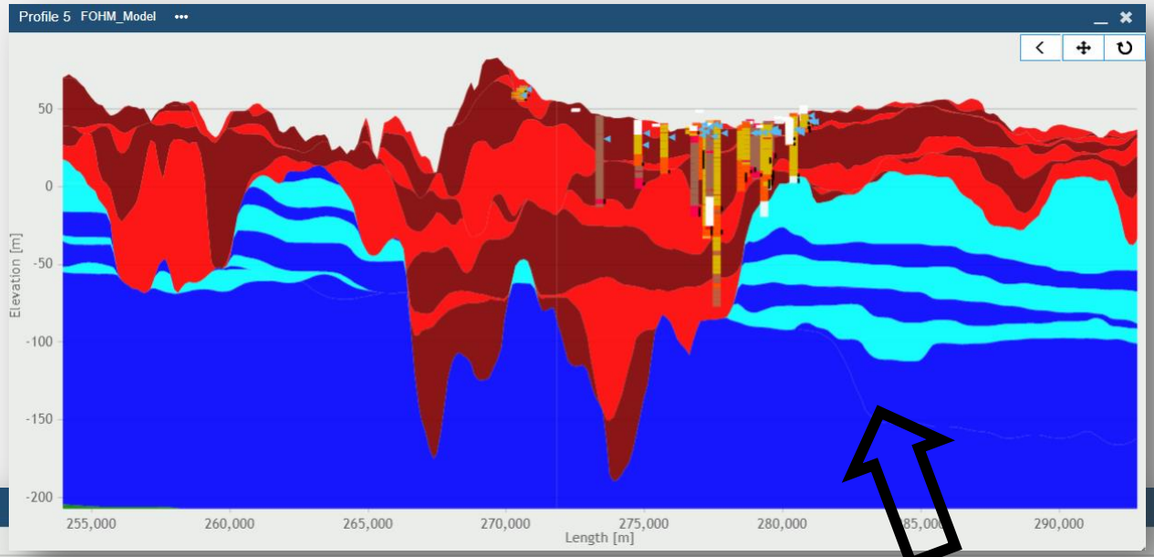


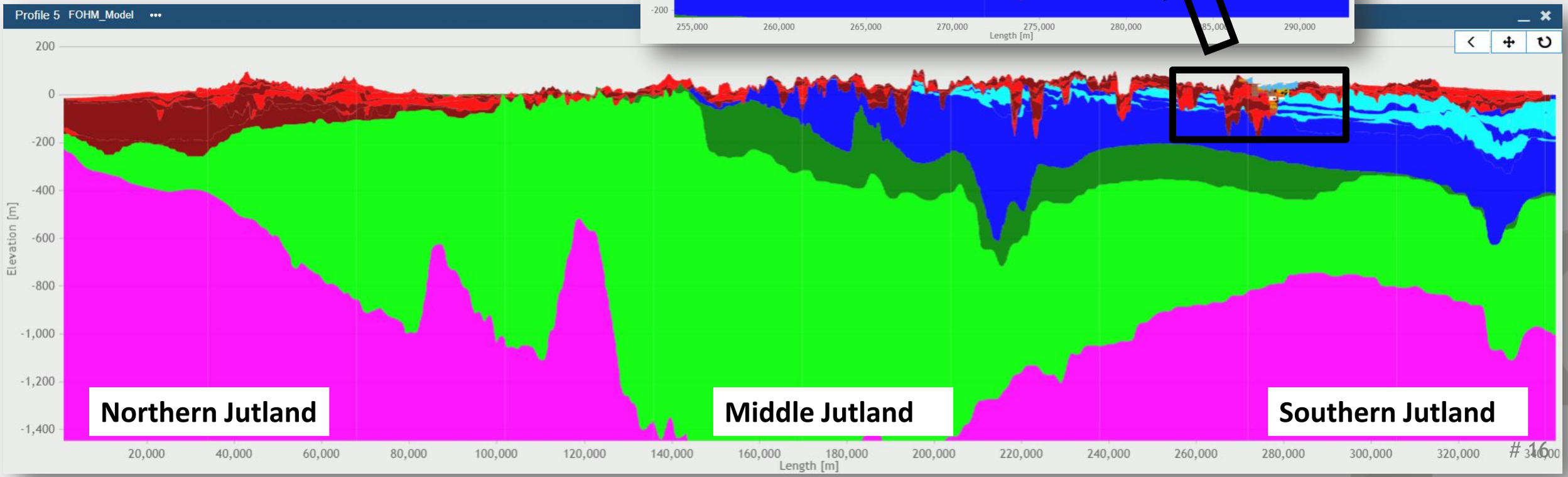
FOHM – cross section

We succeeded
– output examples
Cross sections (user defined).

(Profile below: 345 km)

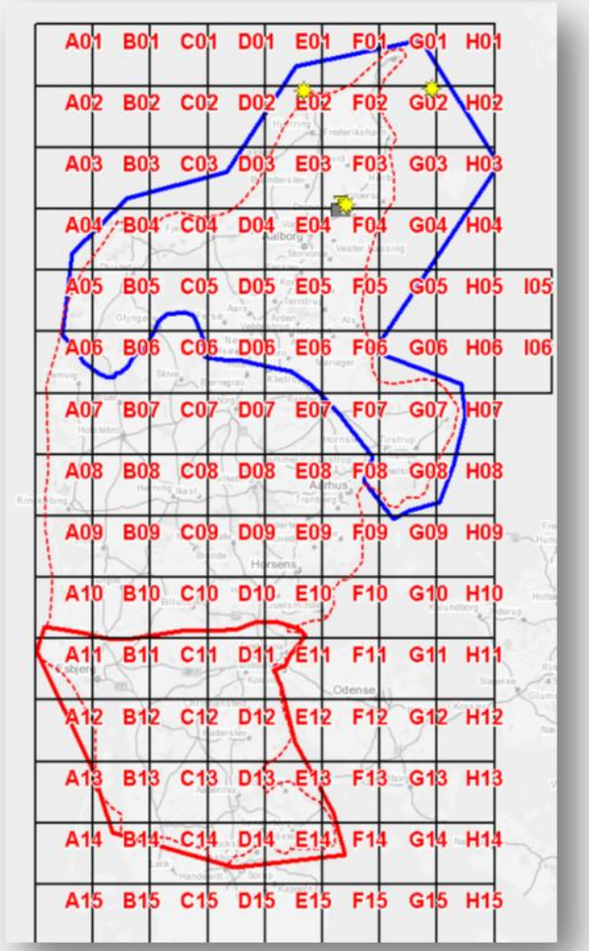






Updating FOHM

Updating - problematic

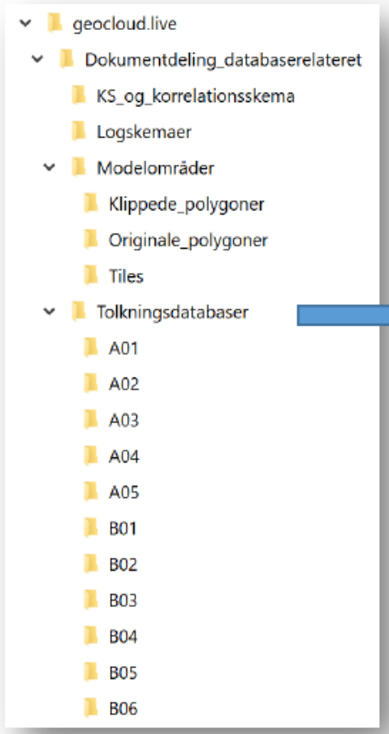


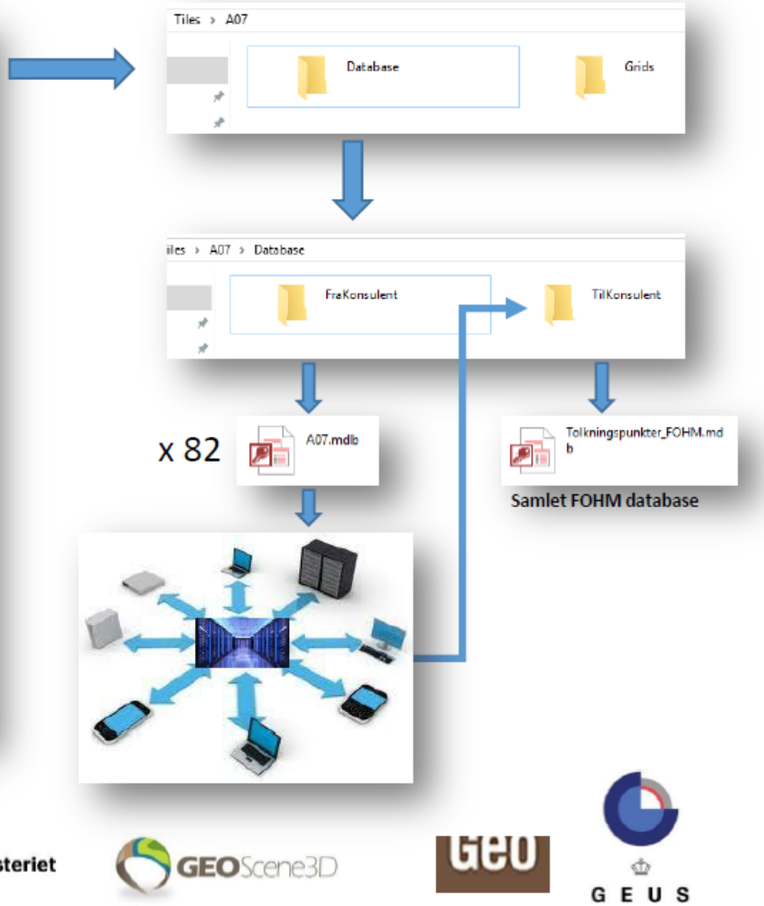
Upload og synkronisering – arbejdsgang

- Login på ftp-server (geocloud.live)
- Her findes mappestruktur

Lidt teknisk info

- Den samlede FOHM-database fylder ca. 1GB
- De enkelte lag rummer fra 567 til 244.896 punkter
- Samlet findes 2.137.665 tolkningspunkter; 1.910.551 kvartære og 227.114 prækvartære





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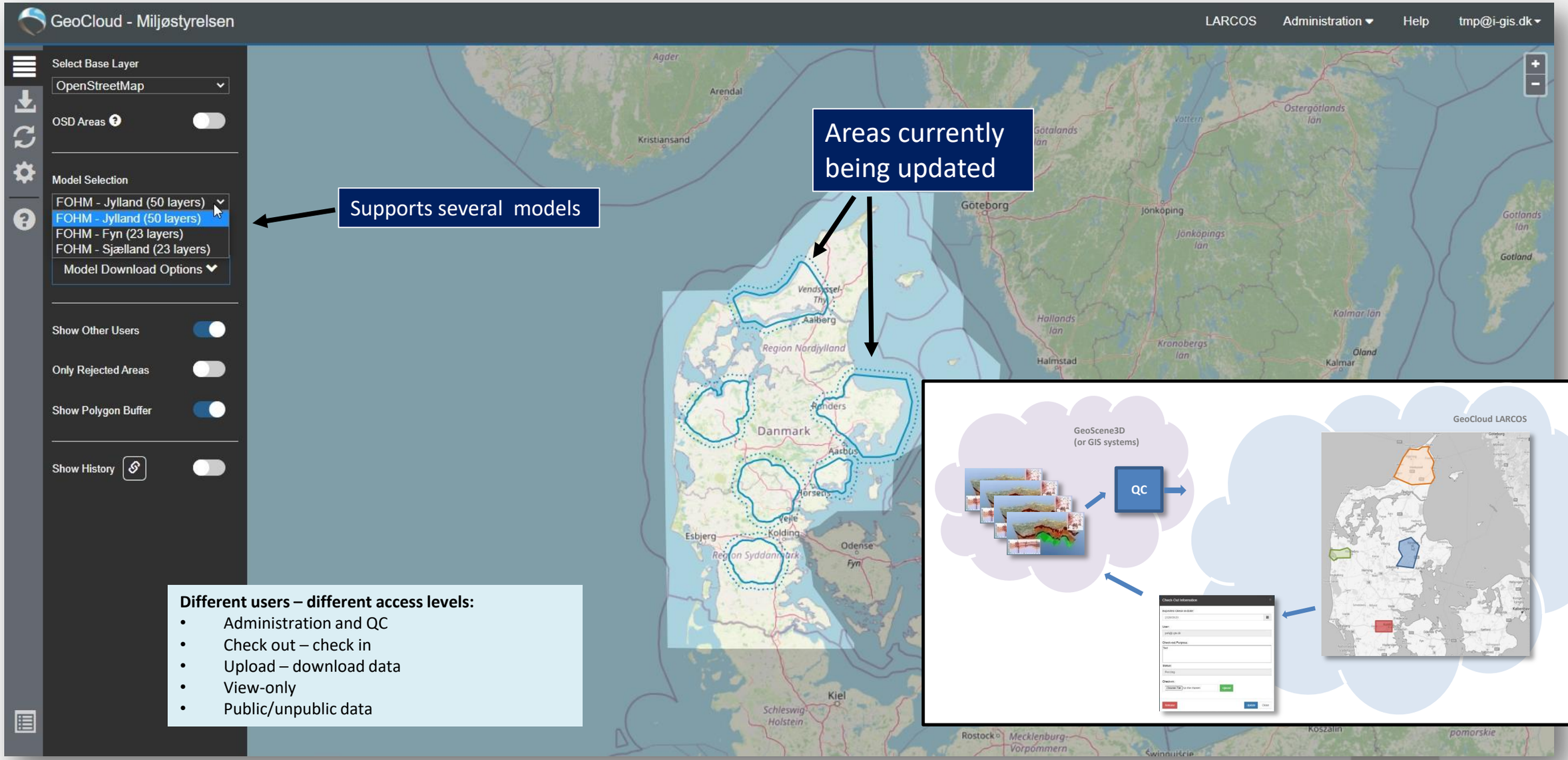
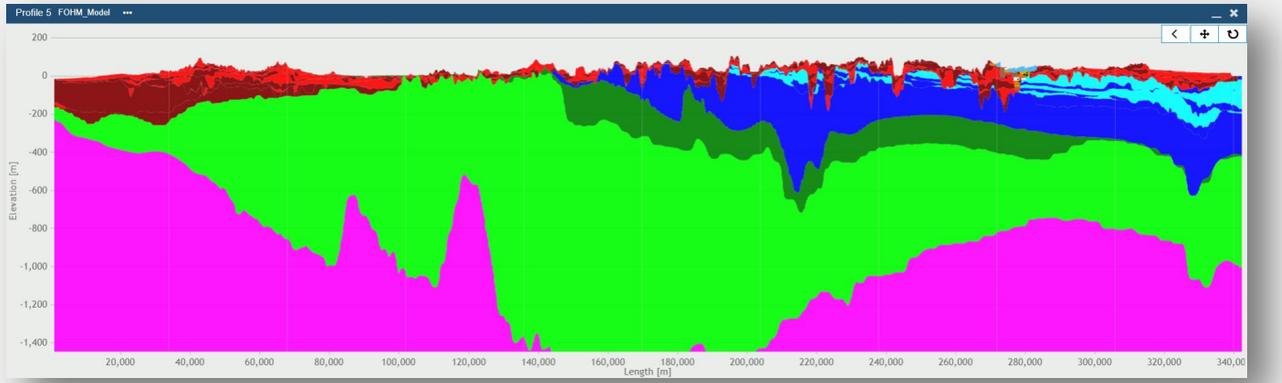
LARCOS system - part of GeoCloud DMS



FOHM/LARCOS in daily use



Since 2019:

Model updates based on:

- New data:
  - Borehole, geophysics etc.

- Specific needs
  - Land use
  - Development planning
  - Sparse data coverage – i.e. large uncertainty

Lessons learned

Many many things but summarized in a few sentences:

… ONE model as reference for the administrative basis

… “one model” with common maximum stratigraphy to define the geologic framework (compromises must be accepted) for further work

… we were able to work closely together, independently of organization

… a need for a common multiuser platform to handle the model and updates

… platform developed, in close collaboration with administrators, stakeholders, the public and consultants.

The LARCOS system is now running the maintenance process

Latest version:
70 layers

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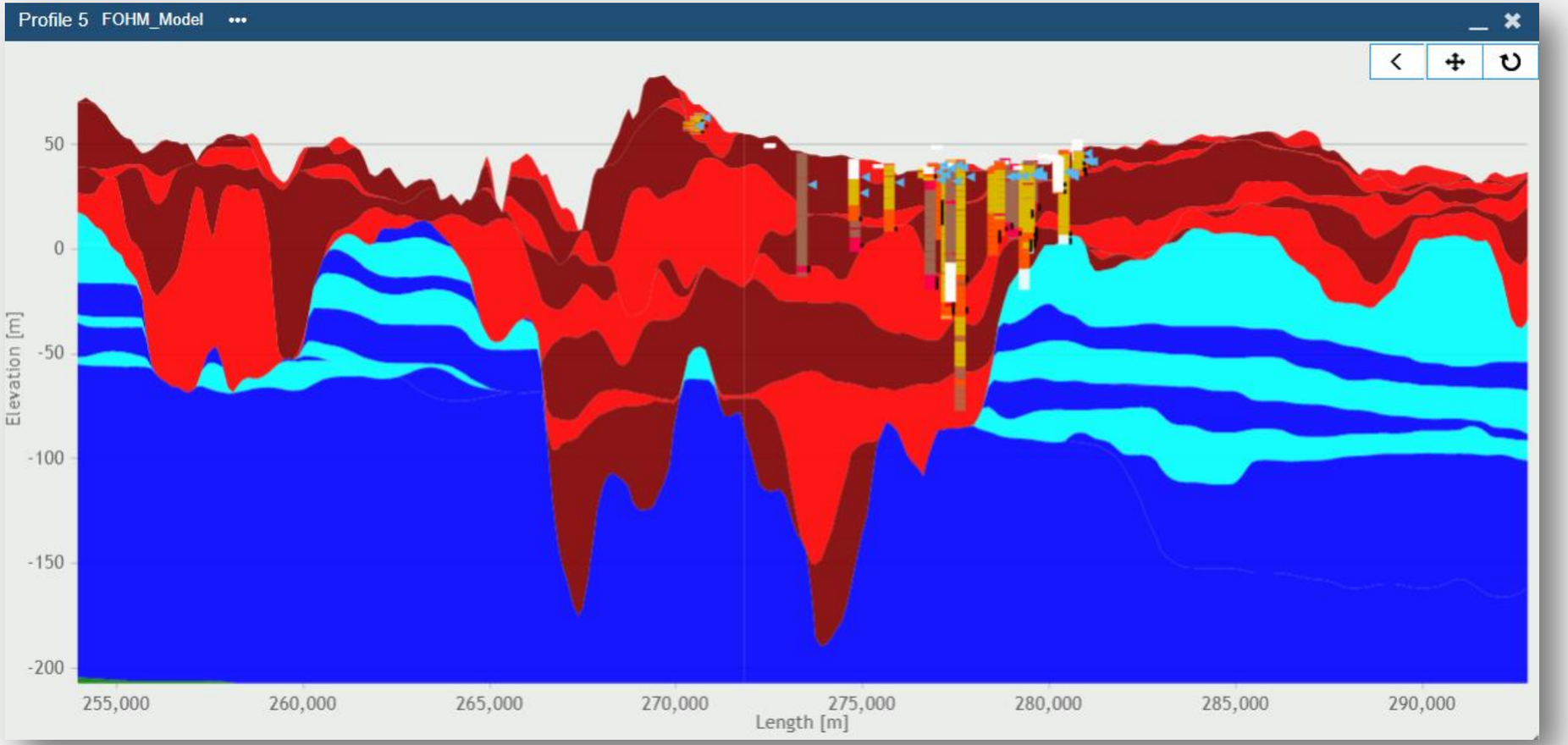
Questions?



Thank you

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