ESF projekts „Starpnozaru zinātnieku grupas un modeļu sistēmas izveide pazemes ūdeņu pētījumiem”

Reconstructing the Groundwater Flow in the Baltic Basin During the Last Glaciation

Tomas Saks, Juris Seņņikovs, Andrejs Timuhins, Andis Kalvāns

ESF EIROPAS SOCIĀLAIS FONDS

EIROPAS SAVIENĪBA

LATVIJAS UNIVERSITATE ANNO 1919

IEGULDĪJUMS TAVĀ NĀKOTNĒ

Līguma Nr. 2009/0212/1DP/1.1.1.2.0/09/APIA/VIAA/060

Contents

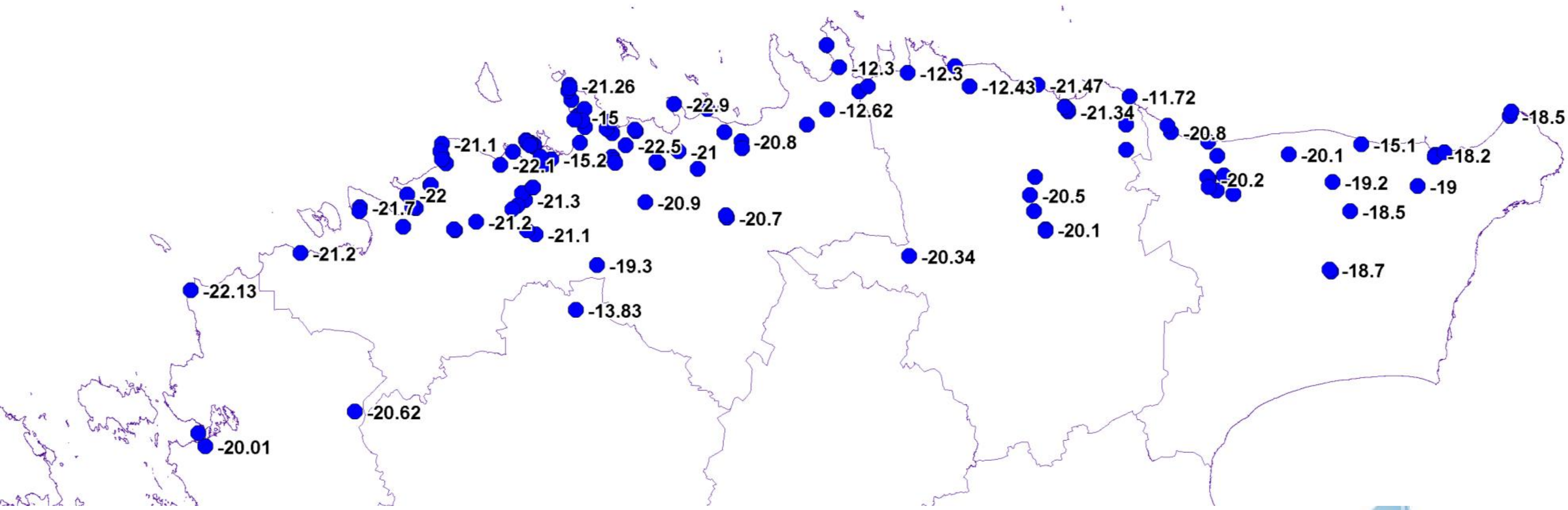
- The age of the groundwater in the Baltic Basin
- Glaciers and meltwater
- Model setup and data
- Results and discussion
- Conclusions

ESF projekts „Starpnozaru zinātnieku grupas un modeļu sistēmas izveide pazemes ūdeņu pētījumiem”
Līguma Nr. 2009/0212/1DP/1.1.1.2.0/09/APIA/VIAA/060

The age of the groundwater in the Baltic Basin

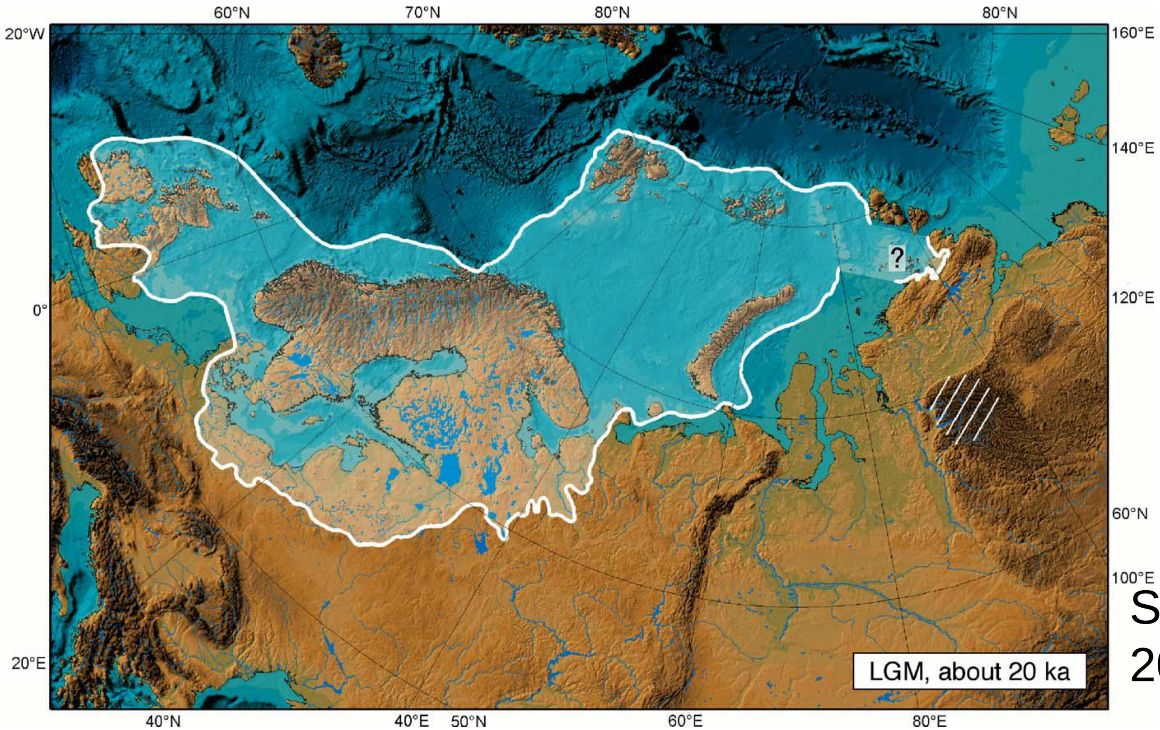
- Groundwater in the Baltic Basin, according to its chemical and isotope composition can be subdivided into three broad age groups:
  - “Contemporary” (Last 10 th. y.)
  - Pleistocene (glacial and interglacial)
  - “Ancient” – Pre-Quaternary

The water of glacial origin



- δO^{18}‰ values of groundwater in the Vendian – Cambrian aquifer system in North Estonia (Radla, 2010).

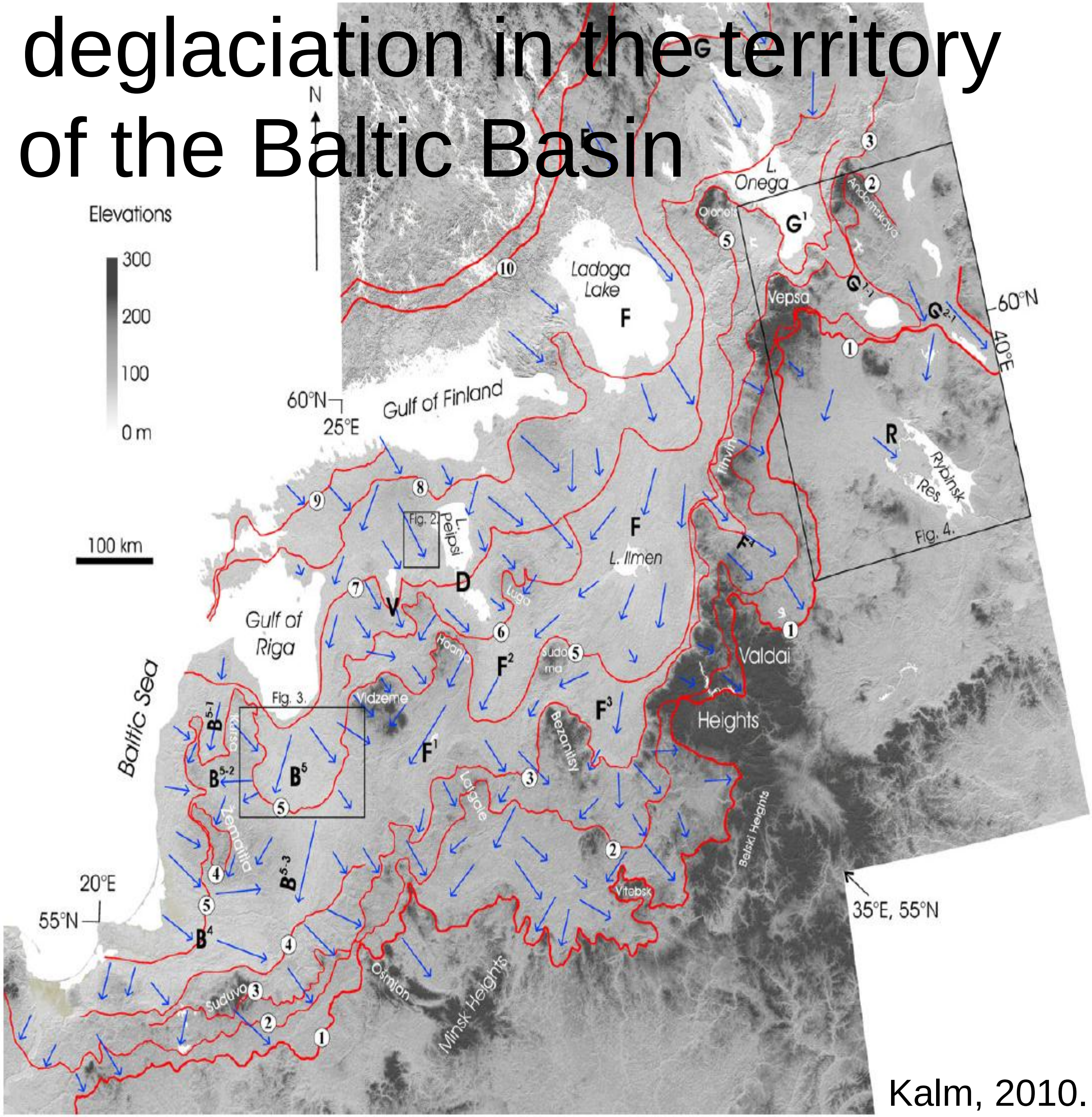
Glacial history of the Baltic Basin



Svedsen et al., 2004

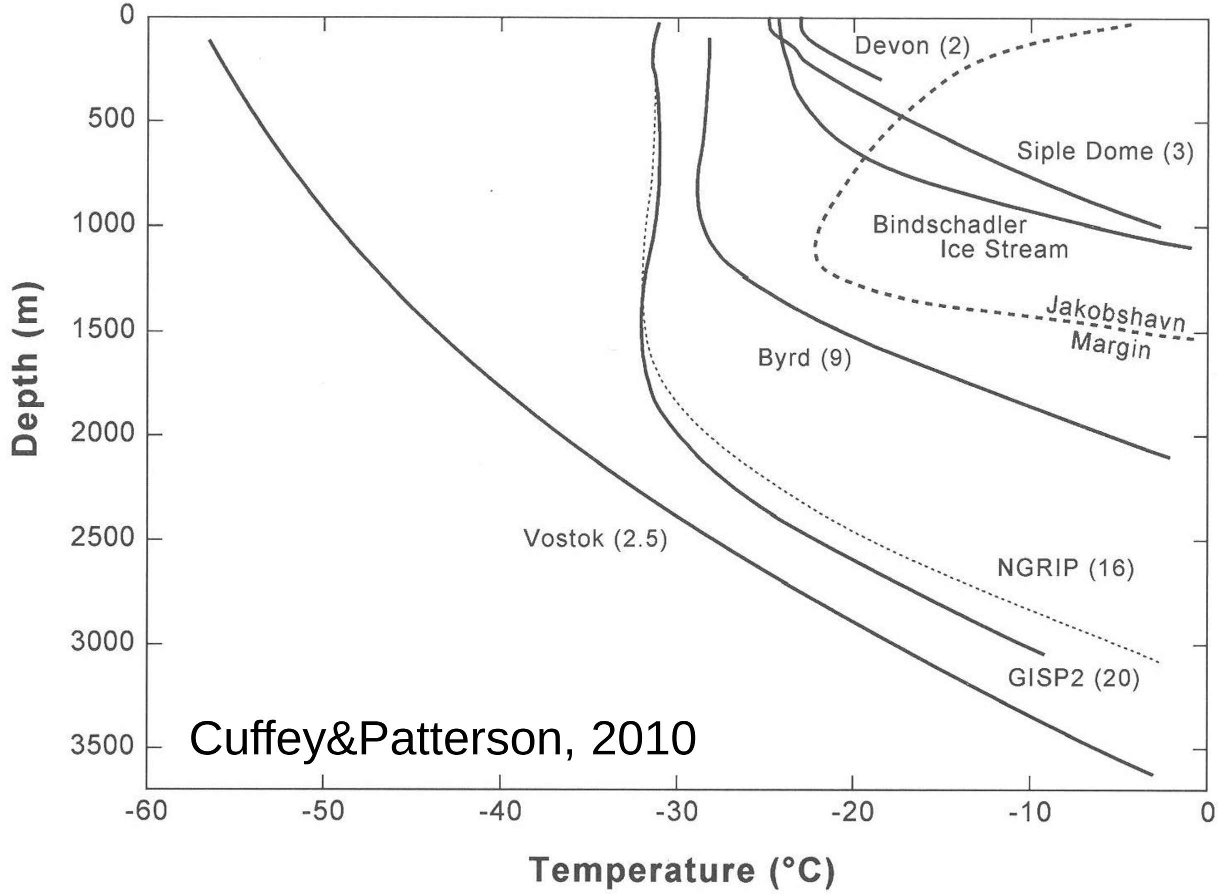
- The Baltic Basin has been covered by the Scandinavian ice sheets at least 4 times
- The last, Late Weichselian, glaciation was present in the Baltic Basin territory for at least 19 thousand years

The last deglaciation in the territory of the Baltic Basin



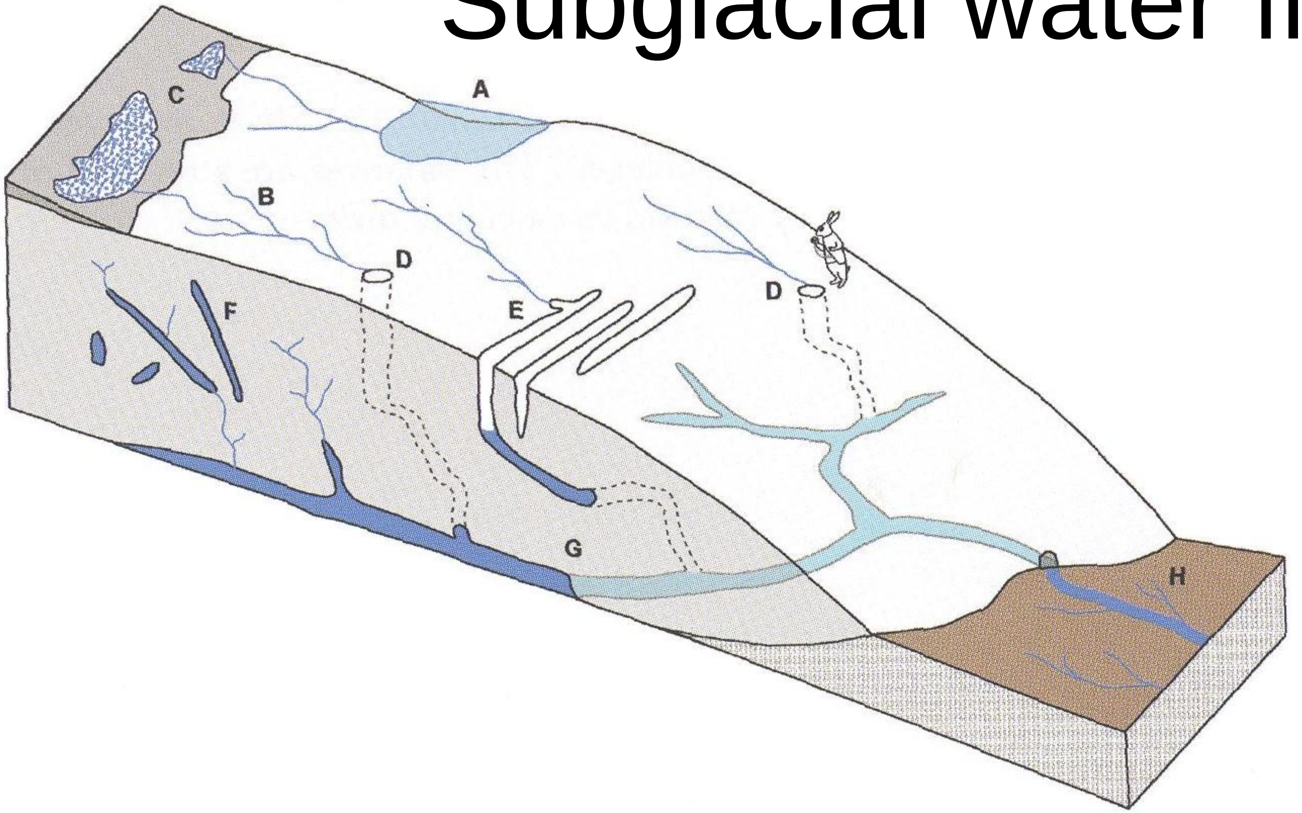
Kalm, 2010.

Thermal regime of the glaciers



- Most of the large ice sheets are warm-based, that is their bed temperature is at pressure-melting point

Subglacial water flow



A – Supraglacial lake;

B – Surface streams;

C – Swamp zones near the edge of the firn;

D – Moulins;

E – Crevasses

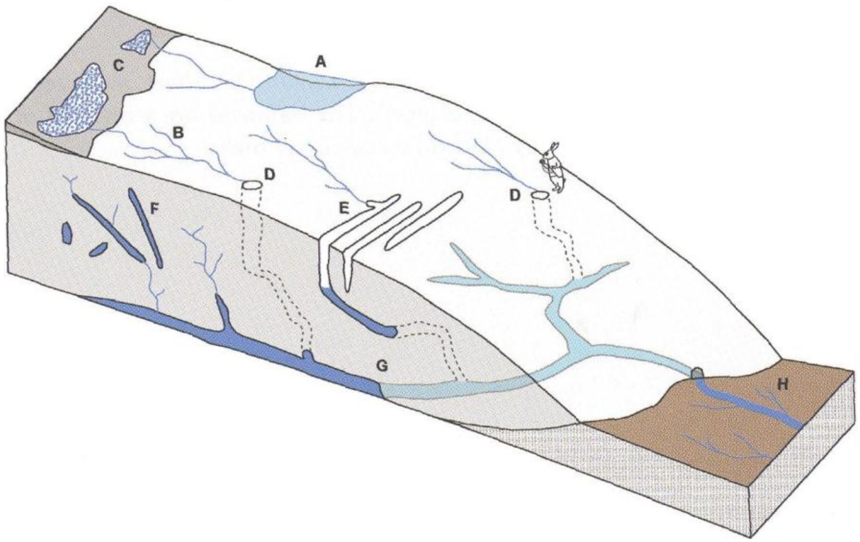
F – Water filled fractures

G – Subglacial tunnels

H – Runoff from the glacier

- Surface meltwater intrudes the glacier base via network of conduits connecting supraglacial water bodies and the glacier base
- Some meltwater can be generated at the base of the glacier itself due to geothermal heat flow and ice deformation heat Most of the water is drained along the ice/bed interface
  - Through R channels
  - Through N channels
  - Through cavity system

Subglacial water flow



A – Supraglacial lake;

B – Surface streams;

C – Swamp zones near the edge of the firn;

D – Moulins;

E – Crevasses

F – Water filled fractures

G – Subglacial tunnels

H – Runoff from the glacier

- For ideally plastic glacier ice water pressure at the base of the glacier is equal to the weight of the glacier (Patterson, 1994)
- Slopes of the glacier surface and its base controls the water flow direction at the glacier base

$\alpha = -11\beta$

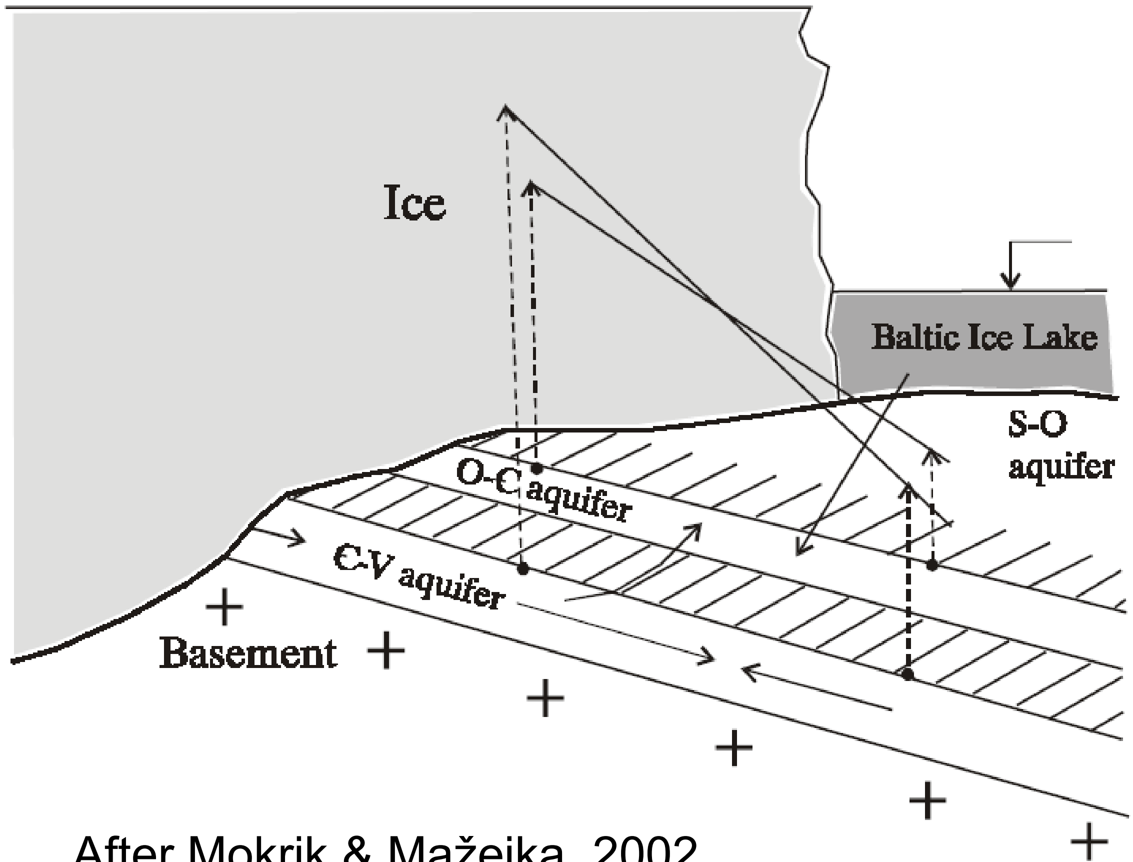
Subglacial groundwater recharge

- Intrusion of the glacier water is controlled
  - By the water conductivity of the sediments at the glacier base
  - The permafrost, that can permanently lock any open pores in the sediments
  - Groundwater pressure in the aquifer

The possible timing of glacial water intrusion in the Baltic Basin

- The Middle Weichselian (~53ka – ~26ka): cold climate conditions between two advances of Scandinavian glaciation
- Late Weichselian glaciation (12 – 28 t.g.): subglacial reacharg
- Baltic Ice Lake(12-10 t.g.), deglaciation stage of last glaciation: subglacial recharge

Intrusion of the glacier water



After Mokrik & Mažeika, 2002

- During the Baltic Ice Lake stage as an intrusion through the taliks in permafrost (Mokrik, Mažeika, 2002)

Intrusion of the glacier water

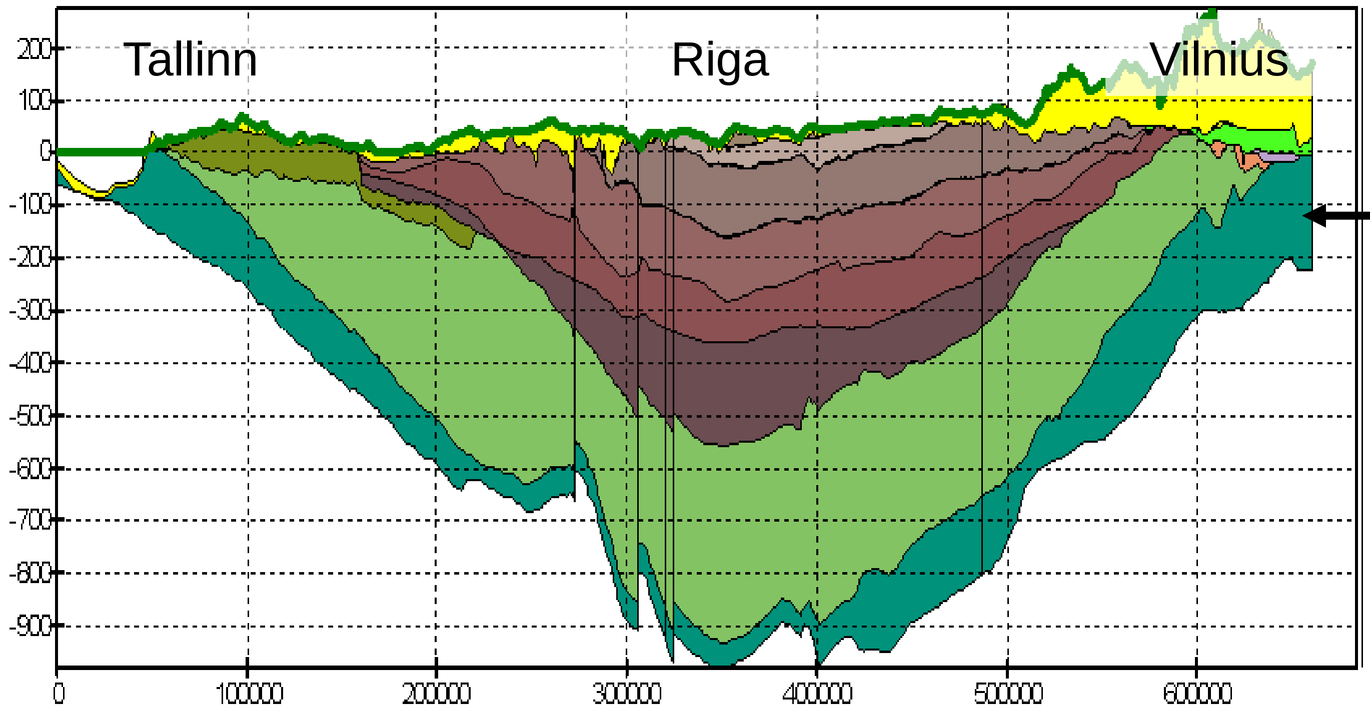
- Intrusion of the meltwater from the glacier is favoured, because:
  - Most of the glacier bed is expected to be at the temperate conditions in the ablation zone
  - Subglacial permafrost is expected to be thawed by the end of the glaciation
  - Very large pressure gradients existed s thousands of years

Aim of the modelling

- During the last glaciation:
  - Was the pressure gradient sufficient enough to reverse the interglacial (like modern) groundwater flow direction in the CM-V system?
  - What were groundwater flow direction and velocities?
  - What was the volume of the meltwater intruded?

Model setup and data

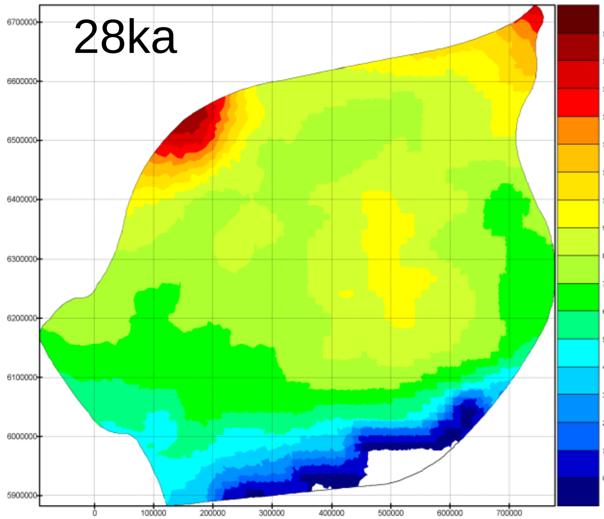
Model setup

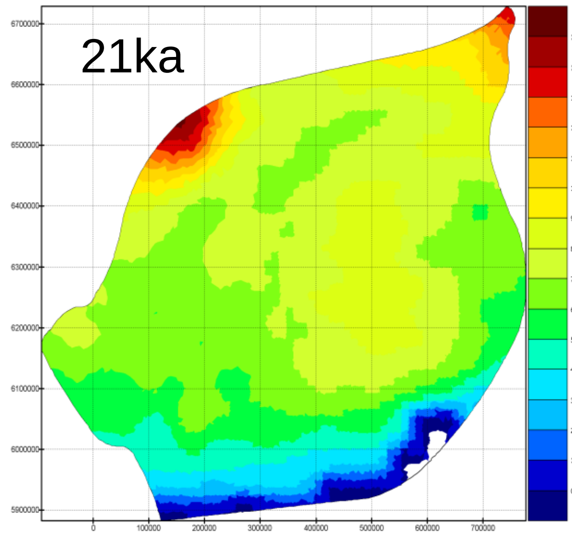


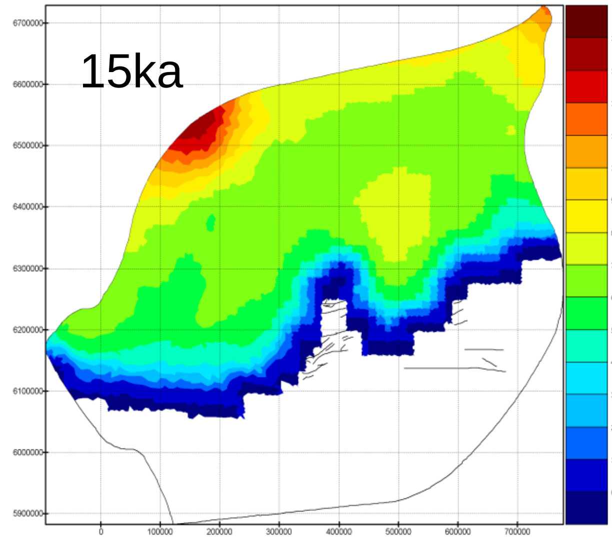
Vendian – Cambrian aquifer

- Calibrated MOSYS/BAB V0
- Geometry corrected for subglacial topography: subsidence of Earth crust surface due to ice weight
- On the surface constant pressure boundary condition calculated from ice thickness data was applied
- 19 consecutive modelling steps spanning the time from 10 – 28ka BP thru the last glacial advance and deglaciation

Input data

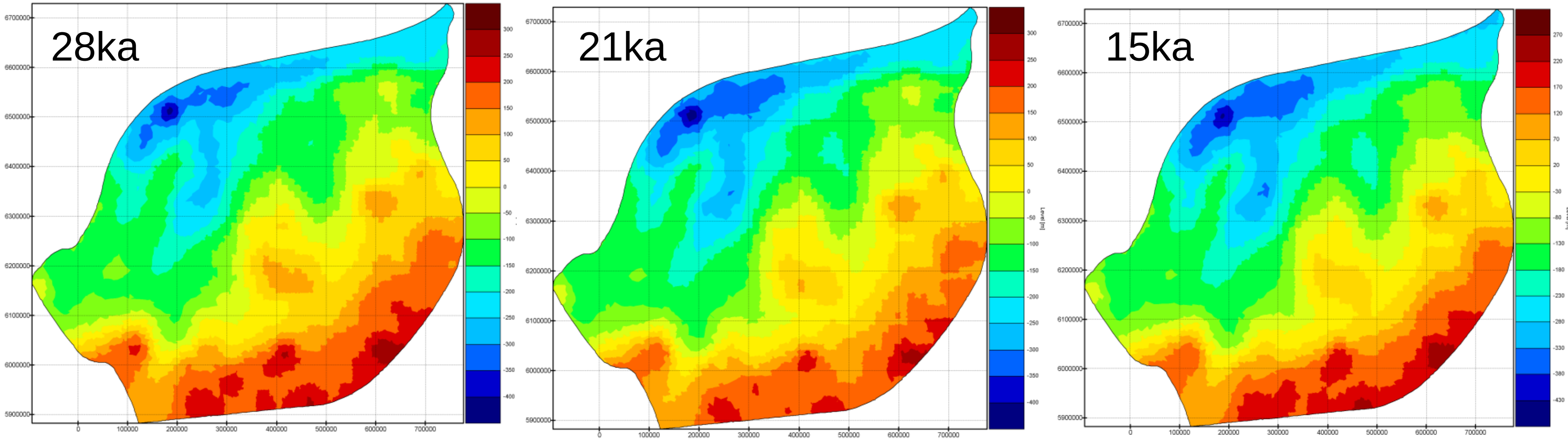






- Ice thickness data for 10 – 28ka BP in 1 ka intervals (Argus, Peltier, 2010)

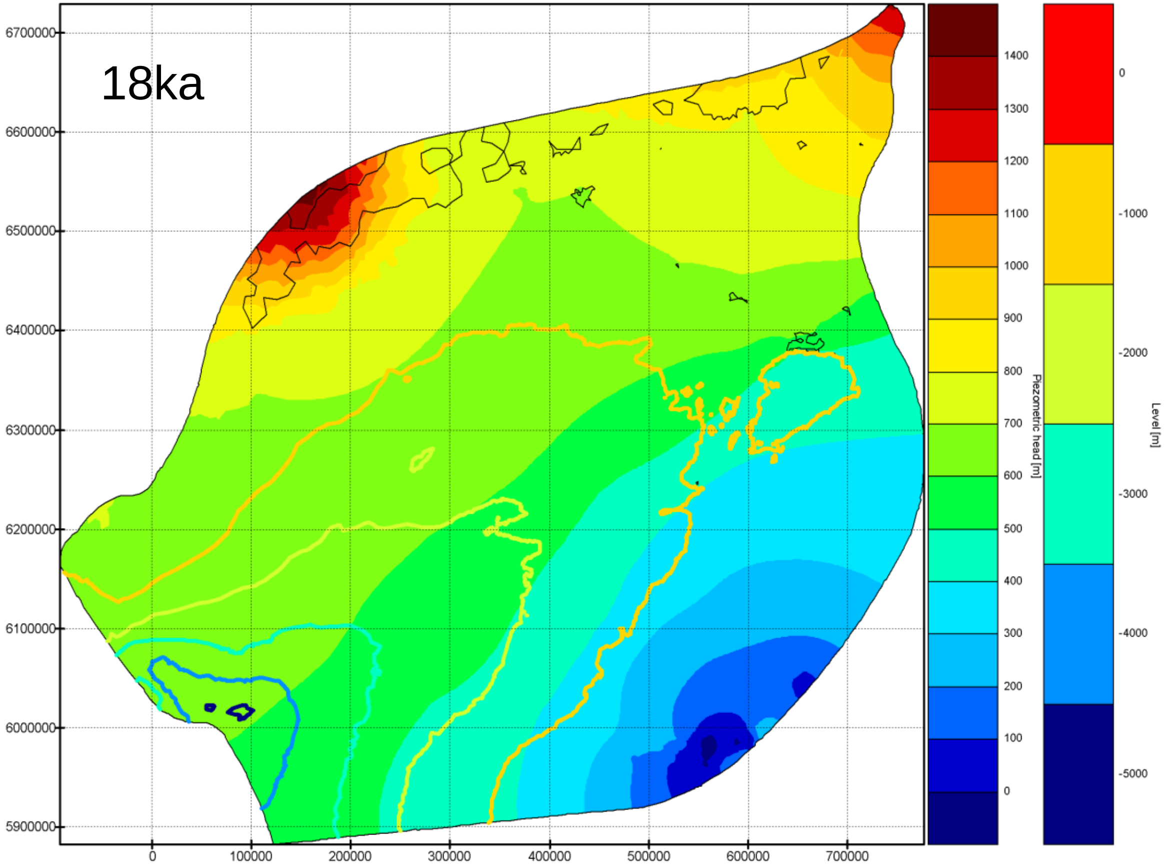
Input data



- Subglacial topography data for 10 – 28ka BP in 1 ka intervals (Argus&Peltier, 2010)

Results

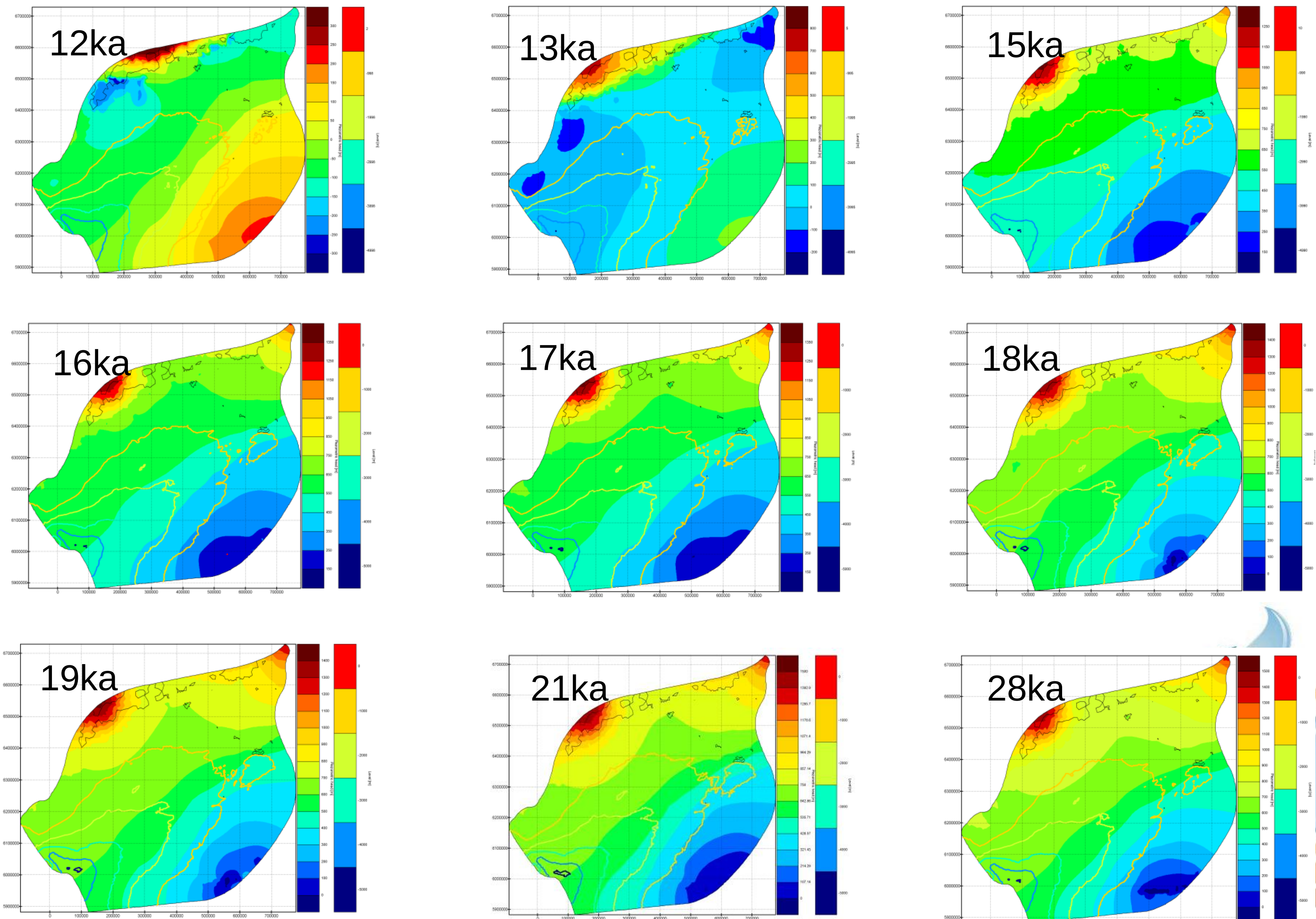
Groundwater flow directions



Two main areas of meltwater intrusion into the Cm-V aquifer system: around Narva and Gotland

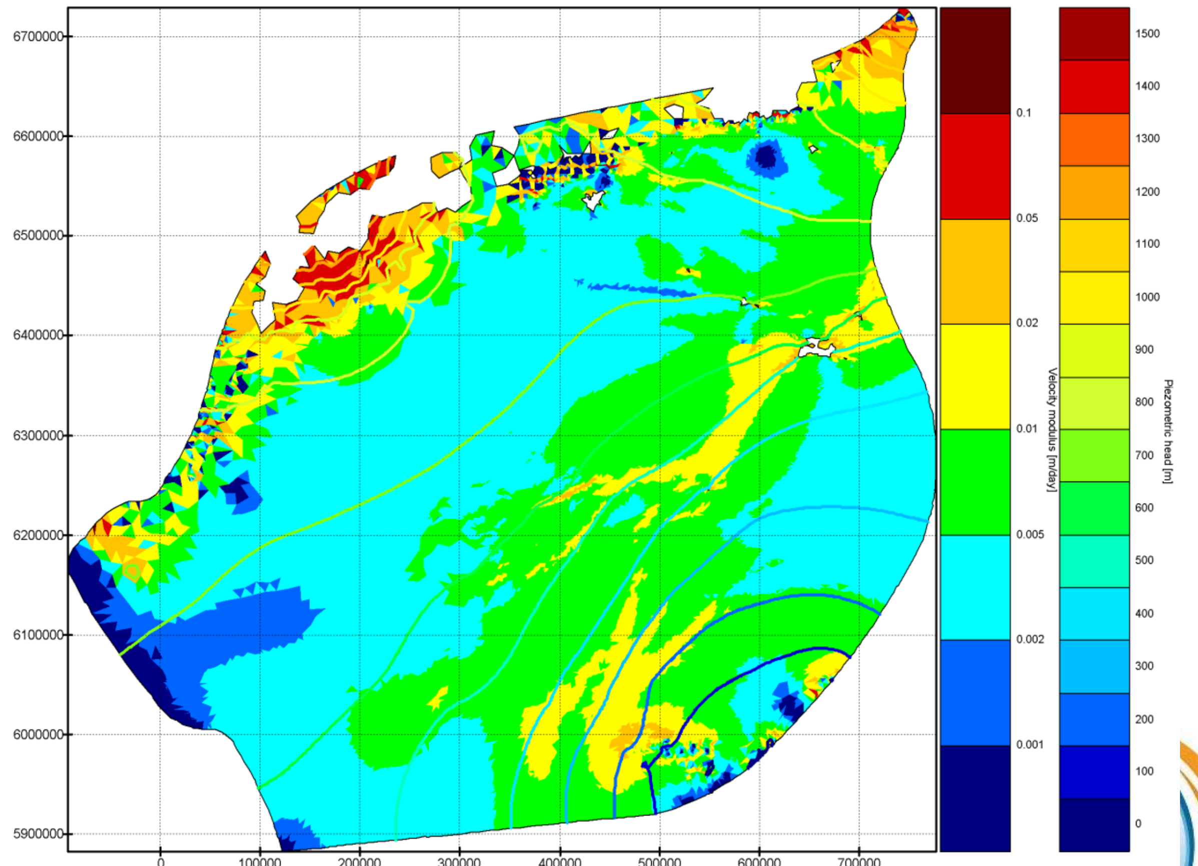
The Western intrusion area has been present for longer time periods

Groundwater flow during the last glaciation



Flow velocities

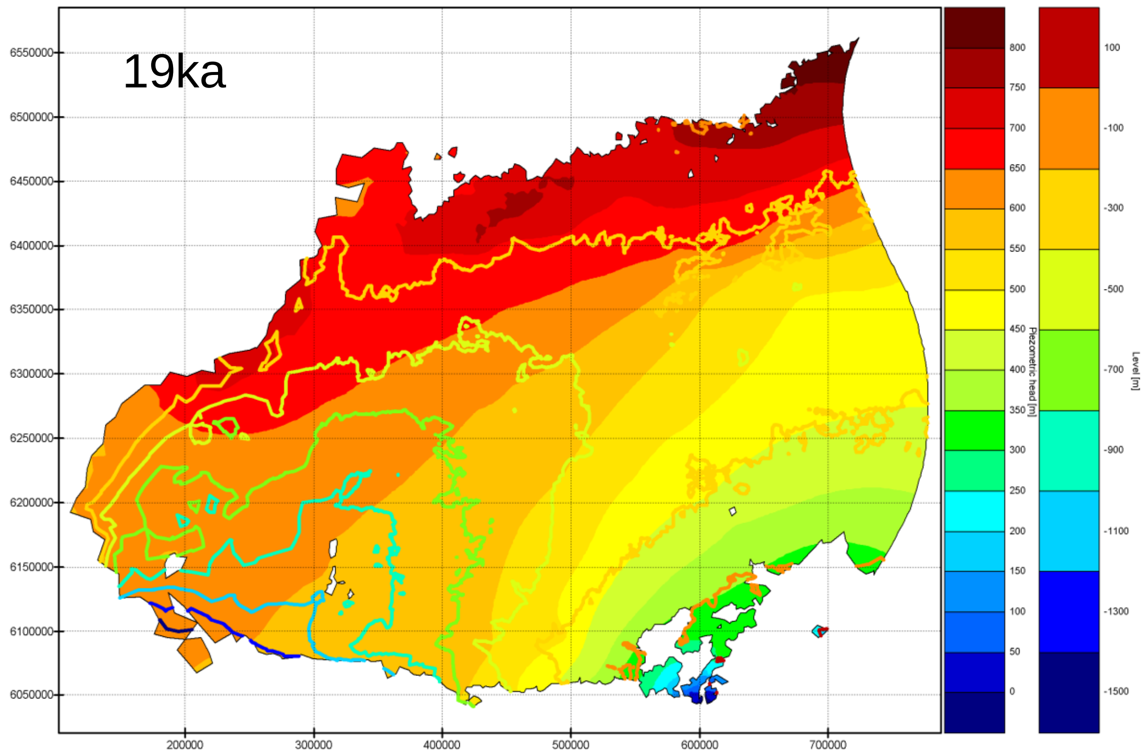
- Maximum velocities near the intrusion
- Groundwater flow velocity modules at around one order of magnitude greater than in modern conditions



Volume and distance of the meltwater intruded

- Assuming that the intrusion “window” was 750 km long and 150 m thick:
  - the total water volume intruded into the Cm-V aquifer system during the 14 th years of glaciation could be up to ~ $2.2*10^{12}$ m^3
  - If the average porosity is 20% this will result in The distance of the intrusion amounts to ~ 100 km penetration
- If the 95% of the meltwater intruded into 2 aquifers of total thickness ~ 50m the depth of the intrusion would be extends to 270 km, corresponding to $2.0*10^{12}$ m^3

Lower Devonian aquifer system



- Lower Devonian aquifer system: a likely candidate to contain glacial meltwater as models suggest large regional pressure gradient during the last glaciation

Identified problems and the future work – 1

- Basal till distribution:
  - The water conductivity of the subglacial sediments is one of the main factors directly influencing the volume of the meltwater intruded and the flow velocities of the groundwater
  - Even a relatively thin till layer of low conductivity can slow down the subglacial groundwater recharge
  - The till distributing and thickness is changing as ice sheet evolves
- Permafrost:
  - Unknown distribution and thickness before the advance of glacier and in periglacial area
  - Unknown rate of degradation under the ice sheet

Identified problems and the future work – 2

- Buried valleys in Northern Estonia:
  - These could serve as intensified infiltration windows
- Uncertainty of the glacial history:
  - the ice distribution, subglacial meltwater availability, glacioisostasic depression of Earth crust
- The currently defined Eastern boundary of the Baltic Basin is irrelevant for the periods when groundwater flow was controlled by the glacier: the model should be extended Eastwards

Conclusions

Conclusions

- Two potential intrusion areas for the Baltic basin: in the East around Narva and in the west around Gotland
- Reversed (as to present) groundwater flow direction could exist for up to 14 thousand years during the last glacial advance
- At the present model setup the meltwater intrusion from the glacier can explain most of the glacier water presence in the Cm-V aquifer system, although only the last glacial advanc was considered
- Model results are likely over-estimations, as several factors, that could hamper subglacial groundwater recharge were not accounted for

References

- Cuffey K.M., Patterson W.S.B. 2010. The physics of glaciers. 4th edition. Elsevier. 636p.
- Mokrik R., Mažeika J. Paleohydrogeological reconstruction of groundwater recharge durinf Late Weichselian in the Baltic Basin. Geologija. Vilnius. No. 39. P. 49-57
- Patterson W.S.B. 2004. The physics of glaciers 3rd. Edition. Elsevier. 480p.
- Raidla V (2010) Chemical and isotope evolution of groundwater in the Cambrian-Vendian aquifer system in Estonia., Dissertationes Geologicae Universitatis Tartuensis 28, Tartu: Tartu Ülikooli Kirjastus
- Saks, T., Kalvans, A., Zelčs, V. *In press.* OSL dating evide Middle Weichselian age of shallow basin sediments in We Latvia, Eastern Baltic. Quaternary Science Reviews*.*
- Svendsen, J.I. *et al*. 2004: Late Quaternary ice sheet histo northern Eurasia. *Quaternary Science Reviews*, **23**, 1229-

Thanks for your attention!

ESF projekts „Starpnozaru zinātnieku grupas un modeļu sistēmas izveide pazemes ūdeņu pētījumiem”
Līguma Nr. 2009/0212/1DP/1.1.1.2.0/09/APIA/VIAA/060