

The Impact of the Last Glaciation on Groundwater Flow in Estonia: A Numerical Study.

Arnaud Sterckx¹, PhD student

Prof. Jean-Michel Lemieux¹

Prof. Rein Vaikmäe²

¹ Department of Geology and Geological Engineering, Laval University, Quebec City, Canada

¹ Centre of Northern Studies, Quebec City, Canada

² Institute of Geology, Tallinn Technical University, Tallinn, Estonia



$\delta^{18}\text{O}$ in Estonian groundwater

Hydrostratigraphic units

- Quaternary deposits
- Devonian
- Silurian - Ordovician
- Cambrian - Ordovician
- Cambrian - Vendian
- Precambrian basement

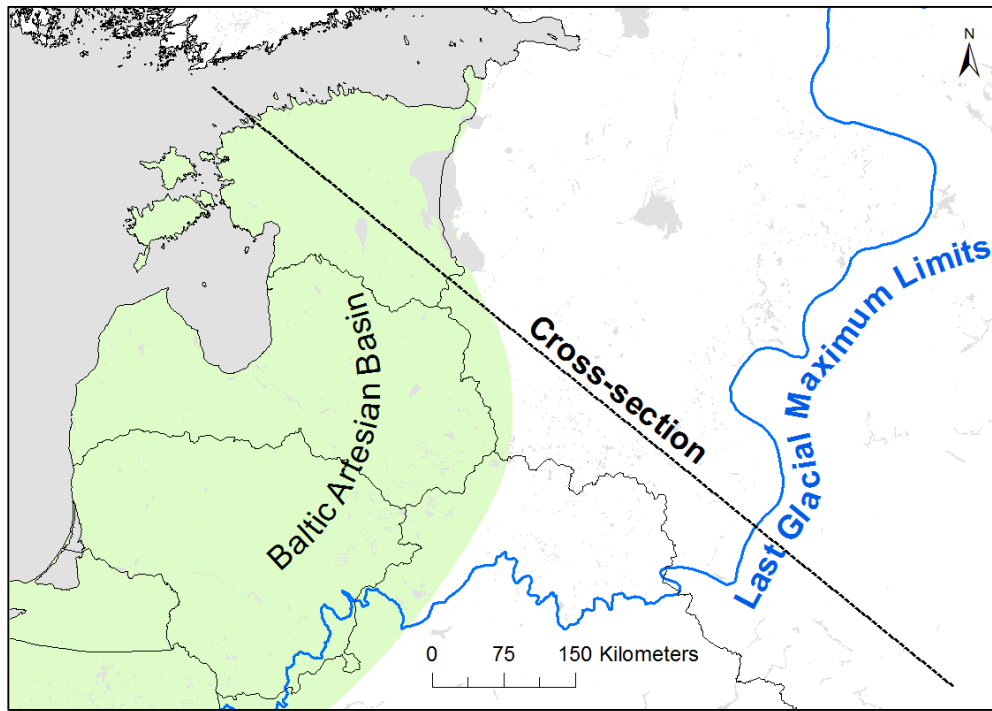
$\delta^{18}\text{O}$ [‰]

- < -19
- 19, -17
- 17, -15
- 15, -13
- 13 <

0 25 50 Kilometers

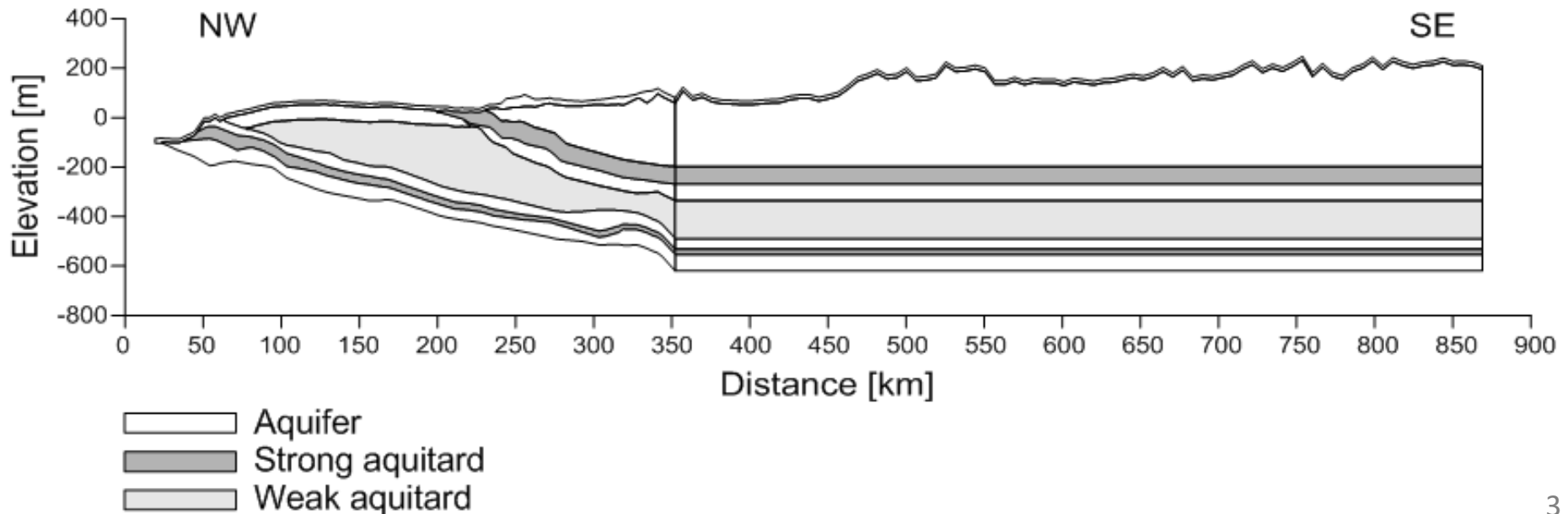


Source of $\delta^{18}\text{O}$ data: Technical University of Tallinn, Institute of Geology, 2014

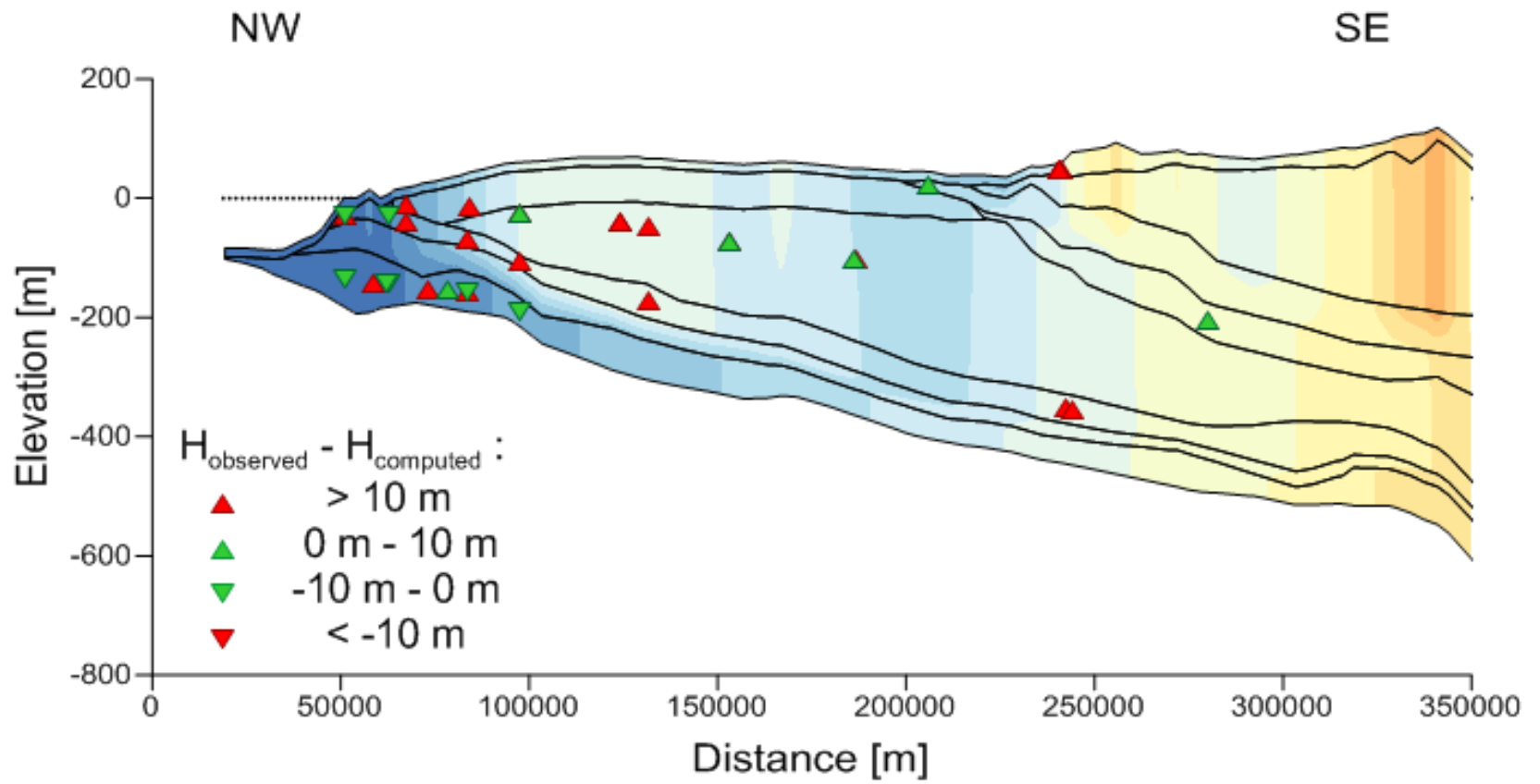



Baltic Artesian Basin hydrogeological model
(Virbulis et al. 2013)

→ 42 layers in total



Hydraulic head [m]

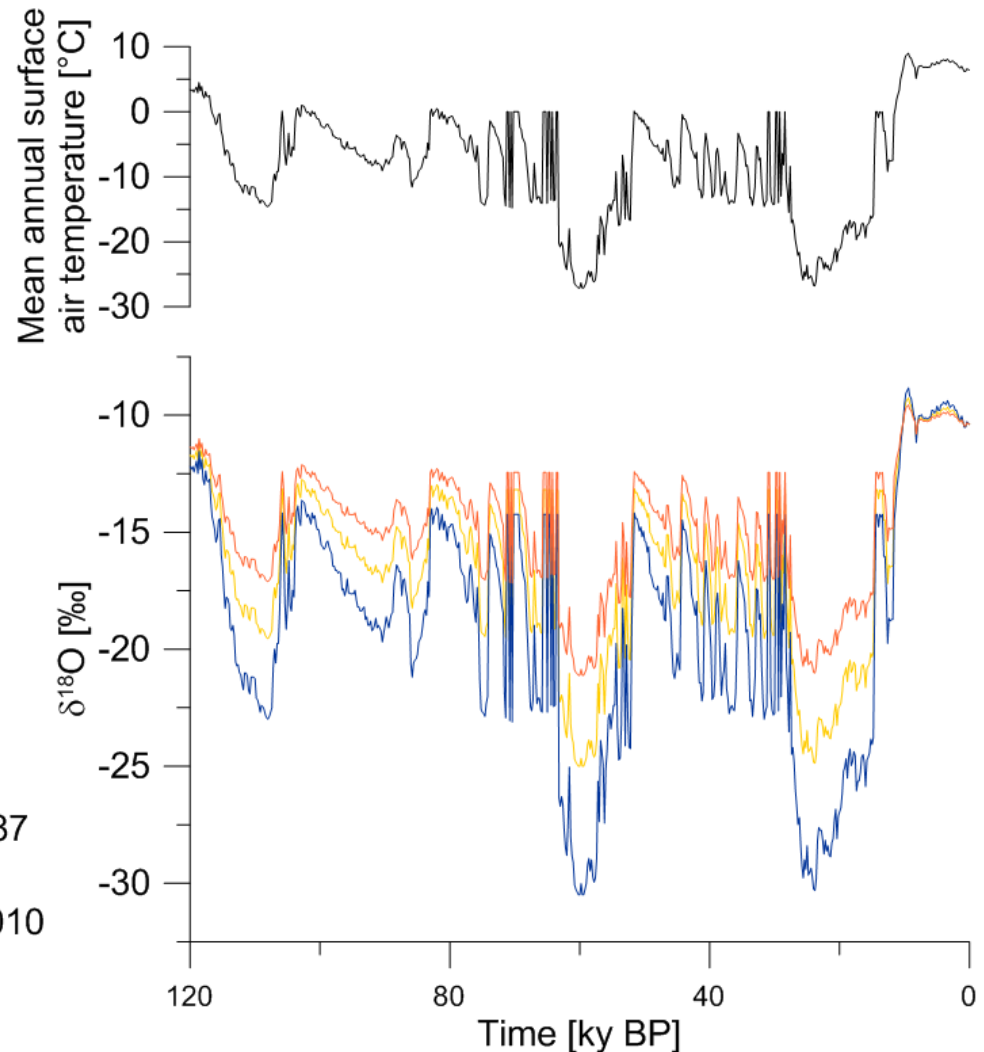


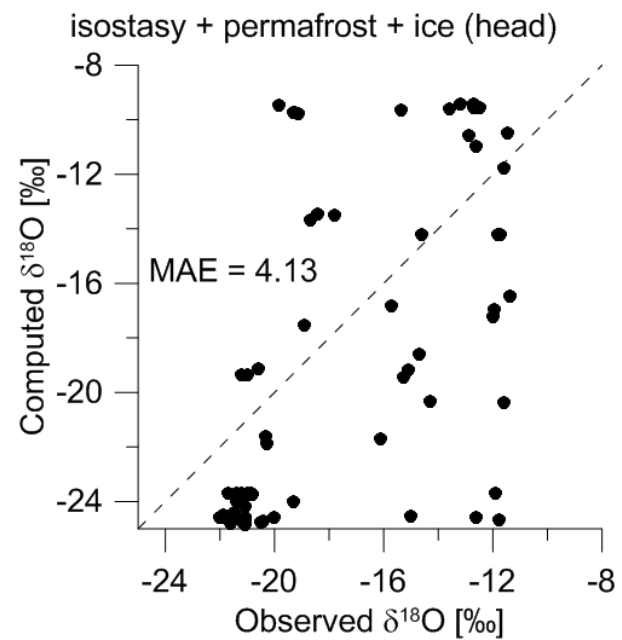
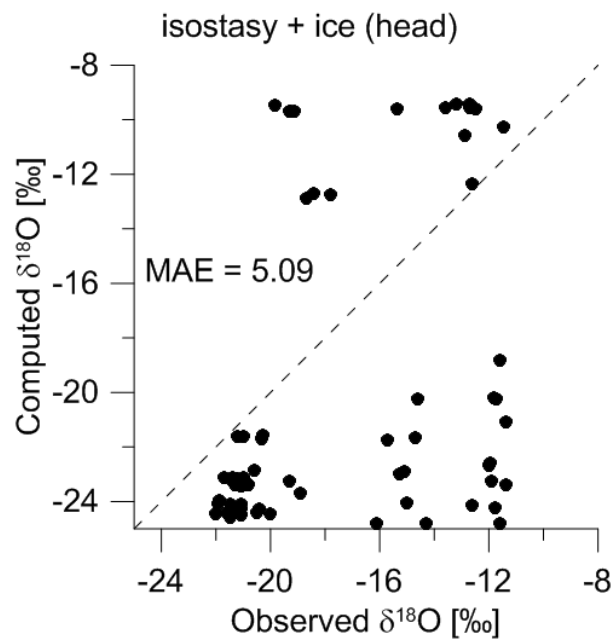
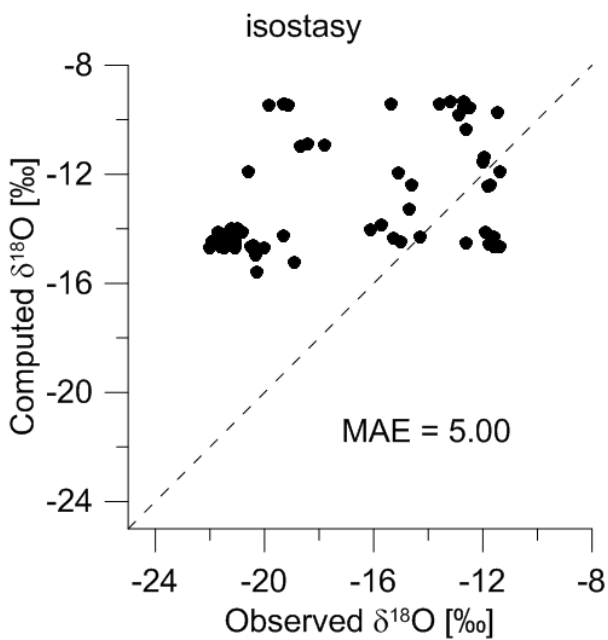
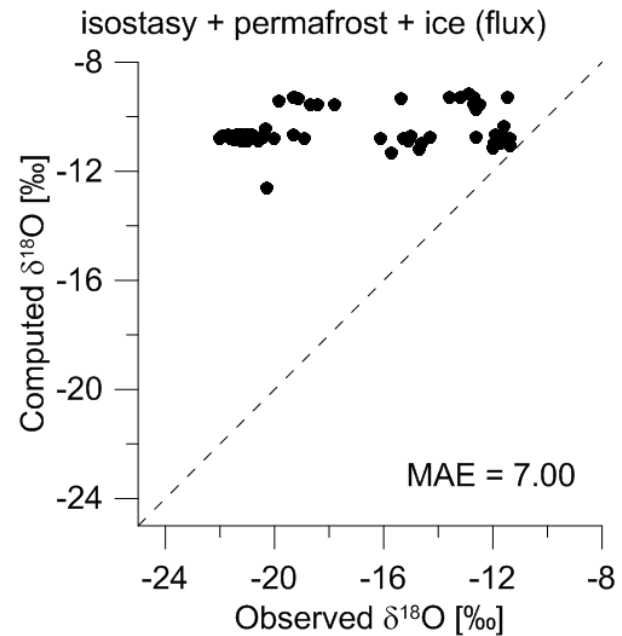
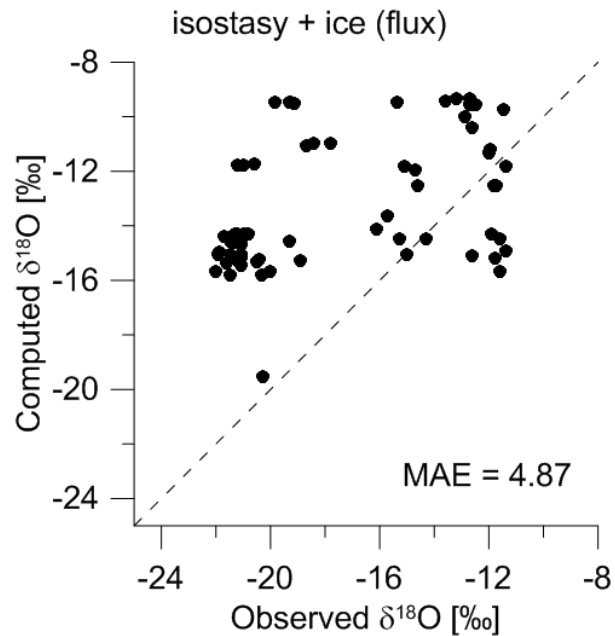
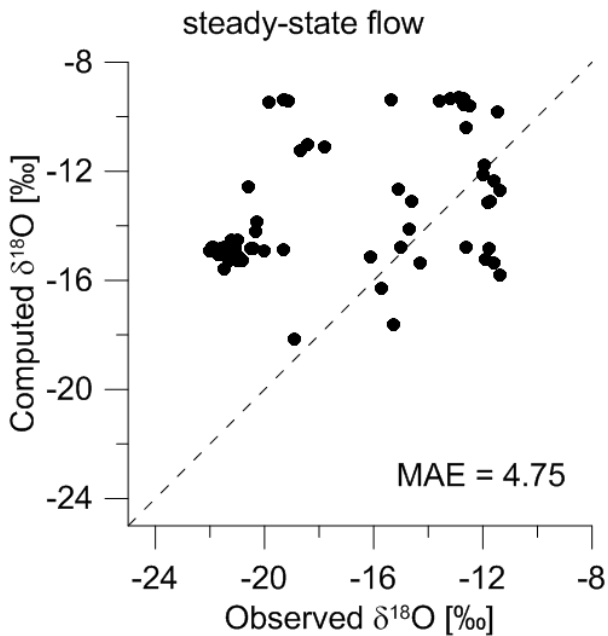
Glacial Systems Model of northern Europe (Tarasov 2014)

Long: 0.5° x Lat: 0.25° data over the last 120 ky:

- Surface elevation
- Ice thickness
- Subglacial meltwater production
- Absolute sea level & lake water depth
- Permafrost thickness
- Mean annual surface air temperature

— Punning et al. 1987
— Conceptual
— Arppe & Karhu 2010





Batch analysis, testing several scenarios

One single glacial event, 3 variables:

- Ice-sheet thickness = [1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3] km
- Start of the Last Glacial Maximum = [25, 24, 23, 22, 21, 20, 19] ky BP
- $\delta^{18}\text{O}$ of meltwater = [-32.5, -30, -27.5, -25, -22.5] ‰

→ 315 simulations

→ “best fit” simulation: MAE = 2.58

2.5 km / 19 ky BP / -32.5 ‰

What's next?

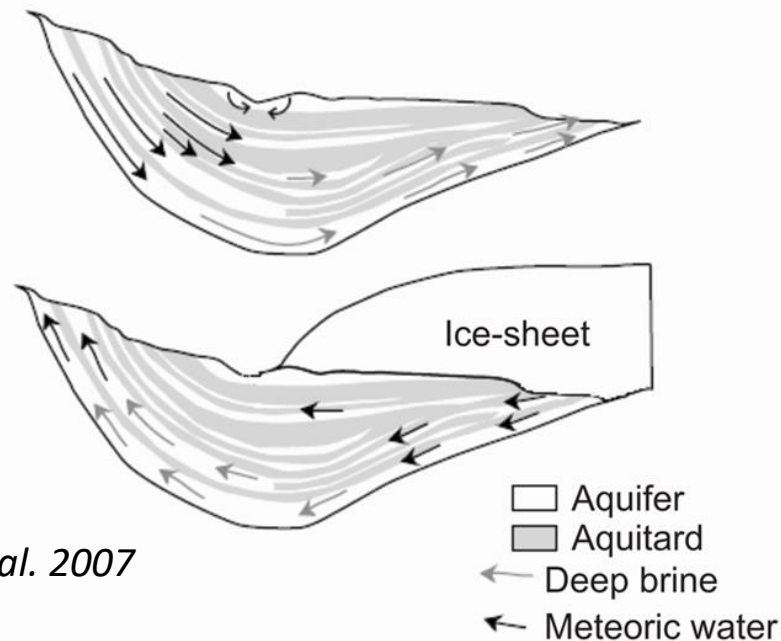
- Compare with the situation in Latvia
- Make some predictive scenarios of the fate of glacial water in Estonia



Lahemaa National Park (northern Estonia)

Thank you for your attention !

- Highly depleted in heavy isotopes (^{18}O and ^2H)
- Recharge temperature inferred from noble gases around $3,5\text{ }^\circ\text{C}$
 - *Recharge in a cooler climate*
- ^{14}C ages vary from 30 to 19 ky BP (Raidla et al., 2012)
- Low salinity ($< 1\text{ g/L}$)
 - *Recharge near the end of the Last Glaciation*



Modified after Person et al. 2007

LEGEND

GLOBAL STRATIGRAPHY			REGIONAL STRATIGRAPHY		INDEX	MAIN ROCK TYPES				
System	Series	Stage	Series	Stage						
NEOGENE			QUATERNARY		Q	Sand, gravel, till, clay, peat (only in cross-section)				
DEVONIAN	Upper Devonian	Frasnian	Upper Devonian	DAUGAVA	D ₁ dg	Limestone, dolostone				
				DUBNIKI	D ₁ db	Dolomitic marl, dolostone				
				PLAVINASE	D ₁ pl	Dolostone, limestone, dolomitic marl				
	Middle Devonian	Givetian	Middle Devonian	AMATA	D ₂ am	Siltstone, breccia-like sandstone				
				GAUJA	D ₂ ga	Sandstone, siltstone				
				BURTNIKI	D ₂ br	Sandstone, siltstone				
ARUKÜLA				D ₂ ar	Sapstone, siltstone					
Eifelian	Middle Devonian	NARVA	D ₂ nr	Dolomitic marl, siltstone, sandstone with concretions						
		PARNU	D ₂ pr	Sandstone, siltstone, dolomitic marl						
SILURIAN	Upper Silurian	Fridolf	Upper Silurian	OHESAARE	S ₂ oh	Dolomitic marl, limestone, siltstone				
				KAUGATUMA	S ₂ kg	Limestone, marl, crinoidal limestone				
				KURESSAARE	S ₂ kr	Argillaceous limestone, marl				
				PAADLA	S ₂ pd	Argillaceous limestone, dolostone, marl				
	Lower Silurian	Wenlock	Homerian	Lower Silurian	ROOTSIKÜLA	S ₁ rt	Argillaceous dolostone, argillaceous limestone			
					JAAGARAHU	S ₁ ja	Limestone, marl, dolostone, biohermal dolostone			
					JAANI	S ₁ jn	Marl, argillaceous limestone, dolostone			
					ADAVERE	S ₁ ad	Marl, limestone			
	Llandovery	Rhuddanian	Aeronian	Lower Silurian	RAIKKÜLA	S ₁ rk	Limestone, dolostone, argillaceous limestone			
					JUURU	S ₁ jr	Argillaceous limestone, marl, dolostone			
					Ordovician	Hirnantian	Hajju	PORKUNI	O ₃ pr	Limestone, dolostone, marl, calcareous sandstone
								PIRGU	O ₃ prg	Limestone, marl
Upper Ordovician	Kattian	Hajju	VORMSI	O ₃ vr	Limestone, marl, argillaceous limestone					
			NABALA	O ₃ nb	Argillaceous and crysocrystalline limestone					
ORDOVICIAN	Middle Ordovician	Darrwillan	Viru	RAKVERE	O ₂ rk	Cryptocrystalline limestone				
				OANDU	O ₂ on	Argillaceous and biohermal limestone, marl				
				KEILA	O ₂ ki	Argillaceous and biohermal limestone, marl, K-bentonite				
				HALJALA	O ₂ hl	Argillaceous limestone, marl, K-bentonite, impact breccia				
				KUKRUSE	O ₂ kk	Argillaceous limestone, kukersite, marl				
				UHAKU	O ₂ uh	Argillaceous limestone, marl, kukersite				
	Lower Ordovician	Darrwillan	Viru	LASNAMÄGI	O ₂ lg	Limestone, argillaceous limestone				
				ASERI	O ₂ as	Limestone with Fe-ooliths				
				Oland	KUNDA	O ₁ kn	Limestone, sandy limestone, kerogenous limestone, glauconitic limestone, limestone with Fe-ooliths			
					Undifferented ¹	O ₁ uk-O ₁ u	Sandstone, graptolite argillite, glauconitic silt-sand- and limestone, limestone			
CAMBRIAN	Series 1-3	Furong	Oland	Undifferented ²	Ca ₂ 3	Sandstone, siltstone, claystone				
				DOMINOPO	Ca ₁ dm	Sand- and siltstone, claystone				
				LONTOVA	Ca ₁ ln	Claystone, siltstone, sandstone				
NEOPROTEROZOIC			KOTLIN	V ₂ kt	Siltstone, siltstone, silty claystone					
MESOPROTEROZOIC				MP	Rapakivi granite, porphyry quartz-porphyr					
PALEOPROTEROZOIC				PP	Complex of gneiss, migmatite, gneisses, crystalline schists, amphibolites etc.					

Hydrostratigraphy

Q	Quaternary deposits
D3	Upper Devonian aquifer
D2	Middle Devonian aquifer
	Narva aquitard
D2-1	Middle-Lower Devonian aquifer
	Ordovician-Silurian aquifer
S-O	Ordovician-Silurian aquitard
Cm-O	Cambrian-Ordovician aquifer
	Lükati-Lontova aquitard
	Voronka aquifer
Cm-V	Kotlin aquitard
	Gdov aquifer
PR	Crystalline basement

Aquifer
Aquitard

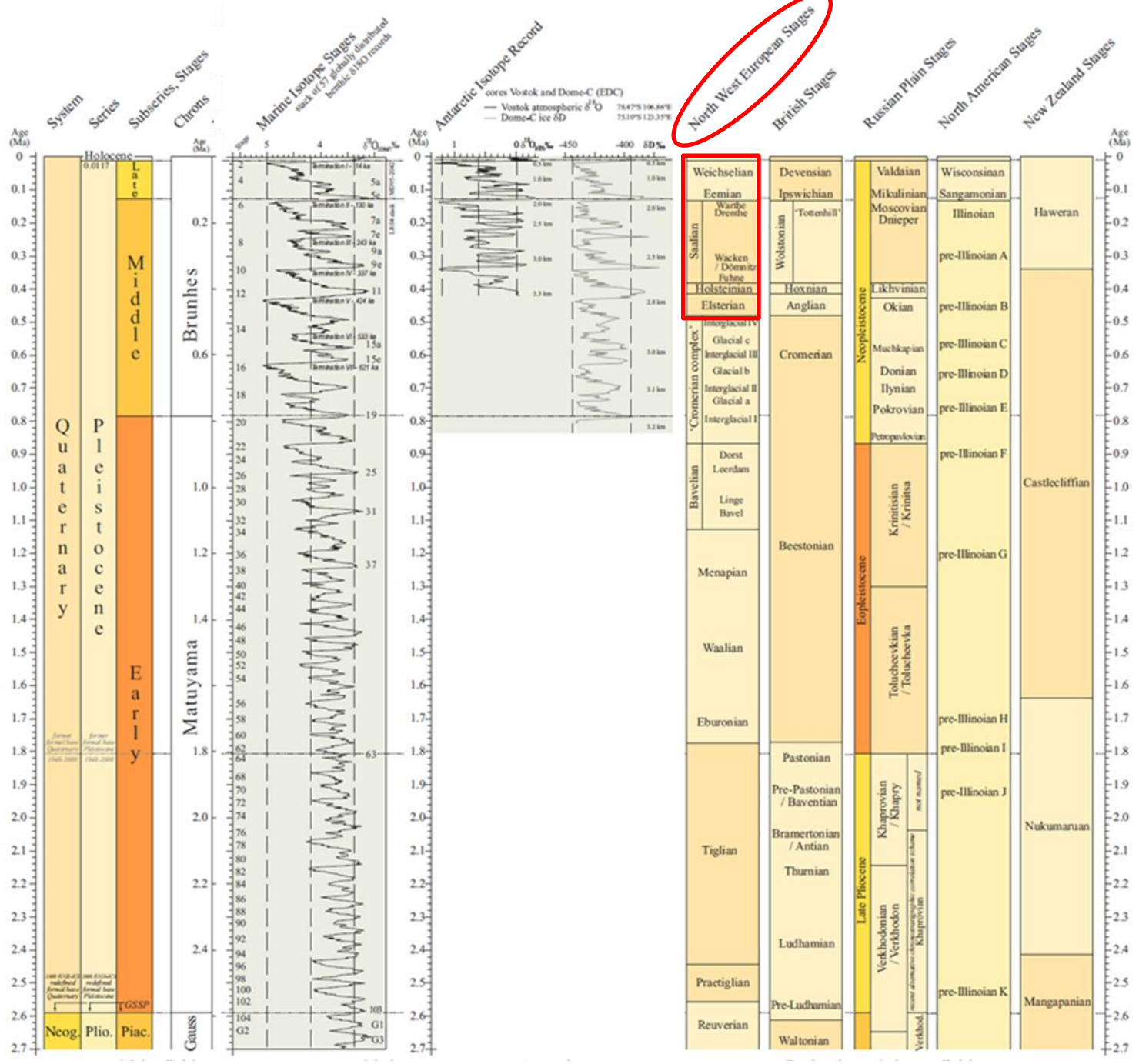
Carbonates

Terrigenous

Carbonates

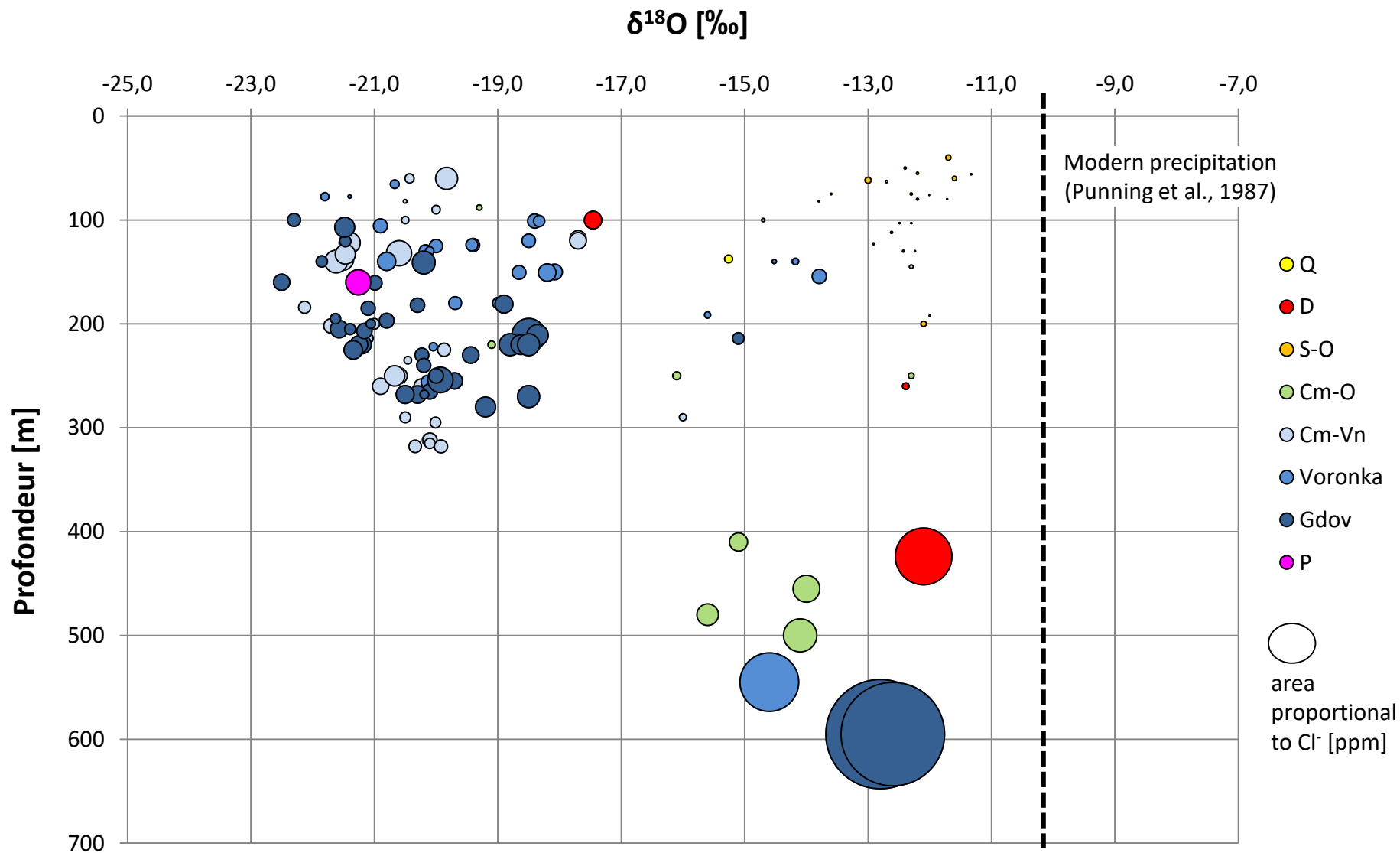
Terrigenous
Crystalline

Fault zone: a) proved, b) supposed Meteorite crater Cross-section line



Modifié d'après
Cohen & Gibbard,
2011

Géochimie et isotopes



Groundwaters Cl- content in Estonia

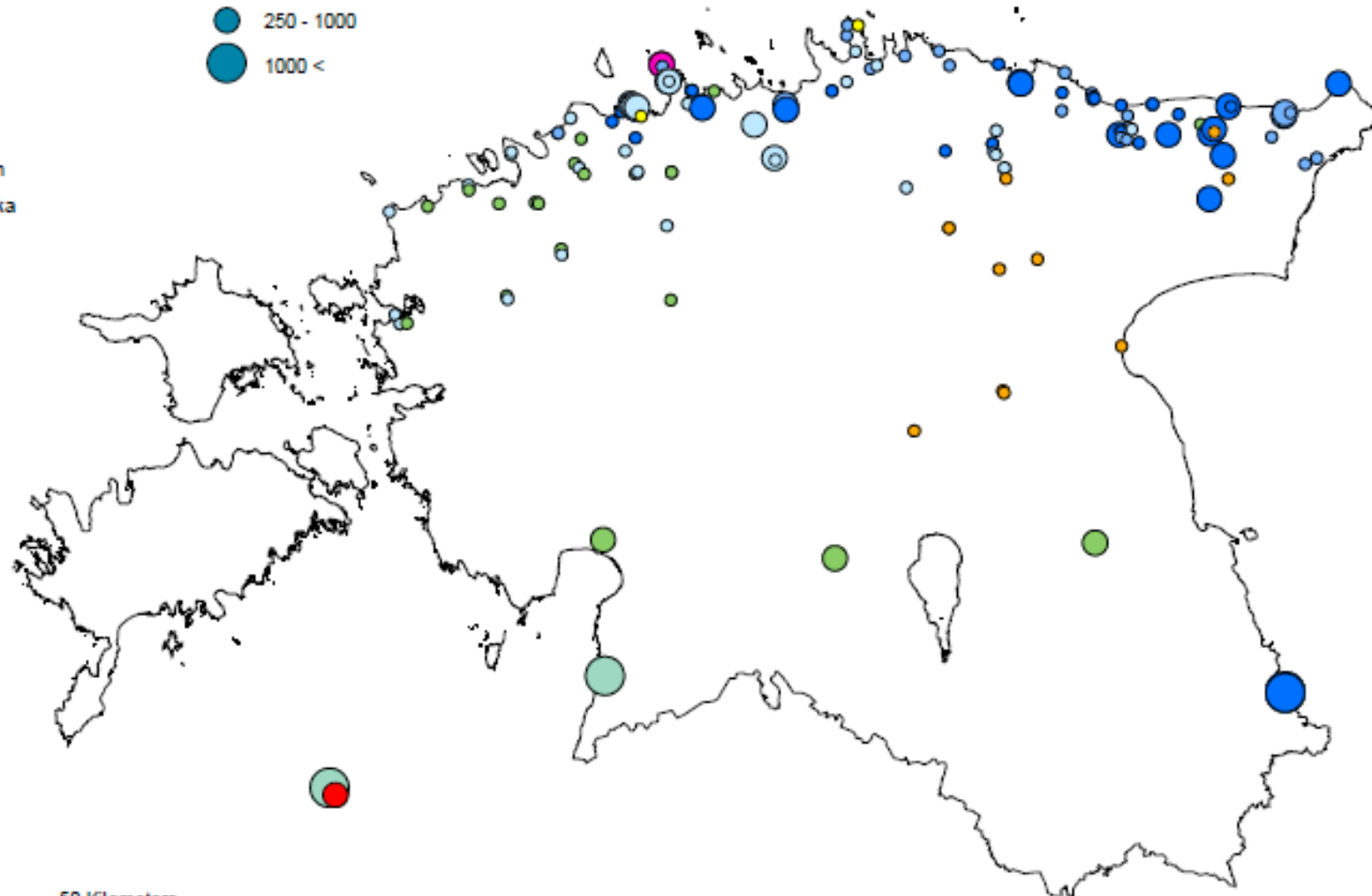


Hydrostratigraphical units

- Q
- D
- S-O
- Cm-O
- Cm-Vn
- Voronka
- Gdov
- P

Cl- [ppm]

- < 250
- 250 - 1000
- 1000 <



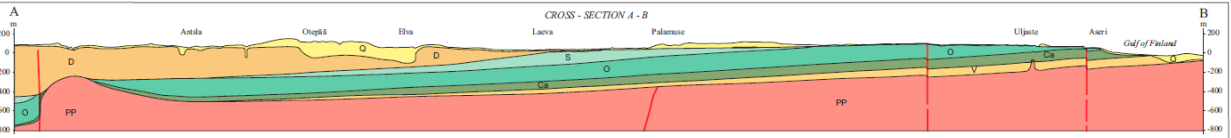
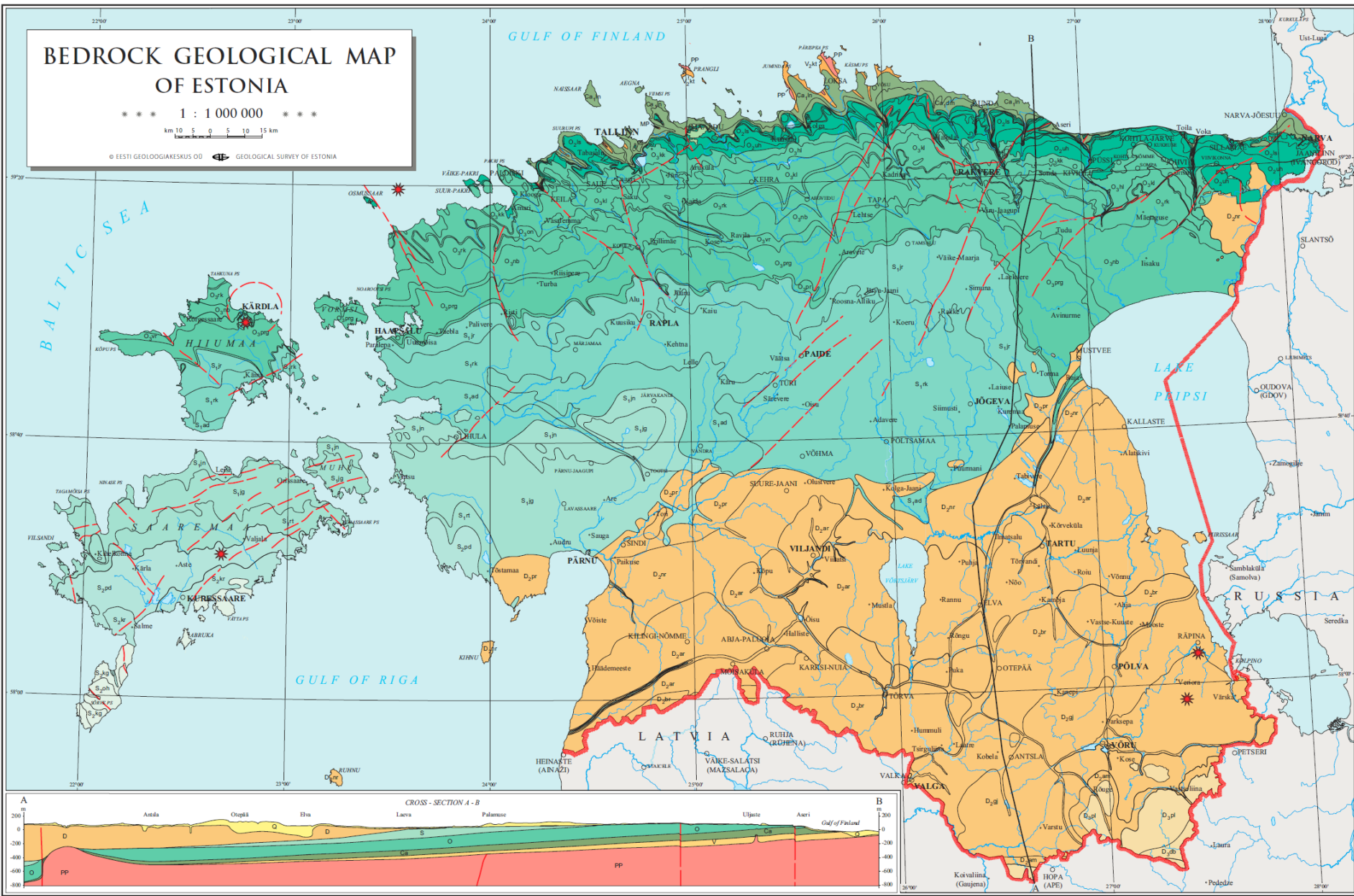
0 25 50 Kilometers

BEDROCK GEOLOGICAL MAP OF ESTONIA

*** 1 : 1 000 000 ***

km 10 5 0 5 10 15 km

© ESTI GEOLOOGIAKESKUS OÜ  GEOLOGICAL SURVEY OF ESTONIA



Map of Estonia

Elevation

- 60 m
- 120 m
- 180 m
- 240 m

