ESF Project „*Establishment of interdisciplinary scientist group and modelling system for groundwater research*"

MECHANISMS OF GROUNDWATER RECHARGE IN THE BALTIC ARTESIAN BASIN

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Introduction

- Groundwater is the important water source for most of BAB area, including Capitals of Baltic states.
- Cambrian-Vendian aquifer is one of a major drinking water source for Northern Estonia, including Tallinn.
- For Central Estonia the Silurian and for Southern Estonia Devonian aquifers are the major water sources.
- For central part of the Basin, including city of Riga Quaternary and Upper Devonian aquifers are of most importance.
- Lithuania have widest range of aquifers, however, majority cities are using Quaternary aquifer.

Study area

Fig. 1. ***Spatial context of Baltic artesian basin***

<u>Characteristics of artesian basin:</u>

Total area: 484 000 m^2

Volume: 579 000 km^3

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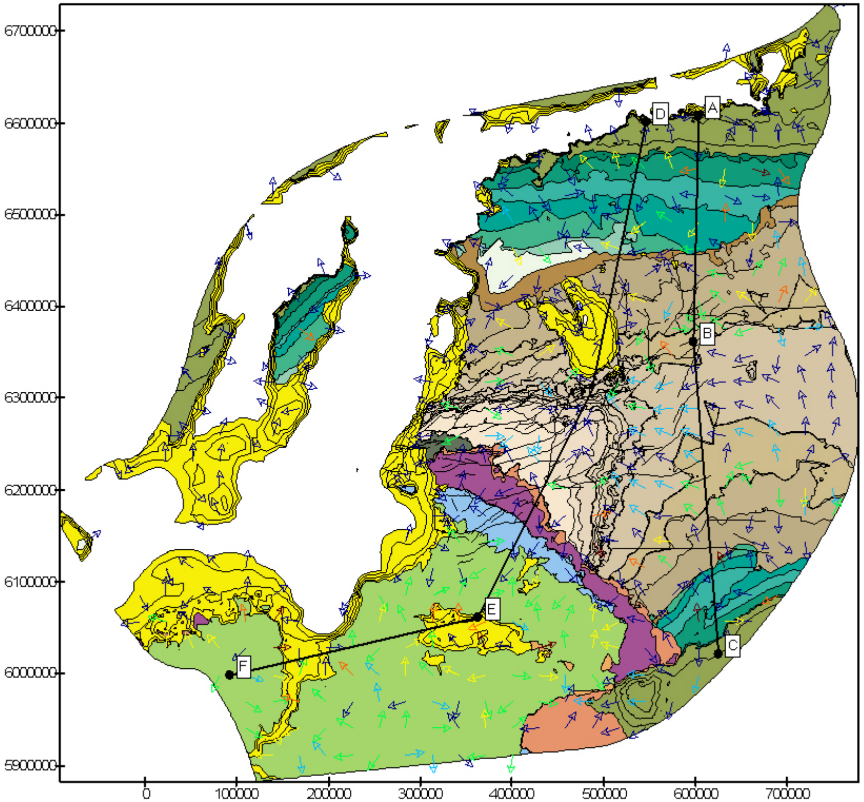
Geological and Hydrogeological setting



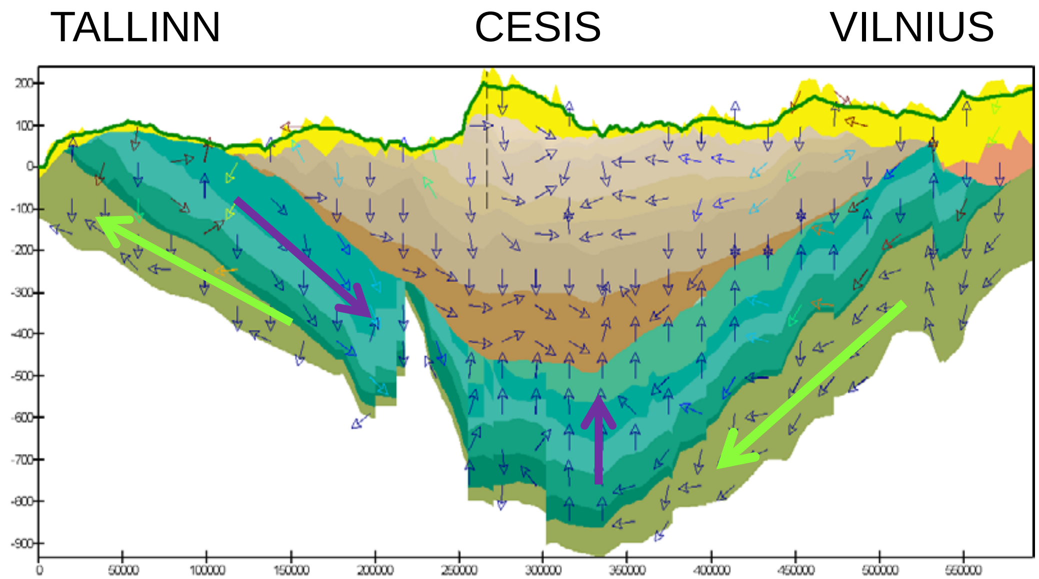


Fig. 3. ***Relative calculated flow velocity modulus at cross section A-B-C.*** *Horizontal axis - distance in meters; vertical axis - depth in meters. Profile line in Fig 2.*

Fig 2. ***Horizontal cross section of BAB at depth -50 m bsl****. Vectors iustrate flow direction and relative flow velocity – more red vectors indicate faster flow velocities, more blue – smaller velocities. Profile lines A-B-C and D-E-F in Fig 3 and Fig 4. EPSG:25884 Baltic TM projection.*

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Geological and Hydrogeological setting

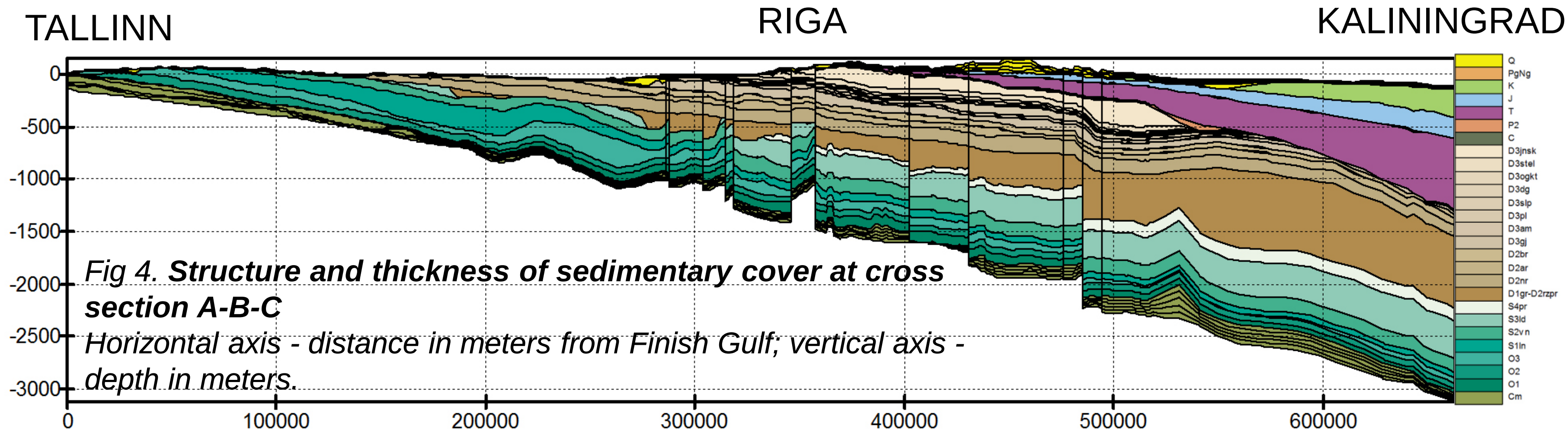

Fig 4. ***Structure and thickness of sedimentary cover at cross section A-B-C***
Horizontal axis - distance in meters from Finish Gulf; vertical axis - depth in meters.

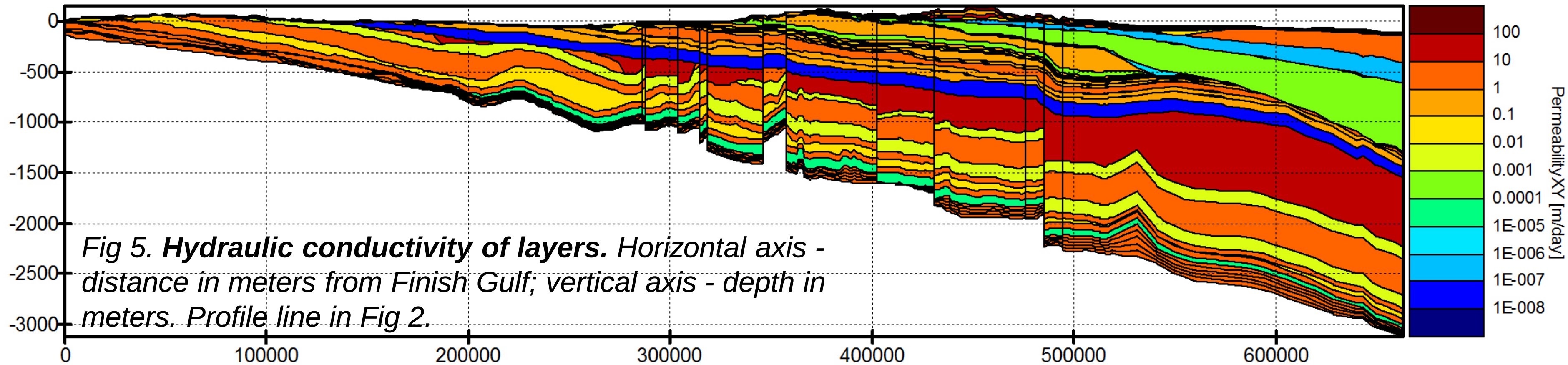

Fig 5. ***Hydraulic conductivity of layers.*** *Horizontal axis - distance in meters from Finish Gulf; vertical axis - depth in meters. Profile line in Fig 2.*

Questions to be answered

- **What is the age composition of studied aquifers?**
- What is spatial difference of stable isotopic composition?
- Is there relationship between stable isotopic composition and other groundwater characteristics?
- What are average stable isotope composition values in particular aquifers?
- How deep modern groundwater can be found?
- How we can distinguish different groundwater end members?

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Water stable isotope data

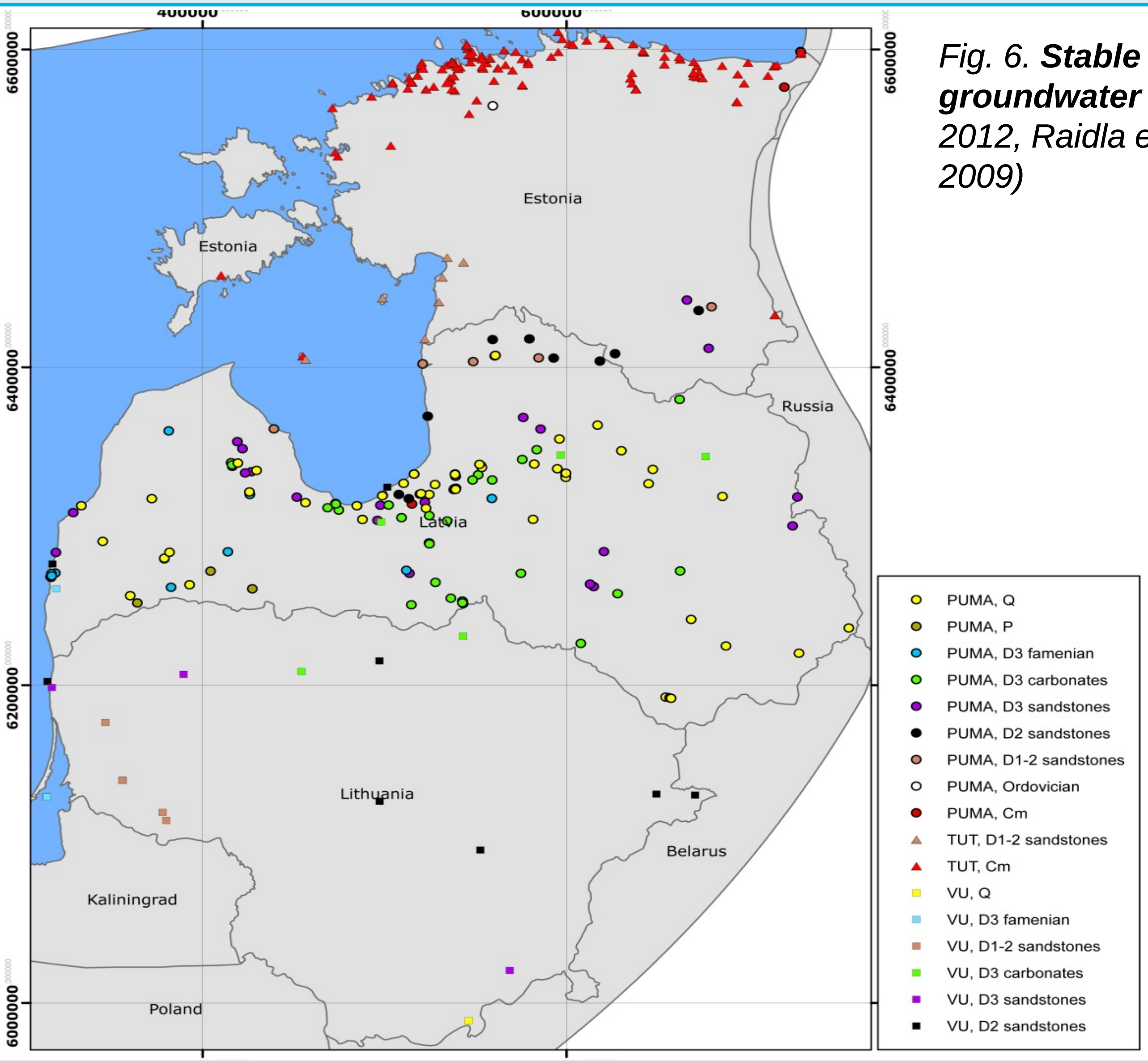

Fig. 6. ***Stable oxygen and deuterium groundwater sampling sites*** *(PUMA, 2012, Raidla et al., 2012; Mokrik et al., 2009)*

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Overview results - chemistry

Aquifer system	Northern part		Central part		Southern part	
	TDS, g/l	Water type	TDS, g/l	Water type	TDS, g/l	Water type
Cambrian - Vendian	0.5 - 20	Ca-HCO3. Na-Cl	80 - 120	Na-Cl	0.5 - 80	Na-Cl. Ca-HCO3
Cambrian - Ordovician	<10	Ca-HCO3. Na-Cl	10-100	Na-Cl	1 - 180	Na-Cl. Ca-HCO3
Silurian	<10	Ca-HCO3. Na-Cl	0.5 - 50	Na-Cl. Ca-HCO3	0.5-200	Na-Cl. Ca-HCO3
Lower-Middle Devonian	<5	Ca-HCO3. Na-Cl	0.5 - 15	Na-Cl. Ca-HCO3	2 - 75	Na-Cl
Middle Devonian	<0.5	Ca-HCO3	0.5 - 3	Ca-HCO3. Na-Cl. Ca - SO4	0.5 - 35	Na-Cl. Ca - SO4
Upper Devonian (sandstones)	<0.5	Ca-HCO3	0.5 - 2	Ca-HCO3	0.5 - 25	Na-Cl. Ca-HCO3
Upper Devonian (carbonates)	<0.5	Ca-HCO3	0.5 - 2	Ca-HCO3. Ca-SO4	0.5 - 4	Na-Cl. Ca-HCO3 Ca-SO4
Carboniferous			0.1-1	Ca-HCO3	0.1-1	Na-Cl. Ca-HCO3
Permian			<0.5	Ca-HCO3	0.5 - 80	Na-Cl. Ca-HCO3
Triasic			<0.5	Ca-HCO3	0.1 - 55	Na-Cl. Ca-HCO3
Jurassic			<0.5	Ca-HCO3	0.1 -3	Na-Cl. Ca-HCO3
Cretaceous					<0.5	Ca-HCO3
Paleogene-Neogene					<0.5	Ca-HCO3
Quaternary	<0.5	Ca-HCO3	<0.5	Ca-HCO3	<0.5	Ca-HCO3

Table 1. ***Approximated description of major aquifers in BAB.*** *(PUMA,2012, Raidla et al., 2012, Mazeika et al.,2009, and Juodkazis, 1989)*

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Project number 2009/0212/1DP/1.1.1.2.0/09/APIA/VIAA/060

Overview results – isotopes, CFC

Aquifer system	Northern part			Central part				Southern part		
	$\delta^{18}O$ values	^{14}C, pmC	^{3}H, TU	$\delta^{18}O$ values	^{14}C, pmC	CFC, ages	^{3}H, TU	$\delta^{18}O$ values	^{14}C, pmC	^{3}H, TU
Cambrian - Vendian	-18.1 to -22.9	1.4 - 12.6	0.5 -2.1	-4.6 to -5.3	x	x	x	x	x	x
Cambrian - Ordovician	-11.4 to -18.9	2.4 - 18.6	1.8 - 21.3	x	x	x	x	x	x	x
Ordovician	-11.7 to -12.2	43.7 - 90.9	13.1 - 21	x	x	x	x	x	x	x
Lower-Middle Devonian	-10.9 to -12.6	x	x	-10.9 to -12.3	x	x	x	-4.5 to -9.9	x	x
Middle Devonian	-10.7 to -11.8	x	x	-10.7 to -13.4	x	>65	x	-9.6 to -12.6	1 - 95	<0.1 - 1
Upper Devonian (sandstones)	-11.1 to -11.3	x	x	-10.2 to -13.2	x	35 - >65	<0.2 -17.6	-11.7 to -13	2.1 - 62.4	0.2 -33
Upper Devonian (carbonates)	x	x	x	-9.4 to -12.2	x	20 - >65	<0.2 - 7.5	-10.4 to -12.2	1.8 - 113	2.1 - 18.3
Quaternary	x	x	x	-8.6 to -12.3	x	20 - 65	<0.2 - 10.4	-10.4 to -11.7	16.3 - 111	0.9 - 17.6

Table 2. ***Approximated description of major aquifers in BAB.*** *(PUMA,2012, Raidla et al., 2012, Mazeika et al.,2009, and Juodkazis, 1989*

Water stable isotopes

Fig.8 $\delta^{18}O$ values in BAB groundwaters versus chloride concentrations

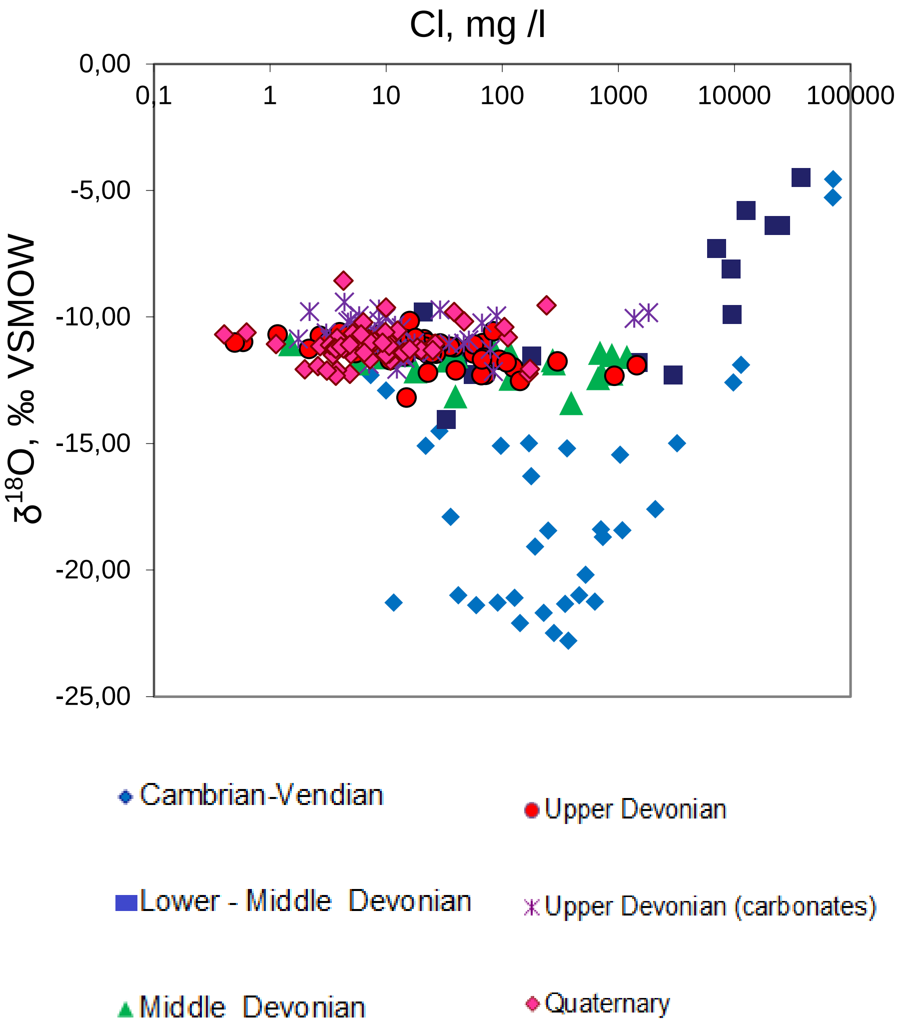
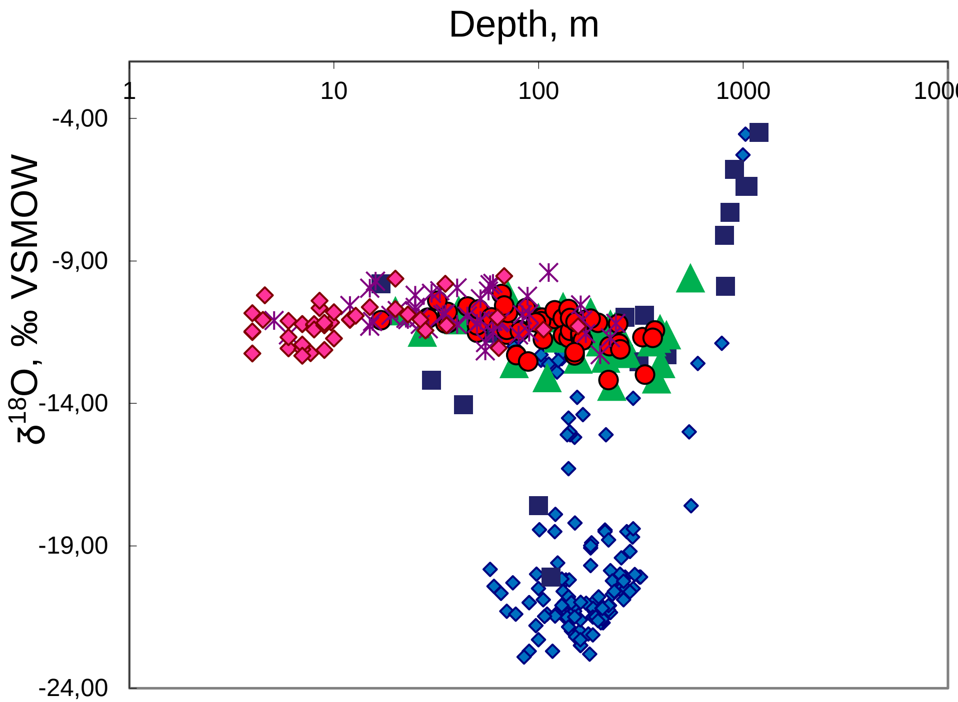


Fig.7 $\delta^{18}O$ values in BAB groundwaters versus depth below surface, depth in log. scale



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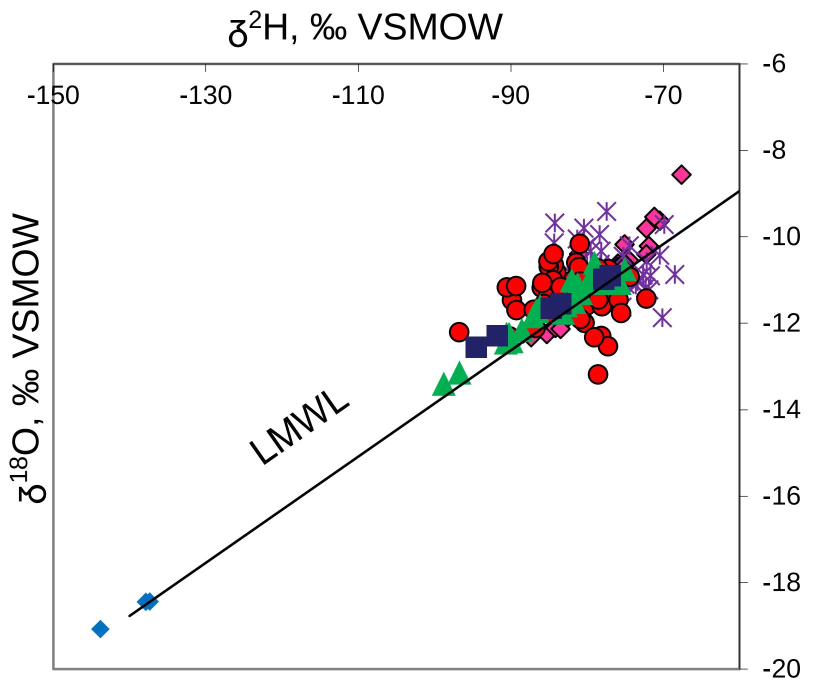
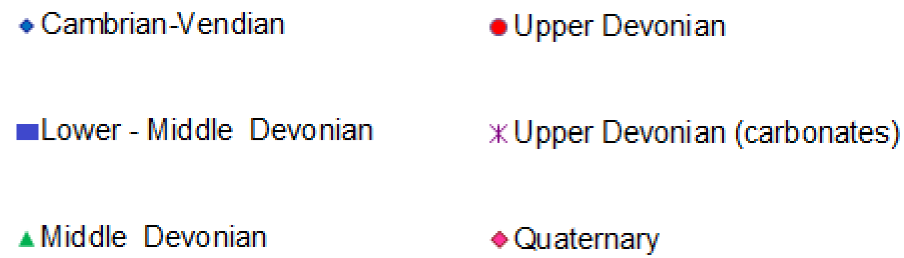
Water stable isotopes





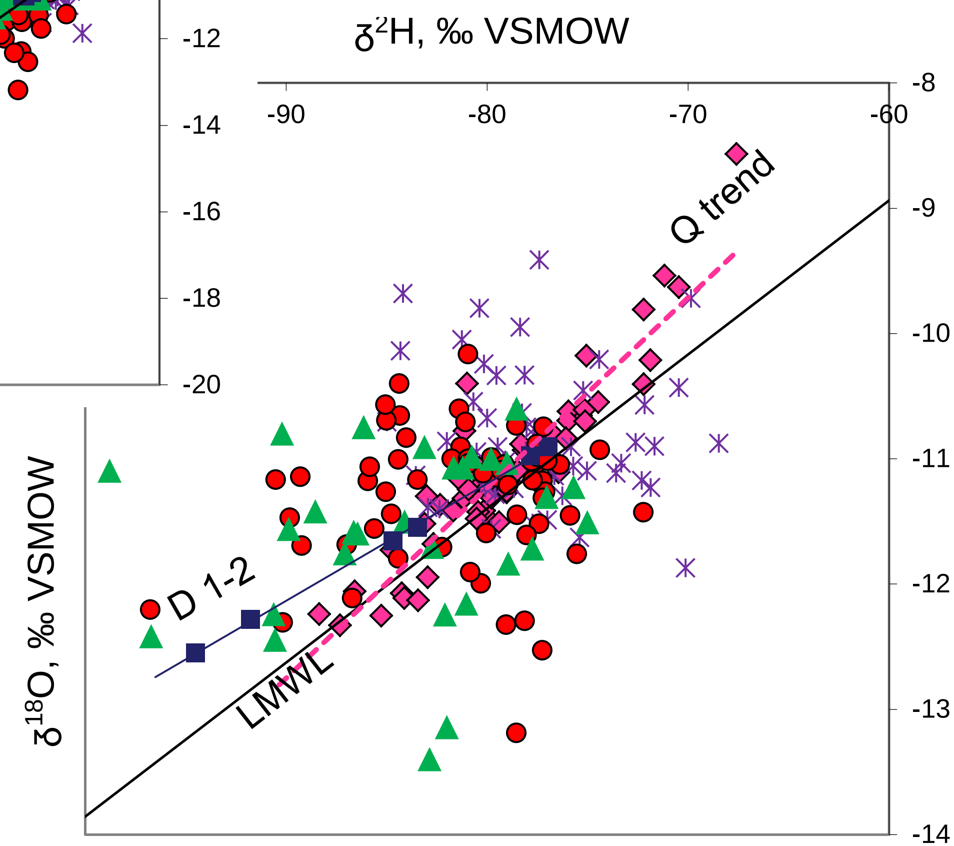


Fig.9 ***$\delta^{18}O$ values in BAB groundwaters versus δ^2H values***

Fig.10 ***Zoomed fig. 10 with trendlines of Quaternary and Lower-Middle Devonian samples***

Atmospheric precipitation: annual mean $\delta^{18}O$= -10.4 ‰ (northern part) and -9.7 ‰ (central part) *(Punning et at., 1987; IAEA, 2006)*

Spatial distribution of ƺ18O in Cm-Vendian

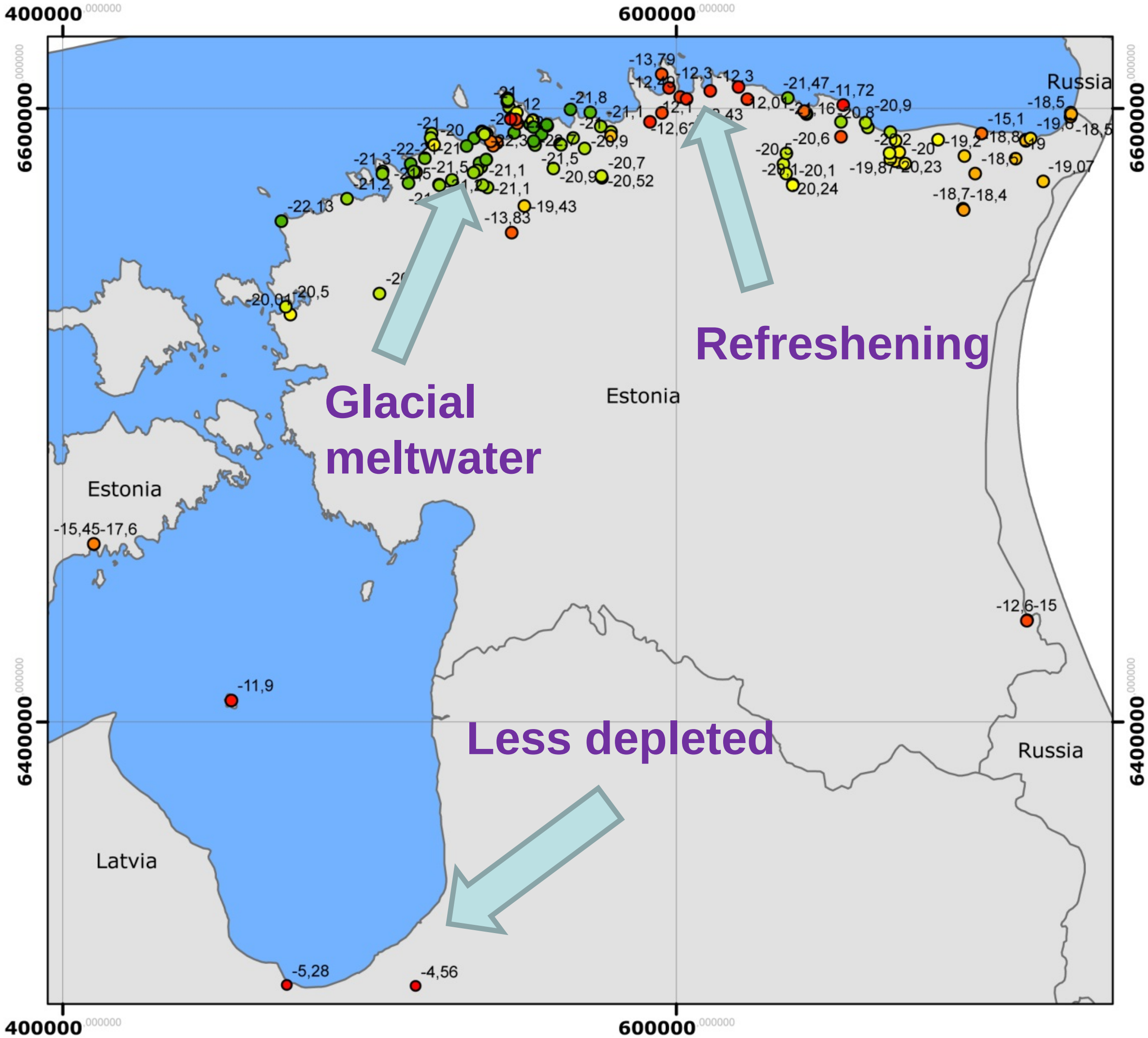


Fig. 11. ***Spatial distribution of ƺ18O in Cambrian-Vendian aquifer****. PUMA, 2012; Raidla et al., 2012*

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Spatial distribution of ʒ18O in D_{1-2} sandstones

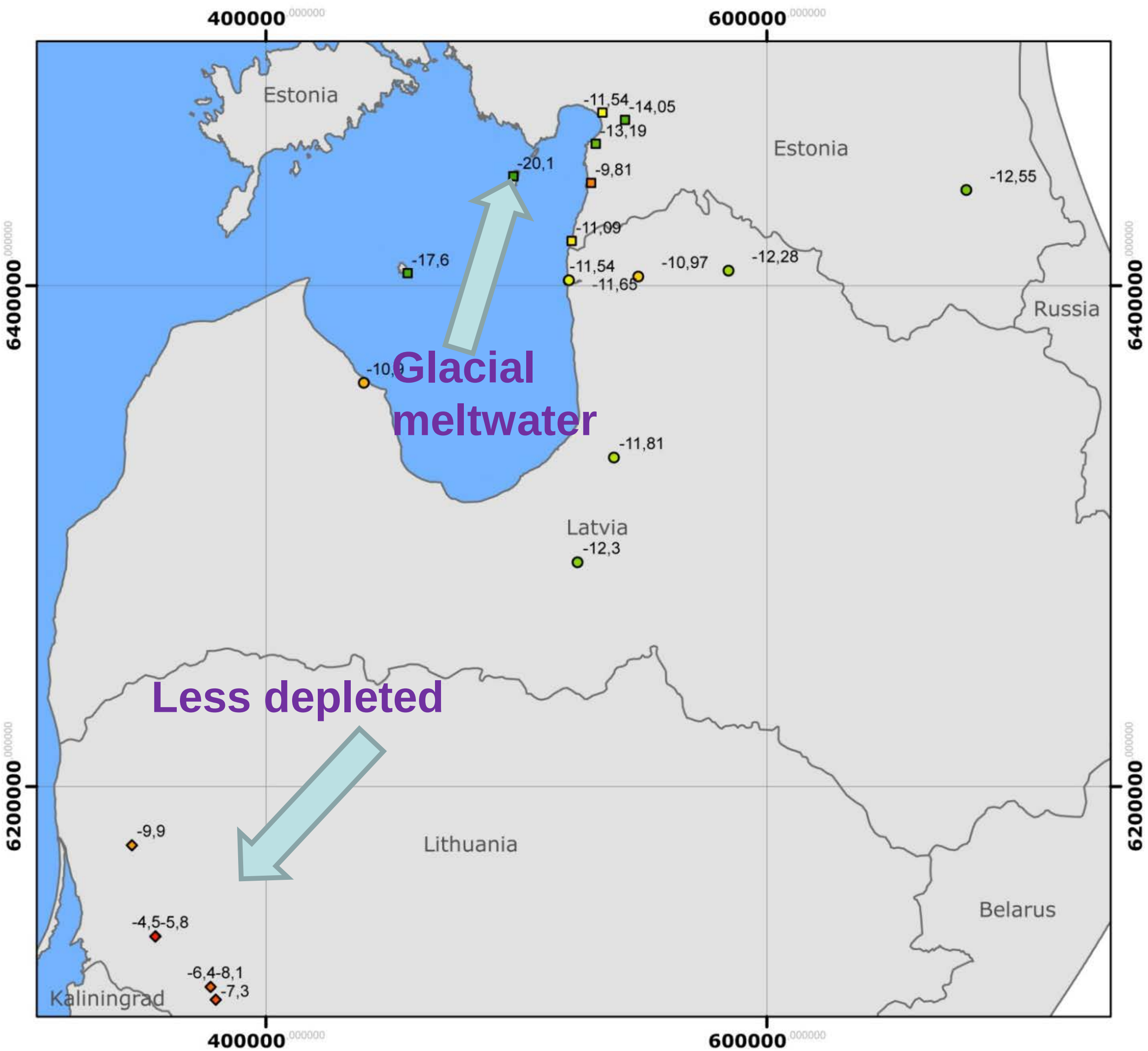

Fig. 12. ***Spatial distribution of ʒ18O in Lower-Middle Devonian aquifer.***

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Spatial distribution of ʒ18O in D_2 aquifer

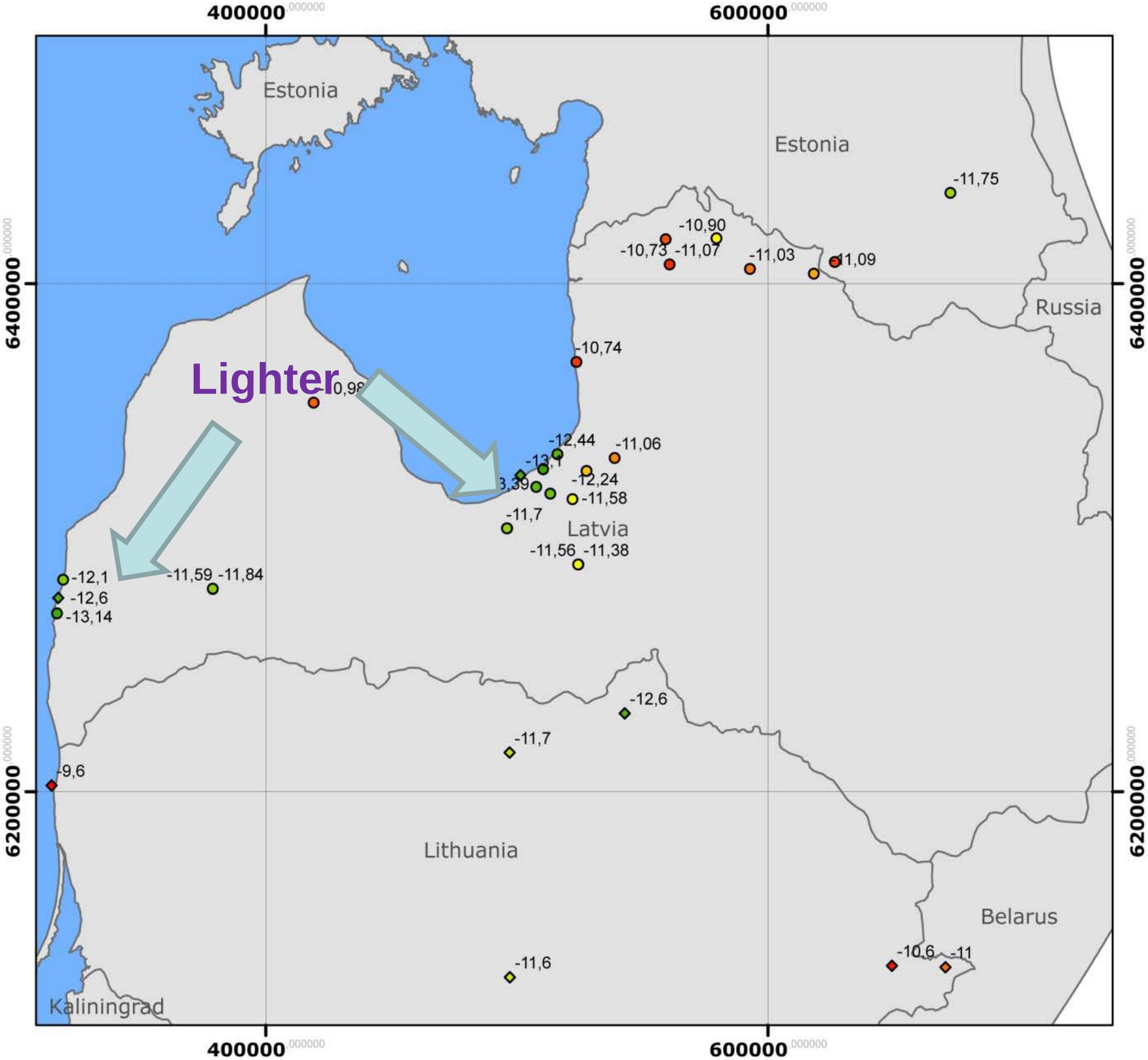

Fig. 13. ***Spatial distribution of ʒ18O in Middle Devonian aquifer.***

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Spatial distribution of ʒ18O in D_3 sandstones

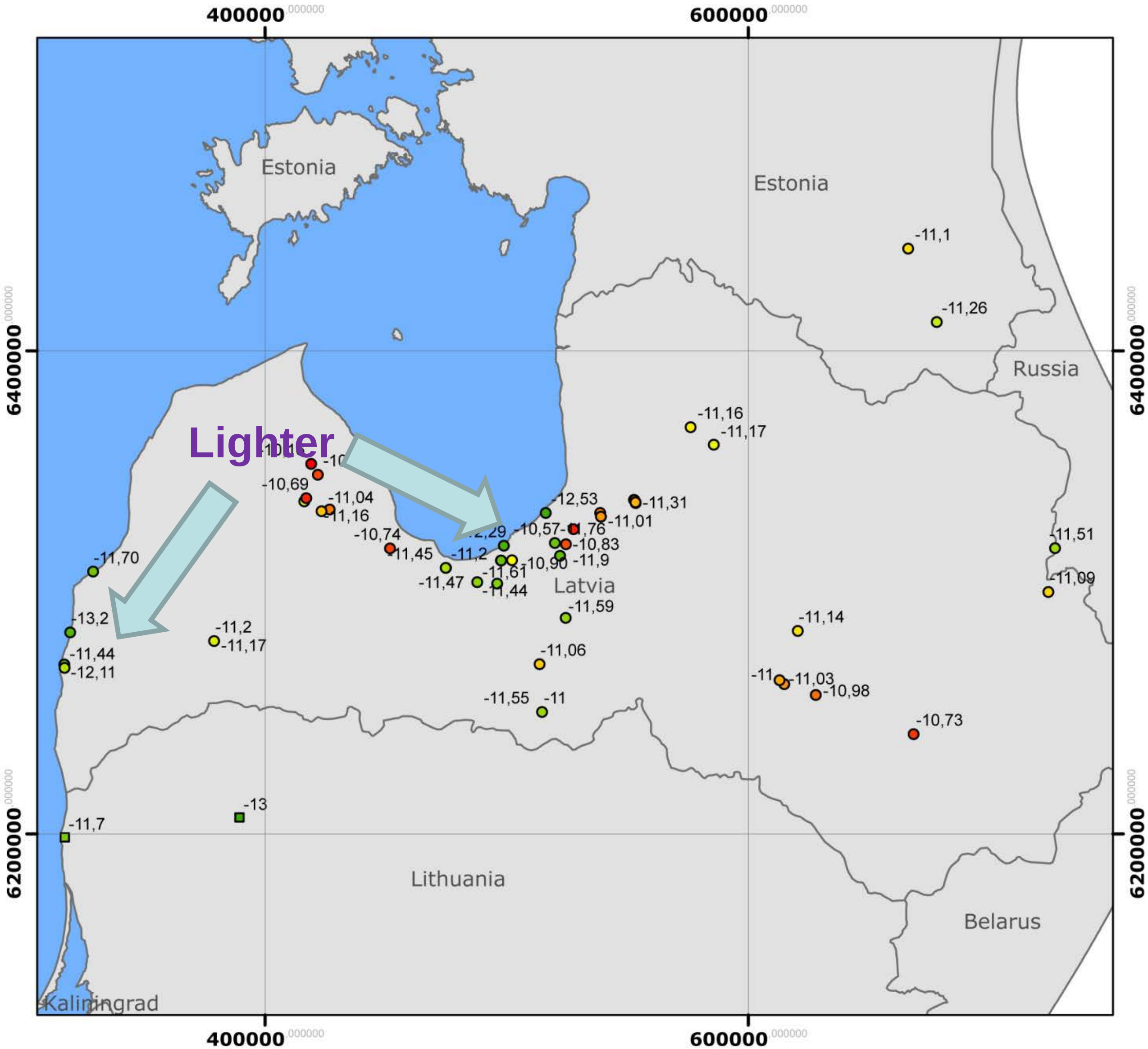

Fig. 14. ***Spatial distribution of ʒ18O in Upper Devonian sandstone aquifer.*** *Data from PUMA project and Mazeika et al.,2009*

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Spatial distribution of ʒ18O in D_3 carbonates

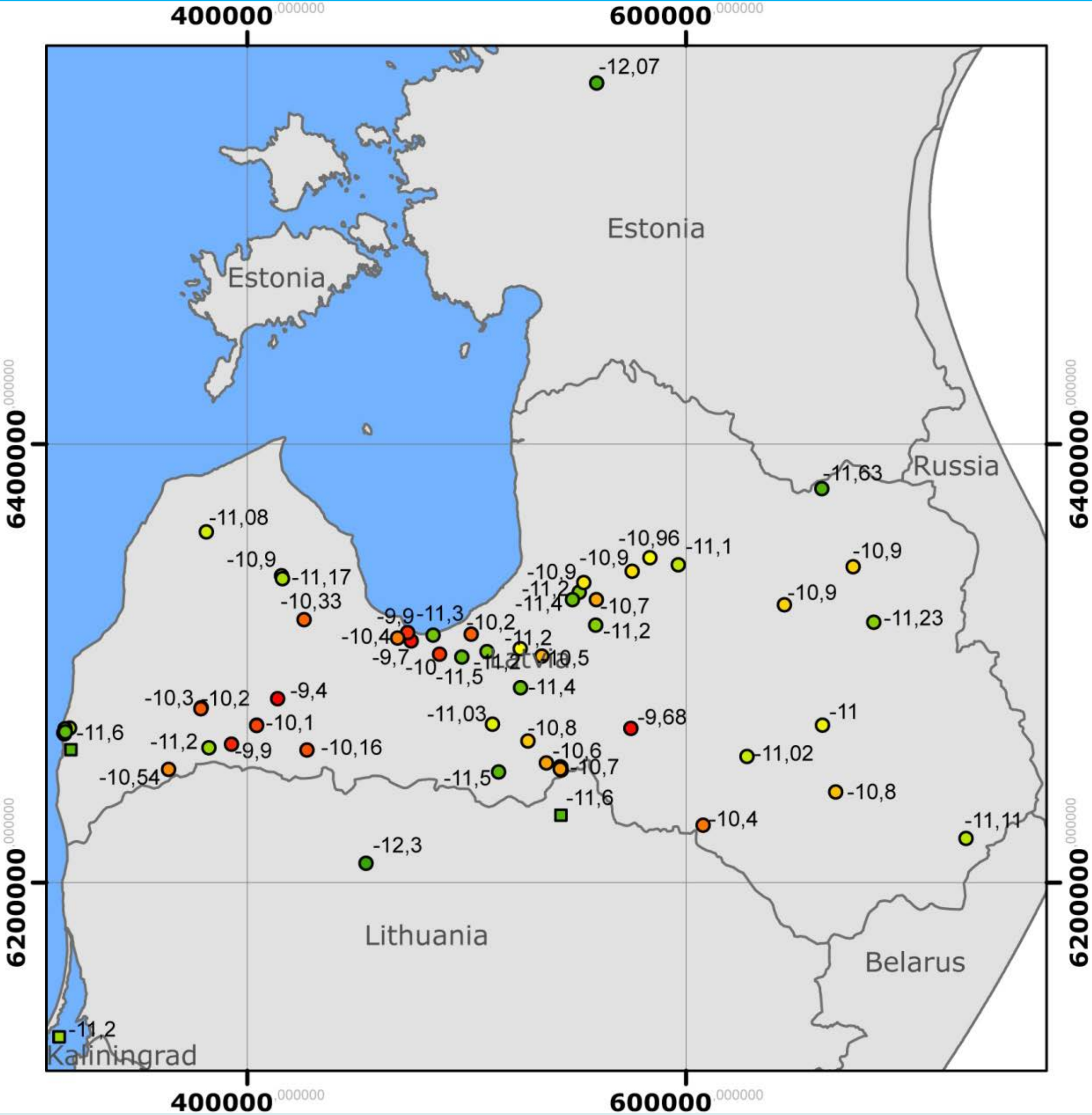

Fig. 15. ***Spatial distribution of ʒ18O in Upper Devonian carbonate aquifer.*** *Data from PUMA project and Mazeika et al.,2009*

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Spatial distribution of ʒ18O in Q aquifer

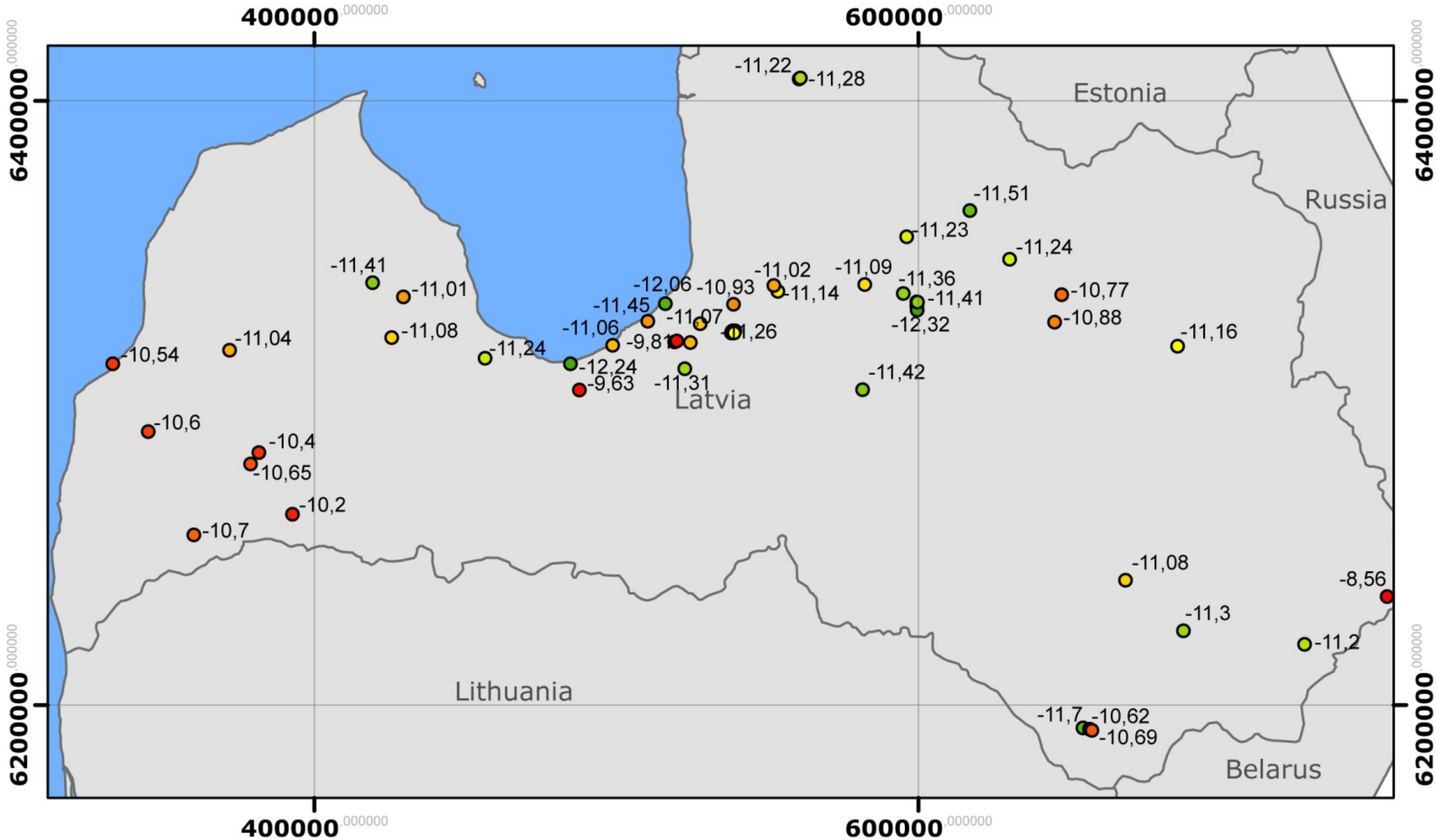

Fig. 16. ***Spatial distribution of ʒ18O in Quaternary aquifer***

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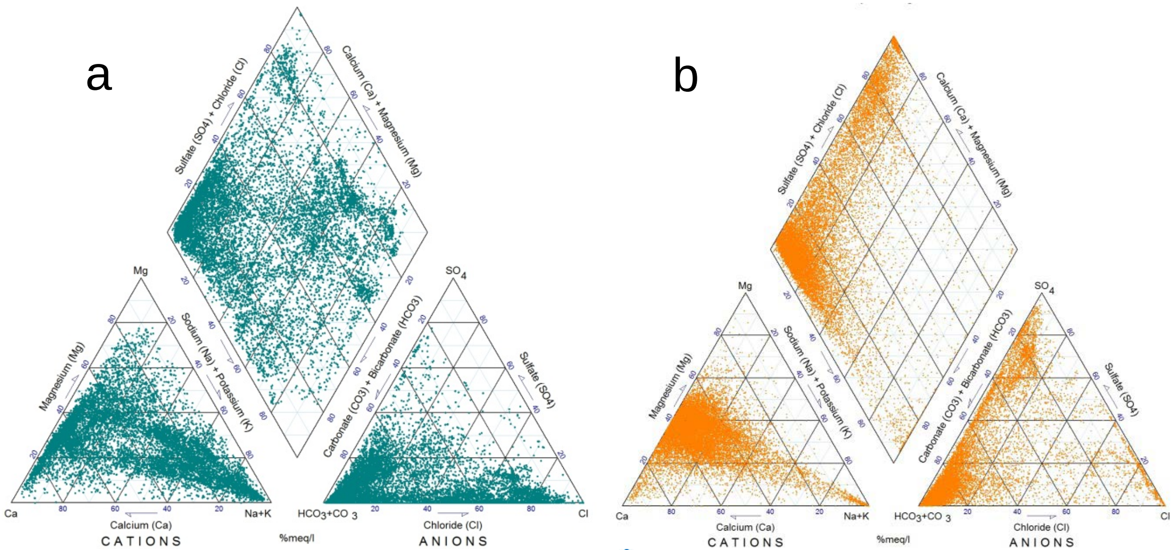
Principal component analysis



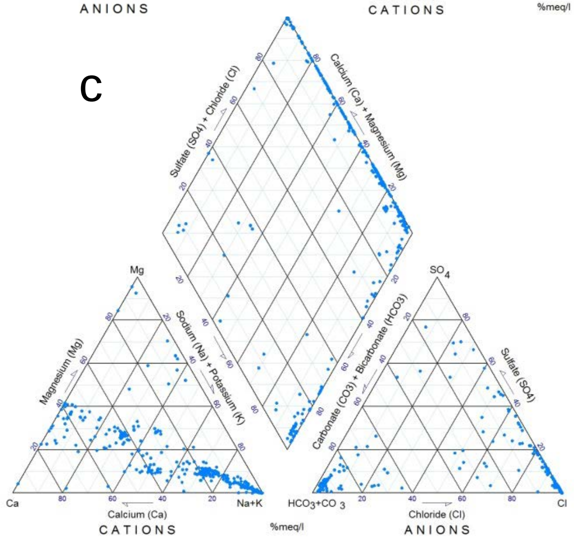


Fig. 17. ***Piper plots,*** *were:*
a) Estonian groundwaters;
b) Latvian groundwaters;
c) Lithuanian groundwaters

Paramteres	Component		
	1	2	3
Depth, below surface	,647	-,106	-,022
$\delta^{18}O$	-,430	,724	,205
$\delta^{2}H$	-,349	,695	,187
Cl	,810	-,265	,063
SO_4	,200	-,094	912
HCO_3	-,066	,622	-,090
Ca	,034	,077	922
K	,859	,019	,116
Mg	,784	,275	379
Na	,857	-,234	,052
Fe	,179	,580	-,077

Table.3. ***Results from principal component analysis*** *(Data from cemtral part of the basin)*

Na - K - Cl - $\delta^{18}O$ - $\delta^{2}H$

$\delta^{18}O$ - $\delta^{2}H$ - HCO_3 – Fe

Ca – SO4 - Mg

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Conclusions

- In the Northern part of BAB three groundwater end-members can be distinguished: fresh and isotopically depleted $\delta^{18}O$ composition of water glacial melt water of Weichelian Ice Age mainly in Cambrian-Vendian aquifer, Na-Ca-Cl composition basin brine with less depleted isotopic values of unknown age and modern meteoric water with stable isotope signal close to nowadays precipitation.
- In the Central part of the basin, fresh Ca-HCO3 and Ca-SO4 type predominate in the upper aquifers were groundwaters have stable isotope signal similar to nowadays precipitation. Age dating with CFC's suggest, that modern groundwater can be found up to 100 meters depth. However in deeper embedded aquifers TDS significantly increases, dominant groundwater type is Na-Cl and stable isotope values become less negative.
- In the southern part of the basin as well groundwaters of modern recharge can be found in the upper part. Groundwaters of Holocene age predominates up to 600 m, in the western part of the basin it was determined that groundwater recharge in Devonian aquifers took place during the last ice age as well, however, stable isotope composition is far less depleted than in northern part.

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Thank you!

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