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Paleowaters in the Cambrian-Vendian (Ediacaran)aquifer system of Baltic Basin - isotopic and Geochemical evolution since Late Pleistocene

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Introduction

Groundwater formation is highly controlled by climatic changes, first of all by such powerful agents as the ice ages. In Europe, the greatest changes in the groundwater formation took place during the last ice age which culminated about 20 000 to 18 000 ^{14}C-years ago. At that time, the ice sheet covered the whole of Scandinavia and the territories of the present-day Baltic States (Figure1).

Changes in the climatic conditions during the Late Pleistocene and Holocene greatly impacted the hydrology and geochemical evolution of groundwaters in northern marginal part of Baltic Basin. Increased hydraulic gradients from melting of km-thick Pleistocene ice sheet reorganized regional-scale groundwater flow in sedimentary aquifers of the northern Baltic coast.

Here we present an overview of the status and origin of groundwaters in the Shallowly buried marginal part of the Cambrian-Vendian (Edicaran) confined aquifer of the Baltic Basin, which is characterised by fresh and isotopically depleted δ^{18}O composition of water, whereas the deeply settled parts of the aquifer are characterized by typical Na-Ca-Cl basinal brines.

Figure 1. Reconstruction of LGM ice sheet extent (Svendsen et al. 1999, Boreas, 28 (1), 234-242)

Methods used

Isotope geochemical investigations were combined with other studies on the Estonian groundwater in order to understand:

- the processes and climate conditions during the palaeorecharge;
- the age structure of deep waters;
- the mixing components and their variation.

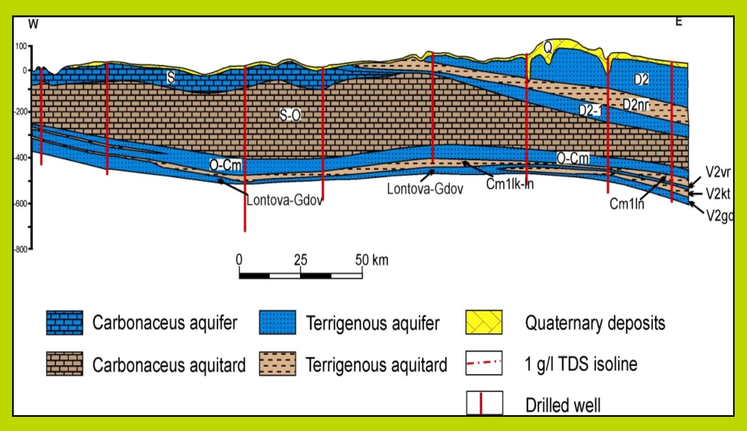
The following isotopic and geochemical tools were applied: ^{3}H, ^{14}C, Noble gas concentration for RT (Ne, Ar, Kr, Xe), ^{85}Kr, ^{4}He, ^{39}Ar, ^{40}Ar/^{36}Ar, δ^{18}O, δ^{13}C, N_2/Ar, ^{15}N/^{14}N, amount and composition of extracted gases (Vaikmäe et al., 2001).

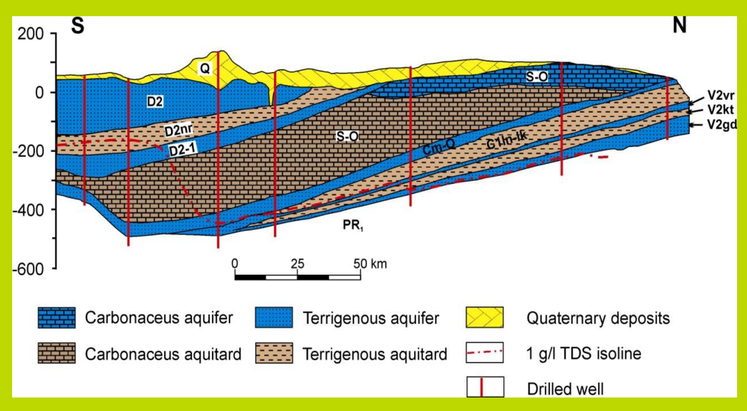
Hydrogeological setting

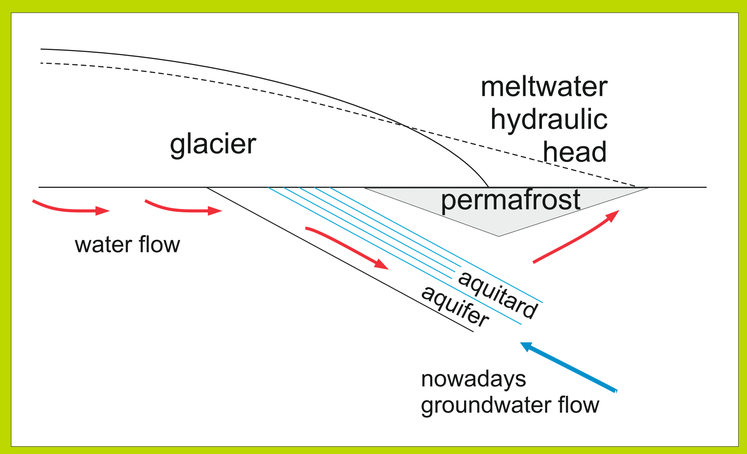
Geologically, Estonia is situated on the slope of the crystalline Baltic Shield sloping southwards at about 3 - 4 m km^{-1}. Here the Lower-Proterozoic gneisses and migmatites of the basement are overlain by Upper Proterozoic (Vendian) and Palaeozoic (Ordovician and Silurian) sedimentary rocks covered by Quaternary deposits (Fig. 2).

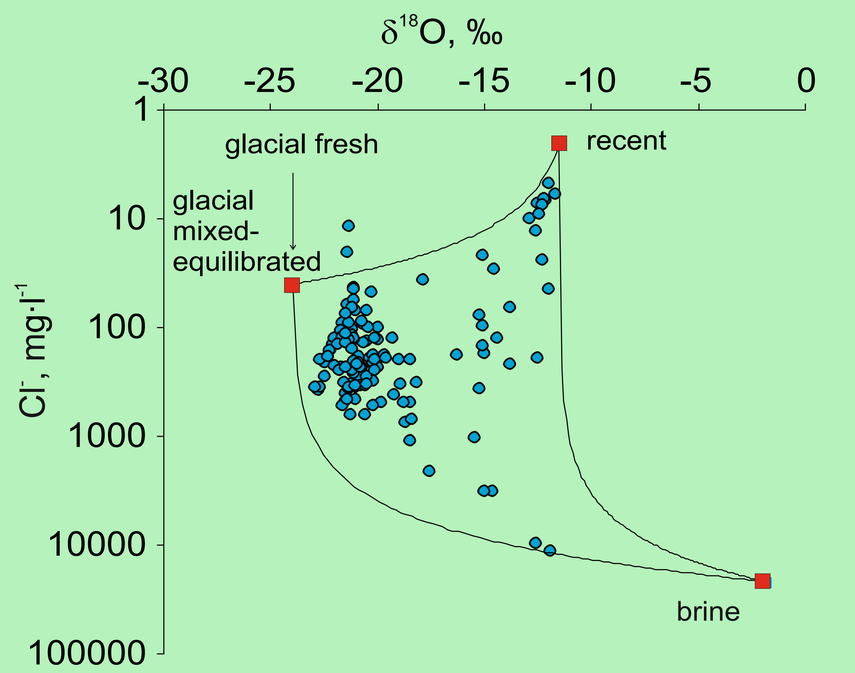
The Cambrian-Vendian aquifer system (Cm-V) is the lowermost of the six aquifer systems of Estonia which thins out in South and West Estonia but in North Estonia its thickness amounts to 90 m. The Cambrian-Vendian aquifer system outcrops along the northern coast of Estonia on the bottom of the Gulf of Finland. In northern Estonia, the aquifer system is, as a rule, confined by 60 to 90m thick clays of the Lontova formation. This aquitard has a strong isolation capacity as its vertical hydraulic conductivity is predominantly only 10^{-7} to 10^{-5} m/d. However, in places the bedrock formations are penetrated down to the crystalline basement by ancient buried valleys, filled mostly with loamy till but sometimes glacio-fluvial gravel occurs in the lower portion of the valleys.

The calculated velocities of deep groundwater movement in the Cambrian-Vendian aquifer system are between $5\cdot10^{-4}$ and $5\cdot10^{-3}$ m/d, which means that during the last about 10 ka the deep groundwater could only have moved forward about several tens of kilometres and a complete water exchange along flow branches would not have been possible. Therefore it is possible that, in natural conditions, the groundwater recharged during the last glaciation has been preserved in the Cambrian-Vendian aquifer system.









Results and discussion

The oxygen isotope composition of groundwater in most of aquifer systems in Estonia ranges from -11.0 to 12.2 ‰. However, the groundwater in the Cm-V aquifer system has a heavily depleted oxygen isotope composition. The values of δ^{18}O vary mainly from -18.1 to -22‰. At the same time, the long term mean annual δ^{18}O values in contemporary precipitation in Estonia are -10.4‰ (Punning *et al.* 1987). Low δ^{18}O values in the Cm-V aquifer are indicative of recharge in cold conditions, whilst low ^{14}C concentrations (1.5 9 pmc) are indicative of long residence time of groundwater. The oxygen isotope and Cl$^-$ stem of northern margin of Cambrian-Vendian aquifer waters suggests a three-component mixing between the meteoric water, glacial meltwater and saline brine (Fig. ..)

Analyses of the gas composition in some samples showed rather high concentration of methane (up to 15.2%). This is indicative of the influence of biogenic reactions in the groundwater, which could cause the low δ^{13}C values, measured in many wells. Results of δ^{13}C analyses in methane samples (up to -78.8‰) also show, that the methane has most probably biogenic origin. Low ^{3}H concentrations in most of studied wells confirm that, as a rule, no detectable intrusion of modern water into the Cm-V aquifer has been occurred during approximately the past 50 years.

Conclusions

A strongly depleted stable isotope composition, absence of ^{3}H and a low radiocarbon concentration are the main indicators of glacial origin of groundwater in the Cambrian-Vendian aquifer system in the northern Estonia. In some wells unexpectedly high gas concentrations have been found. One explanation could be that oversaturation indicates the recharge under high-pressure conditions, e.g. by subglacial meltwater recharge through aquifers. Analyses of the gas composition in some samples showed a rather high concentration of methane. This is indicating the influence of biogenic reactions in the subsurface. Rather negative δ^{13}C values(-74.2‰ and 78.8‰) in two samples also show, that the methane has most probably biogenic origin. The oxygen isotope and Cl$^-$ stem of northern margin of Cambrian-Vendian aquifer waters suggests a three-component mixing between the meteoric water, glacial meltwater and saline brine (Fig. ..)

Based on the isotope and hydrochemical data and considering the palaeoclimatic and palaeoenvironmental situation in Estonia during the late Weichselian time we conclude, that palaeorecharge of Cambrian-Vendian aquifer occurred during the last glaciation by subglacial drainage through the tunnel valleys.

References

Boulton et al., 1995; 1996; Karro et al., 2009 ;Van Weert et al., 1997; Person et al., 2003; 2007 ; Piotrowski, 1997; McIntosh&Walter, 2005; Lemieux et al., 2008; Raidla et al., 2006, 2009. Svendsen et al. 1999;Vaikmäe et al., 2001, 2008.