

RECONSTRUCTION OF GROUNDWATER FORMATION IN THE BALTIC ARTESIAN BASIN THROUGH WATER STABLE ISOTOPES

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INTRODUCTION

Subsurface hydrology of the Baltic Artesian basin has changed rapidly during the Quaternary period. Glacial and several interglacial phases as well as the change in the sea level led to complicated subsurface hydrology and a large difference in groundwater chemical as much as isotopic content. This work aims to give better overview of the groundwater recharge conditions and mechanisms in the central part of the Baltic artesian basin. To maintain better understanding of the processes that took part in the formation of groundwater that can be observed nowadays several methods were applied placing major emphasis on the new oxygen and hydrogen stable isotope ratio results. Additionally large scale modelling as well as hydrochemistry, tritium activity and ages from CFCs dating were used.

Paleowaters usually are isotopically lighter (Clark & Fritz, 2007), that facilitate to detect their presence. Earlier isotopic investigations in the Northern part of the basin indicated glacial melt water intrusion in the Cambrian-Vendian aquifer. Corrected radiocarbon age suggests that this meltwater intrusion took place during the late Weichselian penetrating into aquifer under ice sheet trough tunnel valleys (Raidla, et al., 2008).

Several radiocarbon and stable isotope studies in groundwater have been done at the southern part of the basin, mostly in Northern Lithuania, as well reporting extensive groundwater recharge during the Late Pleistocene, however in Devonian aquifers (Mokrik, et al., 2009); authors suggest that recharge took place under different recharge mechanisms compared with the northern part as well as stable isotope ratios are much less depleted compared to Northern part. So far no similar studies were accomplished in the central part of the basin; thereby no common concept can be done in this particular area. Thus to make clearer picture and possibility to find the mixing line between groundwater bodies of different origin, the new groundwater samples were collected from more than 200 wells mainly in the territory of Latvia. New samples for stable isotope analysis were taken from all sedimentary aquifers up to 2 km depth.

1. STUDY AREA



Fig 1. Spatial context of Baltic Artesian basin.

Baltic artesian basin has an area of approximately 480 000 km². Baltic artesian basin fully covers territory of Latvia, Lithuania and Estonia; also parts of Poland, Russia, and Belarus are included as well as island of Gotland and Baltic Sea (Fig 1).

Sedimentary cover overlays Precambrian crystalline basement and is represented by deposits of Palaeozoic, Mesozoic and Cainozoic eras.

Total thickness of deposits in sedimentary cover varying from few meters in Northern boundary of BAB and South-eastern part, were crystalline basement uncovers. Other natural boundaries of basin are more ambiguous and watersheds occur in different places for each particular aquifer, thereby no strict boundary can be drawn on these margins. Maximum thicknesses of sedimentary cover, accordingly exceeding 4000 m, are situated in South-western edge, which are Polish and Kaliningrad regions (Fig 2)

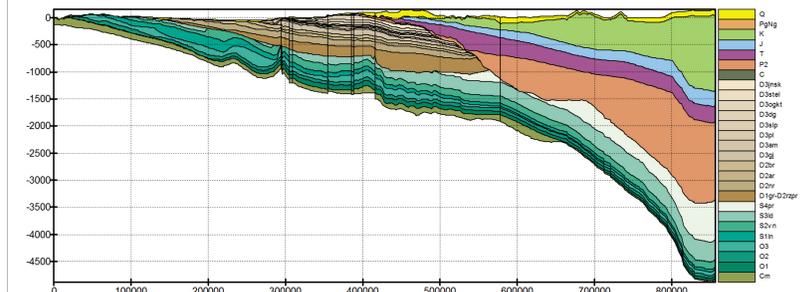


Fig 2. Structure and thickness of sedimentary cover at cross section A-B-C. Horizontal axis - distance in meters from Finnish Gulf; vertical axis - depth in meters. Profile line in Fig 4.

2. HYDROGEOLOGICAL SETTING

Table 1. Hydrogeological setting of Latvia; major water exchange zones and regional aquitards

| Hydrogeological zones | Multi-aquifer system | Main aquifers | | |
|---|---------------------------|------------------------|-----------------------|----------|
| Active water exchange (fresh water) | Quaternary | | | |
| | Upper Permian | | | |
| | Lower Carboniferous | | | |
| | Upper Devonian | Mūru-Ketteru | | |
| | | Jonišku-Akmenes | | |
| | | Stipinū | | |
| | | Katlešu-Ogres | | |
| | | Daugavas | | |
| | Upper and Middle Devonian | Salaspils | | |
| | | Plavīnu | | |
| Amatas | | | | |
| Gaujas | | | | |
| Burtnieku | | | | |
| Delayed water exchange (slightly mineralized water) | Aquitard | Narva | | |
| | | Lower-Middle Devonian | Pērnavas | |
| | | | Rēzeknes | |
| | | | Kemeru | |
| | | | Gargzdu | |
| | | | Silurian - Ordovician | Delimenu |
| | | Cirmas | | |
| | | Tebras | | |
| | | Stagnant zone (brines) | | Lontova |
| | | | | Voronku |
| Crystalline basement | Archean and Proterozoic | Kraslavas | | |

Conventionally aquifers in Baltic are divided in active, delayed and stagnant water exchange zone, according to their chemical composition and water exchange rate (Table 1).

Groundwater in aquifers of active exchange zone probable everywhere has changed during Holocene and usually occurs in Highlands, they are mostly fresh of Ca-HCO₃ or Ca-SO₄ type. However for delayed and stagnant water exchange zone it's a case of another kind they are more saline from brackish to brines and Na-Cl type predominates.

According to mathematical model developed by (Virbulis et al., under revision) aquifers with delayed and stagnant exchange recharge occur only at margins and through faults (Fig 3).

Considering that most of aquifers below region aquitard are well protected and their piezometric levels are higher than upper aquifers, recharge can take place only at some particular distance from margins. Thereby some aquifers might store groundwater for considerable time.

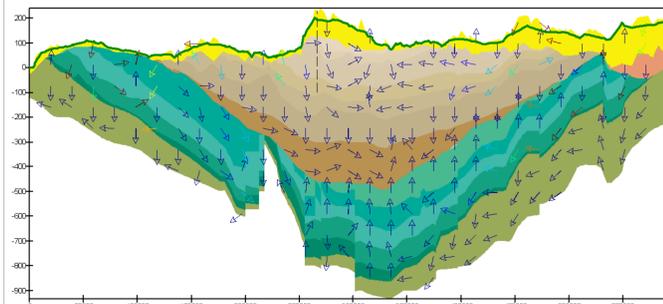


Fig 3. Relative calculated flow velocity modulus at cross section D-E-F. Horizontal axis - distance in meters; vertical axis - depth in meters. Profile line in Fig 4.

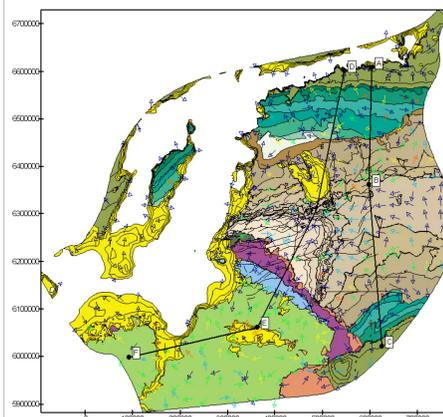


Fig 4. Horizontal cross section of BAB at depth -50 m bsl. Vectors illustrate flow direction and relative flow velocity - more red vectors indicate faster flow velocities, more blue - smaller velocities.

Profile lines A-B-C and D-E-F in Fig 3 and Fig 4.

EPSG:25884 Baltic TM projection

3. DATA

Extensive groundwater sampling for radiocarbon and stable oxygen content have been made in the territory of Estonia as well as in Lithuania, thereby at least some base levels in there are known. According to research by Mokrik et al. (2009) nine isotope samples as well were taken from different aquifers in Latvia on year 1987 and year 2000.

So far no sufficient studies were accomplished in the territory of Latvia; nevertheless considerable amount of stable isotope data from precipitation have been collected during Soviet times, which provide important data about isotopic signal recharging nowadays. According to monitoring data collected during 1980-1988, precipitation long term mean weighted values of meteoric water are -9.74 δ¹⁸O‰ VSMOW and -72.6 δ²H‰ VSMOW respectively, calculated deuterium excess is 11.2 (IAEA, 2006).

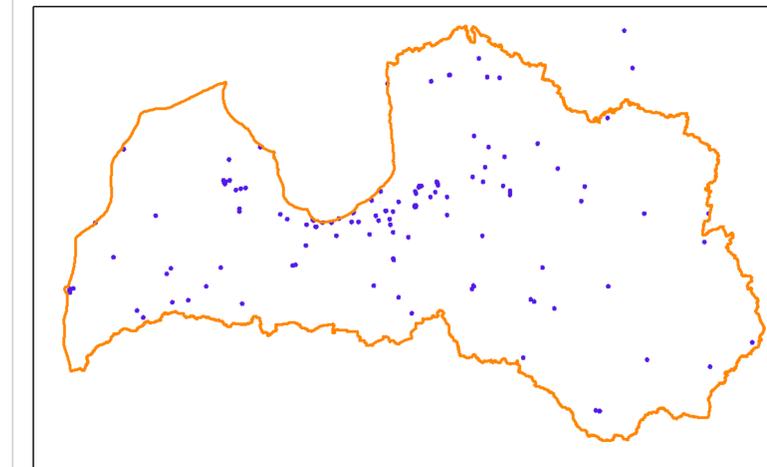


Fig 5. Stable oxygen and deuterium groundwater sampling sites within PUMA project.

Within the PUMA project new groundwater samples from all presented aquifers in Latvia were collected during period starting from September 2010 till March 2012. Totally 340 samples were collected, more or less over all territory of Latvia (Fig 5). Measurements were done in the Institute of Geology at Tallinn University of technologies. Stable oxygen ratio was measured on Mass spectrometer (Thermo Fisher Scientific), deuterium ratios has been measured with Picarro Isotopic Water Analyzer, so far the majority of samples has been analyzed (ranges of values for particular aquifers are summarized in Table 2).

| Layer | Chemistry, TDS and water type | Range of Oxygen-18 ratios δ ¹⁸ O‰ | Deposits |
|--------------------|--|--|--|
| Quaternary | TDS < 1 g/l Ca-HCO ₃ type | -8.75 -12.24 | Till, sand, clays, gravel, peat |
| Permian | TDS < 1 g/l Ca-HCO ₃ type | -10.05 -10.7 | limestone |
| Carboniferous | TDS < 1 g/l Ca-HCO ₃ type | -10.24 | limestone |
| Upper Devonian | TDS < 1 g/l Ca-HCO ₃ type TDS 1-2 g/l Ca-SO ₄ | -9.72 -13.1 | Dolomite, gypsum, limestone, marl, sandstones, clays |
| Middle Devonian | TDS < 1 g/l, Ca-HCO ₃ type TDS 1-5 g/l Na-Cl type | -10.74 -11.86 | Sandstones, clays |
| Lower Devonian | TDS < 1 g/l, Ca-HCO ₃ type TDS 1-35 g/l Na-Cl type | -10.89 -12.65 | sandstones |
| Silurian | TDS 6-100 g/l Na-Cl type | Not measured | Limestone, shale, clays, marl |
| Ordovician | TDS 10-120 g/l Na-Cl type | Not measured | Limestone, shale, clays, marl |
| Cambrian - Vendian | TDS 23-140 g/l Na-Cl type | -4.56 -5.28 | Sandstones, clays |

Additionally to stable isotope samples during the sampling major chemistry, trace elements and some wells were also sampled for Tritium and CFC (Chlorofluorocarbons). Tritium analyses were made in the Institute of geology and geography at the University of Vilnius again CFC were analyzed by laboratory at the Geological Survey of Denmark and Greenland.

Table 2. Approximated description of major aquifers in Latvian part of BAB. Range of isotope ratio from PUMA project samples together with historical data.

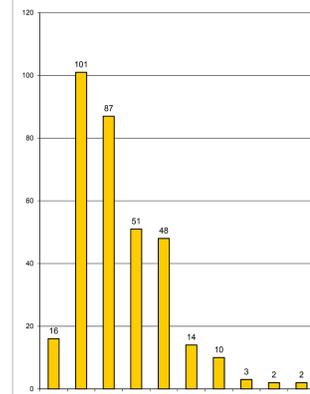


Fig 6. Number of analyzed samples per each aquifer.

4. RESULTS

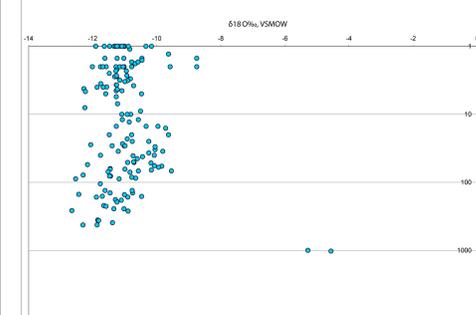


Fig 8. Relation between delta oxygen-18 and sampling depth. Vertical axis in logarithmic scale.

Determination coefficient between stable isotope ratios and tritium (TU) activity is 0.0579, correlation between CFC ages and stable isotope ratios is even less, which is 0.0031. Also mismatch was observed between reported ages of both methods.

Comparison was made between 36 CFC and 34 tritium results, and it should be noted, that CFC and tritium samples were taken during the same sampling campaign.

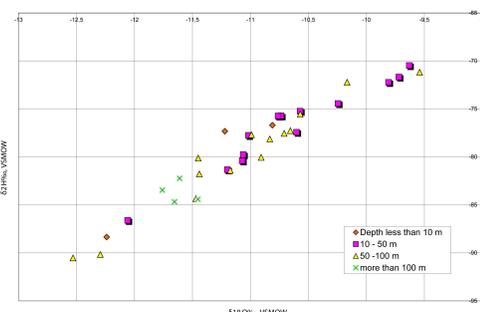


Fig 9. Relation between delta deuterium and delta oxygen-18 in groundwater.

Since it is unknown what is the cause of such mismatch in results between presented ages of Tritium and CFC, it is suggested to use results by both methods just to determine, whether groundwater is of modern recharge or not.

DISCUSSION

Stable oxygen and hydrogen ratios from shallowly embedded aquifers have less characteristic ratios compared to deeper aquifers and usually represent seasonal fluctuations of precipitation. Results are becoming more specific with increasing depth, on the other hand in some areas opposite tendency can be observed.

Ratios of δ¹⁸O in groundwater of Latvia vary in a wide range, from the less depleted -4.56 ‰ VSMOW in brines which in case of Latvia are situated in Cambrian aquifer to more depleted values in the Middle and Lower Devonian aquifers -13.1 ‰ VSMOW. It should be noted, that according to Mokrik (2009) such isotopic content is characteristic at the same depths in Lithuania, but in Lower Devonian aquifers.

As it was considered earlier glacial meltwater from last glaciation intruded in Cambrian-Vendian aquifer in Northern part of BAB, in the central part of Estonia glacial meltwater is mixed more likely with groundwater recharged during Holocene, on the other hand, more Southern part of Estonia, were depth of the aquifer respectively as well as TDS increase, third end member in the mixture appears, with probable longer resistance time. In case of Latvia so far no glacial meltwater traces have been found, even though some anomalies of fresh water occur in Lower Devonian.

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