Identifying the origin of water appearances in salt mines using isotope-aided methodologies:

new insights through combined analyses of water leakages and atmospheric water vapor

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INTRODUCTION

TWO MAIN GROUPS OF WATER APPEARENCES IN SALT MINES:

1. SYNGENETIC BRINES



- In limited quantities
- Saturated brines

SAFE ☺

2. INFILTRATION WATERS



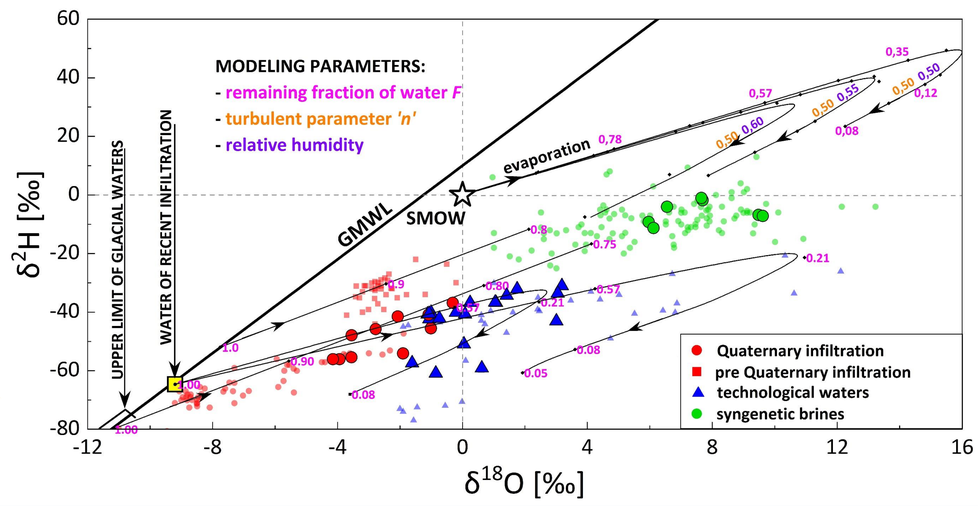
- Originally unsaturated
- Unlimited inflow

DANGEROUS!!!

These two groups can be identified by the stable isotopes of oxygen and hydrogen in water (δ^2H, $\delta^{18}O$)

Catastrophic flood of the Wapno Salt Mine (1977) – isotope warnings ignored





Since these waters interact with mines' atmospheric moisture it's spatio-temporal variability of δ^2H and $\delta^{18}O$ has to be quantified to constrain the models

STUDY AREA

Klodawa Salt Mine

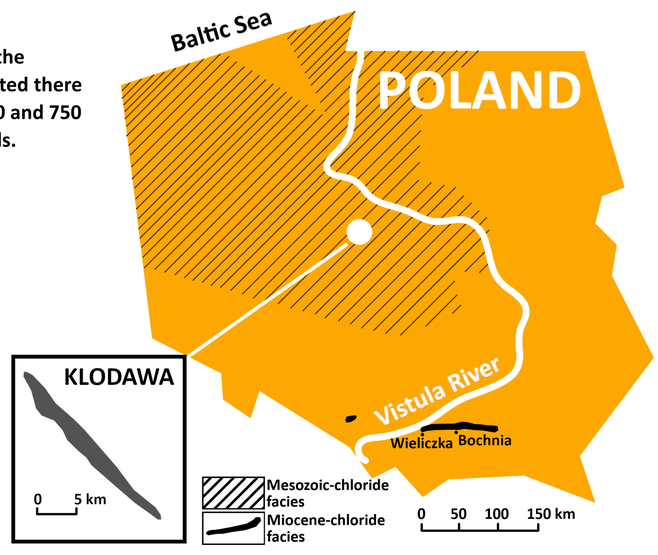




The analysed brines come from the Klodawa Salt Mine. Salt is exploited there at four main levels: 450, 525, 600 and 750 m and several intermediate levels.

The Klodawa deposit is situated in the central part of a 63 km long salt structure. That part pierces through the Mesozoic strata and forms a diapir. The gypsum-clayey cap is at a depth of 40-500 m, up to 250 m thick, and is surrounded by Quaternary and Tertiary water-bearing sediments.

Yearly production of salt is in the order of 600 ktons. The volume of exploitation chambers is approximately 15 millions cubic meters, with typical dimensions 120 x 12 x 12 m (!).



METHODS

Autonomous units allowing collection of monthly composite samples of mines' atmosphere have been installed at 7 representative localities inside the mine and operated for the period of 14 months. The units were also measuring temperature and relative humidity.

Bags filled with mine atmosphere were transported to the laboratory at a controlled temperature to prevent moisture condensation in the sampling bags.

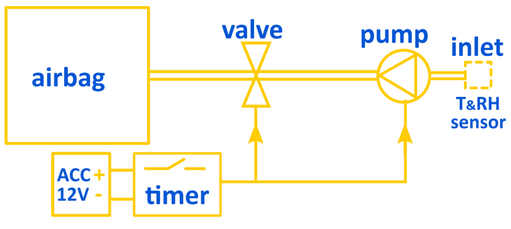
The ^2H and ^{18}O isotope composition of water vapor in the collected air samples was measured in the laboratory using Picarro 2140-*i* laser CRDS analyzer using the dual mode option – measuring gas samples and water standards alternately.

Picarro L2140-i CRDS analyzer



AUTONOMOUS AIR SAMPLER





RESULTS

Spatio-temporal evolution of δ^2H and $\delta^{18}O$ of atmospheric water vapor in the mine

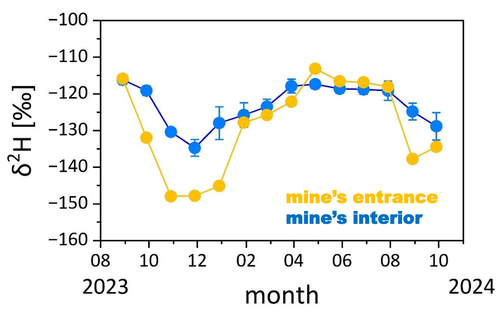


Fig. 1

Changes in the isotopic composition of atmospheric water vapor inside the mine mirror the seasonal variations of isotopic composition of atmospheric moisture outside the mine, although with reduced amplitude.

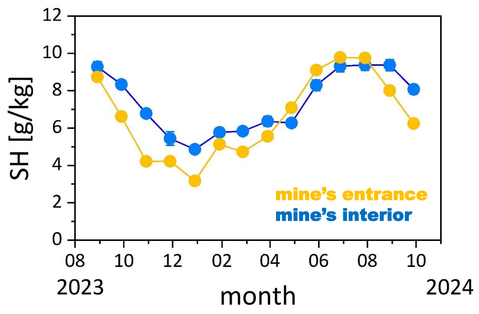


Fig. 2

Comparison of the seasonal evolution of specific humidity (SH) in the atmospheric moisture outside and inside the mine reveals that mines' salt walls operate as a sponge, releasing moisture to the mine's atmosphere during winter time when relative humidity inside the mine remains low (ca. 30%) and adsorbing it during summer time when RH levels inside and outside the mine remain similar.

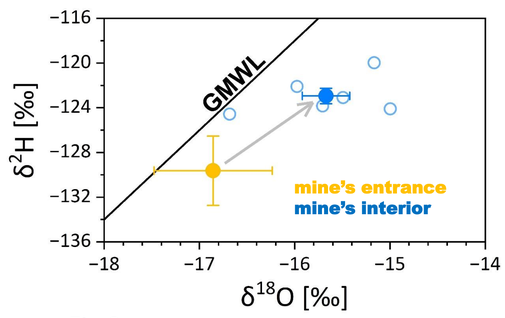


Fig. 3

Dual–tracer representation of the isotope data of water vapor outside and inside the mine reveals that adsorption of atmospheric moisture on the salt walls during summer months and its partial release during winter is accompanied by isotope fractionation in the order of ca. 7 ‰ for deuterium and ca. 1 ‰ for ^{18}O.

Impact of isotope exchange with water vapor on the isotopic composition of monitored brine inflows to the mine

In order to better understand the observed isotopic composition of the brines encountered in the salt mine, the isotopic composition of the theoretical brine with the corresponding chemical composition, which is in equilibrium with the water vapor of the mine atmosphere, was calculated:

δ of the total water (free and bound) in the brine

δ of atmospheric water vapor

$$\delta_B = \Gamma \cdot \left(\frac{1000 + \delta_V}{\alpha_{V-W}}\right) - 1000$$

Correction coefficient [Horita et al., 1993a, 1993b]

Equilibrium fractionation coefficient between water vapor and free water reservoir in the brine

160-600

A pool on the floor of the excavation is located at a distance of approx. 50 m from the constant air flow, in a side, poorly ventilated corridor.



Brine 160-600

The atmospheric water vapor pressure can be either higher or lower than the saturation vapor pressure over the brine which means that both partial evaporation and absorption of atmospheric water vapor can occur. Since 2006 its isotopic composition evolved towards an increasingly negative one, reaching the values close to equilibrium with local atmospheric water vapor in mine.

START: 2006
LEVEL: 600 m
DENSITY: 1.36 g/cm³
MINERALIZATION: 505 g/dm³
PREDOMINANT IONS: Mg^{2+} Cl^-
OUTPUT FLOW: ~0 dm³/h
WATER ACTIVITY: 0.32
RH: 25-49%

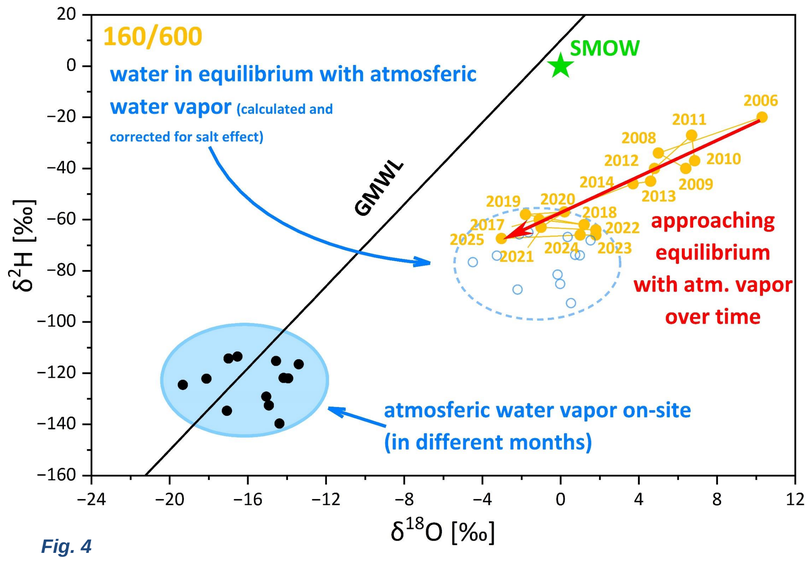


Fig. 4

Brine 106-600

A dampness of the floor and sidewalls in the area of the gallery front. A groove was made 5 m from the front, where brine is collected. The atmospheric water vapor pressure is always lower than the saturation vapor pressure over the brine, which forces effective water evaporation. The isotopic composition suggests that the brine is composed of infiltration water from outside the salt deposit recharged under cold climatic conditions, which makes the brine dangerous from the point of view of mine safety.

START: 1994
LEVEL: 600 m
DENSITY: 1.21 g/dm³
MINERALIZATION: 330 g/dm³
PREDOMINANT IONS: Na^+ Cl^-
OUTPUT FLOW: <0.01 dm³/h
WATER ACTIVITY: 0.75
RH: 30-54%

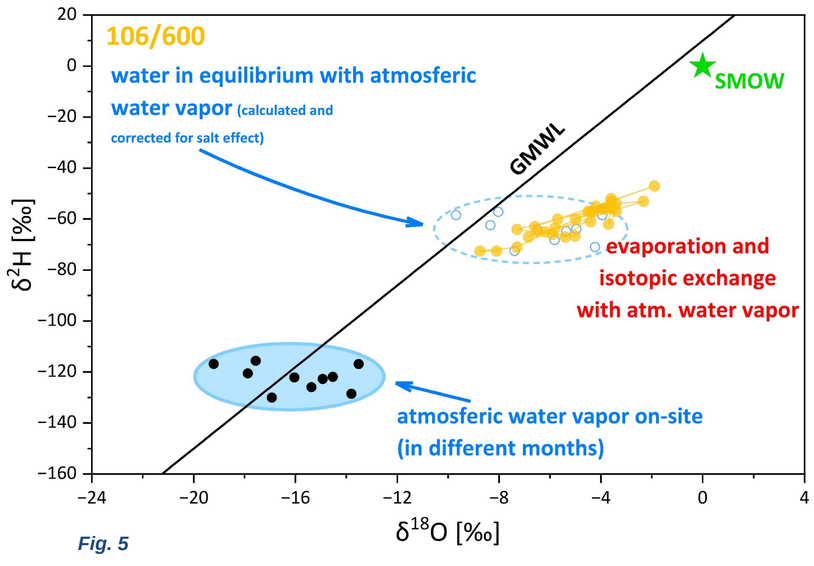


Fig. 5

CONCLUSIONS

① **The origin of water appearance in salt mines can be traced by measuring isotopic composition of brines encountered in those mines.**

② **With innovative sampling technique and laser-based analytical methodologies it was possible to obtain, for the first time, quantitative information about isotopic composition of atmospheric moisture inside the operating salt mine.**

③ **Mapping the isotopic composition of water vapor in mines' atmosphere can greatly improve the effectiveness of isotope monitoring of brines inside the salt mines from the point of view of their safety.**

REFERENCES

Horita J., Wesolowski D.J., Cole D.R., 1993a. The activity-composition relationship of oxygen and hydrogen isotopes in aqueous salt solutions: I. Vapor-liquid water equilibration of single salt solutions from 50 to 100ºC. Geochim. Cosmochim. Acta, vol.57: 2797-2817.

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