Unraveling temperature and hydrological conditions of salt deposits by measuring the speed of sound in halite fluid inclusions

The case of the Last Interglacial Dead Sea

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Microthermometry on fluid inclusions, a paleothermometer for deep rocks

Fluid inclusion
- Definition: microdroplet of liquid trapped in a mineral
- Used for more than 150 years as a thermometer for the genesis of deep rocks (e.g., Sorby 1858)
- The concept: once trapped, the density of the fluid remains constant, thus indicating the temperature of entrapment
- Researchers usually place sample in a temperature-controlled stage, and apply the Pressure-Temperature path shown here on the right to find homogenization temperature (Th) and infer Tf (formation temperature)

https://rohmin.unileoben.ac.at/de/3388/
Microthermometry on halite fluid inclusions: a freezer to force the nucleation of bubbles (Roberts and Spencer, 1995)

As halite is a surface mineral, Th is supposed to provide directly Tf, as the formation pressure is almost 0. Roberts and Spencer (1995) proposed to place halite samples in a freezer to nucleate vapour bubbles, and subsequently perform microthermometry to obtain Th and infer paleolake temperature...

...however, at very low temperatures (-20°C), the trapped fluid, although not frozen, is stretched. It pulls the walls of the fluid inclusions, and as halite is soft, the inclusion collapses and density is modified => Loss of temperature information (Lowenstein et al, 1998; Guillerm et al., in press)
A new technique avoiding the issue of the bubble nucleation (El Mekki-Azouzi et al, 2015; Guillerm et al., in press).

Brillouin spectroscopy of fluid inclusions proposed as a paleothermometer for subsurface rocks

Restoring Halite Fluid Inclusions as an Accurate Palaeothermometer: Brillouin Thermometry Versus Microthermometry

Emmanuel Guillerm (1, 2), Véronique Gardien (1), Daniel Ariztegui (3) and Frédéric Caupin (2)
Brillouin scattering, Brillouin shift and Brillouin spectroscopy

\[ \Delta f_b = \frac{2 n w}{\lambda} \]

- \( \Delta f_b \): Brillouin shift
- \( n \): refraction index
- \( w \): speed of sound
- \( \lambda \): laser emission wavelength

Fluid inclusion

Laser spot

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- We first measure the speed of sound in the all-liquid inclusion (monophasic), at several temperatures.
- We then measure the speed of sound in the inclusion with a vapor bubble (biphasic), at several temperatures.
- The fitted curves cross at a temperature $T_x$ which corresponds to $T_f$ if the inclusion is undamaged and trapped at pressure 0.
The Dead Sea, an outstanding site for paleoclimate reconstructions

- Region of climatic concern, astride Mediterranean and arid climates
- Multiple episodes of halite deposition through geological times, including today
- Monitored for several decades, numerous scientific publications
- Gate out of Africa for Homo Sapiens
The Dead Sea, an outstanding site for paleoclimate reconstructions

The stable deep layer of the Dead Sea mainly catches the long-term fluctuations of climate.

Source: [https://isramar.ocean.org.il/](https://isramar.ocean.org.il/)
Core 5017-1, a 450-meters-long core covering the deposits of the last 200,000 years

Last Interglacial (135,000-115,000 BP): most recent Holocene-like warm period. Very well expressed in the Dead Sea: >80 meters of sediments, including 30 meters of halite.
Seasonal mixing and annual cycle of halite precipitation: the model of Sirota et al. (2016, 2017)

**SPRING**
- Warming
- Undersaturation

**SUMMER**
- Low supersaturation

**FALL**
- Cooling
- High supersaturation

**Late FALL/WINTER**
- Coarse crystals: 
  - Precipitate at bottom of lake in spring/summer
  - ... but record $T_{air}$ of mixing period, i.e. winter!

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1st goal: reconstruction of the Last Interglacial Dead Sea level curve

We noticed that the speed of sound (\(w\)) in biphasic halite fluid inclusions (measured at 20°C) increased upwards in the core. This trend highlights a progressive increase in the density of the Last Interglacial Dead Sea. Assuming no external supply of Na+ and Cl-, this can be used to infer the evaporation degree, ergo relative volume changes.
2\textsuperscript{nd} goal: reconstruction of the Dead Sea paleotemperatures, indication on winter air temperature
Summary

• Brillouin spectroscopy is in position to allow for the reconstruction of:
  ➢ Dead Sea level during the Last Interglacial
  ➢ Deep Dead Sea temperature during the Last Interglacial, interpreted as winter air temperature. Measurements on a contemporary sample perfectly matches monitored temperature

• Increasing speed of sound in biphasic fluid inclusions highlights progressive shrinkage of the lake throughout the period, interrupted at 129-122 kyr

• Preliminary results show that Dead Sea temperatures during the Last Interglacial were mainly lower than today, pointing towards colder winters
Thank you for your attention
References


