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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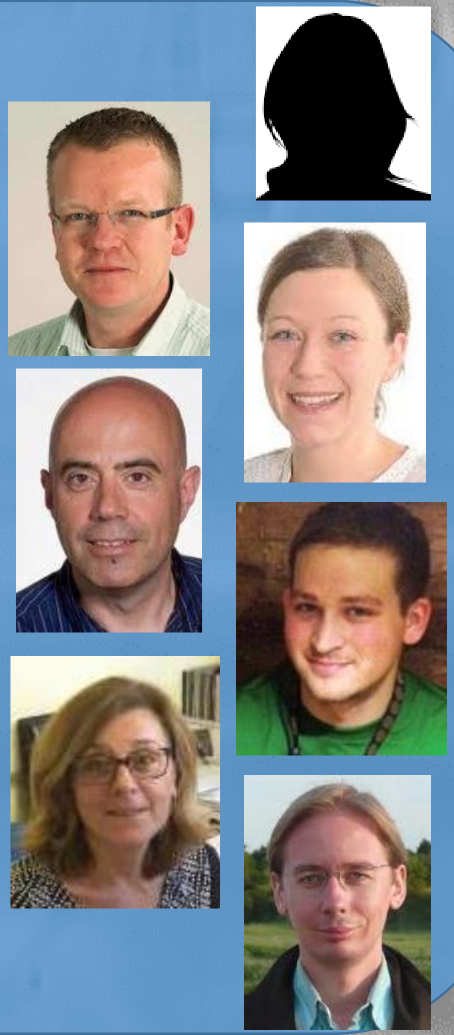

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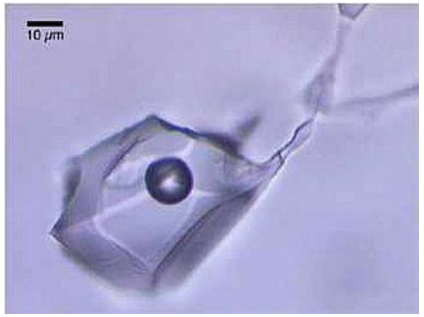
Microthermometry on fluid inclusions, a paleothermometer for deep rocks



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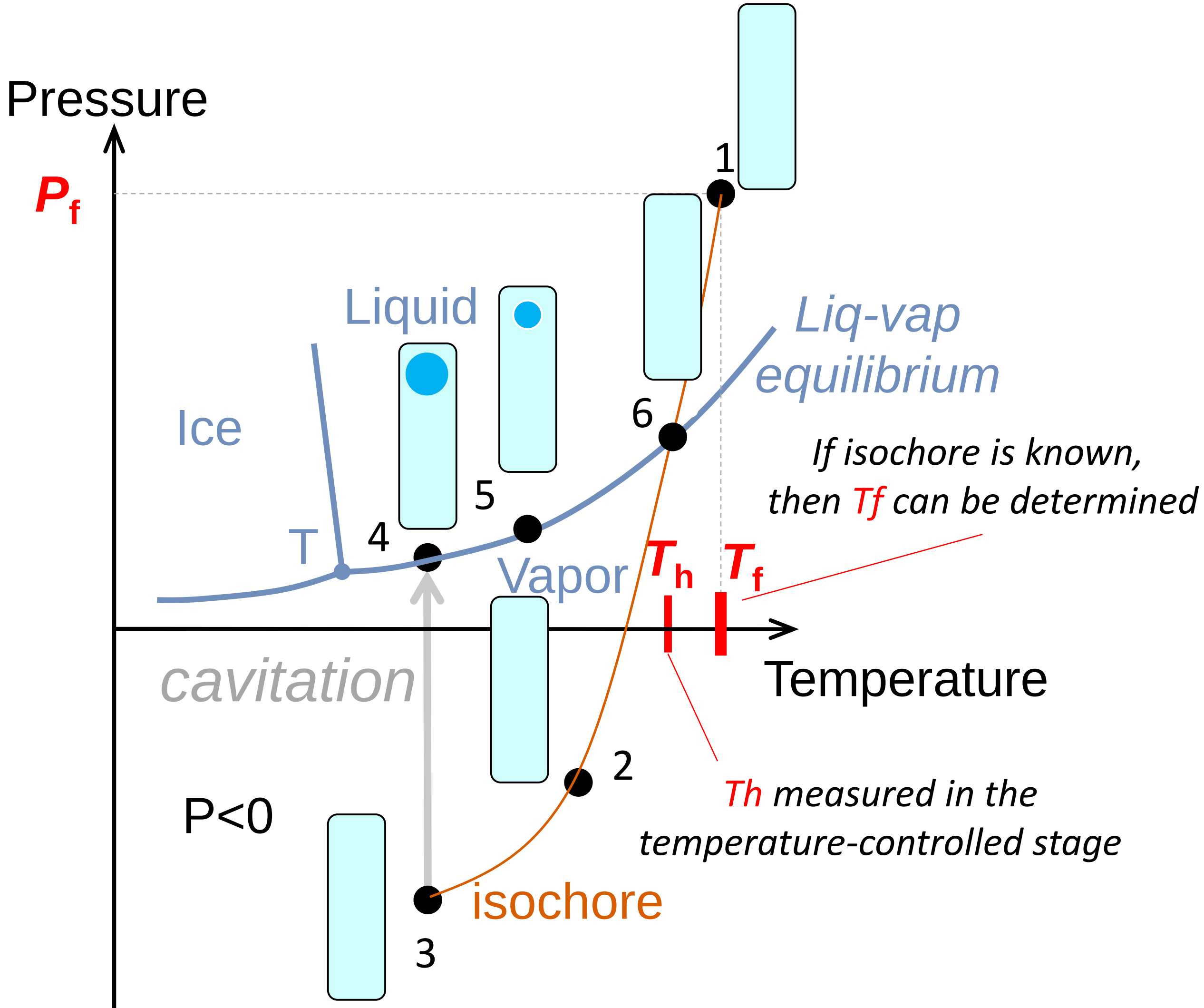
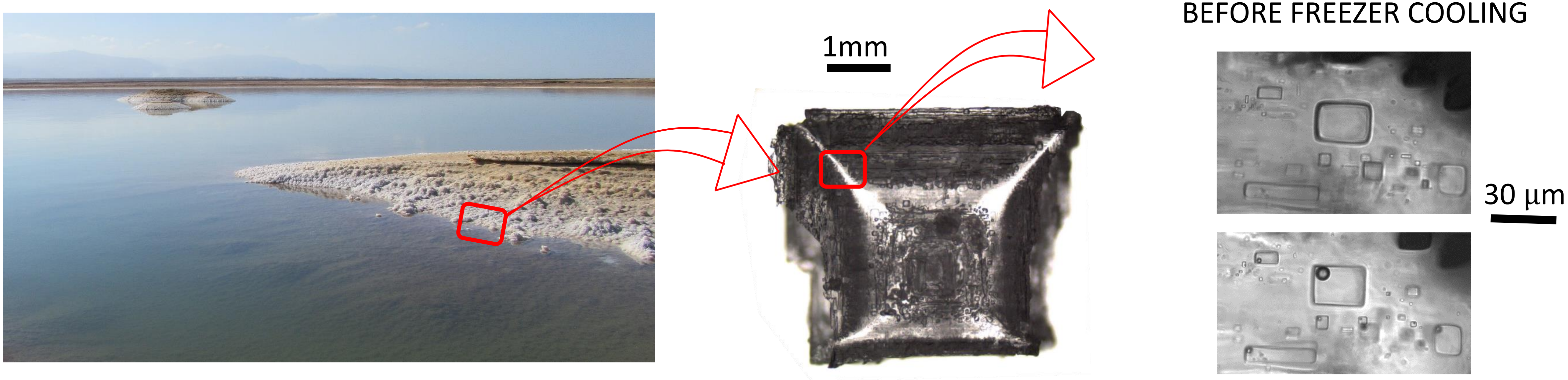
<u>Fluid inclusion</u>

- Definition: microdoplet 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)



Microthermometry on halite fluid inclusions: a freezer to force the nucleation of bubbles (Roberts and Spencer, 1995)



AFTER FREEZER COOLING

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*)

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

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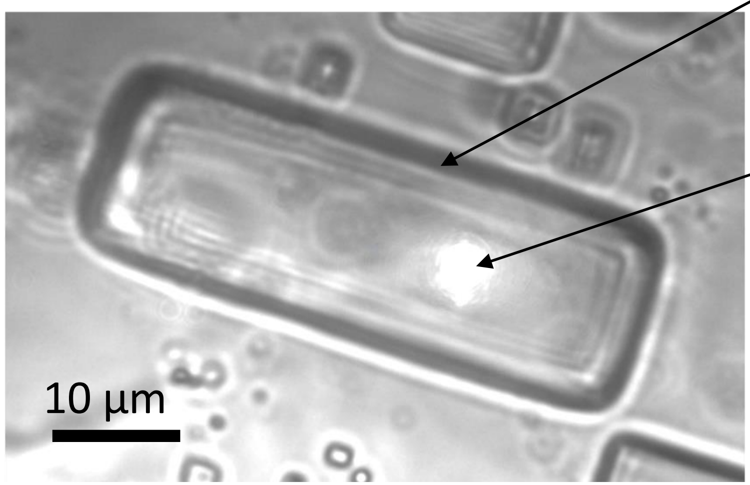
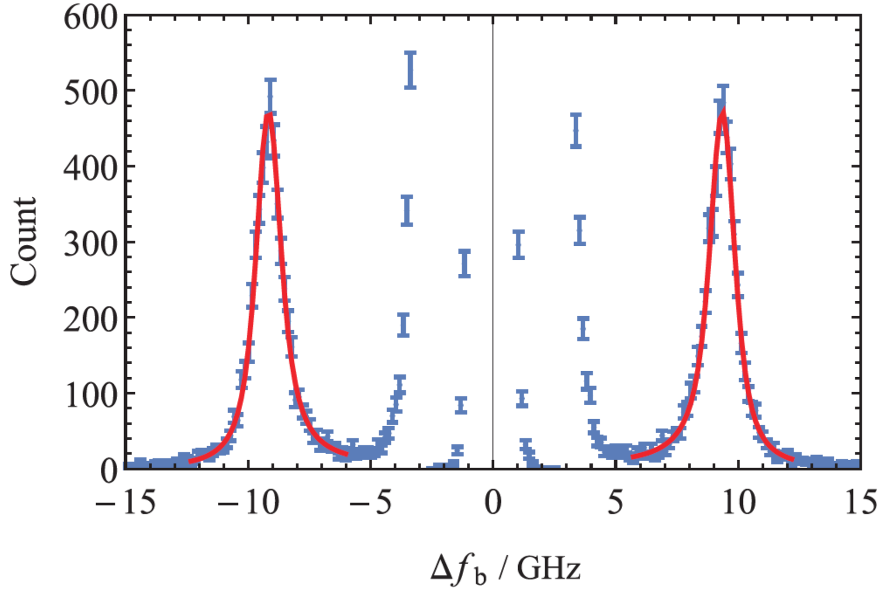
GEOSTANDARDS and GEOANALYTICAL RESEARCH

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

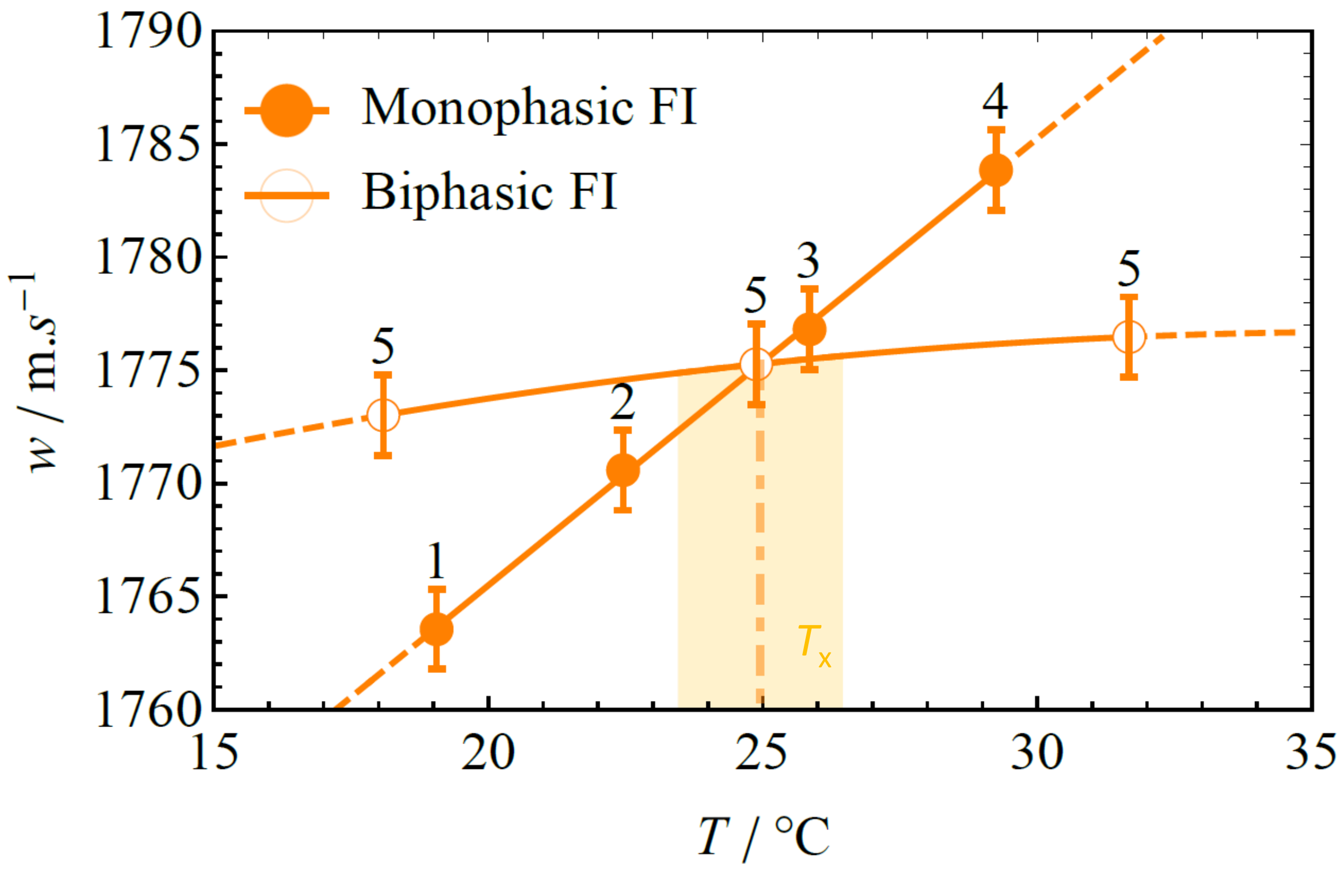




$$\boxed{\Delta f_b = \frac{2\, n\, \boldsymbol{w}}{\lambda}}$$

Δf_b: Brillouin shift
n: refraction index
***w**: speed of sound*
λ: laser emission wavelength

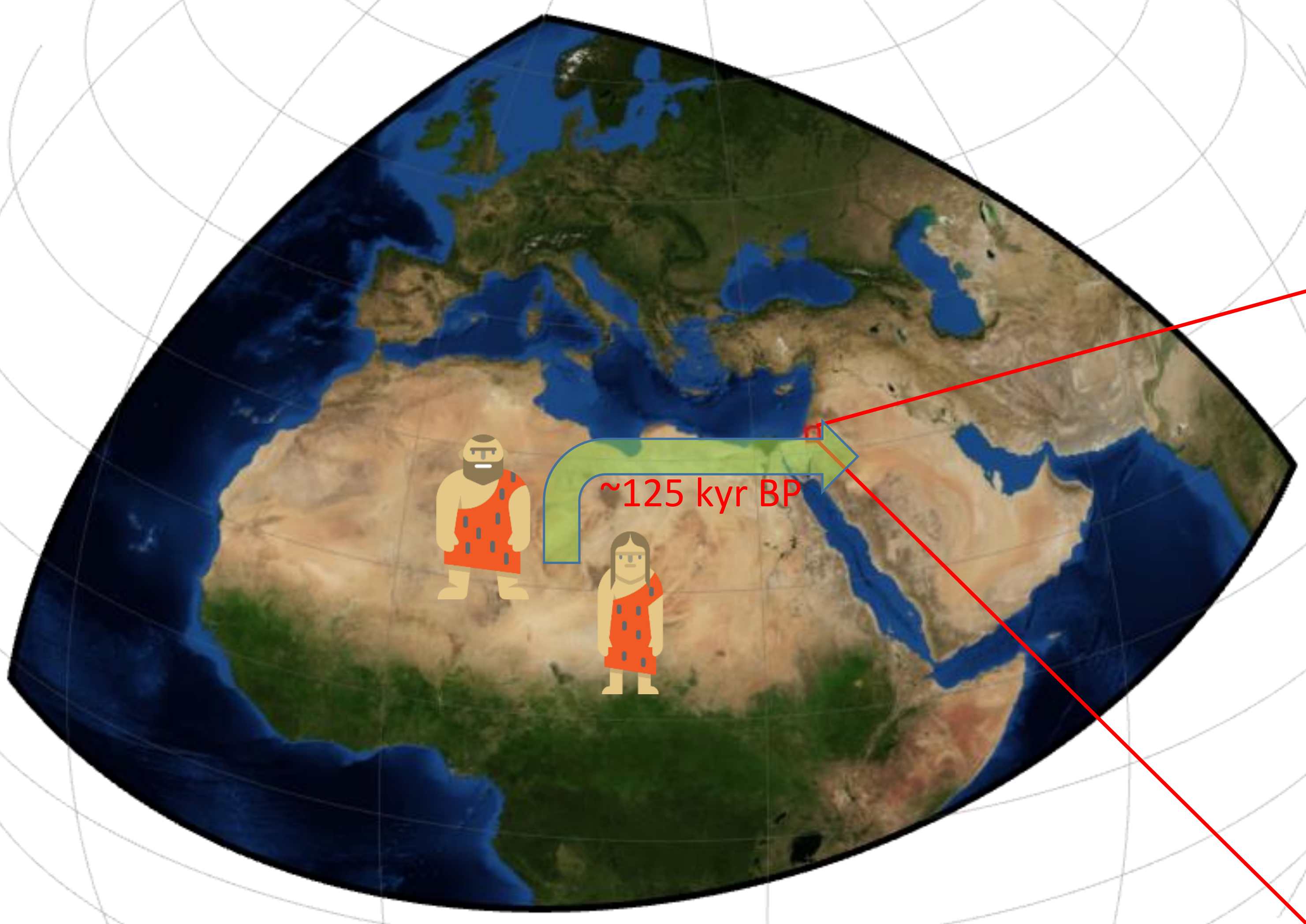
Concept

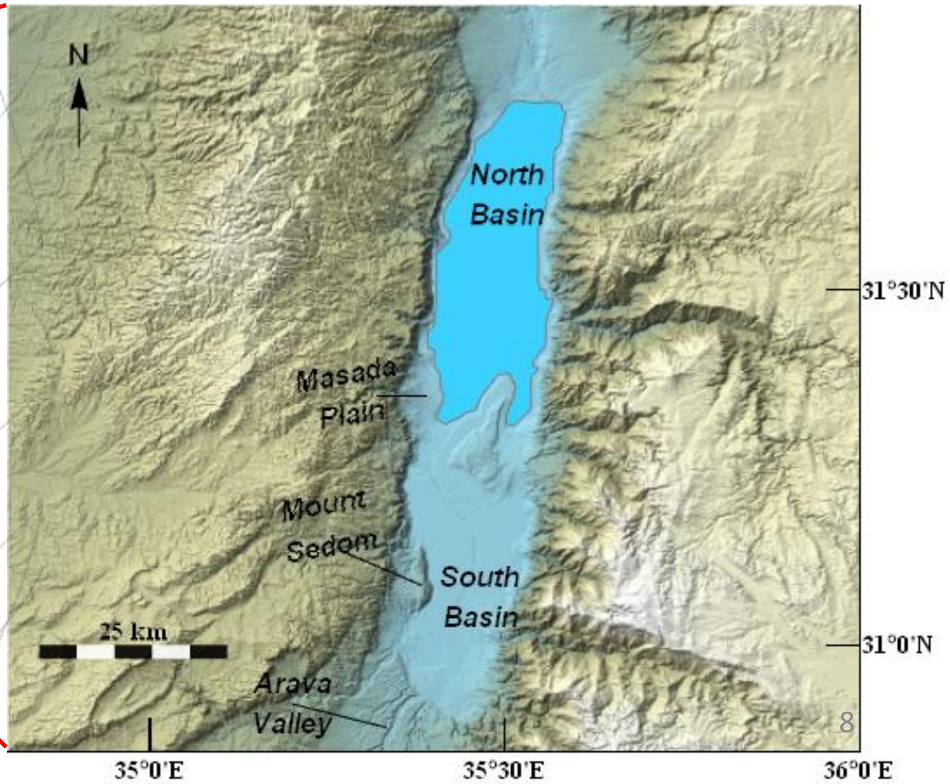


- We first measure the speed of sound in the all-liquid inclusion (monophasic), at several temperatures
- We then measure the speed of sound in the inclusion with a vapor bubble (biphasic), at several temperatures
- The fitted curves cross at a temperature Tx which corresponds to Tf if the inclusion is undamaged and trapped at pressure 0

The Dead Sea, an oustanding site for paleoclimate reconstructions

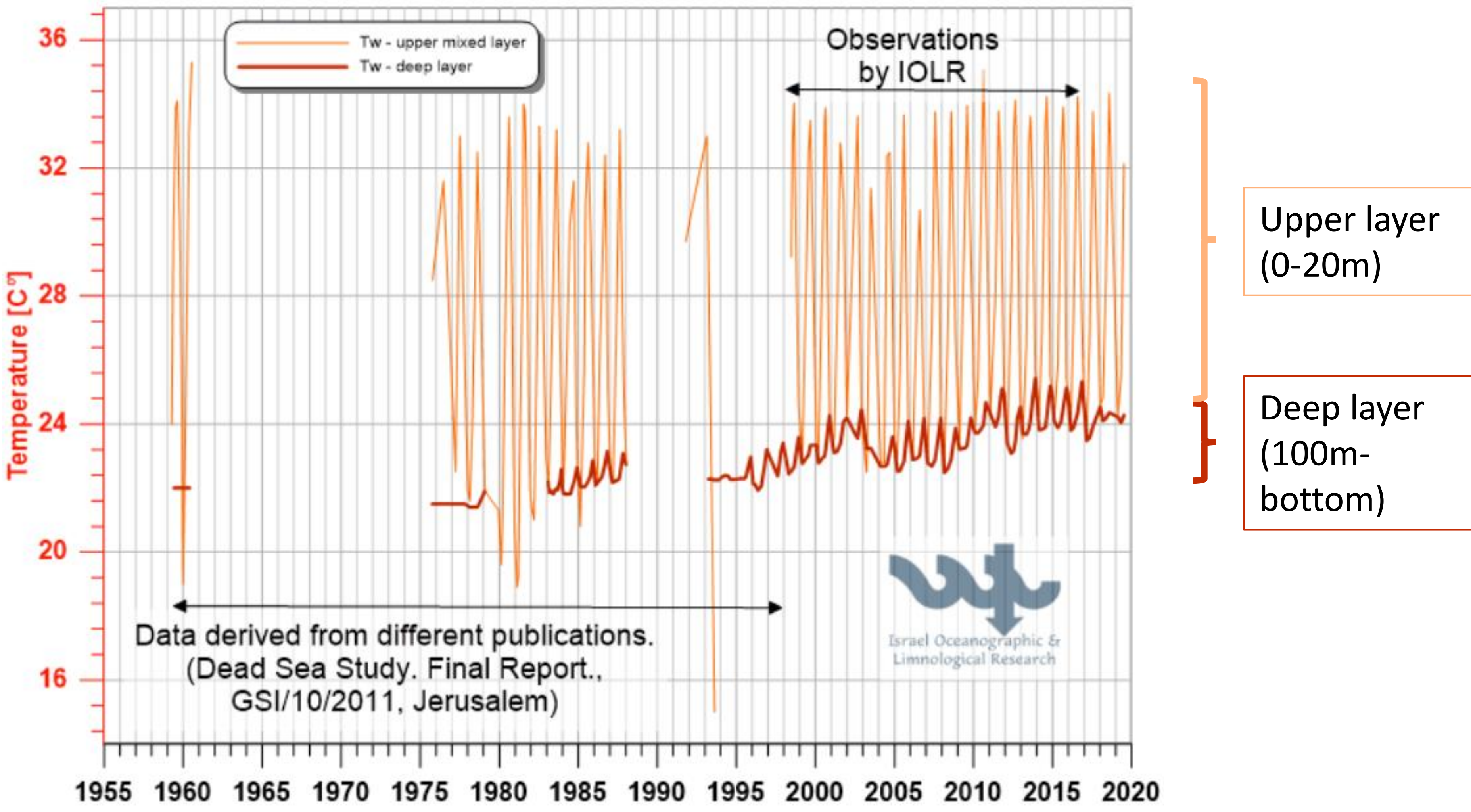
- Region of climatic concern, astride Mediterranean and arid climates
- Multiple episodes of halite deposition through geological times, including today
- Monitored for several decades, numerous scientific publications
- Gate out of Africa for Homo Sapiens





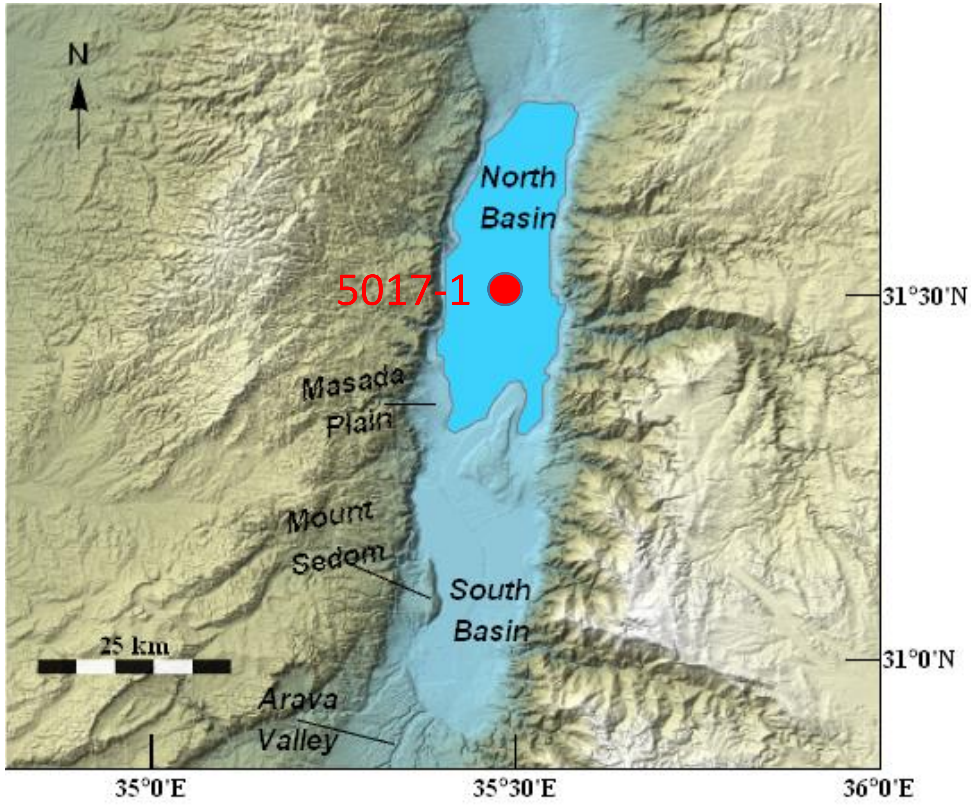
The Dead Sea, an oustanding site for paleoclimate reconstructions

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



Source: https://isramar.ocean.org.il/

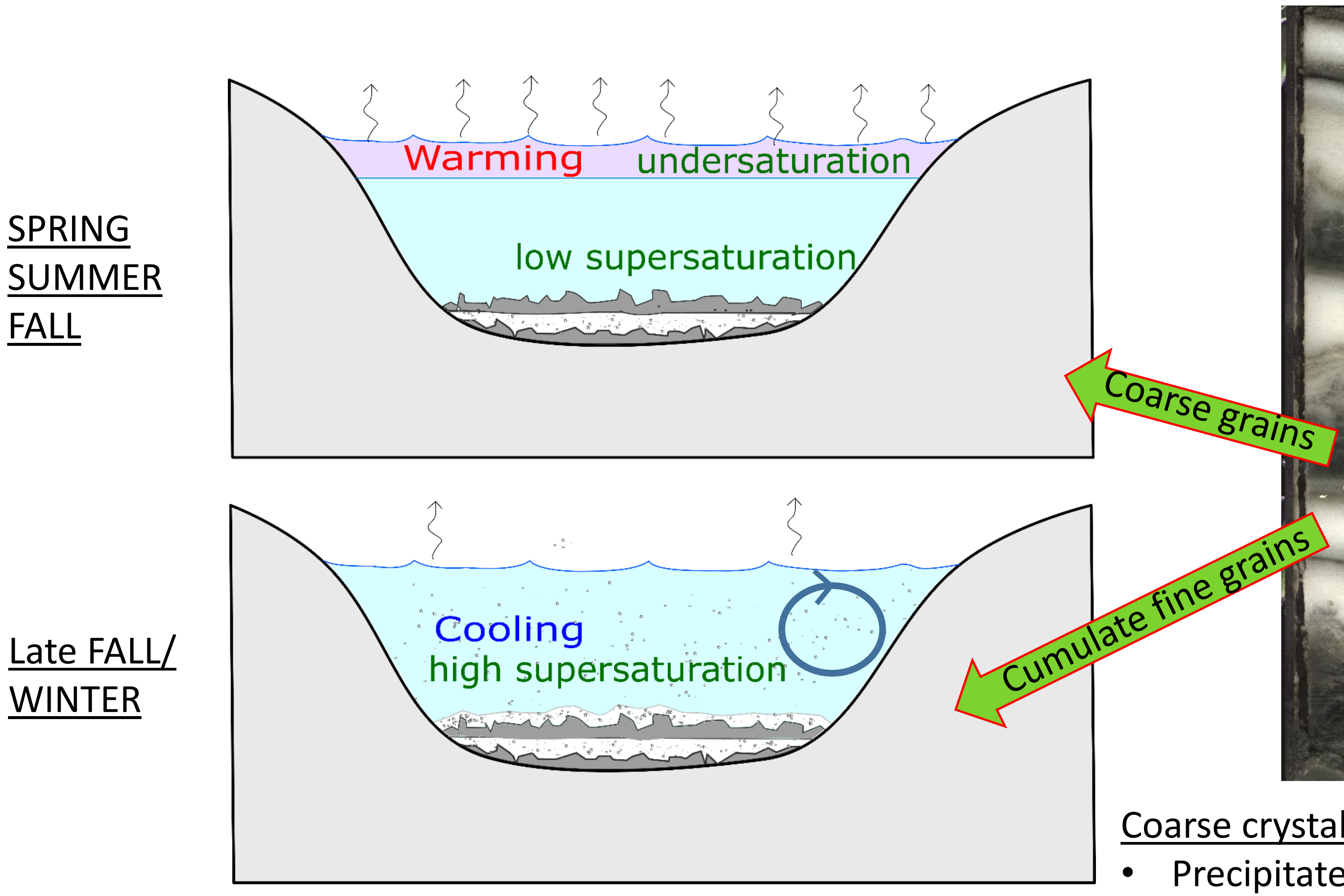
Core 5017-1, a 450-meters-long core covering the deposits of the last 200,000 years

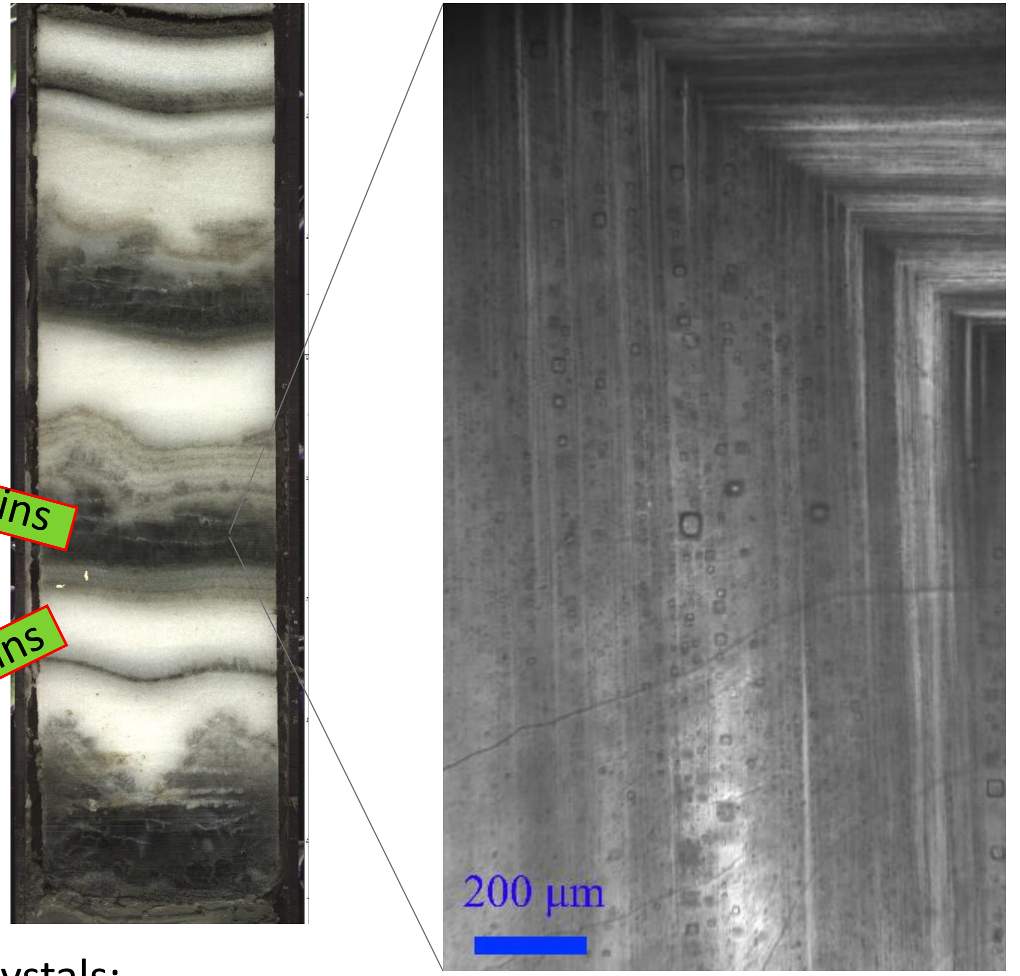


A typical halite deposit of the Last Interglacial Dead Sea in core 5017-1

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)

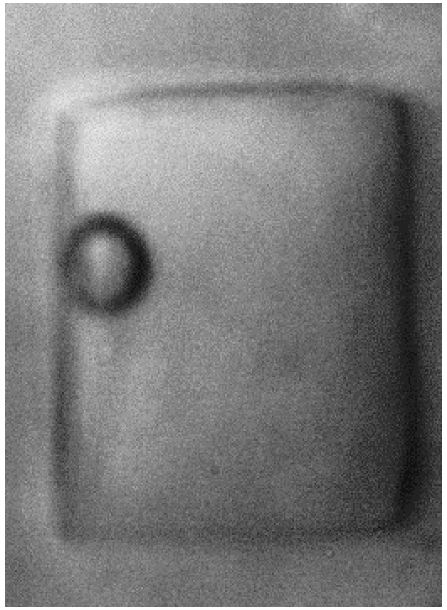


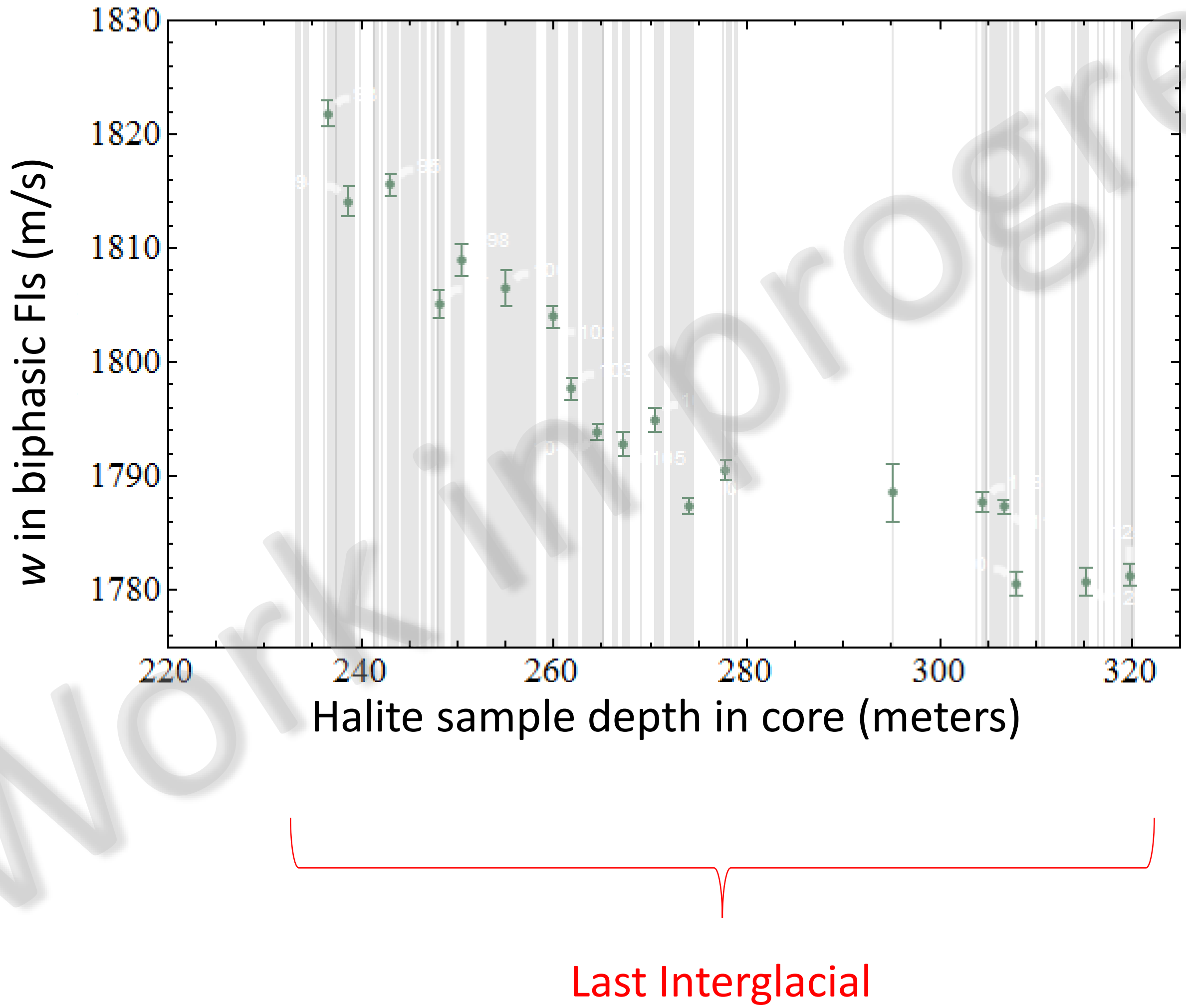


Coarse crystals:

- Precipitate at bottom of lake in spring/summer
- … but record T_{air} of mixing period, i.e. winter !

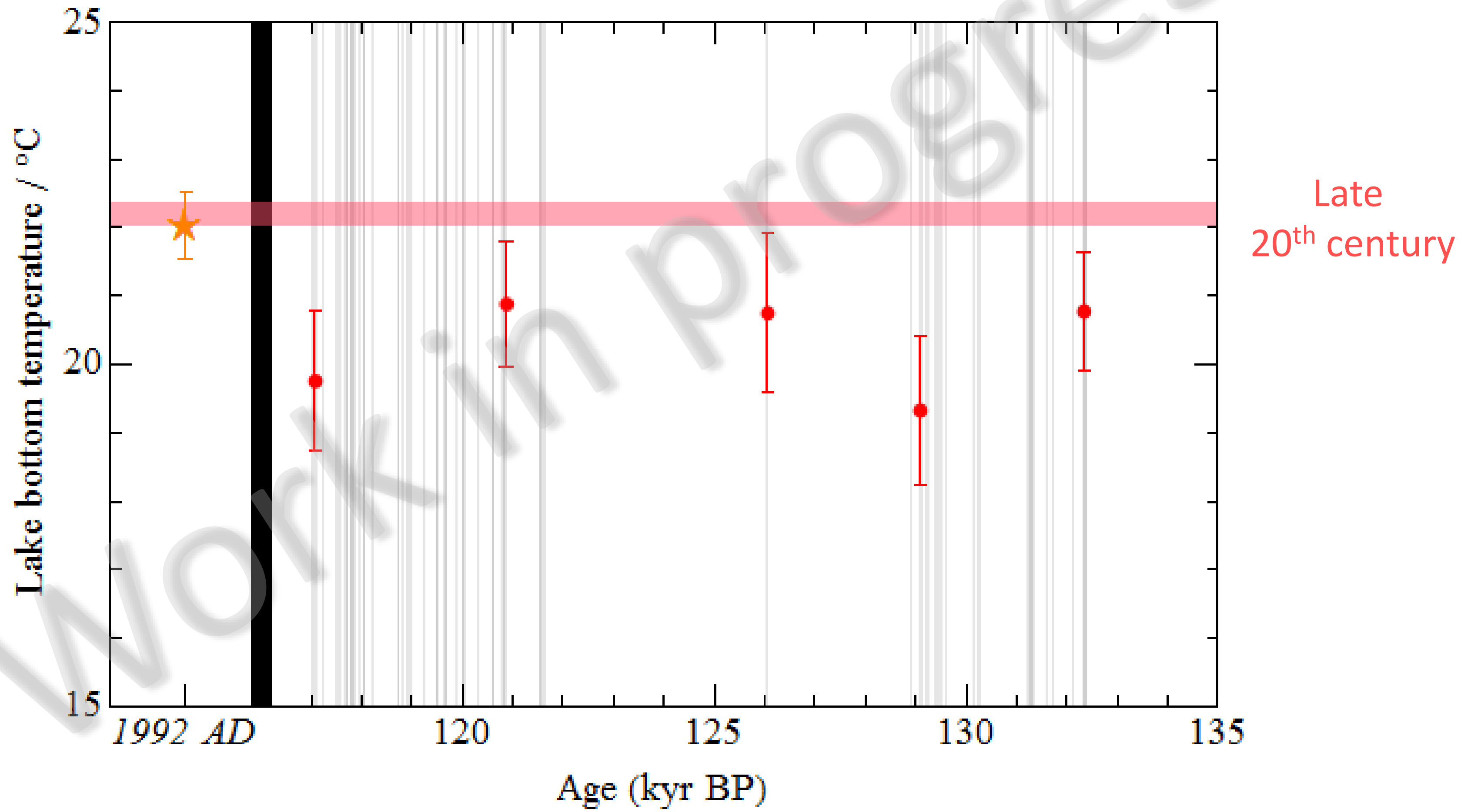
1st goal: reconstruction of the Last Interglacial Dead Sea level curve





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

2nd goal: reconstruction of the Dead Sea paleotemperatures, indication on winter air temperature

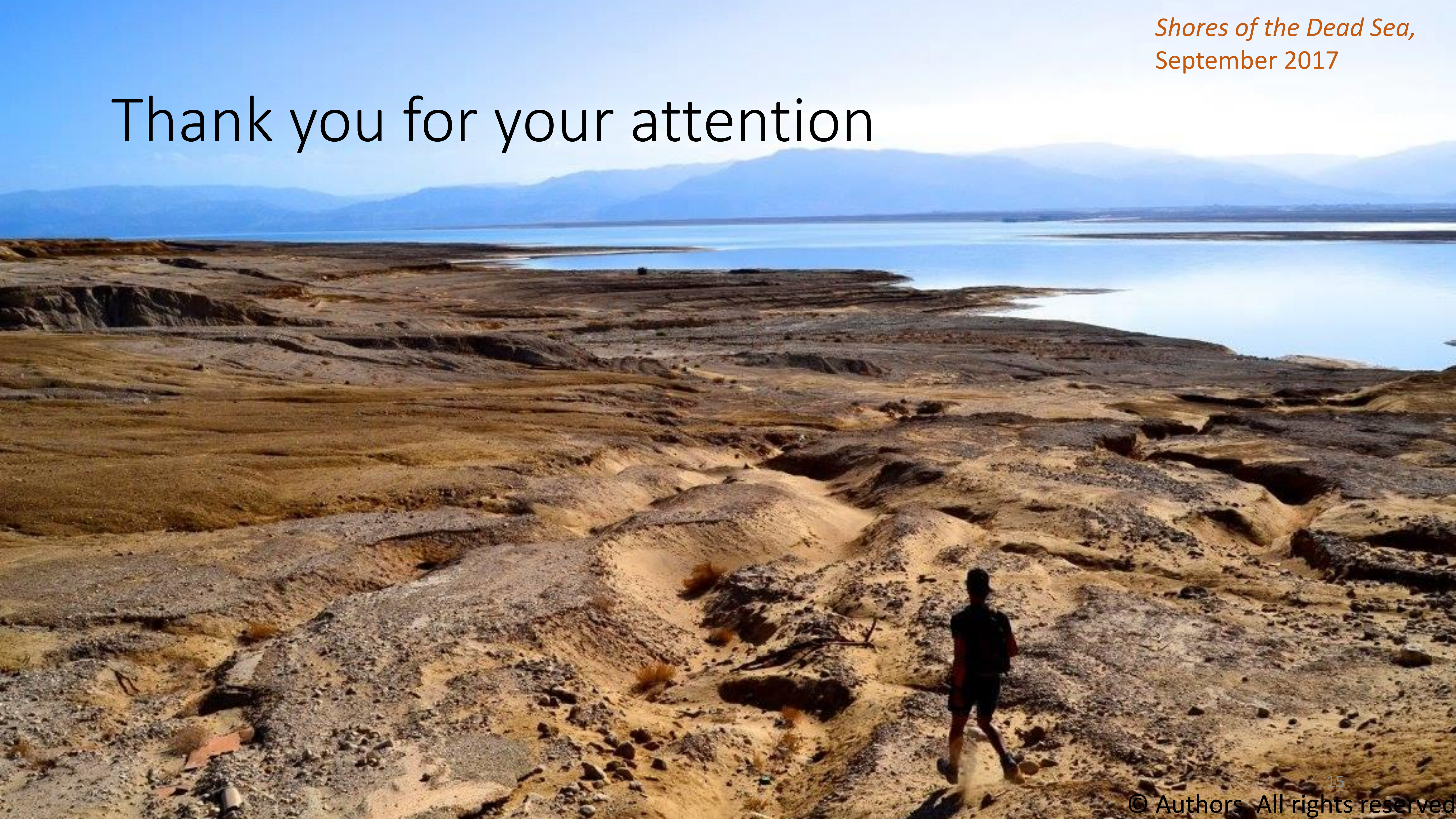


Summary

- 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 129-122kyr

- Preliminary results show that Dead Sea temperatures during the Last Interglacial were mainly lower than today, pointing towards colder winters



Shores of the Dead Sea,
September 2017

Thank you for your attention

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