Gliederung

- **Tracerhydrologie und Hydrochemie**
  - Grundlagen, Ansätze
  - Verfügbare Tracer
- **Natürliche Tracer**
  - Umweltisotope
  - Geogene Tracer
- **Künstliche Tracer und Markierverfahren**
  - Grundlagen
  - Tracergruppen / Eigenschaften

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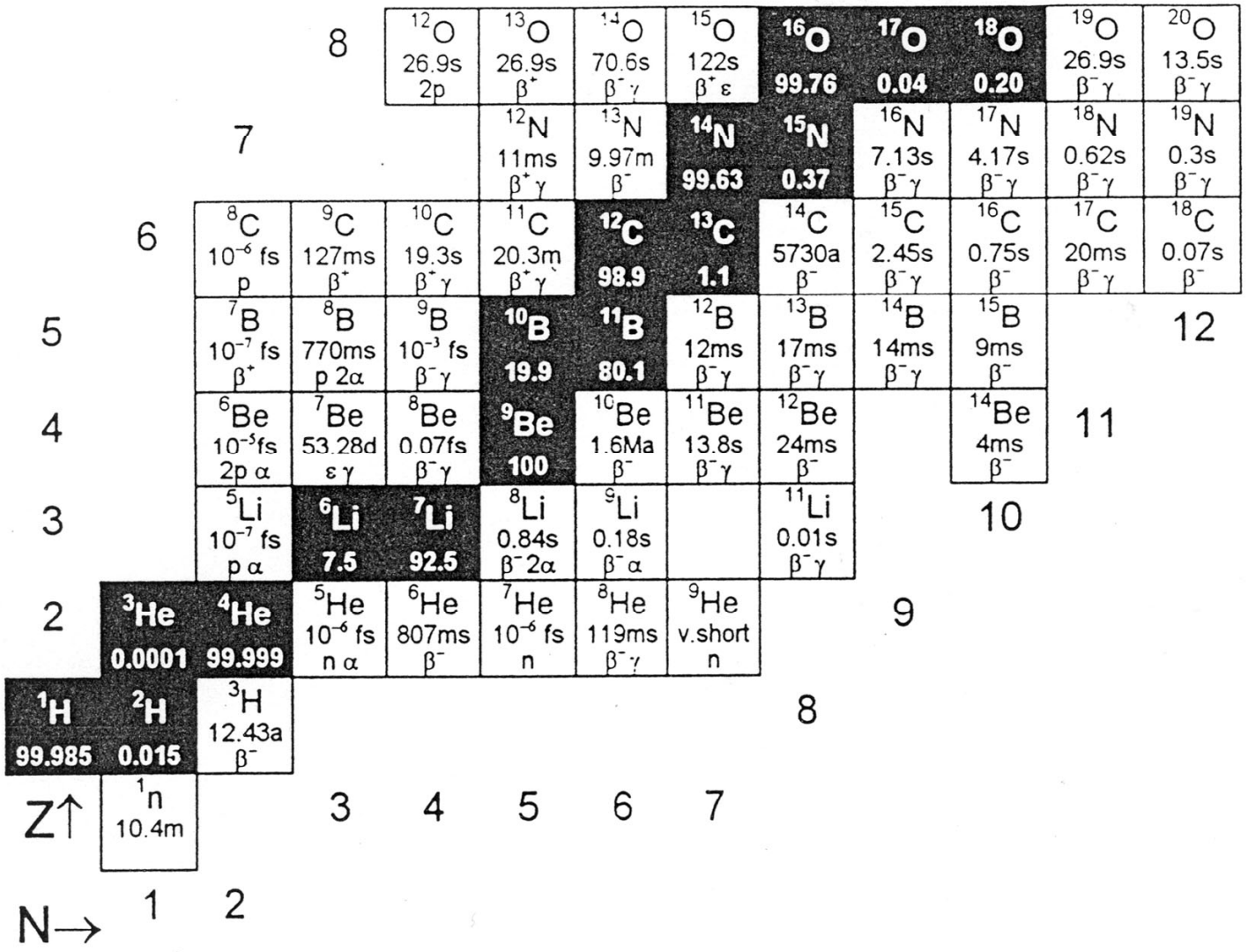
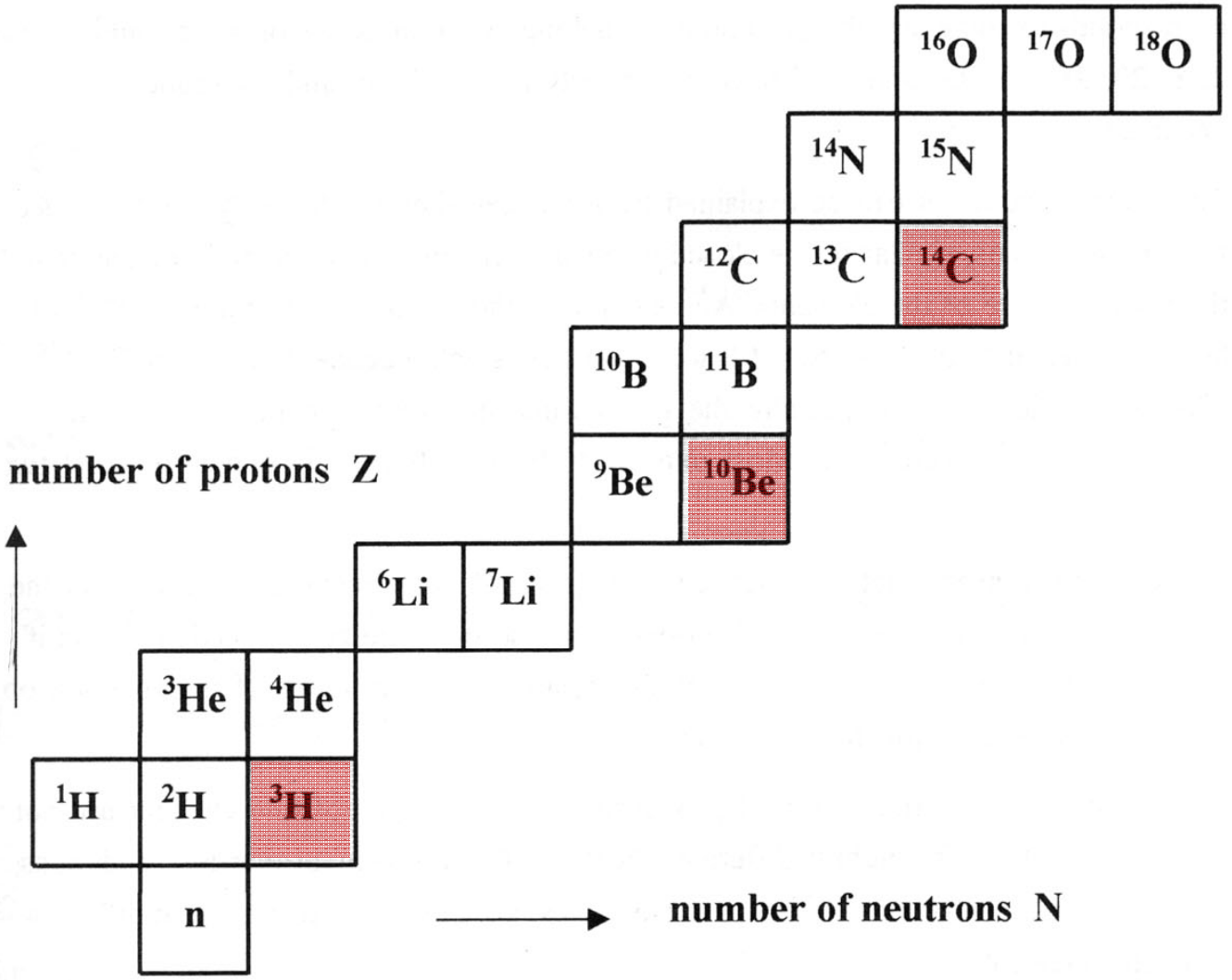
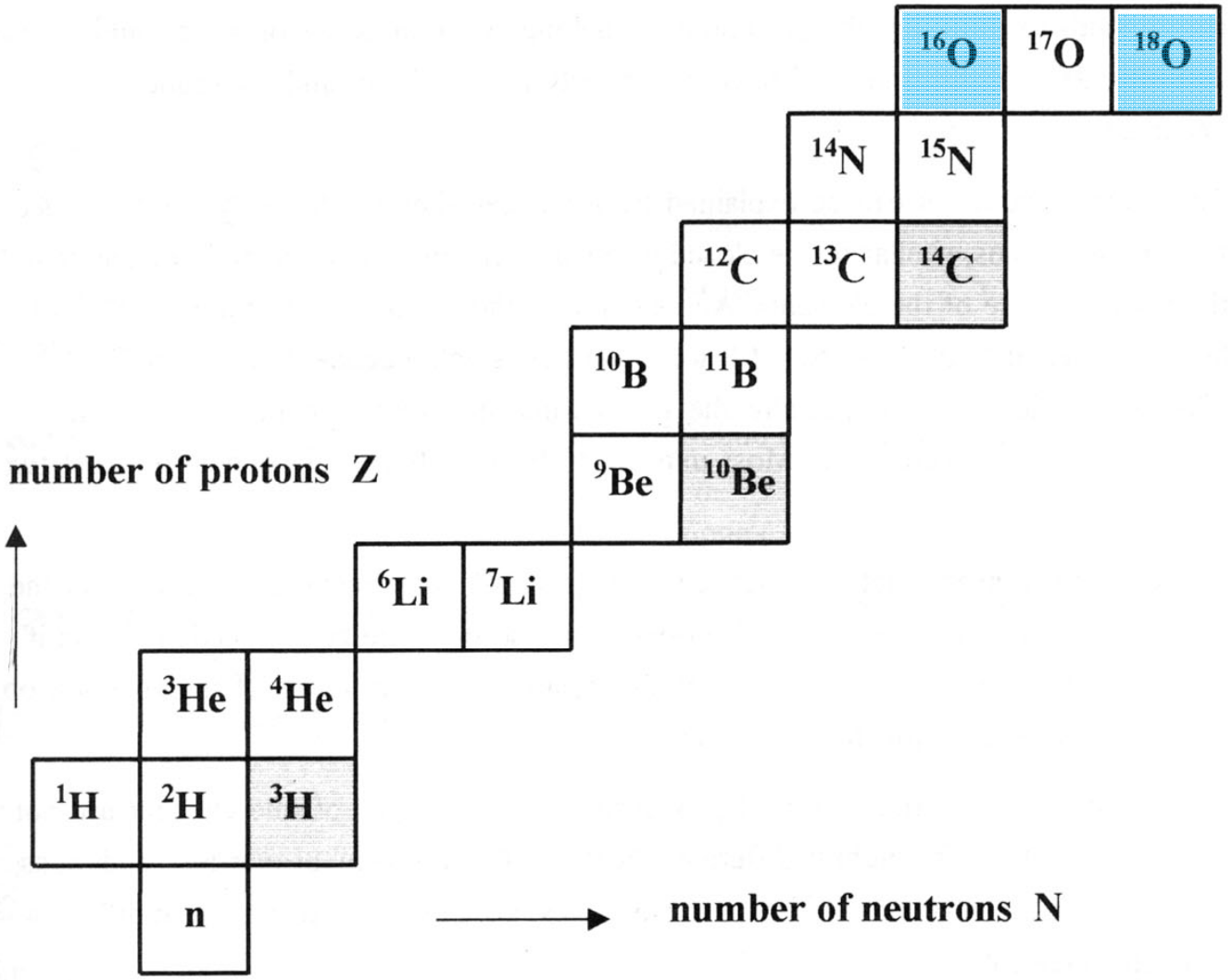
Isotopentabelle: Z (Protonen) und N (Neutronen)



Stabile (weiß) und radioaktive (rot) leichte Isotope



Stabile Isotope des Wassers



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R - Isotopenverhältnis

$$R = \frac{^{18}O}{^{16}O} \quad bzw. \quad \frac{^{2}H}{^{1}H}$$

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Das Isotopenverhältnis

A substance containing the less abundant isotope species N_i and the more abundant isotope N has an isotopic abundance ratio R that is defined by:

$$R = \frac{N_i}{N}$$

For natural oxygen and hydrogen compounds N is much larger than N_i. The isotope species can also be expressed in terms of mole fractions $m = N/(N + N_i)$ and $m_i = N_i/(N + N_i)$. The standard mean ocean water (short SMOW) that has been defined by the International Atomic Energy Agency (IAEA) in Vienna as a common standard for expressing isotope ratios (the so-called Vienna SMOW or V-SMOW) has isotopic abundance ratios of (Baertschi, 1976; Hageman *et al.*, 1970):

$$R_{^{18}O/^{16}O} = \left(\frac{^{18}O}{^{16}O}\right)_{VSMOW} = 2005.2 \pm 0.45^{*}10^{-6}$$

$$R_{D/H} = \left(\frac{^{2}H}{^{1}H}\right)_{VSMOW} = 155.76 \pm 0.05^{*}10^{-6}$$

Leibundgut, Maloszewski & Külls

Die delta-Notation

δ - delta

$$\delta_{\text{Probe}} = \left(\frac{R_{Probe} - R_{Standard}}{R_{Standard}} \right) \cdot 1000 \quad [‰]$$

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Der natürliche Schwankungsbereich

In general, the isotopic abundance ratio of a sample R_{sample} is given with respect to the internationally accepted standard V-SMOW with the isotopic abundance ratio $R_{standard}$.

$$\delta = \frac{R_{sample} - R_{standard}}{R_{standard}}$$

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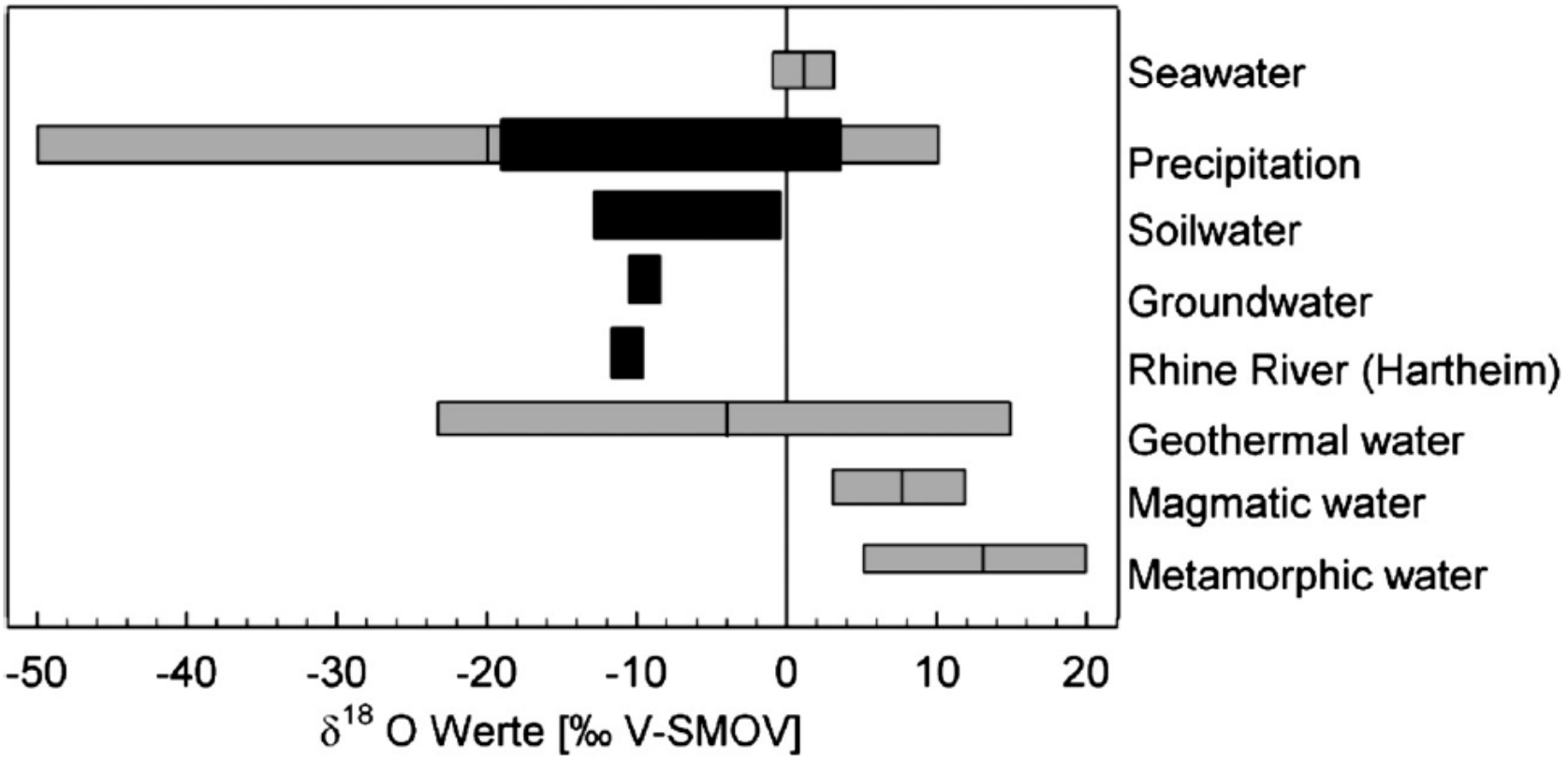
Der natürliche Schwankungsbereich



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α - Fraktionierungsfaktor

$$\alpha = \frac{R_x}{R_y}$$

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Die Anreicherung (engl. Fractionation)

The isotopic composition changes due to fractionation processes. Fractionation occurs if – as a result of a physical or chemical process – the isotopic abundance ratio changes. Phase changes, evaporation, condensation, freezing, sublimation, melting and some chemical reactions are associated with an isotopic fractionation. In order to describe fractionation, a fractionation factor α is used, that is defined by:

$$\frac{dR}{R} = \left(\frac{dN_i}{dN}\right) \Big/ \left(\frac{N_i}{N}\right) = \alpha$$

According to a model suggested by Urey (1947), equilibrium fractionation arises from the exchange of isotopes between different phases (i.e. water and vapour) or chemical species at equilibrium conditions. For a specific reaction at full equilibrium, the degree of fractionation is then expressed by:

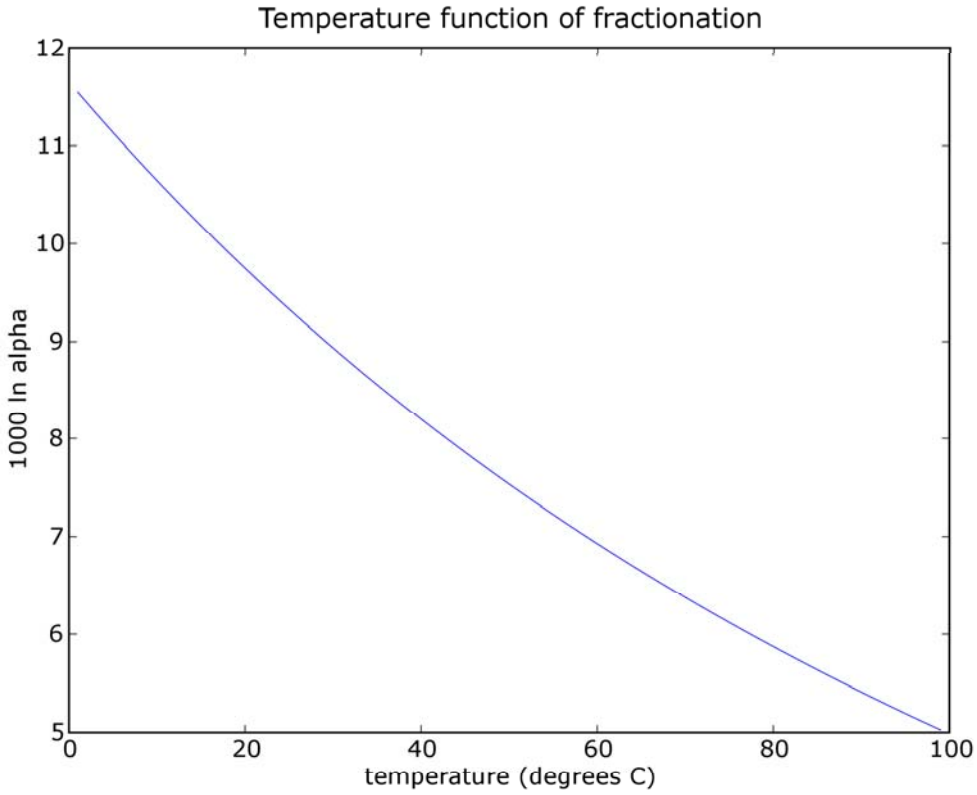
$$\alpha_{A \leftrightarrow B} = \frac{R_A}{R_B}$$

where R_A and R_B represent the isotopic ratios of the two phases A (*water*) and B (*vapour*).

Fraktionierungsfaktor als Funktion der Temperatur

α: Fraktionierungsfaktor errechnet sich aus R_x/R_y

$$10^3 \ln \alpha\ ^{18}O = 1.137\ (10^6/T_K^2) - 0.4156(10^3/T_K) - 2.0667$$



Bei 10° C ist 1000lnα ca. +10.6
Dies entspricht ca. $\delta\ ^{18}O$ 10.6 ‰

° C	1000lna
5.0	11.13
10.0	10.64
15.0	10.18
20.0	9.74
25.0	9.32

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Separation

Δ - separation

$$\Delta_{x\text{-}y} = \delta_x - \delta_y$$

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Anreicherungsfaktor

ε - enrichment factor

$$\varepsilon_{x\text{-}y} = (R_x/R_y\text{-}1)*1000$$

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Alle Definitionen zusammen

$$R = \frac{^{18}O}{^{16}O}$$

$$\delta = \frac{R_{sample} - R_{reference}}{R_{reference}} * 1000‰ = \left[\frac{R_{sample}}{R_{reference}} - 1 \right] * 1000‰$$

$$\Delta_{x-y} = \delta_x - \delta_y$$

$$\alpha_{x-y} = \frac{R_x}{R_y} = \frac{1 + \frac{\delta_x}{1000}}{1 + \frac{\delta_y}{1000}} = \frac{1000 + \delta_x}{1000 + \delta_y}$$

$$\varepsilon_{x-y} = \left(\frac{R_x}{R_y} - 1 \right) * 1000 = (\alpha_{x-y} - 1) * 1000$$

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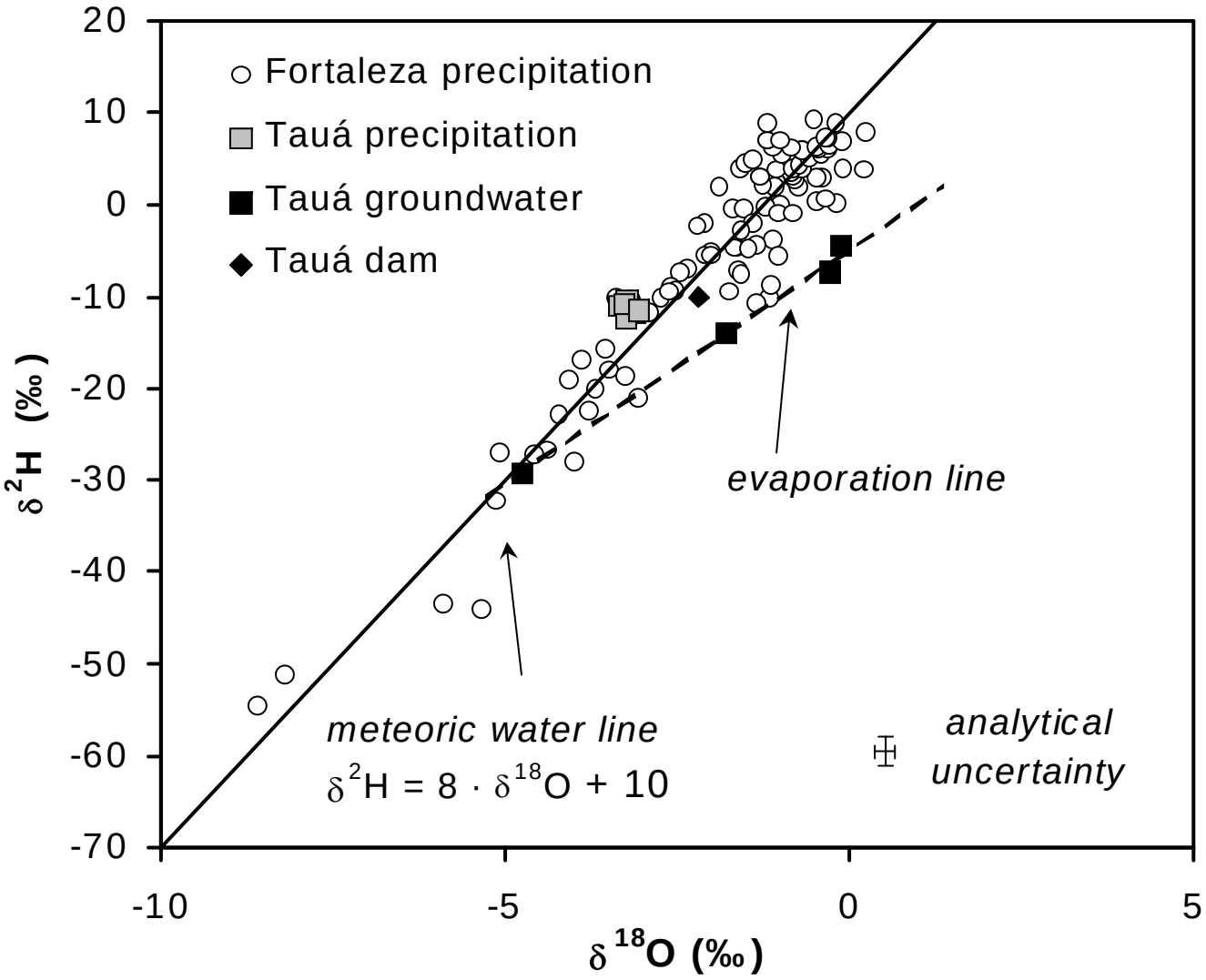
Die Mutter aller Graphiken für Wasserisotope



Globale und regionale ‚Meteoric Water Line‘