Package 'isogeochem'

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Type Package

Title Tools For Carbonate Isotope Geochemistry

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Description This toolbox makes working with carbonate oxygen and clumped isotope data reproducible and straightforward.

License GPL (>= 3)

URL https://github.com/davidbajnai/isogeochem

Encoding UTF-8

LazyData true

Roxygen list(markdown = TRUE)

RoxygenNote 7.1.2

Suggests shades,
knitr,
rmarkdown,
devtools,
spelling,
testthat (>= 3.0.0),
covr

VignetteBuilder knitr

Imports stats,
graphics,
grDevices

Depends R (>= 2.10)

BugReports https://github.com/davidbajnai/isogeochem/issues

Language en-US

Config/testthat/edition 3

R topics documented:

`a18_CO2acid_c` *18O/16O acid fractionation factor*

Description

`a18_CO2acid_c()` calculates the 18O/16O fractionation factor between CO2 produced from acid digestion and carbonate.

Usage

```
a18_CO2acid_c(temp, min)
```

Arguments

`temp`	Acid digestion temperature (°C).
`min`	Mineralogy. Options are `"calcite"` and `"aragonite"`.

Details

calcite (Kim et al. 2015):

$$\alpha^{18}_{CO2acid/calcite} = e^{(3.48\times\frac{1}{T}-0.00147)}$$

aragonite (Kim et al. 2007):

$$\alpha^{18}_{CO2acid/aragonite} = e^{(3.39\times\frac{1}{T}-0.00083)}$$

Value

Returns the 18O/16O fractionation factor.

References

Sharma, T., and Clayton, R. N. (1965). Measurement of ratios of total oxygen of carbonates. Geochimica et Cosmochimica Acta, 29(12), 1347-1353. https://doi.org/10.1016/0016-7037(65)90011-6

Kim, S.-T., Mucci, A., and Taylor, B. E. (2007). Phosphoric acid fractionation factors for calcite and aragonite between 25 and 75 °C: Revisited. Chemical Geology, 246(3-4), 135-146. https://doi.org/10.1016/j.chemgeo.2007.08.005

Kim, S.-T., Coplen, T. B., and Horita, J. (2015). Normalization of stable isotope data for carbonate minerals: Implementation of IUPAC guidelines. Geochimica et Cosmochimica Acta, 158, 276-289. https://doi.org/10.1016/j.gca.2015.02.011

See Also

Other fractionation_factors: `a18_H2O_OH()`, `a18_c_H2O()`, `a_A_B()`

Examples

```
a18_CO2acid_c(temp = 90, min = "calcite")
a18_CO2acid_c(temp = 72, min = "aragonite")
```

`a18_c_H2O` *18O/16O fractionation factor between carbonate and water*

Description

`a18_c_H2O()` calculates the 18O/16O fractionation factor between carbonate and water.

Usage

```
a18_c_H2O(temp, min, eq)
```

Arguments

`temp`	Carbonate growth temperature (°C).
`min`	Mineralogy. Options are `"calcite"`, `"aragonite"`, and `"dolomite"`.
`eq`	Equation used for the calculations. See details.

Details

Options for eq if min = `"calcite"`:

`"FO77"`: O'Neil et al. (1969), modified by Friedman and O'Neil (1977):

$$\alpha^{18}_{calcite/water} = e^{(2.78 \times \frac{1000}{T^2} - 0.00289)}$$

`"KO97-orig"`: Kim and O'Neil (1997):

$$\alpha^{18}_{calcite/water} = e^{(18.03 \times \frac{1}{T} - 0.03242)}$$

`"KO97"`: Kim and O'Neil (1997) - reprocessed to match the IUPAC-recommended acid fractionation factor (see Kim et al. 2007, 2015; and the Vignettes):

$$\alpha^{18}_{calcite/water} = e^{(18.04 \times \frac{1}{T} - 0.03218)}$$

`"Coplen07"`: Coplen (2007):

$$\alpha^{18}_{calcite/water} = e^{(17.4 \times \frac{1}{T} - 0.0286)}$$

`"Tremaine11"`: Tremaine et al. (2011):

$$\alpha^{18}_{calcite/water} = e^{(16.1 \times \frac{1}{T} - 0.0246)}$$

`"Watkins13"`: Watkins et al. (2013):

$$\alpha^{18}_{calcite/water} = e^{(17.747 \times \frac{1}{T} - 0.029777)}$$

`"Daeron19"`: Daëron et al. (2019):

$$\alpha^{18}_{calcite/water} = e^{(17.57 \times \frac{1}{T} - 0.02913)}$$

Options for eq if min = `"aragonite"`:

`"GK86"`: Grossman and Ku (1986) modified by Dettman et al. (1999):

$$\alpha^{18}_{aragonite/water} = e^{(2.559 \times \frac{1000}{T^2} + 0.000715)}$$

Options for eq if min = `"dolomite"`:

`"Vasconcelos05"`: Vasconcelos et al. (2005):

$$\alpha^{18}_{dolomite/water} = e^{(2.73 \times \frac{1000}{T^2} + 0.00026)}$$

Value

Returns the 18O/16O fractionation factor.

References

O'Neil, J. R., Clayton, R. N., & Mayeda, T. K. (1969). Oxygen isotope fractionation in divalent metal carbonates. The Journal of Chemical Physics, 51(12), 5547-5558. https://doi.org/10.1063/1.1671982

Grossman, E. L., & Ku, T. L. (1986). Oxygen and carbon isotope fractionation in biogenic aragonite: Temperature effects. Chemical Geology, 59(1), 59-74. https://doi.org/10.1016/0009-2541(86)90044-6

Kim, S.-T., & O'Neil, J. R. (1997). Equilibrium and nonequilibrium oxygen isotope effects in synthetic carbonates. Geochimica et Cosmochimica Acta, 61(16), 3461-3475. https://doi.org/10.1016/S0016-7037(97)00169-5

Dettman, D. L., Reische, A. K., & Lohmann, K. C. (1999). Controls on the stable isotope composition of seasonal growth bands in aragonitic fresh-water bivalves (unionidae). Geochimica et Cosmochimica Acta, 63(7-8), 1049-1057. https://doi.org/10.1016/s0016-7037(99)00020-4

Vasconcelos, C., McKenzie, J. A., Warthmann, R., & Bernasconi, S. M. (2005). Calibration of the d18O paleothermometer for dolomite precipitated in microbial cultures and natural environments. Geology, 33(4), 317-320. https://doi.org/10.1130/g20992.1

Kim, S.-T., Mucci, A., & Taylor, B. E. (2007). Phosphoric acid fractionation factors for calcite and aragonite between 25 and 75 °C: Revisited. Chemical Geology, 246(3-4), 135-146. https://doi.org/10.1016/j.chemgeo.2007.08.005

Coplen, T. B. (2007). Calibration of the calcite–water oxygen-isotope geothermometer at Devils Hole, Nevada, a natural laboratory. Geochimica et Cosmochimica Acta, 71(16), 3948-3957. https://doi.org/10.1016/j.gca.2007.05.028

Tremaine, D. M., Froelich, P. N., & Wang, Y. (2011). Speleothem calcite farmed in situ: Modern calibration of d18O and d13C paleoclimate proxies in a continuously-monitored natural cave system. Geochimica et Cosmochimica Acta, 75(17), 4929-4950. https://doi.org/10.1016/j.gca.2011.06.005

Watkins, J. M., Nielsen, L. C., Ryerson, F. J., & DePaolo, D. J. (2013). The influence of kinetics on the oxygen isotope composition of calcium carbonate. Earth and Planetary Science Letters, 375, 349-360. https://doi.org/10.1016/j.epsl.2013.05.054

Daëron, M., Drysdale, R. N., Peral, M., Huyghe, D., Blamart, D., Coplen, T. B., et al. (2019). Most Earth-surface calcites precipitate out of isotopic equilibrium. Nature Communications, 10, 429. https://doi.org/10.1038/s41467-019-08336-5

See Also

Other fractionation_factors: `a18_CO2acid_c()`, `a18_H2O_OH()`, `a_A_B()`

Examples

```
a18_c_H2O(temp = 25, min = "calcite", eq = "Coplen07")
a18_c_H2O(temp = 25, min = "aragonite", "GK86")
```

`a18_H2O_OH` *18O/16O fractionation factor between water and hydroxide ion*

Description

`a18_H2O_OH()` calculates the 18O/16O fractionation factor between water and aqueous hydroxide ion.

Usage

```
a18_H2O_OH(temp, eq)
```

Arguments

`temp`	Temperature (°C).
`eq`	Equation used for the calculations. • `Z20-X3LYP`: the theoretical X3LYP/6-311+G(d,p) equation of Zeebe (2020). • `Z20-MP2`: the theoretical MP2/aug-cc-pVDZ equation of Zeebe (2020).

Value

Returns the 18O/16O fractionation factor.

References

Zeebe, R. E. (2020). Oxygen isotope fractionation between water and the aqueous hydroxide ion. Geochimica et Cosmochimica Acta, 289, 182-195. https://doi.org/10.1016/j.gca.2020.08.025

See Also

Other fractionation_factors: a18_CO2acid_c(), a18_c_H2O(), a_A_B()

Examples

```
a18_H2O_OH(temp = 90, eq = "Z20-X3LYP")
```

---

a_A_B *Isotope fractionation factor between A and B*

Description

a_A_B() calculates the isotope fractionation factor.

Usage

```
a_A_B(A, B)
```

Arguments

A	Isotope delta value of A (‰).
B	Isotope delta value of B (‰).

Details

$$\alpha^i E_{A/B} = \frac{\delta^i E_A + 1000}{\delta^i E_B + 1000}$$

Value

Returns the isotope fractionation factor.

See Also

A_from_a() calculates the isotope delta value of A. B_from_a() calculates the isotope delta value of B.

Other fractionation_factors: a18_CO2acid_c(), a18_H2O_OH(), a18_c_H2O()

Examples

```
a_A_B(A = 10, B = 12)
```

A_from_a *Isotope delta from fractionation factor*

Description

A_from_a() calculates the isotope delta value of A from the isotope fractionation factor and the isotope delta value of B.

Usage

```
A_from_a(a, B)
```

Arguments

a	Isotope fractionation factor between A and B.
B	Isotope delta value of B (‰).

Value

Returns the isotope delta value of B (‰).

See Also

a_A_B() calculates the isotope fractionation factor between A and B. B_from_a() calculates the isotope delta value of B.

Examples

```
A_from_a(a = 1.033, B = -10)
```

B_from_a *Isotope delta from fractionation factor*

Description

B_from_a() calculates the isotope delta value of B from the isotope fractionation factor and the isotope delta value of A.

Usage

```
B_from_a(a, A)
```

Arguments

a	Isotope fractionation factor between A and B.
A	Isotope delta value of A (‰).

Value

Returns the Isotope delta value of B (‰).

See Also

a_A_B() calculates the isotope fractionation factor between A and B. A_from_a() calculates the isotope delta value of A.

Examples

```
B_from_a(a = 1.033, A = 10)
```

---

d17O_c *Triple oxygen isotope values*

Description

d17O_c() calculates the equilibrium d18O, d17O, and D17O values of a calcite grown at a given temperature.

Usage

```
d17O_c(temp, d18O_H2O_VSMOW, eq18 = "Daeron19", lambda = 0.528)
```

Arguments

temp	Calcite growth temperature (°C).
d18O_H2O_VSMOW	Water d18O value expressed on the VSMOW scale (‰).
eq18	Equation used to calculate the 18O/16O fractionation factor between calcite and water. Options are like those for calcite in a18_c_H2O() with "Daeron19" being here the default.
lambda	Triple oxygen isotope reference slope. Default 0.528.

Details

$$\theta_{A/B} = \frac{\alpha^{17}_{A/B}}{\alpha^{18}_{A/B}}$$

$$\delta'^{17}O_{H2O,VSMOW} = \beta \times \delta'^{18}O_{H2O,VSMOW} + \gamma \text{ , where } \beta = 0.528 \text{ and } \gamma = 0$$

$$\Delta^{17}O_{CaCO3,VSMOW} = \delta'^{17}O_{CaCO3,VSMOW} - \lambda \times \delta'^{18}O_{CaCO3,VSMOW}$$

Value

Returns a data frame:

1. d18O value of the carbonate expressed on the VSMOW scale (‰).
2. d18O value of the carbonate expressed on the VSMOW scale (‰).
3. D17O value of the carbonate expressed on the VSMOW scale (‰).

References

Guo, W., & Zhou, C. (2019). Triple oxygen isotope fractionation in the DIC-H2O-CO2 system: A numerical framework and its implications. Geochimica et Cosmochimica Acta, 246, 541-564. https://www.doi.org/10.1016/j.gca.2018.11.018

See Also

Other equilibrium_carbonate: D47(), D48(), d18O_c()

Examples

```
d17O_c(temp = 10, d18O_H2O_VSMOW = -1) # Returns the data frame (length = 3)
prime(d17O_c(temp = 10, d18O_H2O_VSMOW = -1)[, 2]) # Returns the d'17O value
d17O_c(temp = 10, d18O_H2O_VSMOW = -1)[, 3] # Returns the D17O value
```

---

d18O_c *Equilibrium carbonate d18O value*

Description

d18O_c() calculates the equilibrium d18O value of a carbonate grown at a given temperature.

Usage

```
d18O_c(temp, d18O_H2O_VSMOW, min, eq)
```

Arguments

temp	Carbonate growth temperature (°C).
d18O_H2O_VSMOW	Water d18O value expressed on the VSMOW scale (‰).
min	Mineralogy. Options are "calcite", "aragonite", and "dolomite".
eq	Equation used for the calculations. Options depend on mineralogy and are listed in a18_c_H2O().

Value

Returns the equilibrium carbonate d18O value expressed on the VSMOW scale (‰).

Note

Use to_VSMOW() and to_VPDB() to convert between the VSMOW and VPDB scales.

References

References are listed in the description of a18_c_H2O().

See Also

d18O_H2O() calculates the d18O value of the ambient water from the d18O value of a carbonate and its growth temperature.

Other equilibrium_carbonate: D47(), D48(), d17O_c()

Examples

```
d18O_c(33.7, -13.54, min = "calcite", eq = "Coplen07")
to_VPDB(d18O_c(temp = 12, d18O_H2O_VSMOW = -6.94,
               min = "aragonite", eq = "GK86"))
```

---

d18O_H2O *Water d18O value*

Description

d18O_H2O() calculates the d18O value of the ambient water from the d18O value of a carbonate and its growth temperature.

Usage

```
d18O_H2O(temp, d18O_c_VSMOW, min, eq)
```

Arguments

temp	Carbonate growth temperature (°C).
d18O_c_VSMOW	Carbonate d18O value expressed on the VSMOW scale (‰).
min	Mineralogy. Options are "calcite", "aragonite", and "dolomite".
eq	Equation used to calculate the equilibrium 18O/16O oxygen isotope fractionation factor between carbonate and water. Options depend on mineralogy and listed in a18_c_H2O().

Value

Returns the water d18O value expressed on the VSMOW scale (‰).

Note

Use to_VSMOW() and to_VPDB() to convert between the VSMOW and VPDB scales.

References

References are listed in the description of a18_c_H2O().

See Also

d18O_c() calculates the equilibrium d18O value of a carbonate grown at a given temperature. temp_d18O() calculates growth temperatures from oxygen isotope data.

Examples

```
d18O_H2O(temp = 33.7, d18O_c_VSMOW = 14.58,
         min = "calcite", eq = "Coplen07")
d18O_H2O(temp = 25, d18O_c_VSMOW = to_VSMOW(-7.47),
         min = "aragonite", eq = "GK86")
```

D47 *Equilibrium carbonate D47 value*

Description

`D47()` calculates the equilibrium carbonate D47 value for a given temperature.

Usage

```
D47(temp, eq)
```

Arguments

`temp`	Carbonate growth temperature (°C).
`eq`	Equation used for the calculation. • `"Petersen19"`: the synthetic-only composite IUPAC-parameter calibration of Petersen et al. (2019). • `"Fiebig21"`: the CDES90 calibration of Fiebig et al. (2021).

Details

"Petersen19":

$$\Delta_{47,CDES90} = 0.0383 \times \frac{10^6}{T^2} + 0.170$$

"Fiebig21":

$$\Delta_{47,CDES90} = 1.038 \times (-5.897 \times \frac{1}{T} - 3.521 \times \frac{10^3}{T^2} + 2.391 \times \frac{10^7}{T^3} - 3.541 \times \frac{10^9}{T^4}) + 0.1856$$

Value

Returns the carbonate D47 value expressed on the CDES90 scale (‰).

References

Petersen, S. V., Defliese, W. F., Saenger, C., Daëron, M., Huntington, K. W., John, C. M., et al. (2019). Effects of improved 17O correction on interlaboratory agreement in clumped isotope calibrations, estimates of mineral-specific offsets, and temperature dependence of acid digestion fractionation. Geochemistry, Geophysics, Geosystems, 20(7), 3495-3519. https://www.doi.org/10.1029/2018GC008127

Fiebig, J., Daëron, M., Bernecker, M., Guo, W., Schneider, G., Boch, R., et al. (2021). Calibration of the dual clumped isotope thermometer for carbonates. Geochimica et Cosmochimica Acta. https://www.doi.org/10.1016/j.gca.2021.07.012

See Also

`temp_D47()` calculates growth temperature from a D47 value.

Other equilibrium_carbonate: `D48()`, `d17O_c()`, `d18O_c()`

Examples

```
D47(temp = 33.7, eq = "Petersen19") # Returns 0.577
D47(temp = 33.7, eq = "Fiebig21") # Returns 0.571
```

D48 *Equilibrium carbonate D47 value*

Description

`D48()` calculates the equilibrium carbonate D48 value for a given temperature.

Usage

```
D48(temp, eq)
```

Arguments

`temp`	Carbonate growth temperature (°C).
`eq`	Equation used for the calculation. • `"Fiebig21"`: the CDES90 calibration of Fiebig et al. (2021). • `"Swart21"`: the CDES90 "PBLM1" calibration in Swart et al. (2021).

Details

"Fiebig21":

$$\Delta_{48,CDES90} = 1.028 \times (6.002 \times \frac{1}{T} - 1.299 \times \frac{10^4}{T^2} + 8.996 \times \frac{10^6}{T^3} - 7.423 \times \frac{10^8}{T^4}) + 0.1245$$

"Swart21":

$$\Delta_{48,CDES90} = 0.0142 \times \frac{10^6}{T^2} + 0.088$$

Value

Returns the carbonate equilibrium D48 value expressed on the CDES90 scale (‰).

References

Bajnai, D., Guo, W., Spötl, C., Coplen, T. B., Methner, K., Löffler, N., et al. (2020). Dual clumped isotope thermometry resolves kinetic biases in carbonate formation temperatures. Nature Communications, 11, 4005. https://doi.org/10.1038/s41467-020-17501-0

Fiebig, J., Daëron, M., Bernecker, M., Guo, W., Schneider, G., Boch, R., et al. (2021). Calibration of the dual clumped isotope thermometer for carbonates. Geochimica et Cosmochimica Acta. https://www.doi.org/10.1016/j.gca.2021.07.012

Swart, P. K., Lu, C., Moore, E., Smith, M., Murray, S. T., & Staudigel, P. T. (2021). A calibration equation between D48 values of carbonate and temperature. Rapid Communications in Mass Spectrometry, 35(17), e9147. https://www.doi.org/10.1002/rcm.9147

See Also

Other equilibrium_carbonate: D47(), d17O_c(), d18O_c()

Examples

```
D48(temp = 33.7, eq = "Fiebig21") # Returns 0.237
D48(temp = 33.7, eq = "Swart21") # Returns 0.239
```

---

devilshole *Devils Hole carbonate d18O time series*

Description

A dataset containing the d18O values of the "original" Devils Hole cores.

Usage

```
devilshole
```

Format

A data frame with 442 rows and 4 variables:

age Interpolated uranium-series age of the sample expressed as thousands of years before present (ka).

d18O_VSMOW Carbonate d18O value expressed on the VSMOW scale (‰).

d18O_error Standard deviation on the d18O value.

core Name of the core (DHC2-8, DHC2-3, DH-11).

Source

https://doi.org/10.3133/ofr20111082

References

Winograd, I. J., Landwehr, J. M., Coplen, T. B., Sharp, W. D., Riggs, A. C., Ludwig, K. R., & Kolesar, P. T. (2006). Devils Hole, Nevada, d18O record extended to the mid-Holocene. Quaternary Research, 66(2), 202-212. https://doi.org/10.1016/j.yqres.2006.06.003

See Also

Other "datasets": GTS2020, LR04

GTS2020 *Oxygen isotope stratigraphy from the Geologic Time Scale 2020: macrofossils*

Description

A dataset containing a compilation of d18O and d13C values of various macrofossils (bivalves, gastropods, belemnites, ammonites) together with information on their age, shell mineralogy, and the climate zone they represent. This dataset is a condensed version of the entire dataset presented in the Geologic Time Scale 2020. Specifically, the full dataset was filtered for those "select" d18O and d13C values that also have age information.

Usage

```
GTS2020
```

Format

A data frame with 9676 rows and 8 variables:

age Age of the sample expressed as millions of years before present (Ma).

d18O_VPDB Carbonate d18O value expressed on the VPDB scale (‰).

d13C_VPDB Carbonate d13C value expressed on the VPDB scale (‰).

mineralogy The mineralogy of the carbonate hard part.

group Taxonomic group of the sample (bivalve, gastropod, belemnite, ammonite).

clim_zone The climate zone the sample represents.

Source

https://download.pangaea.de/dataset/930093/files/GTS2020-App_10.2A.xlsx

References

Grossman, E. L., & Joachimski, M. M. (2020). Oxygen isotope stratigraphy. In F. M. Gradstein, J. G. Ogg, M. D. Schmitz, & G. M. Ogg (Eds.), Geologic Time Scale 2020: Volume 1 (pp. 279-307): Elsevier. https://doi.org/10.1016/B978-0-12-824360-2.00010-3

See Also

Other "datasets": LR04, devilshole

LR04 *A Pliocene-Pleistocene benthic foraminifera d18O stack*

Description

A dataset containing the LR04 benthic d18O stack.

Usage

```
LR04
```

Format

A data frame with 2115 rows and 3 variables:

age Age of the sample expressed as thousands of years before present (ka).

d18O_VPDB Carbonate d18O value expressed on the VPDB scale (‰).

d18O_error Standard error on the d18O value.

Source

https://lorraine-lisiecki.com/stack.html

References

Lisiecki, L. E., & Raymo, M. E. (2005). A Pliocene-Pleistocene stack of 57 globally distributed benthic d18O records. Paleoceanography, 20(1), PA1003. https://doi.org/10.1029/2004pa001071

See Also

Other "datasets": GTS2020, devilshole

mix_d17O *Mixing curves in triple oxygen isotope space*

Description

`mix_d17O()` produces mixing curves between two endmembers (A and B) in triple oxygen isotope space (d18O vs. D17O).

Usage

```
mix_d17O(d18O_A, d17O_A, d18O_B, d17O_B, lambda = 0.528)
```

Arguments

d18O_A	d18O value of component A (‰).
d17O_A	d17O value of component A (‰).
d18O_B	d18O value of component B (‰).
d17O_B	d17O value of component B (‰).
lambda	Triple oxygen isotope reference slope. Default `0.528`.

Value

Returns a data frame:

1. d18O value of the mixture at x% mixing (‰).
2. d18O value of the mixture x% mixing (‰).
3. relative amount of component B in the mixture (%): from 100% A and 0% B to 0% A and 100% B.

See Also

`d17O_c()` calculates equilibrium calcite d18O, d17O, and D17O values for a given temperature.

Examples

```
mix_d17O(d18O_A = d17O_c(10, -1)[1], d17O_A = d17O_c(10, -1)[2],
         d18O_B = d17O_c(100,0)[1], d17O_B = d17O_c(100, 0)[2])
```

`prime` *Converting delta to delta prime*

Description

`prime()` converts "classical delta" values to "delta prime" values.

Usage

```
prime(classical)
```

Arguments

`classical`	"Classical delta" values to be converted (‰).

Details

$$\delta'^{17}O = 1000 \times \ln(\frac{\delta^{17}O}{1000} + 1)$$

Value

Returns the "delta prime" value (‰).

See Also

`unprime()` converts "delta prime" values to "classical delta" values.

Examples

```
prime(10) # Return 9.950331
```

temp_d18O *Oxygen isotope thermometry*

Description

temp_d18O() calculates carbonate growth temperature from oxygen isotope data.

Usage

```
temp_d18O(d18O_c_VSMOW, d18O_H2O_VSMOW, min, eq)
```

Arguments

d18O_c_VSMOW	Carbonate d18O value expressed on the VSMOW scale (‰).
d18O_H2O_VSMOW	Water d18O value expressed on the VSMOW scale (‰).
min	Mineralogy. Options are "calcite", "aragonite", and "dolomite".
eq	Equation used to calculate the equilibrium 18O/16O oxygen isotope fractionation factor between carbonate and water. Options depend on mineralogy and listed in a18_c_H2O().

Value

Returns the carbonate growth temperature (°C).

Note

Use to_VSMOW() and to_VPDB() to convert between the VSMOW and VPDB scales.

References

References are listed in the description of a18_c_H2O().

See Also

d18O_c() calculates the equilibrium d18O value of a carbonate grown at a given temperature.

d18O_H2O() calculates the d18O value of the ambient water from the d18O value of a carbonate and its growth temperature.

Other thermometry: temp_D47(), temp_D48()

Examples

```
temp_d18O(d18O_c_VSMOW = 14.58, d18O_H2O_VSMOW = -13.54,
          min = "calcite", eq = "Coplen07")
```

`temp_D47` *Clumped isotope thermometry*

Description

`temp_D47()` calculates carbonate growth temperature from D47 value.

Usage

```
temp_D47(D47_CDES90, D47_error, eq)
```

Arguments

`D47_CDES90`	Carbonate D47 values expressed on the CDES90 scale (‰).
`D47_error`	Error on the D47 value. Optional.
`eq`	Equation used for the calculation.

- `"Petersen19"`: the synthetic-only composite IUPAC-parameter calibration of Petersen et al. (2019).
- `"Fiebig21"`: the CDES90 calibration of Fiebig et al. (2021), linearized between 8–80 °C.

Details

"Petersen19":

$$\Delta_{47,CDES90} = 0.0383 \times \frac{10^6}{T^2} + 0.170$$

"Fiebig21":

$$\Delta_{47,CDES90} = 0.0391 \times \frac{10^6}{T^2} + 0.1547$$

Value

Returns the carbonate growth temperature (°C), and — if `D47_error` is specified — also the error.

References

References are listed at `D47()`.

See Also

`D47()` calculates the equilibrium carbonate D47 value.

Other thermometry: `temp_D48()`, `temp_d18O()`

Examples

```
temp_D47(D47_CDES90 = 0.577, eq = "Petersen19")
```

temp_D48 *Dual clumped isotope thermometry*

Description

`temp_D48()` calculates carbonate growth temperature from D47 and D48 values.

Usage

```
temp_D48(
  D47_CDES90,
  D48_CDES90,
  D47_error,
  D48_error,
  ks,
  add = FALSE,
  col,
  pch
)
```

Arguments

`D47_CDES90`	Carbonate D47 values expressed on the CDES90 scale (‰).
`D48_CDES90`	Carbonate D48 values expressed on the CDES90 scale (‰).
`D47_error`	Error on the D47 value. Optional.
`D48_error`	Error on the D48 value. Optional.
`ks`	Kinetic slope. Has to be negative!
`add`	Add graphics to an already existing plot? Default: `FALSE`.
`col`	Graphical parameter. Optional.
`pch`	Graphical parameter. Optional.

Details

The function calculates a D47 value as an intersect of two curves: the equilibrium D47 vs D48 curve from Fiebig et al. (2021) and the kinetic slope. The resulting D47 value is then converted to temperature using the `temp_D47()` function and the linearized equation of Fiebig et al. (2021). Specifically, the 4th order polynomial D47_CDES90 vs temperature relationship was linearized between 8–80 °C. The discrepancy between the polynomial and the linearized equation is less than 1 °C in this range.

Value

Returns the carbonate growth temperature (°C).

Contributors

The source code of this function contains elements from the reconPlots package, available at `https://github.com/andrewheiss/reconPlots`

References

References are listed at D48() and D47().

See Also

D47() calculates the equilibrium carbonate D47 value. D48() calculates the equilibrium carbonate D48 value.

Other thermometry: temp_D47(), temp_d18O()

Examples

```
temp_D48(0.617, 0.139, ks = -0.6)
temp_D48(0.546, 0.277, ks = -1)
```

---

to_VPDB *Converting isotope delta from VSMOW to VPDB*

Description

to_VPDB() convert d18O value expressed on the VSMOW scale to the VPDB scale.

Usage

```
to_VPDB(d18O_VSMOW, eq = "IUPAC")
```

Arguments

d18O_VSMOW	d18O values expressed on the VSMOW scale (‰).
eq	Equation used for the conversion. • "IUPAC" (default): the IUPAC recommended equation listed in Brand et al. (2014) and Kim et al. (2015). • "Coplen83": the equation listed in Coplen et al. (1983) and the Hoefs book.

Details

The IUPAC recommended equation to convert between the scales is:

$$\delta^{18}O_{VPDB} = 0.97001 \times \delta^{18}O_{VSMOW} - 29.99$$

Value

Returns the d18O value expressed on the VPDB scale (‰).

References

References are listed at to_VSMOW().

See Also

`to_VSMOW()` converts d18O values expressed on the VPDB scale to the VSMOW scale.

Examples

```
to_VPDB(0)
to_VPDB(0, eq = "Coplen83")
```

`to_VSMOW` *Converting isotope delta from VPDB to VSMOW*

Description

`to_VSMOW()` converts d18O value expressed on the VPDB scale to the VSMOW scale.

Usage

```
to_VSMOW(d18O_VPDB, eq = "IUPAC")
```

Arguments

`d18O_VPDB`	d18O values expressed on the VPDB scale (‰).
`eq`	Equation used for the conversion. • `"IUPAC"` (default): the IUPAC recommended equation listed in Brand et al. (2014) and Kim et al. (2015). • `"Coplen83"`: the equation listed in Coplen et al. (1983) and the Hoefs book.

Details

The IUPAC recommended equation to convert between the scales is:

$$\delta^{18}O_{VSMOW} = 1.03092 \times \delta^{18}O_{VPDB} + 30.92$$

Value

Returns the d18O value expressed on the VSMOW scale (‰).

References

Coplen, T. B., Kendall, C., & Hopple, J. (1983). Comparison of stable isotope reference samples. Nature, 302, 236-238. https://doi.org/10.1038/302236a0

Brand, W. A., Coplen, T. B., Vogl, J., Rosner, M., & Prohaska, T. (2014). Assessment of international reference materials for isotope-ratio analysis (IUPAC Technical Report). Pure and Applied Chemistry, 86(3), 425-467. https://doi.org/10.1515/pac-2013-1023

Kim, S.-T., Coplen, T. B., & Horita, J. (2015). Normalization of stable isotope data for carbonate minerals: Implementation of IUPAC guidelines. Geochimica et Cosmochimica Acta, 158, 276-289. https://doi.org/10.1016/j.gca.2015.02.011

See Also

`to_VPDB()` converts d18O values expressed on the VSMOW scale to the VPDB scale.

Examples

```
to_VSMOW(0)
to_VSMOW(0, eq = "Coplen83")
```

`unprime` *Converting delta prime to delta*

Description

`unprime()` converts "delta prime" values to "classical delta" values.

Usage

```
unprime(prime)
```

Arguments

`prime`	"Delta prime" values to be converted (‰).

Details

$$\delta^{17}O = 1000 \times e^{(\frac{\delta'^{17}O}{1000}+1)}$$

Value

Returns the "classical delta" value (‰).

See Also

`prime()` converts "classical delta" values to "delta prime" values.

Examples

```
unprime(9.950331) # Return 10
```

xDIC *Dissolved inorganic carbon species*

Description

`xDIC()` calculates the relative abundance of the DIC species as a function of solution temperature, pH, and salinity.

Usage

```
xDIC(temp, pH, S)
```

Arguments

`temp`	The temperature of the solution (°C).
`pH`	The pH of the solution.
`S`	The salinity of the solution (g/kg or ‰).

Value

Returns a data frame with the relative abundance of the DIC species:

- Relative abundance of dissolved CO2 (%).
- Relative abundance of bicarbonate ion (%).
- Relative abundance of carbonate ion (%).

Examples

```
xDIC(temp = 25, pH = 7, S = 30)
```

york_fit *Error-considering linear regression*

Description

`york_fit()` calculates the regression parameters of an error-considering linear regression.

Usage

```
york_fit(y, x, x_err, y_err, r = 0)
```

Arguments

`y`	vector of y values. Has to be same the length as x.
`x`	vector of x values.
`x_err`	Error on the x values. Has to be same the length as x.
`y_err`	Error on the y values. Has to be same the length as x.
`r`	Correlation coefficient of x_err and y_err at each data point. Default: `0` (independent errors). Has to be same the length as x. Optional.

Details

Regression fitting method according to York et al. (2004). The algorithm is described in the appendix of Wacker et al. (2014).

Value

A list with regression parameters:

- slope and its standard error
- intercept and its standard error
- weights of the points (normalized to 1)
- residual standard error (sigma)
- R2
- p-value (two-tailed t-test).

Contributors

Julian Tödter

References

York, D., Evensen, N. M., López Martínez, M., & De Basabe Delgado, J. (2004). Unified equations for the slope, intercept, and standard errors of the best straight line. American Journal of Physics, 72(3), 367-375. https://doi.org/10.1119/1.1632486

Wacker, U., Fiebig, J., Tödter, J., Schöne, B. R., Bahr, A., Friedrich, O., et al. (2014). Empirical calibration of the clumped isotope paleothermometer using calcites of various origins. Geochimica et Cosmochimica Acta, 141, 127-144. https://doi.org/10.1016/j.gca.2014.06.004

Examples

```
york_fit(
  x = c(1, 2, 3),
  y = c(1.1, 1.9, 3.2),
  x_err = c(0.1, 0.2, 0.1),
  y_err = c(0.2, 0.1, 0.2))
```

---

york_plot *Regression confidence intervals*

Description

`york_plot()` calculates and optionally plots the confidence intervals of an (error-considering) linear regression.

Usage

```
york_plot(
  x,
  slope,
  slope_se,
  intercept,
  intercept_se,
  cl = 0.95,
  weights = -1,
  add = FALSE,
  col = "black"
)
```

Arguments

x	x values of the data points.
slope	regression slope.
slope_se	Standard error of the slope.
intercept	regression intercept.
intercept_se	Standard error of the intercept.
cl	Confidence level. Default: 0.95.
weights	Weights of the data points. If given, mean & SD of x are computed with the weights. Has to be same the length as x. Optional.
add	Add graphics to an already existing plot? Default: FALSE.
col	Graphical parameter. Optional.

Details

The algorithm is described in the appendix of Wacker et al. (2014).

Value

A list with regression parameters:

- slope and its standard error
- intercept and its standard error
- weights of the points (normalized to 1)
- residual standard error (sigma)
- R2
- p-value (two-tailed t-test).

Contributors

Julian Tödter

References

Wacker, U., Fiebig, J., Tödter, J., Schöne, B. R., Bahr, A., Friedrich, O., et al. (2014). Empirical calibration of the clumped isotope paleothermometer using calcites of various origins. Geochimica et Cosmochimica Acta, 141, 127-144. https://doi.org/10.1016/j.gca.2014.06.004

Examples

```
york_plot(
  x = c(1, 2, 3),
  slope = 1.06,
  slope_se = 1.60,
  intercept = -0.05,
  intercept_se = 0.34,
  cl = 0.98)
```

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