SISALv3: A global speleothem stable isotope and trace element database

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Abstract. Paleoclimate information on multiple climate variables at different spatiotemporal scales is increasingly important to understand environmental and societal responses to climate change. A lack of high-quality reconstructions of past hydroclimate has recently been identified as a critical research gap. Speleothems, with their precise chronologies, widespread distribution, and ability to record changes in local to regional hydroclimate variability, are an ideal source of such information. Here we present a new version of the Speleothem Isotopes Synthesis and AnaLysis database (SISALv3), which has been expanded to include trace element ratios and Sr-isotopes as additional, hydroclimate-sensitive geochemical proxies. The oxygen and carbon isotope data included in previous versions of the database have been substantially expanded. SISALv3, contains speleothem data from 365 sites from across the globe, including 95 Mg/Ca, 85 Sr/Ca, 52 Ba/Ca, 25 U/Ca, 29 P/Ca and 14 Sr-isotope records. The database also has increased spatiotemporal coverage for stable oxygen (892) and carbon (620) isotope records compared to SISALv2 (673 and 430 stable oxygen and carbon records, respectively). Additional meta information has been added to improve machine-readability and filtering of data. Standardized chronologies are included for all new entities together with the originally published chronologies. The SISALv3 database thus constitutes a unique resource of speleothem paleoclimate information that allows regional-to-global paleoclimate analyses based on multiple geochemical

proxies, allowing more robust interpretations of past hydroclimate and comparisons with isotope-enabled climate models and other earth system and hydrological models. The database can be accessed at http://dx.doi.org/10.5287/ora-2nanwp4rk.

1 Introduction

Speleothems, secondary cave carbonate precipitates, are a rich paleoenvironmental archive of geochemical data (Wong and Breecker, 2015). Due to their widespread distribution (Comas-Bru et al., 2020) and their precise chronologies (Henderson, 2006), they can provide paleoclimate data at seasonal (Baldini et al., 2021) to multi-annual resolution spanning millennial and longer time scales (Cheng et al., 2016; Stoll et al., 2022).

The Speleothem Isotopes Synthesis and AnaLysis working group (SISAL WG) is an international effort to synthesize speleothem data under the umbrella of the Past Global Changes (PAGES) project (Comas-Bru et al., 2017; Comas-Bru and Harrison, 2019). The SISAL WG aims to answer critical open questions in paleoclimate science with a focus on regional to global trends and event synchronization. To address these questions, the SISAL WG has been developing standardized and quality checked databases. The first three versions of the database (SISALv1, SISALv1b and SISALv2) provided the paleoclimate community with a growing resource of speleothem geochemical data (Atsawawaranunt et al., 2018; Comas-Bru et al., 2020, 2019), specifically oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotope records, and age-model ensembles, along with an online tool -the SISAL webApp - to increase accessibility to the SISAL database (Hatvani et al., 2024). The SISAL database versions have been exploited (i) to better understand the drivers of speleothem environmental proxies and improve their interpretations (Baker et al., 2019, 2021; Fohlmeister et al., 2020; Treble et al., 2022; Skiba and Fohlmeister, 2023), (ii) to provide a resource on the interpretation of speleothem records at a regional level, identifying key gaps and future work (Kaushal et al., 2018; Lechleitner et al., 2018; Braun et al., 2019a; Burstyn et al., 2019; Deininger et al., 2019; Kern et al., 2019; Oster et al., 2019; Zhang et al., 2019; Lorrey et al., 2020), and (iii) to understand the mechanisms of past climate change including through comparison with isotope-enabled climate models (Comas-Bru et al., 2019; Parker et al., 2021a; Bühler et al., 2022; Parker and Harrison, 2022; Parker et al., 2021b) and other modelling approaches (Skiba et al., 2023).

The new SISALv3 database provides an increased dataset of oxygen and carbon isotope data, interpreted as records of hydroclimate and vegetation dynamics/bioproductivity (Wong and Breecker, 2015), and has been significantly expanded to include data on Sr, Mg, Ba, U, typically tracers for hydrological processes in the karst and cave (Fairchild et al., 2000; Johnson et al., 2006; Fairchild and Treble, 2009; Wassenburg et al., 2016), and P, recognized as tracer for surface bioproductivity (Treble et al., 2003; Borsato et al., 2007; McDonough et al., 2022) (Table 1). Also included are data on Sr-isotopes, as these are an important proxy for hydroclimatic processes and may provide information on local hydrology and soil source, production and/or erosion (e.g., Li et al., 2005; Ünal-İmer et al., 2016; Wortham et al., 2017; Weber et al., 2018; Ward et al., 2019; Utida et al., 2020). Ratios of Sr/Ca, Mg/Ca, Ba/Ca and U/Ca, coupled with $\delta^{13}C$ information, are sensitive to water-rock interactions and residence time (Fairchild et al., 2000; Johnson et al., 2006). An important mechanism that drives variability in these multiple proxies in quantifiable ways is the process of prior calcite/carbonate precipitation (PCP), through which

carbonate precipitated along flow paths in the karst and on the cave roof will lead to altered element concentration in cave drip waters from which the speleothem ultimately precipitates (Fairchild et al., 2000; Day and Henderson, 2013). An increase in PCP usually occurs in times of drought that facilitate increased water-rock residence times and degassing in the karst (Fairchild et al, 2000). The strength of these proxies is that they provide robust climatic and environmental information via a multi-proxy approach that will need to be tailored for different karst and climatic settings (Table 1). The SISAL Working Group is currently working on projects with the new additional proxies to explore and gain more detailed insights. We provide examples of proxy interpretations with linked references, but we must emphasize that this list is not exhaustive, the interpretations are time-scale dependent, and in most cases, multi-proxy approaches are necessary (Table 1). The SISALv3 database, augmented with trace element proxies thus provides a multi-proxy dataset that can be used for long-term drought reconstructions in the past, and to better understand the forcings, mechanisms and periodicities of such events. In addition to the new geochemical data, extensive metadata including information on parameters such as vegetation and karst type as well as entity (i.e. speleothem dataset) images are provided to aid robust interpretations.

The SISALv3 database will allow the systematic and global analysis of stable isotope and trace element variability, and elucidate how trace element data can be used to strengthen climatic interpretations from speleothem oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) records. The database can be accessed at http://dx.doi.org/10.5287/ora-2nanwp4rk.

Proxy	**Potential drivers**	**Selected relevant references**
$\delta^{18}O$	Semi-quantitative temperature reconstruction dependent on the combined effect of temperature dependency of meteoric precipitation $\delta^{18}O$ and in-cave temperature on carbonate $\delta^{18}O$	(Dorale et al., 1998; Mangini et al., 2005; Moseley et al., 2015; Koltai et al., 2017; Wendt et al., 2021; Luetscher et al., 2021; Wolf et al., 2024; Wainer et al., 2011)
	Change in source water composition e.g. as tracers of ice sheet meltwaters during deglaciations	(Stoll et al., 2022; Badertscher et al., 2011; Frumkin et al., 1999; Meckler et al., 2012)
	Change in moisture transport trajectory or change in moisture source (sometimes linked to seasonality)	(Lachniet et al., 2014; Cheng et al., 2016; Luetscher et al., 2021; Frumkin et al., 1999)
	Change in seasonality of precipitation e.g. increase winter rain versus summer rain in different climate states	(Cheng et al., 2009b; Baldini et al., 2019; Cheng et al., 2019; Wang et al., 2001)
	Precipitation amount at the cave site and upstream rainout	(Bar-Matthews et al., 2003; Hu et al., 2008; Cheng et al., 2016; Columbu et al., 2019; Cheng et al., 2013)
	Large-scale circulation and supra-regional climate e.g. the Indian Summer Monsoon	(Cheng et al., 2016; Kathayat et al., 2016)

	Recharge processes and karst flow paths	(Ayalon et al., 1998; Baker et al., 2019; Treble et al., 2022)
$\delta^{13}C$	Semi-quantitative temperature reconstruction linked to changes in vegetation and soil respiration (requires additional proxies e.g. Mg/Ca)	(Genty et al., 2003, 2006; Lechleitner et al., 2021; Stoll et al., 2022, 2023)
	Vegetation density variability e.g. low vegetation density zones versus high vegetation density zones	(Fohlmeister et al., 2020)
	Metabolic pathway e.g. C3 versus C4 pathway	(Baker et al., 1997)
	Hydroclimate through the prior calcite precipitation mechanism and/or drip rate changes (requires additional proxies e.g. Mg/Ca)	(Johnson et al., 2006; Owen et al., 2016; Carolin et al., 2019b; Fairchild et al., 2000)
Mg/Ca	Hydroclimate through the prior calcite precipitation mechanism and/or drip rate changes, potential for semi-quantitative precipitation reconstruction (requires additional proxies e.g. $\delta^{13}C$, Sr/Ca and Ba/Ca, and/or cave monitoring data)	(Johnson et al., 2006; Owen et al., 2016; Carolin et al., 2019b; Fairchild et al., 2000; Warken et al., 2018)
	Hydroclimate through dust activity and marine aerosol input (requires additional proxies e.g. Na/Ca, Sr/Ca and Ba/Ca, and/or cave monitoring data)	(Faraji et al., 2023; Carolin et al., 2019b)
	Hydroclimate through water residence time in soil and karst	(Roberts et al., 1998; Treble et al., 2003; Tremaine and Froelich, 2013)
Sr/Ca	Hydroclimate through the prior calcite precipitation mechanism and/or drip rate changes (requires additional proxies e.g. $\delta^{13}C$, Mg/Ca and Ba/Ca, and/or cave monitoring data)	(Johnson et al., 2006; Owen et al., 2016; Carolin et al., 2019b; Fairchild et al., 2000)
	Aeolian transport (increased confidence in interpretation with $^{87}Sr/^{86}Sr$ data)	(Goede et al., 1998)
Ba/Ca	Hydroclimate through the prior calcite precipitation mechanism and/or drip rate changes (requires additional proxies e.g. $\delta^{13}C$, Mg/Ca and Sr/Ca, and/or cave monitoring data)	(Johnson et al., 2006)
	Growth rate	(Treble et al., 2003)
	Soil mineral weathering	(Riechelmann et al., 2020; Rutlidge et al., 2014)

U/Ca	Hydroclimate through the prior aragonite precipitation mechanism and/or drip rate changes (requires additional proxies e.g. $\delta^{13}C$, Mg/Ca, Ba/Ca and Sr/Ca, and/or cave monitoring data)	(Jamieson et al., 2016)
	Enhanced infiltration via complexes (e.g., uranyl-phosphate) (requires additional proxies e.g. P/Ca)	(Treble et al., 2003)
P/Ca	Biomass cycling including wildfire; enhanced infiltration via complexes	(Huang et al., 2001; Treble et al., 2003; Borsato et al., 2007; McDonough et al., 2022)
Sr isotopes	Hydroclimate through proportional source changes	(Verheyden et al., 2000; Utida et al., 2020)
	Aeolian activity	(Li et al., 2005)

Table 1: Summary of speleothem geochemical proxies included in SISALv3, examples for their possible interpretations, and relevant references.

2 Data and Methods

2.1 New data formatting and processing

All trace elements are reported normalized as ratios with respect to Ca (X/Ca, where X stands for the individual elements) in units of mmol/mol. In the following manuscript, "trace element" refers to the normalized ratio to Ca. A standardized conversion sheet is used to facilitate conversions from gram to mol units (available in the repository). Sr-isotope data is reported as $^{87}Sr/^{86}Sr$ values. For internal consistency, and to facilitate future intercomparison and synthesis studies, the measurement method and reference materials used, and measurement precision are also reported for both trace elements and Sr-isotopes.

Mechanisms relevant to hydroclimate interpretations from speleothems are based on a multi-proxy approach of stable isotopes and one or more trace element ratios. Therefore, the SISALv3 database structure allows for trace element measurements to be added at the depths of the stable isotope measurements on a given entity. However, between 35 and 86% of the records (depending on element) were measured using in-situ techniques, such as laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), and these datasets are typically generated at a higher resolution (10-100 μm) than the stable isotope records (Jochum et al., 2012). These data have been downsampled to the resolution of the stable isotope data for the same speleothem. Downsampling was performed by computing averages (and standard deviations) of the trace element measurements for corresponding stable isotope sampling depths. This implicitly assumes that the same or a (depth-equivalent) parallel sampling track were used for trace elements and stable isotopes and that the isotope sampling was continuous. Downsampling allows the trace element data to be represented by the same depth-age model as the stable isotope record. For records submitted by the authors where the originally published dataset was at higher resolution than reported in the SISAL

database, standardized *.txt datafiles are also available in the repository (see section 5.3 on Code and Data accessibility). No new chronological information or separate age models are reported for these datasets.

2.2 Additional metadata

New metadata fields are included in the Entity table (see database structure; Figure 1) to allow users to select sites with similar environmental conditions and to take account of factors that might influence the interpretation of individual records. These include information on vegetation, land use, land cover, and host rock type above the cave. This information is often missing from publications and was not available from data contributors, so information from data products has been added as additional fields to the database for completeness. Vegetation type and land use information were provided by the original investigators. Additionally, information on land use and land cover was taken from the Copernicus Global Land Service Land Cover database (LCC v3.0.1 Epoch 2019; (Buchhorn et al., 2021, 2020), extracted with a radius of 250 m around the cave site. Information on the carbonate/evaporite host rock at the cave sites was taken from the WOKAM database (Goldscheider et al., 2020) extracted with a radius of 1000 m.

The database also indicates if the trace element content of the host rock and drip water feeding the speleothem is available (but does not include the actual values). Drip height (i.e., the distance the drip falls from the ceiling of the cave to the speleothem), and the difference between dripwater and carbonate $\delta^{18}O$ values are given, based on information provided by the original investigators.

The SISAL WG repository now hosts images of the entities (speleothem sections) and maps of cave sites. These allow users to evaluate petrographic features that may influence the trace element and stable isotopic records and to check whether cave morphology could potentially influence the climate in the cave (Covington and Perne, 2015). The entity table in the database contains fields indicating whether maps and images are available.

2.3 Changes to database structure

The structure of the SISALv3 database (Figure 1) has been changed to accommodate additional data and metadata, and to optimize the organization of information, as described below.

2.3.1 New geochemical data and metadata fields

The elemental ratio for each trace element and the Sr-isotope data are given in individual tables that contain sample identifiers (*sample_id*), the measurement value and the measurement precision. The *sample_id* provides the link to the Sample table and thus links these data to the stable isotope data (Figure 1, Table 2).

Metadata for the measurements are stored in the Entity table. For each elemental ratio (Sr/Ca, Mg/Ca, U/Ca, Ba/Ca and P/Ca), the Entity table indicates whether the data are available ("yes/no/other/unknown"), the measurement method, the laboratory reference materials used and, where applicable, the downsampling methods used. The table also indicates if high-resolution

trace element data is available. For Sr-isotopes, the Entity table specifies whether this dataset is available, what measurement method was employed and how the measurement was standardized (Figure 1, Table 2).

SISALv3 now provides a unique, persistent identifier for each speleothem (*persist_id*) in the Entity table (Figure 1, Table 2). This was needed because there was an increasing issue with non-unique entity names, and to deal with the fact that different datasets from the same stalagmite had different *entity_id*s (e.g., for datasets covering different time periods in the same speleothem). Thus, the field *entity_id* provides a unique identifier for a specific dataset, but not necessarily for a specific speleothem, while the *persist_id* uniquely identifies the speleothem. The *persist_id* were created by combining the *site_id* and *entity_name* (without special characters). There are 838 unique *persist_id*s and 902 unique *entity_id*s in the database.

2.3.2 Changes in existing database fields and options

The fields "geology" and "rock age" were moved from the Site table to the Entity table (Figure 1, Table 2). This was done to allow for variability in these parameters within the same cave system, particularly relevant for the interpretation of $\delta^{13}C$ and trace element data. The field "trace elements" (yes/no) in the Entity table was removed as it is now redundant. The field "iso_std" describing the reference material used for measurement of $\delta^{18}O$ and $\delta^{13}C$ values was moved from the stable isotope tables to the Entity metadata table. A number of options for entries in the metadata fields were changed (Table 3). The majority of these changes were additions to the previously available options in light of the entries made in the 'Notes' section to allow for more "metadata-filterable" database mining. A few options were removed from the metadata fields since they have never been used in previous database versions.

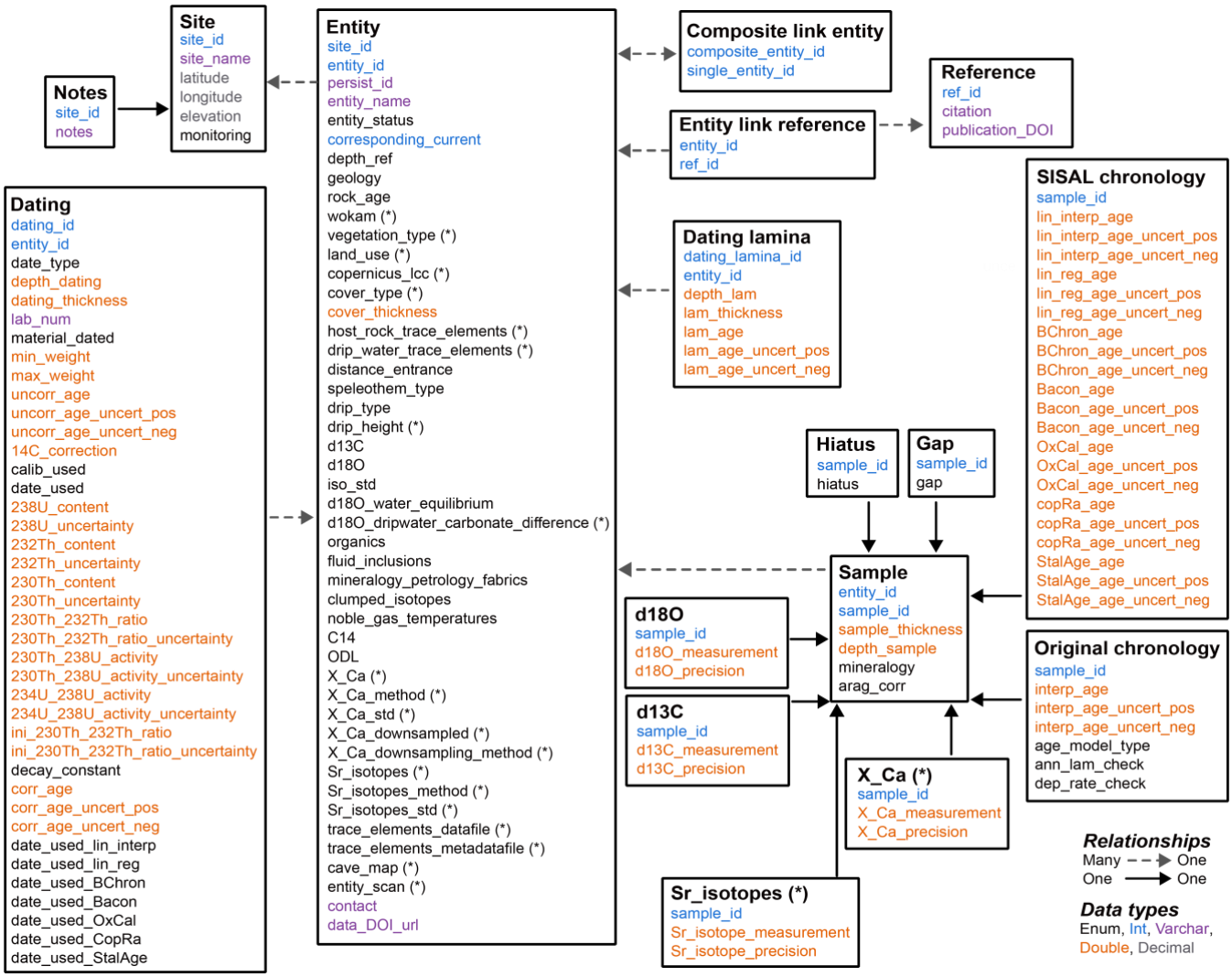

Figure 1: Structure of the SISALv3 database. Fields and tables marked with (*) refer to new information added in SISALv3; see table 2 for details. The colors refer to the format of that field: Enum, Int, Varchar, Double or Decimal. More information on the list of pre-defined menus can be found in the Supplementary information (Table S1). For trace element records, a series of identical tables was generated (labelled X_Ca where X stands for the specific element: Mg, Sr, Ba, U, P).

Action	Field label	Description	Format	Constraints
Changes made to the SITE table				
Field removed	*geology*			
Field removed	*rock_age*			

Changes made to the ENTITY table				
Field added	*persist_id*	persistent, unique identifier for each speleothem	Text	
Field added	*geology*	Information on geology	Text	Selection from predefined list
Field added	*rock_age*	Information on bedrock age	Text	Selection from predefined list
Field added	*wokam*	Information on type of carbonate/evaporite rock from WOKAM database	Text	Added by SISAL SC at database level
Field added	*vegetation_type*	Information on vegetation cover	Text	Selection from predefined list
Field added	*land_use*	Information on land use (publication/data contributors)	Text	Selection from predefined list
Field added	*copernicus_lcc*	Information on land cover from Copernicus land cover classification dataset	Text	Added by SISAL SC at database level
Field added	*cover_type*	Information on land cover (publication/data contributors)	Text	Selection from predefined list
Field added	*host_rock_trace_elements*	Indication whether trace element data from the host rock has been measured	Text	Selection from predefined list
Field added	*drip_water_trace_elements*	Indication whether trace element data from the drip water has been measured	Text	Selection from predefined list
Field added	*drip_height*	Information on drip height (in m)	Numeric	Free to fill
Field added	*iso_std*	Information on reference material used for oxygen and carbon isotope measurements	Text	Selection from predefined list
Field added	*d18O_dripwater_carbonate_difference*	Information on difference between dripwater and carbonate oxygen isotope values	Numeric	Free to fill
Field removed	*trace_elements*			
Field added	*Sr_Ca*	Indication whether Sr/Ca data has been measured	Text	Selection from predefined list
Field added	*Sr_Ca_method*	Information on measurement method for Sr/Ca	Text	Selection from predefined list

Field added	*Sr_Ca_std*	Information on reference material used for Sr/Ca measurements	Text	Selection from predefined list
Field added	*Sr_Ca_downsampled*	Information on whether Sr/Ca data had to be downsampled	Text	Selection from predefined list
Field added	*Sr_Ca_downsampling_method*	Information on downsampling method for Sr/Ca, if applicable	Text	Selection from predefined list
Field added	*Mg_Ca_method*	Information on measurement method for Mg/Ca	Text	Selection from predefined list
Field added	*Mg_Ca_std*	Information on reference material used for Mg/Ca measurements	Text	Selection from predefined list
Field added	*Mg_Ca_downsampled*	Information on whether Mg/Ca data had to be downsampled	Text	Selection from predefined list
Field added	*Mg_Ca_downsampling_method*	Information on downsampling method for Mg/Ca, if applicable	Text	Selection from predefined list
Field added	*Ba_Ca*	Indication whether Ba/Ca data has been measured	Text	Selection from predefined list
Field added	*Ba_Ca_method*	Information on measurement method for Ba/Ca	Text	Selection from predefined list
Field added	*Ba_Ca_std*	Information on reference material used for Ba/Ca measurements	Text	Selection from predefined list
Field added	*Ba_Ca_downsampled*	Information on whether Ba/Ca data had to be downsampled	Text	Selection from predefined list
Field added	*Ba_Ca_downsampling_method*	Information on downsampling method for Ba/Ca, if applicable	Text	Selection from predefined list
Field added	*U_Ca*	Indication whether U/Ca data has been measured	Text	Selection from predefined list
Field added	*U_Ca_method*	Information on measurement method for U/Ca	Text	Selection from predefined list
Field added	*U_Ca_std*	Information on reference used for U/Ca measurements	Text	Selection from predefined list
Field added	*U_Ca_downsampled*	Information on whether U/Ca data had to be downsampled	Text	Selection from predefined list

Field added	*U_Ca_downsampling_method*	Information on downsampling method for U/Ca, if applicable	Text	Selection from predefined list
Field added	*P_Ca*	Indication whether P/Ca data has been measured	Text	Selection from predefined list
Field added	*P_Ca_method*	Information on measurement method for P/Ca	Text	Selection from predefined list
Field added	*P_Ca_std*	Information on reference material used for P/Ca measurements	Text	Selection from predefined list
Field added	*P_Ca_downsampled*	Information on whether P/Ca data had to be downsampled	Text	Selection from predefined list
Field added	*P_Ca_downsampling_method*	Information on downsampling method for P/Ca, if applicable	Text	Selection from predefined list
Field added	*Sr_isotopes*	Indication whether Sr isotope data has been measured	Text	Selection from predefined list
Field added	*Sr_isotopes_method*	Information on measurement method for Sr isotopes	Text	Selection from predefined list
Field added	*Sr_isotopes_std*	Information on reference material used for Sr isotope measurements	Text	Selection from predefined list
Field added	*trace_elements_datafile*	Information on whether the original trace elements data is available in the repository	Text	Selection from predefined list
Field added	*trace_elements_metadatafile*	Information whether original trace element metadata is available in the repository	Text	Selection from predefined list
Field added	*cave_map*	Information whether a copy of cave map is available in the repository	Text	Selection from predefined list
Field added	*entity_scan*	Information whether a scan of the speleothem in the repository	Text	Selection from predefined list
Changes made to the d18O and d13C tables				

Field removed	*iso_std*	Information on reference material used for $\delta^{18}O$ and $\delta^{13}C$ measurements	Text	Selection from predefined list

Table 2: Changes made to the Site, Entity and stable isotope tables compared to SISALv2.

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Table name	**Action**	**Field label**	**Reason**	**Format**	**Constraints**
Entity	Added "mixed (see notes)" option	*speleothem_type*	Standardisation of option across fields	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*speleothem_type*	Standardisation of option across fields	Text	Selected from pre-defined list
Entity	Removed "magmatic" option	*geology*	Not used	Text	Selected from pre-defined list
Entity	Removed "granite" option	*geology*	Not used	Text	Selected from pre-defined list
Entity	Added "dolomite limestone" option	*geology*	Machine-readable format option	Text	Selected from pre-defined list
Entity	Added "marly limestone" option	*geology*	Machine-readable format option	Text	Selected from pre-defined list
Entity	Added "calcarenite" option	*geology*	Machine-readable format option	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*geology*	Option to include free text in notes	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*rock_age*	Option to include free text in notes	Text	Selected from pre-defined list
Entity	Added "mixed (see notes)" option	*rock_age*	Reflect overburden with rocks of different ages	Text	Selected from pre-defined list
Entity	Removed "mixture"	*drip_type*	Replaced with “mixed (see notes)” option	Text	Selected from pre-defined list
Entity	Removed "not applicable"	*drip_type*	Not used	Text	Selected from pre-defined list
Entity	Added "mixed (see notes)" option	*drip_type*	Standardisation of option across fields	Text	Selected from pre-defined list

Entity	Added "other (see notes)" option	*drip_type*	Option to include free text in notes	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*d18O_water_equilibrium*	Option to include free text in notes	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*organics*	Option to include free text in notes	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*fluid_inclusions*	Option to include free text in notes	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*mineralogy_petrology_fabric*	Option to include free text in notes	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*clumped_isotopes*	Option to include free text in notes	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*noble_gas_temperatures*	Option to include free text in notes	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*C14*	Option to include free text in notes	Text	Selected from pre-defined list
Entity	Added "other (see notes)" option	*ODL*	Option to include free text in notes	Text	Selected from pre-defined list
Dating	Added "mixed (see notes)" option	*material_dated*	Align with options in the sample table	Text	Selected from pre-defined list
Dating_lamina	Added "Year of chemistry" option	*modern_reference*	Align with options in the dating table	Text	Selected from pre-defined list
Sample	Removed "secondary calcite" option	*mineralogy*	Not used	Text	Selected from pre-defined list
Sample	Removed "vaterite" option	*mineralogy*	Not used	Text	Selected from pre-defined list
Sample	Added "organic" option	*mineralogy*	Addition of option	Text	Selected from pre-defined list
Sample	Added "other (see notes)" option	*mineralogy*	Option to include free text in notes	Text	Selected from pre-defined list
Sample	Removed "combination of methods" option	*age_model_type*	Standardisation of option across fields	Text	Selected from pre-defined list

Sample	Added "mixed (see notes)" option	*age_model_type*	Standardisation of option across fields	Text	Selected from pre-defined list
Sample	Added "other (see notes)" option	*dep_rate_check*	Option to include free text in notes	Text	Selected from pre-defined list

Table 3: Changes made to the predefined options for metadata fields compared to SISALv2.

3 Quality control

The SISAL WG has used several levels of quality control (QC) and this practice was continued for SISALv3 (Figure 2). The initial data compilation is performed by SISAL regional coordinators and/or in liaison with the data contributors into standardized excel workbooks. The first QC level consists in the expert assessment by the SISAL regional coordinators who double-check completeness of entered data and correctness of measurement units where applicable. Standardized unit conversion sheets for common conversions (e.g. degrees-minutes-seconds to decimal degrees for site information; atomic ratios to activity ratios for dating information; mg/g to mmol/mol for trace element-to-Ca ratios for trace element information) have been provided to regional coordinators (see repository). The completed workbook(s) are subjected to a series of automated QC (e.g., age model matches discreet dating information, hiatuses are placed at the correct depth) by the database managers. When the datasets pass automated QC, and no further corrections are necessary, the dataset workbook and auto generated QC figures are sent to the data contributors for final evaluation and approval. The same workflow has been followed for the *.txt trace element datafiles. The new metadata fields of vegetation_type and land_use that have been added to SISALv3 for entities that were included in SISALv2 from publications. Data already included in SISALv2 has been checked, and mistakes / unknowns identified during previous data analysis or during the process of trace element data addition were corrected. A comprehensive summary of the changes made to existing entities between SISALv2 and SISALv3 is shown in Table 4.

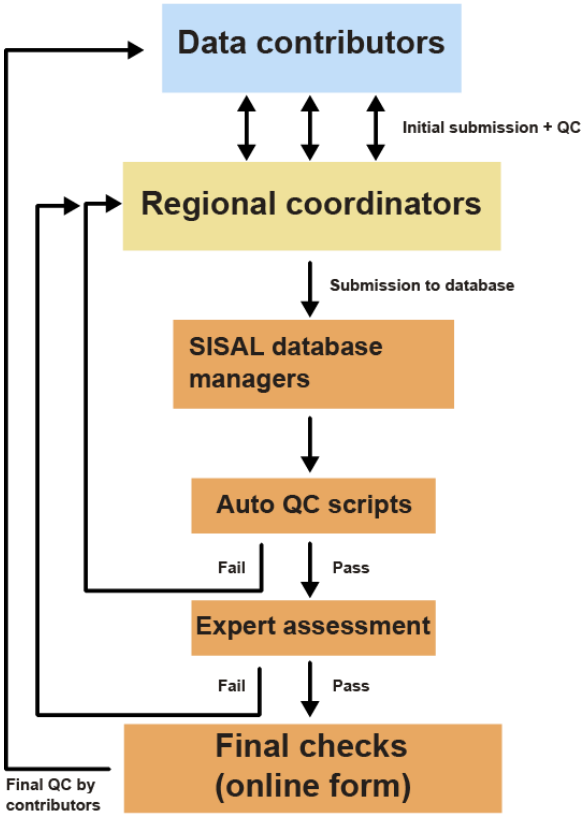

Figure 2: Quality checking workflow adopted for inclusion of datasets in SISAL. The colors indicate different quality check levels: blue - data contributing sources (original authors or datasets deposited in repositories and publication supplementary information); yellow - SISAL regional coordinator group with regional expertise; orange - SISAL database managers.

Modification	**v2 to v3**
Site table	
Number of new sites	72
Pre-existing sites with new entities	37
Entity table	
Number of new entities	211
Entities added to pre-existing sites	71
Entities with updated entity.entity_status	33
Entities with altered entity.corresponding_current	1
Entities with altered geology	106

Entities with altered rock_age	58
Entities with altered entity.cover_thickness	6
Entities with altered distance_entrance	1
Entities with altered d13C	109
Entities with altered d18O	15
Entities with altered organics	9
Entities with altered fluid_inclusions	9
Entities with altered mineralogy_petrology_fabric	14
Entities with altered clumped_isotopes	9
Entities with altered noble_gas_temperatures	12
Entities with altered C14	3
Entities with altered ODL	7
Entities with altered contact	62
Entities with altered data_DOI_url	20
Dating table	
Addition of "event: hiatus" to an entity	1
Changes in hiatus depths	1
Changes in depths of "Event: start/end of laminations"	1
Alterations in dating.date_type	2
Alterations in dating.depth_dating	5
Alterations in dating.material_dated	2
Alterations in dating.min_weight	6
Alterations in dating.max_weight	6
Alterations in dating.uncorr_age	15
Alterations in dating.uncorr_age_uncert_pos	13
Alterations in dating.uncorr_age_uncert_neg	13
Alterations in dating.date_used	27
Alterations in dating.238U_content	89
Alterations in dating.238U_uncertainty	34
Alterations in dating.232Th_content	96
Alterations in dating.232Th_uncertainty	85
Alterations in dating.230Th_232Th_ratio	206
Alterations in dating.230Th_232Th_ratio_uncertainty	200
Alterations in dating.230Th_238U_activity	24

Alterations in dating.230Th_238U_activity_uncertainty	21
Alterations in dating.234U_238U_activity	381
Alterations in dating.234U_238U_activity_uncertainty	433
Alterations in dating.ini_230Th_232Th_ratio	519
Alterations in dating.ini_230Th_232Th_ratio_uncertainty	485
Alterations in dating.decay_constant	77
Alterations in dating.corr_age	71
Alterations in dating.corr_age_uncert_pos	26
Alterations in dating.corr_age_uncert_neg	28
Sample table	
Altered sample.depth_sample	1084
Altered sample.mineralogy	294
Altered sample.arag_corr	294
Entities that had d18O time series altered (changes in depth/ duplicate isotope values)	4
Entities that had d13C time series altered (changes in depth/ duplicate isotope values)	2
Original chronology	
Altered original_chronology.interp_age	7440
References	
How many entities had changes in references?	100
How many citations have a different pub_DOI?	100
Notes	
Sites with notes modified	121

Table 4: Summary of the modifications applied to records in version 2 (Comas-Bru et al., 2020) of the SISAL database. Note that the changes in the dating and sample table were counted by dating_id and sample_id, respectively, which leads to a large number of changes.

4 Overview of database contents

4.1 Trace element and Sr-isotope records

SISALv3 contains 95 Mg/Ca, 85 Sr/Ca, 52 Ba/Ca, 25 U/Ca, 29 P/Ca and 14 Sr-isotope records (Table 5). This corresponds to ~60% of the known published data, based on an assessment by the SISAL WG. There is a clear regional bias in the database with European entities dominating every elemental ratio (Figure 3). The Sr-isotope records are more evenly distributed, with records from every region except Asia and Oceania. Temporal coverage for the combined trace element and Sr-isotope dataset is high during the last 2000 years (~60 entities per 20 year interval) and the Holocene (~60 entities per 250 year interval), and then drops to 20-40 entities per 10,000 year interval for the last glacial cycle (12-120 ka BP, where ka stands for 1000 years and BP for "before present", defined as 1950, Figure 4). Beyond ~120 ka BP, the number of entities gradually decreases until the U-Th dating limit is reached (~640 ka).

Where the original measured laser ablation data have been provided by data contributors, these have been made available as *.txt datafiles in the repository (Table 5). Forty-six trace element records (Mg/Ca: 15, Sr/Ca: 17, Ba/Ca: 4, U/Ca: 5, P/Ca: 5, Sr-isotopes: 2) are only provided in the original format (*.txt files), either because they could not be converted to mmol/mol or because the trace element data were not measured at stable isotope equivalent depths and were at an insufficiently high resolution for accurate resampling. Additional elements that are not included in the database, but have been submitted by data contributors, are also provided as *.txt files (e.g., Mn, Fe, Zn, Th, Pb, K, Na).

Geochemical data	Total number in SISAL	Downsampled by original authors	Downsampled by SISAL	Only in repository
Mg/Ca	95	12	15	15
Sr/Ca	85	11	11	17
Ba/Ca	52	11	9	4
U/Ca	25	2	6	5
P/Ca	29	4	12	5

Table 5: Summary of number of trace element records in SISAL and downsampling methods applied.

4.2 New stable isotope records

SISALv3 provides a significantly expanded oxygen isotope dataset compared to SISALv2 (Table 6, Table 7, Figure 5), with 892 $\delta^{18}O$ records from 365 sites, compared to 673 records in SISALv2. The most significant increases in $\delta^{18}O$ records are in Africa (+28 records), Europe (+73), and the Middle-East (+17; Table 6). SISALv3 contains 334 entities covering the last 2000 years, of which 78 are new (Figure 6). As record density begins to decrease with age (Figure 6), the spatial distribution is reduced as well. For the Last Glacial Maximum (20 – 22 ka BP), SISALv3 contains 92 entities (11 new), while for the Last Interglacial (124 – 126 ka BP), 66 entities are available (15 new). Four $\delta^{18}O$ records previously included in SISALv2 have been modified to correct previous mistakes (Table 4), these are *entity_id*s 110 (CUR4; Novello et al., 2016), 169 (Dim-E3; Ünal-İmer et al., 2015), 447 (JAR4; Novello et al., 2017), and 573 (Gej-1; Flohr et al., 2017).

There has also been a significant increase in the number of $\delta^{13}C$ records added, with 620 records in SISALv3 compared to 430 in SISALv2 (Table 6, Figure 7). At the regional scale, the most significant increases in $\delta^{13}C$ records is for Africa (+23 records), Asia (+33), and Europe (+66, Table 6). The $\delta^{13}C$ record coverage decreases following the same patterns as the trace elements and $\delta^{18}O$ records (Figure 8). Two $\delta^{13}C$ records previously included in SISALv2 have been modified to correct previous mistakes (Table 4), these are *entity_id*s 169 (Dim-E3; Ünal-İmer et al., 2015), and 573 (Gej-1; Flohr et al., 2017).

Region	**$\delta^{18}O$ records in v3**	**Increase compared to v2 (counts)**	**$\delta^{13}C$ records in v3**	**Increase compared to v2 (counts)**
Africa	73	28	63	23
Asia	237	50	105	33
Europe	243	73	213	66
Middle East	60	17	43	14
Oceania	100	11	66	11
North and Central America	88	9	72	9
South America	97	21	54	13

Table 6: Summary of the new $\delta^{18}O$ and $\delta^{13}C$ records added to SISALv3 compared to SISALv2.

site_id	**site_name**	**region**	**latitude**	**longitude**	**persist_id**	**entity_id**	**entity_name**	**citation**
70	Abaco Island cave	Bahamas	26.23	-77.16	70-ABDC12	692	AB-DC-12_2023	(Arienzo et al., 2017)
79	Dim cave	Turkey	36.534	32.1056	79-DIME4	693	Dim-E4_2023	(Ünal-İmer et al., 2016, 2015)

					79-DIM1	754	Dim1	(Rowe et al., 2020)
144	Botuverá cave	Brazil	-27.2247	-49.1569	144-BT2	694	BT-2_2007	(Cruz et al., 2007)
145	Antro del Corchia	Italy	43.9833	10.2167	145-CD31	695	CD3-1_HR	(Drysdale et al., 2020)
						696	CD3-1_LR	(Drysdale et al., 2020)
266	Cueva Victoria	Spain	37.6322	-0.8215	266-VICIII1	697	Vic-III-1	(Budsky et al., 2019; Ros and Llamusí, 2012)
					266-VICIII3	698	Vic-III-3	(Budsky et al., 2019; Ros and Llamusí, 2012)
					266-SR01T	699	SR01t	(Budsky et al., 2019; Ros and Llamusí, 2012)
39	Dongge cave	China	25.2833	108.0833	39-D3	700	D3_2005	(Kelly et al., 2006)
					39-D4	701	D4_2005_Kelly	(Kelly et al., 2006)
120	Ejulve cave	Spain	40.76	-0.59	120-ANDROMEDA	702	Andromeda	(Pérez-Mejías et al., 2019)
192	El Condor cave	Peru	-5.93	-77.3	192-ELCB	703	ELC-B_2021	(Cheng et al., 2021)
115	Hölloch im Mahdtal	Austria	47.3781	10.1506	115-HOL1	704	HOL1	(Li et al., 2021a)
					115-HOL22	705	HOL22	(Li et al., 2021a)
6	Hulu cave	China	32.5	119.17	6-MSL	706	MSL_2021	(Cheng et al., 2021)
10	Jaraguá cave	Brazil	-21.083	-56.583	10-JAR2	707	JAR2	(Novello et al., 2019)
24	Lapa sem fim cave	Brazil	-16.1503	-44.6281	24-LSF13	708	LSF13_2018	(Stríkis et al., 2018)

					24-LSF19	709	LSF19	(Azevedo et al., 2021)
					24-LSF17	710	LSF17	(Azevedo et al., 2021)
					24-LSF13	711	LSF13_2021	(Cheng et al., 2021)
3	Paraiso cave	Brazil	-4.0667	-55.45	3-PAR27	712	PAR27	(Cheng et al., 2021)
					3-PAR15	713	PAR15	(Cheng et al., 2021)
268	Pere Noel cave	Belgium	50	5.2	268-PN955	714	PN-95-5_2018	(Allan et al., 2018)
								Allan et al. (2018)
87	Pindal cave	Spain	43.4	-4.53	87-CANDELA	715	Candela_2023	(Moreno et al., 2010)
						716	Candela_Base	(Stoll et al., 2022)
						717	Candela_Main	(Stoll et al., 2022)
						718	Candela_L	(Stoll et al., 2022)
					87-LAURA	719	Laura	(Stoll et al., 2022)
295	Qadisha cave	Lebanon	34.2439	30.0364	295-QAD1	720	Qad_1	(Nehme et al., 2023)
					295-QAD2	721	Qad_2	(Nehme et al., 2023)
232	Rio Secreto cave system	Mexico	20.59	-87.13	232-RS1	722	RS1	(Serrato Marks et al., 2021)
219	Shennong cave	China	28.71	117.26	219-SN35	723	SN35	(Zhang et al., 2021a)
					219-SN31	724	SN31	(Zhang et al., 2021a)
					219-SN29	725	SN29	(Zhang et al., 2021a)
					219-SN-COMP	726	SN_composite	(Zhang et al., 2021a)

					219-SN17	727	SN17_2021	(Zhang et al., 2021a)
55	Sieben Hengste cave	Austria	46.75	7.81	55-7H12	728	7H-12	(Luetscher et al., 2021)
58	Spannagel cave	Austria	47.08	11.67	58-SPA121	729	SPA121_2021	(Wendt et al., 2021)
					58-SPA146	730	SPA146	(Wendt et al., 2021)
					58-SPA183	731	SPA183	(Wendt et al., 2021)
					58-SPA127	732	SPA127_2023	(Fohlmeister et al., 2013; Welte et al., 2021)
279	Staircase cave	South Africa	-34.2071	22.0899	279-STAIRCASE-COMP	733	Staircase_composite	(Braun et al., 2019b)
236	Toca da Boa Vista	Brazil	-10.1602	-40.8605	236-TBV5	734	TBV5	(Cheng et al., 2021)
					236-TBV13	735	TBV13	(Zhang et al., 2021c)
69	Xinglong cave	China	40.5	117.5	69-XL4	736	XL-4	(Duan et al., 2019, 2022)
296	Amir Timur cave	Uzbekistan	39.4227	66.7632	296-S124	737	S-12-4	(Finestone et al., 2022)
94	Anjohibe	Madagascar	-15.53	46.88	94-ABC1	738	ABC-1	(Li et al., 2020)
297	Bàsura cave	Italy	44.13	8.2	297-BA184	739	BA18-4	(Hu et al., 2022)
298	Belum cave	India	15.1	78.1	298-BLM1	740	BLM-1	(Band et al., 2022)
299	Calabrez	Spain	43.45	-5.13	299-ALICIA	741	Alicia	(Stoll et al., 2022)
300	Careys cave	Australia	-35.07	148.66	300-CC146	742	CC14-6	(Scroxton et al., 2021)
301	Cathedral cave	Australia	-32.617	148.94	301-WB	743	WB	(Markowska et al., 2020)
					301-WC	744	WC	(Markowska et al., 2020)

302	Crevice cave	South Africa	-34.21	22.09	302-CREVICE-COMP	745	Crevice_composite	(Bar-Matthews et al., 2010)
303	Crystal cave, Australia	Australia	-34.1	115	303-CRYS1	746	CRY-S1	(Priestley et al., 2023; Treble et al., 2003)
304	Cueva Bonita	Mexico	23	-99	304-CB4	747	CB4	(Wright et al., 2022)
305	Cueva Rosa	Spain	43.4436	-5.1403	305-NEITH	748	Neith_2022	(Stoll et al., 2022)
						749	Neith_2015	(Stoll et al., 2015)
					305-ARTEMISAR	750	Artemisa_R	(Stoll et al., 2015)
					305-ANGELINES	751	Angelines	(Stoll et al., 2015)
306	Cuíca cave	Brazil	-11.6822	-60.6431	306-PIM4	752	PIM4	(Della Libera et al., 2022)
					306-PIM5	753	PIM5	(Della Libera et al., 2022)
307	Efflux cave	South Africa	-33.41	22.34	307-EFFLUX-COMP	755	Efflux_composite	(Braun et al., 2020)
					307-142843	756	142843	(Braun et al., 2020)
					307-142846	757	142846	(Braun et al., 2020)
					307-142847	758	142847	(Braun et al., 2020)
					307-142848	759	142848	(Braun et al., 2020)
					307-142849	760	142849	(Braun et al., 2020)
308	GD8	Greenland	80.3777	-21.7468	308-GD81SLAB1	761	GD8-1 Slab 1	(Moseley et al., 2021)
					308-GD81SLAB1ORB	762	GD8-1 Slab 1 orb	(Moseley et al., 2021)
					308-GD81SLAB2	763	GD8-1 Slab 2	(Moseley et al., 2021)
309	Goda Mea cave	Ethiopia	9.49	37.66	309-GM1	764	GM1	(Asrat et al., 2018)

310	Golgotha cave	Australia	-34.083	115.05	310-GLS1	765	GL-S1	(Treble et al., 2022)
					310-GLS2	766	GL-S2	(Treble et al., 2022)
					310-GLS3	767	GL-S3	(Treble et al., 2022)
					310-GLS4	768	GL-S4	(Treble et al., 2022)
311	Harrie Wood cave	Australia	-35.7	148.5	311-HWS1	769	HW-S1	(Tadros et al., 2022, 2016)
					311-HWS2	770	HW-S2	(Tadros et al., 2022, 2016)
					311-HW38B	771	HW_38b	(Tadros et al., 2022, 2016)
312	Heifeng cave	China	29.0167	107.1833	312-HF01	772	HF01	(Yang et al., 2019)
313	Herbstlabyrinth cave	Germany	50.6875	8.2058	313-HLK2	773	HLK2	(Waltgenbach et al., 2020)
					313-NG01	774	NG01	(Waltgenbach et al., 2021)
					313-TV1	775	TV1_2021	(Waltgenbach et al., 2021)
						776	TV1_2020	(Waltgenbach et al., 2020)
314	Herolds Bay cave	South Africa	-34.05	22.39	314-HEROLDSBAY-COMP	777	Herolds_bay_composite	(Braun et al., 2020)
					314-162520	778	162520	(Braun et al., 2020)
					314-1625271	779	162527-1	(Braun et al., 2020)
					314-162528	780	162528	(Braun et al., 2020)
					314-1625272	781	162527-2	(Braun et al., 2020)
315	Huangchao cave	China	36.6167	118.3333	315-HC2	782	HC2	(Tan et al., 2020a)
316	Hüttenbläserschachthöhle	Germany	51.3689	7.6547	316-HBSH1	783	HBSH-1	(Weber et al., 2021)

					316-HBSH3	784	HBSH-3	(Weber et al., 2021)
					316-HBSH4	785	HBSH-4	(Weber et al., 2021)
					316-HBSH5	786	HBSH-5	(Weber et al., 2021)
42	Ifoulki cave	Morocco	30.708	-9.3275	42-IFK2	787	IFK2	(Sha et al., 2021)
317	Jiangjun cave	China	22.95	104.8167	317-JJ0406	788	JJ0406	(Wassenburg et al., 2021; Liu et al., 2020)
					317-JJ0403	789	JJ0403	(Wassenburg et al., 2021; Liu et al., 2020)
318	Jinfo cave	China	29.0167	107.1792	318-J12	790	J12	(Yang et al., 2019)
					318-J13	791	J13	(Yang et al., 2019)
319	Jiulong cave	China	27.8	113.9	319-JL1	792	JL1	(Zhang et al., 2021b)
320	Katalekhor	Iran	35.85	48.16	320-KT3	793	KT-3	(Andrews et al., 2020)
100	Katerloch cave	Austria	47.0833	15.55	100-K2	794	K2	(Honiat et al., 2022)
					100-K4	795	K4	(Honiat et al., 2022)
321	Klang	Thailand	8.33	98.73	321-TK7	796	TK7	(Chawchai et al., 2021)
					321-TK20	797	TK20	(Chawchai et al., 2021)
					321-TK40	798	TK40	(Chawchai et al., 2021)
322	Kuna Ba	Iraq	35.09	45.38	322-NIR1	799	NIR-1	(Sinha et al., 2019)
					322-NIR2	800	NIR-2	(Sinha et al., 2019)
					322-NIR-COMP	801	NIR_composite	(Sinha et al., 2019)
323	Kyok-Tash cave	Russia	51.729	85.656	323-K4KYOK	802	K4_kyok	(Li et al., 2021b)

324	La Vallina	Spain	43.41	-4.8067	324-GAEL	803	Gael_2022	(Stoll et al., 2022)
						804	Gael_2015	(Stoll et al., 2015)
					324-GLORIA	805	Gloria	(Stoll et al., 2015)
					324-GARTH	806	Garth	(Stoll et al., 2022)
					324-GULDA	807	Gulda	(Stoll et al., 2022)
					324-LUNA	808	Luna	(Stoll et al., 2022)
					324-GALIA	809	Galia	(Stoll et al., 2022)
221	La Vierge cave	Mauritius	-19.7572	63.3703	221-LAVI157	810	LAVI-15-7	(Li et al., 2020)
					221-LAVI4	811	LAVI-4_2020	(Li et al., 2020)
325	Larga cave	Puerto Rico	18.32	-66.8	325-PRLA1	812	PR-LA-1	(Warken et al., 2020)
326	Linzhu cave	China	31.5167	110.3167	326-LZ15	813	LZ15	(Cheng et al., 2009a)
					326-LZ36	814	LZ36	(Cheng et al., 2009a)
327	Manita peć cave	Croatia	45.3142	15.4754	327-MP2	815	MP-2	(Surić et al., 2021b)
					327-MP3	816	MP-3	(Surić et al., 2021b)
328	Mata Virgem cave	Brazil	-11.62	-47.49	328-MV3	817	MV3	(Azevedo et al., 2019)
329	Matupi cave	Democratic Republic of Congo	1.25	29.82	329-MAT1	818	MAT1	(Dupont et al., 2022)
					329-MAT12	819	MAT12	(Dupont et al., 2022)
					329-MAT23	820	MAT23	(Dupont et al., 2022)
330	Meravelles cave	Spain	40.9488	0.5127	330-MAAT	821	Maat	(Pérez-Mejías et al., 2021)

331	Mizpe Shelagim	Mount Hermon (Levant)	33.32	35.81	331-MS-COMP	822	MS-composite	(Ayalon et al., 2013)
					331-MS1	823	MS-1	(Ayalon et al., 2013)
					331-MS2	824	MS-2	(Ayalon et al., 2013)
					331-MS3	825	MS-3	(Ayalon et al., 2013)
332	Murada	Spain	39.956	3.965	332-INDIANA	826	Indiana	(Torner et al., 2019)
333	Neotektonik cave	Switzerland	46.7833	8.2667	333-M37116A	827	M37-1-16A	(Wilcox et al., 2020)
					333-M37116C	828	M37-1-16C	(Wilcox et al., 2020)
					333-M37123A	829	M37-1-23A	(Wilcox et al., 2020)
334	Nova Grgosova cave	Croatia	45.8188	15.6783	334-NG7	830	NG-7	(Surić et al., 2021a)
					334-NG3	831	NG-3	(Surić et al., 2021a)
335	Ostolo cave	Spain	43.1878	-0.2678	335-OST2	832	OST2	(Bernal-Wormull et al., 2021)
					335-OST1	833	OST1	(Bernal-Wormull et al., 2021)
					335-OST3	834	OST3	(Bernal-Wormull et al., 2021)
336	Pentadactylos	Cyprus	35.27	33.47	336-PENTADACTYLOS1	835	Pentadactylos-1	(Nehme et al., 2020)
337	Pir Ghar cave	Iran	35.23	57.42	337-PG113	836	PG11-3	(Carolin et al., 2019a)
338	Coves del pirata	Spain	39.5046	3.3009	338-CONSTANTINE	837	Constantine	(Cisneros et al., 2021)

339	Pozzo Cucù cave	Italy	40.9	17.16	339-PC	838	PC	(Columbu et al., 2020)
254	PP29	South Africa	-34.2078	22.0876	254-PP29-COMP	839	PP29_composite	(Braun et al., 2019b)
340	Qujia cave	China	35.7	118.4	340-QJ1	840	QJ1	(Zhao et al., 2021)
341	Rey Marcos	Guatemala	15.4277	-90.2807	341-GURM1	841	GU-RM-1	(Winter et al., 2020)
342	Sa balma des Quartó cave	Spain	39.5145	3.3059	342-SEAN	842	Seán	(Cisneros et al., 2021)
					342-MULTIEIX	843	Multieix	(Cisneros et al., 2021)
					342-CIARA	844	Ciara	(Cisneros et al., 2021)
					342-FENI	845	Feni	(Cisneros et al., 2021)
140	Sanbao cave	China	31.667	110.4333	140-SB61	846	SB61	(Cheng et al., 2009a)
343	Sant'Angelo cave	Italy	40.7	17.5	343-SA1	847	SA1	(Columbu et al., 2022)
345	Schratten cave	Switzerland	46.7833	8.2667	345-M6733	849	M6-73-3	(Wilcox et al., 2020)
20	Secret cave	Borneo	4.0848	114.8503	20-SC02	850	SC02_2022	(Buckingham et al., 2022)
346	Shijiangjun cave	China	26.2	105.5	346-SJJ7	851	SJJ7	(Chen et al., 2021)
347	Shizi cave	China	29.6822	106.2881	347-QM09	852	QM09	(Yang et al., 2019)
348	Sudwala cave	South Africa	-25.37	20.7	348-SC1	853	SC1	(Green et al., 2015)
349	Talisman cave	Kyrgyzystan	40.39	72.35	349-F11	854	F11	(Tan et al., 2021)
					349-F2TALISMAN	855	F2_Talisman	(Tan et al., 2021)
293	Tham Doun Mai	Laos	20.75	102.65	293-TM5	856	TM5	(Griffiths et al., 2020)

				102.65	293-TM4	857	TM4	(Griffiths et al., 2020)
				102.65	293-TM11	858	TM11	(Griffiths et al., 2020)
350	Toca da Barriguda	Brazil	-10.16	-40.86	350-TBR14	859	TBR14	(Wendt et al., 2019)
					350-TBR1013	860	TBR10-13	(Cheng et al., 2021)
351	Trapiá cave	Brazil	-5.6	-37.7	351-TRA7	861	TRA7	(Utida et al., 2020)
352	War Eagle	United States of America	34.67	-86.05	352-PPNDA	862	PPnda	(Medina-Elizalde et al., 2022)
250	Wuya cave	China	33.82	105.43	250-WY12	863	WY12	(Tan et al., 2020b)
					250-WY13	864	WY13	(Tan et al., 2020b)
					250-WY14	865	WY14	(Tan et al., 2020b)
					250-WY56	866	WY56	(Tan et al., 2020b)
353	Wintimdouine	Morocco	30.77	-9.49	353-WIN1	867	WIN1	(Sha et al., 2019)
					353-WIN2	868	WIN2	(Sha et al., 2021, 2019)
					353-WIN3	869	WIN3	(Sha et al., 2021, 2019)
					353-WIN-COMP	870	WIN_composite	(Sha et al., 2019)
354	Wulu cave	China	26.05	105.0833	354-WULU30	871	Wulu-30	(Cheng et al., 2021; Liu et al., 2018)
					354-WU88	872	Wu88	(Liu et al., 2023, p.202)
					354-WU37	873	Wu37	(Zhao et al., 2020)
355	Xiniu cave	China	31.5167	110.57	355-XN2	874	XN2	(Zhao et al., 2021)

				110.57	355-XN15	875	XN15	(Zhao et al., 2021)
				110.57	355-XN-COMP	876	XN_composite	(Zhao et al., 2021)
5	Yangkou cave	China	29.0333	107.1833	5-JFYK2	877	JFYK2	(Zhang et al., 2021b)
356	Yangzi cave	China	29.783	107.783	356-YZ1	878	YZ1	(Wu et al., 2020)
357	Yonderup cave	Australia	-31.547	115.69	357-YDS2	879	YD-S2	(McDonough et al., 2022; Nagra et al., 2017, 2016)
358	Zhangjia cave	China	32.5833	105.0833	358-ZJD171	880	ZJD171	(Cheng et al., 2021)
359	Zoolithen cave	Germany	49.7793	11.2829	359-ZOOREZ1	881	Zoo-rez-1	(Riechelmann et al., 2019, 2020)
					359-ZOOREZ2	882	Zoo-rez-2	(Riechelmann et al., 2019, 2020)
360	Bigonda cave	Italy	46.018	11.581	360-BG2	883	BG2	(Johnston et al., 2021)
					360-BG4	884	BG4	(Johnston et al., 2021)
117	Bunker cave	Germany	51.3675	7.6647	117-BU1	885	Bu1_2021	(Waltgenbach et al., 2021)
					117-BU4	886	Bu4_2021	(Waltgenbach et al., 2021, 2020)
361	Kocain cave	Turkey	37.2325	30.7117	361-KO1	887	Ko-1	(Jacobson et al., 2021)
362	Labyrinth cave	Australia	-34.3	115.1	362-LABS1	888	LAB-S1	(Nagra et al., 2017; Priestley et al., 2023)
363	Lake Shasta cave	United States of America	40.804	-122.304	363-LSC2	889	LSC2	(Oster et al., 2020)

					363-LSC3	890	LSC3	(Oster et al., 2020)
12	Mawmluh cave	India	25.2622	91.8817	12-MAW3	891	MAW-3	(Magiera et al., 2019)
364	Naharon	Mexico	20.18	-87.54	364-NAH14	892	NAH14	(Warken et al., 2021)
365	Pot au Feu	Spain	42.52	0.24	365-JUD	893	JUD	(Torner et al., 2019)
366	Savi cave	Italy	45.6167	13.8833	366-SV1	894	SV1	(Belli et al., 2013, 2017)
					366-SV7	895	SV7	(Belli et al., 2013, 2017)
205	São Bernardo cave	Brazil	-13.81	-46.35	205-SBE3	896	SBE3_2021	(Novello et al., 2018, 2021)
225	Chiflonkhakha cave	Bolivia	-18.1222	-65.7739	225-BOTO1	897	Boto 1_2021	(Apaésteguiet al., 2018; Novello et al., 2021)
					225-BOTO3	898	Boto 3_2021	(Apaésteguiet al., 2018; Novello et al., 2021)
					225-BOTO7	899	Boto 7_2021	(Apaésteguiet al., 2018; Novello et al., 2021)
54	Sahiya cave	India	30.6	77.8667	54-SAHA	900	SAH-A_2023	(Sinha et al., 2015)
					54-SAHB	901	SAH-B_2023	(Sinha et al., 2015)
					54-SAHAB-COMP	902	SAH-AB_2023	(Sinha et al., 2015)
344	Sarma cave	Abkhazia (Caucasus)	-25.37	20.7	344-SAR121	848	SAR-12-1	(Wolf et al., 2024)

Table 7: New entities added to SISALv3.

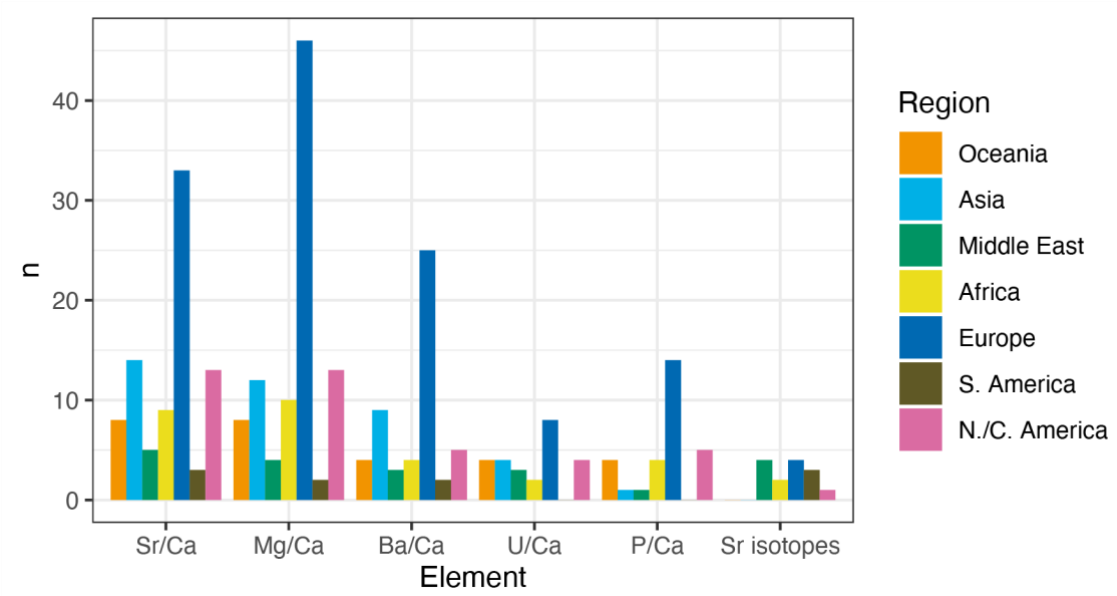

Figure 3: Trace element ratios and Sr isotope records included in SISALv3 by region. Abbreviations: S. America - South America, N./C. America - North and Central America.

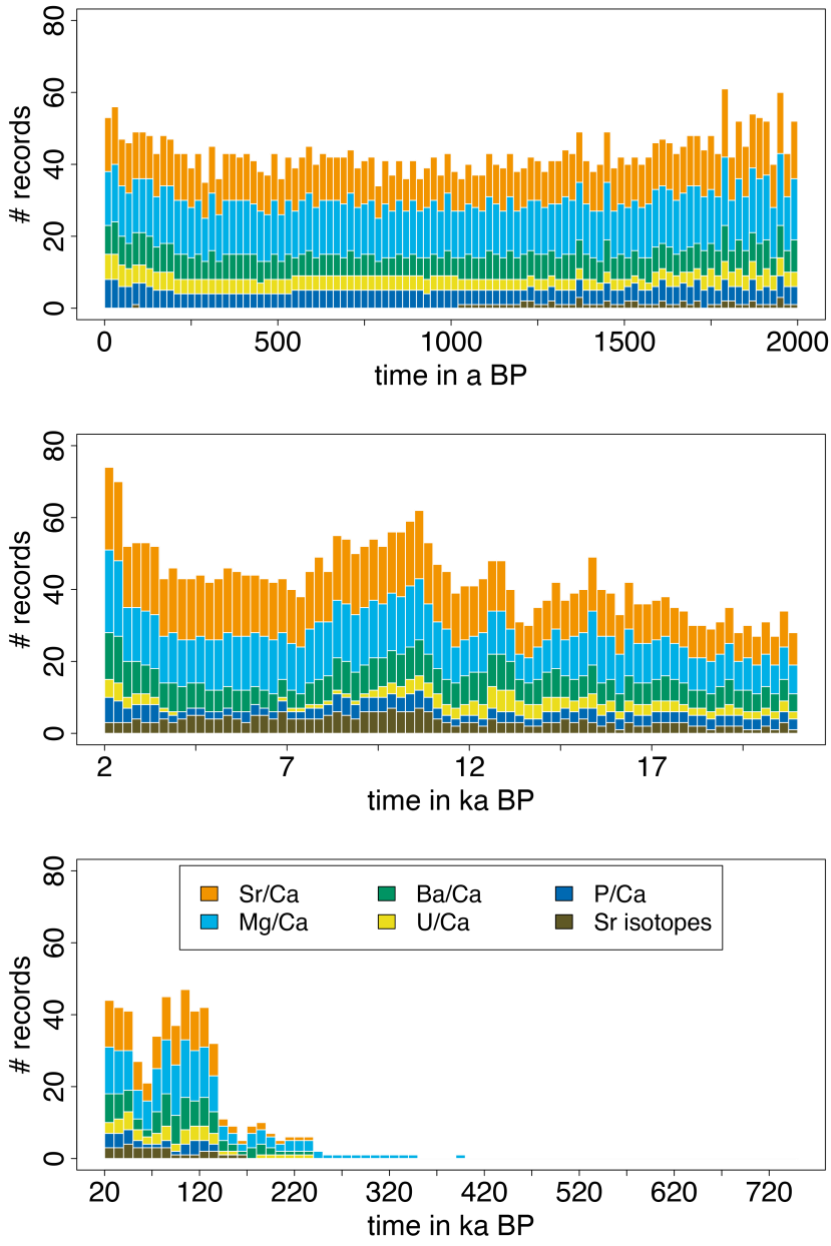

Figure 4: Temporal coverage of the trace element and Sr-isotope records in SISALv3 by region. Entities with multiple trace elements were counted multiple times. Bin sizes: 0-2,000 a (years) BP (top panel) - 20 years; 2,000-21,000 a BP (middle panel) - 250 years; 21,000-750,000 a BP (bottom panel) - 10,000 years.

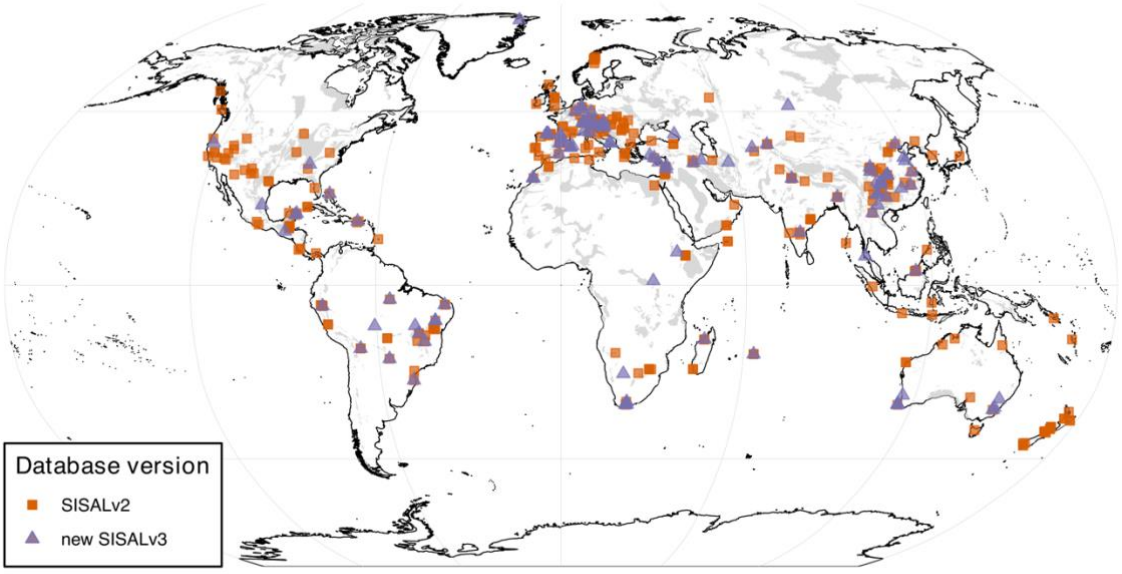

Figure 5: Global map of $\delta^{18}O$ records included in SISAL v2 and v3. The shaded background shows the global karst distribution extracted from the World Karst Aquifer Map (WOKAM, Goldscheider et al., 2020).

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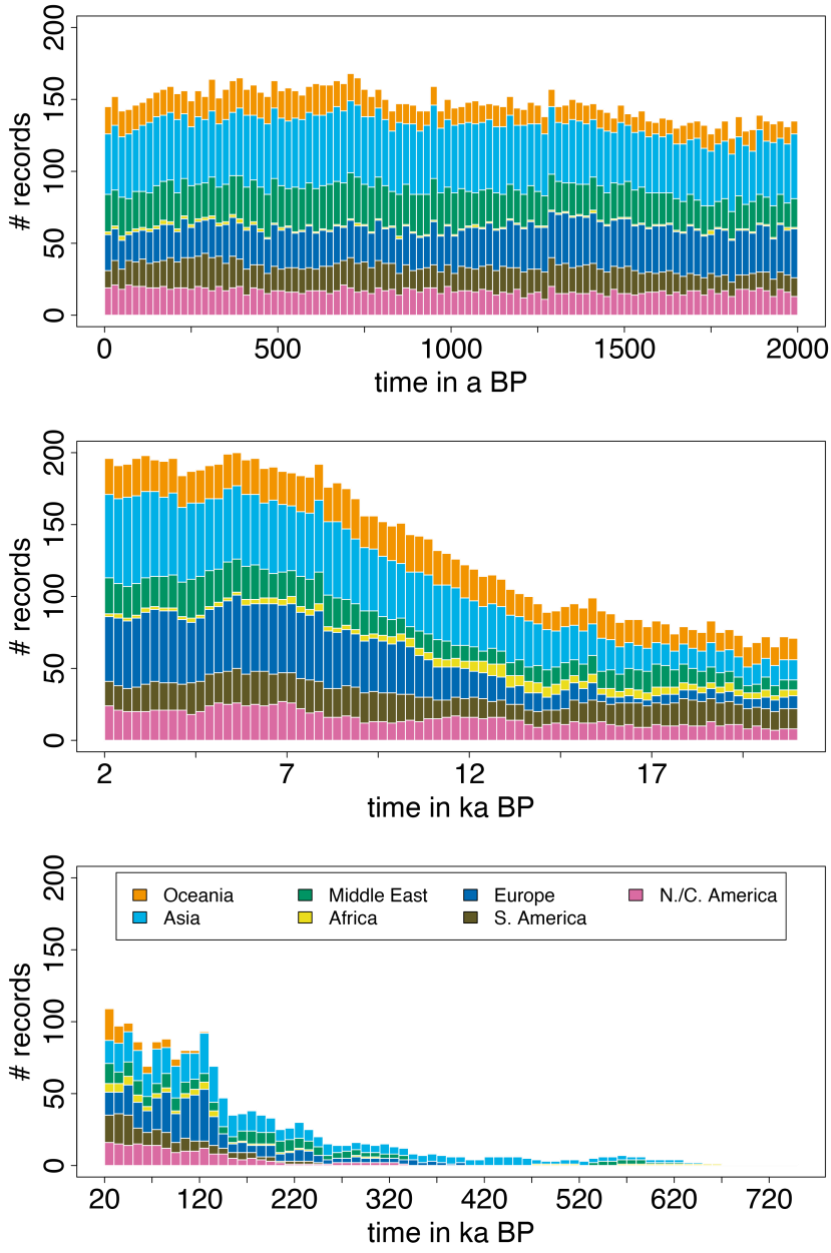

Figure 6: Temporal coverage of the $\delta^{18}O$ records in SISALv3 by region. Bin sizes: 0-2,000 a BP (top panel) - 20 years; 2,000-21,000 a BP (middle panel) - 250 years; 21,000-750,000 a BP (bottom panel) - 10,000 years.

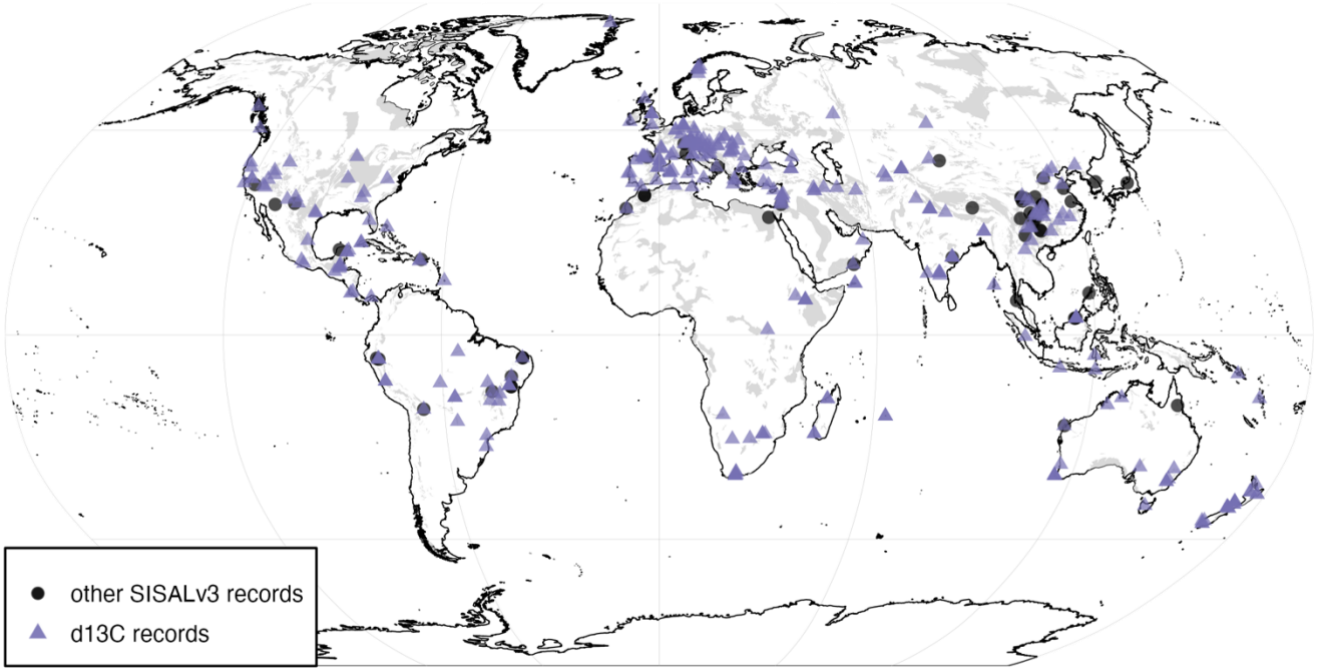

Figure 7: Map of available $\delta^{13}C$ records in SISALv3 compared to all records in the database. The shaded background shows the global karst distribution extracted from the World Karst Aquifer Map (WOKAM, Goldscheider et al., 2020).

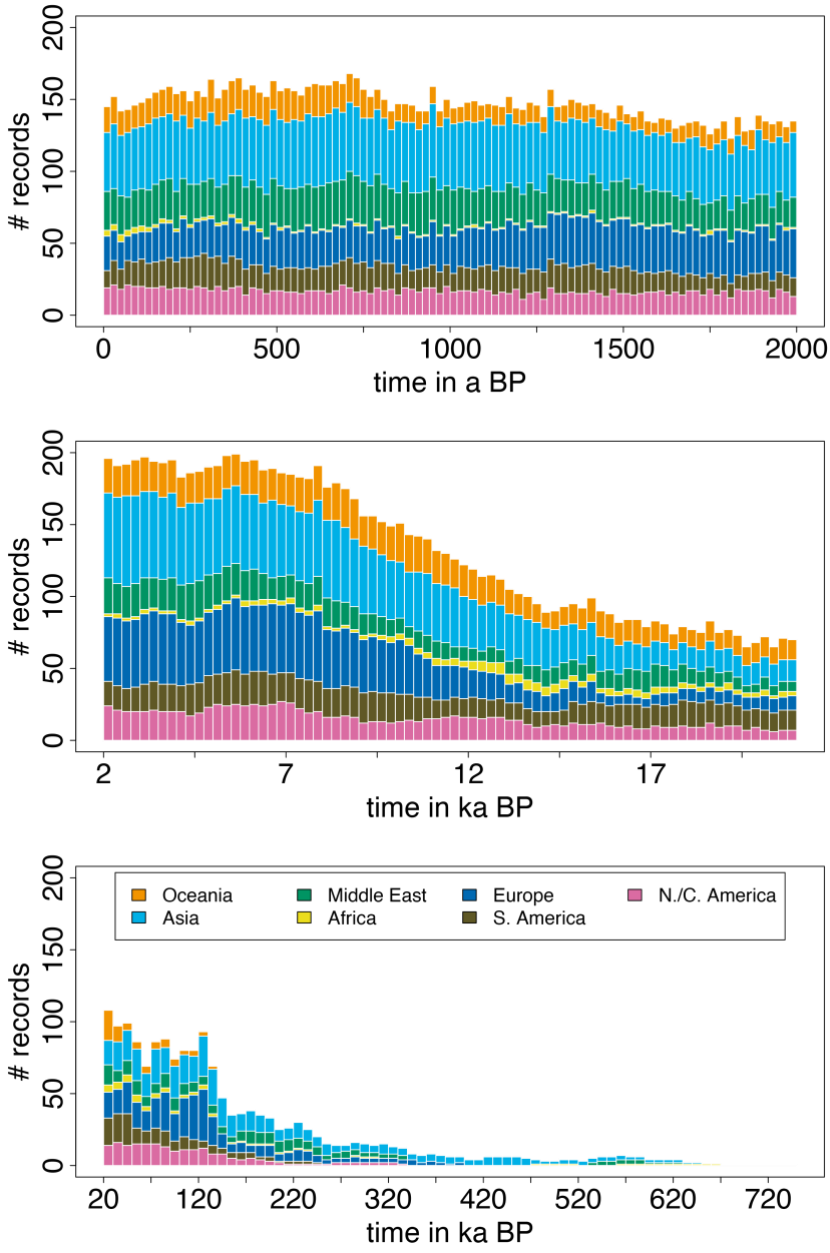

Figure 8: Temporal coverage of the $\delta^{13}C$ records in SISALv3 by region. Bin sizes: 0-2,000 a BP (top panel) - 20 years; 2,000-21,000 a BP (middle panel) - 250 years; 21,000-750,000 a BP (bottom panel) - 10,000 years.

4.3 Vegetation and land cover metadata

Interpretation of the site-to-site variability in speleothem data sensitive to vegetation changes is facilitated by providing information on *vegetation_type* and *land_use*. The dropdown list for these fields includes options typically used in speleothem publications. Additional information provided by the authors (e.g. species names) has been added to the Notes table. About 40% of the database entries lack the author-reported information on land cover (Figure 9c). Satellite-derived land cover classifications provide information for many more sites (unknown: 1.7%; Figure 9d). Forested sites (evergreen, deciduous, and mixed) comprise ~56.5% (Figure 9d), shrub- and grassland makes up 25.1% and this dataset also denotes sites that are affected by anthropogenic land use (managed vegetation, agriculture, urban), which make up 13%.

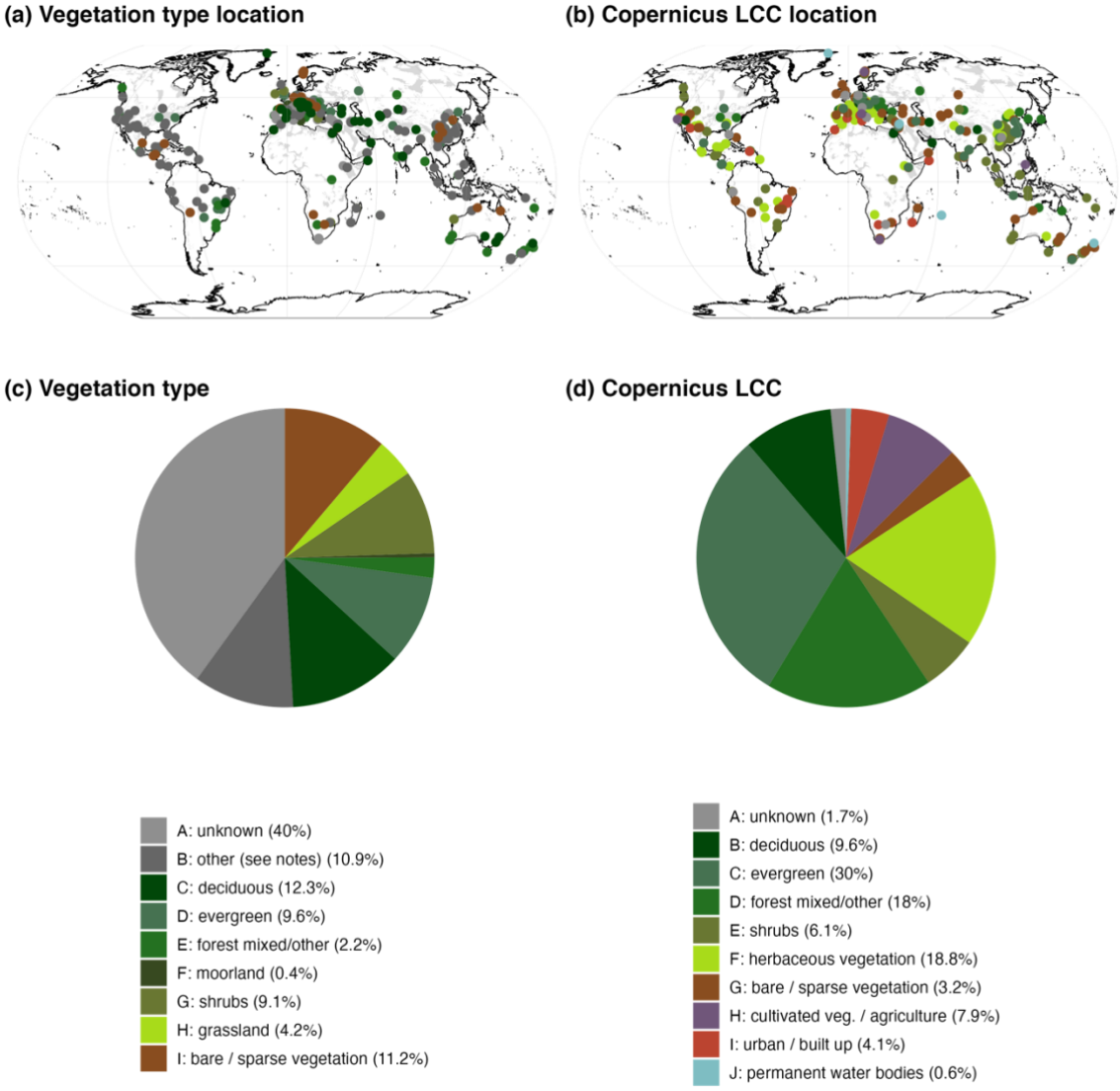

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Figure 9: (a) – vegetation description from the original publications or provided by authors and (b) – land cover categories extracted from the Copernicus LCC database (Buchhorn et al., 2021, 2020) with a radius of 250 m around the cave sites. (c) - pie chart showing the relative proportions of vegetation types as reported by authors. (d) - pie chart showing the relative proportions of land cover types as extracted from the Copernicus LCC database. Background shading in the map shows the
310 *global karst distribution extracted from the World Karst Aquifer Map (WOKAM, (Goldscheider et al., 2020). To allow comparison between the two datasets, the Copernicus LCC vegetation data was grouped into broader categories, e.g., "deciduous" includes all closed and open broad-leaf and needle forest marked as deciduous. The entries in the database are more detailed.*

5 Recommendations for use

The SISALv3 database is a standardized, quality checked dataset that allows regional to global assessments of spatial and temporal trends in multiple environmental proxies from speleothem records. The addition of trace element data at stable isotope equivalent depths to the database together with machine-readable metadata fields allow examination of hydroclimatic controls on speleothem trace element distribution. Metadata fields, including distance from coast (*latitude*, *longitude*, *elevation*), lithology (*geology*, *wokam*), and land cover (*cover_type*, *cover_thickness*, *vegetation_type*, *land_use*, *copernicus_lcc*), allow identification of the primary controls on trace elements. We recommend using multiple cover fields together, based on the analysis type and scope (e.g., time interval considered) since they provide complementary information. Anthropogenic and natural changes in the cover parameters over time need to be considered, and this applies particularly for the cover fields "*vegetation_type*", "*land_use*" and "*copernicus_lcc*", which in most cases may only be applicable for very recent speleothem growth.

Where trace elements are measured on aliquots of the same powder as stable isotopes, the sample-to-sample variability in depth-time space is minimal. Where samples for stable isotopes and trace elements have been drilled at different times or *in situ* methods have been used for trace element measurements, there may be depth-time variability that may impact results. Extensive metadata on sampling and measurement methods, as well as the original high resolution *in-situ* measurements against depth, are provided in the database and linked repository and should be used to check for such impacts. Measurements may also be sensitive to stalagmite petrography; image scans have been provided in the linked repository so the user can evaluate whether this is important for interpretation of the record.

5.1 Code and data availability

The database is available in CSV and SQL format in a repository at https://doi.org/10.5287/ora-2nanwp4rk (Kaushal et al., 2024). This dataset is licensed by the rights holder(s) under a Creative Commons Attribution 4.0 International License: https://creativecommons.org/licenses/by/4.0/. Apart from the workbook used to submit data to the SISAL database and the codes for automatic quality checking, the repository contains additional standardisation sheets (coordinate conversion, grams to moles conversion for trace elements, and atomic activity calculator for U-series data). Moreover, the repository contains all submitted cave maps and entity images in separate zip folders, as well as copyright information for the individual images and an entity scan "wishlist" which details best practices for entity scan images. Standardized trace element datafiles are included separately with their metadata (see section 2), and the codes needed to connect and use the database (described in the Readme file).

The codes for standardisation and downsampling of trace element and Sr-isotope records are available at zenodo 10.5281/zenodo.8234066 (Skiba, 2023); licensed by the right holder(s) under Creative Commons Attribution 4.0 International).

The database contains both the original age model for individual entities and a standardized age modelling ensemble. The original age model often takes account of site- and sample-specific conditions; the standardized age model ensemble allows for robust assessment of age uncertainties and sensitivity testing (Comas-Bru et al., 2020). All codes for constructing the age model ensembles using linear interpolation, linear regression, Bchron, Bacon, copRa, and StalAge can be found at https://github.com/paleovar/SISAL.AM (last access: 23 July 2020; codes licensed by the right holder(s) under a GPL-3 license). These codes are licensed by the right holder(s) under a Creative Commons Attribution 4.0 International. All age model ensembles are available at https://zenodo.org/records/10726619 (Rehfeld and Bühler, 2024). These codes are licensed by the right holder(s) under a Creative Commons Attribution 4.0 International.

The SISALv3 database, like its predecessors, lists the original references, and users are encouraged to consult original authors for interpretative details. The 'SISAL webApp' (http://geochem.hu/SISAL_webApp ; Hatvani et al., 2024) has been updated to provide easy-to-use front-end interface in exploring the latest SISALv3 database. It now allows for querying on various data and metadata fields such as stable isotope records and trace element proxies.

5.2 How to cite the database

The SISALv3 database is a community driven effort to synthesize, standardize and make speleothem data to the wider paleoclimate community. In agreement with the FAIR principles for scientific data management and stewardship, the database itself should be cited (available at https://doi.org/10.5287/ora-2nanwp4rk; Kaushal et al., 2024), together with this publication (and previous version publications). If individual records are extracted from the database, the original publications should also be listed. More details on Terms of Use are provided in the repository (https://doi.org/10.5287/ora-2nanwp4rk; Kaushal et al., 2024).

Author contributions

NK, FL and MW designed the new version of the database. KR and JB ran the SISAL standardized age-depth models for new entities. Downsampling of trace element records to stable isotope resolution was performed by VS and MR. Standardization of trace element datafiles was done by YB and NK. Reworking and additions to the metadata fields were done by KB and KA. JGS and NK collected citations, copyright information and license terms for the cave maps and speleothem images. Regional data collection and screening was coordinated by VA, JLB, SC, AC, LE, JH, IGH, ZK, AK, KK, MK, BM, SMA, CN, VFN, CPM, JR, NS, NiS, CT, BHT, SW, AW, HZ. Quality control of the submitted datasets was performed by MW, FL, and NK, with additional code provided by JF. Figures 1 and 2 were created by FL, Figures 3-9 were created by JB. All authors listed as "Data contributors" provided data for this version of the database or helped to complete existing data entries. FL wrote the paper with input from NK, JB, KR, AB, PT, SPH, and all authors contributed to the final version.

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Competing interests

The authors declare that they have no conflict of interest.

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