MOSAIC (Modern Ocean Sediment Archive and Inventory of Carbon): A (radio)carbon-centric database for seafloor surficial sediments

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Key points paper:

(1) Paper presents global database for marine surficial sediments

(2) Database has a user-friendly interactive app with downloadable data

(3) Provides a new platform to answer key questions in biogeochemistry

Key words:

Ocean Sediments, Organic Carbon, Radiocarbon, ^{13}C, Carbon Sequestration, MOSAIC, Database

Abstract

Mapping the biogeochemical characteristics of surficial ocean sediments is crucial for advancing our understanding of global element cycling, as well as for assessment of the potential footprint of environmental change. Despite their importance as long-term repositories for biogenic materials produced in the ocean and delivered from the continents, biogeochemical signatures in ocean sediments remain poorly delineated. Here, we introduce MOSAIC (Modern Ocean Sediment Archive and Inventory of Carbon; DOI: https://doi.org/10.5168/mosaic019.1, mosaic.ethz.ch, Van der Voort et al., 2019), a (radio)carbon-centric database that seeks to address this information void. The goal of this nascent database is to provide a platform for development of regional to global-scale perspectives on the source, abundance and composition of organic matter in marine surface sediments, and to explore links between spatial variability in these characteristics and biological and depositional processes. The database has a continental margin-centric focus given both the importance and complexity of continental margins as sites of organic matter burial. It places emphasis on radiocarbon as an underutilized yet powerful tracer and chronometer of carbon cycle processes, and with a view to complementing radiocarbon databases for other earth system compartments. The database infrastructure and interactive web-application are openly accessible and designed to facilitate further expansion of the database. Examples are presented to illustrate large-scale variabilities in bulk carbon properties that emerge from the present data compilation.

1. Introduction

Oceans sediments constitute the largest and ultimate long-term global organic carbon (OC) sink (Hedges and Keil, 1995), and serve as a key interface between short- and long-term components of the global carbon cycle (Galvez et al., 2020). Assessments of the distribution and composition of OC in ocean sediments are crucial for constraining carbon burial fluxes, the role of ocean sediments in global biogeochemical cycles, and in interpretation of sedimentary records. Constraining the magnitude of carbon stocks, as well as delineating the sources, pathways and timescales of carbon transfer between different reservoirs (e.g., atmosphere, oceanic water column, continents) comprise essential challenges. In this regard, radiocarbon provides key information on carbon sources and temporal dynamics of carbon exchange. The half-life of radiocarbon is compatible with assessments of carbon turnover and transport times within and between different compartments of the carbon cycle, while also serving to delineate shorter-term (< 50 kyr) and longer-term (> 50 kyr) cycles. Moreover, the advent of nuclear weapons testing in the mid 20th century serves as a time marker for the onset of the Anthropocene (Turney et al., 2018), and a tracer for carbon that has recently been in communication with the atmosphere. With on-going dilution of this atmospheric "bomb spike" with radiocarbon-free carbon dioxide from the combustion of fossil fuels (Graven, 2015; Suess, 1955), radiocarbon serves a particularly sensitive sentinel of carbon cycle change.

Radiocarbon databases or data collections have been established for the atmosphere (e.g. University Heidelberg Radiocarbon Laboratory, 2020), ocean waters (Global Data Analysis Project (GLODAP), Key et al., 2004), and most recently soils (ISRaD; Lawrence et al., 2020), with tree-rings, corals and other annually-resolved archives providing information on historical variations in ^{14}C in the atmosphere and surface reservoirs (Friedrich et al., 2020; Reimer, 2020). At present, no such radiocarbon database exists for OC residing in ocean sediments. As a sensitive tracer of carbon sources and carbon cycle perturbations, there is a clear imperative to fill this information void given that on-going anthropogenic activities directly and indirectly influence ocean sediment and resident OC stocks (Bauer et al., 2013; Breitburg et al., 2018; Ciais et al., 2013; Keil, 2017; Regnier et al., 2013; Syvitski et al., 2003). Materials accumulating in modern ocean sediments also provide a crucial window into how on-going processes that are observable through direct instrumental measurements and remote sensing data manifest themselves in the sedimentary record.

Over 85% of OC burial in the modern oceans occurs on continental margins, with deltaic, fjord and other shelf and slope depositional settings constituting localized hotspots for carbon burial (Bianchi et al., 2018; Hedges and Keil, 1995). As the interface between land and ocean, continental margins comprise a key juncture in the carbon cycle (Bianchi et al., 2018), provide crucial habitats for unique marine ecosystems (Levin and Sibuet, 2012), support a major fraction of the worlds fisheries (Worm et al., 2006), and participate in exchange processes with the interior ocean (Dunne et al., 2007; Jahnke, 1996; Rowe et al., 1994). These ocean settings and their underlying sediments are also amongst those most vulnerable to change (Keil, 2017) through direct perturbations such as contaminant and nutrient discharge from land, loci of intense resource extraction such as bottom trawling (Pusceddu et al., 2014) and mineral and hydrocarbon recovery (e.g., Chanton et al., 2015), as well as indirect effects such as ocean warming (Roemmich et al., 2012), acidification (Feely et al., 2008; Orr et al., 2005) and local or large-scale deoxygenation (Diaz and Rosenberg, 2008; Keeling et al., 2010). Such influences may change not only the amount of carbon sequestered in marine sediments but also its character, with radiocarbon serving as a key metric to detect such change.

At present, an information gap exists between the numerous in-depth biogeochemical investigations of carbon burial focused on geographically-localized regions (e.g., Bao et al., 2016; Bianchi, 2011; Castanha et al., 2008; Kao et al., 2014; Schmidt et al., 2010; Schreiner et al., 2013) and global-scale syntheses that draw upon large suites of bulk OC concentration measurements but are limited in diversity of geochemical information (e.g., Atwood et al., 2020; Premuzic et al., 1982; Seiter et al., 2004, 2005) and lack sedimentological context. Consequently, current global-scale budgets and global-scale Earth System Models (ESMs) do not resolve regional or small-scale variability (Bauer et al., 2013), and are limited by our current understanding of variability in biogeochemical and sedimentary processes that influence sedimentary organic matter composition and reactivity (Arndt et al., 2013; Bao, R. et al., 2018; Levin and Sibuet, 2012; Middelburg, 2018). Snelgrove et al., (2018), for example, argues that robust estimates of sediment carbon turnover are impeded by high spatial variability in sediment carbon properties. Increasingly powerful Region Oceanic Model Systems (ROMS) models (e.g., Gruber et al., 2012) and statistical methods for geospatial analysis (e.g., van der Voort et al., 2018; Atwood et al., 2020) hold the potential to utilize information from local-scale studies and inform ESMs, but these require mining and collation of existing data and merging this with new observations. Spatially-resolved datasets for marine sedimentary OC are beginning to emerge (e.g. Inthorn et al., 2006; Schmidt et al., 2010), including radiocarbon measurements (e.g., Bao et al., 2016; Bosman et al., 2020). The latter information is likely to increase in availability with the advent of natural-abundance ^{14}C measurement via elemental analysis coupled with gas-accepting accelerator mass spectrometry (AMS) systems (McIntyre et al., 2016; Wacker et al., 2010) that enable routine, high-throughput ^{14}C measurements.

Overall, there is a strong need to synthesize information related to not only OC content, but also its composition and depositional context, from separate region-based studies. Merging of this information to provide pan-continental margin ocean floor data resources would enable development of robust budgets and detection in changes in the magnitude or nature of carbon stocks. In addition to the content and radiocarbon characteristics of OC that are of value in constraining the provenance and reactivity of OM (Griffith et al., 2010), other geochemical characteristics of organic matter, including the elemental composition (e.g., C/N ratio) abundance, stable isotopic (^{13}C, ^{15}N) and molecular (biomarker) composition of organic matter, as well as contextual properties such as sedimentation rate, mixed-layer depth, bioturbation intensity, and redox conditions (Aller and Blair, 2006; Arndt et al., 2013; Griffith et al., 2010a) are needed to provide a holistic depositional perspective. With on-going analytical advances that facilitate more rapid and streamlined sediment analysis, it is anticipated that there will be substantial increases in data availability and diversity, highlighting the urgent need to compile, organize and harmonize existing datasets.

2. The MOSAIC database

In this study, we present MOSAIC (Modern Ocean Sediment Archive and Inventory of Carbon) – a database designed to provide a window into the spatial variability in geochemical and sedimentological characteristics of surficial ocean sediments on regional to global scales. MOSAIC represents the starting point of an on-going endeavor to compile from data from prior and on-going studies in order to build a comprehensive, continental margin-centric picture of the distribution and characteristics of organic matter accumulating in modern ocean sediments. The database infrastructure has been configured for facile incorporation of new data, for expansion of included parameters, as well as for retrieval of data in an accessible and citable format. MOSAIC is realized in an interactive web environment which allows users to visualize, select and download data. This infrastructure is built using open-source (or optional open-source) software (SI Table 1). The overarching goal is for MOSAIC to serve as a data platform for the scientific community to explore the nature and causes of spatial patterns of biogeochemical signatures in ocean sediments.

2.1. Database scope and content

2.1.1. Spatial and depth coverage and georeferencing

The focus of MOSAIC is on the coastal ocean (continental margins) with limited inclusion of data from deep ocean settings. Attention is also restricted to surficial sediments (nominally the upper ~ 1m) that are most effectively sampled with shallow coring systems designed to recover an intact sediment-water interface (e.g., hydraulically-damped multicorer, box corer). The rationale is because of the focus on processes associated with deposition, early diagenesis, and burial of organic matter, rather than on down-core investigations used for paleooceanographic and paleoclimate reconstruction. Sediment depth profile data can be primarily used to examine diagenetic profiles, and to constrain sedimentation rates, mixed layer depths, redox gradients, as well as to determine carbon fluxes and inventories.

2.1.2 Scope of data acquisition

The data currently comprising the MOSAIC database was extracted from over two hundred publications. No unpublished data is included in the on-line version, and the focus of the database in this initial phase of implementation is on an initial suite of commonly measured sediment parameters (e.g. sampling depth, carbon content and $\delta^{13}C$) that are available in high abundance. A non-exhaustive list of the most important parameters cataloged in the MOSAIC database can be found in Table 1. A more comprehensive list of parameters that are available in the SQL framework can be found in the Supplemental Information (SI).

2.1.3 Core parameters

The database was established based on selected key parameters, with a particular emphasis on the radiocarbon content of OC, as well as other basic properties that provide broader geochemical and sedimentological context (Table 1). The former include total organic carbon (TOC) and total nitrogen (TN) content, organic carbon/total N ratios, and the carbon isotopic composition ($\delta^{13}C$ and ^{14}C values) of OC. Sedimentological parameters are yet to be implemented in the on-line version but will include parameters such as grain size, mineral specific surface area, mixed layer depth, oxygen penetration depth, sedimentation rate, porosity and dry bulk density.

2.2 MOSAIC Structure

The normalized relational database structure of the MOSAIC database was created using the open-source MySQL software (MySQL Workbench Community for Ubuntu 18 version 6.3.10). The relational aspect of the database means that data (e.g., related to sample or location-specifics) are stored in data tables which are connected (or related) by a unique identifier. "Normalized" implies that in the structure of the database redundancies are eliminated (e.g., a variable such as water depth occurs only once in the database, Codd, 1990). A schematic of the detailed database structure can be found in SI Figure 2. The database structure contains entries for key geochemical parameters pertaining to ocean sediment core samples, including organic matter content, isotopic signature, and composition, as well as texture and sedimentological parameters. Information can be collected for bulk samples as well as, for example, size and density fractions. Furthermore, it is designed to enable additional modules that can accommodate data related to other sample suites such as sinking particulate matter from the ocean water column (e.g., time-series sediment traps), or riverine samples. It includes is an exclusivity option which can be used to indicate if data is in the public domain or not (e.g., pending publication of separate contributions).

Reporting conventions are detailed in the SI Table 2. Units as specified in the original papers were used (listed in SI). Where possible ^{14}C information was collected as Δ^{14}C, alternatively it was collected as Fm, and all Δ^{14}C values were converted to Fm when sampling year was available (Stuiver and Polach, 1977). Ongoing efforts are underway to further harmonize the data and convert all data to Δ^{14}C for the next iteration for the MOSAIC database.

2.3 The MOSAIC Pipeline

There is a five-step pipeline for incorporation of data into MOSAIC. These are: (1) data ingestion, (2) quality control, (3) transformation and structuring and (4) addition to a user-friendly MySQL database interface, which is (5) available for users via a website (Figure 1). This design enables users to query the collected data and augment and extend the existing database using familiar spreadsheet software (Microsoft Excel®, LibreOffice). The associated app allows any user to interactively select, visualize and query data without using database (SQL) syntax (SI Figure 1).

2.3.1 Data ingestion

Input of data to the database is possible by filling in a pre-structured spreadsheet file with set vocabularies. The user selects relevant parameter inputs from drop-down menus that streamline data entry and assist in execution of subsequent SQL queries. Excel files were designed for specific datasets, and within each Excel file there are three sub-tabs corresponding to groups of the normalized MOSAIC SQL database (more details on database structure are provided in the database). These tabs are (i) sample-related tab, (ii) geopoint-related tab (i.e., location), (iii) author-related tab (i.e., paper). Certain variables pertaining to sample coordinates and depth are required for data submission (i.e., latitude, longitude, water depth and sample core depth). In this first version of MOSAIC, filled-in spreadsheet files with specified units and pre-defined lists can be sent to mosaic@erdw.ethz.ch[1] for ingestion into the database.

2.3.3 Data quality

2.3.3.1 Initial data collection

The current MOSAIC dataset was initiated by manual mining of an initial subset of peer-reviewed oceanographic papers that contained substantial TO^{14}C datasets (e.g., Griffith et al., 2010) from different continental margin systems. This enabled the collecting researcher to be trained in the process of data evaluation and handling. MOSAIC was further expanded by extracting data from a broader suite peer-reviewed papers which were found using the search engine Google Scholar, with search terms including “organic carbon in surficial/surface sediments”, “TOC in surficial/surface sediments” and “radiocarbon/^{14}C in surficial/surface sediments”. Data was, where necessary, converted to common units. For instance, all coordinates were converted to the WSG84 coordinate systems, all total organic carbon was converted to percentages, and sample depth to centimeters. More details can be found in SI Table 1.

2.3.3.2 Data quality control

Quality control of the input data is implemented via a python script tailored to the pre-defined spreadsheet files. This script auto-checks the values of key parameters such as latitude, longitude, carbon and nitrogen content, ^{13}C, ^{14}C, $CaCO_3$ content, SiO_2 content and sediment texture-related parameters. The auto-check produces a log file with flags for unexpected values. In turn, the flags point to the exact line containing possible out-of-bound values. For example,

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[1] Data ingestion files MOSAIC_data_input_file.xlsx or MOSAIC_data_input_file.ods are available with this publication

for TOC (%), if values are negative, there will be a prompt "*cannot be negative, please check*", when values are > 2 and <20 there is a prompt "*is quite high. Are you sure it is correct?*" and lastly if values are > 20 there is the prompt "*value is high. Please check units*". Each flag is accompanied by a line number to locate the possibly erroneous data. Additional details can be found in the quality control script in the SI. These flags then trigger a manual quality check of the data by an expert in-house user.

2.3.3 Data transformation and structuring

The next step involves transforming data (using Python code) from Excel into csv files that are compatible with the normalized relational database structure in SQL. This is done by (*i*) adding unique identifiers to the data and (*ii*) transforming the data into appropriate csv files.
Importantly for the database structure, unique identifiers are created for each appropriate database table (SI Figure 2). For example, for a specific location, an individual sediment core may yield multiple samples (i.e., core sections corresponding to different depth intervals), with multiple measurements (e.g., ^{13}C, ^{14}C and %TOC) performed on each sample (section). In this example, the location is assigned a unique geopoint location identifier, the core receives a unique identifier, and each sample (section) is given a unique identifier. These identifiers resurface in each database table (e.g., on compositional parameters), resulting in the possibility of multiple cores and multiple sample identifiers for a single geopoint. For the creation of identifiers, the Python script finds a unique combination of coordinates (i.e., latitude and longitude), assigns an identifier and eliminates duplicates. It repeats this for all primary keys in the database.

2.3.4 MySQL interface

The Excel files designed for facile data ingestion are transformed in order to be compatible with the normalized database using a Python script. This script executes this transformation by auto-creating the compatible csv files, including the unique identifiers for the primary keys. The script can be adapted to a dataset and is provided in the SI. The MOSAIC SQL database allows for a direct upload of csv following data quality assessment, addition of identifiers and creation of csv files. At present, a member of the ETH Biogeoscience group is allocated to undertake this task upon receipt of files.

2.3.5 MOSAIC Website: User access and citing of data

The website (mosaic.ethz.ch) can be cited using the digital object identifier number (DOI) https://doi.org/10.5168/mosaic019.1. Additionally, under the tab “about this app & app version”, the date of the most recent update is included. In order to access data, users do not need to use SQL syntax. Instead, users can select data of interest using drop-down menus or by selecting data via a visual geographic interface. The selected data resulting from the query is shown in a table and can be directly downloaded as a csv file (SI Figure 1). Every datapoint is accompanied by the DOI of the original paper. When querying data through the MOSAIC website, the relational aspects of the database ensures that, for example, when a certain location is selected, all data pertaining to this point appear in the table and are downloaded. For users versed in SQL syntax, all accompanying data is available in SQL code, which can be imported in both MySQL and PostgreSQL graphic user interface software. In this format, all data can be queried in using SQL syntax.

3. Results and Discussion

3.1 Excerpts from the MOSAIC database

We provide examples of information extracted from MOSAIC (https://doi.org/10.5168/mosaic019.1, Van der Voort et al., 2019). The intention here is to illustrate broad-scale variability in OC properties rather than offer in-depth interpretations. Such interpretations would, of course, evolve as the database develops further and as additional parameters are added. The latter will be the focus of subsequent contributions.

We first show the statistical distributions of geochemical properties (Figure 3). On a global scale, TOC contents of marine surface sediments (< 100 cm) are lognormally distributed around ~1 % (mean = 1.63%, median = 1.14%; n= 8688; Figure 3a), consistent with prior observations (Keil, 2017; Seiter et al., 2004, 2005). The distribution of stable carbon isotope ($\delta^{13}C$) values of OC shows two distinct populations (mean = -22.6‰, median = -22.18‰; n = 4297; Figure 3b), likely reflecting relative dominance of terrestrial C3 plant (~-27 ‰) and marine (~-22 ‰) sources (Burdige, 2005; Sackett and Thomson, 1963). Corresponding radiocarbon contents (expressed here as Fm values) exhibit a more unimodal distribution with an average Fm value of ~0.7 (Mean = 0.7, Median = 0.73, n = 709; Figure 3c), highlighting the significant proportions of pre-aged OC in globally distributed marine surficial sediments (Griffith et al 2010).

Carbon isotopic compositions of surface sediment OC exhibit substantial variability when plotted as a function of water depth (Figure 4). Radiocarbon contents are especially variable and generally lower in shallow (coastal) areas where TOC is also relatively low (Figure 4a). Coastal areas are both prone to supply of pre-aged OC from adjacent land masses (e.g., Tao et al., 2015; van der Voort et al., 2017), as well as ageing associated with sediment reworking and lateral transport by bottom currents (Bao et al., 2016; Bröder et al., 2018). A similar pattern of variability is evident in $\delta^{13}C$ values (Figure 4b) which exhibit a larger spread on continental shelves (~-13 to -30 ‰) and converge towards higher (more ^{13}C-enriched) $\delta^{13}C$ values (~- 22 ‰) in the deeper ocean. These trends reflect trajectories and modes carbon supply both from land and the ocean to the seafloor that govern OC sequestration and resulting sedimentary signatures (Bianchi et al., 2007; Burdige, 2005). Distinguishing between and quantifying the relative importance these factors is important for understanding consequences for carbon burial (Arndt et al., 2013; Bao et al., 2019; Bao et al., 2016), and requires ancillary geochemical and sedimentological data (e.g., biomarker signatures, grain size distributions) - information that will be incorporated into a future iteration of the MOSAIC database.

Broad-scale variability in OC characteristics of surface marine sediments also emerges when properties are examined as a function of latitude (Figure 5). For example, despite considerable scatter in stable carbon isotopic compositions, there is a general trend from higher to lower $\delta^{13}C$ values with increasing latitude (Figure 5a). This could reflect latitudinal variations in the carbon isotopic composition of marine phytoplankton (Goericke and Fry, 1994), and/or changes in the proportions and $\delta^{13}C$ values of terrestrial OC inputs (e.g., balance of C_3 vs C_4 vegetation; Huang et al., 2000). Latitudinal trends in ^{14}C are less clear due to a paucity of data with sufficient geographic coverage (Figure 5b), and serve to highlight ocean regions and domains that are presently understudied with respect to this and other sediment variables.

3.2 Scientific value of MOSAIC

The compilation of data and subsequent re-analyses holds the potential to yield novel insights into the distribution and composition of OC accumulating in the contemporary marine environment, shed light on underlying processes, and identify gaps in existing data sets and spatial coverage. For example, the latter is particularly pertinent for ^{14}C data and ancillary measurements that are necessary to broadly apply isotopically-enabled models of organic turnover and burial in sediments (e.g., Griffith et al., 2010; Isla and DeMaster, 2018), as well as to constrain geographic variability in the age distribution of sedimentary OC in an analogous fashion to those of, for example, soil carbon (e.g., Shi et al., 2020). Filling such gaps is also important given increasing interest in developing robust assessments of carbon stocks in coastal marine sediments in the context of future greenhouse gas reporting protocols (Avelar et al., 2017; Luisetti et al., 2020), Moreover, regional-scale data compilation of spatially comprehensive geochemical and sedimentological information (Bao, et al., 2018; Bao et al., 2016), coupled with the application of novel numerical clustering methods (Van der Voort et al., 2018) can facilitate refinement of criteria for delineating biogeochemically provinces (Longhurst, 2007; Seiter et al., 2004), that reflect both source inputs and hydrodynamic regimes, in order to improve carbon cycle budgets and models. Spatially-resolved information on biogeochemical characteristics of seafloor sediments is also value in understanding benthic-pelagic coupling (e.g., Griffiths et al., 2017) as well as the relationships between sediment properties and the diversity and functioning of benthic ecosystems (Middelburg, 2018; Snelgrove et al., 2018). Such examples highlight the value of leveraging existing datasets, connecting various data sources and using other types of analyses (modelling, statistics) in order to garner new insights into underlying processes.

3.3 MOSAIC in context.

MOSAIC complements other ongoing efforts to collect and organize a broad spectrum of geoscientific and related data, such as the extensive PANGAEA data repository (AWI and MARUM, 2020), as well as those with more targeted missions, such as the International Soil Radiocarbon Database (ISRaD; Lawrence et al., 2020). It differs from these and other initiatives with a primary focus on (*i*) pro-actively collating data pertinent to OC burial on continental margins, (*ii*) upper sediment layers (nominally < ~ 1m) that encompass early diagenetic processes and recent deposition (as opposed to down-core studies that seek to reconstruct past ocean and climate conditions), and (*iii*) radiocarbon information that bridges to equivalent databases for other carbon cycle compartments. In this way, we envision that it will serve as a resource to enable “on-stop shopping” for biogeochemical and sedimentological information on continental margin surficial sediments. While thus far data ingested into MOSAIC has been retrieved from the primary research literature, future efforts will focus on harmonizing and linking with other databases in order to improve overall connectivity of information. The MOSAIC database has been designed to be modular and adaptable to accommodate further developments and expansion of its dimensionality, while retaining its overall (radio)carbon-centric focus. In particular, inclusion of ^{14}C data on specific fractions separated, for example, according to sediment density (Wakeham et al., 2009) or thermal lability (Rosenheim et al., 2008), or at the molecular level (e.g. Druffel et al., 2010; Tao et al., 2016). In this context, it is anticipated that MOSAIC will serve as a key research and teaching resource for biogeochemists focusing on contemporary biogeochemical processes as well as seeking to interrogate sedimentary archives to develop records of past oceanographic conditions.

4. Data Availability

The data of the database can be accessed via mosaic.ethz.ch and the DOI is https://doi.org/10.5168/mosaic019.1 (Van der Voort et al., 2019). The timestamp of the most recent update is provided on the MOSAIC main page (about this app & app version) along with the DOI. Users who would like to add data to the database can fill in the data in the Excel® templates that can be found in the SI of this paper and send it to mosaic@erdw.ethz.ch.

5. Conclusion and Outlook

In this paper, we describe the rationale behind as well as development and structure of a database (MOSAIC) focused on OC accumulating in contemporary continental margin sediments. Current data residing within MOSAIC was derived from over 200 peer-reviewed papers, with the intention that this resource will further expand both regarding data density and dimensionality, with a specific emphasis on radiocarbon as an underdetermined yet crucial property for constraining carbon cycle processes. We provide selected examples of spatial variations in bulk geochemical characteristics (e.g., ^{14}C content) of organic carbon, and envision that MOSAIC will serve as a tool to (a) better understand the nature and causes of spatial variability in biogeochemical characteristics of continental margin sediments, which in turn has ramifications for (global) carbon dynamics, seafloor ecology and socioeconomic ramifications of these aspects, and complement existing (e.g., soils, ocean dissolved inorganic carbon) and planned (riverine carbon, oceanic water column carbon) radiocarbon-centric databases for other major carbon pools.

6. Video Supplement

Accompanying this paper is a short instructional video (in SI) which explains to users how to download the data from MOSAIC (https://doi.org/10.5168/mosaic019.1, Van der Voort et al., 2019).

7. Author Contributions

Tim Eglinton led the conceptual development of the MOSAIC project. Tessa Sophia van der Voort designed, structured and filled the SQL database and also created the associated infrastructure in R, Python and Excel/LibreOffice. Thomas M. Blattmann and Daniel Montluçon provided feedback on the database structure and website development and contributed to discussion of the data. Mohammed Usman collected the MOSAIC data and contributed to the data evaluation. Thomas Loeffler enabled the set-up of infrastructure and contributed to the technical components of the paper. Maria Luisa Tavagna contributed to the concept development. Nicolas Gruber contributed to the MOSAIC concept development and project set-up. T.S. van der Voort prepared the manuscript with help of all co-authors.

8. Competing interests

All co-authors declare that they have no competing interests regarding this manuscript.

9. Acknowledgements

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10. Tables and Figures

Table 1 Overview of key variables and their abundance in the MOSAIC database. An exhaustive list can be found in the SI.

	Main variable	Unit	Number of datapoints	Required (Y/N)
Geopoints	Latitude	Degrees (°)	8706	Y
	Longitude	Degrees (°)	8706	Y
Samples Ocean	Exclusivity Clause	Y/N	8706	Y
	Water depth	m	4297	Y[2]
	Sample core depth (average)	Centimeter (cm)	7147	Y
	Sample name	VARCHAR	-	N
	Total Organic Carbon (TOC)	Percentage (%)	8688	N
	$\delta^{13}C$	Permil (‰)	4297	N
	Fm	fraction	709	N
	C:N Ratio	Ratio	504	N
	SiO_2	Percentage (%)	370	N
	$CaCO_3$	Percentage (%)	1668	N
Articles	Article doi	VARCHAR	235	N

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[2] There are ongoing efforts to collect all water depth information, ancillary information will be attained using the GEBCO bathymetric grid (GEBCO, 2020).

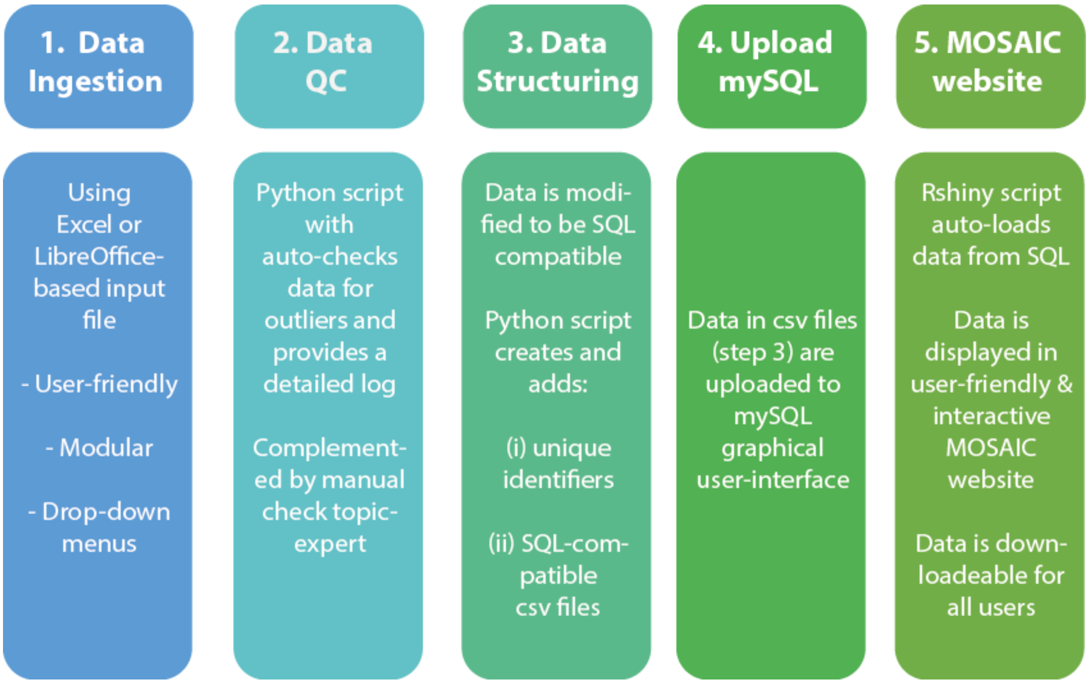

Figure 1 Overview of the MOSAIC pipeline. Data ingestion (1) is done with excel-based input files. Then, (2) data quality control is achieved using is a python script which auto-checks the data for outliers and produces a subsequent log. Afterwards, (3) unique identifiers are added and the data is transformed into SQL-compatible format in Python. Subsequently, (4) data addition to the MOSAIC database occurs within the MySQL GUI, and finally (5), the data is auto-updated within the R environment and the Rshiny app is updated.

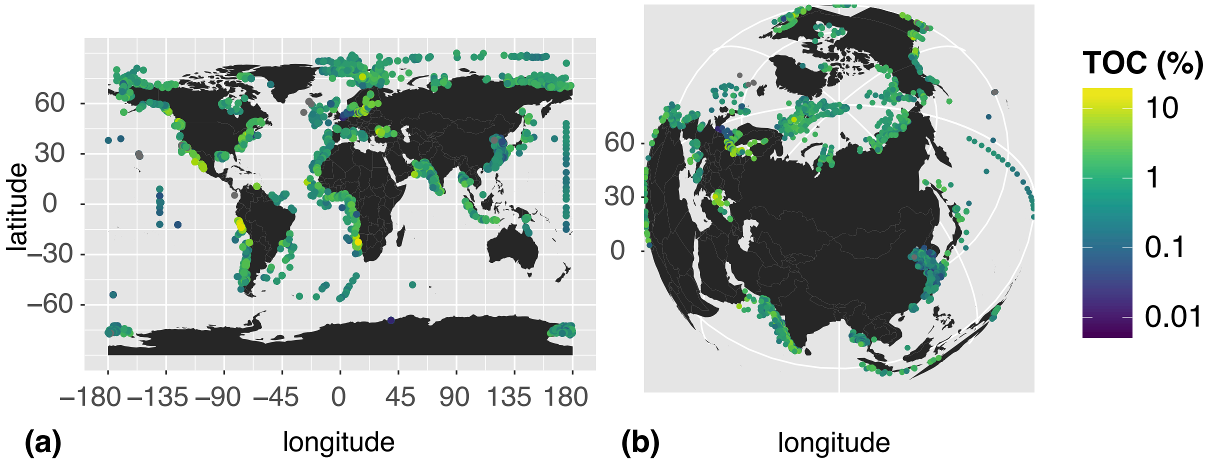

Figure 2 distribution of all datapoints across the globe (a) from a standard projection and (b) from a polar-centric projection. Colours indicate TOC content (%).

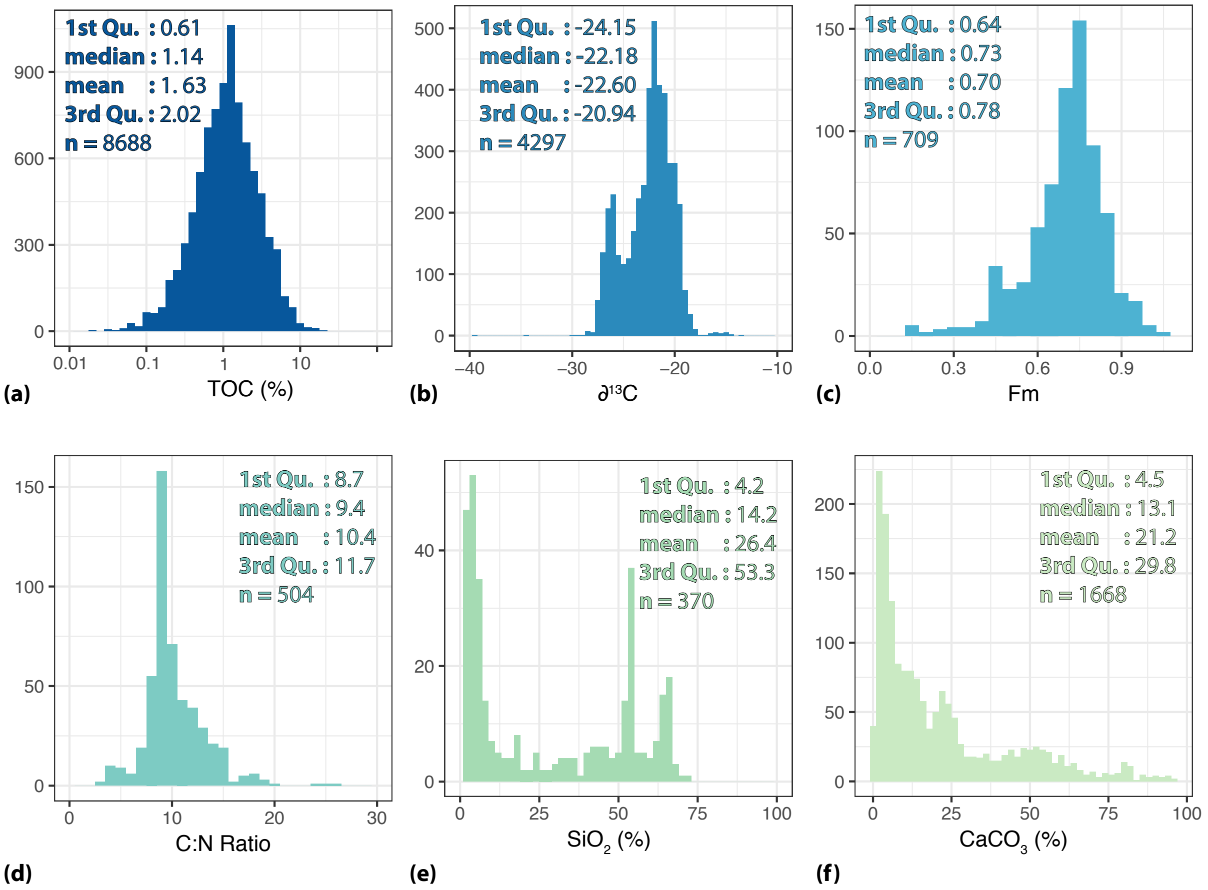

Figure 3 Distribution of data for key sedimentary parameters included in MOSAIC: (a) TOC shows a log-normal distribution which peaks at ~1.1 % and averages around 1.6 %, (b) $\delta^{13}C$ values show two distinct peaks at ~-22 and ~27 permil. (c) radiocarbon shows a strongly depleted signature with the fraction modern value averaging at ~0.7. The (d) C:N ratio global average is ~ 10. The median (e) silicate (SiO_2) and (f) carbonate ($CaCO_3$) contents are ~14%, and ~ 13%, respectively

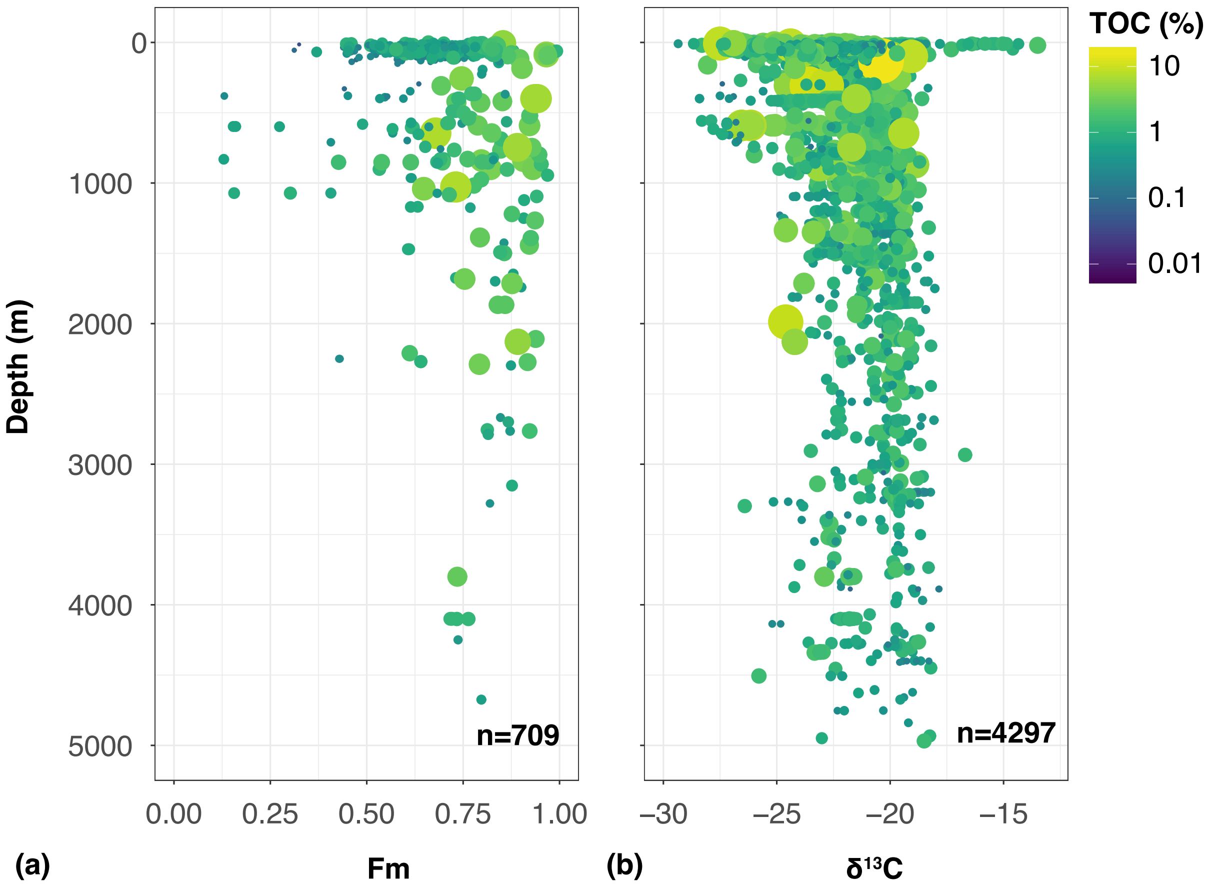

Figure 4 (a) Fraction modern versus depth, bubble size and colour indicate sample TOC content (%). On ocean shelves (shallow depths) we observe generally low TOC values and depleted Fm values. Carbon in deeper oceans show a larger spread in ages and TOC content. (b) δ^{13}C modern versus depth, bubble size and colour indicate sample TOC content (%). On ocean shelves (shallow depths) we observe a large spread in ∂^{13}C values. Carbon in deeper oceans show a smaller spread and converge to less depleted δ^{13}C values.

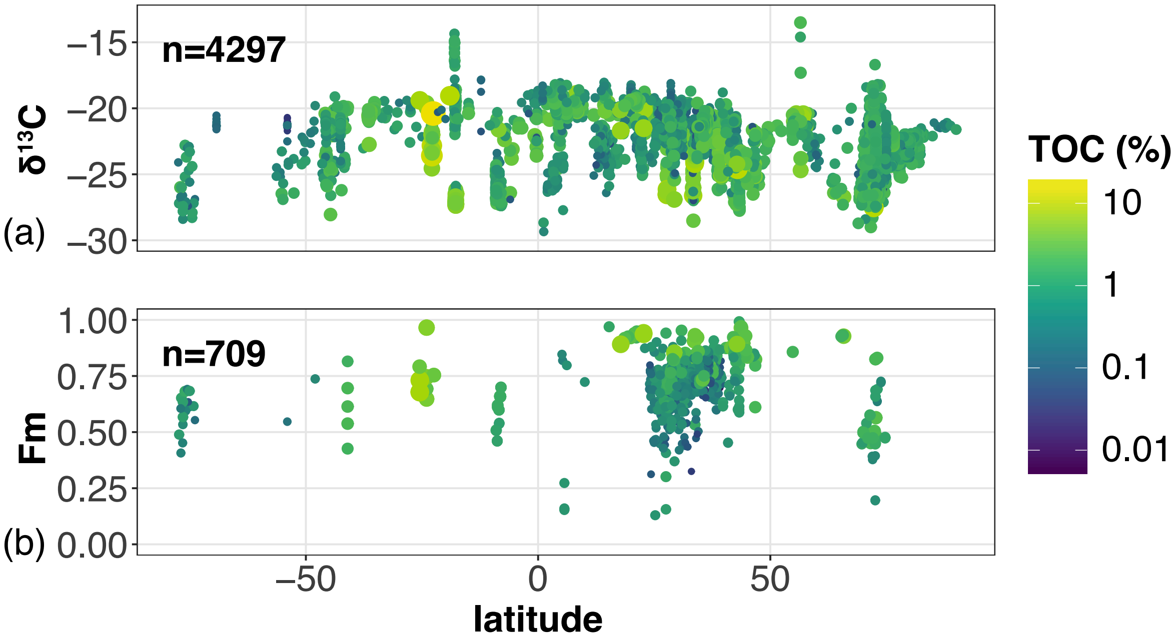

Figure 5 latitude (a) versus δ^{13}C (‰) and (b) Fraction Modern (Fm), colour indicated by TOC content (%). The δ^{13}C tends to be less depleted in the low-latitudes. The Fm shows a sampling bias in the mid-range latitudes and also appears to be less depleted in the lower latitudes.

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