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Marine sediment cores database for the Mediterranean Basin: a tool for past climatic and environmental studies

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Abstract: Paleoclimatic data are essential for fingerprinting the climate of the earth before the advent of modern recording instruments. They enable us to recognize past climatic events and predict future trends. Within this framework, a conceptual and logical model was drawn to physically implement a paleoclimatic database named WDB-Paleo that includes the paleoclimatic proxies data of marine sediment cores of the Mediterranean Basin. Twenty entities were defined to record four main categories of data: a) the features of oceanographic cruises and cores (metadata); b) the presence/absence of paleoclimatic proxies pulled from about 200 scientific papers; c) the quantitative analysis of planktonic and benthonic foraminifera, pollen, calcareous nannoplankton, magnetic susceptibility, stable isotopes, radionuclides values of about 14 cores recovered by Institute for Coastal Marine Environment (IAMC) of Italian National Research Council (CNR) in the framework of several past research projects; d) specific entities recording quantitative data on δ^{18}O, AMS ^{14}C (Accelerator Mass Spectrometry) and tephra layers available in scientific papers. Published data concerning paleoclimatic proxies in the Mediterranean Basin are recorded only for 400 out of 6000 cores retrieved in the area and they show a very irregular geographical distribution. Moreover, the data availability decreases when a constrained time interval is investigated or more than one proxy is required. We present three applications of WDB-Paleo for the Younger Dryas (YD) paleoclimatic event at Mediterranean scale and point out the potentiality of this tool for integrated stratigraphy studies.

Keywords: Database; spatial analysis; marine sediment cores; climatic paleoproxies; Mediterranean Sea

1 Introduction

The Earth's globally averaged surface temperature rose by approximately 0.85°C over the period 1880-2012 [1]. However, regional climates result from complex processes that meaningfully vary with geographical areas and consequently differently respond to changes in climate oscillations.

Despite conflicting opinions on the reliability of paleoclimatic "proxies" and the consistency of results obtained from simulation models for the reconstruction of past climates, homogeneous long term time series remain the only valid analytical tool to study the Earth's dynamic processes of the past, mainly in conditions different from today's. Moreover, they have proven to be crucial in the assessment of accountability of medium and long term predictions models [1–4].

Natural archives as tree rings, spelothems, ice and sediment cores, which contain diatoms, foraminifera, microbiota, pollen and charcoal, represent valuable resources to recover quantitative information on past regional climates and to define high-resolution climatic reconstructions for last millennia [1]. The knowledge of past climatic variations can provide viable insights for prediction of how and to what extent climate might change in the future.

In the last years, many international projects have focused on the development of marine data infrastructures for managing different sets of data from *in situ* and remote observation of the seas and oceans. In particular, the Eu-

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ropean project Geo-Seas (EU-FP7 Seventh Framework Programme) has resulted in an infrastructure that manages data of 26 institutions working in marine geology and geophysics located in 17 European countries. The Geo-Seas infrastructure is aligned with the European directives as well as with the last Framework Program both at the European and global scale as GEO [5], GEOSS [6], GMES [7], EMODNET [8] and INSPIRE [9]. This system also inherits the SEADATANET infrastructure [10] implemented to manage marine sediment, geophysical and oceanographic data and to provide products and services. This infrastructure hosts the data of the EU SeaSed project [11], which in turn collects data from EuroCore [12], EUMARSIN [13] and EUROSeismic [14]. Another important database is published by the National Geophysical Data Center [15], which stores information on marine and lacustrine sediment cores provided by 23 institutions from all over the world. Data from these archives (data center) are mainly metadata on the location of the marine sites and cruises of the last century.

Recently, Italian National Research Program (PNR 2011-2013) supported the Project of Interest NextData [17] focused on retrieval, storage, access and diffusion of environmental and climate data from mountain and marine areas. Concerning the marine areas, this project aimed at collecting and storing paleoproxy data useful to achieve information on past climate of Mediterranean, and to understand through integrated stratigraphic studies the timing of the climatic changes and their main features.

Mediterranean Sea is a semi-enclosed basin with an antiestuarine circulation [18–20] and its geographical location between the arid zone of the subtropical high (north Africa) and the zone affected by westerly air flows [21–23] makes it very sensitive to respond quickly to atmospheric forcing and/or anthropogenic influences. These features make the Mediterranean Sea a natural laboratory for paleoenvironmental studies and past climatic oscillations monitoring.

For the purposes of the present research, we selected and analysed about 200 published scientific papers to recover climatic proxies from over 6000 cores drilled in the Mediterranean Sea. In addition, unpublished data (kindly provided by two CNR research institutes, Istituto di Geologia Ambientale e Geoingegneria- IGAG and Istituto per l'Ambiente Marino Costiero - IAMC) and new sites retrieved in the frame of NextData Project, were also taken into account to implement a new archive suitable for studies on environmental and climatic changes.

Aiming at sharing metadata and paleoclimatic proxies with the scientific community, a logical scheme of a database was defined and then implemented according to the standards required by the project: Geonetwork [24] and Weather and Water Database [25]. The data was also recorded into a Microsoft Access personal database managed by the authors.

The main new outcome of this database is to record for the Mediterranean Basin: a) the cores for which the paleoproxies have been studied (planktonic and benthic foraminifera, pollens, diatoms, dinoflagellates, calcareous nannoplankton, magnetic susceptibility, stable isotopes, radionuclides, AMS ^{14}C age and tephra layers) and the associated references; b) the quantitative paleoproxy data of marine cores acquired during the projects CARG [26], VECTOR [27] and NextData; c) quantitative data on tephra layers, oxygen stable isotope (δ^{18}O) and AMS ^{14}C from Mediterranean marine cores published in the scientific literature.

The database also records the describing features of the oceanographic cruises and cores (metadata) and it takes advantage of a link with a Geographical Information System (GIS) to visualize the data distribution and elaborate thematic maps that supply a synoptic view of data disposal for single proxies.

2 Study area

The Mediterranean Sea, divided into western and eastern basins connected to each other through the Strait of Sicily, occupies an area of about 2.5 million km^2 (Figure 1). Two main tectonic structures, the Hellenic Trench and the Mediterranean Ridge, control the complex physiography of the eastern Mediterranean [28]. Neotectonic processes and fluvio-sedimentary systems mainly feature the seascape, which is characterized by a variable bathymetry, reaching the maximum depths of ca. 4.2 km in the Ionian Abyssal Plain and of ca. 3.2 km in the Herodotus Abyssal Plain.

The continental shelf is narrow off Peleponnese, Crete, and in southern and northern Turkey, whereas it is well developed in the areas under the influence of the Nile River (Levantine Sea) and the Po River (Adriatic Sea), where large portions are shallower than 100 meter [28].

In the western Mediterranean basin the continental shelf is narrow, extending more than 50 km in width only off the Ebro and Rhône Rivers, mainly due to the progradation of deltaic systems (Figure 1); it is also wide off the north of Tunisia, where its morphology is structurally controlled. Bathyal plains occupy large areas located between the Balearic Islands, north of Africa and Sardinia with depths reaching 2.8 km, and in the Tyrrhenian basin with depths up to 3.43 km [28]. Basin floors are shallower,

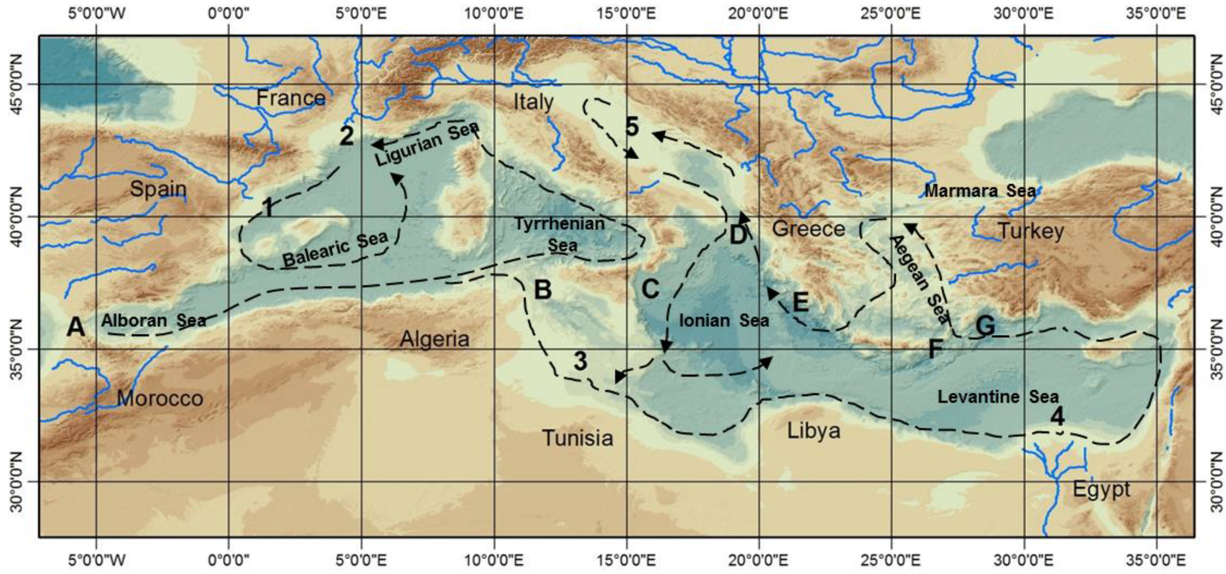


Figure 1: Location map of study area. Black lines follow the path of sea surface water circulation. The numbers indicate the areas with wide continental shelf while the capital letters point out the main straits.

but wider, than those in the east. The Mediterranean Sea is characterized by an anti-estuarine circulation pattern forced by the negative hydrological balance and density gradient with the Atlantic Ocean [29]. The oceanic surface water enters from the Atlantic Ocean, spreads into the Mediterranean Sea, and mixes with “resident” surface waters, to form the Modified Atlantic Water (MAW) located in the upper 100–200 m of the water column. It is characterized by a salinity range from ~36.5 psu at Gibraltar, 38.0–38.3 psu in the western Mediterranean to over 39 psu in the easternmost part of the basin, due to evaporation and mixing [30, 31]. The surface basin circulation is characterized by strong sub-basin scale activity, with mesoscale features, eddies and meanders [32]. The overall antiestuarine circulation of the Mediterranean Sea (entering as nutrient-poor water, out-flowing as nutrient-enriched Levantine Intermediate Water) makes this basin one of the most oligotrophic oceans in the world [33, 34], which shows a significant west–east trophic gradient, with a nutrient depletion increasing eastward [35].

3 Marine sediment sites collection and database design

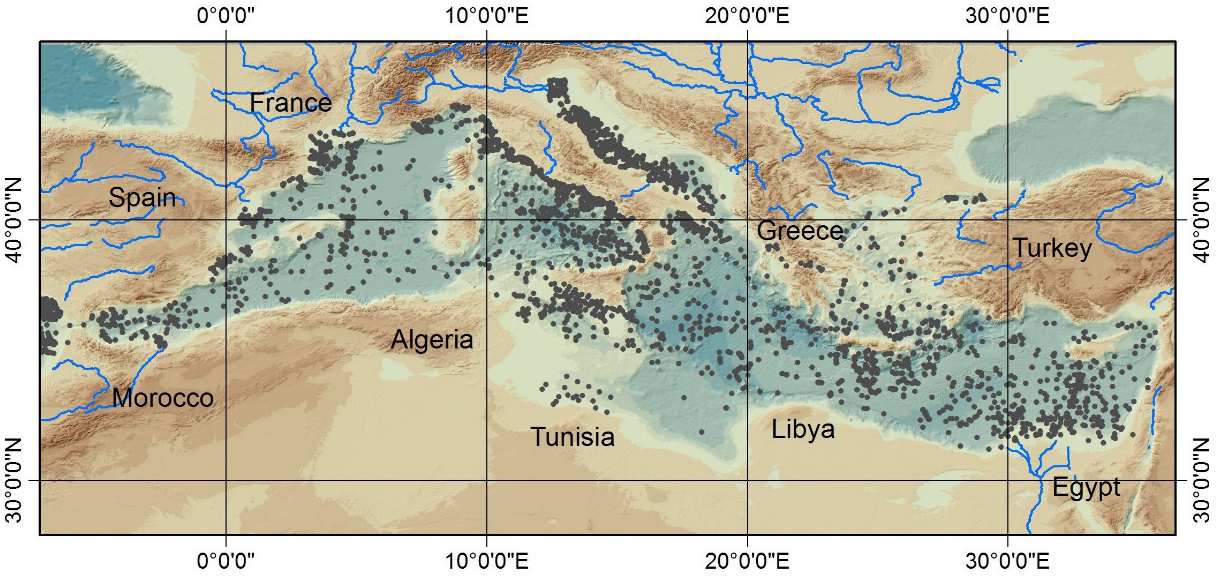
The check of the available data on marine sites, aimed at recognizing the proxies suitable for paleoclimatic and environmental studies, represented the first step of this research. Among all the accessible cores, we considered only those retrieved by drilling device systems that recover undisturbed samples (*i.e.* gravity and piston corer systems). Data of 6000 cores were collected mainly from the previously quoted sources (Figure 2).

This information was used to identify the data objects (entities), the attributes of the data objects (domains), the relation between objects and the integrity constraints. Figure 3A and 3B illustrate the main entities of the database providing both the metadata and quantity data, the primary and the foreign keys, the relation and the cardinality between the entities. Appendix 1 describes in detail the codes structured for the primary keys.

The principal entity of the logical model is labelled “*site”* and it records the geographical position of a single site as well as the main information describing the core samples. The entity “*cruise”* archives the attributes on vessels and cruises (box on the left in Figure 3A).

The entity “*references*” records the information from published scientific literature, such as: the author name, the journal where the article was published and the type of studied paleoproxy. The last field, labelled “*note*”, is dedicated to additional information such as the occurrence of sapropel, geochemical analysis, alkenones analysis, age modelling.

The entity “*site*” is correlated to other entities designed to record quantitative data on *AMS* ^{14}C *age, stable isotopes, tephra* proxies, *benthic and planktonic foraminifera, pollens, diatoms, dinoflagellates*, *calcareous nannoplankton*, *magnetic susceptibility* and *radionuclides* (box on the right in Figure 3A). The core of these entities is



Sea/Ocean	Cores (%)	Sea/Ocean	Cores (%)
Adriatic Sea	11,93	Marmara Sea	1,15
Aegean Sea	4,09	Mediterranean Sea-Eastern Basin	29,77
Alboran Sea	2,77	Mediterranean Sea-Western Basin	13,71
Balearic Sea	1,98	Tyrrhenian Sea	28,79
Ionian Sea	4,70	Strait of Gibraltar	0,02
Ligurian Sea	1,12		

Figure 2: Overview of the location of marine sediment cores (black circles) drilled in the Mediterranean Sea and of their abundance in the single sectors of Mediterranean Sea.

the element "sample", to which each information is linked; the table organization slightly changes in response to the features of the single proxies.

Particular attention was focused on AMS ^{14}C, δ^{18}O and tephra proxies and on their key role in the paleoclimatic studies.

AMS ^{14}C ages and tephra layers are mostly aimed at evaluating the synchrony/diachrony of the climatic changes [36] and to carry out paleoenvironmental studies [37]. For these two proxies, several tables were implemented to register the information reported in the scientific papers.

For the AMS ^{14}C, the depth of sampling, radiocarbon age, calibrated age including error, were recorded in specific fields. The field "note" contains any other useful information (*e.g.* alkenones, Mg/Ca) characterized by a low repeatability and that therefore cannot be registered in a thematic field. Moreover, in the present work all the radiocarbon ages were re-calibrated through the use of the software OxCal 4.2 using the INTCAL13 and MARINE13 dataset [38] and reported in the field "re-calibrated age" (Figure 3B).

The tephra samples were classified as tephra or cryptotephra and for each one the eruption name, source, composition, age, references and correlation with other equivalents were registered (Figure 3B).

For the oxygen isotope, the depth, the age and δ^{18}O values measured on the planktonic foraminifer *Globigerinoides ruber* var. white and *Globigerina bulloides* were recorded in a specific table (Figure 3B). The frame of the database is very flexible, other proxies and new quantitative data (*e.g.* presence of sapropel, chemical analysis of tephra, quantitative data on radionuclides) can be added following an analogous scheme. In Figure 3A, the entities "*holder*", "*device type*" and "*physiographic province*" represent three important dictionaries for: a) ensuring that the values entered into a field are legal to prevent the recording of erroneous values, b) guaranteeing the meaning of each term used within the database, avoiding a different data interpretation, c) sharing information across multiple projects [39, 40].

The database was normalized to avoid the redundancy of data. The performed normalization followed three normal forms: a) the first, a database contain only atomic value (value cannot be divided) and there are no repeating groups (more fields containing the same type of information); b) the second, all non-key attributes are fully func-

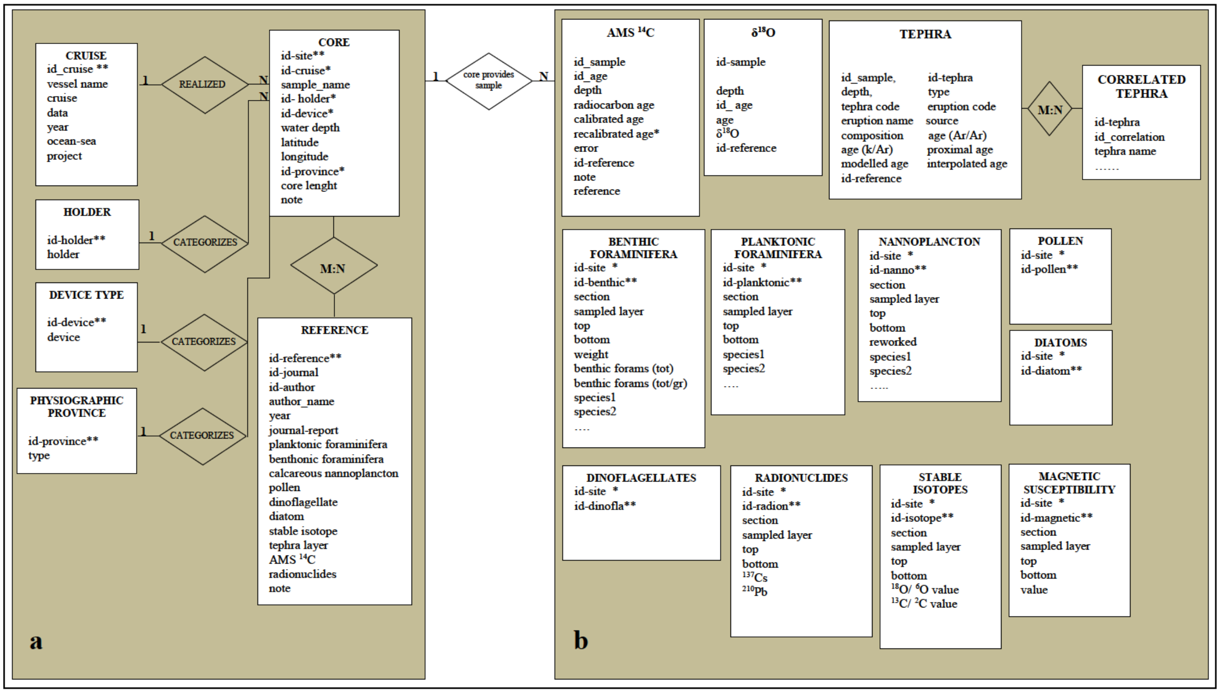


Figure 3: Marine sites entity-relationship diagram, the double asterisk shows the primary key and the single asterisk shows the foreign key. The entities enclosed in the box on the left record the metadata, those in the box on the right record quantitative data from CNR-IAMC projects and from scientific literature.

tional dependent on the primary key and c) the third, there is no transitive dependencies between tables, it arises when one non-key attribute is functionally dependent on another non-key attribute [39, 40].

4 Application programs to implement a database and share data

WDB-Paleo and SHARE GeoNetwork are the systems adopted in the frame of NextData Project to record and share paleoclimatic data (Figure 4A, 4B).

4.1 WDB-Paleo

WDB-Paleo is an adapted version of WDB [25] created to satisfy the need to record paleoclimatic data [41]. This database is initialized in two different ways according to the required data (*SEACORE-SDB* and *ICECORE-IDB*). The WDB is an open-source database (GNU Public License) for the collection of hydrological and oceanographic data, based on the open-source PostgreSQL relational database [42]. This database was founded in 2008 within the PROFF Project of the Norwegian Meteorological Institute (met.no) and is now available with source code in version 1.5.0. The server architecture is composed of a command interface (WDB Command Interface or WCI - loading programs), the core of WDB database itself (developed in Postgresql) and a series of programs to load data from the Data Storage System (Figure 4A).

The data can be extracted from the WDB-Paleo in csv (comma-separated values) files; they can be opened in several programs, even if spreadsheet programs such as Microsoft Excel, Open Office Calc and Google Docs, are the most used by users.

In addition, we chose to implement also a personal database [43] recording the tables previously quoted in the logical model (Figure 3A, 3B).

To date, we implemented the tables, reported in the box on the right of Figure 3A, for all paleoclimatic proxies defined for the cores C90 and C836 (collected in the frame of CARG Project), C90-1m core (collected in the frame of VECTOR Project), and cores C5, C5-2-SW104, C6-SW104, C13-SW104, ND2, ND5, ND6, ND9, ND10, ND11, ND13 (collected in the frame of NextData Project). An example of the quantitative data for planktonic foraminifera and calcareous nannoplankton recorded in WDB-Paleo was reported in Table 1A,B. Several tables were also implemented to reg-

Table 1: Example of planktonic foraminifera (A) and calcareous nannoplankton (B) data recorded into WDB-Paleo.

id_sample	id_planc	section	sample level	top (cm)	bottom (cm)	globigerina bulloides (%)	globigerinita glutinata (%)	gobigerinoides elongatus (%)
IAM00A080	C5_A139	F	100-99	246	247	26,03	4,79	-
IAM00A080	C5_A140	F	99-98	244	245	23,48	6,35	14,92
IAM00A080	C5_A141	F	98-97	243	244	17,44	9,3	-
IAM00A080	C5_A142	F	97-96	241	242	20,57	13,91	14,2
IAM00A080	C5_A143	F	96-95	240	241	32,16	4,02	13,07
IAM00A080	C5_A144	F	95-94	238	239	30,96	3,55	14,21

id_sample	id_nanno	section	sample level	top (cm)	bottom (cm)	emiliana huxley (%)	small Gephyrocap (%)	small Placoliths (%)
IAM00A080	C5_A001	F	100-99	246	247	-	-	99.00
IAM00A080	C5_A002	F	99-98	245	246	65.72	2.123	27.56
IAM00A080	C5_A003	F	98-97	243	244	52.92	0.92	44
IAM00A080	C5_A004	F	97-96	241	242	50.29	0.29	43.19
IAM00A080	C5_A005	F	96-95	240	241	-	-	99.0
IAM00A080	C5_A006	F	95-94	239	240	67.97	3.59	23.20

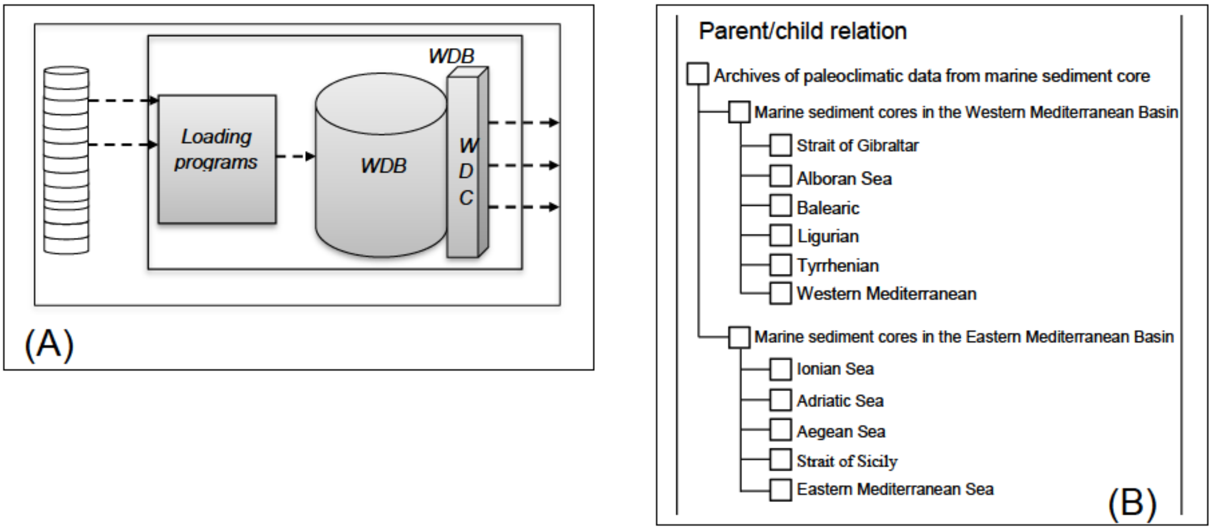


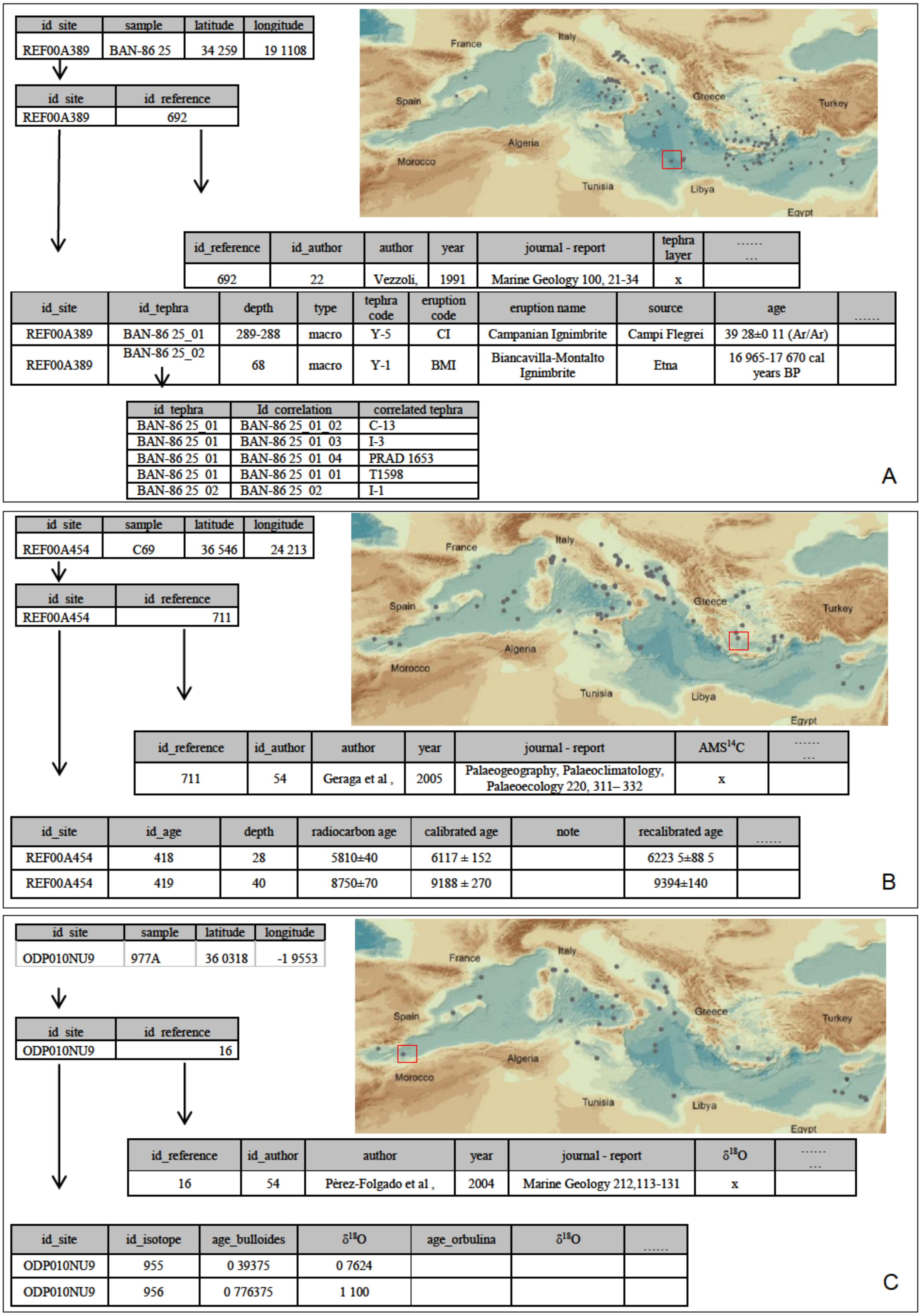
Figure 4: Schematic representation of WDB-Paleo architecture (A) and parent-child scheme adopted to publish marine sediment cores metadata on SHARE GeoNetwork (B).

ister quantitative data on tephra layers, AMS ^{14}C and δ^{18}O paleoproxies from scientific literature (Figure 5A, B, C).

4.2 SHARE GeoNetwork

SHARE GeoNetwork, which currently manages also the paleoclimatic metadata produced by the NextData Project, was implemented to share information on Stations at High Altitude for Research on the Environment [44]. The GeoNetwork software [24] is widely used as the basis of Spatial Data Infrastructures [45–50]; it is part of the Open Source Geospatial Foundation (OSGeo). This software has been developed following the principles of a Free and Open Source Software (FOSS) and is based on International and Open Standards for services and protocols, such as the ISO-TC211 and the Open Geospatial Consortium (OGC) specifications.

The architecture is focused on spatial data, metadata and interactive map visualisation. The system is also fully compliant with the OGC specifications in order to query and retrieve information from Web catalogues (CSW). It supports the most common standards to specifically de-



id site	sample	latitude	longitude
REF00A389	BAN-86 25	34 259	19 1108

id site	id reference
REF00A389	692

id_reference	id_author	author	year	journal - report	tephra layer	....
692	22	Vezzoli,	1991	Marine Geology 100, 21-34	x	

id_site	id_tephra	depth	type	tephra code	eruption code	eruption name	source	age	......
REF00A389	BAN-86 25_01	289-288	macro	Y-5	CI	Campanian Ignimbrite	Campi Flegrei	39 28±0 11 (Ar/Ar)	
REF00A389	BAN-86 25_02	68	macro	Y-1	BMI	Biancavilla-Montalto Ignimbrite	Etna	16 965-17 670 cal years BP	

id tephra	Id correlation	correlated tephra
BAN-86 25_01	BAN-86 25_01_02	C-13
BAN-86 25 01	BAN-86 25 01 03	I-3
BAN-86 25 01	BAN-86 25 01 04	PRAD 1653
BAN-86 25 01	BAN-86 25 01 01	T1598
BAN-86 25 02	BAN-86 25 02	I-1

id site	sample	latitude	longitude
REF00A454	C69	36 546	24 213

id site	id reference
REF00A454	711

id_reference	id_author	author	year	journal - report	AMS^{14}C	....
711	54	Geraga et al ,	2005	Palaeogeography, Palaeoclimatology, Palaeoecology 220, 311– 332	x	

id_site	id_age	depth	radiocarbon age	calibrated age	note	recalibrated age	......
REF00A454	418	28	5810±40	6117 ± 152		6223 5±88 5	
REF00A454	419	40	8750±70	9188 ± 270		9394±140	

id site	sample	latitude	longitude
ODP010NU9	977A	36 0318	-1 9553

id site	id reference
ODP010NU9	16

id_reference	id_author	author	year	journal - report	δ^{18}O	....
16	54	Pèrez-Folgado et al ,	2004	Marine Geology 212,113-131	x	

id_site	id_isotope	age_bulloides	δ^{18}O	age_orbulina	δ^{18}O	......
ODP010NU9	955	0 39375	0 7624			
ODP010NU9	956	0 776375	1 100			

Figure 5: Frames representative of data storing into WDB-Paleo for tephra layers (A), AMS ^{14}C (B) and δ^{18}O (C) paleoclimatic proxy.

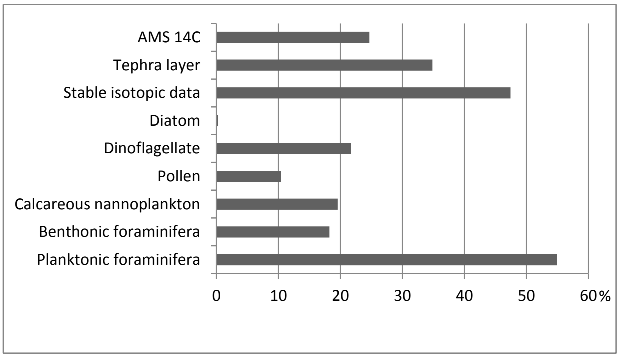


Figure 6: Plot of the availability of information on single proxies for Mediterranean sites, expressed as the percentage of cores where a specific proxy has been investigated over the total number of cores that contain paleoclimatic data.

scribe geographic data (ISO19139 and FGDC) and the international standard for general documents (Dublin Core). Moreover, it uses standards (OGS WMS) to visualise maps through the Internet [51].

The metadata of marine sediment cores were linked together by a parent/child relation according to the scheme reported in figure 4B. The parent is represented by the Mediterranean Basin, while the child is represented by the Western and Eastern Mediterranean basins in turn linked to the child of second order represented by the Mediterranean seas, according to the boundaries published by the International Hydrographic Organization [52] and the names list of the vocabulary "*C16*" [11]. *SHARE GeoNetwork* allows to visualize the geographic location of all cores and of related data reported in the pale grey box in Figure 3A.

5 Data quering and mapping

The main purpose of WDB-Paleo is to pinpoint and improve the state of knowledge on the Mediterranean Sea by recovering biotic and abiotic published proxy data of marine sediment cores useful for reconstructing the past climate of the last ca. 50 kyr. In addition, the spatialization of paleoclimatic proxies, made possible by the link of WDB-Paleo with a GIS framework, allows to draw into maps the geographical distribution of data over the whole Mediterranean basin. This last issue represents an important keypoint to understand the different response of the Mediterranean to climate forcing but also to correctly plan the future Mediterranean oceanographic expeditions minimizing cost and survey time operation.

At present, the about 6000 sites realized in the whole Mediterranean Basin are not uniformely distributed (Figure 2), being denser close to the Italian coasts (Tyrrhenian and Adriatic seas) and in the Eastern Mediterranean Basin (Table 1, Figure 2). This might be a consequence of the utmost scientific interest toward basins characterized by high sedimentation rates, sapropel depositions [53–58] and thermoaline circulation [59].

Apart from the location (ocean/sea field) known for all the cores, and the data source holder available for the 58% of sites, the other information (device type, oceanographic cruise, vessel name, core length, water depth) are retrieved for less than the 40% of the sites. Moreover, only for about 400 sites paleoclimatic proxies are available; planktonic foraminifera (54%) and δ^{18}O data (46%) are the most investigated followed by tephra characterization and AMS^{14}C data (Figure 6). Additionally, multiproxy investigations were very often restricted to the comparison of two proxies.

In the next sub-sections, three applications of WDB-Paleo are illustrated in several maps which provide the spatial distribution and the key role of tephra layers, AMS^{14}C ages and δ^{18}O data for climatic studies of the past. The last 15 kyr is the time interval considered for these applications and the attention was focused on the Younger Dryas or Greenland Stadial I (GS-I) climatic event (11.7-12.95 kyr BP) [60–62]. The recordable outcomes of this event are documented over a wide area in the late glacial period and is recorded as a cold interval [60, 63–66].

5.1 Tephra

The juvenile particles making up tephra layers, together with a minor lithic component, are mostly made of glass fraction and minerals which can be "fingerprinted" by chemical and isotopic methods thus allowing to define the source and sometimes the eruptive event. Since they are the result of "instantaneous" events in terms of geological times [67], tephras are considered powerful "isochronous time-lines" to link archives from different settings and, if a numerical age can be attributed, they become the most suitable proxy used for the age modeling of sedimentary records. Along with the contribution to the paleoenvironmental and paleoclimate research, tephras can also provide a detailed record of volcanic activity and recurrence rates during the Quaternary. This is particularly true when dealing with tephras interbedded within deep sea and lacustrine successions (characterized by continuous records) with no or little sedimentary disturbances. In this case, even thin tephras associated with small, local eruptions or large distal eruptions can be preserved.

In this framework, the WDB-Paleo database provides a number of striking outcomes for correlation of marine archives through tephra deposits. In fact, it makes easy to identify the occurrence of a particular tephra as a result of a simple query, which might either be a specific volcanic source, chemical composition, age or distal equivalent.

Dealing with widespread markers, which represent powerful isochrones, different archives can be linked throughout the Mediterranean. The most representative is Y-5 [68], *i.e.* the tephra corresponding to the huge Campanian Ignimbrite eruption from Campi Flegrei (ca. 39 ka - Figure 7A) [69]. The use of such correlating tools allows to bypass issues from any possible leads or lags of climate changes evidenced by other proxies (*e.g.* foraminiferal distribution, oxygen isotope) at both regional and Mediterranean scales, provided the tephra correlation is correct [70].

Since the database stores all the occurrences of a single tephra, irrespective of the source and the size of the event, it can be useful also for strictly volcanological purposes. Actually, it can help to implement current datasets on ash dispersal, *e.g.* providing new information about the thickness of deposits, rapidly detecting the sites of distal occurrences, and supplying further data to refine the extent of the emplacement area also for the low to medium size explosive events, vital for volcanic hazard assessment.

These latters are often punctuated in the marine record at medial to distal sites by cryptotephras [65]. As an example, Figures 7B, 7B1 present the progressive detail of the outcome of a query regarding the occurrence of the deposits related to the protohistoric interplinian activity, which occurred at Somma-Vesuvius between the Avellino (ca 4.0 cal ka) [71] and the 79 A.D. explosive events. This activity has been throughoutly described from on land sections, but it was almost unknown in the marine settings until the use of cryptotephras has been enhanced in the last decade.

As far as the age range considered in the present paper is concerned, a query to the database with the entry criterion of the YD climatic event, enables the user to detect if any tephra is available to link archives from the different subsets of the Mediterranean Sea. The resulting output (Figure 7C) refers to the Agnano Pomici Principali tephra (11.9–12.1 cal ka) [72], linked to a sub-plinian event occurred at Campi Flegrei and widespread in the Adriatic Sea [73–76], and to Soccavo 1 (12,644 ± 709 cal yr BP, modeled age), recently found in several cores of the Tyrrhenian Sea [77, 78]. According to these results, it is evident that the different dispersal of the two tephras does not allow linking the two marine archives for the YD time span, unless future findings may open new scenarios.

5.2 Oxygen stable isotopes

Stable oxygen isotope (δ^{18}O) analysis are performed on tests of planktonic foraminiferal species retrieved from different size of washing residues (>90 µm, >125 µm and >150 µm) related to the marine environment from which the fossil archives are recovered [60, 65, 79–83]. The oxygen isotopes represent a valid tool for paleoclimate and paleoceanographic studies, because planktonic foraminifera record the changes of the environmental parameters of the water masses in which they live [84–89]. In particular, the oxygen isotope composition of the calcareous tests of foraminifera provides information on water salinity and temperature oscillations [64, 90, 91] and reflects hydrological changes, as the increase in continental run off [79, 82, 83, 92, 93].

Detailed age control for δ^{18}O records has been established for a discrete number of Mediterranean marine records [60, 65, 79, 82, 83, 91, 94–97], consequently, oxygen isotope stratigraphy has become not only a global correlation tool, but also an established dating tool [60, 83, 94, 95, 98].

In this work, we analyse the oxygen isotopic values for two planktonic foraminiferal taxa: *Globigerina bulloides* and *Globigerinoides ruber* var. white, in order to observe the geographical variation of isotopic composition of sea water during the YD climatic event in the Mediterranean basin.

A different isotopic behavior characterizes the two species, since, notwithstanding the same trend of δ^{18}O data and the abrupt positive shift corresponding to the YD interval (Figure 8) [60, 94–96], *G. bulloides* δ^{18}O values are more positive than those of *G. ruber*, reflecting a difference in the ecological niches [99, 100]. In addition, published data on δ^{18}O *G. bulloides* span from 5° (Alboran Sea) to 20° (Adriatic Sea) of Longitude (Figure 9A1), while δ^{18}O *G. ruber* data range from 10° (Tyrrhenian Sea) to 35° (Cyprus) of Longitude (Figure 9B1). In this frame, two maps showing with different simbols the δ^{18}O variations, for the Western (more studied taxon: *G. bulloides*) and the Eastern (more studied taxon: *G. ruber* var. white) Mediterranean seas, were drawn (Figure 9A1, 9B1).

Notwithsatnding few information concerning the specific range of tests size of *G. bulloides* and *G. ruber* white variety are available for the Mediterranean Sea, the greatest part of samples used for the elaboration of δ^{18}O maps have

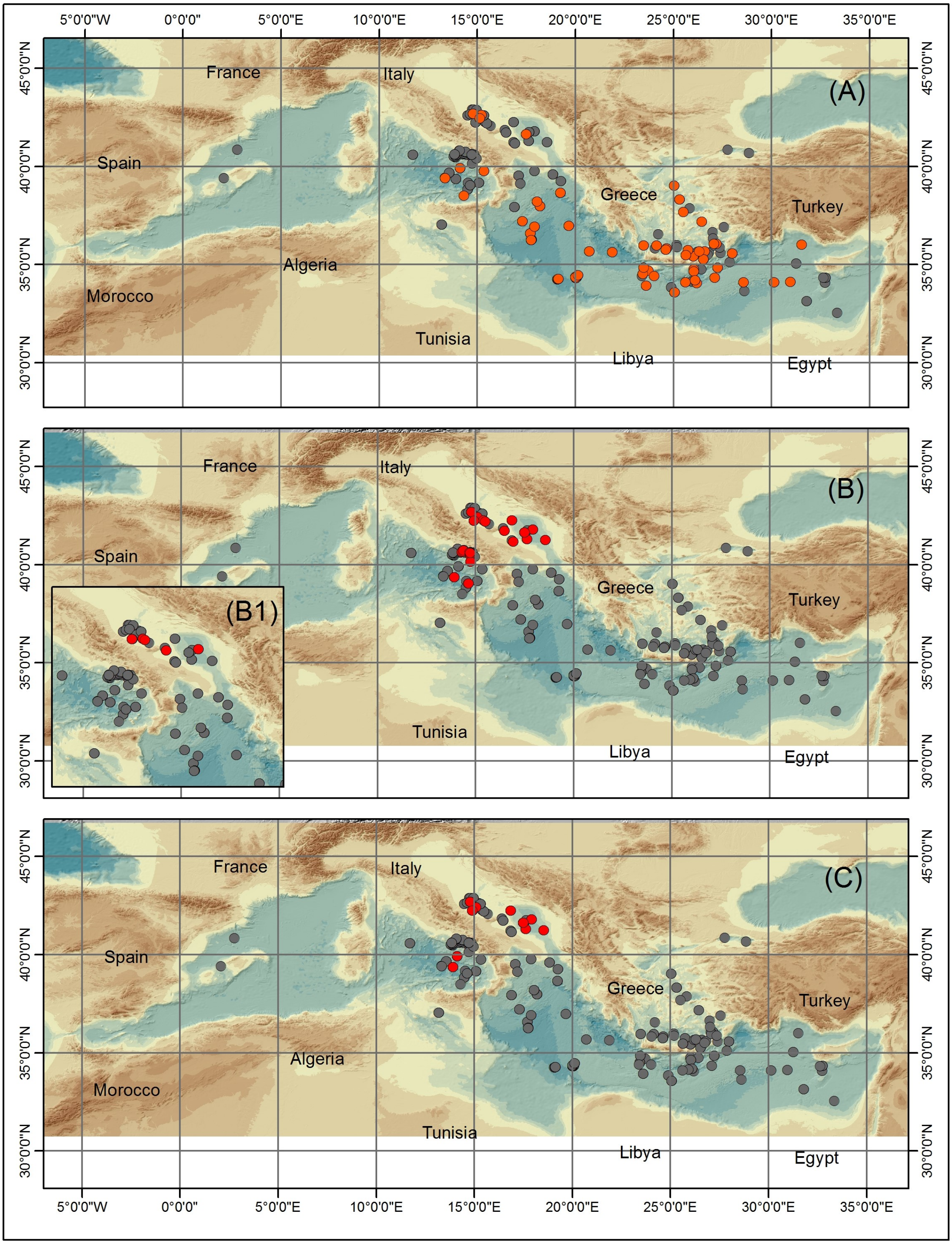


Figure 7: Tephra outcomes from the data stored in WDB-Paleo (gray dots). In detail, the red dots represent: the Y-5 tephra (ca. 39 ka) (A); the protohistoric eruptions tephras (B) and the tephra related to the protohistoric eruption AP2 (ca. 3.2 ka cal age in Santacroce et al., 2008-B1); the Agnano Pomici Principali (ca. 12 ka) and Soccavo 1 (ca. 12.5 ka) tephras (C). See text for age details.

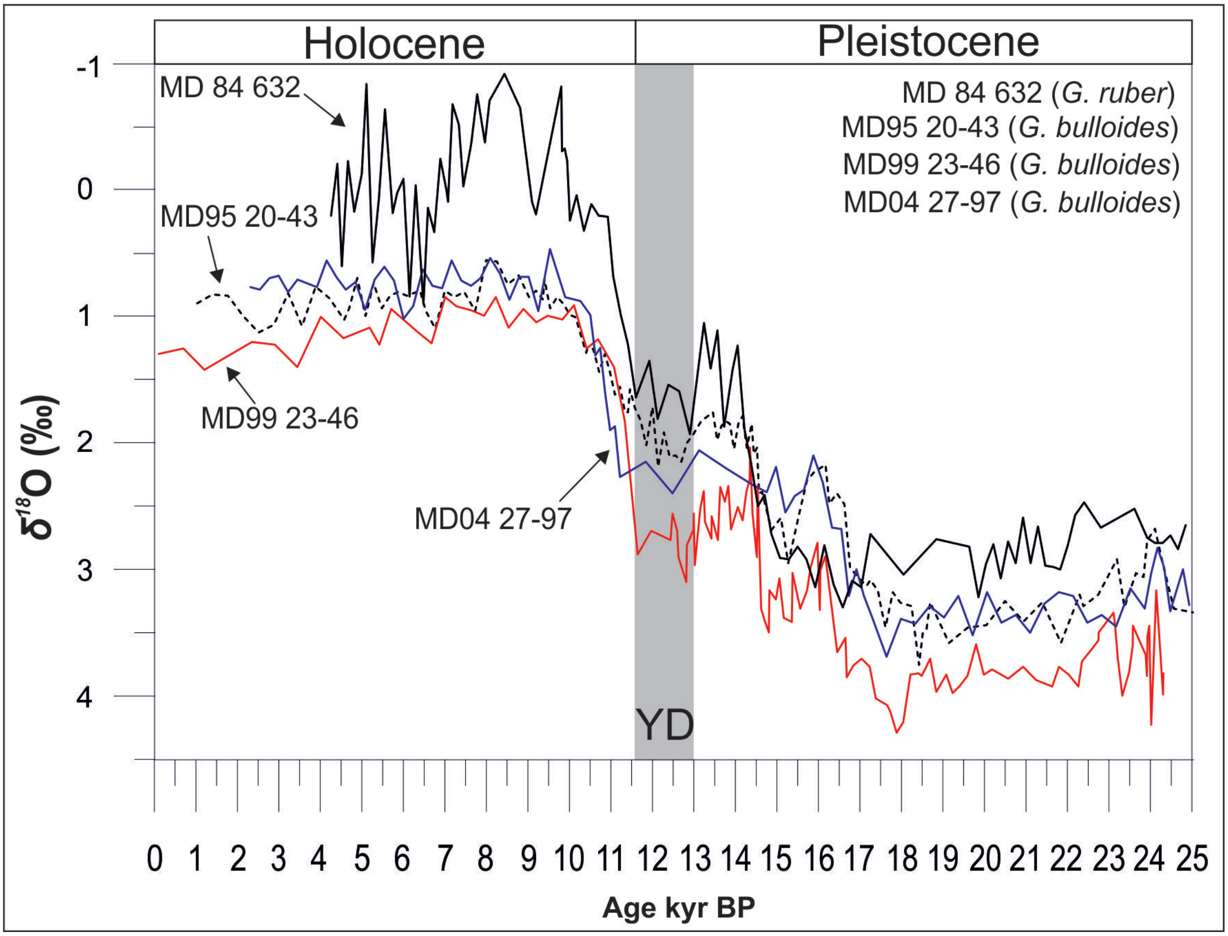


Figure 8: Comparison in time domain between δ^{18}O G. bulloides signals from cores MD95 20-43 (Alboran Sea; [81]), MD99 23-46 (Gulf of Lion [77]), MD04 27-97 (Sicily Channel; [65]) and δ^{18}O G. ruber signals from core MD 84 632 (southeast of Cyprus; [65]). The grey stripe represents the position of the YD event.

a size > 125 micron and only twelve samples were higher than 200 micron. The recent scientific literature [101–103] evidenced no significant differences in δ^{18}O with size fractions of *G. ruber* var. white and no systematic differences with size fractions of *G. bulloides*. In the eastern Mediterranean area, a study on oxygen isotope composition measurements carried out on different morhotypes of *G. ruber* has been performed by Numberger *et al.* [104] since MIS12. The authors stated that the strong similariety in δ^{18}O composition, over the Holocene records, suggests that the *G. ruber* type b "platys" (*G. ruber* var. white sensu lato) appears to share a similar habitat with type a "normal" (*G. ruber* var. white sensu strictu) at ODP Site 964 (Ionina Sea). Recently, Antonarakou *et al.* [105], in the Gulf of Mexico, documented different δ^{18}O composition in *G. ruber* morphotype ss and sl, but the very low resolution measurements during the time interval of YD event, make difficul any consideration.

The *G. bulloides* δ^{18}O values range from 3.64%ffl (north Adriatic and Tyrrehian seas) to 1.38%ffl (Alboran Sea) (Figure 9A1). The higher mean δ^{18}O values are located in the Adriatic and Central Tyrrhenian basins, the former being one of the coldest areas of Mediterranean. Both areas are characterized by high density of water masses that sink creating the Eastern Mediterranean Deep Water [20] and the Tyrrhenian Deep Water, respectively (Figure 9A1). Moreover, a detailed geographical reconstruction, based on the use of Inverse Distance Weithed Interpolation method, of *G. bulloides* δ^{18}O data shows a tripartite subdivision of the Tyrrhenian Sea with two areas, in the north and in the south, wich are characterised by lighter values than the central one (Figure 9A2).

The *G. ruber* δ^{18}O mean values, ranging from 3.21 to 0.35%ffl, are higher in the Sicily channel and Aegean Sea than elsewhere in the Mediterranean (Figure 9B1). This *G. ruber* δ^{18}O signal could be linked to the passage of the Modified Atlantic Water through the Sicily channel and

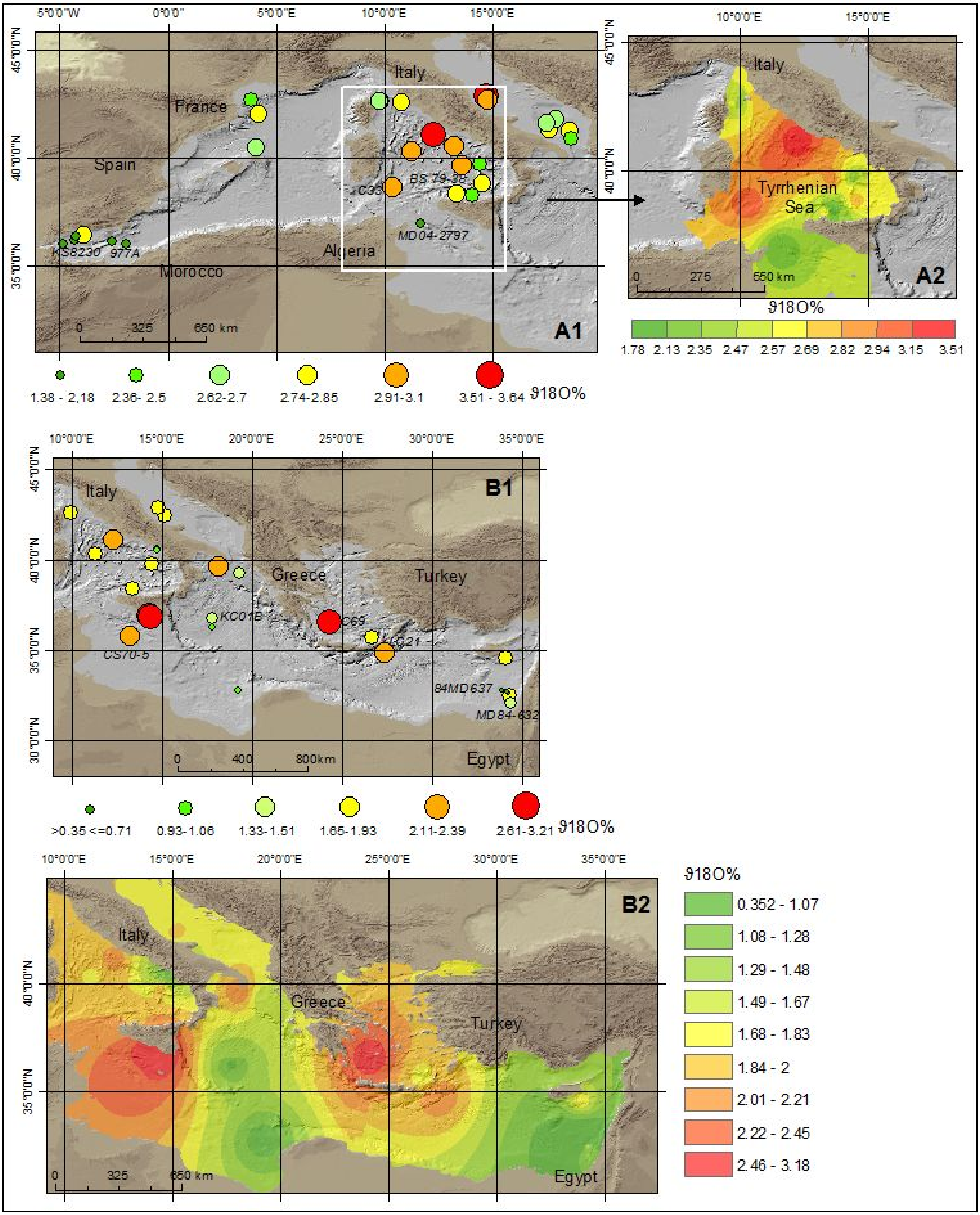


Figure 9: Maps showing the geographical distribution of samples and averaged changes of $\delta^{18}O$ measured on *G. bulloides* (Figs. 9A1, A2) and on *G. ruber* var. white (Figs. 9B1, B2), respectively.

to the lower temperature and salinity concentration of Aegean Sea waters with respect to those of the neighboring zones (Figure 9B1). A grid map similar to that realized for the *G. bulloides* δ^{18}O was drawn for *G. ruber* δ^{18}O data, the geographical reconstruction shows two areas with lighter values located in the Ionian-Sirte Gulf and in the south of Cyprus, and two areas with heavier values in the south Aegean Sea and Sicily Channel (Figure 9B2).

5.3 Accelerator mass spectrometry (AMS) ^{14}C radiocarbon datings

The AMS^{14}C radiocarbon dating method is widely used for integrated stratigraphic studies carried out on the last ca. 30 kyr. In particular, AMS^{14}C data provide tie-points useful to construct age-models and define the sedimentation rates of different sectors of the Mediterranean Basin [82, 106, 107]. For the integrated stratigraphic approach at the Mediterranean scale, it is crucial to know the geographical distribution of the data useful for geochronological and paleoclimatic studies. The distribution map of the AMS ^{14}C data, defined on both benthonic and planktonic foraminifera, at disposal for 88 cores (a total of 572 samples) was hence drawn (white and red points in Figure 10A). The collected AMS ^{14}C data are heterogeneous because of lacking error ranges and calibrated ages that, when available, were achieved through different calibration softwares (calib 4.1 program- [108]; CalPal – [109]). All the available AMS ^{14}C data were here recalibrated by using the latest version of the OxCal software 4.2 with INTCAL13 and MARINE13 dataset [38], and using the mean Mediterranean regional reservoir age of 400 yr [106]. The un-calibrated ^{14}C ages and the associated error are the input parameters used to calculate the new ages reported as 1 and 2σ deviations in cal yrs BP.

It is important to note that only 15 out of 88 cores contain AMS^{14}C dated samples pertaining the Younger Dryas climatic event (red points in Figure 10A). For this cores, AMS^{14}C measurement were performed on planktonic foraminifera with the exception of two cores for which two distinct measurements on benthic foraminifera and pteropods were realized. Age differences between these pairs are minimal and apparently random, indicating that planktic and benthic organisms are equally suitable for ^{14}C-dating in the central Mediterranean region [111]. A multiproxy approach was chosen to integrate the AMS^{14}C data with the depth (cm below sea floor) of oxygen isotope signature corresponding to the position of YD event and a map was drawn for identifying the different position (depth cm bsf) of this event in the Mediterranean Basin (Figure 10B). It is important to point out that the planktonic foraminifera represent an additional valid tool for the determination of the chronostratigraphic framework associated to the YD event. In particular, this time interval is characterised in the Mediterranean by absence and/or strong reduction in abundance of *Globigerinoides ruber* var. white, *Globorotalia inflata* and *G. truncatulinoides* associated with strong abundance increase of *Neogloboquadrina pachyderma* [54, 82, 110, 112–116].

This map can be used to estimate the different sedimentation rates over the last ca. 13 kyr in the Mediterranean Sea. The highest sedimentation rate were obtained for the Alboran Sea, Balearic Islands, Sicily Chanel, South Tyrrhenian Sea and in the North Adriatic Sea (Figure 10B). In addition, a detailed reconstruction of samples depth pertaining to the YD event (cm bsf) between 10° to 20° longitude documents a reduction of sedimentation rate moving from the south Adriatic Sea vs Ionian Sea (Figure 10C).

A shallower position of samples pertaining the YD event also characterizes the central Tyrrhenian Sea than the north and south sectors (Figure 10C). Moreover, the deep position of the YD event in the Sicily Channel evidenced that this zone is a sill separating the Tyrrhenian and the Ionian seas (Figure 10C).

6 Conclusive remarks

WDB-Paleo database proved to be a flexible and easily upgradable tool for past climatic and environmental studies of Mediterranean Sea. Single stored proxies can be processed one at time or integrated to join information and reduce the effects of the lack of data.

At present, WDB-Paleo improves the possibility to:

- recognize the available climatic paleoproxies for both geographical area and specific time interval;
- rapidly identify the availability and distribution of tie-points (dated tephra layers, AMS^{14}C datings);
- draw "isochronous time-lines" needed to link archives from different settings;
- assess the variability of available proxies in response to their geographical distribution, allowing to better understand the potential effects of local conditions on their behaviour;
- rapidly integrate data for multi-proxy investigation in a defined time range.

Moreover in the light of data sharing, the WDB-Paleo can provide the basic information useful to know the avail-

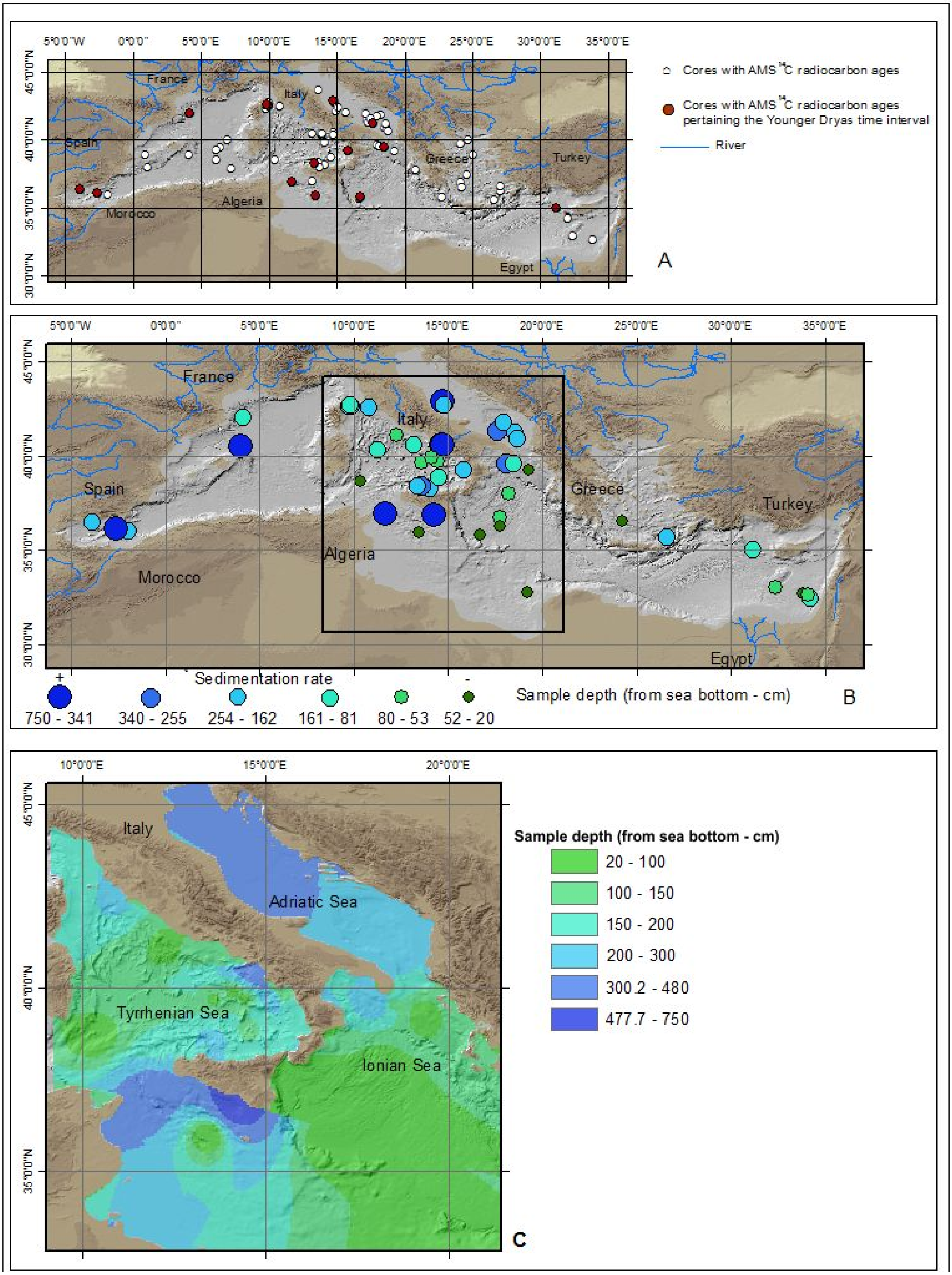


Figure 10: Geographical distribution of AMS^{14}C dated samples (A). Depth (cmbsf) of the Younger Dryas climatic event in all the cores by integrating AMS^{14}C ages and oxygen isotope signature (B). Conturing map of YD depth (cmbsf) in the Tyrrhenian, Ionian and Adriatic seas (C).

able cores and associated proxies, thus it helps to correctly plan future Mediterranean oceanographic expeditions.

Future developments for WDB-Paleo will aim to record: a) new proxies (*e.g.* sapropel, chemical analysis of tephra, quantitative data on radionuclides, Mg/Ca ratio), specifically since they have been already used in the recent literature for relevant reconstructions along the Mediterranean Sea [53, 117–120]); b) new quantitative biotic data, at present in WDP-PALEO are recorded only those retrivied during the cruises of CARG, VECTOR and NEXTDATA projects, c) the possible relations between huge volcanic eruptions and extreme climatic variations recording tephra occurrence at least for the Quaternary Periodan.

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Appendix

The primary key of the entity “site” was defined following the structure of the International Geo Sample Number (IGSN) code (http://www.geosamples.org/aboutigsn, 2014), because several sites, considered in the present work, already have an IGSN code. Moreover it represents a standard that univocally identifies the single site on a global scale. The first three digits of the IGSN represent a name that uniquely identifies the institution registering the site. The last 6 digits of the IGSN are a random string of alphanumeric characters. The IGSN follows the syntax of the URN (Uniform Resource Name), which is composed of a “Namespace Identifier” (NID), a unique short string, and of the “Namespace Specific String” (NSS). The IGSN is a 9-digit alphanumeric code that uniquely identifies samples taken from natural environment (for example: rock specimens, water samples, sediment cores) as well as the related sampling information (sites, stations, stratigraphic sections, etc.). The IGSN is long enough for large institutions to register large numbers of samples (with 10 numbers plus 26 letters for the 6 random digits after the user code, a total of 36^6 = 2,176,782,336 sample identifiers per registrant is available) (http://www.geosamples.org/aboutigsn, 2014).

Furthermore, we adopted a similarly structured code to define the primary key of the identity “cruise”. The first three digits identify the vessel name and the other six digits represent a progressive code formed by two numbers, followed by one letter and two other numbers.

For the identity “reference” we used a code formed by a count number while for the other entities that record quantity data, we used a structured number formed by 7 digits: the first four identify the site while the other three refer to the sample used for quantitative analysis (*i.e.* recognition and counting of foraminifera, isotopic data).

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