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The INQUA Dunes Atlas chronologic database

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ABSTRACT

The INQUA Dunes Atlas project has developed a global digital database of chronological information for periods of inland or continental sand dune accumulation and stabilization. The database comprises information on the site location (including coordinates), dune type, and stratigraphic context, pertinent analytical information (e.g. luminescence procedures), and literature citations to the original data source.

This paper discusses the background to the project, the concept and structure of the chronologic database that forms its core, and gives some examples of the scope of the database and ways in which it can contribute to greater understanding of the spatial and temporal variability in dune development.

1. Introduction

This special issue of Quaternary International comprises a series of papers that summarize the initial results of INQUA Project 0704: Digital Atlas of Quaternary Dune Fields and Sand Seas. The papers in this volume provide a perspective on the state of knowledge of the chronology of dune deposits and landforms in key regions, and highlight the issues of data interpretation and reconstruction of past environments that have developed as the knowledge base has evolved.

1.1. Extent and significance of Quaternary aeolian sand deposits

Inland or continental dune systems of Quaternary age occur on all continents and at all latitudes (Fig. 1). Dune systems are dynamic geomorphic and sedimentary environments that respond directly and indirectly to climate change and variability on a range of temporal and spatial scales. Their response to climate change is governed by the supply of sediment of a size suitable for saltation transport by the wind, the existence of wind energy to erode and transport this material (erosivity or mobility), and the susceptibility of a sediment surface to entrainment of material by wind (erodibility or availability). The interactions between these variables in space and time determine the state of the aeolian system (Kocurek and Lancaster, 1999), resulting in both direct and indirect responses

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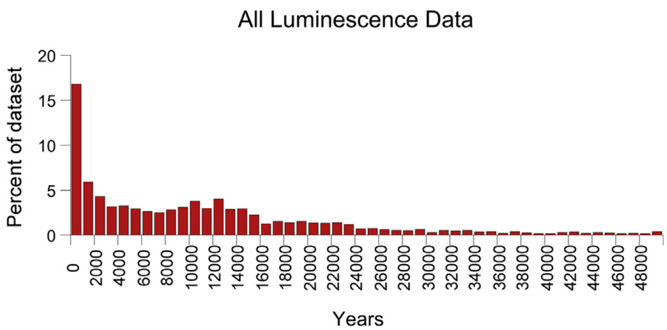

Fig. 1. Histogram of all luminescence ages younger than 50 ka in the database. Note the strong influence of taphonomic decay on the distribution, with an exponential decay of ages with time.

to climate change, including: (1) Activation or stabilization of individual dunes and areas of dunes; (2) Formation of new areas of dunes or the addition of material to existing dunes (dune construction); (3) Erosion of existing dunes or areas of dunes (dune destruction).

The sedimentary and geomorphic record preserved in inland dune systems therefore potentially provides a valuable source of information on past climate conditions, including evidence for periods of dune activity and stability that may be interpretable as records of past aridity (Bateman et al., 2003; Singhvi and Porat, 2008), as well as contributing unique data on past wind regimes (Lancaster et al., 2002; Sridhar et al., 2006; Schmeisser et al., 2010). Prior to the development and application of luminescence dating (Singhvi et al., 1982), periods of aeolian deposition could only be dated indirectly by their stratigraphic or geomorphic relations to deposits or features dated using radiocarbon (e.g. lacustrine deposits; buried soils). Such an approach provides a large amount of data on the chronology of periods of aeolian deposition, but often with a very broad temporal and spatial resolution (e.g. Swezey, 2001).

Luminescence dating provides the means to directly date periods of aeolian deposition, by determining the time elapsed since burial of sediment (Duller, 2004). Application of these techniques has transformed studies of geomorphic and sedimentary environments in deserts and drylands and has necessitated a revision of conventional interpretations of sedimentary records and stratigraphic correlations (Singhvi and Porat, 2008). Although the precise climatic interpretation of luminescence ages for aeolian sands is debated and more complex than once considered (Telfer et al., 2010; Thomas and Burrough, 2012; Bailey and Thomas, 2013; Leighton et al., 2014), the papers in this volume show that it is now possible to develop local and regional histories of dune development and provide more precise correlations of periods of aeolian deposition with other palaeoclimatic proxies and records. These include information on past vegetation communities and records of change in lacustrine and fluvial environments, which act as sediment sources, as well as complementary records, including aeolian components from more continuous ocean cores and loess proxy records. As a result, the palaeoenvironmental significance of periods of aeolian sand accumulation and stability can be better constrained in many areas. At the same time, the complexity of the response to Quaternary climate change has been highlighted.

Papers in this volume indicate that the temporal and spatial patterns of dune construction and/or activity are complex and involve significant, region dependent, time lags. For example, the dune chronology for the southern Sahara shows very few ages from the LGM (Bristow and Armitage, 2016) despite earlier assumptions that dunes were active in this region during this period (Sarnthein, 1978). In many areas, sediment supply plays a very important role in episodes of dune construction, (e.g. Halfen et al., 2016). It is also clear that the Holocene history of many dune fields is more complex than previously thought, with multiple periods of availability-limited dune activity, in some cases resulting from anthropogenic disturbance of vegetation cover (Tolksdorf and Kaiser, 2012; Li and Yang, 2016). Continental or inland dune systems therefore appear to respond, in dynamical terms, to a range of drivers operating at a diversity of temporal and spatial scales. A strong and standardized archive of chronometric records should provide a resource that can help interpret these complexities.

2. The INQUA Dunes Atlas database

The concept of a digital, geographic information system (GIS) based global atlas of Quaternary dunes was first articulated in 2006 and resulted in funding from INQUA (Project 0704) to support a collaboration between colleagues in several countries in a project modeled in large part after the successful DIRTMAP project (Kohfeld and Harrison, 2001). Seed funding from the Desert Research Institute in 2007 enabled discussion with Stephen Wolfe of the Geological Survey of Canada (GSC) who shared his experience with the Geological Survey of Canada database of dunes in Canada, as well as development of a proof of concept database for the Mojave Desert (Lancaster and Kratt, 2007). INQUA sponsored a workshop on the concept of the atlas at the 2007 INQUA Congress in Cairns and a second workshop on the Atlas and its development at the School of Geography, University of Oxford, in early January 2009. The Oxford Workshop resulted in an overarching concept for the atlas and its accompanying database, as well as a draft definition of the database and the fields that it contains. The Oxford Workshop participants agreed that compilations of data for each major dune area would be done by regional workers, with expertise and knowledge of their region and the data available for it (Table 1).

3. Conceptual framework for the database

Four components were identified for the successful development of the geographic database and digital atlas: (1) A database of key Quaternary data (luminescence and radiocarbon ages, and related geologic and geomorphic context); (2) A Geographic Information System for housing spatial and temporal data sets, including maps of dune extent; (3) Google Earth and formatted data sets (for quick viewing of data and for wider audiences); (4) Gridded data for use in data-model comparisons.

Data required for the database are available in many forms, mostly published in the open literature, but other data are available in theses, dissertations and "grey-literature" reports. In many cases, pertinent information on the luminescence methods used and precise geographical locations (coordinates) is only available in the latter sources, or in data deposited with the original publication (e.g. ftp://rock.geosociety.org/pub/reposit/2002/2002117.pdf, for data associated with (Lancaster et al., 2002)).

In order to maintain a consistent standard for the database, the following were identified as key criteria by the INQUA Project Group meeting in Oxford, UK in January 2009: (1) All data entries must be point (not area) data and identify the site from which they are derived and all data points will have a unique identifying number (UIN); (2) Data included in the chronologic database must meet certain standards and there will be different 'data quality' categories defined by information on context and dating protocols (see below); (3) All data must be published, with the definition of published allowing inclusion of grey literature (official reports) and graduate theses and dissertations. By only including data in the

Table 1
Project participants and regional correspondents.

The following people agreed to act as champions for compiling regional databases.

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public domain, there are no copyright or intellectual property rights issues. In addition, users can locate the original source(s) of the data via access to the published paper(s); (4) Data should be entered as is with no interpretation. However, the information included in the metadata will allow for interpretations and inferences; (5) The database and the GIS are searchable on the basis of multiple criteria including various contexts of the source site (e.g. dune type), user-defined time-slices, etc; (6) All data must relate to aeolian sand deposits (e.g. sand sheets, sand ramps) or dunes, but this may include chronologic data from palaeosols in dune sequences, and dated organic material within dune deposits (e.g. hearths).

4. Database structure and content

To be included in the database, data as a minimum has to identify the sample location coordinates, the aeolian deposit type, and the dating method. The full data list for each entry, as far as available, includes the location (region, country, dune field name), latitude and longitude of the sampling point, the type of site (e.g. pit, auger, core, natural exposure, artificial exposure), the type of deposit (e.g. dune, sand sheet) and its geomorphic context (e.g. sand sea, dune field, isolated dune), as well as the morphology of the dune (e.g. linear, crescentic, parabolic, undifferentiated). Stratigraphic information includes the deposit thickness, sample depth, and unit name. Dating information is divided between luminescence and radiocarbon methods. For luminescence ages, the database includes information on the laboratory or sample number, the luminescence age relative to a datum year (if known) and one sigma uncertainty in calendar years, the type of luminescence technique used (e.g. TL, OSL, IRSL), the mineral dated (e.g. Quartz, Feldspar or polymineralic fine grains), the protocol (e.g. Single Aliquot Regeneration or Multiple aliquot methods), corrections applied, and the age model used. Additional analytical information such as water content or dose rates was not included, because this is not provided in many publications. For radiocarbon ages, information includes the sample or laboratory number, the age and one sigma uncertainty in radiocarbon years BP, the method used (e.g. AMS), the delta 13C value, pretreatments and any corrections applied. All data points are referenced to a primary literature citation that allows the user to obtain additional information as needed. A full description of the database structure, fields, and metadata is provided in the supplementary data for this paper.

4.1. Data quality

Data on dune chronology have been generated by many different investigators in an environment in which the dating techniques and analysis methods have evolved rapidly and will continue to change. The database therefore includes metadata to allow quality-control issues to be dealt with objectively. The goal is to provide metadata that allows current and future users of the database to evaluate the information it contains. Metadata categories developed by the INQUA Project Group for luminescence dates include details of the type of luminescence used (e.g. TL, IRSL, OSL); the luminescence protocols adopted; any corrections, and the age model adopted. Similar metadata are included for radiocarbon dates. Users of the database also need to be aware of the confidence level that can be placed on the age information. The group developed four categories of data, as follows (luminescence example given):

Category 1: Sample location (Latitude and Longitude) and age reported
Category 2: Above information, plus data on sample depth, laboratory and/or sample number, luminescence error, and luminescence type
Category 3: Above information, plus data on the mineral and grain size dated, and the dating protocol and corrections used
Category 4: Above information, plus use of SAR and SGR techniques with quality control, and age model reported.

The higher the category number, therefore, the more data that is available for an entry in the database. This is an important element for users who may wish to scrutinize the records in terms of 'data quality' and the robustness of the ages that are published. In this respect it can also be noted that some ages appear more than once in the published literature: where possible the entries in the database cite the source that has the most supporting data available for each individual age.

4.2. Data entry

Regional champions and the project leader have entered data from publications into spreadsheets for each region using a template that provides guidance and a consistent nomenclature. The location and coordinates of the sample sites were checked using Google Earth. In some cases, coordinate information was not provided and had to be interpreted from figures in the original publication, or was obtained by direct contact with the authors. Publication information was checked with the source, at the same time as the URL and doi were obtained.

5. Current status and content of the database

The INQUA Dunes Atlas chronologic database currently (September 2015) contains 3948 luminescence ages and 527 radiocarbon ages. The database is continually being updated as new data becomes available through publication of research results. The distribution of these ages by dune type and region is shown in Table 2 and as a histogram of all ages in Fig. 1. Chronologic and related data are available for all major low and mid latitude inland dune areas. Data are also included for high latitude dune fields (Arctic Canada, Alaska, Greenland, and Antarctica).

5.1. Luminescence ages

The geographic distribution of luminescence ages (Fig. 2) largely reflects the research efforts that have taken place in each major region. Thus, over half of the luminescence ages are from North America (24%), Australia (17%), and southern Africa (15%). The North American ages are mostly from the central and northern Great Plains of the USA and Canada; ages on Australian sands are dominated by the Simpson-Strzelecki and Mallee dune fields; while most ages from southern Africa are from the Kalahari region. Asian ages mainly come from northern China; European ages are dominated by those from the European Sand Belt (Tolksdorf and Kaiser, 2012) while South American ages are mostly from subtropical Argentina and Brazil. Detailed analyses of the records from these areas are discussed in this special issue by Thomas and Burrough (2013), Hesse (2016), Tripaldi and Zárate (2016), Halfen et al., (2016), Li and Yang (2016). The majority of OSL ages (69%) have been determined using SAR protocols (Murray and Wintle, 2000). Most TL ages (18% of total) are from earlier work (prior to 2000). IRSL ages comprise a further 13% and are mostly from North America. The majority of these ages predate the development of post-IR IRSL methods (Thomsen et al., 2008). Prior to the introduction of this post-IR IRSL method, anomalous fading of the luminescence signal from feldspars was a perennial concern.

The distribution of dune ages by dune morphological type (Fig. 3) in part reflects where research has been carried out. Almost a third (30%) of luminescence ages are from linear dunes, reflecting the multiple studies carried out in Australia and southern Africa, as well as the widespread distribution of this dune type. In addition, linear dunes appear to preserve a longer record of dune accumulation compared to other dune types, as they primarily extend rather than migrate laterally (Thomas, 1992; Telfer and Hesse, 2013). Parabolic dunes have been dated extensively in North and South America, and comprise 14% of the luminescence ages in the database. Sand sheet deposits have yielded a further 14% of all ages, in a variety of environments and locations, including wide areas of the European Sand Belt (Hilgers, 2007; Koster, 2009). Crescentic dune records comprise 7.5% of the available ages, in part because lateral migration of this dune type tends to reset the luminescence "clock", making crescentic dunes a less-favorable target for dating. In a significant number of instances (17% of the total), there was insufficient information in the preserved sedimentary and geomorphic record to conclusively identify the dune type – ages in these situations are termed "undifferentiated".

5.2. Radiocarbon ages

The radiocarbon ages currently in the database (Fig. 2) are dominated by those from North America (86%). The majority of ages are derived from buried soils and charcoal derived from fires, or in an archaeological context (e.g. hearths). Most ages are from sites in the boreal and northern Plains regions of Canada. Given the geographic distribution of dated deposits, those from blowout, clifftop, and parabolic dunes, together with sand sheets, are most common. A significant proportion of ages (47%) are from deposits that cannot be assigned to any particular morphologic type (undifferentiated).

6. Data products

The latest version of the basic database is available for download from the project website (http://inquadunesatlas.dri.edu) as a read-only Excel workbook and CSV text files. The database will, in addition, be archived with the National Oceanographic and Atmospheric Administration World Data Center for Paleoclimatology http://www.ncdc.noaa.gov/paleo/wdc-paleo.html, with full documentation as required by the WDC, to ensure the long-term archiving of the database.

The workbooks can be imported directly into a GIS, e.g. ESRI ArcGIS, to allow for searching of the database by any of the fields – e.g. time slice, dune type, OSL method etc. Fig. 4 gives an example of a map produced in this way for the period of the LGM.

Table 2
Distribution of luminescence ages by region and deposit type.

Morphology	Region															
	AFN	AFS	ANT	ARB	ASW	AUS	CAN	CAR	CHN	IND	EUR	EAM	NAM	SAM	N by dune type	% By dune type
Beach ridge	2														2	0.05
Blowout							8		23				39	12	82	2.08
Cliff-top							2								2	0.05
Climbing	12	6				8			5				2		33	0.84
Crescentic	13	5	11	46		59	2	1	31	7	22		92	3	292	7.40
Falling	5					5							36		46	1.17
Foredune						1	3								4	0.10
Interdune	1										11				12	0.30
Lee															0	0.00
Linear	75	292		132		462		1	45		8	92	32	10	1149	29.10
Lunette		182				1							10		193	4.89
Nebkha						1			11				2		14	0.35
Network		58				6		1	6				5		76	1.93
Parabolic	17	2				23	98		21	83	25		272	26	567	14.36
Sand ramp	1	6		6	6				4	34		4	164		225	5.70
Sand sheet	16	47		70		12	15		47	15	162	47	91	26	548	13.88
Sandwedge							7		2		2	5	1		17	0.43
Star									1				4		5	0.13
Undifferentiated	19	3		5		111	15		135	16	92	40	178	65	679	17.20
Zibar				1									1		2	0.05
Number	161	601	11	260	6	689	150	3	331	155	322	188	929	142	3948	
Percent	4.08	15.22	0.28	6.59	0.15	17.45	3.80	0.08	8.38	3.93	8.16	4.76	23.53	3.60		

Extracts of data can be used to make correlations between periods of aeolian accumulation and other paleo-climatic proxies, as illustrated by papers in this special issue (e.g. Halfen et al., 2016)

A version of the database with a limited suite of information about the ages is also available for download as a kml file, which can be imported into Google Earth to explore the context of each age and sample site. This is envisaged as a potentially valuable teaching tool. An example of the Google Earth interface is shown in Fig. 5.

We are actively seeking additional ways to make the dataset available to the broader Quaternary and Geoscience communities and welcome suggestions and ideas from the community.

7. Conclusions

The INQUA Dunes Atlas chronologic database provides the first global compilation of luminescence and radiocarbon ages for aeolian sand deposits. Although by necessity it is a work in

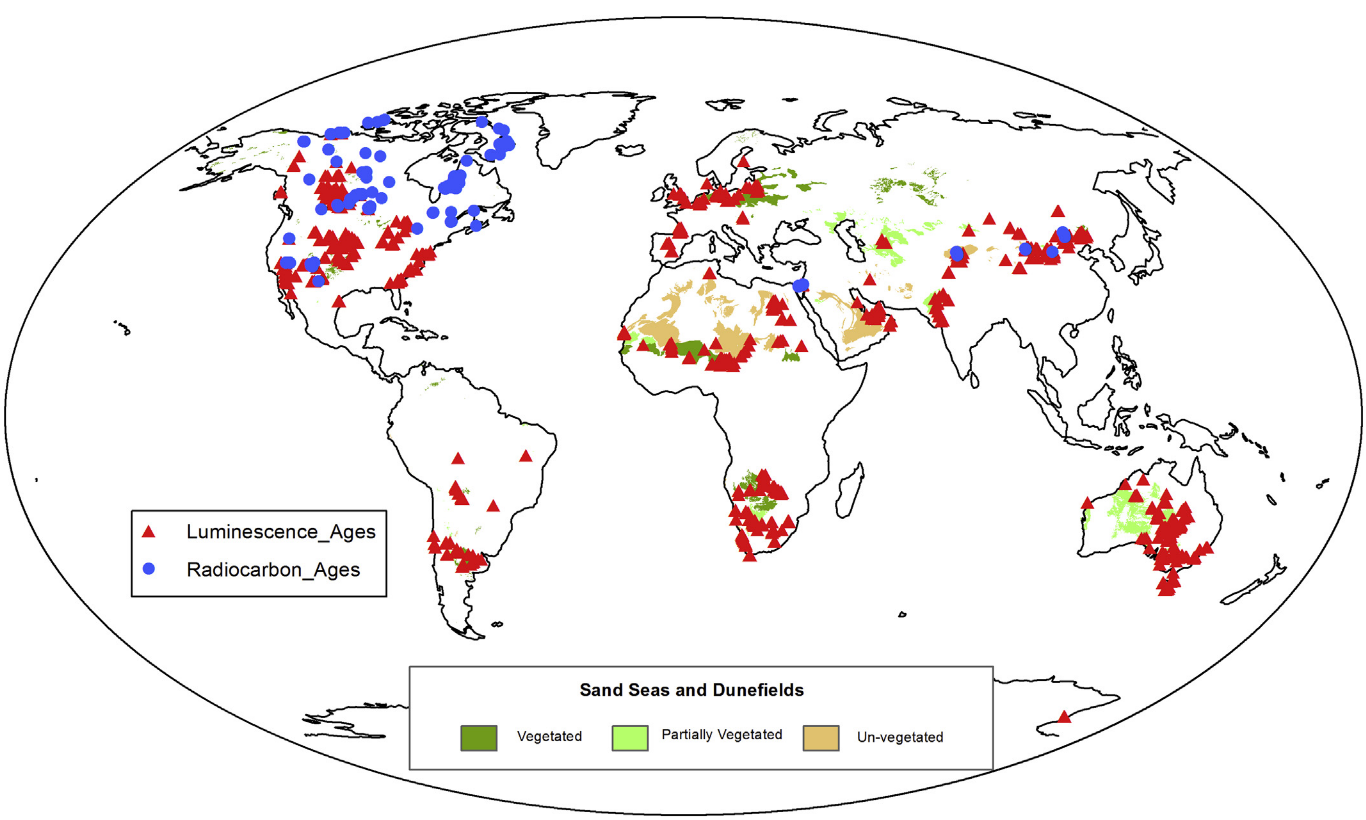

Fig. 2. Geographic distribution of luminescence and radiocarbon ages in the current database (September 2015).

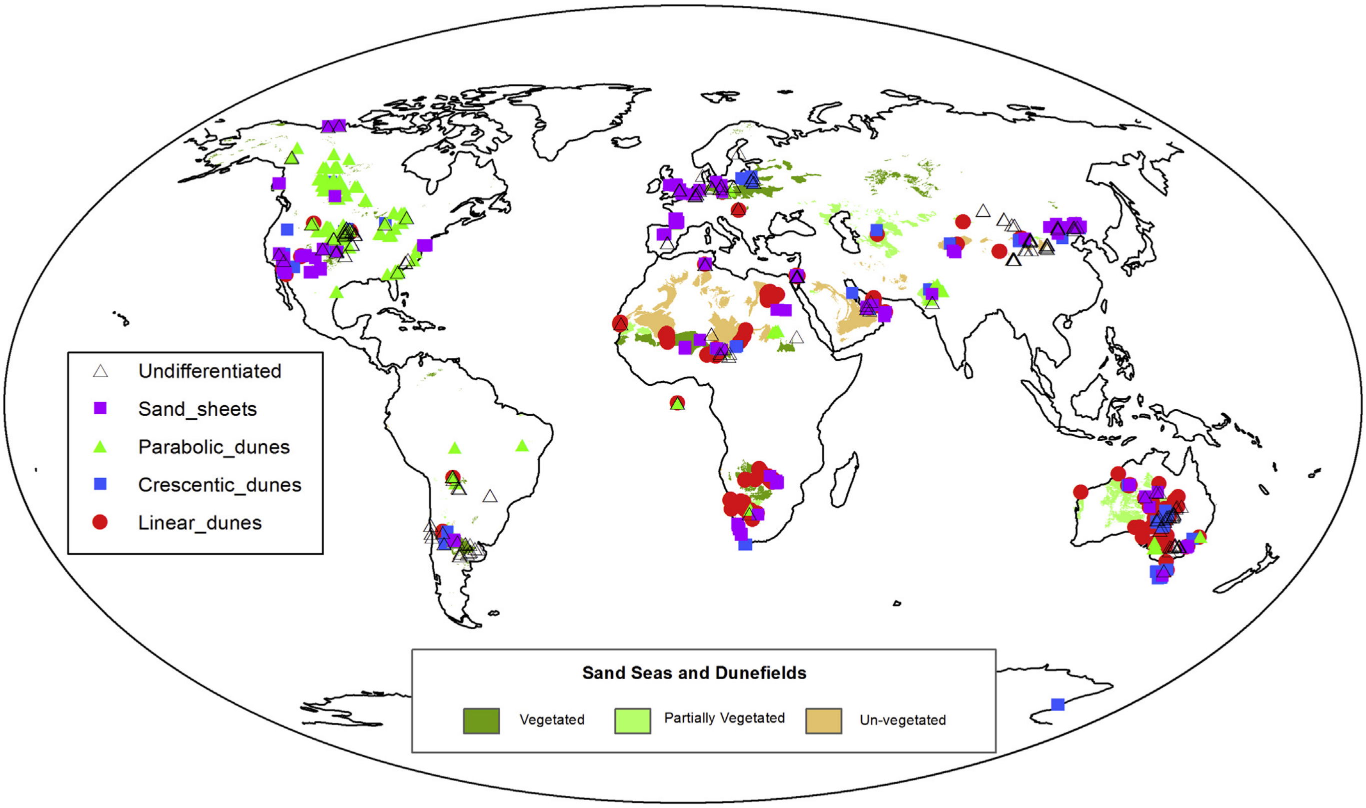

Fig. 3. Geographic distribution of ages classified by major dune types represented in the database.

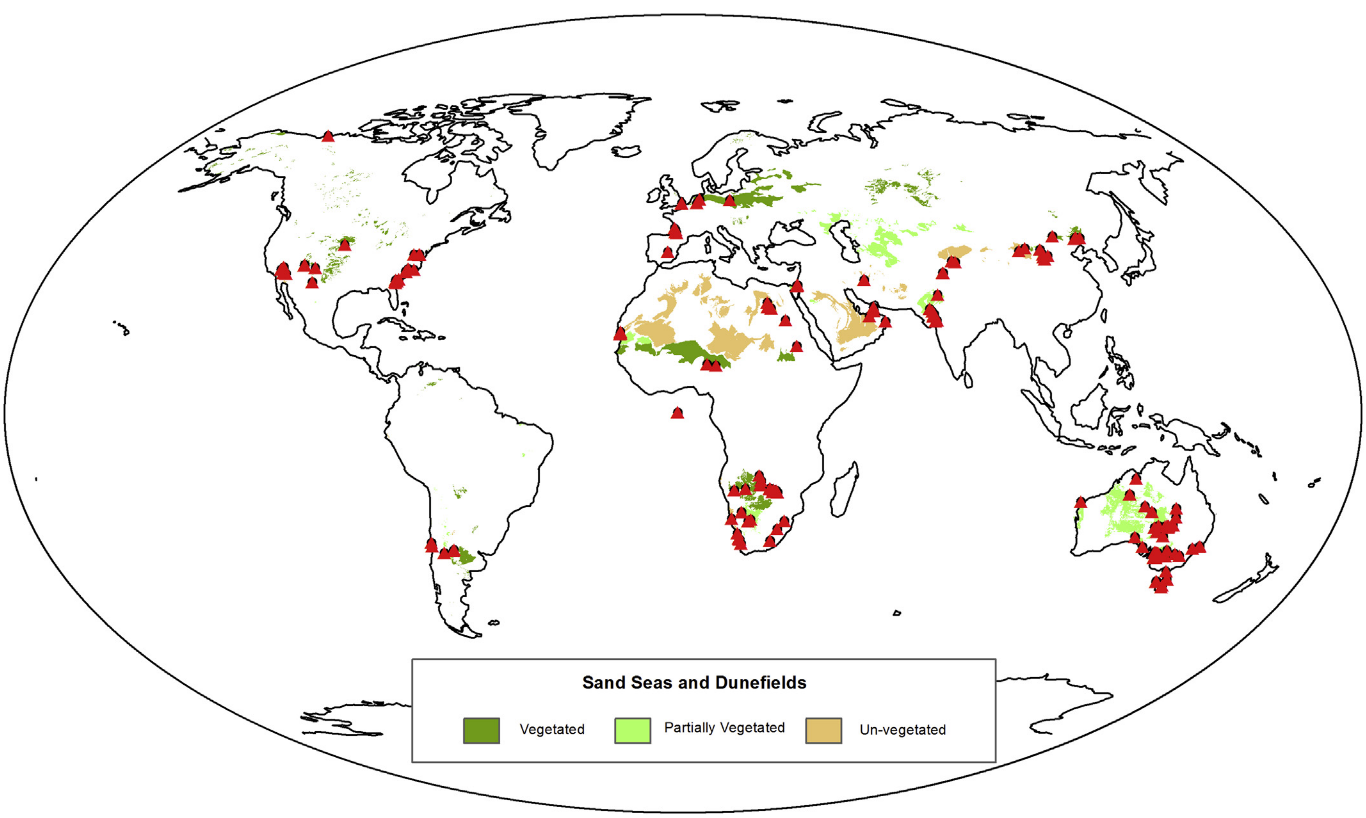

Fig. 4. Example of a time slice map. Luminescence dates for sand accumulation for the period of the last glacial maximum (LGM) defined as 19.5 to 26.5 ka following Clark, P.U., Dyke, A.S., Shakun, J.D., Carlson, A.E., Clark, J., Wohlfarth, B., Mitrovica, J.X., Hostetler, S.W., McCabe, A.M., 2009. The Last Glacial Maximum. Science 325, 710–714.

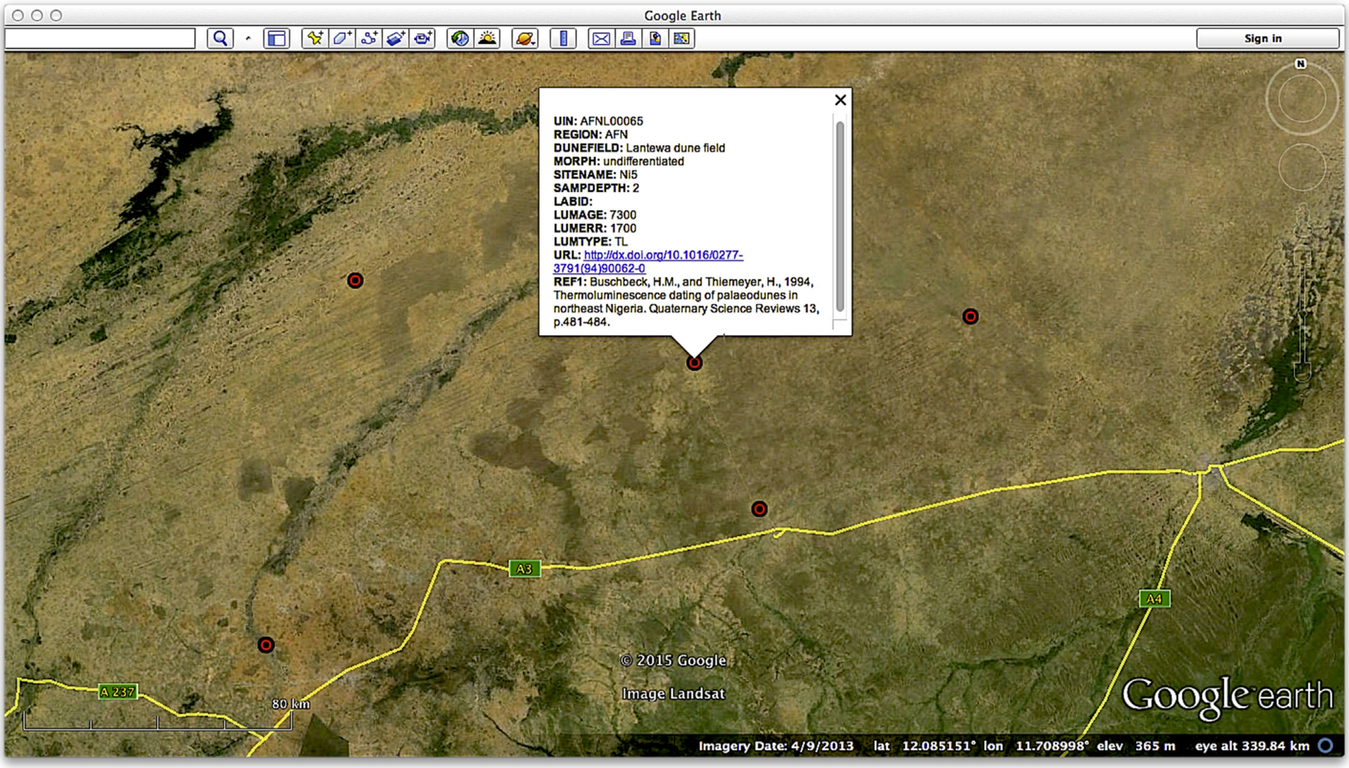

Fig. 5. Example of Google Earth view of a dated site.

progress, the database is a valuable resource that can be used to analyze patterns of dated dune deposits at multiple temporal and spatial scales; correlation of these patterns with other palaeoclimatic proxies; and assessment of the palaeoclimatic and palaeohydrologic implications of periods of aeolian deposition. In addition, the dataset can be used to validate earth system and palaeoclimate model simulations over the past 30–40,000 years.

The compilation of the database highlights several issues with the available luminescence data set, especially the uneven spatial coverage of dated dune deposits, the heterogenous nature of the dune sedimentary record in many areas, and difficulties in clear interpretaions with respect to climate drivers of system activity in the past. It is clear that resolution of these issues to provide a better understanding of dune and dune field responses to Quaternary climate change is not just a matter of additional dates. A systematic dating program that reflects fundamental patterns of dune field sensitivity to climatic and hydrologic changes and relates dated deposits to patterns of dune morphology and sedimentology is needed as a research priority.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quaint.2015.10.044.

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