Quaternary Geochronology 22 (2014) 65–71

Contents lists available at ScienceDirect

Quaternary Geochronology

journal homepage: www.elsevier.com/locate/quageo

Research paper

A new probabilistic technique to build an age model for complex stratigraphic sequences

Martin H. Trauth*

Institut für Erd- und Umweltwissenschaften, Universität Potsdam, 14476 Potsdam, Germany

ARTICLE INFO

Article history:
Received 25 June 2013
Received in revised form
18 February 2014
Accepted 4 March 2014
Available online 20 March 2014

Keywords:
Age-depth modelling
Stratigraphy
Sedimentation rate
Hiatus
MATLAB

ABSTRACT

The age models of fluvio-lacustrine sedimentary sequences are often subject of discussions in paleoclimate research. The techniques employed to build an age model are very diverse, ranging from visual or intuitive estimation of the age-depth relationship over linear or spline interpolations between age control points to sophisticated Bayesian techniques also taking into account the most likely deposition times of the type of sediment within the sequence. All these methods, however, fail in detecting abrupt variations in sedimentation rates, including the possibility of episodes of no deposition (*hiatus*), which is the strength of the method presented in this work. The new technique simply compares the deposition time of equally thick sediment slices from the differences of subsequent radiometric age dates and the unit deposition times of the various sediment types. The percentage overlap of the distributions of these two sources of information, together with the evidence from the sedimentary record, helps to build an age model of complex sequences including abrupt variations in the rate of deposition including one or many hiatuses.

1. Introduction

A precise age-depth model is an important prerequisite for the interpretation of high-resolution paleoclimate records. Unfortunately, these methods, although often published with downloadable computer code, guidelines and work-through examples, are hardly used in paleoclimate research (Blaauw, 2010). Many paleoclimate studies do not provide any information on the algorithm used in calculating the age model, if they ever use one, or they do not provide any information about the ambiguity and uncertainties of the result. The available age-depth modelling techniques used range from (1) visual or intuitive estimation of the age-depth relationship (e.g. Brown and Feibel, 1991; Trauth et al., 2001; Behrensmeyer et al., 2002), (2) linear, polynomial or spline interpolation or regression between the radiometric age dates (e.g. Maher, 1972; Blaauw and Heegaard, 2012), (3) calibrating the stratigraphy to insolation or orbital target curves (e.g. Partridge et al., 1997; Joordens et al., 2011), (4) forward modelling of facies variations in cyclic sections (e.g. Kominz and Bond, 1990, 1992), (5) Monte-Carlo modelling of age distributions along sediment cores (Hercman and Pawlak, 2012) to (6) Bayesian age-depth models (e.g. Steier and Rom, 2000; Steier et al., 2001; Blaauw and Christen, 2011; Blaauw and Heegaard, 2012).

The weakness of many of these techniques is mainly due to a lack of a suitable algorithm for consideration of abrupt changes in the sedimentation rate within stratigraphic sections or cores, including even the possibility of the complete lack of sedimentary layers at certain times (*hiatus*). Building an age model in these situations is complicated by the fact that the sedimentation rates depend strongly on the observed time resolution, with a very strong negative relationship between expected sedimentation rate and averaging time (e.g. Sadler, 1981, 1999) (Fig. 1). Such changes, however, are very common in stratigraphic sequences, for instance in the tectonically-active sedimentary basins of Eastern Africa (e.g. Brown and Feibel, 1991; Trauth et al., 2001; Behrensmeyer et al., 2002). In these basins, the sedimentation rates range from less than 0.1 m kyr^{-1} for diatomite (a sediment composed of the skeletons of silica algae, see Table 1), and 0.1–10 m kyr^{-1} for clastic sediments in lakes (Einsele, 2000; Hinderer and Einsele, 2001), to more than >10 m/kyr for sands (Einsele, 2000), and several meters of volcanic air fall deposits per within a couple of hours, followed by a longer time of no deposition (Fisher and Schmincke, 1984). Whereas the sedimentation rates of most sediment types are well known for lakes in Eastern Africa, the significance of hiatuses are subject passionate discussions (Trauth et al., 2005; Trauth and Maslin, 2009; Owen et al., 2009).

* Tel.: +49 331 977 5810; fax: +49 331 977 5700.
E-mail addresses: trauth@uni-potsdam.de, trauth@geo.uni-potsdam.de.

http://dx.doi.org/10.1016/j.quageo.2014.03.001
1871-1014/

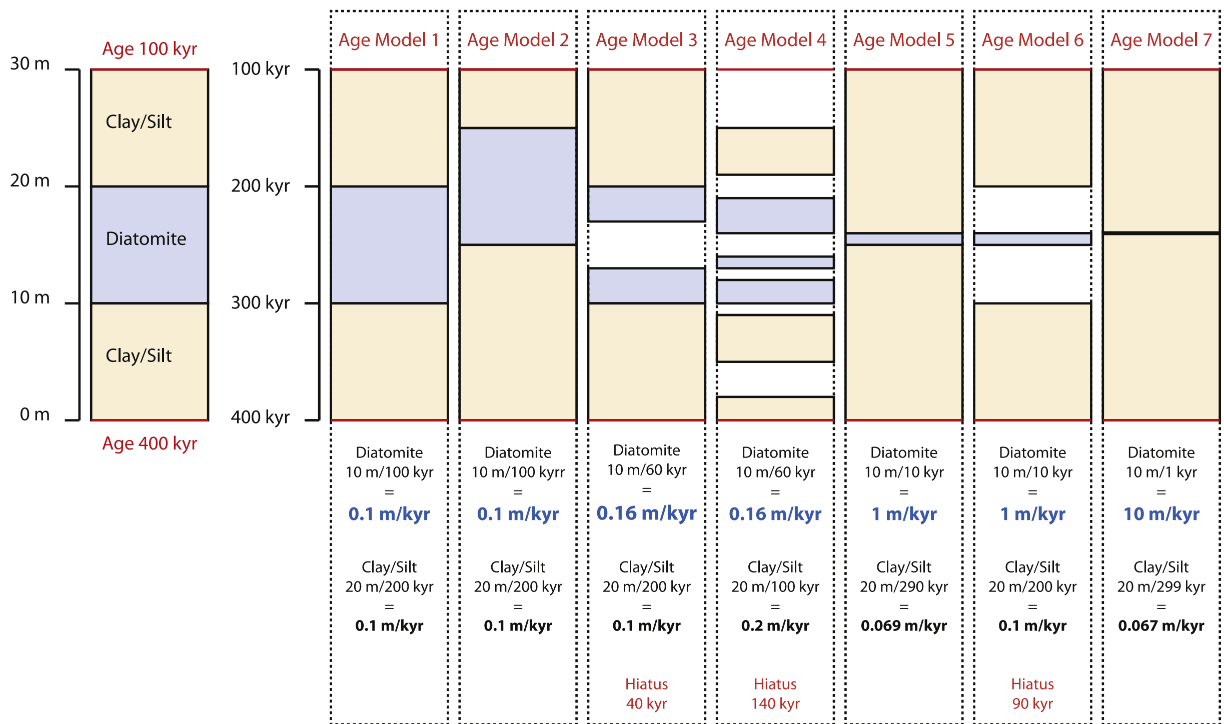

Fig. 1. Possible age models for three layers of clay/silt and diatomite, constrained by two radiometric age dates, 100 and 400 kyr, and their errors. The difference age models include different sedimentation rates, even with similar types of sediment, as well as one or more hiatuses of different duration. The sedimentation rates of the individual types of sediment are averaged over the entire interval. As an example, the lower clay/silt bed in Age Model 2 has a sedimentation rate of 10 m/150 kyr ≈ 0.07 m kyr^{-1} = 0.07 m kyr^{-1}, that of the upper clay/silt bed is 10 m/50 kyr = 0.2 m kyr^{-1} = 0.2 m kyr^{-1}, which averages as 20 m/200 kyr = 0.1 m kyr^{-1} = 0.1 m kyr^{-1}. The choice of the age model has important implications for the sedimentation rate of the diatomite and hence for the duration of lake episode documented by the diatomite.

The possibility of an abrupt change in the sedimentation rate was even regarded as a weakness of a linear over a spline age model, even though these changes exist but are often excluded or ignored in stratigraphic sections, similar to the possibility of hiatuses. Instead, an age model has to be smooth, often by introducing an arbitrary chosen memory in the sedimentation rates along the core, avoiding extreme variations or extremely low or high sedimentation rates, without abrupt changes in the measures of central tendency and dispersion, and without major gaps (e.g. Bronk Ramsey, 2008, 2009; Blaauw and Christen, 2011). Furthermore, it is assumed that a single sediment type, defined by the Gamma-distributed sedimentation rate, occurs through the section, which could be a good model in some lacustrine settings, but is an undue assumption in many sedimentary environments (e.g. Bronk Ramsey, 2008, 2009; Blaauw and Christen, 2011).

Here, I present a new technique to determine the age-depth relationship for stratigraphic sections and sediment cores with extremely fluctuating sedimentation rates, including hiatuses. The technique uses two independent sources of information to build an age model, (1) the time of deposition based on radiometric ages with their Gaussian errors and (2) the typical unit deposition time of the various sediment types (Fig. 2). Although the algorithm has been designed, tested and applied to age dates with Gaussian errors, it can be adapted for other applications quite easily. The agreement, or disagreement, between the two estimates of the time of deposition from two statistically independent sources of information helps to build an age-depth relationship in complex stratigraphic sequences. While this new technique in the case of high-resolution radiocarbon chronologies of relatively young (<10^4 yrs) and homogeneous sediments is not as straight forward as Bayesian techniques, it is superior in older $^{40}Ar/^{39}Ar$ dated sedimentary sequences with extremely fluctuating sedimentation rates and high probabilities for the occurrence of hiatuses.

Table 1
Typical sedimentation rates of diatomite as documented in Quaternary lake sediment sequences from East Africa.

Location	Sedimentation rate	Reference
Gadeb, Ethiopia	0.1 m kyr^{-1}	Gasse 1980
Ol Njorowa Gorge	0.03–0.25 m kyr^{-1}	Bergner and Trauth, 2004
Ol Njorowa Gorge	0.13–0.4 m kyr^{-1}	Trauth et al., 2001
Gicheru	0.5 m kyr^{-1}	Trauth et al., 2007
Olorgesailie	1.0 m kyr^{-1}	Deino and Potts, 1990
Gicheru	1.2 m kyr^{-1}	Trauth et al., 2007
Lake Malawi	>1.3 m kyr^{-1}	Owen and Crossley, 1992
Kariandusi	1.5 m kyr^{-1}	Trauth et al., 2007
Lake Manyara	1.9 m kyr^{-1}	Holdship, 1976
Barsemoi	2.2 (0.3–12) m kyr^{-1}	Deino et al., 2006

2. The system to be modelled

Sedimentary sections consist of a layered sequence of materials with different grain size and composition. The rate of deposition of these materials is described by the *sedimentation rate* (sediment thickness per unit time) or, alternatively, the *accumulation rate* (solid sediment mass per unit area and time, in kg m^{-2} kyr^{-1}) (Einsele, 2000). The sedimentation rate (in m kyr^{-1}) is determined from the sedimentary unit of the thickness z, divided by the time difference t between two radiometric age dates below and above the unit. While the terms sedimentation and accumulation rate are usually used correctly in the literature, there is no consensus on the name of the inverse of the sedimentation rate (time per sediment thickness). I prefer the term *unit deposition time* (in kyr m^{-1}), which