Palaeogeography, Palaeoclimatology, Palaeoecology 307 (2011) 313–323

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

High-frequency cyclicity in a Miocene sequence of the Vienna Basin established from high-resolution logs and robust chronostratigraphic tuning

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A R T I C L E   I N F O

Article history:
Received 7 February 2011
Received in revised form 26 April 2011
Accepted 16 May 2011
Available online 24 May 2011

Keywords:
Integrated stratigraphy
Sedimentation rates
Cyclostratigraphy
Milankovitch cycles
Sub-Milankovitch cycles
Vienna Basin

A B S T R A C T

A high-resolution chronostratigraphic record established by [W.E. Paulissen, S.M. Luthi, P. Grunert, S. Ćorić, M. Harzhauser, Geol. Carp. (2011)] that takes into account variations in sedimentation rates and temporal gaps caused by unconformities and faulting in a research borehole in the Vienna Basin was used to investigate the possible presence of orbital, millennial and centennial periodicities. The sedimentary sequence covers Middle to Late Miocene shallow marine, fluvio-deltaic and lacustrine shales, silt- and sandstones deposited during the transition from a pull-apart basin to the final infill in a compressional regime. Spectral analysis was performed on gamma ray logs and high-resolution electrical borehole images using three different analytical methods over six suitable intervals where continuous and constant sedimentation was identified. The significant periods were found to closely match the orbital cycles of precession, obliquity and short eccentricity, providing a solid basis for the analysis of potential sub-Milankovitch cycles. The significant frequencies encountered at the millennial- to centennial-scale fell for 75% within a relatively narrow time period of 0.25 to 5 kyr, with a concentration of peaks between 1 and 2 kyr (29%) and 500 to 800 years (17%). These periodicities relate closely to the millennial- (Dansgaard–Oeschger and Bond cycles) and centennial-scale climate cycles documented from the Quaternary. It is suggested that the high-frequency cycles observed in the Miocene of the Vienna Basin represent differences in grain size related to cyclic variations in regional precipitation.

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1. Introduction

The study of cyclic patterns in sedimentary records has a long history, mostly because of the often conspicuous rhythmicities observed in many stratigraphic sequences (Einsele et al., 1991, p. 1–19). Detecting cyclic sedimentation patterns and assigning them in a hierarchical manner to different processes and temporal periodicities help the geoscientists understand the origin of sedimentary sequences and the importance of the various driving mechanisms. Thus, many researchers have suggested that orbital cycles influence sedimentary records, initially mostly based on deep sea sediments (Hays et al., 1976; Imbrie and Imbrie, 1979; Imbrie et al., 1984), which lent substantial support to the Milankovitch theory on climate change. Currently there are numerous publications every year documenting cyclicities in the sedimentary record, many of them still from depositional environments with relatively continuous sedimentation, for which a link between orbital climate forcing and sedimentation is suggested. Deposits from shallow water environments have also been studied (e.g. García et al., 1996; van Vugt et al., 2001; Napoleone et al., 2004; Sacchi and Müller, 2004; Steenbrink et al., 2006; Abels et al., 2009), but these are often characterised by substantial sedimentary gaps and sudden changes in sedimentation rates. Age dating in these sequences often does not have the required resolution and accuracy in order to establish the potential imprint of orbital cyclic forcing on the sedimentary record. Therefore, an autocyclic origin often has to be considered as an alternative option to explain rhythmic patterns in such sequences (Burgess, 2006; Muto et al., 2007). Deposits from shallow water environments often also show rapid shifting of the facies belts, resulting in sequences that may not contain sufficient geological time for the longest orbital periodicities (long and short eccentricity) to be detected. These longer cycles are used by a number of authors to constrain the shorter Milankovitch periodicities, attributed to obliquity and precession, in rhythmic sedimentary sequences (e.g. Gale et al., 1999; Weedon et al., 1999; Preto et al., 2001; Lirer et al., 2009). Even shorter periodicities, the so-called millennial- and centennial-scale cycles, have been identified with this approach (Zühlke et al., 2003; Mawson and Tucker, 2009; Boulila et al., 2010).

This paper is based on an approach in which sedimentation rates and hiatuses are determined to a high degree of accuracy with a combination of stratigraphic methods. The depositional setting is in the Miocene of the Paratethyan Vienna Basin and is known to contain stratigraphic gaps and highly variable sedimentation rates (Harzhauser and Piller, 2004; Kováč et al., 2004). This integrated approach combines biostratigraphy, magnetostratigraphy, seismic stratigraphy and lithostratigraphy in a borehole that could be used for research purposes (Paulissen et al., 2011). Age dating of the sediments is obtained from a continuous

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doi:10.1016/j.palaeo.2011.05.029

magnetostratigraphic record by a palaeomagnetic logging tool, combined with biostratigraphic analysis of borehole cuttings that provides the tie-in points to connect the magnetic polarities to the Geomagnetic Polarity Time Scale (GPTS). Seismic data is used to identify temporal gaps in the sedimentary record, caused either by erosion, non-deposition or faulting. The faults identified on the seismic data are then identified on electrical borehole images, resulting in exact locations of these stratigraphic gaps in the borehole. This chronostratigraphic framework is used to determine a complete record of sedimentation rates that takes into account the temporal gaps. It also allows the definition of intervals that are suitable for spectral analysis; these intervals should be devoid of hiatuses and contain relatively constant sedimentation rates.

The spectral analysis is applied on conventional wireline logs, such as the gamma ray log, as well as on electrical borehole images that have a much higher resolution of about 1 cm (the sampling rate is 0.25 cm). Logs have been previously used to analyse potential periodicities in sedimentary sequences (Barthès et al., 1999; Harzhauser and Piller, 2004; Harzhauser et al., 2004; Sacchi and Müller, 2004; Lefranc et al., 2008; Lirer et al., 2009), but the link between the physical characteristics recorded by wireline logs in boreholes and the depositional or diagenetic processes that causes them is often difficult to establish.

The methodology described here thus does not use the a priori assumption that an orbital signal is preserved in the sedimentary record that can be used to establish a high-resolution time calibration (so-called orbital tuning). Rather, it seeks to determine first a high-

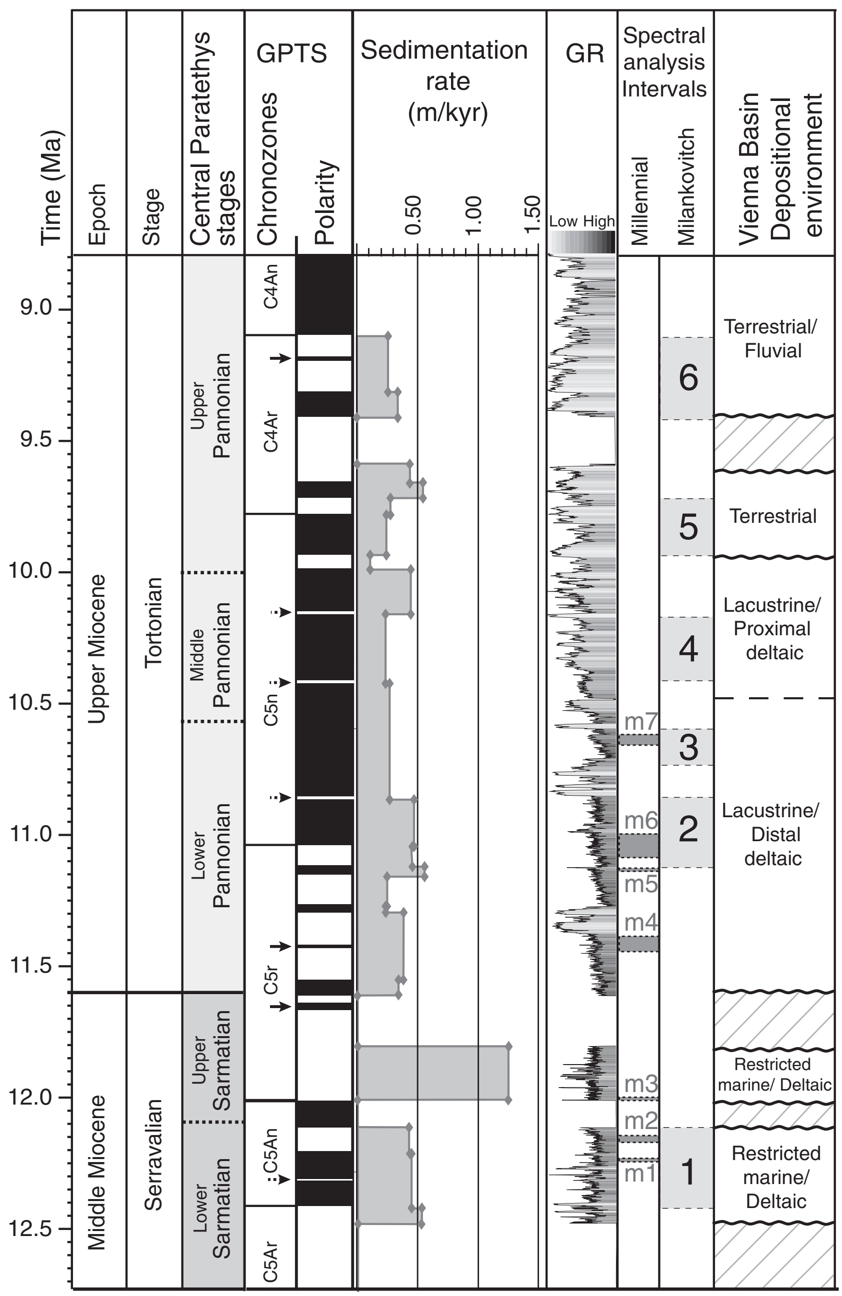

Fig. 1. Chronostratigraphic framework of the research well according to Paulissen et al. (2011) based on seismic data, well correlation, biostratigraphy and magnetostratigraphy for the Sarmatian and Pannonian interval. The Central Paratethyan stages are according to Harzhauser and Piller 2004, Harzhauser et al. (2004) and Strauss et al. (2006) and the Geomagnetic Polarity Time Scale (GPTS) according to Lourens et al. (2004) with solid and dashed arrows on the GPTS indicating the short polarity subchrons and polarity fluctuations as described by Krijgsman and Kent (2004). The sedimentation rates are calculated for the magnetostratigraphic intervals through a combined stratigraphic approach and are not corrected for compaction. The gamma ray log (GR) was stretched linearly between the magnetostratigraphic tie-ins with the stratigraphic gaps taken into account.

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