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Evidence of orbital forcing in lake-level fluctuations in the Middle Eocene oil shale-bearing lacustrine successions in the Mudurnu-Göynük Basin, NW Anatolia (Turkey)

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ABSTRACT

Mudurnu-Göynük basin of the Sakarya Zone in NW Anatolia comprises ca. 1500 m thick Paleocene–Eocene terrestrial to shallow marine succession overlying the Late Cretaceous deeper marine progradational fore-arc sediments. Formed in a foreland setting in relation to southerly situated İzmir–Ankara suture zone, this terrestrial succession (regionally known as Kızılçay group) comprises a thin (<200 m) oil shale-bearing lacustrine section with very good cyclic patterns that potentially serves the quantification of stratigraphy and enlightening the origin of cyclicities of various hierarchy. Our detailed facies analysis on three correlative measured sections showed that mudstone, oil shale and thinner limestone alternations characterize the relatively deeper part of the Eocene lake with probable marine intervention, while thicker limestone, coal, marl and occasional oil shale alternations typify the southern relatively freshwater shoal areas. These facies are frequently organized as meter-scale symmetric to asymmetric transgressive–regressive cycles. Spectral analysis of the mudstone beds and the cycles within the lacustrine succession strongly indicates the occurrence of full bands of Milankovitch with the shortest precession cycle (19 ka) at ca. 2.30 m. Our observations further revealed quite rhythmic thin couplets with estimated durations of 365–730 yr that might represent abrupt climatic changes during deposition. On the other hand, longer duration (ca. 1 Ma) of shoaling and deepening trends in the studied sections were attributed basically to varying subsidence due to tectonic loading in the southerly suture zone. Lastly, regarding the distribution of depositional environments we propose that the oil shale exploration activities should be carried out within a 20 km wide E–W running belt while the southern limits of this belt is more prolific for coal resources.

1. Introduction

The Early Paleogene System has been considered the last warmest and probably ice-free greenhouse period of the earth's history, study of which confronts the earth scientists with challenging problems such as, among others, amplitude and rhythm of eustatic sea level oscillations and nature of climatic changes, and their probable linkages with the orbital forcing as a background external control (Miller et al., 1987; Sloan and Morrill, 1998; Zachos et al., 2001, 2008). Studies in rare long-lived lacustrine archives such as the Green River Formation of Wyoming, Colorado and Utah (West USA) successfully showed influence of earth's orbital parameters upon continental climates in formation of cyclic or quasi-cyclic sedimentary stacking patterns (Fischer and Roberts, 1991; Pietras et al., 2003; Machlus et al., 2008). More detailed cyclostratigraphic works in suitable lacustrine lithologies of the same time frame were able to document the occurrence of bimodal periodicities related to El Nino and sunspot cycles (Ripepe et al., 1991). Although a clear orbital forcing has been demonstrated in marine sedimentary records of the glaciated times Late Eocene onward (Zachos et al., 2001; Miller et al., 2008), occurrence of the Milankovitch type cycles and their mechanism remained controversial in the marine sediments of presumably ice-free Early Paleogene times. Some authors suggest sporadic glaciation/deglaciation events pacing with astronomic forcing (Browning et al., 1996; Dawber and Tripat, 2007; Stickley et al., 2009; Warnaar et al., 2009) while many others envisage by using various proxy data and climate models the absolute lack of glaciation during Early Middle Eocene times (Sloan and Morrill, 1998; Zachos et al., 2001; Lawrance et al., 2003; Burgess et al., 2008), but in this second case the mode of eustatic change and its linkage to the orbital forcing remained partially

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unexplained (Miller et al., 2005, 2008). Another controversial point in the literature is significance and hierarchy of different driving factors in cycle generation in foreland settings such as the one studied here. Although rapid and high frequency vertical movements would be regarded the basic underlying force, there are many evidences for the impact of orbitally driven climate changes upon the higher frequency cycles (Vail et al., 1977; Pujalte et al., 1993; Devlin et al., 1993; Matthews and Perlmutter, 1994; Juhasz et al., 2007).

Here we present a detailed facies and cyclicity account of a marine-influenced lacustrine Middle Eocene oil shale bearing succession from a rapidly subsiding foreland basin in NW Anatolia. It is suggested that the investigation of the nature of cycles and related amplitudes of eustatic changes deduced in this continental to marginal marine setting of mid-latitudinal Eocene world may contribute the understand of the modes of orbital and tectonic forcing in the generation of lacustrine cycles. Additionally we also expect useful insights in terms of oil shale exploration from the overall depositional architecture caused by lower order cyclicity of tectonic origin.

2. Regional depositional patterns in the Eocene of Anatolian basins

As a consequence of the consumption of the Neo-Tethys ocean branches in the north Anatolia by Eocene times, internal deformation of the Anatolian collage begun (Okay and Tüysüz, 1999; Görür and Tüysüz, 2001). An overall north–south shortening of the orogeny mostly resulted in shoaling upward successions topped by marginal marine, evaporitic or non-evaporitic sedimentation in the pre-existing relatively deep fore-arc basins (Görür et al., 1998). Among others, lagoonal to shelf depositional systems in the central and NE Mudurnu-Göynük basin (Saner, 1977, 1980; Ocakoğlu et al., 2007), fluvio-lacustrine and carbonate shelf systems in the Orhaniye and Haymana basins (Kazancı and Gökten, 1986; Koçyiğit, 1991; Ocakoğlu and ve Çiner, 1995; Çiner et al., 1996), deltaic to evaporitic marginal marine sediments in the Çankırı–Çorum basin (Hakyemez et al., 1986; Ocakoğlu, 1997; Kaymakci et al., 2003) and shelf to evaporitic marginal marine systems in the Sivas basin in the east (Cater et al., 1991; Sümengen et al., 1987) has already been documented (Fig. 1A). Owing to

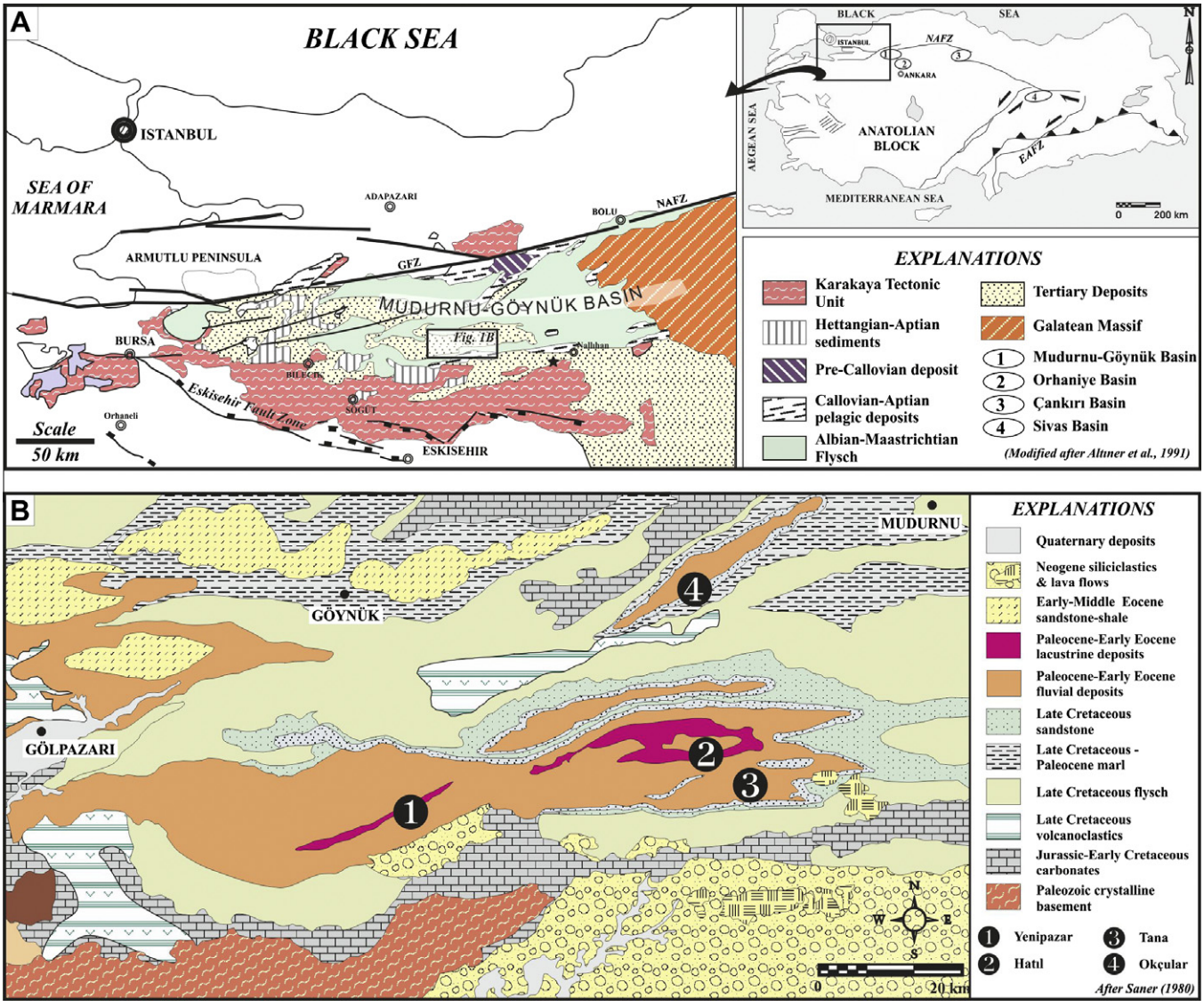

Fig. 1. (A) Simplified geological map of the NW Anatolia (after Altıner et al., 1991) (NAFZ: North Anatolian Fault Zone, GFZ: Geyve Fault Zone, EAFZ: East Anatolian Fault Zone) and (B) the study area (after Saner, 1980).