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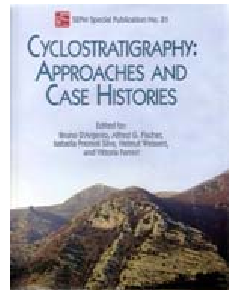

This SEPM Special Publication is the outcome of a meeting on "Multidisciplinary approach to Cyclostratigraphy", organized by the editors in Sorrento, Italy in May 2001. The volume presents contributions on orbital signals in deep-water, carbonate-platform, mixed and detrital-marginal, and lacustrine facies, ranging in age from Triassic to Pleistocene. In the introduction, the editors review the development of ideas and insights into the way in which orbital forcing produces climate variations and resulting cyclicities in sedimentary successions. Since the middle of the 18th century, concepts about astronomical cycles and their influence on climate have been put forward, but only with the advance of astronomy and of modern computation techniques firm proofs could be given.

Chronology and cycle recognition has been a principle focus in much of the research on orbital signals. Proxies for recognizing orbitally induced cyclicities in sedimentary successions include the visual recognition of interference patterns, e.g. between precession and eccentricity, producing the typical bundling of precession cycles in groups of four to five. Moreover, variations in fossil content, stable oxygen and carbon isotope composition, and geochemical proxies are used for the recognition of orbital cycles. Where such cyclicity is not obvious from visual inspection, a variety of time-series analyses is available for the appraisal of its presence. The theoretical background provided by astronomers such as Berger, Loûtre, and Laskar has allowed to link bio- and magnetostratigraphy to the astronomical time scale. On this basis, classical biostratigraphy is now being supplemented by cyclostratigraphy, and improvements in radiometric constants have been proposed. The astro-cyclo-stratigraphic time scale is being expanded back into the Tertiary. Its completion for the whole Phanerozoic may be a matter of time.

After the preface by the editors, the introductory chapter by Fischer and the other editors discusses "Cyclostratigraphic approach to Earth history". Early researchers, such as Adhémar, Gilbert, Bradley and De Geer put forward intuitive ideas, and explained sedimentary rhythmicities and the alternation of glacials and interglacials as being the result of astronomical cycles in precession, obliquity and eccentricity. They were inspired by astronomical studies of d'Alembert, Leverrier and Croll, who recognized that changes in the Earth's orbital eccentricity, obliquity and precession may lead to seasonal and long-term quasi-periodic variations in climate. Milutin Milankovitch combined earlier ideas and proposed an explanation for the succession of glacials and interglacials. In his benchmark work, "Pleistocene temperatures", Emiliani (1955) interpreted Pleistocene variations in $\delta^{18}O$ in terms of astronomically induced temperature changes, and brought the long-ignored theory of astronomical influences on climate back under the attention. Another benchmark work, "Variations in the Earth's orbit: Pacemaker of the Ice Ages" by Hays, Imbrie & Shackleton (1976) was the prelude to the avalanche of research in the last decades.

Pelagic cycles

Sprovieri et al. demonstrate 400-ka $^{87}Sr/^{86}Sr$ variations in the Tortonian Mediterranean, and relate these to 100-150% periodic variations in riverine input. The combined lithological, magnetostratigraphical, and biostratigraphical study reveals that the studied succession can be well correlated to the astronomical parameters. Follow-up studies may allow a more detailed reconstruction of variations in precipitation and runoff from the surrounding continent. Iaccarino et al. reconstruct the high-resolution cyclostratigraphy for the late Langhian to early Tortonian (Middle Miocene) in the Mediterranean, based on calcareous plankton. The authors correlate the sedimentary cycle pattern to a solution of the insolation curve by Laskar, and improve definitions of the Serravallian stages boundaries. In a second contribtution, Sprovieri et al. demonstrate, for a slightly older part of the Miocene (12.3-13.8 Ma, late Langhian to middle Serravallian), the relationship of variations in benthic foraminifer abundances with the 100-ka and 400-ka eccentricity cycles and related oxygenation conditions in deep water.

Grippo et al. continue on earlier work on the Piobicco core by Erba (1988), and show that the Albian in the Umbrian Apennines has been characterized by a generally slow circulation and that precession-related minima in the oxygenation state of deep water are related to phases of slowest circulation, mimicking stagnant-basin conditions. They remark that the presently impending greenhouse state may not reach the strength of the mid-Cretaceous one, but that intensification of the oxygen-minimum zone may well locally affect diurnal migration patterns of marine organisms. Maurer, Hinnov & Schlager discuss the mid-Triassic Buchenstein Formation formed in deep water in between carbonate platforms in the Dolomites. They analyze grayscale scans and gamma-ray well logs of the Seceda core, but remain, after removing calciturbidites and volcaniclastics from the log and applying time-frequency analysis, inconclusive about the question whether the cycles do reflect a Milankovitch signal, indeed.

Carbonate platforms

Carbonate platforms, not being disturbed by terrigenous input and often having the potential to keep pace with rapid sea-level rise, have shown to be excellent recorders of past sea-level changes. Aptian-Albian carbonate-platform cycles in the southern Apennines, analyzed by D'Argenio et al., show the complete spectrum of Milankovitch periodicities and an important sea-level component. The authors successfully correlate the stable-carbon-isotope pattern to the pelagic $\delta^{13}C$ curve, opening the way to arrive at a Cretaceous cyclostratigraphy that will allow correlating cyclic successions in different sedimentary environments. The same group of authors, Wissler et al., corroborates these results in a comparable study of Barremian-Aptian shallow-water carbonates near Naples, where – on the basis of cycles and $\delta^{13}C$ stratigraphy – a close correlation is made to the synchronous pelagic Cismon succession in the Southern Alps in northern Italy, and corrections for the magneto-polarity time scale are proposed. Construction of the Cretaceous time scale is further elaborated on by Strasser, Hillgärtner & Pasquier: cyclicity in Berriasian shallow-marine carbonates is closely related to 20-ka sea-level changes. This allows to monitor the evolution of deposition and of the related ecosystems very closely in the context of sea-level and climate change. Bundle-by-bundle correlation between two shallow-marine carbonate successions of Valangian-Hauterivian age, one near Naples and the other on Sicily, is demonstrated by Ferreri et al. Their work also helps to open the way for the reconstruction of spatial differences in the response of shallow-marine carbonates to variations in climate and eustasy.

Bedding rhythms in shallow-marine carbonates driven by Milankovitch-controlled sea-level changes have been a topic of research ever since Schwarzacher (1947) first described the Triassic Lofer cyclothems. Early studies of cyclicities in the Middle Triassic Latemar platform carbonates in the Italian Dolomites have proposed that they were precession-driven, but later studies, based on ammonites and radiometric dating, disproved this interpretation, and it was proposed that autocyclic processes at least also had a significant influence. Preto et al. continue this discussion, and offer a good example of the application of time-series analysis. Time-frequency analyses show a pattern typical of amplitude modulation of the precession signal by eccentricity variations, confirming earlier results of Goldhammer. However, this interpretation gives a great discrepancy with chronostratigraphic evidence. Although contradictions between calibrations of the cyclicity in the succession remain unresolved, it is concluded that cycles were allogenic in origin, and that they were caused by relative sea-level changes. A second, very detailed study of the Latemar platform carbonates is presented by Zühlke. He concludes that a significant sub-precession periodicity of ~ 4.2 ka is present in the succession, and discusses the possibility of similarities with the Quaternary Dansgaard-Oeschger, Heinrich and Bond cycles.

Mixed and detrital marginal facies

Under this heading, three chapters discuss Milankovitch-driven glacio-eustatic cyclicity in Pleistocene continental shelf and rise sediments in Italy, in the Plio-Pleistocene of the western Antarctic, and orbitally forced cycles in the Purbeckian of Dorset.

Based on seismic profiles, Aiello & Budillon describe the sequence-stratigraphic architecture of Pleistocene prograding sediment wedges on the continental shelf of Apulia as the reflection of glacio-eustatic sea-level variations, regional tectonics and sediment supply. The short eccentricity cycle indeed is the dominant control on sea level, and based on this time control the authors conclude that the rate of uplift of the Apulian foreland decreased during the late Pleistocene. Iorio, Wolf-Welling & Moerz studied Plio-Pleistocene cores drilled on the western Antarctic continental rise during ODP Leg 178. Short and long eccentricity signals emerge from the data and can be well correlated on a regional scale. Cycles consist of poorly fossiliferous clays and silts deposited during glacials, whereas biogenic muds date from interglacial times. Although the full range of orbital periodicities is recognized, the mid-Pleistocene transition (0.9 Ma) from a predominantly obliquity to a prominent eccentricity control, was not recognized in the studied cores. The Middle-Purbeckian shelf sequence in Dorset, studied by Anderson, is a third-order sequence in which fourth-order, fifth-order and sixth-order cycles stand out. Limestones dominate the basal part of the sequences and towards the top shale is the dominant facies. Sequence and cycle boundaries are interpreted as the product of precession-forced sea-level rises and the related cessation of sedimentation, modulated by 100-ka, 400-ka and 2-Ma eccentricity cycles. Interpretations are in line with the results of earlier paleoecological (ostracod and mollusk) studies.

Lacustrine systems

Lacustrine systems are often characterized by very quiet deposition, and it is not amazing that orbital cycles were recognized in such facies already early in the last century. The paleomagnetic susceptibility signal in Plio-Pleistocene intermontane graben deposits in the northern Apennines, studied by Napoleone, Albianelli & Fischer, shows a clear eccentricity-modulated precession cyclicity with, in addition, sub-precession cycles of 7 ka and 4-5 ka. Climate-induced variations in the supply of sediment with varying amounts of magnetite, either from the source terranes or supplied as aeolian dust from elsewhere, are suggested to be the most likely causes. A lacustrine succession in the Pannonian Basin, studied by Sacchi & Müller, was correlated to the global polarity time scale of Cande & Kent, and of Hilgen et al.

Time and cyclicity

In the one but last chapter, Schwarzacher discusses time in stratigraphy, and demonstrates how accumulation rates can be reconstructed with the assumption that similar beds represent similar time intervals. Finally, Hilgen, Schwarzacher & Strasser propose working definitions for cyclostratigraphic studies, as well as a formal codification of Milankovitch cyclicity. Considering that the 400-ka eccentricity cycle is the most stable orbital cycle over prolonged intervals of time, this 400-ka cycle, possibly together with the 2.3-Ma eccentricity cycle, seems most suitable to be used as the framework for as yet floating time scales deeper in the geological past. Such a framework will allow to link cyclical sequences in different sedimentary environments and in different areas, and to reconstruct variations in Earth-surface processes resulting from orbitally induced climate and sea-level change.

As the editors note in the introduction, the complex response of sedimentary systems to the orbital variations requires attention. Much work has been done in recognizing astronomical cyclicities, and much still has to be done to arrive at a complete understanding of the pathways along which the varying insolation signals are transferred into sedimentary sequences. Sediment production by weathering, biogenic production of sediment, precipitation and evaporation indeed all vary with variations in climate, as does sediment transport.

Pelagic, lacustrine and carbonate-platform deposits at intermediate paleolatitudes have provided most examples of astronomically induced sedimentary cycles, being systems that are rather undisturbed by tectonics and located in a climate zone which is sensitive for insolation changes. Of course orbitally induced climate change does affect other depositional systems. However, other features, such as tectonics, autocyclicity and irregular sediment supply, often obscure the astronomical signal.

In certain cases, presented in the book, the precession signal, recognized on the basis of time series analysis, is less than one would expect considering astronomical predictions. In contrast, the obliquity signal, being dominant at high latitudes is sometimes well recognized in low-latitude sedimentary successions. One reason may be that, with the irregular cycle length, the spread around the mean is much larger for the precession than for the obliquity signal, giving a relatively more pronounced expression in spectral curves for the latter. The alternative is that the high-latitude obliquity signal is transferred, through as yet unrecognized pathways, to low latitudes.

The book is a welcome addition to the literature on astronomical cycles. It has been well edited and illustrations are clear and relevant. Most of the contributions are well documented, and will be useful for future studies. The book is to be recommended to libraries of both universities and research institutes.

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