Astronomical time scales for the Swiss and French Jura Mountains (Middle Oxfordian to Late Kimmeridgian)

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Ever since Earth Sciences exist there has been a quest for measuring geological time. Relative time scales have been established through biostratigraphy and are constantly being refined. Radiometric dating furnishes absolute ages but error margins may still be large. Astronomical time scales use the sedimentary or geochemical record of insolation changes and are directly linked to orbital periodicities with known durations. Except for the Quaternary where other dating methods give yearly, decadal, or centennial time resolutions, astronomical time scales offer the highest resolution available for the geologic past. If the sedimentary systems were sensitive enough to record orbitally induced climate changes, and if the general time frame is constrained by radiometric dating, then a time resolution of 20'000 years (corresponding to the cycle of the precession of the equinoxes) can optimally be obtained.
The Oxfordian and Kimmeridgian sediments of the Swiss Jura Mountains has been studied extensively since the 19th century (e.g., Heer 1865). Lithology and biostratigraphy of these mostly shallow-water carbonates are well known (e.g., Trümpy 1980, Gygi 1995). In order to go a step further and analyse in more detail the evolution through time of the depositional environments, high-resolution sequence-stratigraphic and cyclostratigraphic studies have been undertaken. Based on 23 sections logged and interpreted by the Fribourg working group since 1995 (V. Bard, C. Colombié, C. Dupraz, P. Gsponer, W. Hug, P. Jordan, D. Oswald, B. Pittet, N. Rameil, G. Rauber) an astronomical time scale covering the Middle Oxfordian to Late Kimmeridgian interval is presented.
In the platform sections, vertical facies changes define deepening-shallowing depositional sequences, which are hierarchically stacked. Commonly, 5 elementary sequences (the smallest units where facies evolution indicates a relative sea-level change) compose a small-scale sequence, and 4 small-scale sequences make up a medium-scale sequence. The fact that most of the small-scale and medium-scale sequence boundaries can be followed over hundreds of kilometres points to an allocyclic control on sequence formation. Autocyclic processes, however, were superimposed and are recorded mainly on the level of the elementary sequences. Because biostratigraphic information in the shallow-water sections is scarce, a platform-to-basin correlation has been performed. In the sections of the Vocontian Trough, ammonite biostratigraphy on the subzone level is available. The basinal sections feature limestone-marl alternations, whereby one limestone-marl couplet is considered to correspond to an elementary sequence. These are stacked into bundles of 5 and define small-scale sequences, which again build up medium-scale sequences. Furthermore, large-scale sequence boundaries and maximum-flooding intervals can be placed in the biostratigraphic framework.
Sequence-chronostratigraphic charts published for the European basins (Hardenbol et al. 1998) furnish estimations of absolute ages of ammonite zone boundaries and large-scale sequence boundaries. Within this framework, elementary, small-scale, and medium-scale sequences can be counted and their average duration estimated. The values thus obtained are close to the orbital periodicities. It is implied that

elementary sequences correspond to the 20-kyr cycle of the precession of the equinoxes, small-scale sequences to the 100-kyr short eccentricity cycle, and medium-scale sequences to the 400-kyr long eccentricity cycle. The hierarchical stacking of these sequences thus reflects Milankovitch cyclicity.
Between sequence boundary Ox4 in the Plicatilis zone (Middle Oxfordian) and Ti1 in the Hybonotum zone (earliest Tithonian), 68 small-scale (100-kyr) sequences have been identified, which would correspond to a duration of 6.8 myr. According to Hardenbol et al. (1998), the same interval lastet 7.4 myr. The duration of the Kimmeridgian (sensu gallico) is evaluated at 3.3 myr by cyclostratigraphy, whereas Gradstein et al. (1995) give a value of 3.4 myr to this stage. The cyclostratigraphic approach thus may complement and improve absolute dating methods, refine sequence-chronostratigraphic charts, and help determine the duration of biozones. Even if the absolute ages still contain uncertainties related to radiometric dating, the durations of the intervals analysed by cyclostratigraphy can be estimated with a time resolution of a few ten-thousand years ("floating" astronomical time scales).
The precise timing of depositional sequences allows for a very detailed interpretation of sedimentological, ecological, and diagenetic processes. The time resolution approaches that of the Pleistocene and the Holocene where the controlling parameters are much better known than in the deep geologic past. Consequently, sedimentation rates, speeds of evolutionary changes, or the timing of porosity development in reservoir rocks can be evaluated with unprecedented resolution.

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