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Holocene climate dynamics, biogeochemical cycles and ecosystem variability in the eastern Mediterranean Sea

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The past variability of biogeochemical processes and marine ecosystems of the eastern Mediterranean Sea (EMS) is documented in the form of organic-rich sapropels that occurred at northern hemisphere insolation maxima. In order to understand the processes leading from deglacial and Holocene climate variability to the formation of sapropel S1 via changed biogeochemical cycling in the EMS, we integrated results from global and regional Earth system model experiments with biogeochemical and micropaleontological proxy records.

Our results suggest a high spatiotemporal variability of deep-water oxygenation and biogeochemical processes at the sea floor during the late glacial and early Holocene. Changes in trophic conditions of bathyal ecosystems along ocean margins are closely linked to the hydrology of the EMS borderlands; they reflect orbital and sub-orbital climate variations of the high northern latitudes and the African monsoon system. Local trophic conditions were particularly variable in the northern Aegean Sea as a response to changes in riverine runoff and Black Sea outflow. During the time of S1 deposition, average oxygen levels decreased exponentially with increasing water depth, suggesting a basin-wide shallowing of vertical convection superimposed by local signals. In the northernmost Aegean Sea, deep-water ventilation persisted during the early period of S1 formation, owing to temperature-driven local convection and the absence of low-salinity Black Sea outflow. At the same time, severe temporary dysoxia or even short anoxia occurred in the eastern Levantine basin at water depths as shallow as 900 m. This area was likely influenced by enhanced nutrient input of the Nile river that resulted in high organic matter fluxes and related high oxygen-consumption rates in the water column.

In contrast, abyssal ecosystems of the Levantine and Ionian basins lack eutrophication during the early Holocene suggesting that enhanced productivity did not play a crucial role in basin-wide S1 formation. Instead, sapropel formation can be attributed to a long-term persistence of water column stratification. The modeled and observed trends of oxygen consumption rates and deep-water residence times date the initiation of stagnating deep-waters at the start of the deglacial period, thus several millennia prior to S1 deposition. Once oxygen levels fell below a critical threshold, bathyal and abyssal benthic ecosystems collapsed almost synchronously with onset of S1 deposition suggesting a rapid vertical propagation of the oxygen minimum layer. The recovery of bathyal deep-sea benthic ecosystems during the terminal phase of S1 formation is controlled by subsequently deeper convection and re-ventilation over a period of approximately 1500 years; the ultra-oligotrophic abyssal ecosystems reveal a considerably lower recovery potential. After the re-ventilation of the various sub-basins had been completed during the middle and late Holocene, deep-water renewal was more or less similar to recent rates. During that time, deep-sea ecosystem variability was driven by short-term changes in food quantity and quality as well as in seasonality, all of which are linked to millennial-scale changes in riverine runoff and associated nutrient input.