Evidence of Strong Sea Surface Temperature and Salinity Decline after the Tortonian-Messinian Boundary based on Paired Foraminiferal Sr/Ca and $\delta^{18}O$ Analyses

E. Besiou[1], G. Kontakiotis[1], A. Antonarakou[1], P. G. Mortyn[2,3], H. Drinia[1], E. Koskeridou[1], V. Karakitsios[1]

(1) Faculty of Geology & Geoenvironment, School of Earth Sciences, Department of Historical Geology-Paleontology, National & Kapodistrian University of Athens, Panepistimiopolis-Zografou, 15784, Greece, wwweua@hotmail.com
(2) Institute of Environmental Science and Technology (ICTA), Universitat Autònoma de Barcelona (UAB), Edifici Z - Carrer de les Columnes, Bellaterra 08193, Spain.
(3) Department of Geography, Universitat Autònoma de Barcelona (UAB), Spain

Objectives

The late Miocene has been considered as one of the most climatically stable periods of the Cenozoic, characterized by minor long-term cooling and ice growth (Zachos *et al*., 2001). Especially, the Tortonian-Messinian Transition (TMT) is recognized as a priority for paleoenvironmental reconstruction and climate modelling due to the significant paleoenvironmental changes preceding the Messinian Salinity Crisis (MSC) (Blanc-Valleron *et al*., 2002; Drinia *et al*., 2007) and the development of the modern Mediterranean-type climate (Mertz-Kraus *et al*., 2009) respectively. This time window is of particular importance for the paleoceanographic evolution of the entire Mediterranean Sea, because it covers the successive closure of the marine Mediterranean-Atlantic gateways, which culminated in the onset of the MSC. The basin experienced a dramatic hydrological and biological crisis induced by a powerful combination of geodynamic and climatic drivers (Roveri *et al*., 2014; Karakitsios *et al*., 2017a; Krijgsman *et al*., 2018). The change of the Mediterranean's connections with both the Atlantic Ocean and the freshwater Paratethyan basins, caused high-amplitude fluctuations in the hydrology of its basins (Karakitsios *et al*., 2017b; Vasiliev *et al*., 2019), which had a great impact on the subsequent geological history of the Mediterranean area, and on the salinity of the global oceans. The geological expression of this evolution was the omnipresent cyclic marl/sapropel succession because freshwater input was not constant, but strongly pulsed at precessional time-scales (Hilgen *et al*., 1995). In the present study, we present an integrated study based on sedimentological, micropaleontological, and geochemical data from the pre-evaporitic sedimentary sequence of the Faneromeni section (Crete Island, eastern Mediterranean), which provides an excellent illustration of the progressive restriction of the Mediterranean basin in response to paleoclimate. The observed sedimentary cyclicity corresponds to lithological alternations from laminated to indurated homogeneous marls and clayey limestones, and covers the late Tortonian and earliest Messinian stages (7.6-6.7 Ma; Moissette *et al*., 2018). Outcropping marine sediments in Crete, which preserve the foraminiferal signal intact, provide windows into the Mediterranean that have not been recovered by deep sea drilling, because the late Miocene sedimentary record from this area is buried under thick layers of salt deposited when the Mediterranean desiccated.

Methods

The tools used by the Miocene palaeoclimate community have changed over time, and researchers continue to use the most sophisticated and independent techniques available for reconstruction. Proxies have been developed to estimate different aspects of the environment, but surface ocean temperatures and salinities are by far the primary data generated, since together they control ocean water density and thereby thermohaline circulation. Initially, the foraminiferal record was qualitatively evaluated for dissolution by X-ray micro-computed tomography. Stable oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopes were also used to estimate salinities, and indirectly ice volume. Moreover, primary temperature proxies, including foraminiferal Mg/Ca and Sr/Ca ratios, were utilized for the paleotemperature reconstruction. Those proxy techniques have strengths and limitations (Kontakiotis *et al*., 2011, 2016; Antonarakou *et al*., 2019), but each plays an important role in our conceptual understanding of the late Miocene Earth. The use of multiple proxies is of great benefit to gaining more robust and detailed estimates of the palaeoenvironment as long as the relative limitations of various techniques are recognized.

Results

We present the first evidence for changes in the upper water column reflected by sea surface temperature (SST) and salinity (SSS) variations that correlate with pronounced paleoclimatic fluctuations. Our planktonic isotope record, in combination with paired mixed layer Sr/Ca-derived SST data, reveal that the very warm late Tortonian interval was followed by a strong long-term cooling and desalination trend (up to 10^0C and 10‰ respectively) during the earliest Messinian. This change in the upper water column just after the T/M boundary attributed to the paroxysmal phase of the so-called “siphon” event. Especially, the climate shift that occurred at the end of a global carbon isotope decrease suggests that changes in the carbon cycle were instrumental in driving late Miocene climate dynamics (cooling and aridity) in the progressively isolated eastern Mediterranean Sea. The observed salinity variability during that time interval also provides further insights about seasonal freshwater inputs, and gives new support to the much-debated hydrological regime preceding the deposition of evaporites.

Conclusions

This study focuses on and further extends the application of the foraminiferal Sr/Ca paleothermometer to late Miocene Mediterranean sections, and inserts the climate history of this setting into the framework of global climate through this time period. Our findings reveal a non-gradual increase in sea surface salinity prior to the onset of the MSC, but substantial variability in response to climatic oscillations, supporting the concept of a stepwise restriction of the Mediterranean Sea.

References

Antonarakou, A., Kontakiotis, G., Vasilatos, C., Besiou, E., Zarkogiannis, S., Drinia, H., Mortyn, P.G., Tsaparas, N., Makri, P., Karakitsios, V., 2019. Evaluating the effect of marine diagenesis on Late Miocene pre-evaporitic sedimentary successions of eastern Mediterranean Sea. IOP Conference Series: Earth and Environmental Sciences, 221: 012051.

Blanc-Valleron, M.M., PierreI, C., Caulet, J.P., Caruso, A., Rouchy, J.M., Cespuglio, G., Sprovieri, S., Pestrea, S, Di Stefano, E., 2002. Sedimentary, stable isotope and micropaleontological records of paleoceanographic change in the Messinian Tripoli Formation (Sicily, Italy). Palaeogeogr. Palaeoclimatol. Palaeoecol., 185, 255–286.

Drinia, H., Antonarakou, A., Tsaparas, N., Kontakiotis, G., 2007. Palaeoenvironmental conditions preceding the Messinian Salinity Crisis: A case study from Gavdos Island. Geobios, 40, 251–265.

Hilgen, F.J., Krijgsman, W., Langereis, C.G., Lourens, L.J., Santarelli, A., Zachariasse, W.J., 1995. Extending the astronomical (polarity) time scale into the Miocene. Earth Planet. Sci. Lett., 136, 495–510.

Karakitsios, V., Cornée, J.-J., Tsourou, T., Moissette, P., Kontakiotis, G., Agiadi, K., Manoutsoglou, E., Triantaphyllou, M., Koskeridou, E., Drinia, H., Roussos, D., 2017b. Messinian salinity crisis record under strong freshwater input in marginal, intermediate, and deep environments: The case of the North Aegean. Palaeogeogr., Palaeoclimatol., Palaeoecol., 485, 316–335.

Karakitsios, V., Roveri, M., Lugli, S., Manzi, V., Gennari, G., Antonarakou, A., Triantaphyllou, M., Agiadi, K., Kontakiotis, G., Kafousia, N., de Rafelis, M., 2017a. A record of the Messinian salinity crisis in the eastern Ionian tectonically active domain (Greece, eastern Mediterranean). Bas. Res., 29, 203–233.

Kontakiotis, G., Mortyn, P.G., Antonarakou, A., Drinia, H., 2016. Assessing the reliability of foraminiferal Mg/Ca thermometry by comparing field-samples and culture experiments: A review. Geol. Quart., 60 (3), 547–560.

Kontakiotis, G., Mortyn, P.G., Antonarakou, A., Martínez-Botí, M.À., Triantaphyllou, M.V., 2011. Field-based validation of a diagenetic effect on G. ruber Mg/Ca paleothermometry: core top results from the Aegean Sea (eastern Mediterranean). Geochem. Geophys. Geosyst., 12 (9), Q09004.

Krijgsman, W., Capella, W., Simon, D., Hilgen, F.J., Kouwenhoven, T.J., Meijer, P.Th., Sierro, F.J., Tulbure, M.A., van den Berg, B.C.J., van der Schee, M., Flecker, R., 2018. The Gibraltar Corridor: Watergate of the Messinian Salinity Crisis. Mar. Geol., 403, 238–246.

Mertz-Kraus, R., Brachert, T.C., Reuter, M., Galer, S.J.G., Fassoulas, C., Iliopoulos, G., 2009. Late Miocene sea surface salinity variability and paleoclimate conditions in the Eastern Mediterranean inferred from coral aragonite δ18O. Chem. Geol., 262 (3-4), 202–216.

Moissette, P., Cornée, J.-J., Antonarakou, A., Kontakiotis, G., Drinia, H., Koskeridou, E., Tsourou, T., Agiadi, K., Karakitsios, V., 2018. Palaeoenvironmental changes at the Tortonian/Messinian boundary: A deep-sea sedimentary record of the eastern Mediterranean Sea. Palaeogeogr. Palaeoclimatol. Palaeoecol., 505, 217–233.

Roveri, M., Flecker, R., Krijgsman, W., Lofi, J., Lugli, S., Manzi, V., Sierro, F.J., Bertini, A., Carnerlenghi, A., De Lange, G., Govers, R., Hilgen, F.J., Hubscher, C., Meijer, P.T., Stoica, M., 2014. The Messinian Salinity Crisis: Past and future of a great challenge for marine sciences. Mar. Geol., 352, 25–58.

Vasiliev, I., Karakitsios, V., Bouloubassi, I., Agiadi, K., Kontakiotis, G., Antonarakou, A., Triantaphyllou, M., Gogou, A., Kafousia, N., de Rafélis, M., Zarkogiannis, S., Kaczmar, F., Parinos, C., Pasadakis, N., 2019. Large sea surface temperature, salinity, and productivity-preservation changes preceding the onset of the Messinian Salinity Crisis in the eastern Mediterranean Sea. Paleoceanography and Paleoclimatology. 34.

Zachos, J., Pagani, M., Sloan, L., Thomas, E., Billups, K., 2001. Trends, rhythms, and aberrations in global climate 65 Ma to present. Science, 292(5517), 686–693.