Oligocene and Miocene Global Spatial Trends of Shallow-Marine Carbonate Architecture

Julien Michel,[1,*] *Cyprien Lanteaume,*[2] *Alexandre Lettéron,*[2,3] *Jeroen Kenter,*[2] *Michele Morsilli,*[4] *and Jean Borgomano*[3,5]

1. MODIS Pau, 4 Rue Jules Ferry, 64000 Pau, France; 2. Total CSTJF, Avenue Larribau, 64000 Pau, France; 3. Centre Européen de Recherche et d'Enseignement de Géosciences de l'Environnement (CEREGE), UM 34, Aix-Marseille Universite, CNRS, IRD, Collège de France, INRAE OSU Institut Pythéas, 3 Place Victor Hugo, Case 67, 13331 Marseille Cedex 03, France; 4. Università degli Studi di Ferrara, Dipartimento di Fisica e Scienze della Terra, Via Giuseppe Saragat 1, 44122, Ferrara, Italy; 5. Chaire TOTAL-AMIDEX, Carb3E Energie-Environnement-Education, 3 Place Victor Hugo, Case 67, 13331 Marseille Cedex 03, France

ABSTRACT

The present study provides the baseline status of the spatial distribution of carbonate platforms for the Oligo-Miocene interval. The resulting global trend quantitatively shows the decreasing growth potential of shallow-marine carbonates toward higher paleolatitudes. Such a global trend provides a geological context and external constraints for local and regional interpretations of specific case studies. Furthermore, the direct relationship between carbonate accumulations and paleoclimatic regions shows that, using such a qualitative and quantitative data set for calibration, paleoceanographic models could be utilized for the prediction of the global distribution of carbonate stratigraphic architecture.

Online enhancements: appendix tables, appendix references.

Introduction

Outcrop and subsurface geological data are, as a rule, a biased, incomplete and selective sample of their mother population, which has limited access and has been limited in preservation. In most sedimentary systems, uncertainties, which are related to processes such as, but not limited to, erosion and diagenesis, cannot be quantified (cf. Kidwell and Bosence 1991; Wright and Burgess 2005). In such a data-challenged context, statistical and geostatistical methods might not be relevant. To overcome such data limitations, concepts and models of critical processes and controlling factors are always utilized in sedimentary geology studies (Miall and Miall 2001). Hence, deterministic but uncertain scientific approaches are applied to identify spatial and temporal trends and predict geological properties (Borgomano et al. 2020). For instance, global spatial trends of carbonates, the topic of the present article, offer an independent tool to constrain local and regional carbonate sedimentary models and to study paleoclimate change (Lees and Buller 1972; Parrish and Curtis 1982; Whalen 1995; Kiessling et al. 2003; Markello et al. 2008). In addition, such works improve our understanding of geological characteristics and controlling parameters as well as global carbonate prediction (Wilson 1975; Davies et al. 2019; Michel et al. 2019; Pohl et al. 2019).

Global paleoceanographic trends of shallow-marine carbonates were formalized by the concepts of photozoan-heterozoan grain associations (James 1997) and precipitation modes of carbonate factories (Schlager 2003, 2005). In turn, these specific carbonate production modes are associated with particular stratigraphic architecture and sequence stratigraphic stacking that can be recognized using the deterministic interpretation of outcrop and subsurface data. Simplistically, skeletal carbonate production

Manuscript received May 21, 2020; accepted October 10, 2020; electronically published January 20, 2021.

* Author for correspondence; email: julien.michel@modis.com.

[The Journal of Geology, 2020, volume 128, p. 563–570] 0022-1376/2020/12806-0004$15.00. DOI: 10.1086/712186

can be classified into (1) photozoan associations sensu James (1997) or T-factory sensu Schlager (2003, 2005), which are characterized by autotrophic, mainly phototrophic, biota such as hermatypic corals, show the highest growth potential, rapidly fill accommodation space, and create flat-topped platforms with relatively steep slopes—these associations were historically referred to as "tropical" carbonates; and (2) heterozoan associations sensu James (1997) or C-factory sensu Schlager (2003, 2005), which are characterized by heterotrophic biota such as bryozoans, show lower growth potential, do not fill accommodation space, and build architecture which resembles that of siliciclastic deposits—these associations were historically referred to as "cool-water" carbonates (cf. Schlager 2003, 2005, for more details). In the modern era, the distribution of carbonate factories closely relates to oceanographic parameters and in particular net primary productivity, sea-surface temperatures, and sea-surface salinities (e.g., Laugié et al. 2019). Such trends follow basic ecological concepts showing the role of oceanographic patterns in controlling carbonate production (Wilson 2012; Hallock 2015) and can be quantified (Kleypas et al. 1999; Laugié et al. 2019). Paleoclimate modeling shows the applicability of such concepts given the consistency of physical and chemical principles (Davies et al. 2019; Pohl et al. 2019). These applications as well as global case study reviews (Kiessling et al. 2003; Michel et al. 2018) concern only carbonate grain association or precipitation mode, not the associated stratigraphic architecture. Because James (1997) and Schlager (2005) demonstrated that the nature of carbonate grain associations can be linked to paleogeography throughout most of the Phanerozoic, in this article we test if carbonate factory models and their stratigraphic architecture can be reliably predicted at a global scale.

The Oligo-Miocene interval was selected to implement this approach because data are relatively abundant and it is considered to exhibit well-preserved and referenced paleoecological, paleoenvironmental, and stratigraphic attributes of carbonate systems (e.g., Wilson 2002, 2015; Gatt and Gluyas 2012; Pomar et al. 2017). Nonetheless, beyond the conceptual schemes of "tropical" versus "cool-water" carbonates (T-factory or photozoan vs. C-factory or heterozoan of Schlager 2005, and James 1997, respectively), no attempt has been made to understand global distributional trends of stratigraphic architecture for the Oligo-Miocene interval. What we are investigating in this article is the validity of the spatial relationship between carbonates and paleoclimatic regions in the rock record (Wilson 2008; Michel et al. 2019). In particular, we propose to establish the spatial trends of stratigraphic architecture in terms of overall depositional shape and thickness that could be related to paleoenvironmental, mostly paleoceanographic, parameters. These trends could then be used as baseline status to study biotic and paleoclimatic changes, which are not analyzed here.

Methods

An extensive bibliographic study reviewed 145 case studies to classify and map outcrop and subsurface carbonate accumulations of the Oligo-Miocene interval excluding the Messinian stage (from 34 to 11 Ma; table A1 [tables A1–A3 are available online]). Referenced bibliographic databases include the Mediterranean reviews of Esteban et al. (1996), Perrin and Bosellini (2012) and Pomar et al. (2017), the Southeast Asia review of Wilson (2002), the global PaleoReefs database of Kiessling and Flügel (2002), the Caribbean review of Johnson et al. (2008), and the Oligo-Miocene transition review of Mutti et al. (2010). This compilation comprises 86 outcrops and 59 subsurface case studies. A remarkable gap in the present data set is the Pacific region; apart from the Marshall Islands and Midway Atoll, Oligo-Miocene shallow-water carbonates appear to be poorly defined in terms of sedimentology, morphology, or dating (e.g., Bougainville Guyot−Vanuatu, Northern Line Islands, and Tuamotu; Bourrouilh-Le Jan and Hottinger 1988; Lyle et al. 2016; Ocean Drilling Program Reports) or only detected in resedimented carbonate around Malekula Island−Vanuatu, central Pacific, and Emperor Seamounts (Schlanger 1981). This gap highlights that the Pacific record of carbonate platforms is certainly incomplete and underrepresented.

Grain association, sedimentary profile, and stratigraphic architecture, the latter being defined by the maximum thickness and geometric shape of the overall carbonate accumulation, were determined at the platform scale following the conceptual schemes of James (1997) and Schlager (2005). Platform profiles were determined as ramp, distally steepened ramp, or flat-topped platform (Read 1985; Pomar 2001). Because of lack of chronostratigraphic data, maximum thickness is not well constrained and might include sediments other than Oligo-Miocene ones. A deterministic approach was used to classify natural geological case studies into conceptual categories, which are defined upon key criteria (cf. James 1997; Schlager 2005; Michel et al. 2019). Thus, specific biota, facies, and geometric shape of the overall carbonate accumulation were reported to classify each case study as a unique carbonate system following the nomenclature of Laugié et al. (2019) and Michel et al. (2019).

The paleogeographic positions of the case studies were reconstructed using the Scotese Paleomap Project and the GPlates software (Müller et al. 2018). Global patterns of carbonate accumulations were then compared with paleoceanographic maps (von der Heydt and Dijkstra 2006). No specific chronostratigraphic studies were carried out to investigate carbonate factory changes within case studies. Neither biotic nor paleoclimatic changes were studied here; rather the baseline status of shallow-water carbonate distribution of the entire Oligo-Miocene interval is shown. Following up on the works about carbonate reef and platform distributions of Kiessling et al. (1999, 2003), we study the global spatial trends of carbonate platforms.

Observations of Oligo-Miocene Global Carbonate Distribution

A diverse array of carbonate systems developed worldwide, ranging from skeletal and mixed carbonate-siliciclastic accumulations of different geometries to small and extensive ramp systems and isolated carbonate platforms (figs. 1*C*, 2*C*). Out of 145 possibilities, data availability allowed us to convincingly identify 133 case studies in terms of grain associations, 111 case studies in terms of sedimentary profiles, 55 case studies in terms of stratigraphic architectures, and 113 case studies in terms of carbonate factories (tables A1, A2). To evaluate the size of carbonate accumulations, 136 "maximum thicknesses" and 99 "widths along dip" were extracted or extrapolated from available data. From these case studies, maximum recorded thickness ranges from 2 to 2450 m (Santa Cruz in Argentina and Maldives, respectively) and dip width displays values from less than a kilometer to nearly 700 km (Aruba Island in the Netherland Antilles and Murray Basin in Australia, respectively; table A1).

Grain association shows a consistent global trend with high paleolatitudes exclusively occupied by heterozoan and mixed heterozoan-siliciclastic deposits (cf. James and Jones 2015; Michel et al. 2018). Within the tropical to subtropical paleolatitudes, a mixture of corals, red algae, and foraminifers characterize most sedimentary deposits ("rhodalgal," "LB-foralgal," and "coralgal" sensu Kindler and Wilson 2010). The recorded abundances of corals appear to show a global trend; greater abundances of corals are mentioned in the literature at lower latitudes. This trend, however, remains unquantified.

Shallow-water carbonate accumulations show a great diversity of shapes and sizes (figs. 1*C*, 2*C*). Nonetheless, a consistent global trend exists with specific architectures occurring only in particular regions (figs. 1, 2). The thickest, generally flat-topped platform accumulations are found on the western side of tropical oceans in the Caribbean, East Africa, and Southeast Asia mainly. Extensive, thick carbonate systems occur in the southern Mediterranean region and in the Middle East. The mid-paleolatitude, northern Mediterranean region generally hosts smaller carbonate accumulations. Specific heterozoan systems showing significant thicknesses from 80 to 500 m are recorded in southern Australia and New Zealand.

A large number of sedimentary profiles are interpreted in the literature and include ramps and flat-topped platforms. In most cases, facies belt transitions and original topographic slope angles cannot be determined from the available rock record. Indirect interpretations are based on specific grain associations, localized depositional reliefs (e.g., reefs), and type of basin margin. Of 145 case studies, 42 ramps, 14 homoclinal ramps, 2 seaways, and 53 flat-topped platforms were defined in this study (table A1). No consistent, straightforward global trend of facies belt succession could be determined beyond classical schemes (Wilson 1975; Buxton and Pedley 1989; Brandano et al. 2017).

Oligo-Miocene Global Trend of Shallow-Marine Carbonate Architecture

The thorough bibliographic review highlights the fact that outcrop and subsurface data alone do not allow defining the sedimentary characteristics of carbonate systems. Each case study only offers very limited data in comparison with the whole, original carbonate system from the coastline to the platform margin in terms of paleoecosystem, sedimentary profile, and geometry. To fill this gap, only the use of concepts and models that show consistent geological trends allows placing into a paleoenvironmental context and thus constraining the interpretation of sedimentary systems.

The growth potential of Oligo-Miocene shallow-marine carbonates decreases toward higher paleolatitudes as shown by the nonexclusive trend of accumulation thickness records (figs. 1*D*, 2*D*). The carbonate factory scheme of Schlager (2005) allows understanding the processes controlling such a global trend in terms of carbonate production, which follows simple paleoceanographic patterns (figs. 1*A*, 1*B*, 2*A*, 2*B*; cf. Schlager 2005; James and Jones 2015). Thick (hundreds of meters), flat-topped platform accumulations (T-factory sensu Schlager 2005, or photozoan-T-factory sensu Michel et al. 2019) are

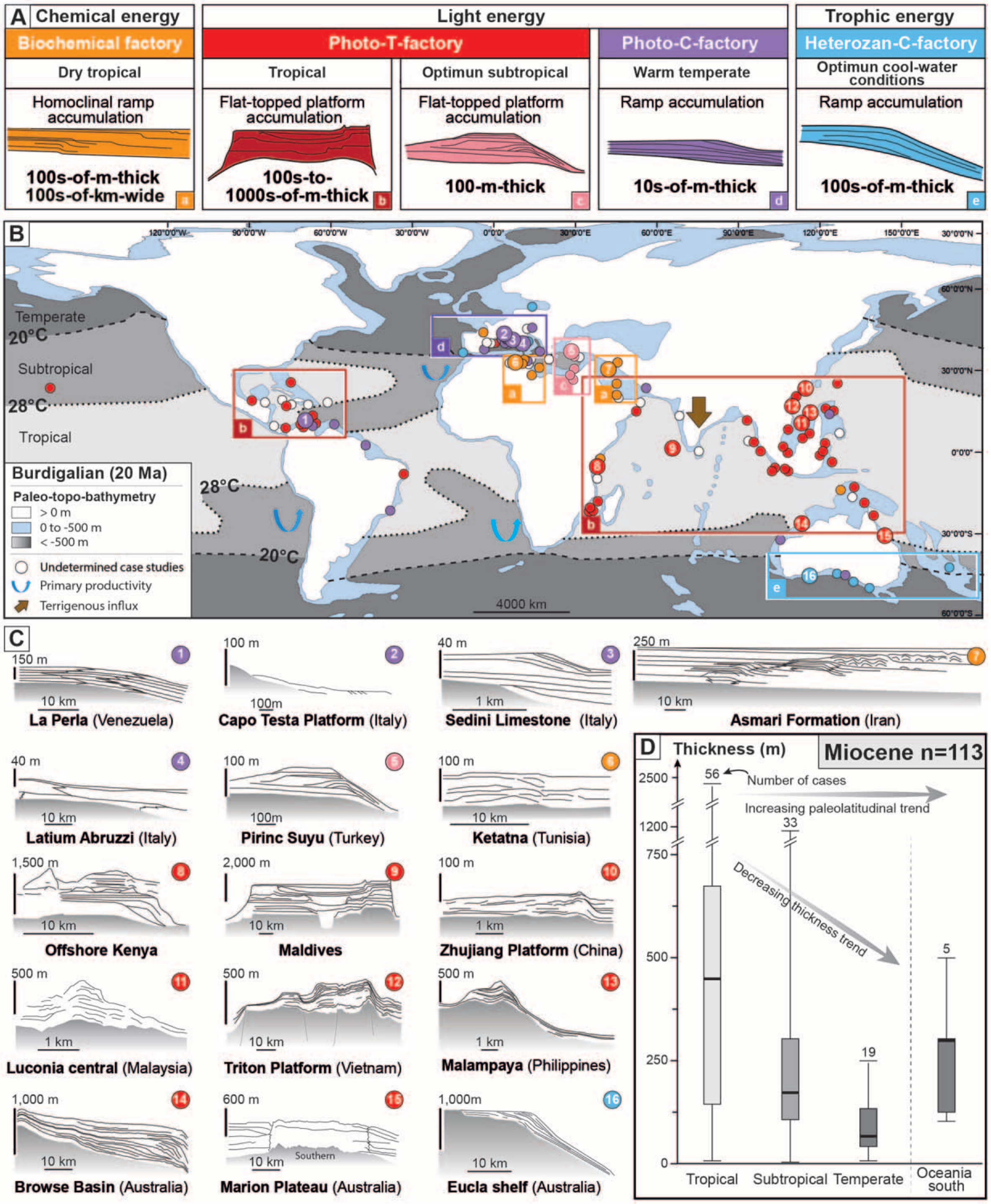

Figure 1. Global distribution of Miocene shallow-marine carbonates (cf. text and table A1 for related bibliographic references and case study details). *A*, Conceptual scheme of global trend of carbonate factories in terms of carbonate accumulation geometry and thickness (and width for the biochemical factory). *B*, Miocene case studies and main carbonate paleoclimatic regions (paleogeographic map from Scotese Paleomap Project; paleo-sea-surface temperatures from von der Heydt and Dijkstra 2006). *C*, Selected examples of carbonate stratigraphic architecture redrawn from literature. *D*, Median, maximum, minimum, and 75% and 25% quartile values of Miocene carbonate thickness through paleolatitudes.

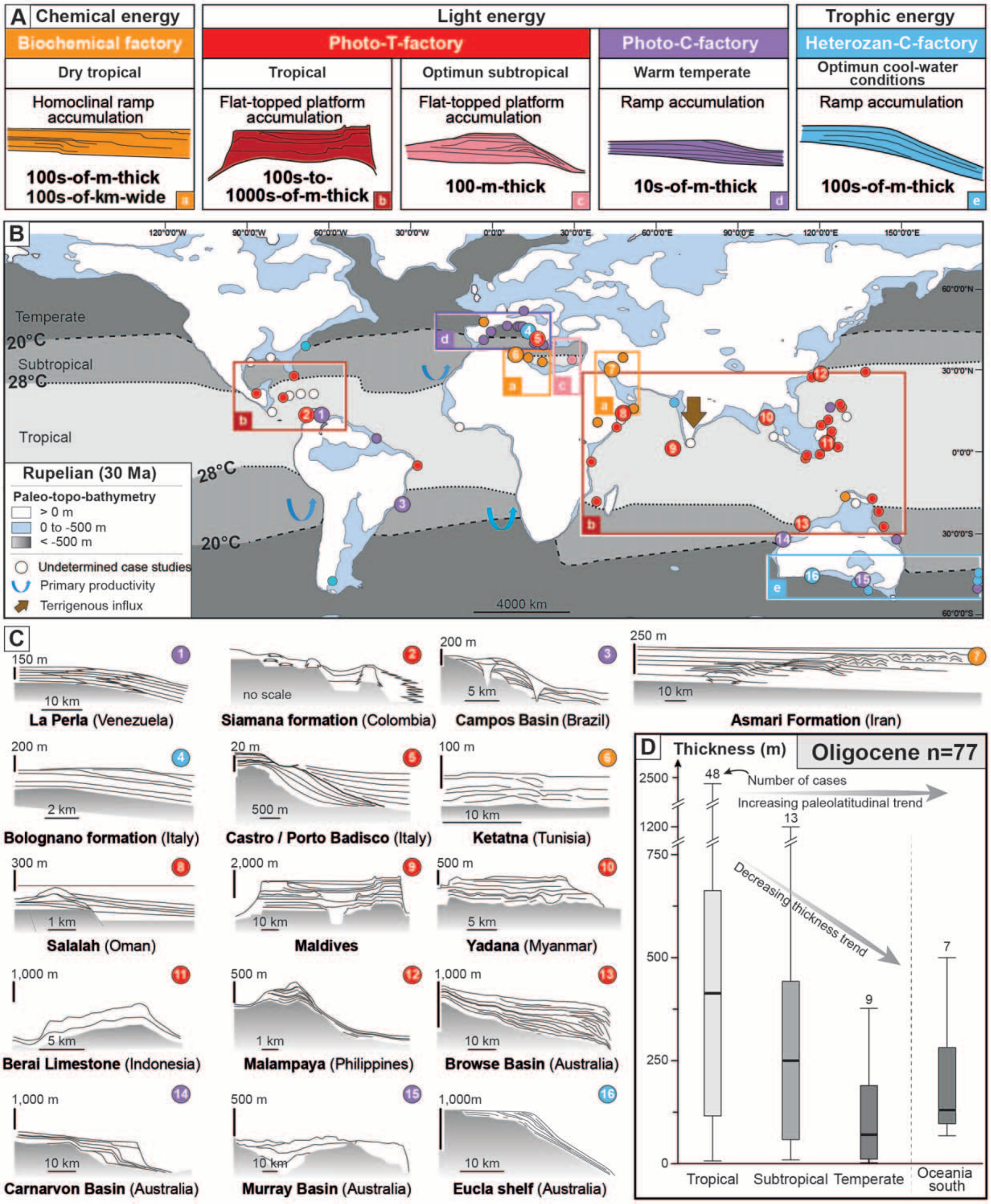

Figure 2. Global distribution of Oligocene shallow-marine carbonates (cf. text and table A1 for related bibliographic references and case study details). *A*, Conceptual scheme of global trend of carbonate factories in terms of carbonate accumulation geometry and thickness (and width for the biochemical factory). *B*, Oligocene case studies and main carbonate paleoclimatic regions (paleogeographic map from Scotese Paleomap Project; paleo-sea-surface temperatures from von der Heydt and Dijkstra 2006; please note that alternative paleogeographic interpretation exists about the eastern Mediterranean seaway opening and closure; e.g., Perrin and Bosellini 2012). *C*, Selected examples of carbonate stratigraphic architecture redrawn from literature. *D*, Median, maximum, minimum, and 75% and 25% quartile values of Oligocene carbonate thickness through paleolatitudes.

found in oligotrophic tropical waters (figs. 1, 2). Toward higher paleolatitudes, shallow-water carbonate systems tend to decrease in size. The tropical to subtropical eastern Mediterranean region (Cyprus, Israel, Lebanon, and Turkey) shows relatively thick (100 m) but relatively small (kilometers lateral extent) flat-topped accumulations (T-factory). The subtropical to warm-temperate northern Mediterranean and European region generally displays tens-of-meters-thick deposits interpreted as ramp systems (photo-C-factories sensu Michel et al. 2019).

Other paleoclimatic regions, which are characterized by different carbonate systems, do not fit into this direct latitudinal and temperature-related thickness trend of shallow-marine carbonates (figs. 1*D*, 2*D*). The southern Oceania region shows relatively large "cool-water" carbonate systems (heterozoan carbonates or C-factory; up to 500-m thick; Great Australian Bight; table A1) that occur in diverse tectonic and basinal settings (passive margin, enclosed gulfs, and tectonically active settings). These carbonate systems are controlled by marine primary productivity and/or subtropical to warm-temperate paleoclimate (James and Jones 2015; Michel et al. 2018). The relatively large size of these systems relates to a specific set of conditions that are (1) a relatively warm nontropical paleoclimate (James and Lukasik 2010), (2) occurrences of relatively high marine productivity that promotes a prolific heterotrophic biota development (James and Bone 2011), and (3) very low terrigenous input during most of the Cenozoic interval as a consequence of a very flat hinterland and overall arid paleoclimate (James and Bone 2011).

The tropical to subtropical southern Mediterranean and Middle East regions show some thick, particularly extensive systems (biochemical factories sensu Michel et al. 2019; figs. 1, 2). These specific regions are characterized by tectonic settings such as foreland basin and passive margin that are located in relatively enclosed paleogeographic zones with a dry tropical paleoclimate. The resulting extensive, flat platform paleophysiography (probably corresponding to shallow, tens of meters water paleodepth) favors evaporation and increasing water temperatures and salinities. These specific paleoenvironmental conditions lead to the construction of stratigraphic architectures that are not easily captured due to low reliefs and extensive lateral extents (e.g., Asmari Formation, Iran; van Buchem et al. 2010).

Geometric shapes of carbonate systems result from the complex interplay of diverse parameters including carbonate production, tectonically induced substratum movements, sea level variability, and local parameters such as substrate paleophysiography and hydrodynamics (e.g., wave height and intensity). Each individual parameter can influence a specific architecture in a certain direction but is difficult to isolate and estimate. However, Oligo-Miocene carbonates show a globally consistent, predictable signal of carbonate production and growth potential beyond the specific role of other parameters such as accommodation and preservation (figs. 1, 2; tables A2, A3). Further studies of accommodation, especially tectonic and basinal settings of case studies, would certainly add further constraints about the observed global trend (cf. Bosellini 1989; Bosence 2005; Wilson and Hall 2010).

Implications

The study of Oligo-Miocene shallow-marine carbonates shows that, beyond the complexity of carbonate systems (e.g., Pomar and Hallock 2008), the conceptual scheme of global distribution of carbonate factories sensu Schlager (2005) can be quantified in the sedimentary record. On the one hand, these global trends of carbonate accumulations can serve as a baseline to interpret specific case studies and identify the role of more local controlling parameters within specific tectonic, basinal, paleoceanographic, paleoclimatic, and sea level contexts. This general baseline status of carbonate platform distribution furthermore constitutes a prerequisite knowledge to study paleoclimate change throughout the Oligo-Miocene interval. On the other hand, such global trends can be utilized for prediction in data-poor areas. The thickness and geometric shape of Oligo-Miocene carbonate accumulations are largely controlled by the occurrence of the different carbonate production modes. In turn, the global distribution of carbonate production is related to primary paleoclimatic and paleoceanographic patterns that can be reconstructed using paleoclimate models (cf. Schlager 2005; Michel et al. 2019). The presented qualitative and quantitative data set can then be compared with paleoceanographic models to predict carbonate association, thickness, and stratigraphic architecture (e.g., Davies et al. 2019; Laugié et al. 2019; Michel et al. 2019; Pohl et al. 2019).

ACKNOWLEDGMENTS

Thanks are expressed to Total E&P for funding a significant part of the project and for granting permission to publish. The project leading to this publication (JB) has received funding from the Excellence Initiative of Aix-Marseille University, AMIDEX, a French "Investissements d'Avenir" program. P. Miralles

(MSc student within the project) and colleagues from Aix-Marseille University-CEREGE and ISS (Total, Pau) are thanked for fruitful discussions. An anonymous reviewer and D. B. Rowley are thanked for their constructive reviews. A literature review like this always will be incomplete, and we apologize to those works we may have overlooked or insufficiently taken into account.

REFERENCES CITED

Borgomano, J.; Lanteaume, C.; Philippe, L.; Fournier, F.; Montaggioni, L.; and Masse, J.-P. 2020. Quantitative carbonate sequence stratigraphy: insights from stratigraphic forward models. Am. Assoc. Pet. Geol. Bull. 104:1115–1142.

Bosellini, A. 1989. Dynamics of Tethyan carbonate platforms. *In* Crevello, P. D.; Sarg, J. L.; Wilson, J. F.; and Read, J. F., eds. Controls on carbonate platform and basin development. SEPM Spec. Publ. 44:3–13.

Bosence, D. 2005. A genetic classification of carbonate platforms based on their basinal and tectonic settings in the Cenozoic. Sediment. Geol. 175:49–72.

Bourrouilh-Le Jan, F. G., and Hottinger, L. C. 1988. Occurrence of rhodolites in the tropical Pacific—a consequence of mid-Miocene paleo-oceanographic change. Sediment. Geol. 60:355–367.

Brandano, M. I.; Cornacchia, I.; and Tomassetti, L. 2017. Global versus regional influence on the carbonate factories of Oligo-Miocene carbonate platforms in the Mediterranean area. Mar. Pet. Geol. 87:188–202.

Buxton, M. W. N., and Pedley, H. M. 1989. A standardized model for Tethyan Tertiary carbonate ramps. J. Geol. Soc. Lond. 146:746–748.

Davies, A.; Hunter, S. J.; Gréselle, B.; Haywood, A. M.; and Robson, C. 2019. Evidence for seasonality in early Eocene high latitude sea-surface temperatures. Earth Planet. Sci. Lett. 519:274–283.

Esteban, M.; Braga, J. C.; Martin, J.; and de Santiesteban, C. 1996. Western Mediterranean reef complexes. *In* Franseen, E. K.; Esteban, M.; Ward, W. C.; and Rouchy, J.-M., eds. Models for carbonate stratigraphy from Miocene reef complexes of Mediterranean regions. Tulsa, OK, Soc. Sediment. Geol., p. 55–72.

Gatt, P. A., and Gluyas, J. G. 2012. Climatic controls on facies in Palaeogene Mediterranean subtropical carbonate platforms. Pet. Geosci. 18:355–367.

Hallock, P. 2015. Changing influences between life and limestones in Earth history. *In* Birkeland, C., ed. Coral reefs in the Anthropocene. Dordrecht, Springer, p. 17–42.

James, N. P. 1997. The cool-water carbonate depositional realm. *In* James, N. P., and Clarke, J. A. D., eds. Cool-water carbonates. SEPM Spec. Publ. 56:1–20.

James, N. P., and Bone, Y. 2011. Neritic carbonate sediments in a temperate realm: southern Australia. Dordrecht, Springer, 254 p.

James, N. P., and Jones, B. 2015. Origin of carbonate sedimentary rocks. Chichester, Wiley.

James, N. P., and Lukasik, J. J. 2010. Cool- and cold-water neritic carbonates. *In* James, N. P., and Dalrymple, R. W., eds. Facies models (Vol. 4). St. John's, Geol. Assoc. Canada, p. 369–398.

Johnson, K. G.; Jackson, J. B. C.; and Budd, A. F. 2008. Caribbean reef development was independent of coral diversity over 28 million years. Science 319:1521–1523.

Kidwell, S. M., and Bosence, D. W. J. 1991. Taphonomy and time-averaging of marine shelly faunas. *In* Allison, P. A., and Briggs, D. E. G., eds. Taphonomy, releasing the data locked in the fossil record. New York, Plenum, p. 115–209.

Kiessling, W., and Flügel, E. 2002. PaleoReefs—a database on Phaneorozoic reefs. *In* Kiessling, W.; Flügel, E.; and Golonka, J., eds. Phanerozoic reef patterns. SEPM Spec. Publ. 72:77–92.

Kiessling, W.; Flügel, E.; and Golonka, J. 1999. Paleoreef maps: evaluation of a comprehensive database on Phanerozoic reefs. Am. Assoc. Pet. Geol. Bull. 83:1552–1587.

———. 2003. Patterns of Phanerozoic carbonate platform sedimentation. Lethaia 36:195–225.

Kindler, P., and Wilson, M. E. J. 2010. Carbonate grain associations: their use and environmental significance, a brief review. *In* Mutti, M.; Piller, W. E.; and Betzler, C., eds. Carbonate systems during the Oligocene-Miocene climatic transition. Int. Assoc. Sediment. Spec. Publ. 42:35–48.

Kleypas, J. A.; McManus, J. W.; and Meñez, L. A. B. 1999. Environmental limits to coral reef development: where do we draw the line? Am. Zool. 39:146–159.

Laugié, M.; Michel, J.; Pohl, A.; Poli, E.; and Borgomano, J. 2019. Global distribution of modern shallow-water marine carbonate factories: a spatial model based on environmental parameters. Sci. Rep. 9:29–31.

Lees, A., and Buller, A. T. 1972. Modern temperate-water and warm-water shelf carbonate sediments contrasted. Mar. Geol. 13:M67–M73.

Lyle, M.; Pockalny, R.; Polissar, P.; Lynch-Stieglitz, J.; Bova, S.; Dunlea, A. G.; Ford, H.; et al. 2016. Dynamic carbonate sedimentation on the Northern Line Islands Ridge, Palmyra Basin. Mar. Geol. 379:194–207.

Markello, J. R.; Koepnick, R. B.; Waite, L. E.; and Collins, J. F. 2008. The Carbonate Analogs Through Time (CATT) hypothesis and the global atlas of carbonate fields—a systematic and predictive look at Phanerozoic carbonate systems. *In* Lukasik, J. J., and Schlager, W., eds. Controls on carbonate platform and reef development. SEPM Spec. Publ. 89:15–46.

Miall, A. D., and Miall, C. E. 2001. Sequence stratigraphy as a scientific enterprise: the evolution and persistence of conflicting paradigms. Earth-Sci. Rev. 54:321–348.

Michel, J.; Borgomano, J.; and Reijmer, J. J. G. 2018. Heterozoan carbonates: when, where and why? a synthesis on parameters controlling carbonate production and occurrences. Earth-Sci. Rev. 182:50–67.

Michel, J.; Laugié, M.; Pohl, A.; Lanteaume, C.; Masse, J.-P.; Donnadieu, Y.; and Borgomano, J. 2019. Marine carbonate factories: a global model of carbonate platform distribution. Int. J. Earth Sci. 108:1773–1792.

Müller, R. D.; Cannon, J.; Qin, X.; Watson, R. J.; Gurnis, M.; Williams, S.; Pfaffelmoser, T.; Seton, M.; Russell, S. H. J.; and Zahirovic, S. 2018. GPlates: building a virtual Earth through deep time. Geochem. Geophys. Geosyst. 19:2243–2261.

Mutti, M.; Piller, W. E.; and Betzler, C. 2010. Carbonate systems during the Oligocene-Miocene climatic transition. Int. Assoc. Sediment. Spec. Publ. 42, 300 p.

Parrish, J. T., and Curtis, R. L. 1982. Atmospheric circulation, upwelling, and organic-rich rocks in the Mesozoic and Cenozoic eras. Palaeogeogr. Palaeoclimatol. Palaeoecol. 40:31–66.

Perrin, C., and Bosellini, F. R. 2012. Paleobiogeography of scleractinian reef corals: changing patterns during the Oligocene-Miocene climatic transition in the Mediterranean. Earth-Sci. Rev. 111:1–24.

Pohl, A.; Laugié, M.; Borgomano, J.; Michel, J.; Lanteaume, C.; Scotese, C. R.; Frau, C.; Poli, E.; and Donnadieu, Y. 2019. Quantifying the paleogeographic driver of Cretaceous carbonate platform development using paleoecological niche modeling. Palaeogeogr. Palaeoclimatol. Palaeoecol. 514:222–232.

Pomar, L. 2001. Types of carbonate platforms: a genetic approach. Basin Res. 13:313–334.

Pomar, L.; Baceta, J. I.; Hallock, P.; Mateu-Vicens, G.; and Basso, D. 2017. Reef building and carbonate production modes in the west-central Tethys during the Cenozoic. Mar. Pet. Geol. 83:261–304.

Pomar, L., and Hallock, P. 2008. Carbonate factories: a conundrum in sedimentary geology. Earth-Sci. Rev. 87:134–169.

Read, J. F. 1985. Carbonate platform facies models. Am. Assoc. Pet. Geol. Bull. 69:1–21.

Schlager, W. 2003. Benthic carbonate factories of the Phanerozoic. Int. J. Earth Sci. 92:445–464.

———. 2005. Carbonate sedimentology and sequence stratigraphy. Tulsa, OK, SEPM Concepts Sediment. Paleontol. 8, 200 p.

Schlanger, S. O. 1981. Shallow-water limestones in oceanic basins as tectonic and paleoceanographic indicators. *In* Warme, J. E.; Douglas, R. G.; and Winterer, E. L., eds. The Deep Sea Drilling Project: a decade of progress. SEPM Spec. Publ. 32:209–226.

van Buchem, F. S. P.; Allan, T. L.; Lauren, G. V.; Lotfpour, M.; Moallemi, A.; Monibi, S.; Motiei, H.; et al. 2010. Regional stratigraphic architecture and reservoir types of the Oligo-Miocene deposits in the Dezful Embayment (Asmari and Pabdeh Formations) SW Iran. *In* van Buchem, F. S. P.; Gerdes, K. D.; and Esteban, M., eds. Mesozoic and Cenozoic carbonate systems of the Mediterranean and the Middle East: stratigraphic and diagenetic reference models. Geol. Soc. Lond. Spec. Publ. 329:219–263.

von der Heydt, A., and Dijkstra, H. A. 2006. Effect of ocean gateways on the global ocean circulation in the late Oligocene and early Miocene. Paleoceanography 21: PA1011.

Whalen, M. T. 1995. Barred basins: a model for eastern ocean basin carbonate platforms. Geology 23:625–628.

Wilson, J. L. 1975. Carbonate facies in geologic history. Berlin, Springer, 471 p.

Wilson, M. E. J. 2002. Cenozoic carbonates in Southeast Asia: implications for equatorial carbonate development. Sediment. Geol. 147:295–428.

———. 2008. Global and regional influences on equatorial shallow-marine carbonates during the Cenozoic. Palaeogeogr. Palaeoclimatol. Palaeoecol. 265:262–274.

———. 2012. Equatorial carbonates: an Earth systems approach. Sedimentology 59:1–31.

———. 2015. Oligo-Miocene variability in carbonate producers and platforms of the Coral Triangle biodiversity hotspot: habitat mosaics and marine biodiversity. Palaios 30:150–168.

Wilson, M. E. J., and Hall, R. 2010. Tectonic influence on SE Asian carbonate systems and their reservoir quality. *In* Morgan, W. A.; George, A. D.; Harris, P. M.; Kupecz, J. A.; and Sarg, J. F., eds. Cenozoic carbonate systems of Australasia. SEPM Spec. Publ. 95:13–40.

Wright, V. P., and Burgess, P. M. 2005. The carbonate factory continuum, facies mosaics and microfacies: an appraisal of some of the key concepts underpinning carbonate sedimentology. Facies 51:17–23.