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RESEARCH PAPER

Controls on the terrigenous fractions in Early Kimmeridgian shallow-water carbonate deposits in Southern Iberia

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Abstract

Two Kimmeridgian shallow-marine carbonate successions (mid-shelf), sharing a similar paleoclimatic framework (climatic zone), were previously explored using carbonate chemostratigraphy. Before, the goal was to detect signals related to paleoplatform bottom physiography, degree of connection with oceanic waters and overall circulation patterns. In this contribution, complementary bulk mineralogical composition and clay mineral fractions are investigated to contrast and complement previous information, aiming for a more complete overview of continent-ocean dynamics along shallow-carbonate platforms of southern Iberia. The goal is now to explore complex patterns of continental influence along proximal settings and their relative spatial distribution across differentiated settings without relevant difference in paleolatitude. The choice of both stratigraphic sections is based on this distinctness: Rocha Poço (Algarve Basin, Portugal) represents a more restricted and relatively proximal setting, in contrast to Puerto Lorente (South Iberian Paleomargin, S Spain) placed at a relatively more open and probably distal shallow-water context. Accordingly, quartz content was higher at Rocha Poço, especially at the lower siliciclastic interval of this section. Quartz contribution fades out at Puerto Lorente, where it was mainly controlled by short-lived terrigenous pulses. Clay mineral assemblages also differed, being more varied (smectite, illite and traces of kaolinite) and abundant at Rocha Poço, and generally leaner at Puerto Lorente. At the latter site, terrigenous pulses do not contribute to clay mineral abundance, only showing abundant illite at the topmost horizons. New information retrieved from mineralogical data provided evidence on depositional contrasts resulting from local differences in platform configuration, allowing a better understanding of mechanisms controlling the terrigenous fraction in the shallow-water carbonates analyzed.

Keywords Paleoenvironmental events · Kimmeridgian · Shallow-water carbonates · Mineralogy · X-ray diffraction

Resumen

Dos sucesiones de sedimentos marinos carbonatados de aguas someras (plataforma media), en un contexto climático similar (zona climática), fueron previamente investigadas mediante el análisis quimioestratigráfico de las fases carbonatadas. El objetivo entonces fue la identificación de señales relacionadas con la fisiografía de las plataformas, el grado de conexión con las aguas oceánicas y los patrones generales de circulación de las corrientes marinas. En esta contribución se investiga la composición mineralógica complementaria de la muestra total y los minerales de la fracción arcillosa con el objetivo de contrastar y complementar la información previa, así como para obtener una visión más completa de la dinámica de la interacción continente-océano en plataformas carbonatadas poco profundas y distantes en el sur de Iberia. En detalle, se persigue la caracterización de los patrones complejos de la influencia continental en áreas epicontinentales, neríticas proximales, así como su distribución espacial relativa en emplazamientos distanciados, pero sin diferencias notables en paleolatitud. La elección de los perfiles está basada en el contraste de sus diferencias: El perfil de Rocha Poço representa un emplazamiento marino relativamente proximal y comparativamente confinado, mientras el perfil de Puerto Lorente muestra rasgos de un

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contexto marino más abierto y probablemente algo más distal. En consecuencia, el contenido en cuarzo registrado en Rocha Poço fue más alto, especialmente en el intervalo siliciclástico basal, mientras que en Puerto Lorente muestra estrecha relación con eventos de aportes terrígenos. Las asociaciones minerales de la fracción arcilla también muestran diferencias. Son más diversificadas y abundantes en Rocha Poço (esmectita, illita y trazas de caolinita), mientras que en Puerto Lorente los eventos de aportes terrígenos no incrementaron la fracción arcilla, que solo muestra illita abundante en los horizontes más jóvenes. La nueva información obtenida de la fracción arcilla evidencia contrastes en las condiciones de depósito que resultan de diferencias locales en la configuración de las plataformas, lo que ha permitido una mejor comprensión de los procesos que controlaron la fracción terrígena en los carbonatos de aguas poco profundas analizados

Palabras clave Eventos paleoambientales · Kimmeridgiense · Carbonatos someros · Mineralogía · Difracción de rayos X

1 Introduction

1.1 Global climate during early Kimmeridgian times and a related context for the South Iberian Paleomargin

The Late Jurassic climate experienced shift to drier conditions with respect to previous Jurassic times (Abbink et al., 2001; Boulila et al., 2022), was globally warm, with relatively low latitudinal thermal gradients, reduced and no permanent ice caps at high-latitude (Moore et al., 1992a; Valdes & Sellwod, 1992; Rees et al., 2000; Rais, 2007), while a zonally differentiated climate included a Inter Tropical Convergence Zone (ITCZ) larger than today and with irregular layout. At a global scale, the environmental dynamics forced by monsoonal winds would be more relevant than that derived from regional/local winds, especially for large land masses (Parrish et al., 1982; Hallam, 1984; Chandler et al., 1992; Weissert & Mohr, 1996), but conditioned by the reduced thermal gradient. In general, biocalcification was favored under "normal" trophic conditions (Weissert & Erba, 2004), while dysoxic waters have been modelized for westernmost Tethys during Late Jurassic and earliest Cretaceous times (Scotese & Moore, 2014a). Kimmeridgian times were comparatively "cooler" (cool greenhouse conditions s. Holz, 2015), showing increasing temperature during the major transgressive interval of the Early Kimmeridgian (Dercourt et al., 1994; Dera et al., 2011) even in Suboreal areas (Wierzbowski et al., 2013). High-frequency temperature fluctuations have been identified in Early Kimmeridgian marl-limestone couplets from SE France and interpreted as DO analogous rhythms of low latitude (Boulila et al., 2022).

Overall, climatic models show Iberia between 20–30ºN and 10–15ºE, exposed to easterlies far from storm and monsoon tracks (Ross et al., 1992: subtropical cyclone storms 10ºN–10ºS in summer and 20ºN in winter; Colombié et al., 2018 for northwards winter storms but potential influence of tropical cyclones), under low precipitation (Moore et al., 1992b), and with negligible relief in terms of the paleotopographic ranges modeled. The SE Iberia faced water masses with sea surface temperature ca. 30ºC (Moore et al., 1992b) and under rather intricate marine currents (Moore et al., 1992a, 1992b showing dominant easterlies vs. westerlies when topography is approached, respectively; Demko & Parrish, 1998; Scotese & Moore, 2014a, 2014b) resulting from irregular sea bottoms across the epioceanic fringe, including hypothetical bidirectional flows (Challinor & Hikuroa, 2007 based on Parrish, 1992). SE Iberia was relatively close to areas of precipitation < evaporation centered in NW Africa during summer and showing annual net evaporation in winter (Moore et al., 1992b; Ross et al., 1992; Weissert & Mohr, 1996). There is no evidence of relevant inland relieves in southern Iberia (within the lower range of models by Moore et al., 1992b). Hence, amongst regions without huge orography and close to low-latitude large warm water masses (surface waters > 27 ºC; Moore et al., 1992a), southern Iberia would experience ocean stabilizing modulations of temperature (Moore et al., 1992b; Rees et al., 2000). –i.e., a climatic context prone to small fluctuations (the maritime greenhouse effect in Kyessling et al., 1999) aside from those potentially related to tectono-eustatic events.

During the Late Jurassic, Iberia has been interpreted to be placed within an interval of latitude between 20ºN and slightly above 30ºN (Fig. 1A), close to the connection of the west Tethys with the Hispanic Corridor growing through the Central N. Atlantic Basin (Ross et al., 1992; Decourt et al., 1994; Ford & Golonka, 2003; Vrielynck & Bouysse, 2003; Ziegler et al., 2003; Rais, 2007; Brigaud et al., 2008; Schettino & Turco, 2009; Boulila et al., 2022). During the Late Jurassic, the S-SE paleomargin of Iberia was structured as an epicontinental shelf system dominated by a ramp model with locally variable abrupt shelf-breaks (the Prebetic and lateral equivalents), which connected with the epioceanic environment southwards (the Subbetic; synthetic view in Olóriz, 2002, and references therein). In the latter, bottom physiography was irregular according to trends of finally arranged SW–NE lineaments of epioceanic swells and troughs. North-to-south, landwards-to-seawards, swell ranges are the External Subbetic, the Internal Subbetic, and lateral equivalents. North-to-south troughs are the Intermediate Units, the Median Subbetic Zone, and lateral equivalents, and the southernmost basin separated by oceanic crust from the also physiographically complex Alboran Domain. The later here refers to epioceanic-oceanic environments respectively (Olóriz, 2000 and references therein), southwards from the

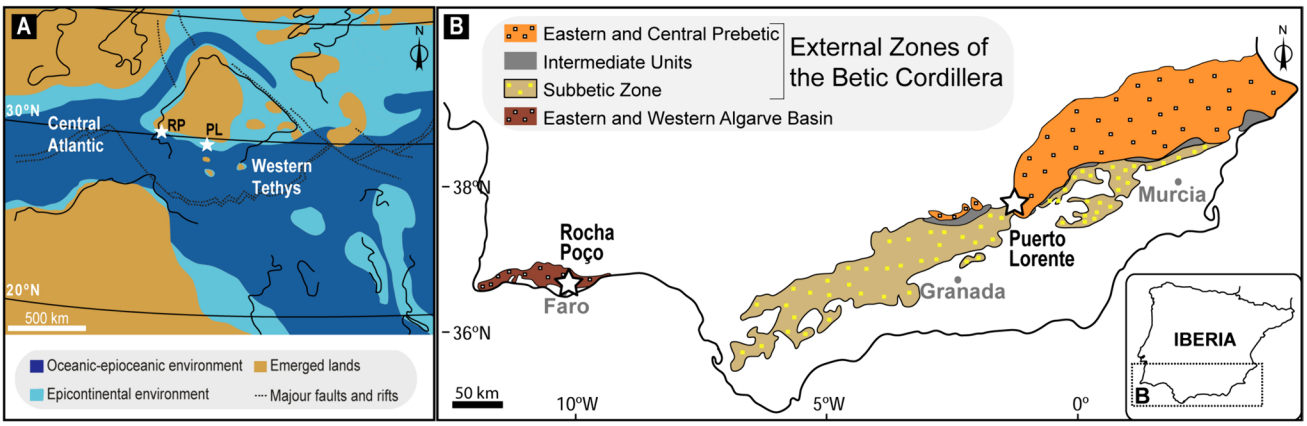

Fig. 1 Geographical location of the studied sections (**stars** indicate locations of the studied sections). **A** Late Jurassic paleogeographic reconstruction of western and central Tethyan realm. Plate tectonic setting from Stampfli and Borel (2002) and depositional environments after Thierry et al. (2000); **B** Regional distribution of major geological units along the Betic Cordillera (modified from García-Hernández et al., 1980)

External zones of the Betic Cordillera at its western extreme, merging with equivalent environments southwards from the Algarve. A 5–10 km wide huge pile of volcanic rocks that represents the Median Subbetic Volcanic Ridge (Mid-Subbetic Volcanic Ridge of at least 700 m high during the Late Jurassic; Comas et al., 1986), was active in the central part of the Median Subbetic Trough partially forcing subdivision of this trough in a southern and a northern arm, within a volcanic strip across ca. 300 km. The latter figure especially applies when pillow lavas 160 Ma old, eastern from the central sector of the Median Subbetic (Fliert et al., 1979) are considered. These represent the oldest Upper Jurassic pillow lavas reported, giving an Early Oxfordian age according to present revisions of absolute ages (GTS, 2020) and, hence, older than those of Early Tithonian age reported by Comas et al. (1986) from the Central Subbetic.

In the central sector of the Betic Cordillera epicontinental shelves (the Prebetic Zone and lateral equivalents) freely connected with the Tethyan epioceanic environment (the Subbetic Zone, lateral equivalents and southernmost basins) through shelf-breaks facing the adjacent troughs —the Intermediate Units and lateral equivalents.

A wider palaeogeographic context S-SE Iberian paleomargin shows the alluded Alboran Domain as part of a complex frame of epioceanic-oceanic troughs, with variable continuity throughout the Iberian and north African distal palaeomargins, resulting from extensional to hyperextensional regimes during the Jurassic, with a special pulse during the Late Jurassic-Early Cretaceous. Major epioceanic-oceanic passages were related to the West Ligurian or Betic arm and the East Ligurian-Maghrebian arm of the western Tethys, both merging into the trantensional zone connecting westward to the growing Hispanic Corridor forced by the evolution of the Central North Atlantic Basin. These two major oceanic arms contoured at least one main microcontinent, block, plate, or microplate, first named as the Alboran subplate and the mesomediterranean subplate (Andrieux et al., 1971; Durand-Delga & Fontboté, 1980), and then the ALKAPECA palaeogeographic Domain (Bouillin et al., 1986), assumedly fragmented during Cenozoic times. The above mentioned Alboran Domain refers to the western extreme of such a microcontinent, whose interpretations are debated up today (Angrand & Mouthereau, 2021; Moragues et al., 2021; and references therein), but without palaeoenvironmental incidence for our contribution.

In the area investigated in the Algarve (southern Portugal, SW Iberia), the epicontinental shelf system included a huge carbonate shelf westward, and distal shallow carbonate banks identified by ocean drilling southwards (Boillot et al., 1974; Baldy et al., 1977; Mougenot et al., 1979, among others) labelled the southern sector of the Algarve Basin by Marques and Olóriz (1989a, 1989b). Offshore wells and outcrops westwards to the growing central North Atlantic show that carbonates with common dolomitization dominated deposition during Kimmeridgian times (Rocha, 1976; Pereira, 2013). In the Alentejo Basin, Lower Kimmeridgian deposits included corals and low diversified dinocysts from partly confined comparatively small basins (lagoons and shallow waters) where pollen and spores were more abundant than marine foraminifera (Borges et al., 2011). Reef growth was assumed diverse across ramp, basin, and slope environments during Kimmeridgian times (Kiessling et al., 1999).

Eastwards from the huge carbonate shelf and northwards from the distal shallow carbonate banks, a depression formed the northern sector of the Algarve Basin or Central-Eastern Algarve Basin (Marques & Olóriz, 1989a, 1989b). This was a rather restricted neritic environment confined westwards

and southwards by shallow carbonates, and northwards by Hercynian lands of SW Iberia, but it was devoid of raised bottoms eastward that would hinder an open connection of bottom waters from the Central-Eastern Algarve Basin with Tethyan oceanic waters. This context agrees with the eastwards increasing in fine clastics vs. carbonates in the southern offshore wells mentioned. Hence, the expected direct transportation of clays from the Central-Eastern Algarve Basin southwards to the ocean was distorted and/or disabled.

1.2 Overview and current interest of comparing deposition in proximal settings from Southern Iberia: a lower Kimmeridgian example

Unravelling paleoenvironmental conditions from ancient carbonate archives is a challenging task. In order to explore an innovative and more holistic approach, the Late Jurassic carbonate record from the southern paleomargin of Iberia has been under investigation. Under strict biostratigraphic control, a selection of several stratigraphic sections along Southern Portugal, Southern Spain and the Majorca Island configured a proximal to distal transect, covering a wide variety of depositional environments from epicontinental to epiocanic and providing a unique overview of the sedimentary dynamics in time and space (Coimbra, 2011).

The most relevant outcomes from both the Rocha Poço and Puerto Lorente sections, here under scope, are briefly summarized to place the current research in a wider context. Particular carbon and oxygen isotope composition of the epicontinental Rocha Poço section were explored in Coimbra et al. (2014). Of particular relevance, it allowed to identify a syn-depositional forcing under the local influence of non-marine water on the middle shelf (mixing of marine and freshwater primary signals), coupled with a later diagenetic component related to the presence of interstitial fluids (freshwater/brackish) during burial in the lowermost more porous, permeable silty facies. As for the more spongiolithic facies, active organic matter decay related to significant microbialite occurrence agrees with slight differences in C and O-isotope composition, denoting decreasing continental influence and a differentiated diagenetic pathway when compared to typical Ammonitico Rosso facies from the epioceanic fringe, whilst maintaining a comparable stratigraphic trend regarding Lower Kimmeridgian epioceanic records (Coimbra et al., 2015).

Apart from the described complex C and O-isotope record, elemental abundance throughout the Rocha Poço section was equally enlightening when compared to coeval epioceanic signals (Coimbra et al., 2015). Major differences in elemental record related to a depositional setting including geochemically different nearshore waters, even more relevant for intervals of higher continental influence. A persistent influx from continental sources was detected, coupled with a marked influence of active reefal growth in the vicinity of this area.

Due to the highly informative nature and singular relevance of the geochemical record at the epicontinental Rocha Poço section, this section was later compared with the probably more distal, but equally shallow-water section outcropping at Puerto Lorente (External Prebetic) to test the sensitivity and reliability of carbonate chemostratigraphy (Coimbra et al., 2019). Maximum impact of continental influence was evidenced at the Rocha Poço section, fading out along the mixed carbonate-fine siliciclastic rhythmic deposition in the more open Puerto Lorente section. Local forcing by upwelling in the surroundings of a coral fringe was deduced for the Rocha Poço section, and the geochemical signature of hydrothermal influence was differentiated from terrigenous pulses. Furthermore, the influence of tectonic activity affecting nearshore/coastal water masses was depicted in both sections.

After an in-depth geochemical characterization of the carbonate fraction of the selected sections in Southern Iberia, the challenge of complementing this information with independent mineralogical (bulk and clay fraction) data brings new light into previously studied materials. In this way, the goal is to provide complementary evidence to refine interpretations on the controls on terrigenous fraction distribution patterns in differentiated shallow-water settings along Southern Iberia and the forcing paleoenvironmental dynamics. The applied approach combines several tools that were designed to be applicable to a wide range of materials and fields of research, resulting in cost-effective and/or time-saving solutions that optimize data visualization and perception.

2 Studied sections, geological and paleoenvironmental context

The interpretation of geological and paleoenvironmental evolutions of the selected two epicontinental sections is approached on the basis of both favorable outcrop conditions and a tight biochronostratigraphic control (Marques, 1983; Marques & Olóriz, 1989b, 1992; Olóriz & Rodríguez-Tovar, 1993a, 1993b, Coimbra et al., 2019; Figs. 1 and 2), here improved punctually. The Rocha Poço section represents epicontinental deposition along the SW Iberian paleomargin, in the eastern Algarve Sub-basin in southern Portugal (Fig. 1A and B). Irregular bottoms in the latter resulted from N-S strike-slip faults and extensional tectonics E-W combined with salt movements (Manupella et al., 1988). Eco-sedimentary conditions in the eastern and western sub-basins differed throughout the Jurassic due to persistent shallow carbonate shelf-system conditions westwards. Offshore boreholes identified southern carbonate shelf or blocks that seem to represent the external edge of epicontinental conditions

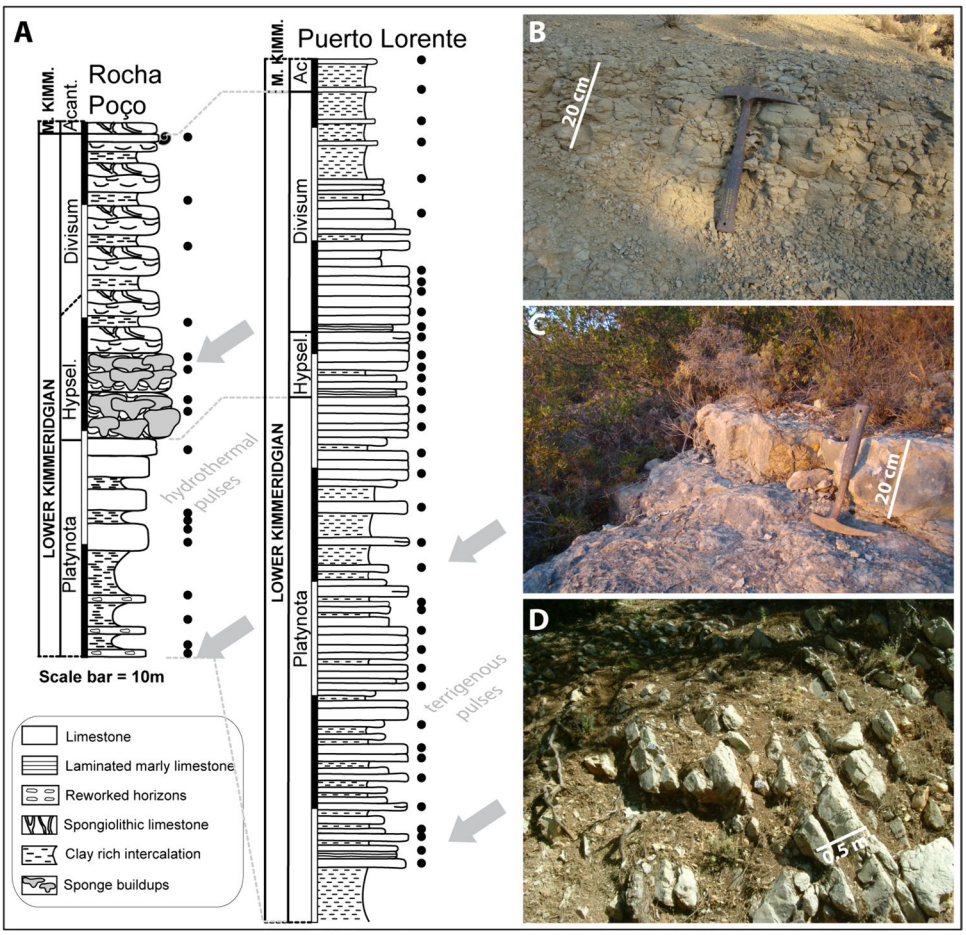

Fig. 2 Stratigraphic representation of comparable time intervals for the Rocha Poço and Puerto Lorente sections. **A** lithofacies variability and lateral correlation among sections. **Dots** indicate stratigraphic sampling density; **arrows** indicate pulses identified in previous works (terrigenous and hydrothermals, Coimbra et al., 2015, 2019). **B to D** Field views representative of the siliciclastic interval at the lowermost portion of the Rocha Poço section, the spongiolithic limestone at Rocha Poço and the typical succession of limestone beds at Puerto Lorente section (supplementary field photos can be found in Coimbra et al., 2019). Biostratigraphy at the ammonite biozone level on the left

(Marques & Olóriz, 1989a), or part of a more complex margin north of the Newfoundland-Gibraltar Fault Zone, being southwards open-sea Tethyan oceanic-epioceanic waters. In the restricted mid-neritic shelf of the eastern Algarve Subbasin irregular bottoms favored local developments of bioherms with sponges and/or corals (Marques, 1985; Ramalho, 1985; Rosendhal, 1985; Leinfelder, 1993), and changes in facies and stratigraphic discontinuities are common throughout the Oxfordian and the Lower Kimmeridgian (Marques & Olóriz, 1989b). The previous arguments point towards paleoenvironmental variability, including nutrients and bottom currents amongst others.

Coimbra et al. (2019) provided a detailed analysis of environmental conditions favoring spongiolitic facies and sponge buildups. Some complementary observations apply: Relative eutrophication would be locally reinforced by upwelling rather than continental runnof. Upwelling events on a mid-shelf will force increasing nutrients and relative lowering of sea-water temperature, phytoplankton blooms and the related food-web reducing water transparency, and the occurrence of heterothophic massive sponges dominant in carbonate-fine silicilastic sediments as a rapid response with notable growth, which would be especially fueled in relatively enclosed sites or in proximal sites (Hallock & Schlager, 1986; Birkeland, 1987; Wilkinson, 1987; Wood, 1993, 1998). The growth of microbial communities and suspension-feeding metazoans would benefit mixotrophic sponges towards heterotrophy based on dissolved and particulate organic matter exported during pulses of higher productivity, and mesotrophic conditions (see Olóriz et al., 2003, 2006 and references therein for supplementary interpretation of Oxfordian sponge buildups and spongiolithic limestones westward in the Prebetic), under persistent dominance of mixed deposition of carbonates and fine clastics while precipitation of inorganic cement increased (Wilkinson, 1987; Wood, 1998). Amongst the microfossils identified by Coimbra et al. (2019), the combined occurrence of *Tubiphytes* s. Flügel (2010) and remains of hexactinellid spicules confirms analogy with well-known Late Jurassic sponge-*Tubiphytes* reefs (Flügel, 2010; note that Mesozoic *Tubiphytes* have been referred as *Crescentiella* n. gen. proposed by Senowbari-Daryan et al., 2008 to separate from Paleozoic *Tubiphytes* based on the structure of the symbiotic cyanobacterial encrustments on “hard bio-subtrates”); remains of hexactinellid spicules and the meagre occurrence of calcified zoospores of, or single-celled, planktic algae

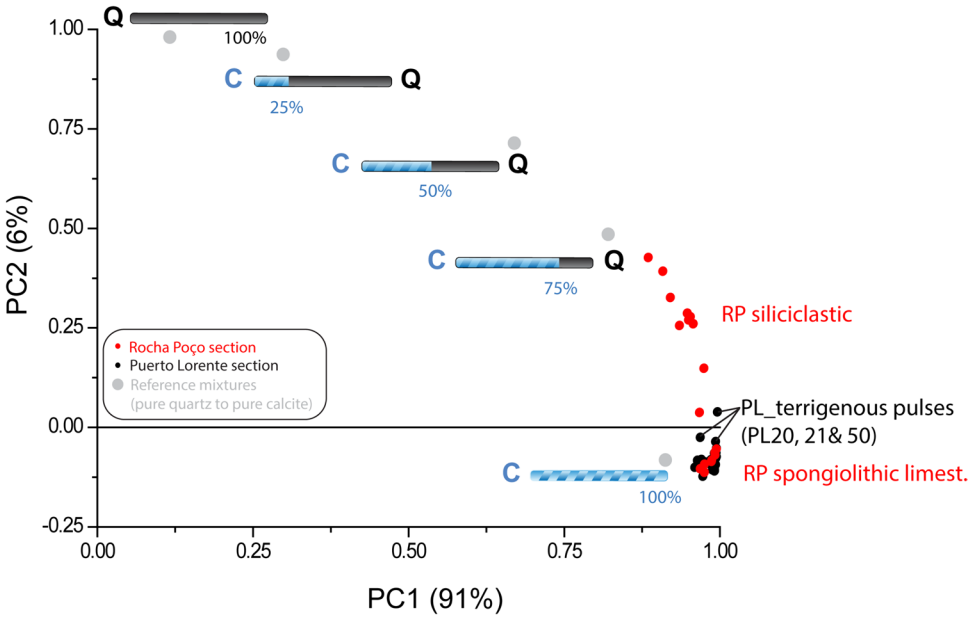

Fig. 3 Results of Principal Component Analysis (PCA) of bulk mineralogical XRD spectra, compared to pure quartz and calcite compositions, as well intermediate progressive increments in calcite (Q: quartz; C: calcite)

(*Globochates*), together with absence of *Sacoccoma*, are compatible with outer-middle shelf conditions. In addition, reworked miliolids and fine- and locally medium-size quartz without identifiable hummocky stratification also points to a mainly low depositional scenario across the outer-middle shelf, dominated by wackestones and local sponge buildups on low relieves related to salts movements.

Inner-shelf conditions favoring homogenized carbonate sedimentation occurred during the mid-Late Kimmeridgian before the peak regression of latest Jurassic-earliest Cretaceous times (Marques, 1985; Manupella et al., 1988; Marques & Olóriz, 1989b), in accordance with that revealed in the epicontinental shelf system across southern Iberia (Marques et al., 1991; Pereira, 2013; and references therein).

The Rocha Poço section of reference shows two well-marked stratigraphic intervals (Fig. 2A): 20 m of silty limestones and marls in the lower part, underlying to 28 m beginning with local buildups followed by spongiolithic limestones and related facies (Peral and Cerro da Cabeça Formations) (Marques, 1985; Ramalho, 1988; Coimbra et al., 2014). At the lower 8 m of the spongiolitic interval huge development of sponge buildups occurs (Fig. 3B). Without latitudinal difference between the Algarve Basin and the central Prebetic, distinctive tectonics was active during the Early Kimmeridgian. Salt tectonics in the eastern Algarve Sub-basin forced high bottom irregularities, while bottom instability and differential subsidence were registered in the mixed carbonate-silicilastic rhythmites in the Prebetic, where outer-shelf areas corresponding to the comparatively distal Internal Prebetic during the Platynota Chron experienced local synsedimentary sliding (Olóriz & Rodríguez-Tovar, 1998).

In the Cazorla sector in the External Prebetic, the Puerto Lorente section (Figs. 1 and 2) shows Kimmeridgian deposits belonging to mid-shelf eco-sedimentary conditions within the epicontinental shelf-system of the Betic Cordillera (Fig. 1), without clear possibility for a more precise interpretation about its precise paleogeographic setting. Overall, the External Prebetic was a low energy, enlarged eastward shelf showing distally steepened ramp whose outer part corresponds to the Internal Prebetic, which represent outer-shelf environments south to south-eastward, shelf-break and steep slope separated epicontinental and epioceanic waters and, hence, its eco-sedimentary domains. The latter indicated by the northernmost, adjacent trough –the Intermediate Units– and then by the complex of NE-SW swells-and-troughs belonging to the front of the allocthonous Subbetic (Olóriz, 2002 and references therein for extended treatment). The Puerto Lorente section represents deposition on a comparatively raised bottom within the neritic zone, which registered condensed, hiatal deposition during Oxfordian and oldest Kimmeridgian times (Bimammatum pro parte and Planula chrones). The combined record of *Sutneria galar* and *S. platynota* in a ferruginized surface on top of the Upper Oxfordian succession indicates condensation higher than the assumed for within-habitat time-averaging (Olóriz, 2000). Therefore, it implicates hiatal deposition and biostratigraphic condensation, being the interpreted age for the ferruginized surface ("hardground" or hardground of AA) to be determined by the youngest fossil registered (*Sutneria platynota* according to Olóriz & Rodríguez-Tovar, 1993a, 1993b). Marques et al. (1991) envisaged probable hiatuses related to the ferruginized surface, affecting unknown horizons of the Planula and Platynota zones, while the non-record of *Sutneria platynota* type

A Schairer (1970) in Olóriz and Rodríguez-Tovar (1993a) indicates absence of at least unknown horizons belonging to the lower part of the Platynota Zone, which agrees with the lack of complex ribbing in ataxioceratin ammonites from the lower part of the overlying marly interval. All of this allows the improving of the interpretation made by Olóriz and Rodríguez-Tovar (1998), assuming morphotype correlation of Franconian and Prebetic *Sutneria platynota*. Difficulties found by Olóriz and Rodríguez-Tovar (1998) for the biostratigraphic recognition of hiatuses in the uppermost Oxfordian are assumed given the information available at present. Overlies a three meter-thick interval of siliciclastics useful for correlation at regional scale (Fig. 2), thus revealing Early Kimmeridgian instability at the lowermost Platynota Zone. It corresponds to the local record of a tectonic pulse preceding abrupt increases in subsidence in the Iberian subplate (Acosta, 1989; Olóriz et al., 2012, and references therein), as well as in northwest Africa and Submediterranean Europe (Marques et al., 1991; Leinfelder, 1993; Aurell et al., 2002; Colombié et al., 2014). The following 100 m of marly and silty limestone rhythmite (Lorente Fm.; Pendas, 1971), were deposited under warm climate with slight changes in the precipitation-evaporation ratios, as indicated by clay mineralogy (López-Galindo et al., 1994). Olóriz and Rodríguez-Tovar (1998) assumed a subtropical, maybe seasonal, climate based on mineralogical analyses by López-Galindo et al. (1991) and Rodríguez-Tovar (1993, and references therein). The stratal patterns point to tectono-eustatic forcing on relatively shallow sea bottoms, while background control on sedimentation in the middle part was mainly due to orbital forcing, long- and short-term eccentricity and precession rather than obliquity cycles; interactions with eustasy occurred in the upper part of the section (Olóriz et al., 1992; Olóriz & Rodríguez-Tovar, 1998). López-Galindo et al. (1991) first identified the influence of bottom topography on clay minerals distribution.

The stratigraphic correlation between the two selected sections at Rocha Poço (S. Portugal) and Puerto Lorente (S-SE Spain) was based on ammonite biochronostratigraphy at the biozone and subbiozone level (Marques, 1983; Marques & Olóriz, 1989a, 1992; Olóriz & Rodríguez-Tovar, 1993a, 1993b), here refined (Fig. 2B). Guide-fossils in successive ammonite assemblages at the biozone level are *Sutneria platynota*, *Crussoliceras divisum*, *Orthaspidoceras uhlandi* and *Taramelliceras compsum*.

Coimbra et al. (2019) investigated geochemical signals related to paleoplatform bottom physiography, degree of connection with oceanic waters and overall circulation patterns in the two Kimmeridgian shallow-marine carbonate sections of interest. The Fe and Mn coupling was evident in both sections, revealing overall terrigenous inputs along both epicontinental areas, being related elemental supply more significant for the Rocha Poço section, especially in the lowermost siliciclastic interval (Fig. 2A and C). Peaks in siliciclastic input denote sharp transitions probably related to local tectonic pulses rather than reactivations of the hydrological cycle, agreeing thus with major geochemical forcing due to hydrothermal contribution, i.e., syndepositional submarine volcanic activity (identified pulses indicated in Fig. 2A). This activity is typically characterized by sharp Mn input without major Fe changes, among others such as related hydrothermal discharges through fracture zones in the highly structured SW Iberia paleomargin and related oceanic-epioceanic areas close to the growing connection to the Hispanic Corridor. In summary, differential forcing in processes affecting the South Iberian paleomargin during early Kimmeridgian times, including a variable degree of continental influence fading out in less restricted settings.

To provide an in-depth overview of these patterns, mineralogical analysis was performed to contrast and complement previous information, aiming for a more complete overview of the influence of the continent-ocean dynamics along shallow mixed carbonate-siliciclastic platforms. Hence, using mineralogical data will provide new evidence on depositional contrasts resulting from local differences in platform physiography, among others, allowing a better understanding of the mechanisms controlling the terrigenous fraction in shallow-water carbonates.

3 Materials and methods

A total of 55 samples (18 from Rocha Poço; 37 from Puerto Lorente) were selected, including a variety of lithofacies ranging from carbonate-rich facies at Puerto Lorente, carbonate-rich spongiolithic facies at Rocha Poço and samples with lower carbonate content corresponding to the siliciclastic interval at Rocha Poço. Bulk mineralogical composition was determined by X-ray diffraction (XRD) with Cu-Kα radiation, carried out on non-oriented mounts of previously grinded samples, using a Malvern Panalytical Phillips X'Pert PW3040/60 equipped with X´Pert 2.0 and Profit software at the facilities of the Department of Geosciences, University of Aveiro, Portugal. Scans were run between 4 and 65º 2θ for bulk (non-decarbonated) samples and between 2 and 20º 2θ of oriented powder mounts of fine (clay) fractions for clay mineral identification. Clay mineral identification was obtained after decarbonatation. Decarbonatation protocol followed the guidelines provided by Coimbra et al. (2021), using 2N acetic acid solution at 50 ºC for one

hour reaction time. Scans were run between 2 and 20° 2θ on oriented powder mounts for fine (clay) fractions in the air-dry state (natural sample), as well as with glycerol saturation and heat treatment at 500 °C. After decarbonatation, the insoluble residue was also measured to access the mineral assemblage not destroyed by this procedure. Peak identification was performed manually (following Brindley & Brown, 1980) and abundance is compared based on peak intensity of each mineral, as highlighted in Coimbra et al. (2022).

Statistical analysis of XRD results (here Principal Component Analysis- PCA) was performed to compare the obtained bulk mineralogy diffractograms with standards of endmember composition of 100% quartz to 100% calcite, also including stepwise increment in calcite content (25%, 50%, 75%). PCA was favored for highlighting similarities and differences in the patterns detected (see Wold et al., 1987 for detailed description) since this reduction technique includes several samples within one single diagram, thus providing a very intuitive visual output. A total of 60 diffractograms were processed using PCA in only a few minutes, including 5 standard composition samples and the 55 diffractograms comprising the focus of the experimental essay. This approach allows a fast overview of sample variability, bypassing successive interpretations of spectra.

Additionally, a customised display of raw XRD data was performed following Coimbra et al. (2022), generating 3D models to provide a clear overview of the complex mineralogical dataset obtained, also allowing an expedite comparison between both studied sections.

4 Results

4.1 PCA analysis of diffractogram spectra

Principal component scores indicated the relative contribution of each sample for the respective principal component. When compared to standard composition of pure quartz and calcite, as well as mixtures of both at 25% increment of calcite, samples from Rocha Poço and Puerto Lorente fall within the compositional range of 25% to absent quartz (Fig. 3), also evidencing lower carbonate content in the siliciclastic interval at Rocha Poço section when compared to terrigenous intervals at Puerto Lorente section. Specifically, samples denoting higher abundance of quartz correspond to the siliciclastic interval representing the lower portion of the Rocha Poço section (Fig. 2A, C), decrease towards lower contents for samples corresponding to previously identified terrigenous pulses at

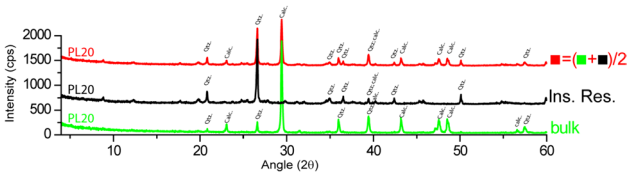

Fig. 4 Example of the mineralogical approach applied to the studied sections (here XRD spectra from sample PL20 from the base of the Puerto Lorente section). Note that including bulk mineralogy along with insoluble residue (red) results in a more representative characterization of the materials under scope (see text for details)

Puerto Lorente (Fig. 2A). In contrast, samples belonging to the spongiolithic upper portion of Rocha Poço and most Puerto Lorente samples fall within the PCA space enclosing to samples denoting high calcite content.

4.2 3D models of mineralogical assemblage

Sample processing as described in Sect. 3 results in two sets of diffractograms: bulk mineralogy and the insoluble residue measured after decarbonatation (example in Fig. 4). Due to the carbonate nature of the samples, the bulk mineralogy spectrum is largely dominated by the intensity of calcite peaks, obscuring other minerals. After decarbonatation this peak is eliminated, and the remaining mineralogical assemblage can be fully appreciated. In order to highlight the contribution of the complete mineralogical assemblage, both spectra were summed and divided by two, the later step serving to reduce exaggeration in peak intensity (Fig. 4). The resulting spectra were expanded under 3D model computation.

For the more restricted setting at Rocha Poço (Fig. 5A), bulk mineralogy results revealed a stratigraphic trend of abundant quartz still reaching this area, but decreasing as calcite deposition dominated the upper portion of the sedimentary record. In contrast, for the comparatively open location at Puerto Lorente, stratigraphic abundance of quartz is very restricted, punctual (Fig. 6A), verified mainly as sharp and prominent peaks, coinciding with previously identified pulses of continental influx (Fig. 2).

The clay fraction also provided very distinct patterns at each of the sections investigated. The more restricted and relatively proximal setting at Rocha Poço revealed a significantly higher abundance of smectite and illite when compared to the more open and relatively distal site of Puerto Lorente, and this is especially relevant at the lowermost portion of this section (Fig. 5B). Limited occurrence of kaolinite is also characteristic for this relatively proximal Rocha Poço site. At the more open and probably relatively distal site (Puerto Lorente section), clay mineral abundance was overall lower, comprised mainly by illite and (irregular) illite/smectite, with small amounts

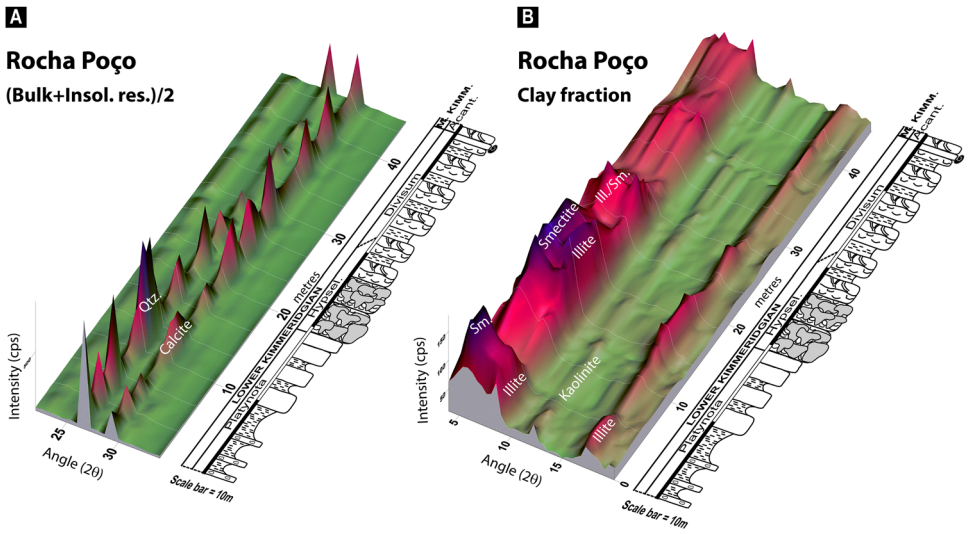

Fig. 5. 3D modelling of raw XDR intensity data for the Rocha Poço section, highlighting the most significant results (lithology as in Fig. 2A). **A** Bulk mineralogy showing stratigraphic variation of quartz and calcite. Peaks with highest amplitude (primary peaks) are identified as calcite, quartz based on peak position. **B** Clay fraction 3D model. In all models, peak width is exactly as obtained from XRD measurements. Secondary/tertiary less intense peaks of these same minerals are not identified here for reasons of simplicity (except for illite in the clay fraction spectra)

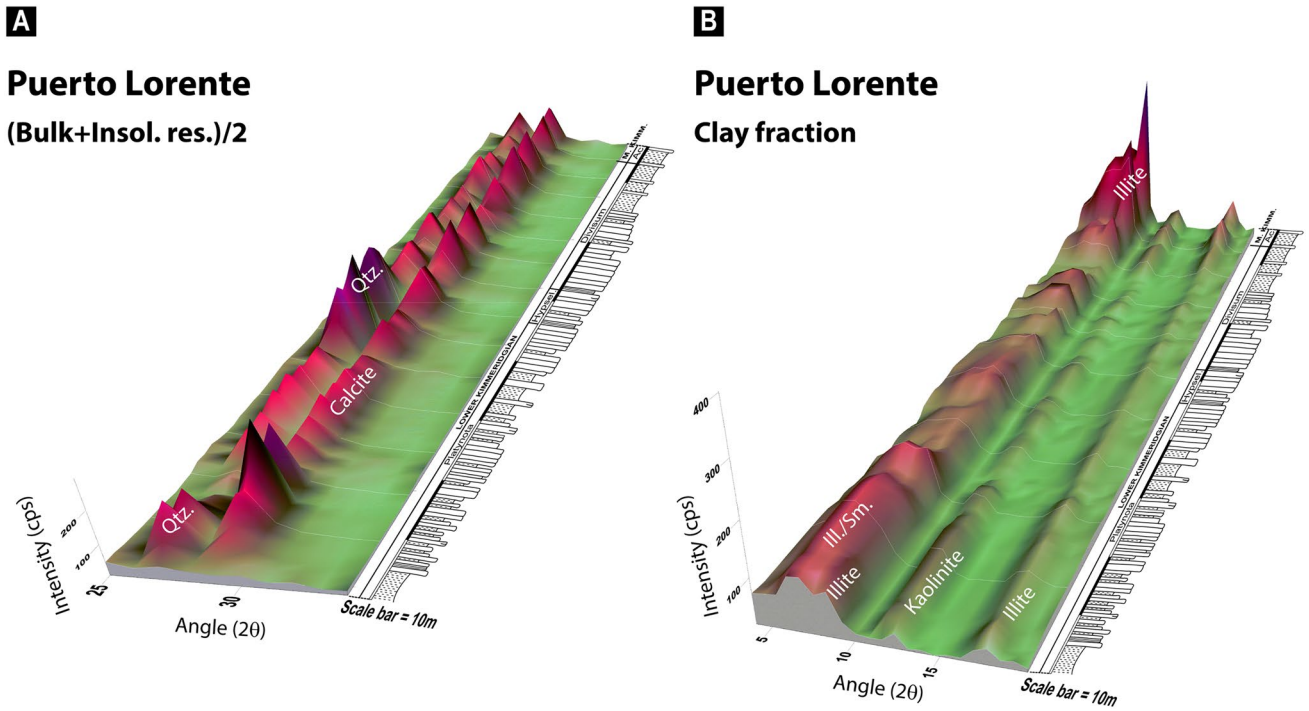

Fig. 6. 3D modelling of raw XDR intensity data for the Puerto Lorente section, highlighting the most relevant results (lithology as in Fig. 2A). **A** Bulk mineralogy showing stratigraphic variation of quartz and calcite. Peaks with highest amplitude (primary peaks) are identified as calcite and quartz based on peak position. **B** Clay fraction 3D model. Peak width is exactly as obtained from XRD measurements. Secondary/tertiary less intense peaks of these same minerals are not identified here for reasons of simplicity (except for illite in the clay fraction spectra)

of kaolinite (Fig. 6B). At the lowermost portion of the Puerto Lorente section, a slightly higher contribution of illite and interstratified illite/smectite is verified along with small amounts of kaolinite, decreasing towards the

mid-portion of this section. A conspicuous increase in illite and illite/smectite is observed towards the top of this section, a trait that is not recognized along any other bulk mineralogical nor geochemical proxies indicating elevated terrigenous input (Figs. 2 and 6) based on the assumption of low diagenetic imprint (see below).

5 Interpretation and discussion

5.1 Diagenetic considerations on clay mineral assemblages

When interpreting clay mineral associations extracted from ancient sedimentary records, factors as sedimentary reworking, diagenesis mainly through burial derived temperature and tectonics (Raucsik & Merényi, 2000; Thiry, 2000; Ruffel et al., 2002; Arostegui et al., 2006; Godet et al., 2008; Lanson et al., 2009; Coimbra et al., 2021; Boulila et al., 2022) and/or authigenesis may alter the primary assemblage of clays, thus obscuring their original paleoclimatic signal. Possible indicators of fair preservation of clay mineral assemblages include records of abundant smectite along with variations in smectite/illite ratios in marls-limestone couplets and preference of illite in marly levels (Boulila et al., 2022); persistent records of opposite values amongst key clay minerals (Deconnick et al., 1996); high smectite contents indicating relatively low burial-temperature and diagenesis (Godet et al., 2008; Deconnick et al., 2019); coherence with geochemical records (Coimbra et al., 2021); distribution of clay species according to sea-levels, currents and/or winds (Raucsik & Merényi, 2000; Hattem et al., 2017). On the assumption that significant alteration can be ruled out, several clay species can be successfully used as indicators of paleoclimatic conditions for the Mesozoic period (Raucsik & Merényi, 2000; Ruffell et al., 2002; Schnyder et al., 2006; Pellenard & Deconinck, 2006; Raucsik & Varga, 2008; Dera et al., 2009; Gertsch et al., 2010; Boulila et al., 2022) –see Fig. 7 for synthetic comparison of averaged clay mineral assemblages from the Lower Kimmeridgian in separate areas of Europe and N. Africa). As clay mineral assemblages can largely depend on local factors, regional studies provide a more reliable paleoclimatic signal (Dera et al., 2009) –see Fig. 7. Local forcing mechanisms and climatic changes can thus be disentangled based on the distribution of clay species over time and space, here further discussed in the context of available geochemical and sedimentological data (Coimbra et al., 2014, 2019).

The most landward setting at Rocha Poço has been previously proved to receive a higher original volume of freshwater along the inner and middle shelf, as interpreted by Coimbra et al. (2014), which agrees with the occurrence of land influence on "coralligenous" facies, even local emersion, across the Algarve Basin (Rosendhal, 1985), with the interpreted 40–50 m depth for sponge buildups (Marques, 1983) in mid-shelf conditions (Ramalho, 1985). Additionally, the silty-to-fine sandy character of the more siliciclastic facies at the base of Rocha Poço allows to assume higher porosity and permeability, in turn promoting a higher water/rock ratio (Coimbra et al., 2014 for full details). Despite previous demonstration that the geochemical record of the carbonate fraction in these facies reflects the influence of meteoric diagenesis, the obtained clay fraction record does not necessarily follow this trend. In fact, several aspects point towards negligible impact of diagenesis in the clay assemblage of the more siliciclastic facies at Rocha Poço: (i) it reveals abundant smectite, a well-known temperature sensitive clay mineral (Arostegui et al., 2006; Boulila et al., 2022) indicating that these deposits have not experienced significant burial –i.e., a corresponding temperature clearly below the 45ºC-80ºC interval of smectite disappearance (Daoui et al., 2010; Deconinck et al., 2019); (ii) interstratified species as illite/smectite are not dominant along the obtained assemblage, suggesting limited illitization rate and excluding elevated burial temperatures which would severely impact this clay mineral (Środón, 1984), as well as foreseeable higher, comparable values for illite/smectite in the two section analyzed; (iii) the stratigraphic abundance of clay minerals across the siliciclastic interval at Rocha Poço follows the pattern of previously identified terrigenous pulses (Fig. 2), aside from the increased porosity favoring diagenetic alteration. Based on the previous, the stratigraphic distribution of clay species across the siliciclastic interval at Rocha Poço section is considered to reflect depositional conditions (Fig. 7 for wide regional comparison).

As for the remaining facies at Rocha Poço and the Puerto Lorente record, geochemical signatures of the carbonate fraction were previously attributed to the differential influence of forcing mechanisms operating along the south Iberian paleomargin (Coimbra et al., 2014). The potential of preservation of clay species is thus elevated, and again in close agreement with previously identified terrigenous and/or hydrothermal pulses related to tectonic activity resulting in paleomargin structuring (fracture zones and local/regional faults forcing the registered pulses of instability). Clay mineral distribution along both sections is therefore considered to be a suitable proxy for reconstructing regional geodynamic context forcing terrigenous contribution at these areas and related paleoenvironmental conditions at its corresponding hinterlands.

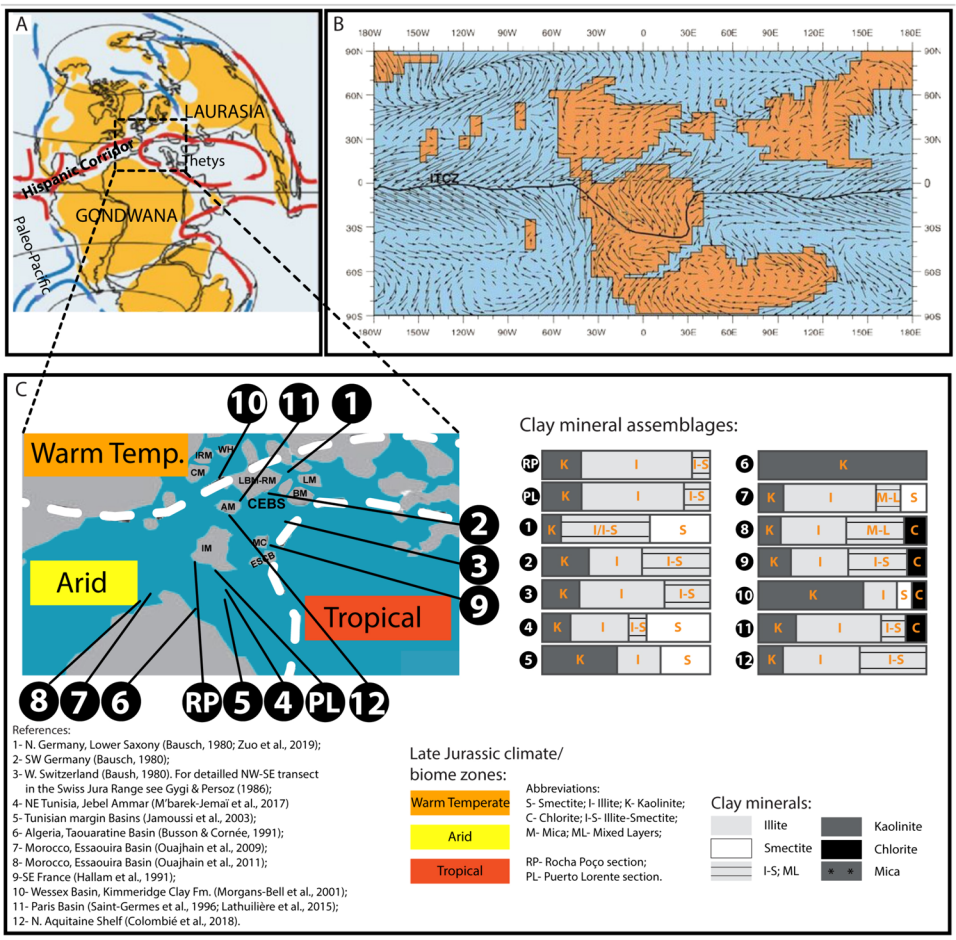

Fig. 7 Paleogeography, climatic zones, global surface currents, global surface winds and averaged composition of clay minerals for early Kimmeridgian times around Iberia. **A** Late Jurassic paleogeography and major sea-surface currents (after Damborenea et al., 2013; red pattern for warm and blue pattern for colder waters). Note that the fragmentation of the Pangea resulted in the development of several marine corridors, among them the Hispanic Corridor and those between Iberia and Africa, affecting oceanic circulation patterns. **B** Simulated surface winds from the Late Jurassic global climate model by Moore et al., (1992a, 1992b). Note that during winter seasons weak-to-moderate northern easterlies would barely affect southern Iberia, while northern Iberia would be affected by moderate northern westerlies and relatively weak storms only during winter, all of this being under the assumption of the low-topography scenario – "500 m plateaus"–modelized by Moore et al., (1992a, 1992b). **C** Synthetic Paleogeography from Kiessling et al. (1999) and Scotese and Wright (2018), combined and modified. *AM* Armorican Massif (Huang et al., 2009). *BM* Bohemian Massif (Colombiè, 2002; Kriwet & Klug, 2004; Zuo et al., 2018a, 2018b, 2019). *CEBS* peri-Tethyan Central European Basin System (Pieńkowski & Schudak et al., 2008; Zuo et al., 2019). *CM* Cornubian Massif (Oschmann, 1988; Huang et al., 2009; Atar et al., 2019). *ESCB* Ebro-Corsican-Sardinian Block (Angrand & Mouthereau, 2021; Nembrini et al., 2021). *IM* Iberian Massif. *IRM* Irish Massif (Pearce et al., 2010; Turner et al., 2018). *LBM-RM-BM* London-Brabant-Rhenish & Boemian Massifs with possibility for at least one seaway between the Rhenish and the Bohemian massifs, with assumed variable depth, in Ziegler, 1992; Brigaud et al., 2008; Thies & Leidner, 2011; Adler, 2013; Hrbek, 2014; Zuo et al., 2018a, 2018b, 2019; Boulila et al., 2022 *vs.* emerged continuity in between these massifs in Colombiè, 2002; Kriwet & Klug, 2004; Pieńkowski & Schudak et al., 2008; Hesselbo et al., 2009; Uhl et al., 2012; Schönlaub, 2016; Turner et al., 2018. Intermittent neritic seaways are here favored (dotted). *LM* Lusatian Massif (Kriwet & Klug, 2004; Pieńkowski & Schudak et al., 2008; Thies & Leidner, 2011; Zuo et al., 2018a, 2018b). *MC* Massif Central (Boulila et al, 2022). *WH* Welsh High (Turner et al., 2019; Atar et al., 2020). Averaged clay mineral distribution of selected Kimmeridgian case studies distributed around the Iberian Plate, including this work (after Bausch, 1980; Busson & Cornée, 1991; Hallam et al., 1991; Morgans-Bell et al., 2001; Jamoussi et al., 2003; Ouajhain et al., 2009, 2011; Lathuilière et al., 2015; M'barek-Jemaï et al., 2017; Colombié et al., 2018; Zuo et al., 2019)

5.2 Mineralogical record and regional paleoenvironmental events

Quartz is present at higher abundance at both sections in correspondence with the events previously identified as geodynamically active pulses, including pulses of distant, diffusive hydrothermal influence and terrigenous inflow (Figs. 2, 5 and 6). The highest pick of quartz at the Rocha Poço separates two relevant amounts in smectite, and thus probably denotes a tectonic pulse that interrupted a

steady-state pattern of fluctuations in quartz inflows or, alternatively and less probable, a climatic forcing event. High values of quartz at the bottom and middle Puerto Lorente section correlate with tectonic pulses during Platynota chron times under HST (Highstand Systems Tract) conditions. Platynota chron deposits were interpreted as a tectono-eustatic sequence (Olóriz & Rodríguez-Tovar, 1998) starting with a widely recognized instability in western Tethys (Marques et al., 1991). Heterochrony in the second peak of quartz, clearly later in Rocha Poço, seems to reinforce a local forcing effect but at this site could be combined with progradation during Hypselocyclum times under late HST to earliest LST (Lowstand System Tract) conditions. The fact that quartz grains inflows reached both depositional settings attests for their relative proximal position regarding shoreline, allowing to differentiate the Puerto Lorente section as the relatively open (relatively distal?) site in the middle shelf, considering the less significant contribution of quartz at this site (Fig. 6), specially from the mid-section towards the topmost horizons.

Higher combined records of quartz and illite/smectite most probably related to the combination of sea-level rise and tectonic instability (Rocha Poço section), as was identified in the Late Jurassic of the Boulonnais (Hatem et al., 2017). Heterochrony of the noticeable increases of illite/smectite mixed-layers (mid-upper intervals at the Rocha Poço section vs. the lowermost interval at the Puerto Lorente section) reveals changing environmental conditions for deposition and probably early diagenesis, as well as in the tectonic context, through space and time (Godet et al., 2008).

Overall clay mineral contribution supports the previous differentiation among both settings, being more significant at Rocha Poço, a relatively enclosed site in the outer-middle shelf. The fact that the Rocha Poço area was more enclosed when compared to Puerto Lorente is also evident, retaining concomitantly abundant quartz and clay minerals (Fig. 5). Comparatively, at Puerto Lorente, quartz grains become scarcer at the mid-section, whilst clay minerals are overall scarce, to be abundantly recorded only at the topmost portion of the stratigraphic interval, which recorded increasing marly sediments during early mid-Kimmeridgian times under early-HST conditions. This context agrees with the supersequence turnover across Iberia, NW Africa, and the central North Atlantic Basin during early-late Kimmeridgian times, twofold division, (Marques et al., 1991), as well as with starting coarse-up sedimentation and progradation across the western central North Atlantic Basin (Pereira, 2013). Even so, the precise correlation of the respective time resolution scales is at most roughly available, and some diachrony of records could be expected from separated areas.

The isolate increase of illite/smectite and illite in the upmost interval at the Puerto Lorente section is relevant because it is uncoupled with any comparable increase in clastics (quartz), opposes its usual strong correlation (Gertsch et al., 2010; Boulila et al., 2022), and could inform about smectite transformation in more marly sediments (Godet et al., 2008). Accordingly, a complex intertwined of syn-depositional to post-depositional forcing is envisaged. The dominance of rhythmic deposition of relatively thin marly and limestone couplets accords with the paleoenvironmental trend exposed above, and the lack of concomitant changes in kaolinite content (Šimkevičius et al., 2003) reinforces the role of some diagenetic influence. In fact, the transition from lower to mid-Kimmeridgian deposits coincides with high sea level and occurrence of some diagenetic effect (see Coimbra et al., 2019 for details on diagenesis). This suggests that as sea level rises reaching the aggradation phase (early-to-middle HST), the Puerto Lorente site evolved from a sedimentary bypass area where deposition of terrigenous finer materials was not dominant, towards a relatively more distal depositional zone where under decreasing current energy the presence of clay minerals become more dominant in detriment of quartz, which in turn settles closer to shoreline. This trend accounts for the observed absence of quartz at the topmost levels recording a significant peak of illite and illite/smectite (Fig. 6). Hence, the major increase of illite at the top of this section relates to increase of fine clastics during aggradation-to-initial progradation within HST conditions and the corresponding differential transportation according to floatability; the latter could combine with decreasing chemical weathering (Šimkevičius et al., 2003). Persistence of kaolinite without changes throughout this section is interpreted as a likely climatic signal.

The specific clay species identified in both sections are differentiated, providing a tentative diagnosis of the local paleoclimatic conditions at the respective hinterlands and potential sources of these minerals. Smectite, illite and illite/smectite are the most dominant species at Rocha Poço, with very scarce kaolinite. In contrast, the Puerto Lorente section is characterized by being overall clay-leaner, only showing a prominent illite peak during highest sea-level times.

Smectite and related mixed-layer clays (illite/smectite) are the most abundant clay species throughout the Rocha Poço section, largely following previously identified pulses of diffusive hydrothermal activity (Fig. 2A and 5). Smectite and related interstratified clays are commonly associated to volcanic activity, since it can be found in metalliferous deposits and ash-fall accumulations, both being here absent, or form via submarine weathering of basaltic lava or volcanic sediments and glass (Paquet, 1970; Chamley & Masse, 1975; Singer, 1984; Borchardt, 1989; Chamley, 1989; Cuadros et al., 2011; Duchamp-Alphonse et al., 2011), as well as from tropospheric dusts (Kimblin, 1992; Deconinck & Chamley, 1995). Their favored origin is thus coherent with periods of enhanced volcanic and/or faulting activity in the westernmost Tethys close to the

connection with the growing Hispanic Corridor (Coimbra & Olóriz, 2018). In such a geodynamic context, since the occurrence of volcanic particles, metaliferous deposits and/or hydrothermal vents (chymneis) must be proven, distant venting as well as diffusive hydrothermal influence related to faulting could be responsible for records of pulses of smectite increases. All of this fitting also a scenario of slow erosion rates or erosion of soil horizons formed over long periods of time, to poorly-drained soils and seasonally arid climates (Pearson, 1990; Fürsich et al., 2005). Due to selective sorting, smectite's relatively small size results in preferential deposition in low-energy distal environments. The enclosed nature of the Rocha Poço area accounts for the abundant presence of retained smectite, which allow to consider an alternative (or combined) source. High smectite content (typically > 65%) in clay assemblages is clear evidence of limited burial diagenesis (Boulila et al. (2022), which accords with records in the two sections investigated (Figs. 5 and 6), far from the lowest temperature estimated for smectite withdrawal (Daoudi et al., 2010) and therefore being of detrital origin in a dry and seasonal climate (Godet et al., 2008). Hence, recorded smectite values would indicate deposition of detrital clays under arid/semi-arid and/or seasonal climatic regime at low latitude (Gertsch et al., 2010). Aside from intervals with extremely high values of smectite (lower part at Rocha Poço) probably corresponding to higher aridity and/or erosion (Deconink et al., 2019), smoother standard fluctuations in smectite values most probably relate to rhythmic oscillations of forcing factors (i.e., steady-state conditions of "normal climate"). In contrast, persistent lower but fluctuating values of kaolinite would inform about the overdominance of a low precipitation regime at low latitude with modulated, smoothed, warm temperatures, as well as a constant low biogeochemical weathering, both which resulting from the balancing influence of warm coastal waters of the salty Tethys Ocean (Ross et al., 1992; Godet et al., 2008; Dera et al., 2009; Scotese & Wright, 2014a, b). Such a smoothed signal precludes hypothetical evidence of a relevant monsoonal influence, supplemented by the NW orientation of the coast. In such a context and given the identified trends in smectite and kaolinite contents, no clear evidence of differential segregation due to respective particle size and floatability contrasts with the expected "normal" behaviour across epicontinental ramps (Chamley, 1989; Raucsik & Merényi, 2000; Godet et al., 2008; Gertsch et al., 2010), such as is well-known in the Late Jurassic of the Boulonnais, SE France (Deconink et al., 1996; Hesselbo et al., 2009).

Illite and related mixed layer minerals (e.g., illite–smectite) can be found particularly in arid and semi-arid regions, where poorly drained areas ensure minimum leaching. Sedimentary records with abundant detrital illite can thus reflect minimum physico-chemical (and biological) weathering under cold or, in this case, dry climate phases of a mild monsoonal regime, corresponding to low hydrolyzing conditions (Chamley, 1989; Robert & Chamley, 1991), also informing on low degree of diagenetic influence.

Kaolinite is the least abundant clay species recorded throughout both sections (Figs. 5 and 6). It's abundance typically results from the decay of most aluminium silicate parent rocks via highly hydrolytic weathering reactions under warm humid climate (Gaucher, 1981; Chamley, 1989), i.e., humid phases in a monsoonal regime. When scarce in ancient depositional environments, detrital kaolinite indicates low rates of weathering in the hinterland due to low water/rock ratio (Hallam, 1984; Wignall & Ruffell, 1990; Velde, 1992).

In summary, clay mineral species identified at both sections can be attributed to diffusive hydrothermal activity related to faulting at Rocha Poço as well as to overall warm and dry/arid climate conditions accounting for low rates of weathering at the source areas. Based on the above, a Mediterranean-like climate with low runoff is suggested for the area corresponding to the studied sections at the SE Iberia during early Kimmeridgian times, which would be comparatively less humid than interpreted for S. Germany by Uhl et al. (2012).

6 Conclusions

The mineralogical approach applied to previously explored stratigraphic sections provided new and complementary information, including:

- pulses of diffusive hydrothermalism that were identified in all mineralogical components, characterized by abundant quartz provided by nearby areas and equally abundant smectite that can be attributed to local hydrothermal influence coming from fracture zones.
- terrigenous pulses identified both in geochemical and bulk mineralogical data were not very expressive in the clay mineral record, indicating that the Puerto Lorente area was a comparatively bypass area with respect to fine terrigenous materials.
- a conspicuous increase in the clay mineral content towards the topmost horizons of this rhythmic carbonate-siliciclastic deposit as a novel feature, related to a sea-level rising trend and related increase in distality at the Puerto Lorente section.
- Deduced Southern Iberia paleoclimatic conditions are compatible with arid/semi-arid warm climate belt proposed for this region during the Late Jurassic.

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Data availability Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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