

Marine flooding event in continental Triassic facies identified by a nothosaur and placodont bonebed (South Iberian Paleomargin)

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Received: 1 August 2012 / Accepted: 4 January 2013 / Published online: 30 January 2013
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Abstract Sudden marine flooding within otherwise continental successions of the Triassic is unusual. The Tabular Cover of the SE paleomargin of the Iberian Massif is characterized by continental Triassic redbed facies composed of sandstones and siltstones, with gypsum-rich levels in the transition to Jurassic limestones. These Triassic deposits were developed in a fluvial-coastal system and they are 300 m thick in the Puente Génave-Villarodrigo area, eastern Jaén Province, Spain. An unexpected sandstone-limestone unit in the lower part of this formation, recognized over more than 30 km, contains marine reptile bones in a storm bed or tsunami deposit. The lower part of this unit is characterized by a sandstone with sedimentary structures indicative of high-energy conditions as well as by fossil remains of marine reptiles. This bed ranges from 0 to 90 cm in thickness, and in some outcrops pinches out rapidly within a few meters. The upper part of the studied unit is a limestone with common trace fossils and abundant remains of marine reptiles, comprising isolated and fragmented pieces of sauropterygians (nothosaurs, pachypleurosaur, and placodonts). Most abundant are vertebrae and ribs. In some outcrops, the top of this bed presents a dense accumulation of well-preserved small gastropods. The

limestone is overlain by red siltstones and sandstones. The studied unit is interpreted as a marine deposit representing a high-energy event and records exceptional marine flooding in a distal fluvial environment, in fact the only open-marine deposit in the Villarodrigo section. The sedimentary structures in the lower part of the unit are typical of high-energy deposits and indicate deposition in a single episode, probably related to a storm surge or a tsunami. The fragmentation, disarticulation, and dispersion of the vertebrate bones and the imbrication of bioclasts are consistent with a high-energy event that favored the concentration of bones according to size and density.

Keywords Red beds · Vertebrates · Taphonomy · Geochemical proxies · Events · Triassic

Introduction

Much of the Triassic in the Iberian Peninsula is represented by continental redbeds (e.g., Simon 1987; Pérez-López 1998; Pérez-López and Pérez-Valera 2007; Bourquin et al. 2011; Fortuny et al. 2011; Soria et al. 2011; López-Gómez et al. 2012), as in other Western expressions of the succession. The continental facies (redbeds) occur along the southeastern edge of the Iberian Variscan Massif (Meseta) as a belt of horizontal redbeds, or so-called Tabular Cover. To the east, the Germanic Basin, extending over Germany, Poland, and other central European countries such as Switzerland, France, Belgium, and the Netherlands, displays the classic three-part succession of the Germanic Triassic, the continental Buntsandstein and Keuper, separated by the marine Muschelkalk (e.g., Röhl 1990; Geluk and Rohling 1997; Costamagna and Barca 2002; El-Ghali et al. 2009; Kowal-Linka and Bodzioch 2011; Menning

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et al. 2011). The continental redbeds are monotonous and hard to date and any marker horizon, such as a marine flooding level, may provide dating evidence that is key for correlation and interpreting changing environmental conditions in these generally inland basins.

Marine reptiles such as nothosaurs and pachypleurosaurs have been found in many Spanish localities (Sanz 1976, 1983a, b; Alafont 1992; Sanz et al. 1993; Rieppel and Hagdorn 1998), mainly in Muschelkalk facies. In the Betic Cordillera, scarce marine reptiles may be found in Muschelkalk and Keuper facies, but always as isolated fossils together with marine invertebrates (Niemeyer 2002). Alafont (1992) described some fossil bones of nothosaurs and placodonts in the Tabular Cover corresponding to the families Nothosauridae, Pachypleurosauridae, and Placochelyidae. Niemeyer (2002) studied the Ladinian Muschelkalk facies from the Hornos-Siles

Formation of the Prebetic (Betic Cordillera) and identified disarticulated fossil remains of marine reptiles corresponding to prolacertiforms (such as *Tanystropheus*) and Superorder Sauropterygia (families Pachypleurosauridae, Nothosauridae, and Cyamodontidae).

The Tabular Cover of the Iberian Massif in the South-eastern Paleomargin (Fig. 1) is characterised by continental Triassic deposits in typical redbed facies unconformably overlying the Paleozoic basement. The facies are mainly continental red sandstones and siltstones, with gypsum-rich levels in the transition to the overlying Jurassic limestones. The Triassic deposits (Chiclana de Segura Formation; Fig. 1b) were developed in a fluvial-coastal system during the Middle to Late Triassic (Fernández 1977). This formation is almost 300 m thick in the Puente Génave-Villarodrigo area (eastern Jaén province, Spain), and constitutes a monotonous succession (Figs. 1b, 2).

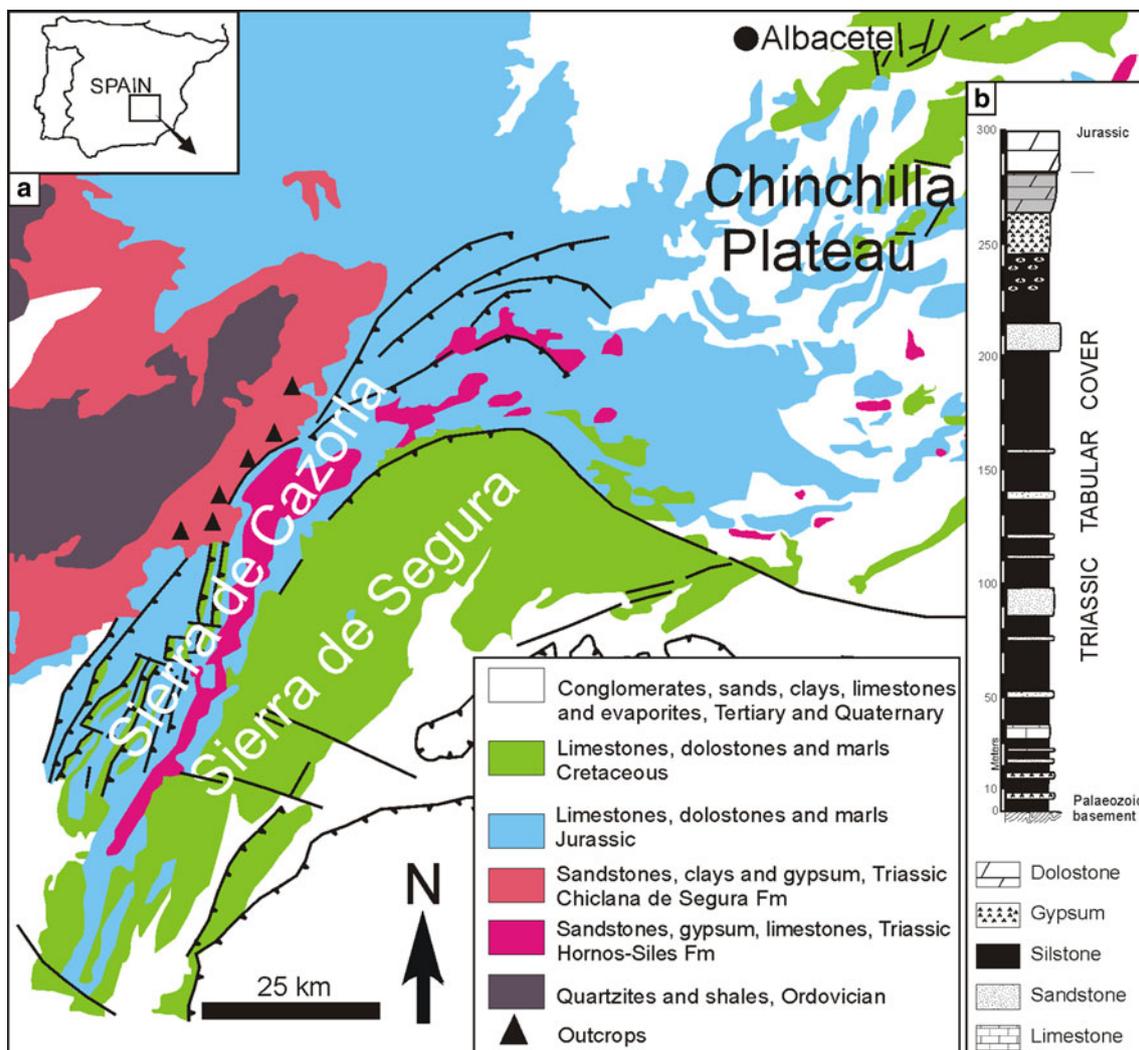


Fig. 1 a Geological setting of the studied area with location of the outcrops in the Triassic Tabular Cover. b General Triassic succession of the Tabular Cover

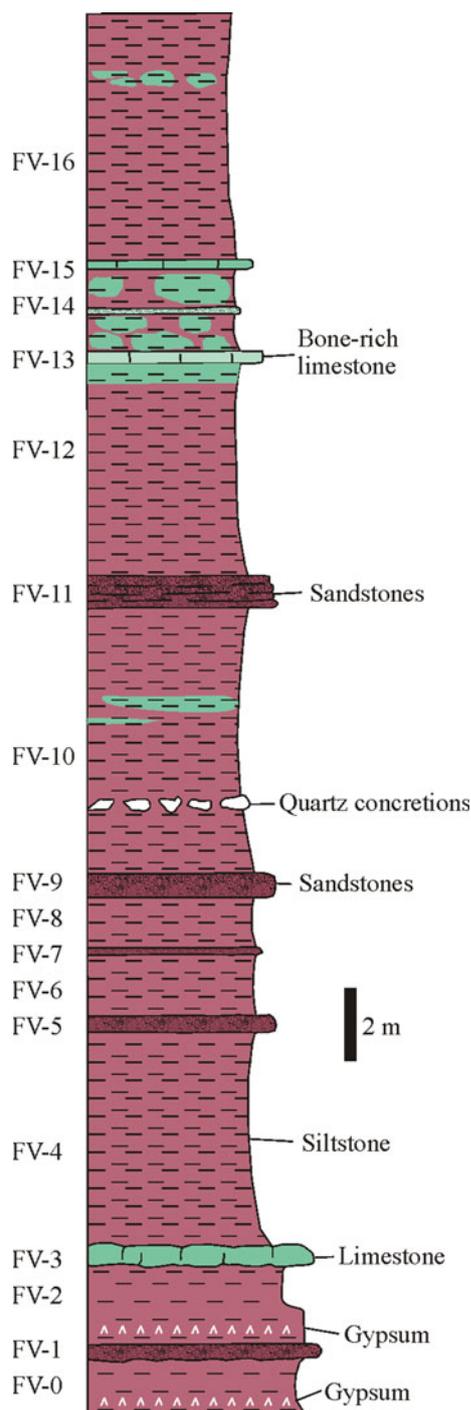


Fig. 2 Detailed Villarodrigo section with location of the bone-rich limestone bed

From the Germanic Facies (Hornos-Siles Formation) of the southern domain in the Betic Cordillera (Prebetic) towards the Tabular Cover in the North (Fig. 1), Muschelkalk carbonates disappear and evaporites are progressively scarcer (López-Garrido 1971; Arche et al. 2002). Therefore, redbeds of the Tabular Cover are uniform and monotonous and this makes it difficult to differentiate

stratigraphic intervals without clear marker horizons. Only in the upper part of the Chiclana de Segura Formation have some authors differentiated some units (K1 to K5; Suárez et al. 1986; Ortí and Pérez-López 1994). Rare marine incursions into these redbed successions may provide marker horizons that may be detected over wide areas.

For this reason, the present study reports a marine flooding event, depicted by a limestone bed in the lower part of this formation, which can be recognized over a distance of more than 30 km. Moreover, the record of certain marine reptiles may be useful for determining the age of this fossil-poor continental formation. The sedimentological, paleontological, and geochemical characterization of this particular event may establish it as a correlation bed in the Tabular Cover. The results obtained provide further information about coastal environments and marine incursions. In detail, this study contributes to the knowledge of storm deposits in coastal environments.

Geological setting

The Chiclana de Segura Formation has been hard to date. For example, Besems (1981) detected palynological evidence for both Ladinian and Norian ages in the Linares-Alcaraz region (SE Spain), based on samples from different levels.

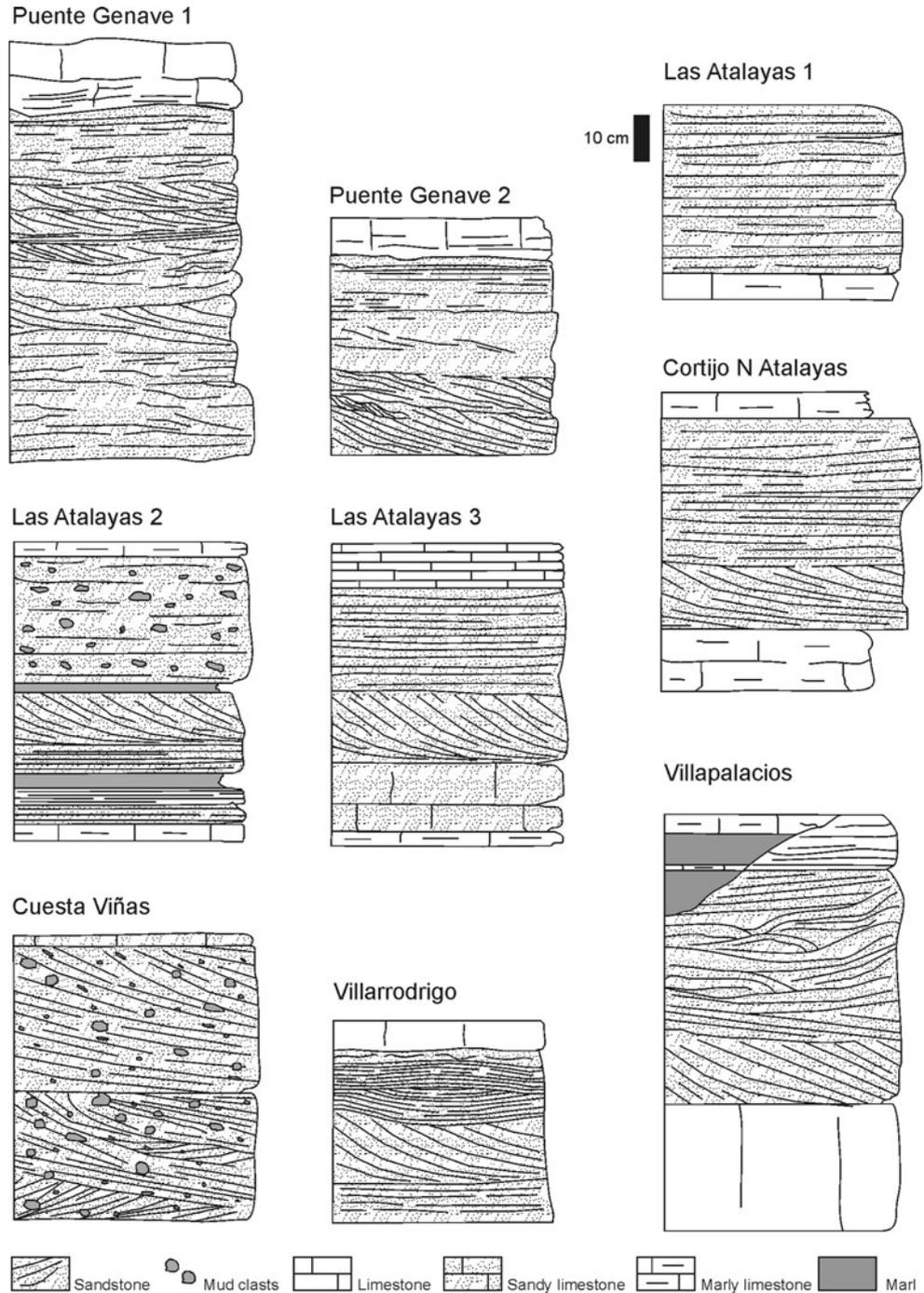
Laterally, the redbeds of the Tabular Cover change to the “Germanic facies” in the External Zones of the Betic Cordillera, where marine deposits are well developed in Muschelkalk facies consisting of carbonates (Siles Formation and Cehegín Formation; Pérez-Valera and Pérez-López 2008).

Nine outcrops of redbeds (Fig. 3) have been studied from Puente Génave to Villapalacios: Puente Génave (38°20′56″N, 2°48′15″W), Las Atalayas 1 (38°24′14″N, 2°45′22″W), Las Atalayas 2 and 3 (38°24′14″N, 2°45′25″W), Cortijo Atalayas (38°24′35″N, 2°45′04″W), Cuesta Viñas (38°25′27″N, 2°44′41″W), Villarodrigo Road (38°28′47″N, 2°41′04″W), Villarodrigo section (38°28′54″N, 2°41′00″W), and Villapalacios Road (38°33′09″N, 2°38′47″W). Vertebrate remains are only abundant in the Villarodrigo section and Cortijo Atalayas, but the other sections are essential for understanding the lateral variability of the studied event bed.

Methods

The stratigraphic interval under study was sampled over more than 30 km in a longitudinal transect of the Tabular Cover parallel to the South Iberian Paleomargin. In different outcrops, we studied sedimentary structures of the

Fig. 3 Detailed sections of the event unit analyzed from the localities Puente Génave, Atalayas, Cortijo Norte Atalayas, Cuesta Viñas, Villarodrigo, and Villapalacios. These sections show the great variability in thickness and sedimentary structures of the unit in the investigated area

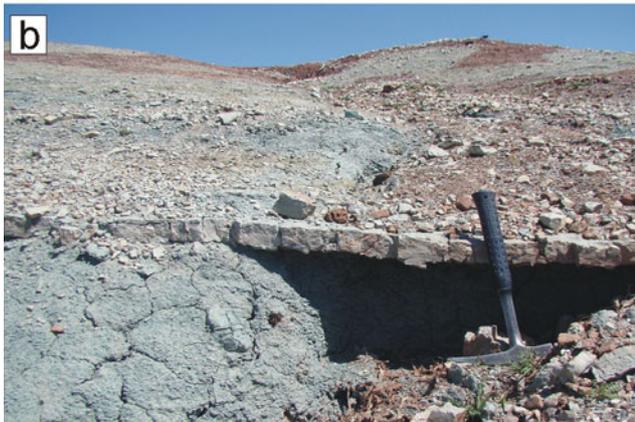
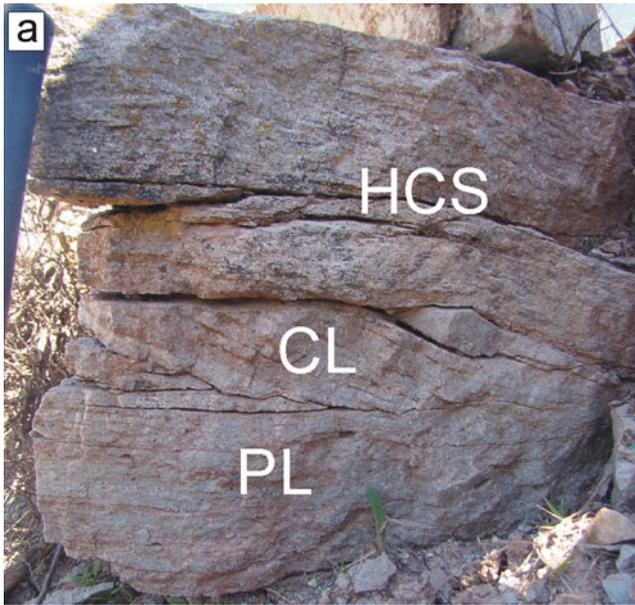


limestone beds intercalated in silt and sandstone lithofacies. For a more detailed stratigraphic analysis, the Villarodrigo section (VR) was selected, and microfacies of the limestone beds were analyzed in 11 thin-sections from the bonebed level using a petrographic microscope.

The mineralogical composition of the bones was determined by X-ray diffractometry (XRD) using a Siemens D-5000 diffractometer (Universidad de Jaén).

A geochemical analysis was carried out to evaluate potential stratigraphic fluctuations at Centro de Instrumentación

Fig. 4 Field view of the event unit in the Puente Génave-Villarodrigo area, which is composed of sandstone in the lower part and limestone in the upper part. **a** Typical sedimentary structures of the lower part of the VR-13 level (*PL* horizontal lamination, *CL* cross-lamination, *HCS* hummocky cross-stratification) which laterally disappear within a few meters. **b** Limestone bonebed at Villarodrigo reducing in thickness northwards. The sandstone bed is absent. **c** Example of the top surface of the limestone bonebed with a vertebra. **d** Field view of the studied unit at Las Atalayas 3. **e** Wave ripples at the top of the sandstone bed at Las Atalayas 1 (scale bar 5 cm). **f** Different fossil bones (vertebrae and ischium) in the bonebed at the Las Atalayas outcrop (scale bar 5 cm)



Científica (CIC) of the Universidad de Granada. Whole-rock analyses of major elements were done using X-ray fluorescence (XRF) in a Philips PW 1040/10 spectrometer. Trace elements were analyzed using an inductively coupled plasma mass spectrometer (ICP-MS), the Perkin Elmer Sciex-Elan 5000.

In order to compare trace element proportions in samples with variable carbonate and clay contents, it is usual to normalize trace element concentrations to aluminium content (Calvert and Pedersen 1993). Paleoproductivity was assessed by using the ratios Ba/Al, Sr/Al, and P/Ti. For the analysis of redox conditions, different proxies, such as Co/Al, V/Al, Ni/Al, Mo/Al, and V/Cr ratios, were applied throughout the section.

Some of the bones were prepared with a pneumatic air pen in order to remove the limestone matrix. A taphonomic analysis was carried out on 61 fossil bones to reconstruct paleoenvironmental and sedimentary conditions and to identify autochthonous or allochthonous sources, which is crucial in interpretation. Key parameters were size, degree of fragmentation, disarticulation, and mineralization. Thin-sections and XRD of fossil bones were carried out to determine the type of preservation. Fragments of fossil bones were mounted and coated with gold for scanning electron microscopy (SEM). Secondary electron images were made to study internal ultrastructure and crystal morphology. These analyses were performed using the FEI Quanta 400 at the CIC of Universidad de Granada.

Results

Lithofacies

The event unit under study is usually composed of two parts, a sandstone at the base and a limestone bed with vertebrate remains at the top (Fig. 3). The base of this event unit is usually irregular. These deposits are included in a red (locally green) sandstone and siltstone interval. The studied beds are clearly identifiable by the white color, the sedimentary structures, and the presence of carbonates usually located in a green stratigraphic interval of the succession (Figs. 3, 4, 5). Carbonates are mainly located in the upper part of the unit but in any section the base is composed by sandy limestones and marly limestones (Las Atalayas sections and Villapalacios section; see Fig. 3). Sieving samples of these marly limestones for microfossils produced negative results.

Sedimentary structures of the sandstones of the lower part (Fig. 5) are mainly parallel lamination and cross lamination, and locally hummocky cross-stratification (Villarodrigo outcrop, Fig. 4a) and paleochannels (Fig. 5a, h). Moreover, water escape structures locally distorted the sedimentary

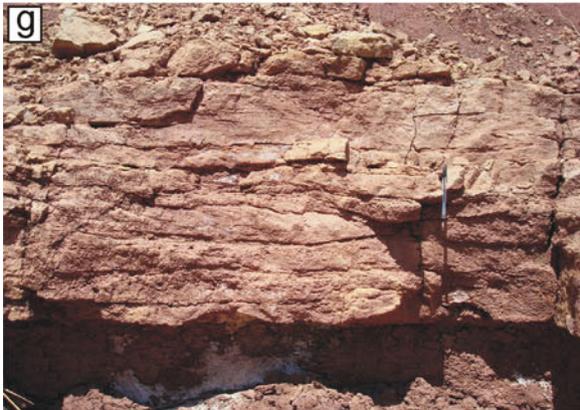
structures in the upper part of the sandstone. At some localities, the sandstone contains quartz pebbles and mud clasts (Fig. 5d, e). Both, sedimentary structures and thickness of the sandstone are very variable (<90 cm).

In the Villarodrigo outcrop the limestone bed is preceded by a grey sandstone bed of very variable thickness (0–50 cm) that shows a succession of parallel lamination, followed by high-angle cross-lamination, hummocky cross-stratification and wave-ripple lamination at the top (Fig. 4a). The grey sandstone bed is composed of quartz grains (40–80 µm), mica, and scarce bioclasts. Some isolated marine vertebrate remains are recorded. This high-energy bed pinches out rapidly within a few meters, constituting a body with a convex base.

The limestone bed is of variable thickness (5–30 cm; Figs. 3, 4). This limestone is characterized by a bioturbated base and abundant marine vertebrate fossils that increase in abundance towards the top (Figs. 4c, f, 6). In the Villarodrigo and Las Atalayas outcrops this is a bonebed *sensu stricto* (Fig. 4f), according to the definition of Hagdorn and Mutter (2011). The trace fossils are *Thalassinoides* and *Spongeliomorpha* (A.A. Ekdale, pers. comm.; Fig. 6). The style of branching seems in some cases *Phycodes*-like, with several branches coming from a single point, and there are some semicircular structures that resemble *Rhizocorallium*, a very common trace fossil in the Triassic. Interestingly, bioglyphed burrows seem to be particularly abundant in the Early Triassic, which Buatois and Mangano (2011) interpreted as related to poor development of mixgrounds after the end-Permian mass extinction.

The microfacies is a wackestone at the base with quartz grains, lumps, indeterminate mollusc bioclasts and gastropods, whereas the upper part of this bed is a packstone of small gastropods and some bivalves, together with quartz grains and micritic lumps (Fig. 7). Locally, undeterminable algal or microbial filaments are recorded (Fig. 7d). The gastropods and bivalves show a high degree of fragmentation and imbrication. The sedimentary infilling of the gastropods is composed of both dark micrite and sparite. In the upper half of the bed, quartz grains are an important component in the microfacies, increasing in abundance towards the top in a coarsening-upwards sequence. Above the limestone bed, sedimentation continues with red siltstones and sandstones.

Fig. 5 Field view of the lower sandstone bed in the Puente Génave-Villarodrigo area, SE Spain. **a** Paleochannel at the Villapalacios outcrop. **b** Cross-lamination at the Villapalacios outcrop. **c** View of the Cuesta Viñas outcrop. **d** Detail of the cross-lamination at the Cuesta Viñas outcrop with mud clasts (*white arrows*). **e** Detail of the base of the sandstone bed with pebbles, Cuesta Viñas outcrop. **f** Cross-lamination (*white arrow*) at Puente Génave 2 in the lower sandstone interval. **g** Sandstone interval with irregular bodies showing cross-lamination at Puente Génave 1. **h** Sandstone interval with a paleochannel (*white arrow*) at Puente Génave 1



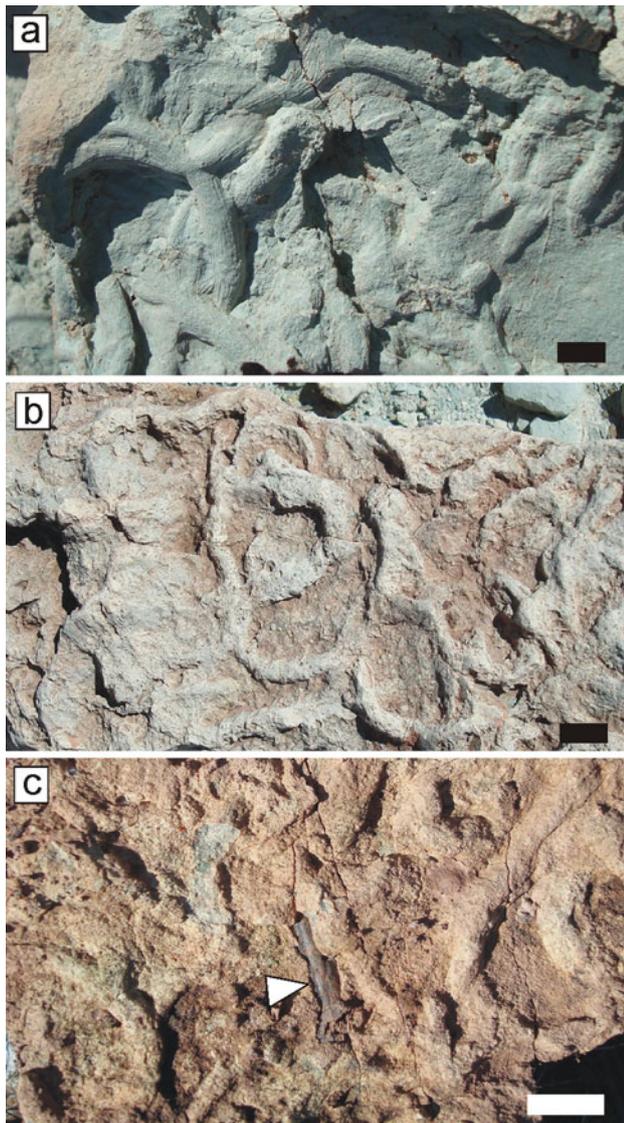


Fig. 6 Trace fossils at the base of the limestone bonebed in the Villarodrigo section, SE Spain. **a** Bioglyphed burrows of *Spongiomorpha*. **b, c** Branching *Thalassinoides* galleries and fragments of fossil bones. Scale bar 1 cm

Geochemistry

Analysis of redox conditions is based on redox-sensitive trace elements (Co, Ni, V, Mo, and Cr), which are less soluble under reducing conditions, resulting in syngene enrichment under oxygen-depleted conditions (Wignall and Myers 1988; Nagao and Nakashima 1992; Calvert and Pedersen 1993; Jones and Manning 1994; Powell et al. 2003; Siebert et al. 2003; Jiménez-Espejo et al. 2007; Gallego-Torres et al. 2010). These redox-sensitive elements react under reducing conditions, forming CoS, NiS, VO(OH)₂, thiomolybdates, and (Cr, Fe)(OH)₃, and coprecipitate with sulphides, mainly pyrite (FeS₂) and chalcopyrite ((Cu, Fe)S₂), and are not usually remobilized

during diagenesis in the absence of post-depositional replacement of oxidizing agents (Tribouillard et al. 2006).

The stratigraphic evolution of the ratios reveals slight fluctuations throughout the succession (Fig. 8), and two significant variations located at the top of the section in samples VR-13 (bonebed) and VR-15. In the bonebed, important relatively high values are seen in the Ni/Al, Mo/Al, Co/Al and V/Cr ratios. In the next limestone level (VR-15), a new increase in those ratios is identified.

As for the paleoproductivity proxies, the Ba/Al ratio shows very low values throughout the section and a local high value in the last limestone level VR-15, while Sr/Al and P/Ti present a peak with maximum values in VR-13 and VR-15 (Fig. 8).

Nothosaurs and placodonts

Bones and bone fragments are mainly located at the top of the limestone bed (Figs. 4f, 9). They consist of isolated and fragmented pieces of aquatic reptiles of the Superorder Sauropterygia (Nothosauria, Pachypleurosauria, and Placodontia). These animals are exclusively marine (Rieppel and Wild 1996), hence identifying the environment of deposition; such abundant remains of exclusively marine reptiles would be hard to explain in continental facies. The most abundant remains are vertebrae, ribs, scapulae, teeth, and osteoderms (Figs. 9, 10, 11). The mean size of the remains is 40 mm, and the longer specimens are ribs and limb bones. The largest fossil, an ischium, is almost 12 cm long (Fig. 4f). In proportions, 59 % of the bones are vertebrae, and other bones are less common (large bones such as limbs and ribs, 25 %; platy bones such as pelvic elements and pectoral girdles and osteoderm fragments, 15 %; and indeterminate remains). The ribs all show the characteristic massive, pachyostotic internal structure seen in most marine reptiles (Fig. 10a). Only one fragment of jaw has been identified, being a maxillary fragment with a typical conical tooth with fine vertical ridges and circular cross section (Fig. 11i).

Limb bones are normally broken across the epiphysis, rarely with rounded surfaces (Fig. 10b). Other fractures in large bones of limbs and ribs are transverse and probably related to diagenesis. The characteristic compact vertebrae are usually well preserved (Figs. 10, 11). The typically high neural spines of Nothosauria are commonly well preserved, whereas the centrum is commonly separated and lost. This is due to the disarticulation of centra and neural arches as is typical in bonebeds. The main distortions in the vertebrae are fractures in neural spines and transverse processes (Fig. 11f, g). The platy bones are usually fragmented around the margins. Sand-sized bone fragments are noted in thin-section. The larger skeletal elements are identified as primarily from nothosaurs, by comparison

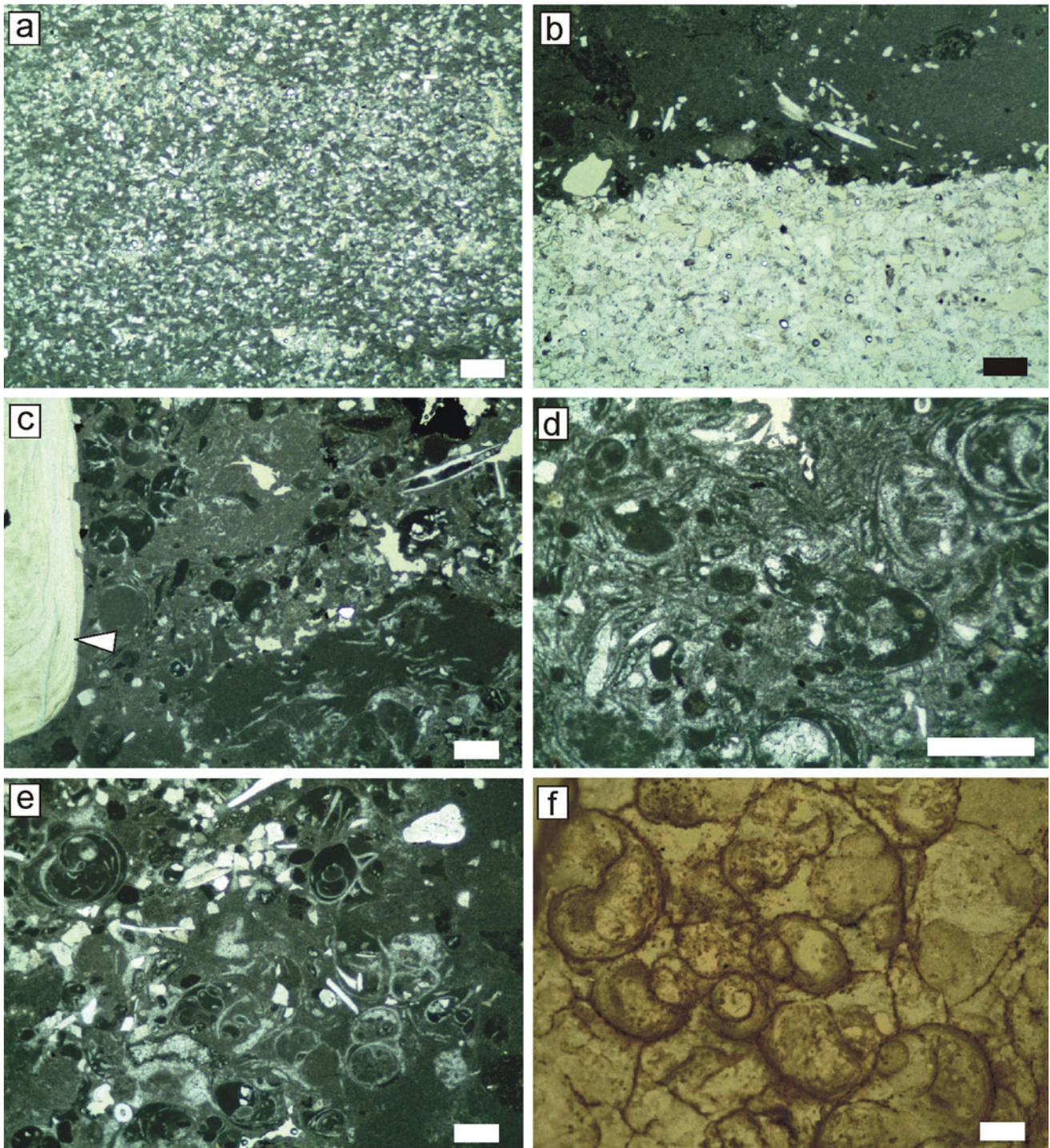


Fig. 7 Microfacies, Villarodrigo section. **a** Quartz-rich sandstone with carbonates and some clay minerals from the lower sandstone interval. **b** Transition from the lower sandstone to the limestone bonebed. **c** Wackestone of lumps with a fossil bone (*white arrow*). **d** Filaments of undifferentiated algae or microbes at the top of the limestone bonebed. **e** Small gastropods at the top of the limestone bonebed. **f** View of the surface of the bonebed with abundant gastropods. *Scale bar 1 mm*

with descriptions of complete material from the Germanic Basin (e.g., Rieppel and Wild 1996), and because of their size—pachypleurosaurs are generally, but not always, considerably smaller.

The placodont osteoderms are mainly isolated fragments with numerous polygonal bony plates. Placodont teeth are common in bed VR-13, characterized by the typical broad and flattened morphology with well-preserved enamel.

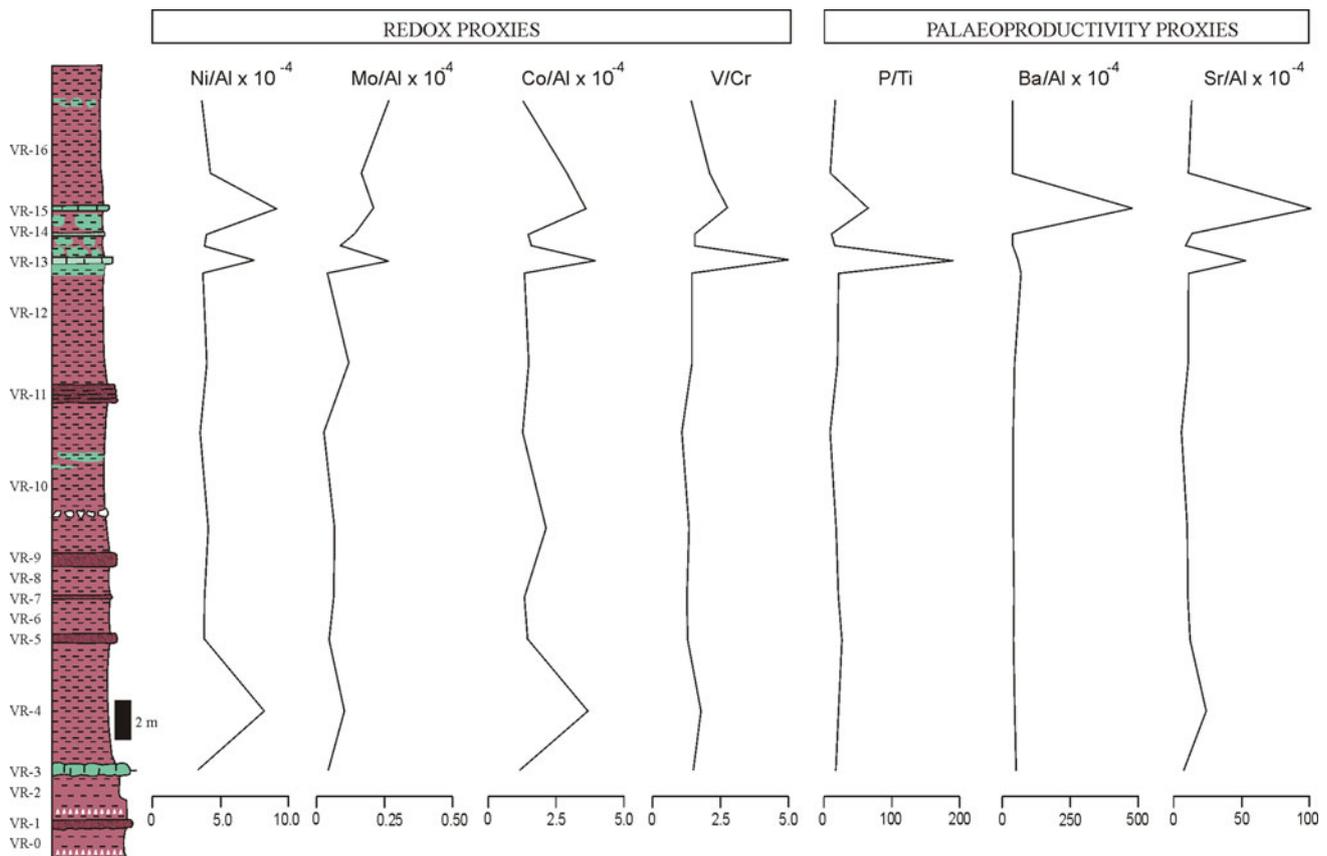


Fig. 8 Stratigraphic distribution of redox and paleoproductivity proxies in the Villarodrigo section

The fossil bones are preserved primarily as francolite with local malachitization and pyritization (Fig. 10e–g), concentrated in the inner parts of the bone remains. The analysis of SEM images of six fragments of different bones indicates strong mineralization of the remains with absence of original bone structure. The francolite crystals are smaller than $0.5 \mu\text{m}$ and the structure is cryptocrystalline. The appearance is compact and dense, with thin laminae of calcite and locally bunches of acicular francolite crystals infilling cylindrical cavities.

Fish remains are not preserved in the studied deposits (including analysis of sieved samples), in spite of the fact that Niemeyer (2002) found in the Muschelkalk facies of the Hornos-Siles Formation some remains corresponding to the orders Selachii, Palaeoniscoidea, Subholostei, and Crossopterygii.

In the Villarodrigo sector, level VR-13 presents a dense accumulation of well-preserved small gastropods on the top surface.

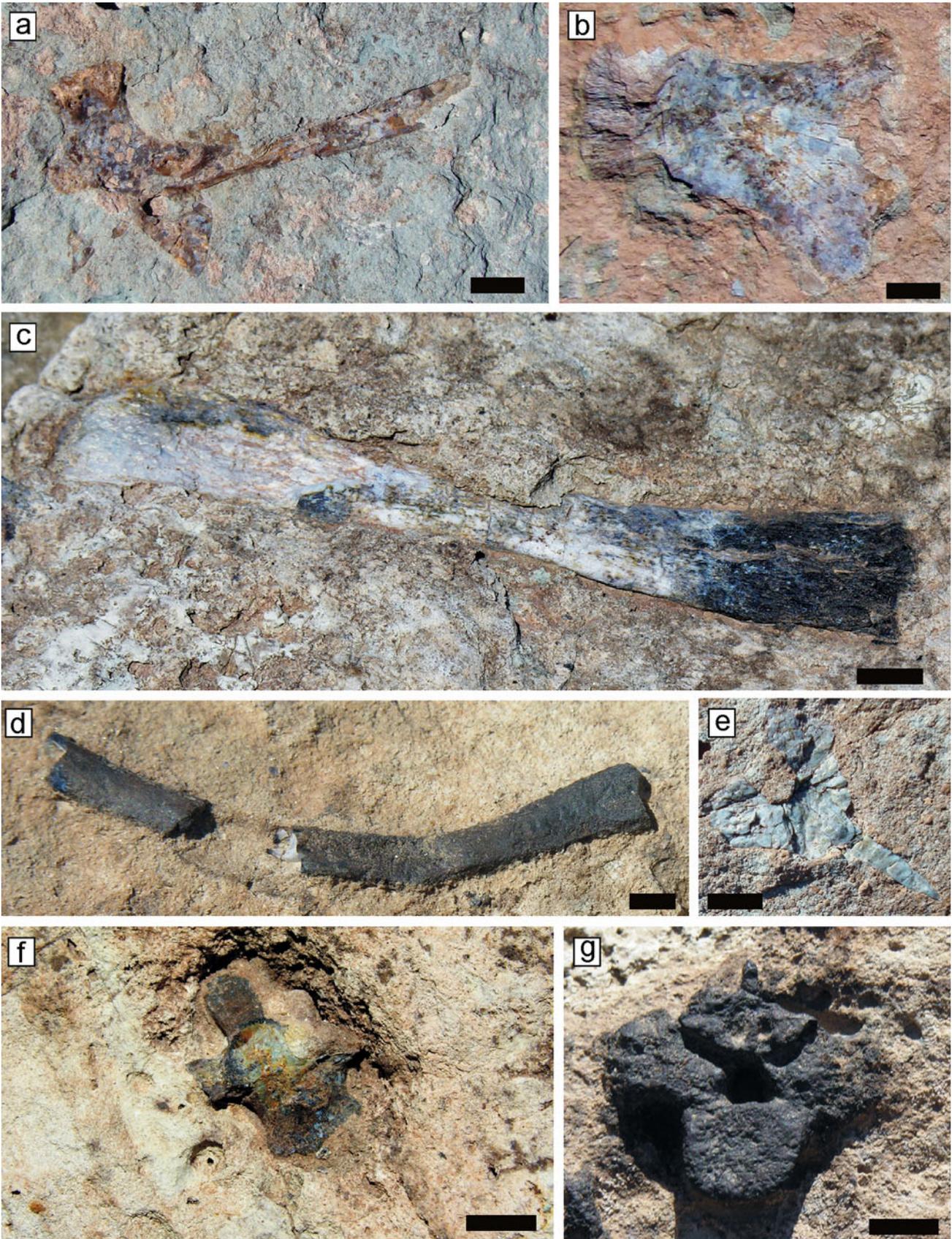
Interpretation

The record of nothosaur fossil remains suggests the sediments are no later than Carnian, because this clade became

extinct by the end of the Carnian. In this sense, Hagdorn and Rieppel (1999) demonstrated that certain marine reptiles can be useful index fossils.

The sedimentary structures noted in the lower grey sandstone at different outcrops indicate high-energy conditions of deposition. These sedimentary structures are typical of storm deposits and indicate that the bed was deposited in a single episode, probably associated with an exceptional storm (hurricane) or a tsunami producing the flooding of a coastal plain developed in the Tabular Cover.

Fig. 9 Isolated bones of marine reptiles from the Chiclana de Segura Formation (Middle Triassic) of the Villarodrigo (a–c, e) and Las Atalayas sections (d, f, g) in the Puente Génave-Villarodrigo area, eastern Jaén Province, SE Spain. Vertebrae (a, b, e–g), a limb bone (c), and a rib (d) of a nothosaur, all as preserved in the rock. **a** Neural arch of a dorsal vertebra in right lateral view, with the prezygapophysis to the right, part of the centrum below, and an elongate element, possibly the neural spine of *Nothosaurus (mirabilis* clade; H. Hagdorn pers. comm.). **b** Lateral view of a vertebral neural spine. **c** Limb bone, most likely a femur (it is not a nothosaur humerus, as they are generally short and broad). **d** Rib from the mid-thoracic region showing pachyostosis (infilling of pore spaces to create extra weight). **e–g** Three vertebrae, one in cross section (e), showing the neural spine pointing down, another (f) showing parts of the centrum and neural arch, and one (g) showing the posterior view of the massive centrum, transverse processes, and postzygapophyses, with the neural spine broken off. All scale bars 10 mm





◀ **Fig. 10** Isolated bones of marine reptiles from the Chiclana de Segura Formation (Middle Triassic) of the Villarodrigo section, in the Puente Génave-Villarodrigo area, eastern Jaén Province, SE Spain. **a** A rib (**a**), limb bones (**b–d**), and parts of vertebrae (**e–i**) of nothosaurs, all extracted from the rock. **a** Heavily built thoracic rib. **b** Partial femur (or humerus), with shaft and lower end damaged. **c** Possible scapula, with broken blade (*top*), and proximal end below, or a fragment of a neural arch of *Nothosaurus* with long spinal process, but identity uncertain. **d** Ischium showing the proximal end (*top*), where it contacts the ilium and pubis, and the distal flaring blade, expanding towards the mid-line where both elements contact each other. **e** Partial centrum and neural arch with malachite mineralization. **f** Vertebral centrum, split through the center with pyrite and malachite in the internal parts. **g** Centrum and probable elongate neural spine. **h** Anterior view of dorsal neural arch of *Nothosaurus* showing the right-hand square-sided transverse process complete, and the right-hand one damaged, the widely spaced prezygapophyses in the middle of each transverse process, and the midline diverging zygosphen articulation faces immediately below the neural spine (cf. Rieppel and Wild 1996, fig. 18A). **i** Neural arch of a smaller vertebra

The sedimentary structures of the lower part of the bed, the sandstones, could be related to overwash as a consequence of an exceptional storm producing a storm surge. Other examples of marine bonebeds from the Triassic of central and northwestern European continental shelves are not equivalent, because the bones were reworked in shallow settings and transported basinward by storms (Seilacher 1970; Sykes 1977; Reif 1982; Storrs 1994; Suan et al. 2012).

The sandy limestone and marly limestone located at the base of some sections (Las Atalayas sections and Villapalacios section) could be related to coastal ponds previous to the flooding event in spite of the fact that macrofossils and microfossils are absent.

The trace fossils at the base of the limestone bonebed appear to be burrows that were excavated in a firmground by an animal (arthropod?) with sturdy legs that produced longitudinal scratches in the burrow walls as it crawled back and forth. *Spongiomorpha* is a branching burrow with bioglyphed walls often found associated with major stratigraphic surfaces (Gibert and Robles 2005; Gibert and Ekdale 2010).

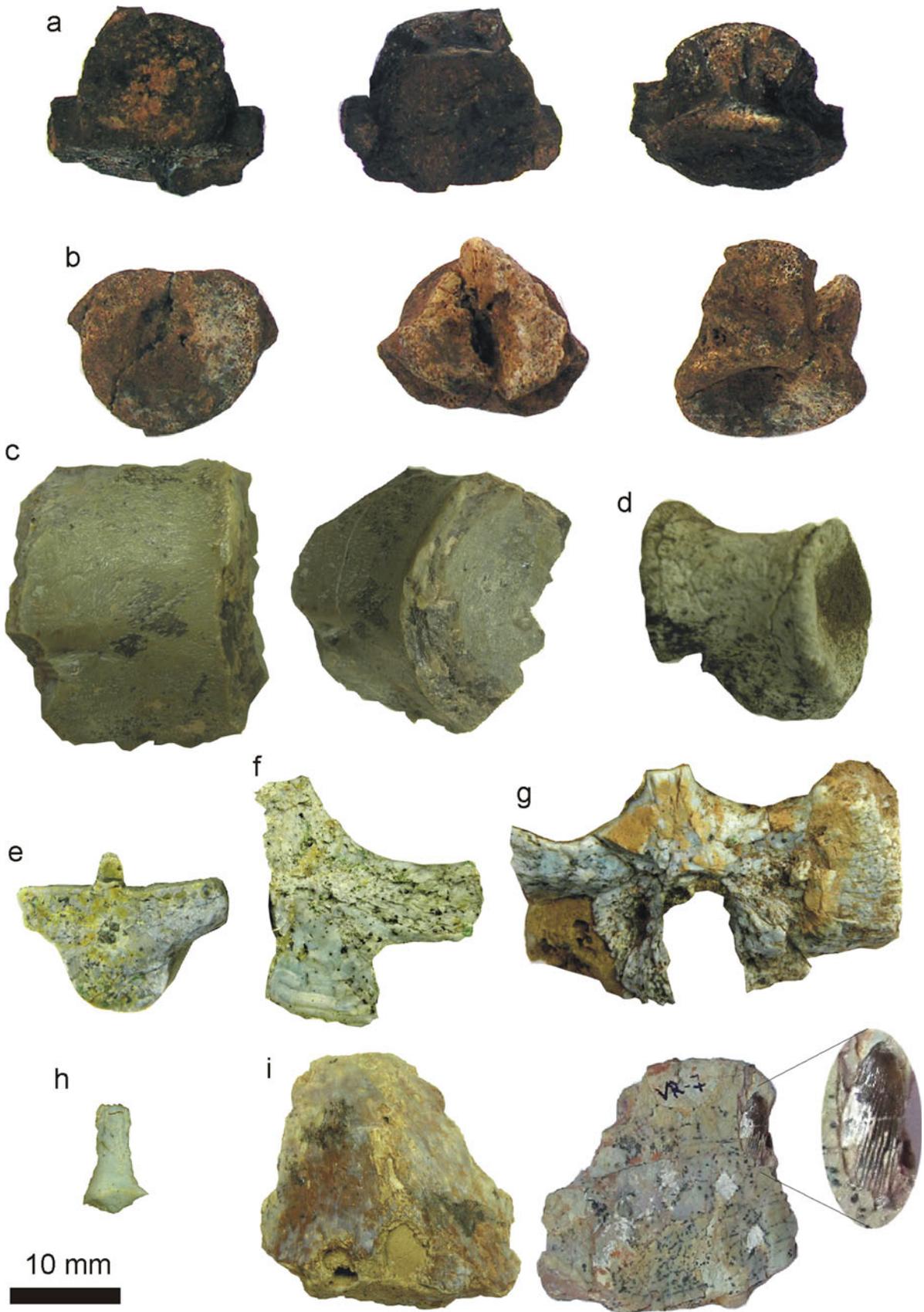
The record of marine vertebrate and invertebrate fossil remains, as well as the presence of *Thalassinoides* and *Spongiomorpha*, indicates a marine origin. In fact, these beds (VR-13 and VR-15) are the only open-marine deposits recognized in the whole of the Villarodrigo section and in other outcrops in the Tabular Cover in the lower part of the Chiclana de Segura Formation. The fragmentation, disarticulation, and dispersion of the bones and the imbrication of bioclasts are consistent with a high-energy event. The presence of vertebrate remains with signs of abrasion and fragmentation as a result of pre-fossilization is, according to Hagdorn and Mutter (2011), a key characteristic for

considering the bed VR-13 as a bonebed *sensu stricto*. The accumulation of bones in a horizon at the top could be related to the hydrodynamics of the currents. The bones were transported, in some cases probably exhumed from the sea bottom, by the currents and accumulated in this bed in some localities. This was favored by the different density of bones (porous structure) compared with lithoclasts. This explains why bones are the largest components in the rock because they could perhaps have been transported further than rocks of similar size. Moreover, the topography of the flooded terrains affected the current dynamics and the concentration of the bones in some outcrops.

Therefore, both the grey sandstone and the limestone are interpreted as marine deposits representing a high-energy event, and they record an exceptional marine flooding event in a distal fluvial environment. Storm deposits are typical in marine, epicontinental carbonates of Muschelkalk facies in the Betic Cordillera (Siles and Cehegín Formation; Pérez-Valera and Pérez-López 2008; Pérez-López and Pérez-Valera 2012), but they had not been described from the Tabular Cover.

The stratigraphic evolution of the elemental ratios in the lower part of the Chiclana de Segura Formation (Fig. 8) reveals two significant variations in redox conditions and palaeoproductivity at the top of the Villarodrigo section, coinciding with the two limestone levels (VR-13 and VR-15). The abrupt increases in the Ni/Al, Mo/Al, Co/Al, and V/Cr ratios indicate a strong fluctuation in redox conditions. These geochemical proxies are congruent with the transition from oxic conditions characterizing fluvial deposits to comparatively oxygen-poor marine conditions (drowning-pools or lagoons). The drowning of the wide coastal plane by the flooding event resulted in the formation of pools with thinly laminated sediment and absence of water circulation and oxygen replenishment. This high-stress environment was favorable for colonization by r-type strategists. Accordingly, the dense accumulation of small gastropods at the top of the unit is interpreted to reflect the colonization of dysoxic and probably brackish waters by opportunists. The pyrite and malachite in the inner parts of the bones (Fig. 10) could be congruent with reducing conditions at the bottom and in the pore water. A similar interpretation has been made in other cases where pyrite has accumulated within the pore spaces of fossil bones (e.g., Wings 2004; Shapiro and Spangler 2009; Danise et al. 2012), in some cases interpreted as evidence of bacterial activity.

The paleoproductivity proxies indicate higher values in the limestone beds, which supports their marine origin. The opportunistic behavior reflected in the accumulation of small gastropods is related to nutrient input and oxygen-restricted conditions, whereby nutrient increase favors proliferation of r-type strategists. Moreover, the nutrient



◀ **Fig. 11** Isolated bones of marine reptiles extracted from the rock from the Chiclana de Segura Formation (Middle Triassic) at the Las Atalayas (a, b) and Villarodrigo sections (c–i), in the Puente Génave-Villarodrigo area, eastern Jaén Province, SE Spain. Different views of almost complete vertebral centra possibly of a nothosaur such as *Simosaurus*, with slightly concave articulation facets (a, b). Fragments of vertebral centra (c–e), incomplete neural arches (f, g), a dorsal spine (h), and a partial jaw (i). The jaw of a nothosaur or pachypleurosaur with a tooth emerging from the bone (see detail of the image). The tooth is probably unerupted, and is visible because of the breakage; it shows deep, straight longitudinal grooves, running from near the tip down the length of the visible portion of the crown; the unerupted tooth tip being smooth

level could be increased by strong currents, which reworked the bottom sediment during the short-lived transgression.

Conclusions

The studied unit, composed of a sandstone and a limestone bed rich in bones, represents a marine flooding event of a fluvial-coastal system developed during the Triassic (red beds) in the Tabular Cover of the Southeastern Paleomargin of Iberia.

The lower part of the studied event unit is a sandstone with rare remains of marine reptiles. The sedimentary structures are typical of high-energy conditions, and indicate final deposition in a single episode, probably related to a storm surge or a tsunami.

The upper part of the studied event unit is a limestone bed with common trace fossils and abundant fossils of marine reptiles, in some outcrops comprising a bonebed. The bones are mainly located at the top of the bed and consist of isolated and fragmented pieces of nothosaurs, and secondarily pachypleurosaur and placodonts. The top of this bed contains a shell bed of well-preserved small gastropods. This bed is interpreted as deposited in drowning-pools with a thin sheet of water (few decimeters). The redox proxies and the taphonomy of the bones (with pyrite in the inner parts) corroborate this interpretation and the absence of water circulation and oxygen replenishment. The proliferation of small gastropods at the top of this bed is related to high-stress conditions.

Above the limestone, sedimentation continued with red siltstones and sandstones. This unit constitutes the only open-marine deposit recognized in the Tabular Cover. The fragmentation, disarticulation, and dispersion of the bones and their imbrication are consistent with a high-energy event that favored the accumulation of bones according to their size and density.

Storm deposits are typical in marine, epicontinental carbonates of Muschelkalk facies in the Betic Cordillera (Siles and Cehegín formations), but they had not been

described before in the inland basin represented by the Tabular Cover.

This bone-bearing marine event bed is a distinctive feature of the monotonous continental Triassic deposits of the Tabular Cover, and therefore it is a valuable tool for regional correlation. The importance of this bed is higher, taking into account the abundance of marine reptile remains since they are the only vertebrate remains recorded in Triassic rocks from the Tabular Cover and the External Zones of the Betic Cordillera of southern Spain.

Acknowledgments This research was supported by Projects RYC-2009-04316 (Ramón y Cajal Program), P08-RNM-3715 (Junta de Andalucía), UJA2011/12/17 (Universidad de Jaén-Caja Rural de Jaén), CGL2009-10329, and the RNM-200 group (Junta de Andalucía). We are grateful to Gloria Jodar (Centro de Estudios Sierra de Segura) for assistance in the first field work, and Prof. Jordi María de Gibert (Universidad de Barcelona) and Prof. Tony Ekdale (University of Utah) for advice on the trace fossils. We are grateful to Dr. Fernando García for discussions on sedimentology. We are also enormously grateful to reviewers Alberto Pérez-López and Hans Hagdorn as well as the editor Franz T. Fürsich for their corrections and comments.

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