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ORIGINAL ARTICLE

# Buildings that 'Speak': Ichnological Geoheritage in 1930s Buildings in Piazza della Vittoria (Genova, Italy)

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**Abstract**

The geoheritage value of sedimentary building stones has mainly focused on physical sedimentary structures and body fossils. By contrast, little attention has been placed on the geoheritage significance of ichnofabrics, which are the sedimentary fabrics that have been reworked by organisms. This study aims to fill this gap by analysing the ichnofabric found on the buildings of Piazza della Vittoria, in Genova (Italy). Here, unusually visible and well-preserved specimens of the fossil burrow *Bichordites* are observed on the historical buildings designed by Marcello Piacentini, one of the local most prominent architects of the 1930s. The *Bichordites* of Piazza della Vittoria are winding meniscate burrows with a central string-like structure. Here, we interpret this ichnofabric as the result of the activity of a community of echinoids bioturbating a sand wave system. We have also located the historical quarry that provided material for the studied buildings with the same ichnofossils exposed. Surprisingly, the cuts on display on the buildings are much nicer than those in the outcrops and more taxon specific characteristics can be observed just on the tiles rather than in the field. For all these reasons, the geoheritage value of the Piazza della Vittoria ichnofabric relies in its unique scientific significance, the cultural value, and its potential future applications in research, teaching, urban geotourism and reference site.

**Keywords** Building stones · Dimension stones · Ichnology · Palaeontology · *Bichordites* · Ichnofabric

## Introduction

> "Architecture is a visual art and the buildings speak for themselves"
>
> – Julia Morgan, architect

Since Neolithic times, humankind has strongly relied on rocks to create buildings, structures and sculptures (Pereira and Marker 2016). As such, building stones are fundamental elements of cultural landscapes worldwide, being recognized as heritage features under the cultural, historical, archaeological, architectural and aesthetical perspective (Brocx and Semeniuk 2019; Todaro 2019). In addition, building stones can be of geoheritage significance in that they (1) manifest features important to the geological sciences in education and research, (2) raise the consciousness of the public and (3) are rare or of major historical/cultural value (Brocx and Semeniuk 2019).

In sedimentary building stones, any of these heritage aspects is intimately linked to fabric and colour, both of which commonly depend on the biophysical processes acting in the depositional environment. For instance, weathering of iron minerals in a semi-arid depositional environment is responsible for the red colour of the Exeter Castle (UK) and Silves Castle (Portugal), built with the Permian-Triassic New Red Sandstone (Building Stones Database 2020) and the Late Triassic "Grés de Silves", respectively. Lisegang rings are

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spectacular diagenetical features of the Late Cambrian Umm Ishrin sandstones where the city of Petra was built (Seilacher 2008). Permian winds originated the cross-laminated fabric of the building stone used for the Wribbenhall Railway Viaduct (UK) (Building Stones Database 2020). The eighteenth-century fountain in Piazza Unità (Trieste, Italy) bears abundant fossil of Cretaceous rudists; this provides a 'blooming' aspect to the building stone, which is indeed known as 'Flowery Aurisina' ('Aurisina Fiorito'). Several other examples of the geoheritage importance of fossil-bearing building stones have been described worldwide (e.g., Robinson 1993, 1997; Silva and Cachão 1998; Cachão et al. 1999; Gaffikin 1999; Sutherland 2000; Pätzold 2002; Fernandes and Corrêa 2007; Fernandes et al. 2008; Silva 2009; Palacio-Prieto 2014; Rodrigues et al. 2014).

Whilst physical sedimentary structures and body fossils are widely recognized as determinants of the fabric of sedimentary building stones, the role of biological reworking (bioturbation) is almost ignored. Bioturbation can take several forms, including tunnels created by burrowing trilobites (Neto de Carvalho and Baucon 2016), trails produced by insects (Minter et al. 2007), displacement of soil by plant roots (Alonso-Zarza et al. 2008) and footprints left by dinosaurs (Mateus and Milan 2009). Bioturbation tends to replace the primary fabric of sediment by the ichnofabric, the overall fabric of a sediment that has been reworked by organisms (Taylor et al. 2003).

In the context of geoheritage, there is little and sparse reference to ichnofabric-bearing building stones. This is surprising because ichnology, the study of life-substrate interactions, is explicitly cited in the landmark paper of Brocx and Semeniuk (2007) about the history, definition, scope and scale of geoheritage. A prominent exception are the flagstones of the cities of Araraquara and S. Carlos, Brazil (Fernandes and Corrêa 2007; Fernandes et al. 2008). Sandstones from the Botucatu Formation were quarried since the beginning of the twentieth century; only in Araraquara 585 trace fossil-bearing flagstones, including tracks of dinosaurs, early mammals and insects, were identified and protected under Municipal Law (Francischini et al. 2020). Another example is the case of at least seven villages of the mountain area of Sierra de Peña de Francia, near Salamanca (Spain), with special emphasis to Monsagro, where the inhabitants has selectively collected since the middle twentieth century rock slabs from the Lower Ordovician Armorican Quartzite covered by trilobite burrows (*Cruziana*) and other trace fossils to decorate façades, streets, communal fountains and even the walls of the church (Martínez-Graña et al. 2016; Gutiérrez-Marco et al. 2019). The application of *Cruziana* slabs in the decoration of public buildings can be found nowadays in Portugal in some villages from Central Portugal, including Penha Garcia, Matagosa and the isolated Chapel of 'Nossa Senhora dos Matos' (Neto de Carvalho and Cachão 2005).

Despite these prominent examples, the study of ichnofabrics in building stones has been ignored not only in the field of geoheritage, but also in the field of ichnology itself. Exceptions are few, and sparse in time. For instance, one of the earliest published reports of trace fossils in building stones is that of Shrock (1934), briefly describing worm-like trace fossils from the building stones of Wisconsin, USA; these ichnofabric-forming traces were recently attributed to the ichnogenus *Neoeione* by Boyd and McIlroy (2018). Some of the best-known exceptions are represented by the research on the Spanish ornamental stone known as *Bateig Fantasia* Stone, which bears abundant echinoderm burrows (*Bichordites*) (Bland et al. 2001; Gibert and Goldring 2007, 2008). A new genus and species (*Lapillitubus montjuichensis*) of fossil burrow has recently been detected in the building stones of the modernist architecture of Barcelona (Belaústegui and Belaústegui 2017; Belaústegui et al. 2018). It should be noted that building stones can also foster studies on vertebrates, as shown by the dinosaur tracks reported from the 1930s bridges of the Gettysburg National Military Park, USA (Kenworthy and Santucci 2006).

This study aims to fill these gaps by analysing the ichnofabric found on the buildings of Piazza della Vittoria, Genova, Italy. Here, remarkably visible and well-preserved specimens of the trace fossil *Bichordites* can be observed on the historical buildings designed by Marcello Piacentini, one of the most prominent starchitects of the 1930s. In light of these observations, the goal of this paper is to answer the following research questions:

1) What is the behaviour and palaeoenvironment corresponding to the Piazza della Vittoria ichnofabric?
2) Why the architect Marcello Piacentini used ichnofabric-bearing rocks as building stones in the Piazza della Vittoria?
3) What is the geoheritage value of the Piazza della Vittoria ichnofabric?
4) What is the extraction site of the ichnofabric-bearing building stones?

## Materials and Methods

This paper examines the ichnofabric preserved in the building stones of Piazza della Vittoria, Genova, Italy (N 44° 24′ 11″, E 8° 56′ 40″) (Fig. 1) and those of 'Cava Vecchia' ('Old Quarry', N 44° 9′ 44″, E 8° 19′ 2″; Verezzi, SV) (Fig. 2). The ichnofabric-bearing building stones have been sedimentological and ichnologically described on a cm-scale in March 2019 and January 2020. Bioturbation intensity was quantified using the bioturbation index (BI), the grades of which are BI 0 (no bioturbation), BI 1 (1–4% bioturbation:


**Fig. 1** The urban study site: Piazza della Vittoria. **a** Location of the buildings bearing the fossil burrow *Bichordites*. Dashed lines indicate the borders of Piazza della Vittoria. Legend in Fig. 2a. The map is based on OpenStreetMap data. **b** Pillars with a dense *Bichordites* ichnofabric and the arch located at the center of Piazza della Vittoria. Shadows and highlights have been adjusted with the open source software GIMP to reproduce a wider range of luminosity

sparse), BI 2 (5–30% bioturbation: low); BI 3 (31–60% bioturbation: moderate); BI 4 (61–90% bioturbation: high); BI 5 (91–99% bioturbation: intense); and BI 6 (100% bioturbation: complete) (Reineck 1967; Frey and Pemberton 1985; Gingras et al. 2011). Width of 14 specimens was measured using a ruler. The studied ichnofabric was photographed and georeferenced using a camera with integrated GPS (Nikon AW-100).

The same approach was followed during fieldwork, which was carried out at the quarry known as Cava Vecchia (Fig. 2a). The field site was selected because it is the most likely extraction site of the ichnofabric-bearing building stones of Piazza della Vittoria. This is demonstrated by historical documents (dossier n.19/36 and 49/37 Archivio Storico di Genova) reporting that the architect Marcello Piacentini used an ornamental stone from the surroundings of Finale Ligure. In this area, the only geological unit with the characteristics of the ichnofabric-bearing building stones is the Finale Ligure Limestone. Based on existing literature about this unit (Bonci et al. 2019a, b), the ichnofabric-bearing building stones present the same texture, colour, and body fossils of the Verezzi Member of the Finale Ligure Limestone. This unit crops out in a very restricted area (less than 2 km$^2$; Fig. 2b), within which Cava Vecchia is the largest historical quarry.

The stratigraphic succession exhibited in the study area comprises the Verezzi Member (Miocene; Langhian-Serravallian) of the Finale Ligure Limestone (Aquitanian-Serravallian) (Fig. 2). Three thin sections were realized from rock samples and observed at the petrographic microscope (Leitz Laborlux 12 Pol) and at the stereomicroscope (Exacta+Optech GZ808). In this paper, we use the building stone nomenclature listed in Table 1.

## Geologic, Architectonic and Historical Setting

### Historical and Architectonic Setting

Piazza della Vittoria has been designed by Marcello Piacentini, who won the first public concourse (1923) for the project of a new, modern square in Genova and a commemorative altar for the World War I fallen soldiers (Cevini 1989; Balletti and Giontoni 1990; Brancucci and Spesso 2016). Because of many contrasts between local administration, genoese architects, local building companies and the central government, the realization works had been delayed and started in the 1930s (Cevini 1989; Balletti and Giontoni 1990;

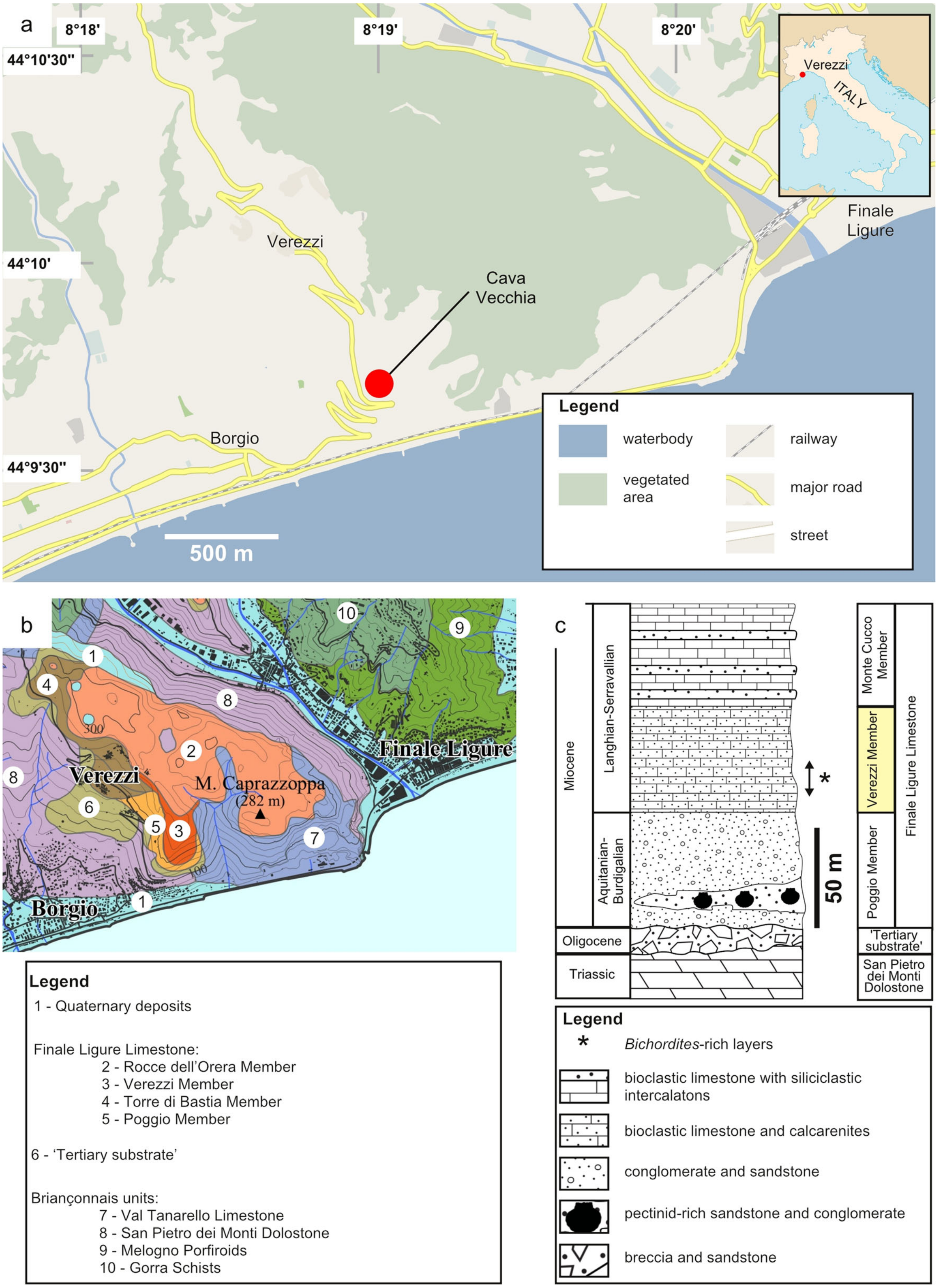


**Fig. 2** The field study site: Cava Vecchia. **a** Location of the study site. **b** Geological map of the study site and its surroundings. In the pictured area four of the five members of the Finale Ligure Limestone crop out. Modified from Bonci et al. (2019a). **c** Stratigraphical scheme of the field study site. Scheme based on Boni et al. (1968). The studied unit (Verezzi Member) is highlighted. It should be noted that in the study site three of the five members of the Finale Ligure Limestone crop out

**Table 1** Definitions of the major building stone terms used in this paper

| Term | Definition | Reference |
|---|---|---|
| Building stone | A general, nongeneric term for any rock suitable for use in construction | Neuendorf et al. (2005) |
| Cladding slab | Thin slab of stone used as external, non-load-bearing covering to building structure | McMillan et al. (1999); Primavori (2004) |
| Dimension stone | Building stone that is quarried and prepared in regularly shaped blocks according to specifications | Neuendorf et al. (2005) |
| Efflorescence | Product of the crystallization of substances, generally with a whitish colour and powdery/stringy appearance on the surface of a stone artefact | Primavori (2004) |
| Flagstone | Fissile, micaceous laminated sandstone, suitable for roofs and pavements | McMillan et al. (1999) |
| Ornamental stone | Generic term embracing all natural stones that can be used as ornamental material essentially with cladding and coverage functions, subordinately with structural functions | Primavori (2004) |
| Pillar | Free-standing vertical block of stone, circular or polygonal in plan | McMillan et al. (1999) |

Brancucci and Spesso 2016). The definitive project consisted in a square surrounded by six buildings with the memorial altar in the geometric centre. All the design and construction phases were supervised by Piacentini, but there were also other architects who contributed at the modern square design: Beniamino Bellati, Aldo Camposampiero, Cristoforo Ginatta and Giuseppe Tallero (Cevini 1989; Balletti and Giontoni 1990; Brancucci and Spesso 2016).

The ichnofabric-bearing building stones are here identified as Pietra di Verezzi ('Verezzi Stone', also known as Pietra Lara), which is the commercial name given to a type of Pietra di Finale dimension stone s.l. (Bonci et al. 2019b). From a stratigraphic perspective, the Pietra di Verezzi belongs to the Verezzi Member of the Finale Ligure Limestone.

## Geologic Setting

The Finale Ligure Limestone crops out in a very limited area (approximately 5 $km^2$) of the Ligurian Alps (Italy), comprising the towns of Verezzi, Finale Ligure, Calvisio and Boragni. Following Vanossi et al. (1984) and Giammarino et al. (2002), the Finale Ligure area is largely dominated by tectonic units of the Briançonnais Domain (upper Carboniferous—upper Jurassic in the study area). According to the same authors, these units are unconformably overlain by post-orogenic to recent sedimentary deposits, among which the Finale Ligure Limestone and its 'Tertiary substrate'. The Finale Ligure Limestone Formation has been formally established by Boni et al. (1968) and accepted by Dallagiovanna et al. (2011); Brandano et al. (2015) replaced the formal 'Finale Ligure Limestone Formation' with the informal unit 'Pietra di Finale Formation' and provided more refined age for this unit. According to Boni et al. (1968), the Finale Ligure Limestone is transgressive on the Tertiary substrate or directly on the Briançonnais units.

The Finale Ligure Limestone Formation is approximately 150-m thick and is dominated by bioclastic limestone facies. The fossil content of the Finale Ligure Limestone is abundant and includes corals, bivalves, brachiopods, echinoids, shark teeth, foraminifera and codiacean and coralline algae. In this paper, we follow the stratigraphic nomenclature of Boni et al. (1968) because it is correctly formalized, whereas 'Pietra di Finale' is a name pertaining to trade, historical/archaeological and touristic context. Therefore, in this work, we follow the nomenclature of Boni et al. (1968) and the biostratigraphical dating of Brandano et al. (2015). Accordingly, the Finale Ligure Limestone is formed, from bottom to top, by five members:

1. Poggio Member (about 60-m thick; Aquitanian—Burdigalian): conglomerate and sandstone with minor calcarenite lenses. Bivalve fossils are abundant.
2. Torre di Bastia Member (25–70 m; Aquitanian—Burdigalian): marl, claystone and sandstone with abundant benthic and planktonic foraminifera.
3. Verezzi Member (about 50 m; Langhian—Serravallian): bioclastic limestone with frequent bivalve coquina. Calcarenite and sandstone locally found. The fossil record includes echinoids, bivalves, solitary corals, brachiopods, shark teeth and trace fossils.
4. Rocce dell'Orera Member (15–40 m; Langhian—Serravallian): bioclastic limestone with abundant siliciclastic fraction. Conglomerate and sandstone facies are also common. Fossil record includes bryozoans, barnacles, echinoids, bivalves, brachiopods, shark teeth, and rare corals, codiacean algae and benthic foraminifera.
5. Monte Cucco Member (about 200 m; Langhian—Serravallian): bioclastic limestone. Sandstone and conglomerate lenses are rare. Fossils are abundant and include corals and codiacean algae, bryozoans, barnacles, echinoids, bivalves, brachiopods, shark teeth, and rare coralline algae and benthic foraminifera.

The depositional environment of the Finale Ligure Limestone is not yet fully understood. Two major environmental interpretations have been proposed: the gulf hypothesis (Boni et al. 1968) and the mixed wedge hypothesis (Brandano et al. 2015). According to the first hypothesis, the depositional environment of the Finale Ligure Limestone was a gulf with a relatively restricted connection with the open sea. Sedimentation took place on a shallow water abrasion platform at the foot of a marine cliff. Here, carbonate sedimentation was developed, locally influenced by siliciclastic inputs from the continent. Otherwise, the mixed wedge hypothesis, which specifically focuses on the upper part of the Finale Ligure Limestone (Verezzi Member, Monte Cucco Member, and Rocce dell'Orera Member) considers the depositional setting as a mixed carbonate-siliciclastic prograding wedge where halimedaceans flourished under a constant and conspicuous terrigenous input.

The paleogeographic domain of the Finale Ligure Limestone is difficult to ascertain because its petrographic and palaeontological features differ from those of coeval units of the Tertiary Piedmont Basin (NW Italy) or of the SE France and N Corsica (Bonci et al. 2019a and references therein). However, on the basis of the modern geographic position and the tectonic setting (as discussed by Marini 1986), a Ligurian-Balearic Ocean pertinence seems to be the more reliable hypothesis.

The Verezzi Member, which is the source of the ichnofabric here investigated, consists of reddish bioclastic limestone with frequent shell coquinas; the siliciclastic fraction is subordinate (Boni et al. 1968; Bonci et al. 2019a). The fossil content includes very abundant pectinids (e.g. *Chlamys bollenensis* (Mayer-Eymar), *Aequipecten macrotis* (Sowerby), *Aequipecten malvinae* (Dubois de Montpéreux) and *Talochlamys multistriata* (Poli), abundant echinoids, rare solitary and colonial corals, brachiopods (*Terebratula* spp. and *Gryphus* spp.), oysters, small shark teeth, small benthic forams (mainly textulariids and miliolids) and fragments of halimedacean algae (Boni et al. 1968; Brandano et al. 2015; Bonci et al. 2019a). The depositional setting is interpreted to be comprised between the shoreface-offshore transition (Brandano et al. 2015).

## Results

The Piazza della Vittoria ichnofabric consists of biocalcarenites reworked by the ichnogenus *Bichordites* (Fig. 3). The host rock is reddish in colour and is frequently rich in bivalve body fossils, which are mostly represented by disarticulated and fragmented shells of pectinids. Observations at the Cava Vecchia field site indicate that the *Bichordites*-bearing layers alternate with virtually unbioturbated layers, which consist of cross-bedded biocalcarenites, or shell coquinas. Canalizations are visible and

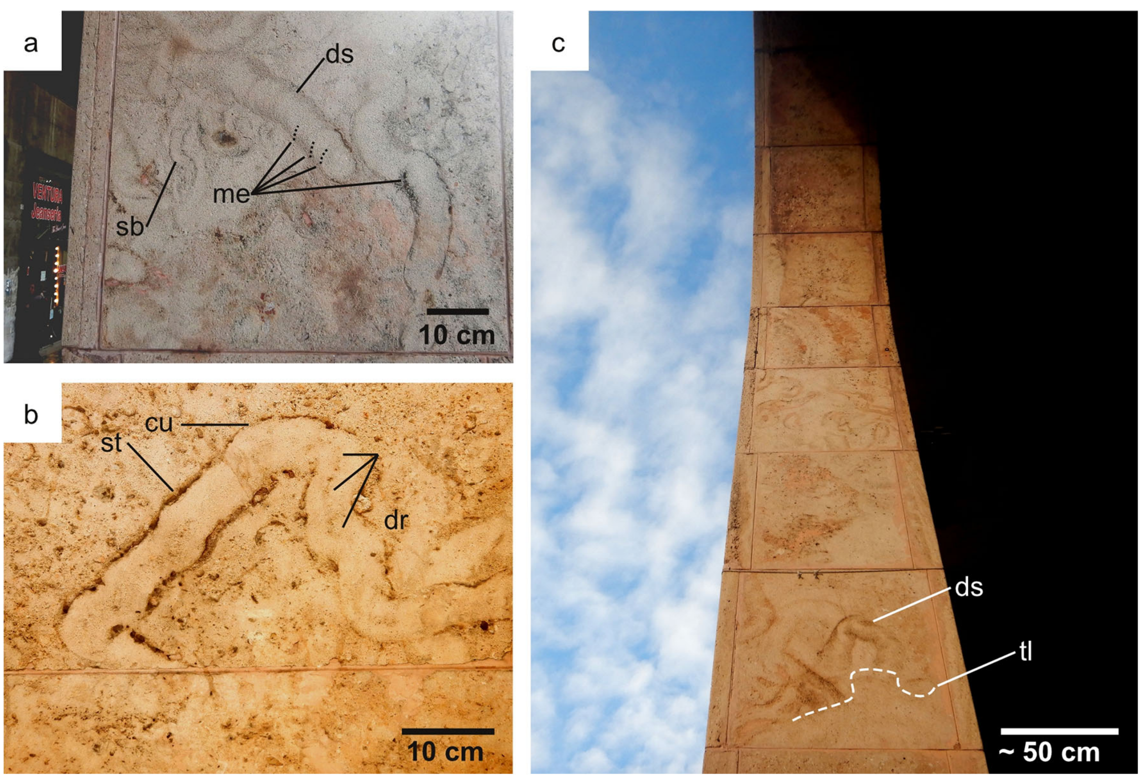


**Fig. 3** General features of the *Bichordites* ichnofabric. **a** *Bichordites* showing meniscate texture (me) and dark margins (ds). Small specimens (sb) are associated with larger ones. **b** *Bichordites* consisting of curved (cu) and straight (st) segments. Drain (dr) is visible in the central part of the structure. **c** Vertical support of an arch with numerous ichnofabric-bearing slabs. Several specimens of *Bichordites* are truncated along the same line (tl), thus suggesting an erosional episode. Sides of the traces (ds) are darker than their central parts

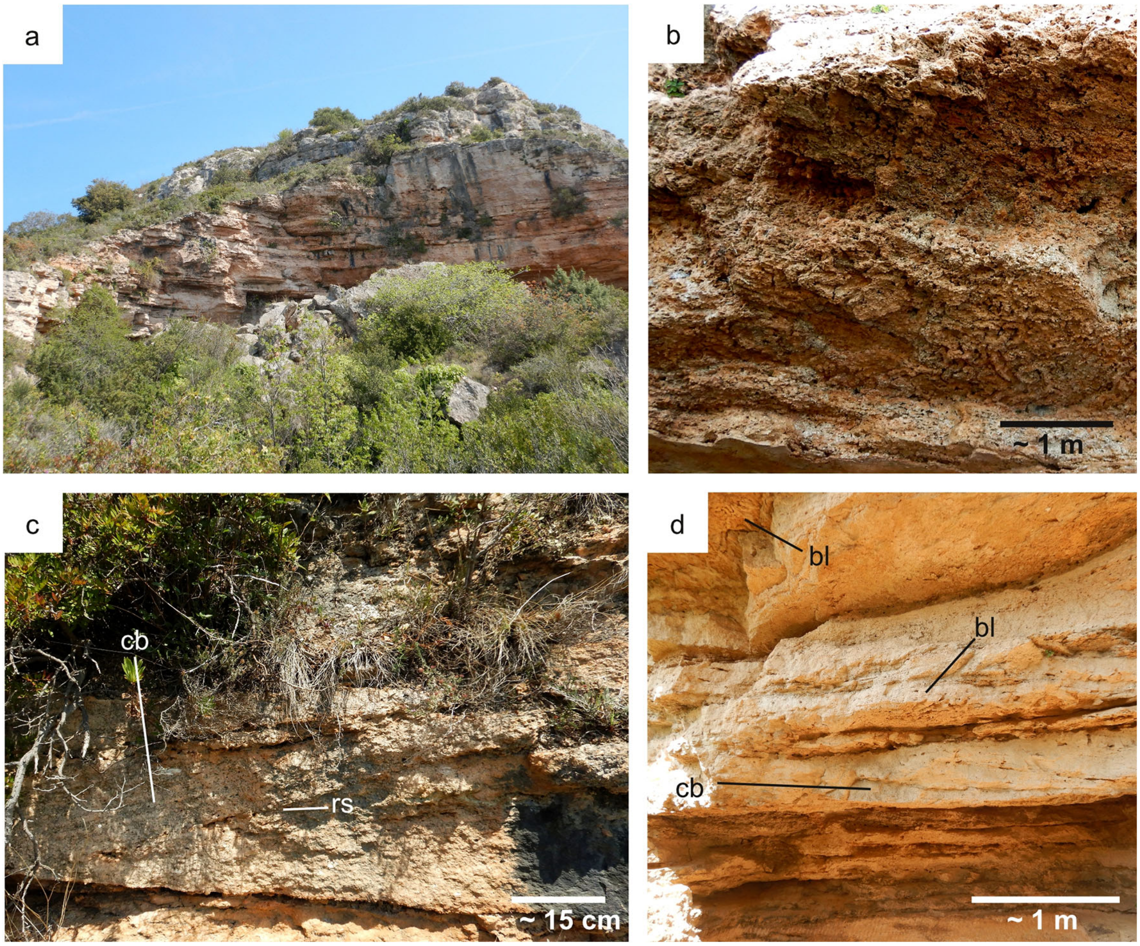


**Fig. 4** The Cava Vecchia quarry. **a** General overview of the quarry's remain. **b** Intensely bioturbated layer. **c** Planar cross-bedding (cb) with reactivation surfaces (rs). **d** Bioturbated layers (bl) and mud drapes cross-beds (cb)

are never exceeding 1.5 m in size, mud drapes are present at specific intervals and are alternating with low-angle cross stratified beds (Fig. 4). Layer thickness typically ranges between 1 and 3 m.

Thin sections of the biocalcarenites of the Cava Vecchia show a very subordinate (< 5%) siliciclastic fraction, comprising quartz, mica (biotite and white mica) and feldspars (Fig. 6). Opaque phases (oxides-hydroxides) are also common. However, sparry cement and bioclasts are largely dominant in the observed thin sections. The bioclastic fraction includes fragments of bivalves, bryozoans, solitary corals, codiacean (halimedacean?) algae, coralline algae and benthic forams. Porosity is high.

The *Bichordites* of Piazza della Vittoria are winding, coplanar burrows presenting a crudely meniscate texture (Fig. 3a). Burrow width ranges from 3.0 to 7.9 cm. Rare specimens present a central string-like structure (referred as to drain, e.g. Belaústegui et al. 2017) that cross-cut menisci (Fig. 3b). Traces appear darker at their margins, thus indicating a different texture with respect to the more central areas of the burrow (Fig. 3c). The difference in texture is also suggested by differential weathering, i.e. the margins of each specimen of *Bichordites* are normally more weathered than the rest of the trace (Fig. 5). This is observed also in the field site (Cava Vecchia).

Bioturbation intensity is typically moderate (BI3) to intense (BI5). On the horizontal plane, large bioturbated patches show sharply transitions to areas without distinct burrows (Fig. 7). The full extent of each bioturbated patch is not fully determinable from the Piazza della Vittoria specimens because of the limited size of the slabs and logs. However, field observations at the Cava Vecchia site suggest that bioturbated patches can be tens of meters wide and ca. 1–1.5-m thick. Within-patch observations suggest that individuals of the same size tend to occur together in the same bioturbated patch (size segregation), although some exceptions have been observed.

At Piazza della Vittoria, several vertical sections of *Bichordites* can be observed (Fig. 8a). In oblique sections, *Bichordites* reveals its meniscate organization and, more rarely, an apex-like structure (Fig. 8b). In transverse sections, *Bichordites* typically present hemispherical outlines (Fig. 8c). Intriguingly, thin sections show no textural contrast between *Bichordites* and its matrix (Fig. 6).

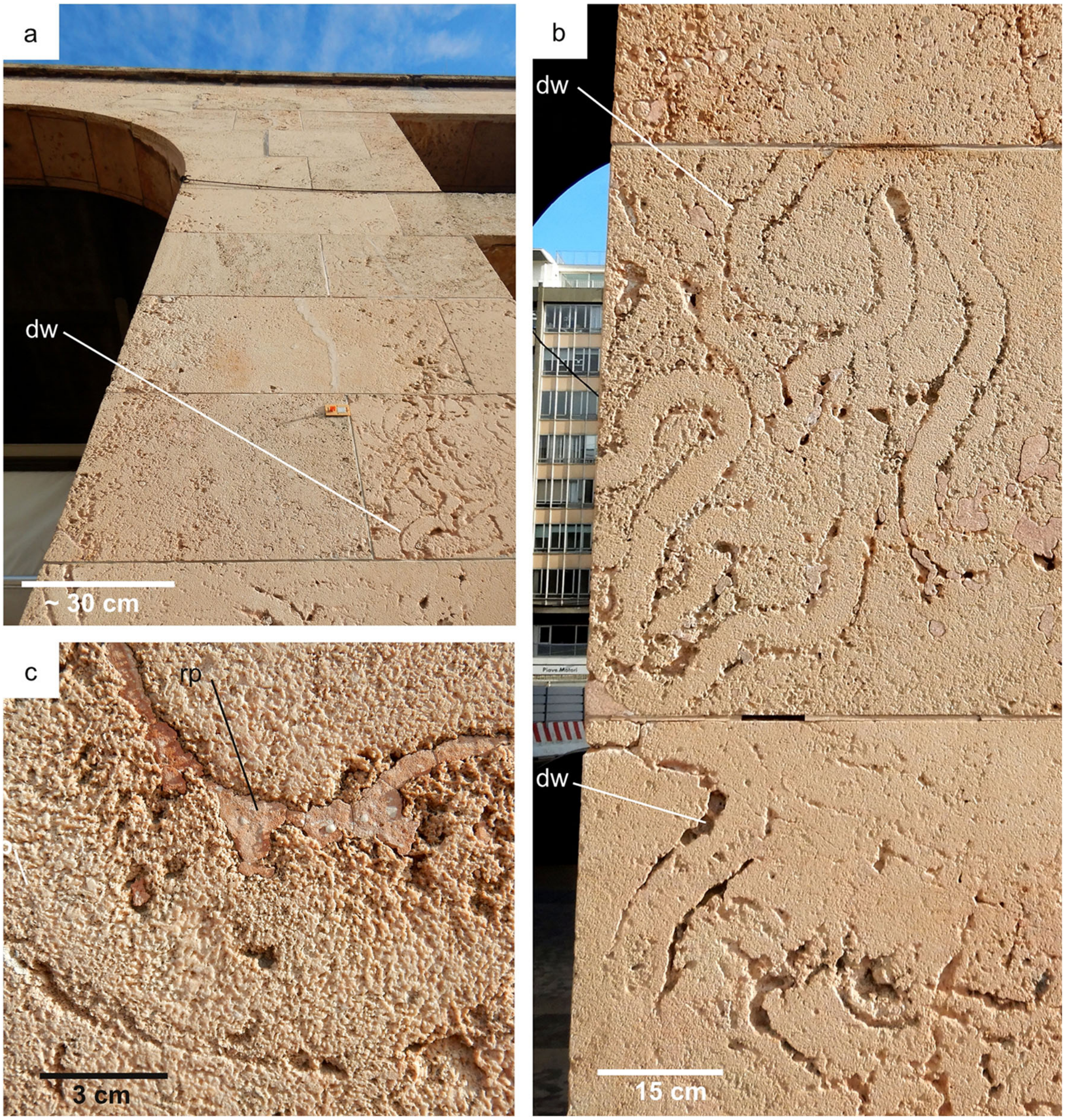


**Fig. 5** Differential weathering. The margins of *Bichordites* are selectively weathered as a result of differences in texture. **a** The *Bichordites* ichnofabric can be spotted at distance because of differentially weathered burrow margins (dw). **b** Tortuous specimens of *Bichordites* showing differentially weathered sides of the burrow (dw). **c** Differential weathering in *Bichordites* influenced conservation strategies, as shown by the parts restored with putty (rp)

The vertical distribution of bioturbation has been determined at the Cava Vecchia field site. Here, bioturbated layers (BI3–5) alternate with virtually unbioturbated cross-bedded layers (sporadically heterogeneous distribution of bioturbation sensu Gingras et al. 2011). In a single case, *Bichordites* selectively reworks a channel-like structure of metrical width, leaving the surroundings unbioturbated (Fig. 9b).

## Discussion

The results of this study show that the ichnological characteristics of Piazza della Vittoria are fully comparable with those of Cava Vecchia. However, the degree of manifestation of the trace fossils (trace fossil visibility sensu Savrda 2007) of Piazza della Vittoria is better than that of the Fossil Quarry, for which reason we placed emphasis on the Piazza della Vittoria ichnofabric. Conversely, sedimentary structures (e.g. cross-bedding) are visible in the field site only. Consequently, the interpretation that follows is based on both the urban and field site and can be applied to the Verezzi Member.

### Behaviour and Tracemaker

Most of the *Bichordites* from Piazza della Vittoria are self-avoiding winding traces, which suggests a feeding behaviour.

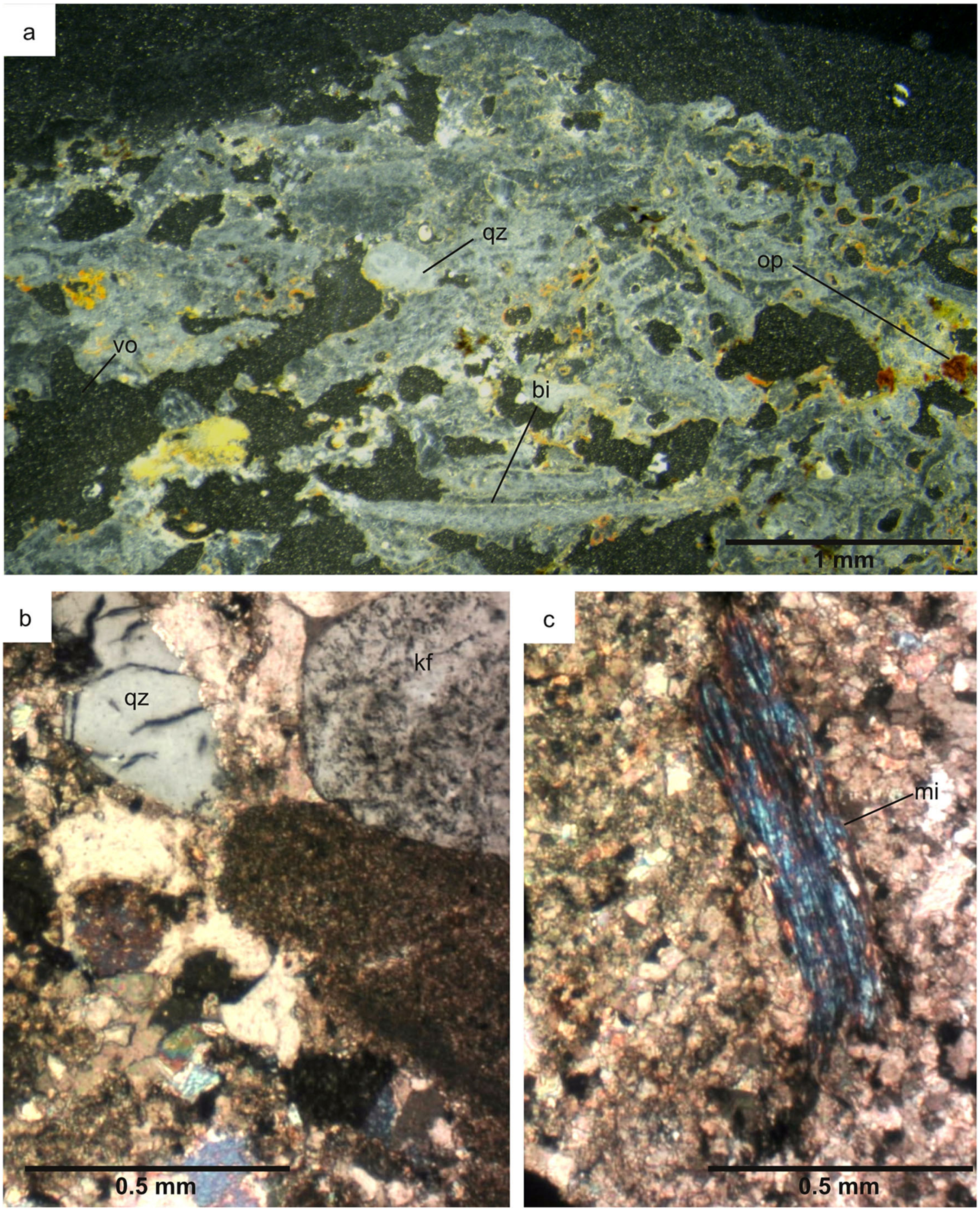


**Fig. 6** Microfacies analysis of the Verezzi member. The samples have been collected at Cava Vecchia. **a** Fill of *Bichordites* with quartz (qz), opaque phases (op, probably hydroxides) and a bivalve fragment (bi). Picture imaged at the stereomicroscope against a black background. Incident light. **b** Texture of the Verezzi member. The microphotograph shows quartz (qz) and K-feldspar (kf). Picture imaged at the polarizing microscope, transmitted light, crossed nicols. **c** Microphotograph showing white mica (mi) and sparry cement. Picture imaged at the polarizing microscope, transmitted light, crossed nicols

In fact, self-avoiding is an efficient resource-finding movement strategy because it prevents exploring areas that have been already explored (Seilacher 2007). This fits with the classical interpretation of *Bichordites* (D'Alessandro and Uchman 2007; Gibert and Goldring 2007; Nara 2013; Caruso 2015; Bernardi et al. 2019).

The *Bichordites* of Piazza della Vittoria consist of a meniscate part and, when preserved, a smaller central string.

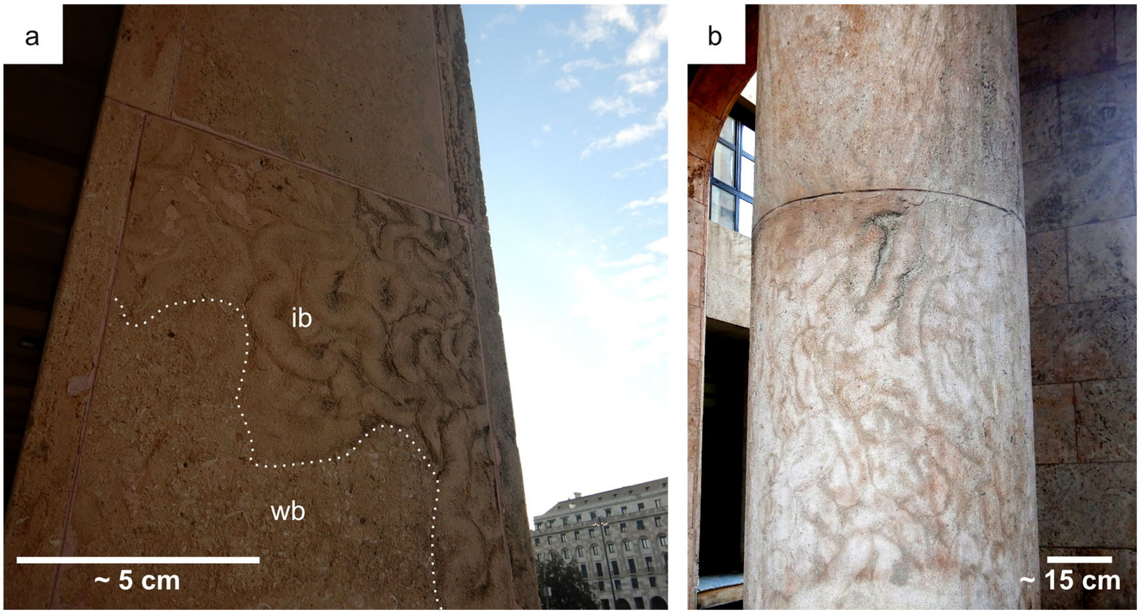


**Fig. 7** Bioturbation distribution. **a** Sharp transition (dotted line) between an intensely burrowed area (ib) and an area without distinct burrows (wb). The transition could possibly reflect a high-energy erosional event. **b** Pillar displaying an intense bioturbation intensity

Following the traditional interpretation of *Bichordites* (Gibert and Goldring 2008; Belaústegui et al. 2017), the meniscate part is the product of backfilling, i.e. the echinoid tracemaker excavated sediment in the front and then transported it to the posterior part, where it was packed with mucus. The central string corresponds to a cylindrical tube (drain) constructed to conduct water away from the burrow (Belaústegui et al. 2017). The open drain was kept behind by action of the subanal tuft spines and the corresponding tube feet (Gibert and Goldring 2008; Belaústegui et al. 2017). The presence of a single drain distinguishes *Bichordites* from the similar trace fossil *Scolicia* (Smith and Crimes 1983; Belaústegui et al. 2017).

The ichnogenus *Bichordites* is an iconic ichnogenus documented from the Palaeocene onwards (Grimmberger et al. 2013; Villegas-Martín and Guimar 2017). *Bichordites* is attributed to echinoids (Gibert and Goldring 2007, 2008), which are abundant in the Finale Ligure Limestone. Despite the abundance, the echinoid diversity of the Finale Ligure Limestone is relatively moderate and comprises a regular urchin (*Stylocidaris*) and irregular echinoids of the order Clypeasteroida (*Clypeaster*), Spatangoida (*Spatangus*) and Echinolampadoida (*Echinolampas*) (Issel 1886; Mammì 2008). Among these, *Stylocidaris* and *Clypeaster* can be ruled out as producers of *Bichordites* because their body plan is not compatible with the shape and function of the burrow. *Bichordites* has been traditionally attributed to irregular echinoids of the *Echinocardium* group and, more recently, to spatangoids of the family Maretiidae and Eupatagidae (Bromley and Asgaard 1975; D'Alessandro and Uchman 2007; Gibert and Goldring 2007, 2008; Bernardi et al. 2011; Villegas-Martín and Guimar 2017). However, no echinocardiid, maretiid or eupatagid echinoids have been found in the Finale Ligure Limestone. Therefore, the *Bichordites* tracemarkers might have been either the spatangoids or the echinolampadoids, as only those are found. Alternatively, the *Bichordites* tracemakers may have not been documented yet from the studied unit.

## Environment of the Bichordites ichnofabric

The interpretation of depositional environments is probably the best-recognized application for trace fossils (Knaust 2017). In fact, trace fossils are accurate environmental proxies because they are in situ manifestations of behaviour, which in turn depends on the prevailing environmental conditions (Frey and Seilacher 1980). Compared with body fossils, the environmental information potential of trace fossils is more specific because trace fossils are rarely transported (Taylor et al. 2003). This feature is particularly valuable for interpreting the Verezzi Member because bivalve fossils show clear evidence of transport, i.e. fragmented and disarticulated valves. When considering physical sedimentary structures alone, information can be gathered only about conditions at the time of deposition, which in many cases can be anomalous (McIlroy 2004). By contrast, trace fossils provide also information about conditions subsequent to the time of deposition. Trace fossils are particularly useful as environmental proxies in successions where sedimentary structures are poorly visible, e.g. because they have been obscured by animal or plant activity (Taylor et al. 2003). This is clearly the case of the studied succession.

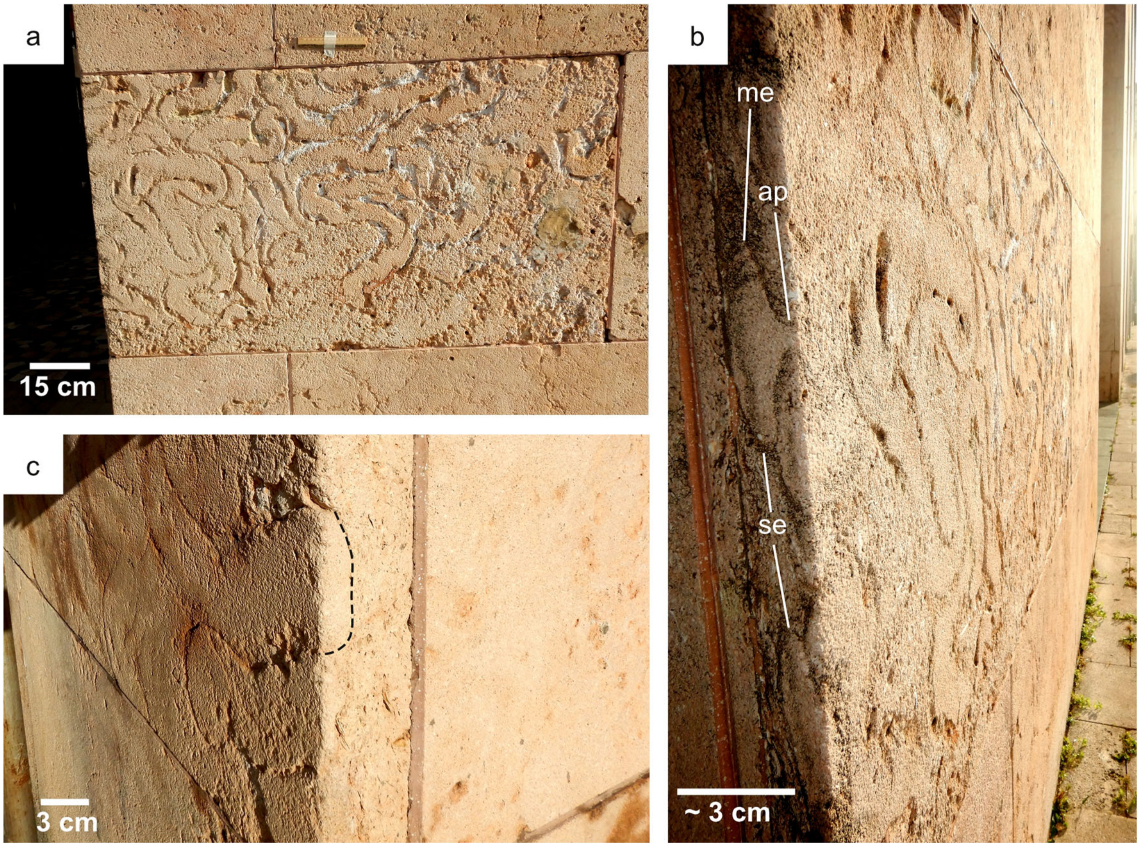


**Fig. 8** *Bichordites* in vertical section allow to study the shape in 3d. **a** Cladding slab with *Bichordites* burrows evidenced by white saline efflorescences. **b** Vertical sections of *Bichordites* (se), one of which shows an apex-like structure (ap) and meniscate organization (me). **c** Section of *Bichordites* (dashed line) where the continuity with the palaeohorizontal is well-manifested

Ichnofabric analysis is a highly effective means of documenting bioturbated sedimentary fabrics and interpreting their environment (McIlroy 2008). The characteristics of an ichnofabric depend on physical, chemical and ecological controls (grain size, sedimentation rate, oxygenation, nutrition, salinity, ethology, community structure and succession), as well as tiering and colonization style (Taylor et al. 2003). Consequently, the logic of this section is deriving the physicochemical parameters responsible for the characteristics of the *Bichordites* ichnofabric from Finale Ligure Limestone; these physicochemical conditions can suggest the depositional setting of the *Bichordites* ichnofabric, i.e. an environment in which the derived condition can coexist.

The studied ichnofabric is characterized by a single ichnofabric-forming taxon, that is, *Bichordites.* Trace fossil diversity is commonly taken to be a proxy for the degree of physicochemical stress, i.e. highly diverse ichnoassociations reflect optimal conditions, low-diversity ones suggest environmental stress (Gingras et al. 2011). Ichnofabrics with few taxa can also derive from optimal conditions and complex tiering, e.g. deep-tier structures tend to obliterate shallow-tier ones (Bromley 1996; Taylor et al. 2003). Nevertheless, there is no evidence of such processes in the studied ichnofabric. Consequently, the low diversity of the Piazza della Vittoria ichnofabric is here interpreted as a highly stressed environment in which only the *Bichordites* behaviour allowed survival.

Low oxygenation is a common source of environmental stress, but the backfilled nature of *Bichordites* allows to reject this hypothesis. Backfilling prevents a direct connection between the tracemaker and the water column; hence, it requires well-oxygenated porewaters. In the specific case of spatangoid echinoids, connection with the seafloor was only periodically maintained by constructing a vertical respiratory shaft (Gibert and Goldring 2007, 2008). A similar interpretation has been provided for the similar echinoid burrow *Scolicia* (Löwemark et al. 2006; Gibert and Goldring 2008; Uchman and Wetzel 2011; Crippa et al. 2018).

The studied ichnofabric has been produced by echinoderms, which characteristically live within narrow ranges of salinity (Benton and Harper 2009). This suggests that the Piazza della Vittoria ichnofabric was produced under normal marine salinity. This interpretation is also supported by the large size of the studied *Bichordites*, whereas reduced size is one of the most notable characteristics of brackish water ichnofaunas (Buatois and Mángano 2011; Gingras et al.

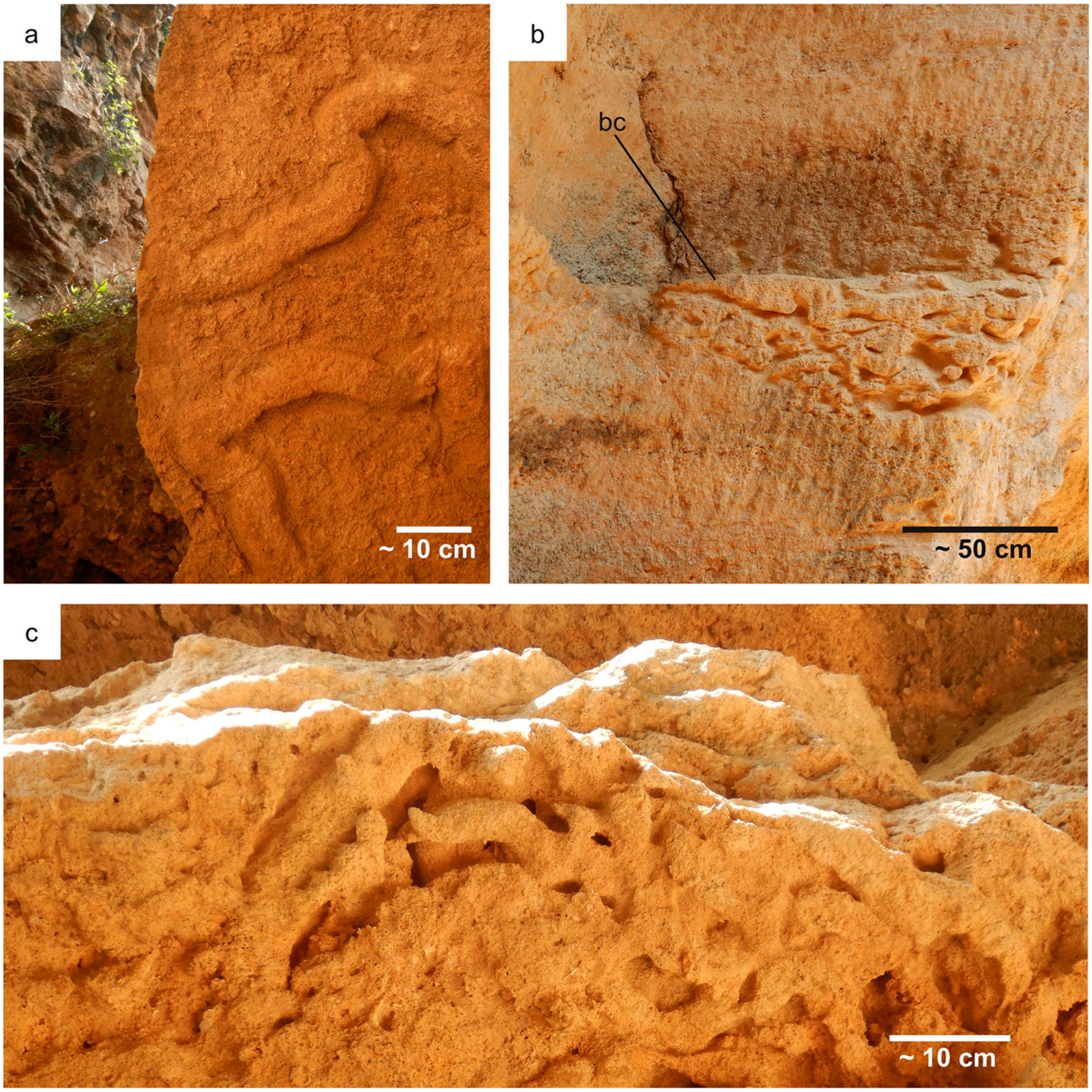


**Fig. 9** *Bichordites* at the Cava Vecchia quarry. **a** Winding specimens of *Bichordites*. **b** *Bichordites* selectively bioturbating a channel fill (bc). **c** Intensely bioturbated layer base

2011; Baucon and Neto de Carvalho 2016). Backfilling also indicates that the substrate was necessarily unconsolidated at the time of the colonization, i.e. it was a softground. Indeed, the *Bichordites* tracemaker backfilled its burrow by moving sand grains from its front to the back; this would have been clearly impossible in partially (firmgrounds) or completely (hardgrounds) consolidated substrates.

Shifting substrates explain the observed low ichnodiversity. In fact, *Bichordites* is regarded as a typical trace of highly shifting substrates (Nara 2013), which are a major source of environmental stress in benthic environments (Buatois and Mángano 2011). Specifically, shifting substrates and rapid sedimentation prevent colonization by most benthic animals, except for rapid burrowers (Nara 2013). This is the case of echinocardids, which burrow to a depth of 15 cm and could move through the sand at a speed of 6–8 cm/h (Buchanan 1966).

The present latitudinal distribution of infaunal echinoids, together with their trace fossil record, suggests the application of *Bichordites* as a palaeoclimatic proxy. Accordingly, *Bichordites* is a common component of temperate and tropical/subtropical climates but is not present in the Arctic zone (Goldring et al. 2004; Crippa et al. 2018). The climatic interpretation provided here is in line with that of Brandano et al. (2015), suggesting that the Verezzi Member deposited in a humid climate with active carbonate production. Identity of the tracemaker provides a broad indication of the bathymetric range, although it should be noted that bathymetry exerts only an indirect control on trace fossil distribution. One of the modern

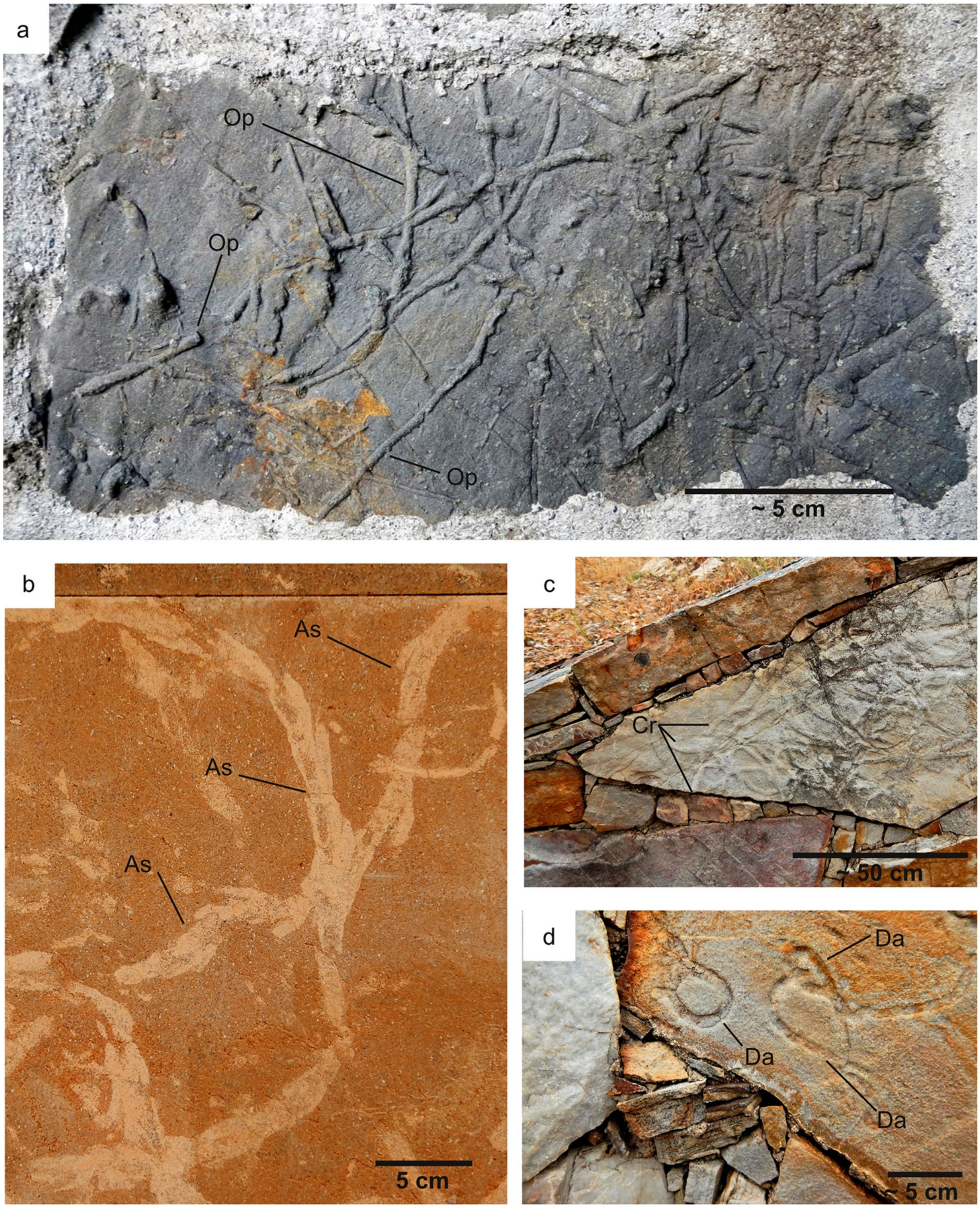


**Fig. 10** Exterior architecture and ichnofabrics. **a** Stone wall with an ichnofabric dominated by *Ophiomorpha* (Op). The host rock comes from the Eocene flysch of Cormons. Parco Piuma, Gorizia, Italy. **b** Several specimens of *Asterosoma* (As) are observed in a cladding slab from Cesarea Street, Genova, Italy. **c** Dry stone wall with several trilobite burrows (*Cruziana;* Cr). Armorican Quartzite, Ordovician of Naturtejo UNESCO Global Geopark. Ichnological information about this geological unit is found in previous papers (Neto de Carvalho 2006; Neto de Carvalho and Baucon 2016). **d** Dry stone wall at Mosqueiro viewpoint, Naturtejo UNESCO Global Geopark with the fossil burrow *Daedalus halli* (Da). Armorican Quartzite, Ordovician. For more ichnological information on *Daedalus* from this geological unit*,* see Neto de Carvalho et al. (2016a)

producers of *Bichordites,* the echinoid *Echinocardium cordatum,* lives at depths from 6 to 15 m in the Tyrrhenian Sea; deeper (50 m) occurrences are associated to storm deposits (D'Alessandro and Uchman 2007). Even


**Fig. 11** Ichnofabrics as tiles. **a** Numerous trilobite burrows (*Cruziana*) are preserved in each of the building stones of this hotel and restaurant. Sierra de Peña de Francia, Spain. Ordovician. **b** Floor tile with winding specimens of the trace fossil *Psammichnites.* Moher, Ireland. **c** Intensely burrowed building stone in the façade of S. Fosca Church in Venice, Italy. The yellow panel says 'first built in 1297; last modification in 1741'. Rosso Ammonitico facies

deeper occurrences (up to 230 m) have been reported but outside from the Tyrrhenian Sea (de Jesus and da Fonseca 1998; D'Alessandro and Uchman 2007; WoRMS 2020).

The alternation between intensely bioturbated layers and virtually unbioturbated ones (Fig. 4d) suggests fluctuating environmental conditions. In fact, the distribution of trace fossils reflects the degree of stability and temporal persistence of physicochemical conditions (Gingras et al. 2011). Consequently, the observed sporadically heterogeneous distribution of bioturbation is the result of persistent spatio-temporal variability in environmental conditions. A question might, therefore, arise: which were the fluctuating conditions?

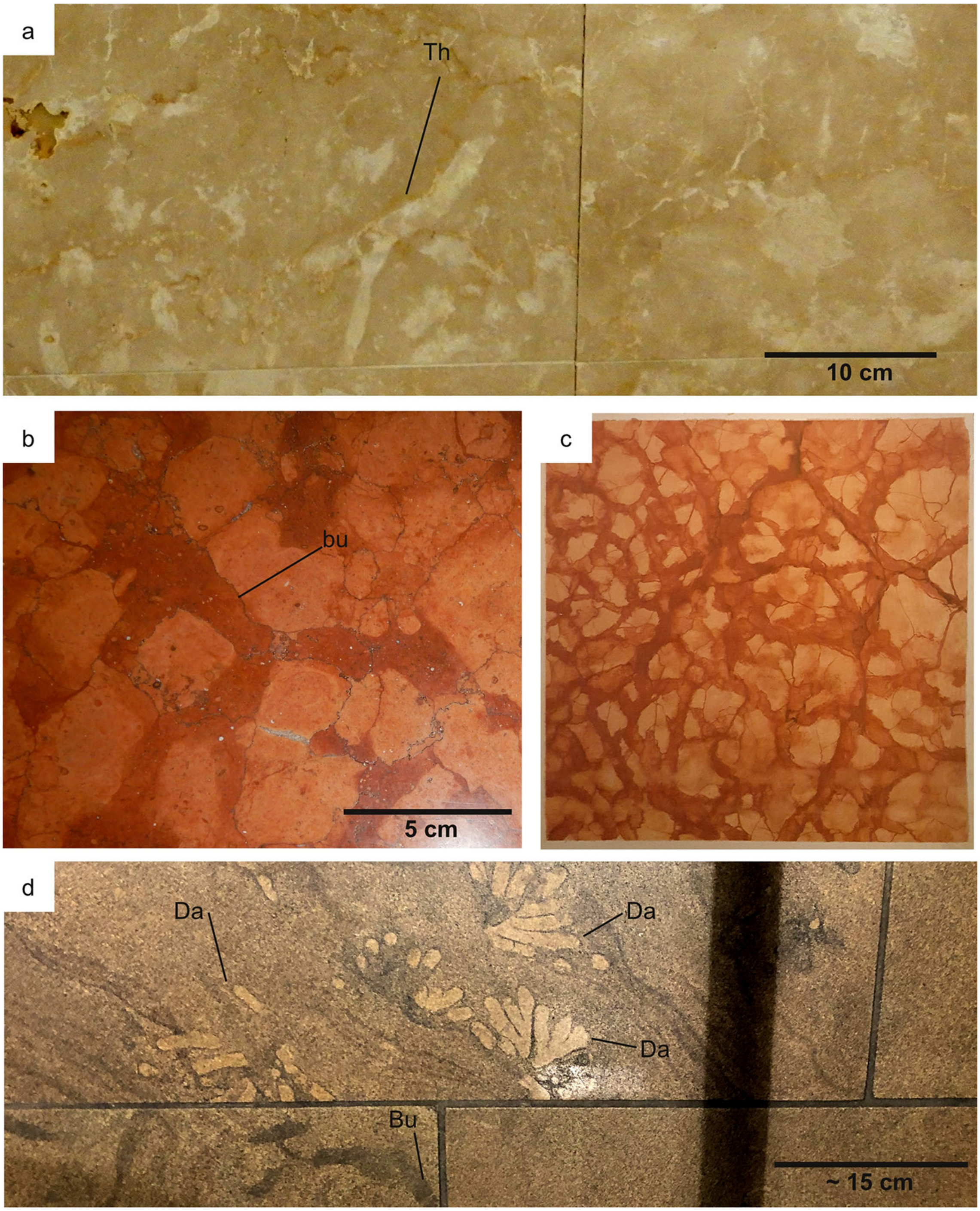


**Fig. 12** Interior architecture and ichnofabrics. **a** Wall tile with the branched burrow *Thalassinoides* (Th). Unknown age. Brignole station, Genova, Italy. **b** Stone bar of a café with several burrows (bu). Rosso Ammonitico, Jurassic. Arenzano, Italy. **c** Painting imitating Rosso Ammonitico. Note the detailed representation of the burrows which commonly characterize Rosso Ammonitico facies. Artwork by Miata Marcolini. **d** Floor tile with the foraging burrow *Dactyloidites* (Da) and other burrows (bu). Unknown age. Eataly building, Trieste, Italy

The sedimentation rate is a plausible answer because high bioturbation intensities are difficult to achieve unless sedimentation rates are at least sporadically slow, whereas very low levels of bioturbation commonly correlate to elevated rates of sedimentation (Gingras et al. 2011). In addition, hydrodynamic energy and shifting substrates may have played a role. For instance, it has been shown that during times of continuous bar and dune migration under the action of vigorous currents, organisms may be unable to colonize the shifting substrate (Hofmann et al. 2012). Accordingly, the colonization window (i.e. the duration of time potentially available for colonization to take place; Taylor et al. 2003) was brief during the deposition of the Verezzi Member. According to this interpretation, echinoids colonized the seafloor during relatively short periods of favourable conditions, followed by heightened intensity of stress factors (hydrodynamic energy, shifting substrates, sedimentation rate).

On the horizontal plane, large bioturbated patches abruptly transition to areas without distinct burrows. These sharp transitions could reflect comparably abrupt spatial changes in environmental conditions. However, the sharp transitions found in Piazza della Vittoria are accompanied by the truncation of otherwise continuous traces (e.g. Fig. 3c). For this reason, these transitions are interpreted as the product of high-energy events that first eroded bioturbated sediments, and then filled the erosional through. In other words, these sharp transitions indicate a post-colonization erosional event rather than a syn-colonization ecological process. In other cases, bioturbation is clearly subsequent to erosion, as manifested by bioturbated channel fills (Fig. 9b). In these cases, bioturbating organisms followed the nutrient-rich fill of channels.

The environment of the Piazza della Vittoria ichnofabric was a temperate to tropical ecosystem characterized by (1) normal marine salinity; (2) well-oxygenated porewaters; (3) erosional events; (4) fluctuating environmental conditions, with stressed conditions presenting (5) high sedimentation rate, (6) highly shifting substrates and (7) high hydrodynamic energy.

These features are characteristic of sand waves, which are large wave-like bedforms on the seafloor, being a few metres high and spaced hundreds of metres apart. In fact, sand waves are common features of shallow, sandy marine and estuarine environments where strong tidal currents are a dominant force (Field et al. 1981). Specifically, tidal sand waves are generally associated with strong currents in the range of 0.5 to 1 m/s (Tonnon et al. 2007). In the Messina Strait (Italy), where sand waves are a common bedform, currents higher than 5 m/s have been measured (Santoro et al. 2002). In the studied unit, evidence of current-swept seafloors does not only come from trace fossils but also sedimentary structures, i.e. cross-bedding (Fig. 4c, d). Sand wave systems are typified by rapid sedimentation and highly shifting substrates (Nara 2013); the migration speed of sand waves can reach several meters per year (Santoro et al. 2002).

For these reasons, the *Bichordites* ichnofabric of Piazza della Vittoria is here interpreted to represent a sand wave system, deposited in close proximity of the fair-weather wave base, bordering the lower shoreface conditions. Accordingly, the colonized seafloor was strongly influenced by tides and, less intensely or sporadically, by waves. This interpretation is supported by multiple lines of evidence. Nara (2013) studied a *Bichordites* ichnofabric from the Pleistocene of Japan, suggesting that the *Bichordites* ichnofabric typically represents sand wave deposits regardless of its water depths or driving processes. The link between *Bichordites* and sand waves is strongly supported by actualistic observations, e.g. the modern producer of *Bichordites* (*Echinocardium cordatum*) has been observed in sand wave troughs at approx. 30 m of depth (Weber et al. 2004). Our interpretation runs on the same line with the sedimentology-based interpretation of Nembrini et al. (2017), according to which the Verezzi Member represented a sand wave system. The presence of mud drapes points to gently shallower conditions or anyway less energetic with alternating conditions of bedload transport and slack water stages. Such structures can sporadically be associated with sand waves (Allen 1982), but their co-occurrence can point to an alternation of wave to tide dominated settings.

Sand waves can be produced by different current types, e.g. tidal currents, storm-induced currents, fair-weather-generated currents and gravity flows (Nara 2013). Tidal currents are a plausible process to explain the sand waves of the Verezzi Member because of the frequent tidal signatures such as the canalizations. Indeed, the sedimentological record of the Verezzi Member includes reactivation surfaces and mud drapes (Fig. 4), which are typically interpreted to reflect tidal influence (Nichols et al. 2007). The very limited spatial distribution of the Verezzi Member (less than 1 $km^2$; Fig. 2b) suggests a space-constrained depositional environment. A possible analogue is represented by the strait of the Golden Gate in California, where tidal currents accelerate (current velocity > 2.5 m/s) towards the San Francisco Bay and produce a field of sand waves (Barnard et al. 2006). Accordingly, the Verezzi Member could have represented a sand wave system at a bay mouth. It should be noted that the strait scenario is proposed here as a new working hypothesis and further tectono-sedimentary data are needed to test it.

## Geoheritage Value of the Piazza della Vittoria Ichnofabric

Geoheritage encompasses features of geology, at all scales, that are intrinsically important sites or culturally important sites offering information or insights into the evolution of the Earth; or into the history of science, or that can be used for research, teaching or reference (Brocx and Semeniuk 2007, 2019). The *Bichordites* ichnofabric of Piazza della Vittoria reflects all these characteristics.

First, the building stones of Piazza della Vittoria are scientifically important because, without the building stones themselves, it would have been challenging to describe the ichnofabric of the Verezzi Member and derive a palaeoenvionmental reconstitution from it. In fact, the Verezzi Member crops out in a very limited area (less than 1 $km^2$) where the characteristics of the *Bichordites* ichnofabric are not as nicely evident as in Piazza della Vittoria.

Second, Piazza della Vittoria is a culturally important site because it represents a prominent example of monumentalist architecture. The presence of the *Bichordites* ichnofabric in many of the building stones of Piazza della Vittoria poses significant challenges to the conservation of the monuments. Understanding the primary fabric changes, the degree of bioturbation and mineralogical composition of the burrow backfilling and margins is of considerable importance for the application of methods that may prevent differential weathering and can be effective in the restoration of pillars and façades.

Third, the public can appreciate the behaviour of past organisms and their paleoenvironmental significance through the building stones of Piazza della Vittoria. This raises the geological consciousness of the public and, following Brocx and Semeniuk (2019), it, therefore, represents another geoheritage aspect of the ichnofabric-bearing building stones. The ichnofabric-bearing building stones of Piazza della Vittoria can be easily used for research, science non-formal education and communication, as a complement for geotourism activities. Thanks to these three characteristics, the studied buildings can communicate scientific, cultural and behavioural aspects to the visitor of Piazza della Vittoria. Paraphrasing the opening quote of this paper, attributed to the prominent architect Julia Morgan (see Benaroya 2018: p. 194), the buildings of Piazza della Vittoria speak through their ichnofabrics.

The present case study encourages the appreciation of the geoheritage value of other ichnofabric-bearing building stones, which are commonly used in many urban contexts (Fig. 10, Fig. 11). It is also especially interesting the work that have been developed in the city of Araraquara, State of S. Paulo, Brazil (Francischini et al. 2020). A municipal law establishes the regulations for protection and restoring, and against destruction or misuse, of the flagstones applied in the old town sidewalks, which are rich in dinosaur and other tracks of scientific relevance. The local museum has an inventory with the distribution of the trace fossil-bearing flagstones and their conservation status. It also develops educational and geotourist activities as an extension of the museum agenda. These activities contribute for the cultural offer of the city and raise awareness not only of the local community, but of a broader national and international audience interested in geoscientific/naturalistic subjects, about the significant paleontological heritage that is available in such unique conditions. This may be the trigger for the development of a geotourism product based on a unique, unrepeatable experience (Neto de Carvalho 2009). This is the case of some villages of Sierra de Peña de Francia, in Castile and León, Spain (Fig. 11a). Restaurants, public buildings and many private buildings, especially in the village of Monsagro, have been decorated since 1950s with quartzite slabs profusely bioturbated mostly by trilobite trace fossils, creating a unique identity. This identity based on the paleontological (ichnological) heritage is now explored in Monsagro through the recent development of an urban route starting from an interpretative centre dedicated to exploring the trace fossils exhibited in the streets (Martínez-Graña et al. 2016). The definition of this unique geotourism product is providing conditions for raising the offer of services that contribute with a positive feedback to enhance the identity and the quality of the product itself. This is the case of the rural hotel named after the main trace fossil, *Cruziana*, in the neighbour village of Serradilla del Arroyo (Castile and León, Spain).

*Bichordites* ichnofabric from Piazza della Vittoria and the Cava Vecchia could be integrated in a broader geotourist route of the city of Genova that combine the appreciation and understanding of historical monuments with the nature connection and the natural history of the region provided by the building stones, natural and man-used outcrops, landscape-interpreting viewpoints and geomorphosites, similar to other geotourist routes already developed in urban areas (Silva and Cachão 1998 and Silva 2009 for Lisbon; Rodrigues et al. 2014 and Rodrigues and Agostinho 2016a, b, c for three cities in the Algarve region of Portugal; Pätzold 2002 for Bremen; Stern et al. 2006 and Del Lama et al. 2015 for S. Paulo; Liccardo et al. 2008 and 2012 for Curitiba; Palacio-Prieto 2014 for the City of Mexico; Kubalíková et al. 2020 for Brno; Díez-Herrero and Vegas-Salamanca 2011 for Segovia; and Fernández-Martinéz and Castaño-de-Luis 2013 for Burgos, among several other examples).

## Why Marcello Piacentini Used Ichnofabric-Bearing Building Stones?

Trace fossils are beautiful. This may seem a subjective opinion, but historical evidence clearly indicates that humans developed an aesthetical appreciation for trace fossils and ichnofabrics as texture differentiators of ornamental rocks.

In fact, calcarenite blocks with trace fossils (*Scolicia, Cardioichnus, Ophiomorpha, Gastrochaenolites*) appear to have been deliberately chosen as building stones of the monumental tombs (*tholoi*) of La Pastora and Marrubilla (Seville, Spain; Third Millennium BCE), probably to highlight specific decorative or symbolic meanings (Cáceres et al. 2019; see also Cáceres et al. 2014). Statistical data from Late Palaeolithic archaeological sites demonstrate that humans selectively collected molluscs with bioerosional trace fossils (*Oichnus*) to use them as items of personal adornment (Baucon et al. 2012 and references therein). Trace fossils sparked the visual interest of Leonardo da Vinci (Baucon 2010a) and other emblematic figures of the Renaissance such as Konrad Gesner, Johann Bauhin and Ulisse Aldrovandi (Seilacher 2007; Baucon 2010b). The Renaissance naturalist Ulisse Aldrovandi called two specimens of trace fossils (*Cosmorhaphe* and *Gastrochaenolites*) 'pulcherrimas,' or 'beautiful' (Baucon 2009). Aldrovandi also dealt with ichnofabrics in ornamental stones by using snakes to represent the ichnofabric of the 'Verona Stone', which is an ornamental stone extracted from the Jurassic Rosso Ammonitico Formation (Baucon 2010b). When artists imitate Rosso Ammonitico using a technique known as *faux marbling,* ichnofabric-forming burrows are reproduced (Fig. 12b–c); this demonstrates that ichnofabrics are perceived as an integral part of the aesthetical value of building stones. The same phenomenon is reported for body fossils, e.g. painted rudist biofabrics, imitating those of the building stone known as 'Lioz', can be seen in many churches and chapels all over Portugal (Silva 2009; see also Barreto et al. 2010).

The reason for this aesthetic appreciation is explained by the fact that trace fossils are rich in structure. In fact, studies on visual perception (Sprott 1993; Sphear et al. 2003) proved that humans have an aesthetic preference for fractal objects and images with intermediate fractal dimension. These features are found in many trace fossils; being rich in structure, such traces have been acknowledged for their instant aesthetic appeal (Baucon 2010b).

This instant aesthetic appeal explains either the long-standing human interest for trace fossils or the use of some ichnofabric-bearing geological units as a source for building stones, both for exterior (Fig. 10) and interior (Fig. 12) applications. This double side is well-exemplified by the trilobite burrows of Penha Garcia (Portugal). In fact, the inhabitants of Penha Garcia have admired for centuries the fossil burrows, calling them 'Painted Snakes' (Neto de Carvalho et al. 2014), and also used ichnofossil-bearing building stones as a decoration.

It should be noted that not all ichnofabric-bearing building stones may have been quarried for their ichnofabric-related aesthetic qualities (colour, grain texture and pattern). For instance, the Cormons Flysch is the only building stone outcropping in the area of Parco Piuma (Gorizia, Italy); hence, availability, not ichnofabrics, is likely to have played a primary role in its choice (Fig. 10a). The ichnofabric of the Canelas slates (Neto De Carvalho et al. 2016b) is remarkable but poorly visible to the untrained eye, hence their appreciation as building stones is likely to derive from aesthetic qualities other than those related to ichnofabrics. In other cases, however, the colour and the pattern of some building stones markedly derive from ichnofabric-forming trace fossils (Fig. 12a, b).

Because of the aesthetic appeal of trace fossils, a question might arise: did the starchitect Marcello Piacentini choose the Pietra di Verezzi for the aesthetical value of its ichnofabric? The answer necessarily relies on the history of Piazza della Vittoria. This history is somehow peculiar, because Piacentini supervised the Piazza della Vittoria project, for which the general standards were fixed, but in every building project there were flexible decorative alternatives chosen by each designer (Cevini 1989; Balletti and Giontoni 1990; Brancucci and Spesso 2016). Other architects contributed at the modern square design, i.e. Beniamino Bellati, Aldo Camposampiero, Cristoforo Ginatta and Giuseppe Tallero. This is reflected by the use of different ornamental stones in the entrance halls decoration or for the main facades. For instance, in the Nafta Palace, Ginatta chose Travertino stone, instead Piacentini decided for a local ornamental stone from Finale Ligure (dossier n.19/36 and 49/37 Archivio Storico di Genova). Consequently, it was Piacentini himself that choose the bioturbated Verezzi Stone. Closeness to the extraction site is likely to have played a role in this choice since the Verezzi quarry is less than 100 km from Piazza della Vittoria. However, at the same distance, there are other quarries with different varieties of the Pietra di Finale stone with comparable mechanical properties. For this reason, it is likely that the choice of Piacentini was guided by the aesthetical qualities of the Verezzi Stone, which partly derives from its *Bichordites* ichnofabric.

This aesthetic role of ichnofabrics could be extended to at least some of the historical applications of the Verezzi Stone. The extensive use of the Pietra di Verezzi seems to begin around the mid-sixteenth century in Genova with the large construction sites (e.g. Nostra Signora Assunta di Carignano, Chiesa del Gesù, stately homes of Strada Nuova, Palazzo Balbi), in Savona (e.g. Sanctuary of Nostra Signora della Misericordia), in Loano (Savona province, e.g. the cloister of the Madonna del Carmelo) (Conventi and Murialdo 2019; Murialdo 2019a, b, c). The use of other commercial varieties of the Pietra di Finale seems to have taken place earlier, i.e. in the Roman age. A widespread use of the Pietra di Verezzi occurred in the twentieth century when it was used as facing stone for building façades and colonnades in Genova (e.g. Piazza della Vittoria, Piazza Dante, Palazzo Custo,) and Savona (e.g. Seminario Diocesano), but also for sculptures (e.g. Monumento al Marinaio, Genova; Monumento ai Caduti, Pietra Ligure, Savona) (Murialdo and Servente 2019). The abundance of *Bichordites* ichnofabrics in Genova suggests that the Verezzi Member was intensely quarried in the past. It is worthwhile to note that in 1600s the scientist Giovanni Antonio Magini reported Pietra di Finale Stone as an appreciable building stone known as 'arena congelata' (frozen sand) rich in shells, teeth and fish bones (Santamaria 2019).

## Conclusions

This study analysed for the first time the abundant and well-preserved fossil burrows characterizing the 1930s buildings of Piazza della Vittoria, Genova. The fossil burrows, produced by irregular echinoids, replaced the primary fabric of the sediment by an ichnofabric. Characteristics of the ichnofabric have enabled to propose a new palaeoenvironmental reconstitution of the Verezzi Member of the Finale Ligure Limestone. Accordingly, the Piazza della Vittoria ichnofabric represent the colonization of a sand wave system which possibly deposited at the mouth of a narrow strait. This interpretation would have been challenging without the Piazza della Vittoria ichnofabric, thus underlining its geoheritage value. Through the ichnofabric visible at Piazza della Vittoria, the public can explore ancient behaviours and ecosystems. Consequently, the studied ichnofabric can be used for research, teaching, geotourism or reference, which enhances the geoheritage significance of the Piazza della Vittoria ichnofabric. As suggested in the introduction, ichnofabric-bearing building stones 'speak' of ancient organisms, behaviours and environments. This case study allows recognising ichnofabric as a major geoheritage aspect in sedimentary building stones. Scientific research, including assessment of ichnofabric-bearing concentrations of building stones in urban areas and their quarry provenances, conservation conditions and protection status, as well as their applicability in broader educational programs and geotours are, thus, highly recommended.

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## Compliance with Ethical Standards

**Conflict of Interest** The authors declare that they have no conflicts of interest.

## References

Allen JRL (1982) Mud drapes in sand-wave deposits: a physical model with application to the Folkestone beds (early Cretaceous, southeast England). Philos Trans R Soc A 306:291–345

Alonso-Zarza AM, Genise JF, Cabrera MC, Mangas J, Martín-Pérez A, Valdeolmillos A, Dorado-Valiño M (2008) Megarhizoliths in Pleistocene aeolian deposits from Gran Canaria (Spain): Ichnological and palaeoenvironmental significance. Palaeogeogr Palaeoclimatol Palaeoecol 265:39–51. https://doi.org/10.1016/j.palaeo.2008.04.020

Balletti F, Giontoni B (1990) Una città tra le due guerre: culture e trasformazioni urbanistiche. De Ferrari Editore, Genova

Barnard PL, Hanes DM, Rubin DM, Kvitek RG (2006) Giant sand waves at the mouth of San Francisco Bay. Eos (Washington DC) 87:285–289

Barreto JM, Pinto A, Rosato C, Rios D, Oliveira NS (2010) Rochas ornamentais na geologia urbana: Uma das sete maravilhas portuguesas no mundo. VIII Congresso Nacional de Geologia 15(54):1–4

Baucon A (2009) Ulisse Aldrovandi (1522-1605): the study of trace fossils during the Renaissance. Ichnos 16:245–256. https://doi.org/10.1080/10420940902953205

Baucon A (2010a) Leonardo Da Vinci, the founding father of ichnology. Palaios 25:361–367. https://doi.org/10.2110/palo.2009.p09-049r

Baucon A (2010b) Da Vinci' s *Paleodictyon*: the fractal beauty of traces. Acta Geol Pol 60:3–17

Baucon A, Neto de Carvalho C (2016) Stars of the aftermath: *Asteriacites* beds from the Lower Triassic of the Carnic Alps (Werfen Formation, Sauris di Sopra), Italy. Palaios 31:161–176. https://doi.org/10.2110/palo.2015.015

Baucon A, Bordy E, Brustur T, Buatois LA, Cunningham T, de C, Duffin C, Felletti F, Gaillard C, Hu B, Hu L, Jensen S, Knaust D, Lockley M, Lowe P, Mayor A, Mayoral E, Mikuláš R, Muttoni G, Neto de Carvalho C, Pemberton SG, Pollard J, Rindsberg AK, Santos A, Seike K, Song HB, Turner S, Uchman A, Wang YY, Yi-ming G, Zhang L, Zhang WT (2012) A history of ideas in ichnology. In: Knaust D, Bromley RG (eds) Trace fossils as indicators of sedimentary environments, Developments in sedimentology, vol 64. Elsevier, Amsterdam, pp 3–43

Belaústegui Z, Belaústegui A (2017) Modernist architecture in Barcelona reveals a new trace fossil from the Miocene of Montjuic (NE Spain). Geol Acta 15:169–186

Belaústegui AZ, Muñiz F, Nebelsick JH et al (2017) Echinoderm ichnology: bioturbation, bioerosion and related processes. J Paleontol 91:643–661. https://doi.org/10.1017/jpa.2016.146

Belaústegui Z, Belaústegui A, Muñiz F (2018) Fósiles urbanos, un patrimonio que pasa inadvertido. AEPECT Enseñanza de las Ciencias de la Tierra 26(1):118–121

Benaroya H (2018) Building habitats on the moon: engineering approaches to lunar settlements. Springer

Benton MJ, Harper DAT (2009) Introduction to paleobiology and the fossil record. John Wiley & Sons

Bernardi M, Boschele S, Ferretti P, Avanzini M (2011) *Bichordites monastiriensis*: traccia di escavazione di echinidi nei sedimenti oligocenici della Valsugana. Stud Trent Sci Nat 88:311–314

Bernardi AM, Boschele S, Ferretti P, Avvanzini M (2019) Echinoid Burrow *Bichordites monastiriensis* from the Oligocene of NE from the Oligocene of NE Italy. Acta Palaeontol Pol 55:479–486. https://doi.org/10.4202/app.2009.0064

Bland BH, Gibert JM, Goldring R (2001) A fossil whodunnit. Geol Today 17(6):229–230

Bonci MC, Cabella R, Faccini F, Firpo M, Mandarino A, Piazza M (2019a) Geologia, paleontologia e geomorfologia della Pietra di Finale. In: G Murialdo, R Cabella, D Arobba (eds), Pietra di Finale. Una risorsa naturale e storica del Ponente ligure. Istituto Internazionale di Studi Liguri ONLUS - Bordighera (IM), 10–32

Bonci MC, Cabella R, Piazza M Tedeschi F (2019b) Le "facies" della Pietra di Finale: un atlante. In: G. Murialdo R, Cabella R, Arobba D (eds), Pietra di Finale. Una risorsa naturale e storica del Ponente ligure. Istituto Internazionale di Studi Liguri ONLUS - Bordighera (IM), 45-60

Boni P, Mosna S, Vanossi M (1968) La Pietra di Finale (Liguria Occidentale). Atti dell'Istituto di Geologia dell'Università di Pavia, XVIII, pp 102–150

Boyd C, McIlroy D (2018) The morphology and mode of formation of *Neoeione* igen. nov. from the Carboniferous of northern England. Paläontol Z 92:179–190

Brancucci G, Spesso M (2016) Le pietre liguri nell'architettura di Genova. L'età del fascismo, Franco Angeli

Brandano M, Tomassetti L, Frezza V (2015) *Halimeda* dominance in the coastal wedge of Pietra di Finale (Ligurian Alps, Italy): The role of trophic conditions. Sedimentary Geology 320:30–37. https://doi.org/10.1016/j.sedgeo.(2015).02.001

Brocx M, Semeniuk V (2007) Geoheritage and geoconservation: history defintion scope and scale. J R Soc West Aust 90:53–87

Brocx M, Semeniuk V (2019) Building stones can be of geoheritage significance. Geoheritage 11:133–149

Bromley RG (1996) Trace fossils: biology, taphonomy and applications, second edi. Chapman & Hall, London

Bromley RG, Asgaard U (1975) Sediment structures produced by a spatangoid echinoid: a problem of preservation. Bull Geol Soc Denmark 24:261–281

Buatois LA, Mángano MG (2011) Ichnology: organism-substrate interactions in space and time. Cambridge University Press, Cambridge / New York

Buchanan JB (1966) The biology of *Echinocardium cordatum* (Echinodermata: Spatangoidea) from different habitats. J Mar Biol Assoc U K 46:97–114

Building Stones Database (2020) The building stones database. In: From "a Thousand Years Build. with Stone." http://www.buildingstones.org.uk/the-building-stones-database/

Cáceres LM, Muñiz F, Rodríguez-Vidal J, Vargas JM, Donaire T (2014) Marine bioerosion in rocks of the prehistoric tholos of La Pastora (Valencina de la Concepción, Seville, Spain). J Archaeol Sci 41: 435–446

Cáceres LM, Vargas JM, Muñiz F, Donaire T, Sanjuán LG, Odriozola C, Rodríguez-Vidal J (2019) Natural "megalithic art" at Valencina (Seville): a geoarchaeological approach to stone, architecture, and cultural choice in Copper Age Iberia. Archaeol Anthropol Sci 11: 4621–4641

Cachão M, Freitas MC, Silva CM (1999) Geologia Augusta: Património, Geologia urbana e Cultura. Comunicações I Seminário Património Geológico Português, Lisboa, p 10

Caruso C (2015) *Bichordites monastiriensis* ichnofabric from the Pleistocene shallow-marine sandstones at Le Castella (Crotone), Ionian Calabrian, southern Italy. Rivista Italiana di Paleontologia e Stratigrafia

Cevini P (1989) Genova anni '30, da Labò a Daneri. Sagep Editrice, Genova

Conventi M, Murialdo G (2019) L'impiego della Pietra di Finale e le tecniche murarie dall'Età romana all'Altomedioevo. In: G. Murialdo, R. Cabella, D. Arobba (eds), Pietra di Finale. Una risorsa naturale e storica del Ponente ligure. Istituto Internazionale di Studi Liguri ONLUS - Bordighera (IM), 123-162

Crippa G, Baucon A, Felletti F, Raineri G, Scarponi D (2018) A multidisciplinary study of ecosystem evolution through early Pleistocene climate change from the marine Arda River section, Italy. Quat Res (United States) 89:533–562. https://doi.org/10.1017/qua.2018.10

D'Alessandro A, Uchman A (2007) *Bichordites* and *Bichordites-Rosselia* ichnoassemblages from the lower Pleistocene Tursi Sandstone (Southern Italy). SEPM Spec Publ 88:213–221

Dallagiovanna G, Gaggero L, Seno S, Felletti F, Mosca P, Decarlis A, Pellegrini L, Poggi F, Bottero D, Mancin N, Lupi C, Bonini L, Lualdi A, Maino M, Toscani G (2011) Note illustrative della Carta Geologica d'Italia alla scala 1:50.000 - foglio 228 Cairo Montenotte. ISPRA - Regione Liguria, Litografia Artistica Cartografica s.r.l. 156 p

de Jesus CD, da Fonseca CL (1998) First record of 13 echinoderm species on the southwest coast of Portugal. Bol Inst Esp Ocean 15:343–349

Del Lama EA, Bacci DLC, Martins L, Garcia MGM, Dehira LK (2015) Urban geotourism and the Old Centre of São Paulo City, Brazil. Geoheritage 7(2):147–164

Díez-Herrero A, Vegas-Salamanca J (2011) De roca a roca, descubre el património geológico de la ciudad de Segovia. Ayuntamiento de Segovia, Concejalía de Turismo

Fernandes MA, Corrêa RC (2007) Patrimônio icnofossilífero das vias públicas da cidade de São Carlos, SP: resgate histórico, científico e cultural como referência para um museu a céu aberto. In: Carvalho IS, Cassab RCT, Schwanke C, Carvalho MA, Fernandes ACS, Rodrigues MAC, Carvalho MSS, Arai M, Oliveira MEQ (eds) Paleontologia: Cenários de Vida. Interciência, Rio de Janeiro, pp 151–162

Fernandes MA, Francischini H, Carvalho IS (2008) Paleoicnologia Urbana: o patrimônio fossilífero de Araraquara, Estado de São Paulo, Brasil. Mem Not 3:455–462

Fernández-Martinéz E, Castaño-de-Luis R (2013) Geoturismo en la Ciudad de Burgos. In: Vegas J, Salazar A, Díaz-Martínez E, Marchán C (eds) Patrimonio geológico, un recurso para el desarrollo, Cuadernos del Museo Geominero, n 15. Instituto Geológico y Minero de España, Madrid

Field ME, Nelson CH, Cacchione DA, Drake DE (1981) Sand waves on an epicontinental shelf: northern Bering Sea. Mar Geol:233–258

Francischini H, Fernandes MA, Kunzler J, Rodrigues R, Leonardi G, Carvalho IS (2020) The ichnological record of Araraquara sidewalks: history, conservation and perspectives. Geoheritage 12:50. https://doi.org/10.1007/s12371-020-00472-5

Frey RW, Pemberton SG (1985) Biogenic structures in outcrops and cores. Bull Can Petrol Geol 33:72–115

Frey RW, Seilacher A (1980) Uniformity in marine invertebrate ichnology. Lethaia 13:183–207. https://doi.org/10.1111/j.1502-3931.1980.tb00632.x

Gaffikin P (1999) Set in stone: a geological guide to the building stones of Belfast. Environment and Heritage Service, 60

Giammarino S, Giglia G, Capponi G, Crispini L, Piazza M (2002) Carta Geologica della Liguria, a scala 1: 200.000. Laboratorio di Cartografia Digitale e GIS, Dipartimento di Scienze della Terra dell'Università di Siena

Gibert JM, Goldring R (2007) An ichnofabric approach to the depositional interpretation of the intensely burrowed Bateig Limestone, Miocene, SE Spain. Sediment Geol 194:1–16. https://doi.org/10.1016/j.sedgeo.2006.04.008

Gibert J, Goldring R (2008) Spatangoid-produced ichnofabrics (Bateig Limestone, Miocene, Spain) and the preservation of spatangoid trace fossils. Palaeogeogr Palaeoclimatol Palaeoecol 270:299–310. https://doi.org/10.1016/j.palaeo.2008.01.031

Gingras MK, MacEachern JA, Dashtgard SE (2011) Process ichnology and the elucidation of physico-chemical stress. Sediment Geol 237: 115–134. https://doi.org/10.1016/j.sedgeo.2011.02.006

Goldring R, Cadée G, D'Alessandro A, et al (2004) Climatic control of trace fossil distribution in the marine realm. In: Mcilroy D (ed) The Application of Ichnology to Palaeoenvironmental and Stratigraphic Analysis. Geological Society of London, Special Publications, 228, London, pp 77–92

Grimmberger G, Hoffmann R, Kautz R (2013) Erstfund der Lebensspur *Bichordites monastirensis* in einem paläozänen Geschiebe. In: G. Hoffmann R, Kautz R (eds) Geschiebekd. Aktuell. pp 19–25

Gutiérrez-Marco JC, Martínez-Graña AM, González-Delgado JA (2019) Monsagro (Salamanca, Spain): an "Ordovician village" built with *Cruziana* and other trace fossils from the Armorican Quartzite. In: Proceedings of the 13th International Symposium omn the Ordovician Sysyem. pp 63–66

Hofmann R, Gabriela MMA, Elicki O, Shinaq R (2012) Paleoecologic and biostratigraphic significance of trace fossils from shallow- to marginal-marine environnments from the Middle Cambrian (stage 5) of Jordan. J Paleontol 86:931–955

Issel A (1886) Catalogo dei fossili della Pietra di Finale. Boll del Reg Com Geol Ital 17:27–43

Kenworthy JP, Santucci VL (2006) A preliminary inventory of NPS paleontological resources found in cultural resource contexts, part 1: general overview. In Lucas, S.G, et al. (eds.), America's antiquities (proceedings of the 7th Federal Fossil Conference). New Mexico Museum of Natural History Science, Albuquerque, NM. Bulletin 34, 70-76

Knaust D (2017) Atlas of trace fossils in well core: appearance, taxonomy and interpretation. Springer, Alphen aan den Rijn

Kubalíková L, Kirchner K, Kuda F, Bajer A (2020) Assessment of urban geotourism resources: an example of two geocultural sites in Brno, Czech Republic. Geoheritage 12(7). https://doi.org/10.1007/s12371-020-00434-x

Liccardo A, Piekarz G Salamuni E (2008) Geoturismo em Curitiba. Mineropar, 122

Liccardo A, Mantesso-Neto V, Piekarz G (2012) Geoturismo urbano – educação e cultura. Anu Inst Geocienc 35(1):133–141

Löwemark L, Lin Y, Chen H-F, Yang TN, Beier C, Werner F, Lee CY, Song SR, Kao SJ (2006) Sapropel burn-down and ichnological response to late Quaternary sapropel formation in two ~400 ky records from the eastern Mediterranean Sea. Palaeogeogr Palaeoclimatol Palaeoecol 239:406–425. https://doi.org/10.1016/j.palaeo.2006.02.013

Mammì I (2008) Pectinids and echinoids of the Pietra di Finale in the historical collection in the Dipteris. University of Genova, Italy

Marini M (1986) Deformazioni fragili e semifragili nella Pietra di Finale (Liguria occidentale). Atti della Società Toscana di Scienze Naturali, Memorie, serie A, 93, 31–55

Martínez-Graña AM, Serrano L, González-Delgado JA, Dabrio CJ, Legoinha P (2016) Sustainable geotourism using digital technologies along a rural georoute in Monsagro (Salamanca, Spain). Int J Digit Earth 10:121–138. https://doi.org/10.1080/17538947.2016.1209582

Mateus O, Milan J (2009) A diverse Upper Jurassic dinosaur ichnofauna from Porto Dinheiro track assemblage. Lethaia 43:245–257. https://doi.org/10.1111/j.1502-3931.2009.00190.x

McIlroy (2004) The application of ichnology to Palaeoenvironmental and stratigraphic analysis. Geological Society of London, London

McIlroy D (2008) Ichnological analysis: the common ground between ichnofacies workers and ichnofabric analysts. Palaeogeogr Palaeoclimatol Palaeoecol 270:332–338. https://doi.org/10.1016/j.palaeo.2008.07.016

McMillan AA, Gillanders RJ, Fairhurst JA (1999) Building stones of Edinburgh, 2nd edn. Edinburgh Geological Society, Edinburgh

Minter NJ, Krainer K, Lucas SG, Braddy SJ, Hunt AP (2007) Palaeoecology of an Early Permian playa lake trace fossil assemblage from Castle Peak, Texas, USA. Palaeogeogr Palaeoclimatol Palaeoecol 246:390–423. https://doi.org/10.1016/j.palaeo.2006.10.009

Murialdo G (2019a) La Pietra di Finale nel Medioevo e nella prima Età moderna (fine X - inizi XVI secolo). In: G. Murialdo, R. Cabella, D. Arobba (eds), Pietra di Finale. Una risorsa naturale e storica del Ponente ligure. Istituto Internazionale di Studi Liguri ONLUS - Bordighera (IM), 199-306

Murialdo G (2019b) La Pietra di Finale dalla ricostruzione di Giovanni I Del Carretto alla committenza marchionale rinascimentale (1450-1535). In: G. Murialdo, R. Cabella D. Arobba (eds), Pietra di Finale. Una risorsa naturale e storica del Ponente ligure. Istituto Internazionale di Studi Liguri ONLUS - Bordighera (IM), 307-392

Murialdo G (2019c) "La pietra denominate di Finale": usi e diffusioni della Pietra di Finale in Età moderna (XVI-XVIII secolo). In: G. Murialdo, R. Cabella, D. Arobba (eds), Pietra di Finale. Una risorsa naturale e storica del Ponente ligure. Istituto Internazionale di Studi Liguri ONLUS - Bordighera (IM), 393-460

Murialdo G, Servente D (2019) La Pietra di Finale tra la fine del XIX e il XX secolo: il grande epilogo di una storia secolare. In: Murialdo G, Cabella R, Arobba D (eds) Pietra di Finale. Una risorsa naturale e storica del Ponente ligure. Istituto Internazionale di Studi Liguri ONLUS, Bordighera, pp 529–564

Nara M (2013) The *Bichordites* ichnofabric in the Pleistocene current-generated sand ridge complex. Spanish J Palaeontol 29:191–202

Nembrini M, Berra F, Porta G Della, Fiorani S (2017) Facies characterization and depositional model of the Pietra di Finale Formation (Miocene, Liguria, N Italy). J Mediterr Earth Sci (abstracts XIII Geosed Congr IX:185

Neto de Carvalho C (2006) Roller Coaster Behavior in the *Cruziana* Rugosa Group from Penha Garcia (Portugal): implications for the Feeding Program of Trilobites. Ichnos 13:255–265. https://doi.org/10.1080/10420940600843740

Neto de Carvalho C (2009) *Cruziana* d'Orbigny, 1842 em Portugal: da interpretação paleobiológica à consagração como Produto Geoturístico. Paleolusitana 1:33–42

Neto de Carvalho C, Baucon A (2016) Giant trilobite burrows and their paleobiological significance (Lower-to-Middle Ordovician from Penha Garcia, Portugal). Comun Geológicas 103:71–81

Neto de Carvalho C, Cachão M (2005) A Bicha Pintada (Milreu – Vila de Rei): Paradigma ecléctico das hierofanias com origem bioglífica. Zahara 5:77–90

Neto de Carvalho C, Rodrigues JC, Baucon A (2014) "Fossil Art": the importance and value of the palaeobiodiversity in the Naturtejo Global Geopark, under UNESCO (Portugal). Comun Geol 101

Neto de Carvalho C, Baucon A, Gonçalves D et al (2016a) *Daedalus* mega-ichnosite from the Muradal Mountain (Naturtejo Global Geopark, Central Portugal): between the Agronomic Revolution and the Ordovician Radiation. Comun Geológicas 103:59–70

Neto de Carvalho C, Couto H, Figueiredo MV, Baucon A (2016b) Microbial-related biogenic structures from the Middle Ordovician slates of Canelas (Northern Portugal). Comun Geol:103

Neuendorf KKE, Mehl JP Jr, Jackson JA (2005) Glossary of geology. American Geological Institute, Alexandria

Nichols G, Williams E, Paola C (2007) Sedimentary processes, Environments and Basins

Palacio-Prieto JL (2014) Geoheritage within cities: urban geosites in Mexico City. Geoheritage 7(4):365–373

Pätzold J (2002) Naturbausteine der Bremer Innenstadt. Bremer Geo-Touren, Marum, Bremen 2:50

Pereira D, Marker B (2016) The value of original natural stone in the context of architectural heritage. Geosciences 6:1–9. https://doi.org/10.3390/geosciences6010013

Primavori P (2004) Lessico del settore lapideo - Stone sector lexicon. Zusi Editore, Verona

Reineck HE (1967) Parameter von Schichtung und bioturbation. Geol Rundsch 56:420–438

Robinson E (1993) A geological walk in Southwark. Proc Geol Assoc 104(40):285–299

Robinson E (1997) The stones of the Mile End Road: a geology of Middlemiss country. Proc Geol Assoc 108(3):171–176

Rodrigues, LA Agostinho, M (2016a) Faro – urban geology and paleontology guide. Centro Ciência Viva de Lagos

Rodrigues, LA Agostinho, M (2016b) Lagos – urban geology and paleontology guide. Centro Ciência Viva de Lagos

Rodrigues, LA Agostinho, M (2016c) Tavira – urban geology and paleontology guide. Centro Ciência Viva de Lagos

Rodrigues LA, Agostinho M, Manteigas R (2014) Geologia e Paleontologia Urbanas – potencialidades e aplicações em três cidades do Algarve. Comunicações Geológicas 101(Especial III): 1359–1363

Santamaria R (2019) "Tutta d'un colore tra bianco e rosso": la Pietra di Finale nelle carte d'archivio genovesi. In: Murialdo G, Cabella R, Arobba D (eds) Pietra di Finale: Una risorsa naturale e storica del Ponente Ligure. Istituto Internazionale di Studi Liguri, Finale Ligure, pp 461–478

Santoro VC, Amore E, Cavallaro L, Cozzo G, Foti E (2002) Sand waves in the Messina Strait, Italy. J Coast Res 36:640–653

Savrda CE (2007) Taphonomy of trace fossils. In: Miller W (ed) Trace fossils. Concepts, Problems, Prospects, Amsterdam, pp 92–109

Seilacher A (2007) Trace fossil analysis. Springer, Berlin

Seilacher A (2008) Fossil art: an exhibition of the Geologisches Institut Tubingen University Germany. CMB Publishing, Denmark, 98 pp

Shrock RR (1934) Probable worm castings ('coprolites') in the Salem Limestone of Indiana. Proceedings of the Indiana Academy of Sciences 44:174–175

Silva CM (2009) "Fósseis ao virar da Esquina": um percurso pela paleontologia e pela geodiversidade urbana de Lisboa. Paleolusitana 1:453–463

Silva CM, Cachão M (1998) “Paleontologia urbana”. Percursos citadinos de interpretação e educação (paleo)ambiental. Comunicações do Instituto Geológico e Mineiro 84(2):H33–H35

Smith AB, Crimes TP (1983) Trace fossils formed by heart urchins - a study of *Scolicia* and related traces. Lethaia 16:79–92

Sphear B, Clifford CW, Newell BR, Taylor RP (2003) Universal aesthetic of fractals. Comput Graph 27:813–820

Sprott JC (1993) Automatic generation of strange attractors. Comput Graph 17:325–332

Stern AG, Riccomini C, Fambrini GL, Chamani MAC (2006) Roteiro Geológico pelos edifícios e monumentos históricos do Centro da Cidade de São Paulo. Revista Brasileira de Geociências 36(4): 704–711

Sutherland DS (2000) Ecclesiastical geology. In: Hancock PI, Skinner BJ (eds) The Oxford companion to the earth. Oxford University Press, Oxford, pp 292–295

Taylor A, Goldring R, Gowland S (2003) Analysis and application of ichnofabrics. Earth-Science Rev 60:227–259

Todaro S (2019) The Potential Geosite of the “Libeccio Antico” Quarries : a sedimentological and stratigraphic characterisation of ornamental stone from Mt Cocuccio, Custonaci Marble District, Sicily. Geoheritage 11:809–820

Tonnon PK, van Rijna LC, Walstraa DJR (2007) The morphodynamic modelling of tidal sand waves on the shoreface. Coast Eng 54:279–296

Uchman A, Wetzel A (2011) Deep-sea ichnology: the relationships between depositional environment and endobenthic organisms, 1st edn. Elsevier B.V, Amsterdam

Vanossi M, Cortesogno L, Galbiati B, Messiga B, Piccardo GB, Vannucci R (1984) Geologia delle Alpi Liguri: dati, problem, ipotesi. Mem Soc Geol Ital 28:5–75

Villegas-Martín J, Guimar R (2017) Journal of South American Earth Sciences *Bichordites* from the early Eocene of Cuba: significance in the evolutionary history of the spatangoids. J S Am Earth Sci 80: 404–410. https://doi.org/10.1016/j.jsames.2017.10.008

Weber A, van Dalfsen J, Passchier S, et al (2004) Eco-morphodynamics of the North Sea seafloor and macrobenthos zonation. In: Marine Sandwave and River Dune Dynamics – 1 & 2 April 2004 - Enschede, the Netherlands. pp 308–313

WoRMS (2020) World Register of Marine Species (WoRMS). www.marinespecies.org. Accessed 25 Jan 2020