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SHORT NOTE: ONE WORM IN THREE SUBSTRATES: NEOICHNOLOGICAL ANALYSES OF U-SHAPE STRUCTURES IN THE GOLFO NUEVO BEACHES, PATAGONIA, ARGENTINA

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ABSTRACT

Neoichnology is an actualistic view of how organisms are connected with the place where they live, providing modern models and ideas that serve as analogous. At Chubut province (Patagonia), in the Golfo Nuevo beaches lives a polychaete that inhabits at the same time in rocky abrasion platforms and sandy intertidal sediments. The traces made by the worm can be compared with *Caulostrepsis*-like in hard substrates while in soft-sediments are comparable with *Skolithos*-*Arenicolites*- like structures. The worm builds a "chimney" over the substrate, that can be removed by tidal activity, and incorporated into the surroundings as an "ichnoclast". The present short note is intended to describe this occurrence and discuss its importance to ichnology.

INTRODUCTION

Neoichnology constitutes one of the major lines of research concerning the interaction between the biosphere and the lithosphere, adding information on the animal-substrate relationship, and constitutes a powerful tool to reconstruct the health of paleomarine ecosystems (Dashtgard and Gingras, 2012; La Croix *et al*., 2022). In this regard, most of the neoichnological studies have so far been based on invertebrate activities on soft-sediment surfaces of marine and marginal marine settings (e.g. Gingras *et al*., 1999; Hauck *et al*., 2009; Dashtgard, 2011; Ayranci *et al*., 2014) and to a lesser extent in continental environments (e.g. Davies *et al*., 2007; Genise *et al*., 2009; Hamer and Sheldon, 2010). The physicochemical features of these environments control the type and intensity of bioturbation (Dashtgard and Gingras, 2012). Neoichnological studies have been developed on marginal marine settings with different tidal ranges (Hauck *et al*., 2009), but there are no examples of bioturbation in fully-marine settings of macrotidal ranges (>4m). In the same way, examples of modern bioturbation

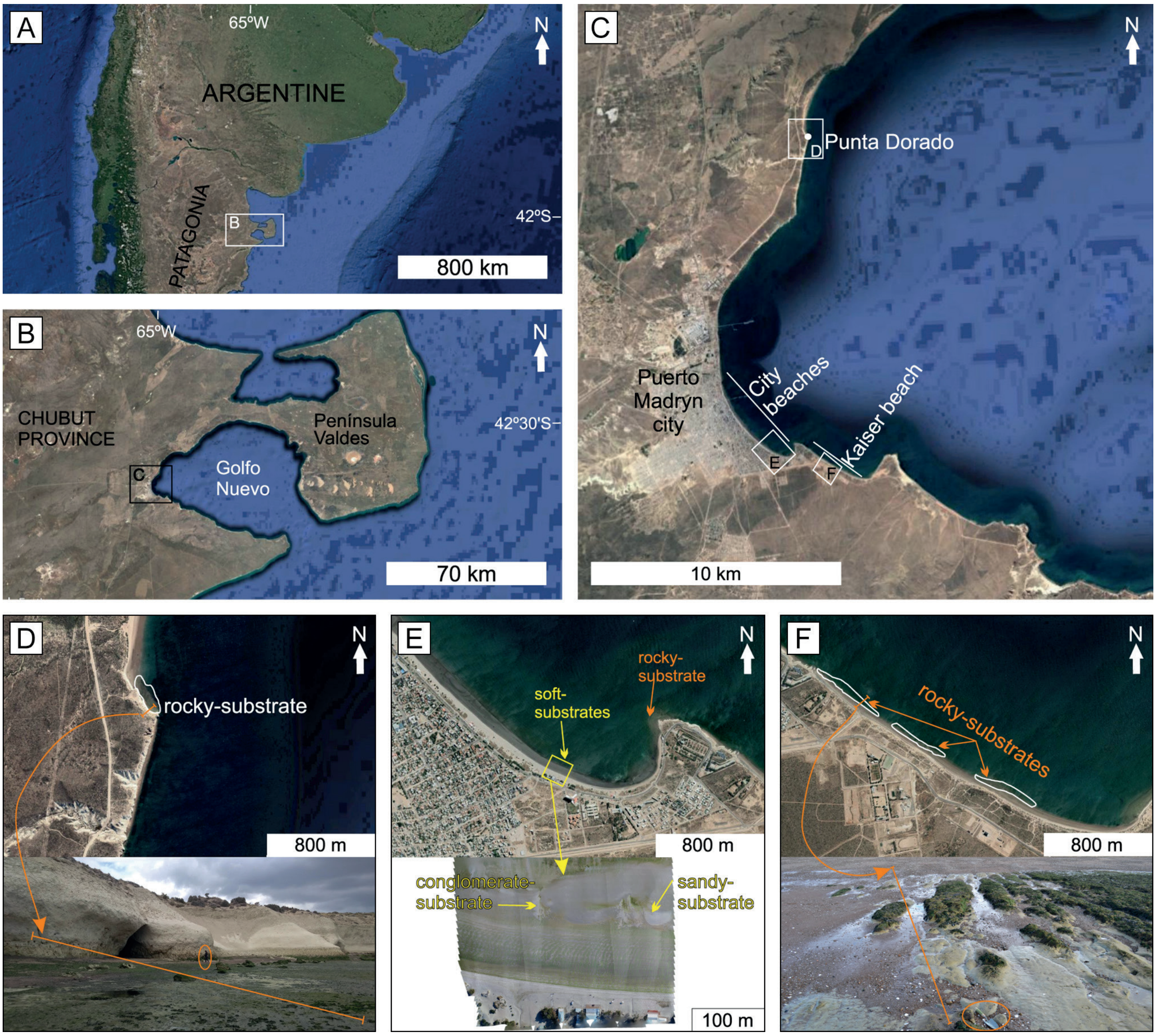

Figure 1. Study area. a, b) Location of the Golfo Nuevo in the Argentinean Sea context. **c)** Puerto Madryn city and the three coastal zones analyzed. **d)** Rocky intertidal substrates (abrasion platforms) at the Punta Dorado locality. **e)** Sandy- and conglomerate beaches in the city zone. **f)** Rocky intertidal substrates (abrasion platforms) at Kaiser Beach. Scale: in d) person = 1.7m; f) shovel= 30cm.

by one organism in different substrates are not common in the ichnological and sedimentological literature, but they can be found digging into the biological sciences (e.g. Radashevsky *et al*., 2019 and references therein), published from a complementary perspective.

The Golfo Nuevo (Chubut province, Fig. 1) constitutes an interesting case study for neoichnology in a fully-marine context, showing macrotidal coasts and cold waters. The objectives of this short note are: firstly, to identify the traces made by worms of *Boccardia proboscidea* (Annelida: Spionidae) both in hard- and-soft-substrates; second, to classify the traces using known ichnotaxa; and finally, promote a discussion that helps in reconstructions of past depositional settings.

STUDY AREA AND METHODS

The modern Argentine littoral along Patagonia is characterized by sandy and coarse sandy substrates in the north while gravel-sandy sediments in most of the central and southern regions (i.e. Parker *et al.*, 1997). Rocky cliffs are found along several coastal sectors in between. They are characterized by high coasts formed on volcanic Jurassic and Tertiary rocks and Quaternary sediments. The tidal range is mostly macrotidal (> 4 m) in many areas (Golfo San Matías and Golfo Nuevo; from Puerto Deseado to Tierra del Fuego). Most of the Patagonian littoral is characterized by open marine conditions in temperate and Subantarctic cold temperate waters, with salinity ranging from ca. 34 - 34.5 ‰ and temperatures reaching 3–11 ºC in winter and 5.5-14.5 ºC to 18 ºC in summer (Hoffmann *et al.*, 1997). Two main shallow oceanic currents influence the modern Argentine littoral: especially, from the south the cool (subantarctic) Malvinas Current (MC; 5-19ºC and 33.5‰) (Piola *et al.*, 2018) and northwards, the warm (subtropical) Brazilian Current (BC; 19-27ºC and 35-37‰). In this Patagonian context, the Golfo Nuevo is located in Chubut province (Fig. 1), developed in a fully-marine embayment, of macrotidal coast and cold waters.

At the coastal sector near Puerto Madryn city observations concerning neoichnology were made at sandy- and rocky-beaches. Sedimentological descriptions and sampling were carried out while traces were photographed in detail. Samples of traces were obtained for laboratory studies at the binocular loupe.

RESULTS

In the coastal sector of the Golfo Nuevo, at Puerto Madryn city (Fig. 1), the U-shape traces were identified in different beaches and substrates. The trace-maker was found on sandy- and rocky-coasts in the study area, living at the intertidal zone. It is the annelid *Boccardia proboscidea* (Annelida: Spionidae), an invasive annelid arriving from the northern hemisphere (Radashevsky *et al.*, 2019 and references therein).

In the first example, the traces were recorded in hard substrates developed as abrasion platforms in the intertidal zone. Lithologically they correspond to siltstones that belong to the Miocene Gaiman Formation (Cuitiño *et al.*, 2019). The second case is developed on intertidal bars, in soft sandy substrates. Finally, the same traces (and the trace-makers) are recorded in a non-cemented, but firm, orthoconglomarate at the intertidal zone.

Traces in substrate-1

The traces were firstly studied in hard substrates for the excellent preservation that they show, and the U-shape traces can be considered as *Caulostrepsis*-like structures into the abrasion platforms (Figs. 1D-F; 2). The intertidal area (Fig. 2 A-C) has two configurations, intertidal sandy backshore (Fig. 2B) or intertidal abrasion platform-cliff (Fig. 2C). In any case, the traces are recorded in the rocks cropped out in the intertidal zone. The trace-maker was found in situ in the hard substrate (Fig. 2D-F). In transversal view the traces show a U-shaped morphology of up to 3cm and the cross-section of the tubes is 1-2 mm wide (Fig. 2 G-I). In plain view, it is possible to recognize multiple two-joined openings (Fig. 2D, J-M). The traces are normally filled with black sand and are homogeneously distributed throughout the rock surface (Fig. 2M), but in some cases, it was observed that traces follow preferential zones of the abrasion platform, mainly into the scours (Fig. 2 N-O).

Traces in substrate-2

The second substrate where the traces were recorded is a loose, fine-grained sandy intertidal dune (Figs. 1E, 3A). In this case, the traces present a sandy-agglutinated wall that protrudes off the surface up to 5mm with a diameter of 2-3mm (Fig. 3B-D). The sandy tubes are resistant to the tidal current action, and they also can be recorded as “ichnoclasts” in the ripple depressions (Fig. 3E). In other cases, the traces show a clean external surface, without a wall (Fig. 3F). This situation was observed at the lab after one month in the binocular loupe (Fig. 3G), showing the high potential of preservation of the traces.

The traces in substrate-2 can be assigned as S*kolithos*-*Arenicolites*-like structures.

Traces in substrate-3

The third type of substrate is an orthoconglomerate, constituted by pebbles (up to 3cm) with a fine-grained sandy matrix (Figs. 1E, 3A). In this case, the traces are present in two different ways (as in the second substrate): (1) with a sandy wall or (2) without a wall. In figure 3B is possible to observe small (1mm wide) tubes in the sandy matrix, and below the sediment the trace-makers are present

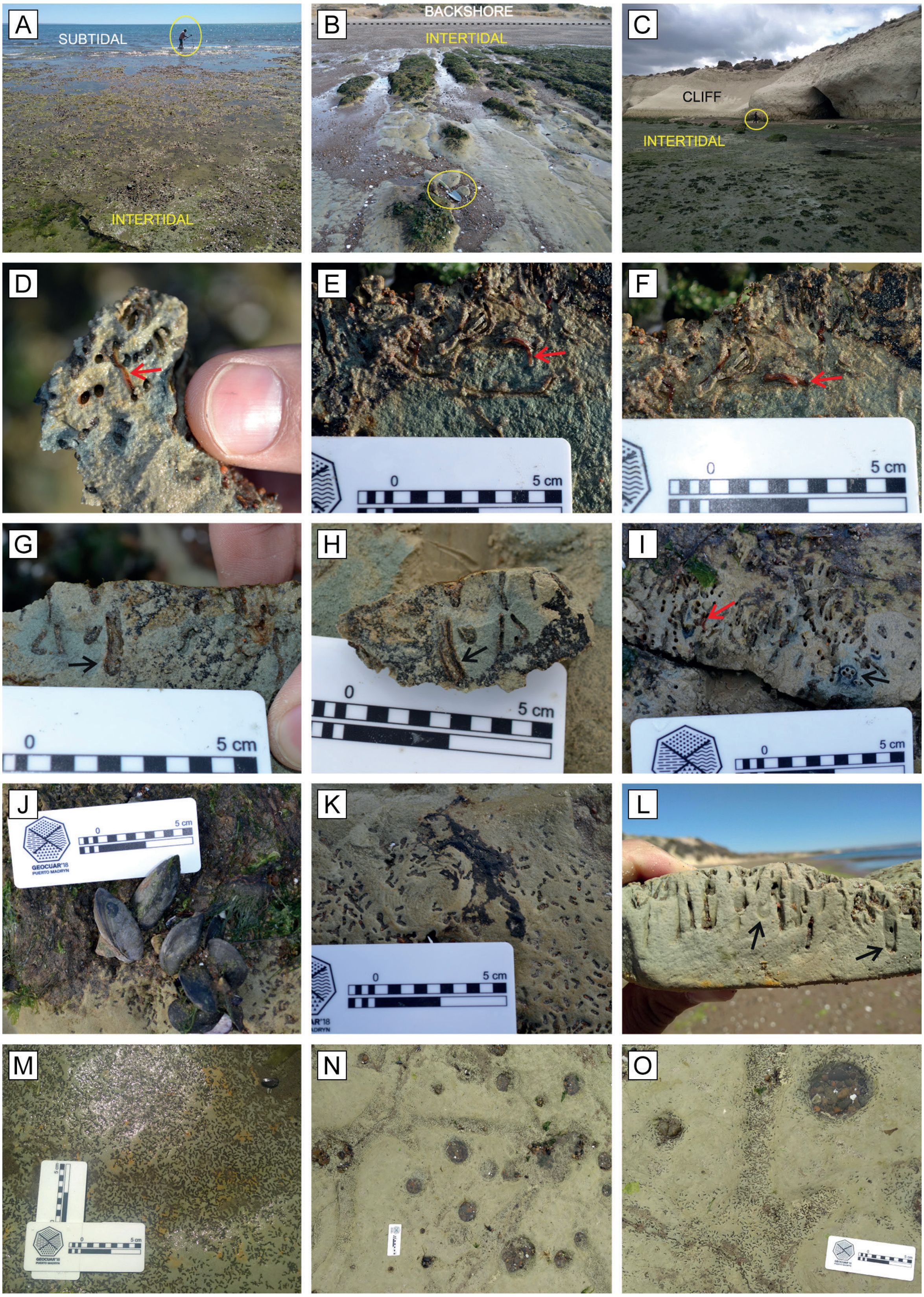

Figure 2. Traces in hard substrates. a, b, c) Intertidal abrasion platforms at the study area. In b) the intertidal area is closed to backshore dunes, while in c) it finishes with a cliff. **d-l)** different views of the traces developed on the silt deposits of the Miocene Gaiman Formation. The red arrow marks the trace-maker in situ. In j) the relationship with other organisms (bivalves) is shown. **m-o)** View of the intense bioturbation, either at the whole surface or concentrated at the scours. Scale: in a, c) person = 1.7m; c) shovel= 30cm.

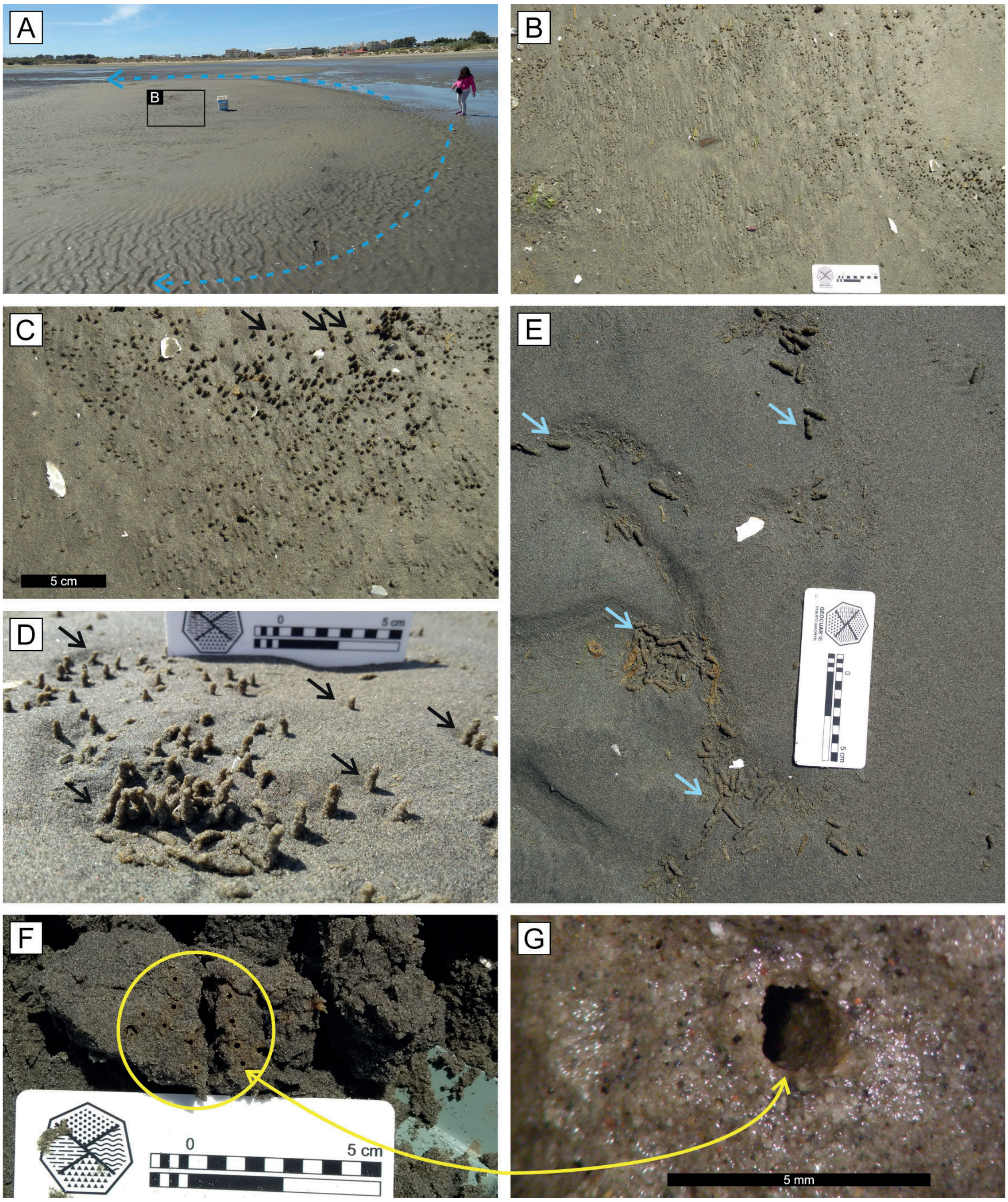

Figure 3. Traces in loose, sandy substrates. a) General view of the sandy dune, limited by return channels (blue dash lines). **b-d)** Pictures showing the density of traces in the intertidal sand, where it is clear the sandy wall of the traces protruding from the bottom (black arrows). **e)** "Ichnoclasts" distributed in the ripples around the traces (blue arrows). **f,g)** Sample of the bioturbated sand showing the consistency of the tubes and the oxidizing halo around them. Note that the picture g) was taken one month after sampling. Scale: in a) person = 1.4 m.

(Fig. 3C). In other areas of the same conglomerate deposit, the traces are developed without a sandy-wall (Fig. 3D-E) with a diameter of 1-2 mm wide.

Similar to substrate-2, the traces can be assigned as *Skolithos-Arenicolites*-like structures.

DISCUSSION AND CONCLUSIONS

Traditionally, it is assumed that one ichnotaxon can be produced by different organisms and that one organism can produce different traces. Nevertheless,

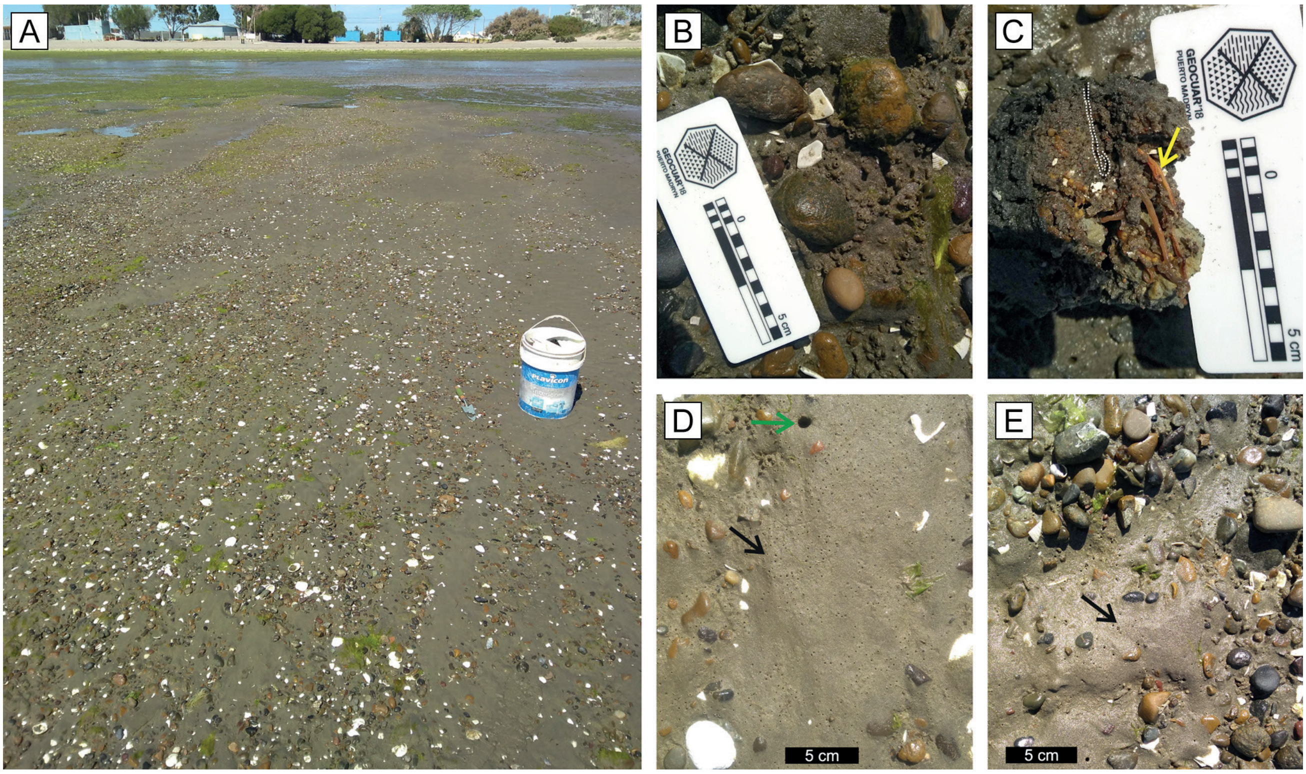

Figure 4. Traces in firm, orthoconglomerate substrates. a) General view of the orthoconglomerate deposits at the beach. It is important to highlight that this deposit was sampled in 2020 but it can be observed on Google Earth images since 2018, showing its persistence. **b-e)** Pictures of traces developed on conglomerates with different proportions of sandy-matrix. In c) the trace-maker in situ (yellow arrow) and in d) an associated trace (green arrow). Scale: bucket= 50 cm.

the presence of one trace-maker in different substrates is not a common case study. It is highly known that ichnotaxa can be preserved on different lithologies on the fossil record (examples in Buatois and Mángano, 2011), but the presence of one worm in three different substrates here documented is an interesting highlight for the ichnological community. The substrate is considered one of many controlling factors for trace development (together with oxygenation, salinity, turbidity, energy and others), influencing the trace-maker method required to burrow (Bromley, 1996). In this case study, this trace is developed on rocky substrates composed of Miocene siliciclastic siltstones, while the same worm was registered making similar traces in soft substrates (sand and orthoconglomerate), showing different adaptations of the organism for living in the coastal region of the Golfo Nuevo. These adaptations and strategies were previously known in biological works (e.g. Radashevsky *et al.*, 2019 and references therein), but uncommonly discussed in ichnological literature. This lets us think that there is a world full of information waiting to be read by other eyes and thoughts. Especially for studies of paleodiversity, it is very important to generate information about the trace-makers, not just to document what kind of traces are originated by a particular taxon, but to imperatively know if the same organism can generate different structures on different substrates or if the traces change under variable environmental conditions (see Zonneveld, 2016 for a discussion of this topic).

The sandy-agglutinated wall is recorded at the three substrates considered (Figs. 2-4) but preserved in diverse ways. At hard-substrate and orthoconglomerate sediments, the sandy wall is a projection of the tube that comes out from the bottom surface up to 2-3mm. In the case of sandy substrates, the sandy wall is not only a surficial extension of the infaunal tubes, but also generates “ichnoclasts”, recovered in the ripples near the traces. This situation was mentioned by Bromley (1996), who described it as “Chimney-building worms”, and also mentions the relationship between the “chimneys” and ripples. In the case study at Golfo Nuevo, the erosion and redeposition of the “ichnoclasts” is related to tidal current activity. Another interesting aspect to consider is that these trace-makers change the substrate not just physically, but also chemically, as it is shown by the presence of an oxidized halo around some tubes (Figs. 2D-I, 3F). Considering bioerosion, the traces can be assigned to *Caulostrepsis*-like, which is one of the most common traces in the marine Quaternary deposits at Patagonia (e.g. Richiano *et al.*, 2017; 2021). On soft sediments, the traces fit the classification as *Arenicolites*-like structures. The traces are very similar in shape and size, made by one trace-maker but registered in different lithologies. According to Bertling et al. (2007), “very few living borer species are common to more than one such substrate”. Nevertheless, even when the substrate is not considered an ichnotaxobase, they recommend keeping the names separated, as they provide important information about the trace-maker behaviour.

Finally, more studies are needed on neoichnological aspects all around the world (especially in the Southern Hemisphere) to help reconstruct the paleo communities and environments of the sedimentary record and paleodiversity with lesser uncertainties.

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