



Numerous Sublinear Sets of Holes in Sediment on the Northern Mid-Atlantic Ridge Point to Knowledge Gaps in Understanding Mid-Ocean Ridge Ecosystems

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On 13 July 2004, during an expedition exploring biodiversity along the northern Mid-Atlantic Ridge, an ROV dive recorded videos of numerous sublinear sets of holes in sediment at ca. 2,082 m depth. The location was north of the Azores. Each set appeared track-like. Lengths of individual series ranged from < 1 m to many meters. Each was straight or gently curved. Some series intersected or crossed. Close examination of the holes showed them to be elongate, with the long axis parallel to the axis of the series. The holes were ca. 6 × 1.5 cm, with distance between holes similar to hole length. The holes that appeared to be most recently formed were each surrounded by raised sediment. Holes that appeared older were partly filled with sediment and the raised surrounding sediment was less obvious. Overall, these lebensspuren created small-scale heterogeneity in the local soft-bottom benthic ecosystem. The source of the holes or how they were constructed is unknown, but the raised sediment may indicate excavation by an infaunal organism or digging and removal by e.g., a feeding appendage of a large epifaunal animal. None of our closeups showed any sign of living organisms inhabiting the holes. Whether the holes were connected beneath the sediment surface was not visible. The traces observed are reminiscent of ichnofossils reported from deep marine facies. We hope that future studies of the lebensspuren we report here will resolve the mystery of what created them.

Keywords: lebensspuren, ichnofossils, ROV, Azores, MAR-ECO

INTRODUCTION

“Lebensspuren” is a term used in early reports of photography of the deep-sea bottom (Ewing and Davis, 1967; Heezen and Hollister, 1971). It translates as “life traces” and refers to patterns in surface sediments resulting from bioturbation. The study of these extant life traces (neochronology) is a modern equivalent of paleoichnology, which is generally concerned with fossilized tracks, trails, burrows, borings, or other trace fossils (ichnofossils) and integrates paleontology, sedimentology, and biology. Understanding the distribution and diversity of lebensspuren is ecologically important because these traces introduce a variety of small-scale heterogeneity in surface sediments and affect

the accumulation of pelagic detritus at the sediment-water interface. Furthermore, lebensspuren are often the only indication in visual surveys of the presence of infaunal or mobile animals capable of avoiding camera platforms.

The decade-long Census of Marine Life (CoML) was a global program to increase knowledge of marine biodiversity (McIntyre, 2010). One field project within CoML, entitled Patterns and Processes of the Ecosystem of the Northern mid-Atlantic (MAR-ECO), focused on the Mid-Atlantic Ridge between Iceland and the Azores (Bergstad et al., 2008; Vecchione et al., 2010) using a broad suite of methods (Wenneck et al., 2008). Although often thought of as primarily hard substrate, the Mid-Atlantic Ridge is largely covered with sediment (Niedzielski et al., 2013; Priede et al., 2013a). At one of the sediment-covered MAR-ECO locations, we encountered numerous widespread lebensspuren in a pattern that seemed reminiscent of tracks from an unknown animal. We describe here those traces in the sediment and consider their similarity to ichnofossils.

METHODS

The flagship expedition for the MAR-ECO project was conducted on the R/V *G.O. Sars* during June–July 2004. Among the methods employed was a series of dives with two remotely operated vehicles (ROVs). These dives observed and recorded standard-definition video of benthic epifauna and substrata at 22 locations between the Azores Archipelago and the Charlie-Gibbs Fracture Zone, with bottom depths surveyed between 900 and 3,500 m.

The ROVs were equipped with four parallel lasers for measurement. However, laser measurement was problematic

on the dive described below because two of the lasers were not functioning. The remaining two were from different pairs (i.e., opposite corners of the square pattern) and therefore illuminated different distances from the ROV, resulting in a parallax problem. We therefore used objects of known size (shells of the pteropod *Clio recurva*, maximum reported length ca. 3 cm) near the holes to estimate the size of the holes. Distances from previously published locations were calculated using the NOAA Latitude/Longitude Distance Calculator.¹

RESULTS

On 13 July 2004, ROV *Bathysaurus* was used to explore benthic habitats centered around 2,082 m depth in the vicinity of 42° 56' N 028° 36' W (Figure 1). Video was recorded throughout the dive (Figure 2). During a period of > 1 h the ROV traversed areas where surface sediments were perforated by many sublinear series of holes. Bottom depths of these observations were 2,074–2,097 m and the near-bottom temperature was 3.6°C.

Lengths of individual series ranged from < 1 m (Figure 2C) to many meters (Figure 2A). Each series was nearly straight (Figure 2C) or gently curved (Figure 2B). Some series intersected or crossed. Close examination of the individual holes showed them to be elongate, with the long axis parallel to the axis of the series. Based on comparison with nearby shells of *Clio recurva*, the holes were ca. 6 × 1.5 cm, with distance between holes similar to hole length. The shape of the holes varied from narrow and acute (Figure 2H) to a more

¹<https://www.nhc.noaa.gov/gccalc.shtml>

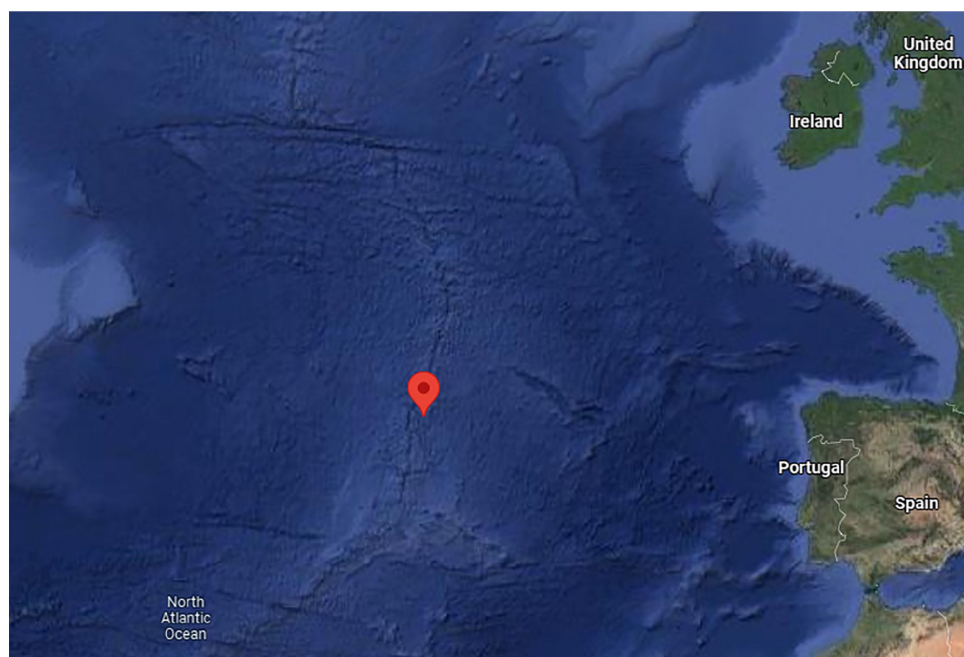


FIGURE 1 | Google Maps representation of the dive location (42° 56' N 028° 36' W), on the Mid-Atlantic Ridge north of the Azores Archipelago.

rounded appearance (**Figure 2G**). The holes that appeared to be most recently formed were each surrounded by raised sediment (**Figures 2C,F**). Holes that appeared older were partly filled with sediment and the raised surrounding sediment was less obvious (**Figure 2E**). In areas where the seafloor

was covered by extensive phytodetritus, the holes were often filled with phytodetritus (**Figure 2C**). None of our closeups showed any sign of living organisms inhabiting the holes (**Figures 2G,H**). Nor could we detect subsurface connections between adjacent holes.

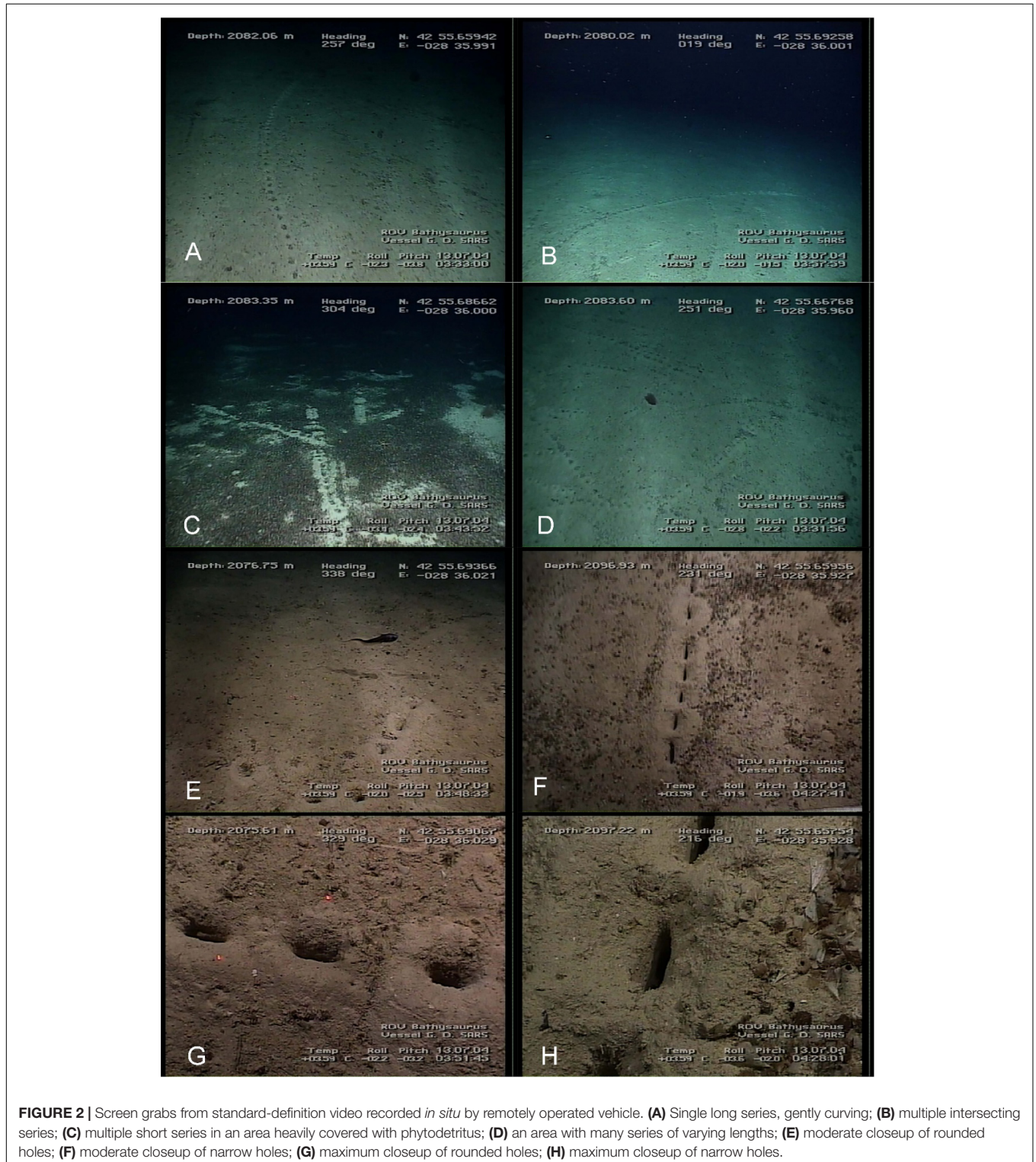


FIGURE 2 | Screen grabs from standard-definition video recorded *in situ* by remotely operated vehicle. **(A)** Single long series, gently curving; **(B)** multiple intersecting series; **(C)** multiple short series in an area heavily covered with phytodetritus; **(D)** an area with many series of varying lengths; **(E)** moderate closeup of rounded holes; **(F)** moderate closeup of narrow holes; **(G)** maximum closeup of rounded holes; **(H)** maximum closeup of narrow holes.

DISCUSSION

When we first encountered these formations, we referred to them as track-like (Vecchione et al., 2010). We speculated that they may have been caused by a large benthic crustacean, such as the blind lobster (*Acanthacaris caeca*). However, there is no evidence to support that speculation.

Bell et al. (2013), following Przeslawski et al. (2012), quantified many types of lebensspuren at four locations in the vicinity of the Charlie-Gibbs Fracture Zone explored by the ECOMAR project (Priede et al., 2013b), all far north of the location we describe here. Our rounded-hole morphotype is similar to a type they termed “pogo stick tracks” of indeterminate origin, but the latter appeared to have even more rounded holes, grading to circular. The latter was found only at their SouthEast station (SE; 49° 02′ N, 027° 41′ W), with very low occurrence there. They also mentioned a type termed “Indeterminate perforated trail” encountered in low numbers at their NorthWest station (NW; 53° 59′ N, 036° 07′ W). Whereas their SE station is closest to our location (682 km), the NW station is farthest from it (1,345 km). The linear series of holes we report here may be related to either of these rare categories in Bell et al. (2013) study, but in contrast to their rarity at the locations farther north, our series comprise the dominant small-scale structure in surface sediments of the area on which we report. South of our location, Heezen and Hollister (1971) observed “crater rows” at three sites, 1,471–1,723 m water depth, around the Azores.

The raised sediment may possibly have been pushed aside by insertion of e.g., a feeding appendage of a large epifaunal animal but it may alternatively indicate excavation by infauna. Therefore, it is not clear whether these should be considered crawling, feeding, or residence structures (three of the five categories considered by Bell et al., 2013). The traces we observed are reminiscent of ichnofossils, such as *Paleomeandron*, reported from deep marine facies (Buatois et al., 2001), although the latter is smaller and is interpreted as a system of burrows having vertical shafts, which appear at the sediment surface as a series of paired holes. This interpretation of surface elements of such “graphoglyptid” trace fossils as a horizontal subsurface tunnel (Seilacher, 1977; Fan et al., 2018) connected upward to the surface of the sediment would not be visible in our videos. However, the paired series of holes characteristic of *Paleomeadron* appear more complex than the observed burrows reported here. Other trace fossils that might be analogs include *Treptichnus pedum* or *Hormosiroidea canadensis*, as illustrated by Laing (2018) with possible explanations by Crimes and Anderson (1985) for how such traces may have been produced. But *T. pedum* is even smaller than *Paleomeandron* and occurs in Lower Paleozoic shallow marine deposits. Other *Treptichnus* are mostly continental traces. *Hormosiroidea canadensis* was included in

Saerichnites in Uchman (1995), a fact overlooked in the Ph.D. thesis by Laing (2018).

Perforation of the sediment by numerous holes would affect the vertical distribution in nearby sediment of oxygenated pore water, in turn affecting habitat suitability for infauna. Additionally, the local aggregation of sediment backfilling old holes and the very local accumulation of phytodetritus within the holes would change small-scale availability of food for epifaunal grazers and surface-deposit feeding infauna.

We think our current state of knowledge about these lebensspuren is similar to early studies of extant lebensspuren identified as *Paleodictyon* based on resemblance to other ichnofossils. Those geometric traces are widespread in deep-sea sediments (Durden et al., 2017). Subsequent investigation has inferred the inhabitants of such geometric traces may be a compressed form of a hexactinellid sponge adapted to sedimentary substrate (Rona et al., 2009) but this inference is not considered to be confidently resolved (Durden et al., 2017). Our goal here is not to inventory known ichnofossils and identify our traces as the same as, or related to, the most similar fossil. We simply want to point out that the fossil record includes traces in deep-marine facies that are similar to these locally abundant traces in the deep-sea sediment of the Mid-Atlantic Ridge. Although we don't know what caused them, similar processes have likely been going on in deep sedimented areas for a very long time. We hope that future studies of the unknown lebensspuren we report here will resolve the mystery of what created them and their roles in mid-ocean ridge ecosystems.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. These data can be found here: original videos on which this contribution are based are available from the Institute of Marine Research, Norway.

AUTHOR CONTRIBUTIONS

OB planned and arranged ROV dives. MV drafted manuscript which OB revised. Both authors participated equally in conducting and interpreting observations.

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