Marine Geology 397 (2018) 72–78

Contents lists available at ScienceDirect

Marine Geology

journal homepage: www.elsevier.com/locate/margo

# Lateral variability of ichnofabrics in marine cores: Improving sedimentary basin analysis using Computed Tomography images and high-resolution digital treatment

Francisco J. Rodríguez-Tovar[a,*], Javier Dorador[a,c], Anxo Mena[b,c], F. Javier Hernández-Molina[c]

[a] *Dpto. Estratigrafía y Paleontología, Facultad de Ciencias, Universidad de Granada, 18002 Granada, Spain*
[b] *Dpto. Xeociencias Mariñas e O.T., Universidade de Vigo, 36310 Vigo, Spain*
[c] *Dept. Earth Sciences, Royal Holloway University of London, TW20 0EX Egham, United Kingdom*

ARTICLE INFO

*Keywords:*
Ichnofabrics
Computed Tomography
High resolution image treatment
Galicia Bank
Deep-water sedimentary environments
Last Glacial Maximum
Heinrich Event 1

ABSTRACT

Major ichnofabric attributes may be related to a number of limiting marine parameters for tracemakers with paleoenvironmental significance, including ocean/atmosphere dynamics. This is why ichnofabric analysis has proven to be a very useful tool in sedimentary basin analysis — as well as in other Earth Science disciplines — although it is a comparatively recent approach in ichnological research. Ichnofabric characterization is usually based on 2D visual observations of a single view in both outcrops and cores. Yet ichnofabric features can vary vertically and laterally within a very short-distance, which may lead to misinterpretations. Here, a new methodological approach is presented, allowing for a more objective evaluation of ichnofabric features, based on the high-resolution digital treatment of Computed Tomography images on marine sediments cores. The method evaluates variations in ichnoassemblages, cross-cutting relationships, and the degree of bioturbation structures in nearby selected images pertaining to several sections of the same interval of a core. Average values of the obtained data imply a significant improvement of the resolution than 2D observations, and therefore a more precise and objective characterization of ichnofabrics. The usefulness of the method and its differences with respect to traditional ichnofabric analysis are exemplified by a study of the gravity core FSG09-10 (Galicia Bank domain, NW Iberian Peninsula), showing as a very significant tool to interpret paleoenvironmental changes (i.e., sedimentation rate, nutrient availability, and bottom water oxygenation) from the Last Glacial Maximum (LGM) to Heinrich Event 1 (HE1). This example reveals the importance of proposed methods in order to characterize the ichnofabrics, including their lateral variability, with clear implications for future research on basin analysis.

## 1. Introduction

Ichnofabric analysis has undergone rapid growth in recent decades, demonstrating its usefulness for a number of Earth Science disciplines, and especially for paleoenvironmental interpretations in sedimentary basin analysis. This significant change is due to a refined definition of the ichnofabric concept (see Ekdale et al., 2012, for a recent review). The elements of an ichnofabric may be related to a number of factors, involving: a) biological (e.g., ethology and mode of fabrication, evolution of tracemakers), b) physical (e.g., grain size, composition of the substrate, oxygenation, nutrient levels, salinity, sedimentation rate), and c) taphonomic aspects (e.g., Ekdale et al., 1991; Droser and Bottjer, 1993; Taylor et al., 2003). Such controls on ichnofabric features have paleobiological and paleoenvironmental significance, including ocean/atmosphere dynamics, determining the usefulness of the ichnofabric approach in disciplines as paleobiology, paleoceanography, stratigraphy, or sedimentology, with special implications for basin analysis. At present, the ichnofabric approach is based on the integration of an array of data, including detailed information on major ichnofabric attributes such as primary sedimentary structures, ichnological diversity, ichnological features (i.e., dimensions of ichnotaxa), cross-cutting relationships, tiering structure and degree of bioturbation structures (Taylor et al., 2003; Buatois and Mángano, 2011; Ekdale et al., 2012). Recently, a method based on a high-resolution digital image treatment was applied to modern marine cores, facilitating trace fossil visualization, hence ichnotaxonomic determination (Dorador et al., 2014a; Dorador and Rodríguez-Tovar, 2015; Dorador and Rodríguez-Tovar, 2018 for a recent review), as well as quantification of the degree of bioturbation (Dorador et al., 2014b), analysis of penetration depth (Dorador and Rodríguez-Tovar, 2014), and characterization of cross-

* Corresponding author.
*E-mail addresses:* fjrtovar@ugr.es (F.J. Rodríguez-Tovar), javidr@ugr.es (J. Dorador), anxomena@uvigo.es (A. Mena), javier.hernandez-molina@rhul.ac.uk (F.J. Hernández-Molina).

https://doi.org/10.1016/j.margeo.2017.12.006
Received 22 September 2017; Received in revised form 8 December 2017; Accepted 17 December 2017
Available online 24 December 2017
0025-3227/ 

cutting relationships (Rodríguez-Tovar and Dorador, 2015). The method has been successfully applied to ichnofabric analysis (Rodríguez-Tovar and Dorador, 2015; Dorador and Rodríguez-Tovar, 2016).

The ichnological analysis of well cores advanced significantly in the late twentieth century, in particular when applied to deep-sea drilling cores obtained during the Ocean Drilling Program (ODP), Deep Sea Drilling Project (DSDP) and Integrated Ocean Drilling Program or International Ocean Discovery Program (IODP) expeditions, providing useful information from the subsurface material (e.g., Knaust, 2012, 2017). As underlined by Knaust (2012, 2017), ichnological research on cores can be key for interpretations of depositional environments and stratigraphic surfaces of sequence/genetic significance, among others. Yet ichnological analysis of cores also has its disadvantages, including a limited scope or restricted surface (narrowness), the almost exclusive availability of two-dimensional core slabs perpendicular or oblique to bedding, and the absence of 3D information (Bromley, 1996; Knaust, 2012, 2017). When viewing vertical slices in cores in two dimensions, individual slabbed sections are usually available, but in most cases they correspond to the central part of the core, with just a few centimeters of lateral extension. In such cases a partial or limited image of the core is obtained, complicating characterization of ichnofabric attributes such as trace-fossil identification, cross-cutting relationships, or bioturbation abundance. These drawbacks could lead to misinterpretations if short-distance lateral changes in the ichnofabric attributes are substantial, that is very important as in the case of variations in the distribution of porosity and permeability due to bioturbation, affecting reservoir fluid flow (Gingras et al., 2007, 2012, 2015; Pemberton and Gingras, 2005; Knaust, 2009, 2013; Baniak et al., 2014). Lateral heterogeneity in shallow marine ichnofabrics probed in outcrop, based on vertical cross-sections at 5 m intervals of three adjacent beds, showed the need for an improved understanding of lateral variability in ichnofabrics (McIlroy, 2007).

Recently, high resolution Computed Tomography has been demonstrated very useful to reconstruct the architecture of biogenic structures (Hale et al., 2015). When working with cores, Computed Tomography (CT) facilitates a complete view of the core, providing numerous planes of sections and from different angles, thereby enhancing lateral observation of ichnofabric features and any changes present. Accordingly, application of the high-resolution digital image treatment to several CT images from the same section of modern marine cores, could improve ichnofabric analysis and detailed interpretation. The main aim of this work is to describe new advances in the recently presented high-resolution digital image treatment by its application to CT images from marine cores. The gravity core FSG09-10, from the Galicia Bank, at the NW Iberian Peninsula (Fig. 1) displays significant short-distance lateral changes in ichnofabric features, highlighting an interpretation from the Last Glacial Maximum (LGM) to Heinrich Event 1 (HE1). The implications of this new technique for ichnofabric characterization on cores are considered and some future considerations for sedimentary basin analysis are discussed.

## 2. Geological setting

The Galicia Interior Basin (GIB) is a narrow (100 km) N-S orientated basin (Fig. 1). It is located at the NW Iberian margin, bordered by the Galicia Bank on the west and the Galicia Continental Slope on the east. The depth of the GIB ranges between 2500 and 3000 m. Along GIB, three domains are identified attending to the main sedimentary processes of each one (Fig. 1). In the eastern part, the continental slope domain represents pelagic (Holocene), hemipelagic and contourite processes; the central part of the basin records the alternation of hemipelagic and pelagic processes and the western part of the basin, close to the Galicia Bank, appears pelagic (Holocene), hemipelagic and turbiditic processes. Glacio-marine intervals (Ice Rafted Debris, IRD), identified as Heinrich Events are present along the entire basin.

The gravity core FSG09-10 (42.14°N; 10.51°W; 2779 m water depth; 230 cm long; Fig. 1) was recovered, together with other cores from the GIB to analyze the sedimentological and environmental evolution of the basin (Mena, 2014). This core is located in the Galicia Bank domain, in the west part of the GIB (Fig. 1). Core FSG09-10 consists of poorly sorted sandy mud associated to with hemipelagic, turbiditic and IRD layers facies (Mena et al., 2015). The base age of this core is around 52 ka. Pelagic sediments are restricted to the Holocene, and the hemipelagic, turbiditics and IRD layers appear in the rest of the core (Mena et al., 2015). Interlayered between the hemipelagic facies, four IRD layers (identified with Heinrich Events 1, 4, 5 and 5a) are registered, and two turbiditic intervals which appear at the base of the Holocene, and between 18 and 39 ka (Mena, 2014; Mena et al., 2015).

## 3. Methods

High-resolution digital CT imagery has been shown to be very useful for the ichnological analysis of modern marine cores from IODP Expedition 339 (e.g., Dorador et al., 2014a, 2014b; Dorador and Rodríguez-Tovar, 2015; Rodríguez-Tovar et al., 2015a, 2015b; Takashimizu et al., 2016; Hodell et al., 2017). This methodology has been successfully applied to ichnofabric analysis on individual sections

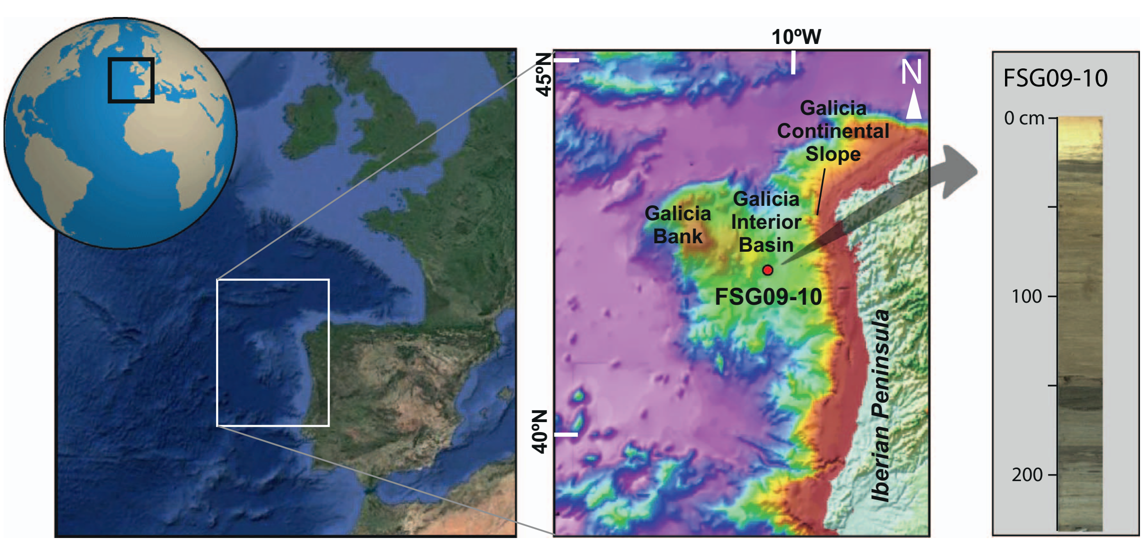


**Fig. 1.** Location and sedimentary record of gravity core FSG09-10 in the NW Iberian Peninsula.