

Quantitative estimation of bioturbation based on digital image analysis



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ABSTRACT

Quantitative determination of modification of primary sediment features, by the activity of organisms (i.e., bioturbation) is essential in geosciences. Some methods proposed since the 1960s are mainly based on visual or subjective determinations. The first semiquantitative evaluations of the Bioturbation Index, Ichnofabric Index, or the amount of bioturbation were attempted, in the best cases using a series of flashcards designed in different situations. Recently, more effective methods involve the use of analytical and computational methods such as X-rays, magnetic resonance imaging or computed tomography; these methods are complex and often expensive. This paper presents a compilation of different methods, using Adobe® Photoshop® software CS6, for digital estimation that are a part of the IDIAP (Ichnological Digital Analysis Images Package), which is an inexpensive alternative to recently proposed methods, easy to use, and especially recommended for core samples. The different methods – “Similar Pixel Selection Method (SPSM)”, “Magic Wand Method (MWM)” and the “Color Range Selection Method (CRSM)” – entail advantages and disadvantages depending on the sediment (e.g., composition, color, texture, porosity, etc.) and ichnological features (size of traces, infilling material, burrow wall, etc.). The IDIAP provides an estimation of the amount of trace fossils produced by a particular ichnotaxon, by a whole ichnocoenosis or even for a complete ichnofabric. We recommend the application of the complete IDIAP to a given case study, followed by selection of the most appropriate method. The IDIAP was applied to core material recovered from the IODP Expedition 339, enabling us, for the first time, to arrive at a quantitative estimation of the discrete trace fossil assemblage in core samples.

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1. Introduction

The beginning of the twenty-first century has witnessed a rapid growth in ichnological research, which has become relevant in a wide range of fields, e.g., palaeobiology, palaeoecology, biostratigraphy, sedimentology, and most recently reservoir characterization, involving biologists, palaeontologists and sedimentologists. In some of these disciplines, the quantitative determination of a modification of primary sedimentary features by bioturbation can prove fundamental. Such is the case of reservoir and aquifer characterization, and the impact of trace fossils and their associated ichnofabrics on fluid-flow properties, including sediment permeability and porosity (Cunningham et al., 2012; Gingras et al., 2012).

The intensity of bioturbation is characterized by the use of semi-quantitative index schemes (i.e., Marengo and Bottjer, 2011; Ekdale et al., 2012; Knaust, 2012), the most common ones being the “Bioturbation Index” (BI) (Reineck, 1963) and “Ichnofabric Indices” (ii) (Droser

and Bottjer, 1986). The “Bioturbation Index” of Reineck (1963), later revised by Taylor and Goldring (1993), was initially applied to box cores and has a scale from Bioturbation Index = 0 (no bioturbation) to 6 (completely bioturbated). In turn, the “ichnofabric indices” of Droser and Bottjer (1986), widely used in ichnological research, range from ichnofabric index = 1 (no bioturbation) to ichnofabric index = 6 (sediment nearly or totally homogenized), and rely on the use of flash cards for an easy visual assessment of the intensity of bioturbation. A modification of the ichnofabric indices, the “Bedding Plane Horizontal Index” (BPHI), was proposed by Miller and Smail (1997) for the degree of bioturbation on originally horizontal planes. All three methods are easy to apply and inexpensive; however, they are mainly based on visual observation, using grades or scores that represent different ranges of percentage, thus bearing the possibility of a subjective inaccuracy for estimation of bioturbation intensity.

In the wake of the early semi-quantitative approaches of Reineck (1963), Droser and Bottjer (1986) and Taylor and Goldring (1993), more objective methods appeared that involved either grid-based techniques, computer-aided image analysis or advanced image technology (Marengo and Bottjer, 2011). Grid-based methods, which can be used with different scales of grids, are particularly useful for estimating the quantity of bioturbation on bedding planes or on vertical cross-sections (Heard and Pickering, 2008; Marengo and Bottjer, 2010). They are inexpensive and simple to perform, requiring little specialized equipment, but they are time-consuming and accuracy depends on grid

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and trace sizes. Computer-aided image analysis has been used to improve the visibility of complex ichnofabrics in photographs (Magwood and Ekdale, 1994; Dorador et al., 2014), and to estimate the amount of bioturbation (Francus, 2001; Löwemark, 2003). Computer-aided image analysis is appropriate for specialized applications, such as thin-sections or x-radiographs, and sometimes calls for the use of scanning electron microscopy; a further limitation is the reduced field of view. Image techniques, such as x-radiography (e.g., Löwemark, 2003; Marengo and Bottjer, 2008), computed tomography (e.g., Fu et al., 1994; Dufour et al., 2005), and magnetic resonance imaging (e.g., Gingras et al., 2002), have been recently applied to acquire information on trace fossils and ichnofabrics, but scarcely applied for estimation of the amount of bioturbation (e.g., Dufour et al., 2005). Except for x-radiographs, imaging techniques as computed tomography and magnetic resonance imaging are complex and very expensive.

This paper presents a novel, easy to use, and inexpensive package (IDIAP; Ichnological Digital Analysis Images Package) of different methods for digital estimation of discrete trace fossil assemblage in digital images using Adobe® Photoshop® software CS6. The method can be applied on images of samples acquired from outcrops and cores, but is especially appropriate for the latter due to the specific features of cores (i.e., limited size, restricted surface, among others) making ichnological research difficult. The package consists of three different methods enabling its application in a great variety of material having different sediment and ichnological features. We demonstrate the usefulness of the IDIAP by applying it to core material from the IODP Expedition 339 (Fig. 1).

2. Ichnological Digital Analysis Image Package (IDIAP)

The Ichnological Digital Analysis Images Package (IDIAP) integrates three methodologies of digital image analyses: the “Similar Pixel Selection Method (SPSM)”, the “Magic Wand Method (MWM)” and the “Color Range Selection Method (CRSM)” (Fig. 2). IDIAP provides a quantitative assessment of the percentage of area occupied by discrete trace fossils in core material. Depending on the particular sediment and its ichnological features, any one of the three methods may be considered more appropriate, or an integrative approach using all of them may be best.

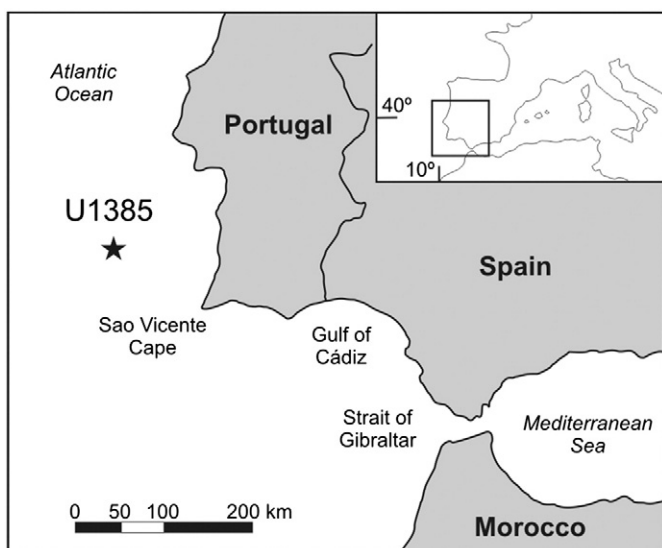


Fig. 1. Geographical map showing the west Iberian Margin with location of site U1385 from the IODP Expedition 339.

2.1. Similar Pixel Selection Method (SPSM)

This method allows finding pixels on the full image with values in the range of those pixels registered in a previously selected particular area, which correspond to the studied trace fossil. It is useful when objects need to be selected with a variable range of colors because an area with a certain number of pixels is chosen. In cases where objects cannot be defined by only one pixel color, this method has a major advantage. A representative area within the desired object is selected using any Photoshop selection tool. After that, click ‘Select’ in the menu bar and choose ‘Similar’. The method’s great disadvantage, however, is that the selection sensitivity cannot be modified; it is not useful if the difference between pixels is low. Further, it can only be executed once; if there are different objects of different colors, they cannot all be selected. The SPSM may be considered as a more complete and easier method than the one presented by Honeycutt and Plotnick (2008). The method used by Honeycutt and Plotnick (2008) is an automatic quantitative method to determine the Bioturbation Index using the complex software Matlab 7.1 ® from digital images, based on gray-level matrices (one value per pixel) while the SPSM uses an easier software based on digital color images (three values per pixel).

2.2. Magic Wand Method (MWM)

This method alludes to the ‘Magic Wand Tool’ used by Coimbra and Olóriz (2012) for the manual selection of objects; this tool selects pixel nearby (by default) having similar variations of color of the previously selected pixel. The maximum percentage difference between the reference pixel and the selected pixels is defined by a parameter called ‘Tolerance’. This method has been used to derive percentage estimations of bioclasts and other applications, but not to ichnological data, based on pixel counting using Adobe® Photoshop® software CS2 (e.g. Perring et al., 2004; Johansson et al., 2008). It can be time-consuming, especially if there are small objects in the image, calling for clicks on each object to be selected. However, it affords the great advantage of multiple executions. To proceed, the ‘Magic Wand Tool’ is selected and one representative pixel within each object is chosen. The sensitivity is controlled by ‘Tolerance’ that can be modified in the menu bar until obtaining the desired selection. To add more than one object, simply click on the ‘Add to selection’ option in the menu bar and click on a new object. Especially, when objects are large and possess more than one color this method is useful. Additionally, the method can be modified to be applied to the complete given image. It even works with smaller objects when these clearly differ from the background.

The pixels selected can be manually modified with different tools if there is any object whose selection is not possible with one of these automatic methods.

2.3. Color Range Selection Method (CRSM)

This method is based on the localization of pixels in the whole image that are similar to only one manually selected. It shares a great advantage with the SPSM: the selection extends over the full image, but in the case of the CRSM only one representative pixel can be selected, while in the SPSM all pixels registered in the selected particular area are considered by the method. The method allows choosing a selection or a desired pixel range with the modification of a parameter called ‘Fuzziness’. This method is the quickest and most useful when there are a lot of small objects of the same or similar color. In order to execute it choose ‘Select’ from the menu bar and click on ‘Color range...’, and a window opens. You may define the reference color to extend the selection, but the best and easiest way to select similar objects is to choose ‘Sampled Colors’. Under this option, the cursor is a sampled color, and you have to click on a representative pixel of the object color. Then, a selection takes place, and it can be viewed in a little window so that the

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