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Litho- and biofacies analysis of postglacial marine mud using CT-Scanning

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ABSTRACT

Marine silty clay deposited during the Late-Wisconsinian postglacial marine transgression of eastern Québec (Goldthwait Sea) is ubiquitous in the sedimentary column of intertidal zones of the St-Lawrence Estuary. This mud is very compact and limits the penetration of organisms composing the modern *Macoma balthica* community. In order to describe the characteristics of intertidal sediments containing Goldthwait Sea mud, axial tomography (CT-Scan) is used. CT-Scan is a non-destructive method that can be used to describe sediment characteristics (grain size, mineralogy, primary and secondary sedimentary structures, fabric, shape and roundness, bedding contact), and to obtain high resolution, 3D representations of structures within sediment cores. Based on differences in the densities of analysed materials, the different lithologies, lithofacies, and organisms within the core can be discriminated, and a quantification of the volume occupied by the different components of the material can be made. Here, CT-Scan images provide information on the distribution, orientation and interweaving of thanatocœnosis shell beds that alternate with massive or faintly laminated postglacial marine mud beds, as well as on ichnofacies characteristics. In addition, we show 3D images of bioturbation structures within the recent sediment layer, which is distinguished from the underlying Goldthwait Sea mud. When coupled with conventional sedimentary (grain size statistics) and radiochronological (^{14}C) analyses, these data provide information which is valuable for identifying depositional processes within sedimentary environments.

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1. Introduction

The Laurentide Ice Sheet (LIS) is estimated to have retreated from the southern sector of the St-Lawrence Estuary between 13 500 and 12 500 years BP (Dionne, 1977; Dyke and Prest, 1987). Immediately following its retreat, marine waters invaded this glacio-isostatically depressed basin to form the Goldthwait Sea transgression (e.g., Dionne, 1977). During this postglacial transgression, large volumes of fine sediments were transported and deposited in this marine setting, mostly through turbid meltwater plumes emanating from the glacial margin in contact with the open sea (Syvitski and Praeg, 1989). Following deglaciation, glacio-isostatic recovery led to emergence of land that was previously submerged under 140 m of water (Dionne, 1977, 2001; Locat, 1977; Hétu, 1998). This fall in relative sea level (RSL) brought postglacial marine silty clay sediments deposited in deep waters to what is now the intertidal zone, where they can be easily sampled. These sediments are now covered by a thin veneer of coastal massive muddy sand and the upper parts are periodically eroded by storms, forming lag beds. Today, the sedimentation rate is weak and allows colonization by the *Macoma balthica* community (Desrosiers and Brêthes, 1984). This contrasts with the massive sedimentation which led to the presence of shell beds in the compact marine sediment layer (Dionne, 1977).

The description of a sedimentary environment at the core scale is difficult because the quality of this description is a function of observational quality. The use of axial tomodensitometry (CT-Scan), as described in the present study, improves sedimentary analysis power, since it is a very sensitive tool with regards to size and internal variation within the analysed sample.

CT-Scan has been used by sedimentologists for both qualitative and quantitative evaluations of sediment density, state of compaction and depositional origin (Crémer et al., 2002). More recently, CT-Scan has been used to identify and quantify the space occupied by benthic organisms in the sedimentary column (De Montety et al., 2003; Michaud et al., 2003; Mermillod-Blondin et al., 2003). This method

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allows us to better understand the behaviour of these organisms and their bioturbation and bioirrigation processes, as well as to identify and quantify ancient bioturbation traces, or ichnofacies (Michaud et al., 2003). As opposed to traditional methods, CT-Scan allows us to obtain a 3D representation of sedimentary structures without destroying the cores (Crémer et al., 2002; De Montety et al., 2003), thereby allowing us to follow the succession of events at a particular study site. With the digital data obtained, it is possible to discriminate sedimentary features by their respective density, and to automatically quantify the volume occupied by certain structures within the core (Dufour et al., 2005).

In this paper, we apply the CT-Scan technique to analyse and reconstruct the depositional environment and processes of Goldthwait Sea silty clay beds from their deposition to the development of modern benthic communities.

2. Materials and methods

Three sediment cores (20 cm in length; 10 cm in diameter) were collected in the upper reaches of the intertidal zone of Baie du Ha! Ha!, Parc National du Bic, on the south shore of the St-Lawrence River, Québec (Fig. 1). The cores were analysed with a *Siemens* Somatom Volume Access scanner at the *Institut National de Recherche Scientifique — Eau-Terre-Environnement* (INRS-ETE; Quebec City, Canada). During the analysis, each core was run through a crown consisting of a rotating X-Ray source with 600 vertical receptors. This system emits rays from all angles across the sample which are then recorded by the receptors. Samples are analysed following a helicoidal movement that allows a study of the core from all the directions in space. Attenuated intensities of the rays are then transmitted to the computer. The image is created by digital reconstruction of the signal received on each receptor (Boespflug et al., 1994; Wellington and Vinegar 1987). The OSIRIS (Ligier et al., 1994) and OSIRIX medical softwares allow us to visualize and manipulate the images in order to outline sedimentary structures, sediment bed geometry, variations in density and biogenic structures (Crémer et al., 2000).

The scanner functions as described by Michaud et al. (2003) and De Montety et al., (2003), with the following improvements: 1) tomographic intensity (TI) values are represented by a greyscale of 4096 values corresponding respectively to 0.1% variations in density; 2) transverse sections of the cores have a pixel resolution of 0.20 mm, and longitudinal sections have a pixel resolution of 1 mm; 3) 3D images, representing a range of density values selected by the operator, can now be reconstructed by the scanner — for example, living organisms and biogenic structures (tubes, galleries, etc.), fossils and stones can be visualized.

For each sediment core, a tomogram, representing densities along a longitudinal plane for the entire length of the core, was obtained. Then, from scans of 1 mm-thick transverse sections, 3D reconstructions of living and fossil organisms (shells, worms, etc.) were made.

Based on the transverse sections obtained, we developed a method for the automated quantification of the space occupied by living benthic organisms and biogenic structures, such as galleries and other water-filled spaces within the sediments (Dufour et al., 2005). For each transverse section, the curve depicting the number of pixels according to TI values, expressed in Hounsfield Units (HU) (Fig. 2) shows secondary peaks to the left of a theoretical Gaussian curve, whose mean equals the average TI of the least dense class of sediments in that section; the proportion of pixels to the left of the theoretical curve depends on the degree of sediment occupation by living organisms and biogenic structures. Through calibration, TI values of −1000 and 0 correspond to air and pure water, respectively. Organic matter (i.e., all matter produced by dead and alive organisms) values are somewhat higher than water, reaching about 700 HU; a TI value that was obtained when the space occupied by a benthic organism was selected manually. Consequently, the difference

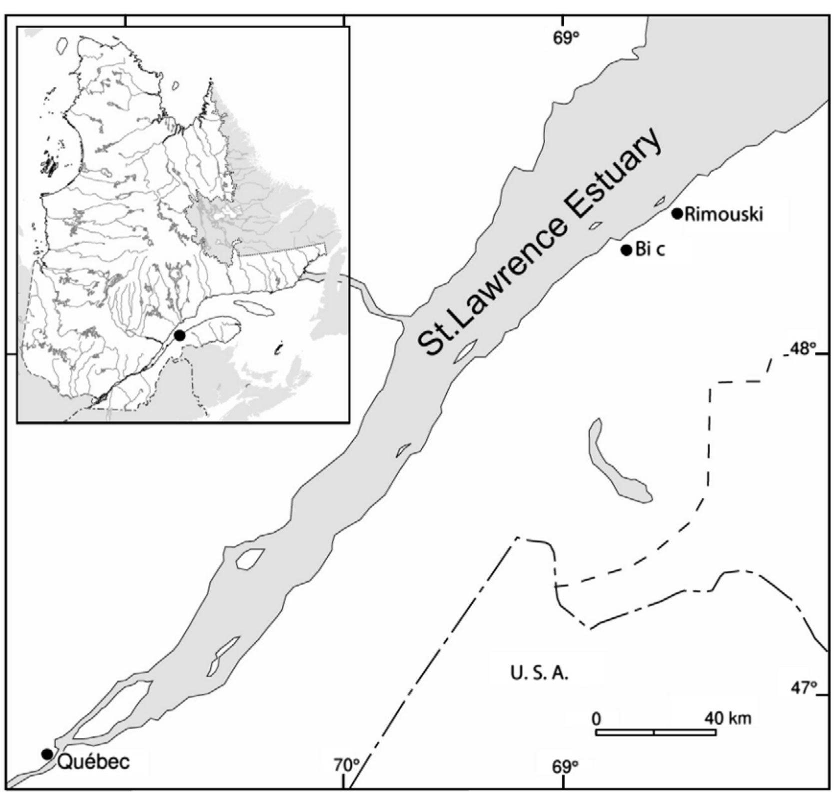

Fig. 1. Location of the Bic National Park, Québec (Canada).

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