AN *IN SITU* RADIOGRAPHIC SYSTEM FOR IMAGING MARINE SEDIMENT

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Abstract: This paper introduces a radiographic system for imaging marine sedimentary structures *in situ*, as an alternative to the currently used intrusive and tedious process of imaging extracted core samples in the laboratory. The system consists of a small isotopic source and a film incorporated into a device that can penetrate the sediment. The design of the device is introduced, and the results of mock-up experiments conducted to demonstrate the feasibility of the concept are presented.

Introduction: Extracted cores of marine sediments are x-rayed in the laboratory [1], to facilitate the analysis of its properties, sedimentary structure (formation mechanism), and biological content. Sediment cores are typically shaped as rectangular or cylindrical columns, extracted from marine sediment floors by a suitable coring technique [2]. These cores are then sliced into thin sections suitable for radiography. The quality and reliability of x-ray radiography of extracted cores depend to a large extent on the physical integrity of the collected sediment samples and on the precision of extraction. Extracted cores are frequently stored for long periods before slicing or radiography, which increases the probability of desiccation (drying), alteration and contamination of core [3]. Saw marks might also remain in the sliced sample, obscuring structural details [2]. This intrusive and tedious process can be overcome by performing *in situ* imaging.

Obviously, *in situ* imaging cannot be performed with a conventional x-ray machine, but can be readily conducted with a small radioisotopic source. We, therefore, conceived the system shown in Figure 1, which consists of a mechanism to hold the source and a radiographic film in place, and enable their insertion into (and removal from) the sediment, in a manner similar to that used in oil well-logging devices employed in petroleum exploration [4]. To our knowledge, this concept of *in situ* radiography of sediment was not explored before.

As Figure 1 shows, the introduced system employs a mechanism similar to that used in existing coring mechanisms. A radioisotopic source capsule is mounted at the end of a source guiding rod that enables its insertion into the sediment. The small size and self-powered nature of radioisotopes, and their ability to sustain underwater conditions of marine sediment, makes them particularly suited for this application. A waterproof film holder is to be positioned on the periphery of the device to hold the film during radiation exposure.

In order to reduce image geometric-unshaprness, it is necessary to maintain some distance between the source and the object. This can be accommodated in the confined space of the *in situ* device by creating a vacated core between the source and the imaged section, while keeping the source at the periphery, as shown in Figure 2.

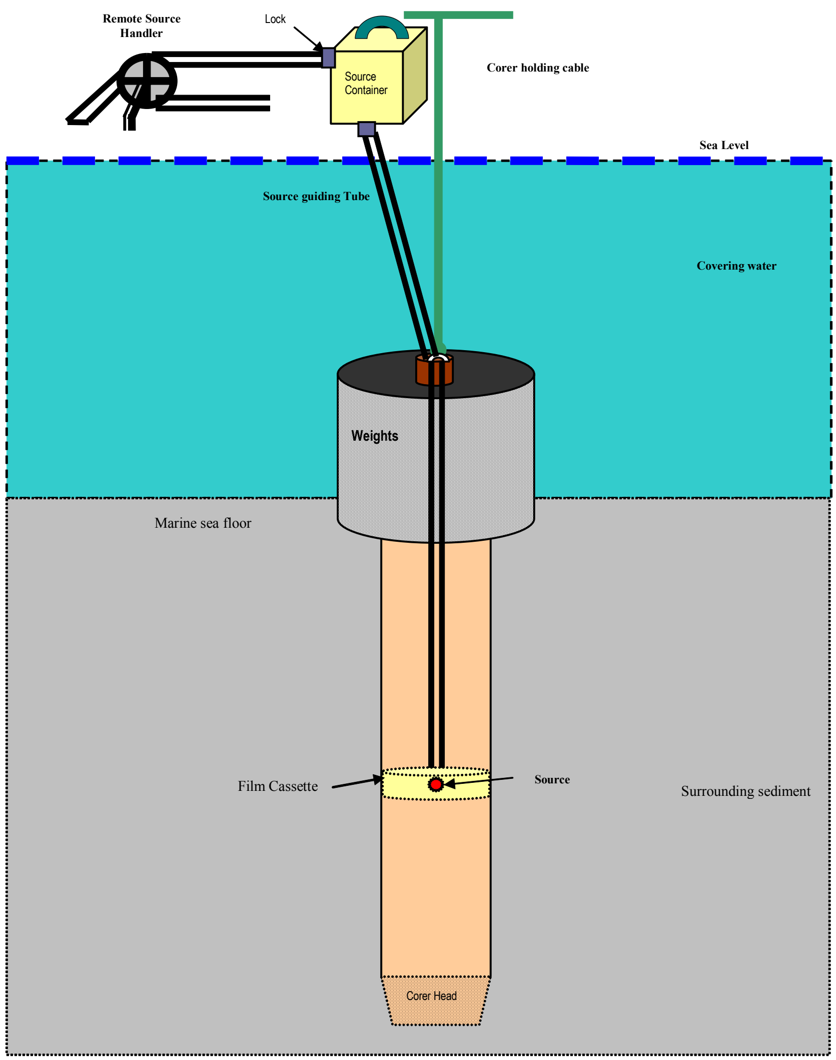

Figure 1: Schematic diagram of a conceived *in situ* radiographic system.

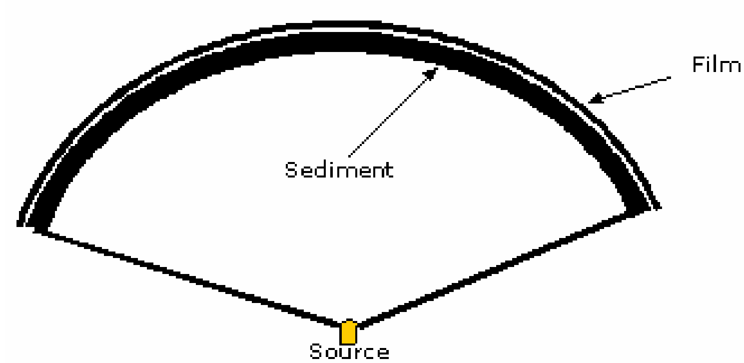

Figure 2: Source-object-film arrangement.

Results: In designing this system [5], the thickness of the radiographed sediment is fixed at a value of 25 mm, which is the value used in the conventional practice of x-ray radiography. A thicker section makes it difficult to decipher subtle variations in sediment structure, while a very thin layer may not contain sufficient structural details. This thickness of sediment necessitates the use of a photon source in the tens of keV energy range. Therefore, an ^{241}Am source (60 keV, 432.1 y half-life) was employed in the testing process. Such a source was used in the industrial radiography of aluminum alloys and thin steel specimens [6]. The adequacy of this source selection was examined by radiographing a sediment sample (15 mm x 8 mm x 25 mm thick) consisting of a homogenous mixture of grain sand and a sedimentary material composed of bentanite (50%), silt (20%) and shale fragments (30%), providing a density of 2153 kg/m^3. The sample was enclosed within a 1.75 mm thickness of sheet metal (mild carbon steel) to hold the grainy unconsolidated sediment. To measure image quality, four small carbon steel drill bits, of diameters 1.0, 0.8, 0.75, 0.52 mm, respectively, were placed in front of the sample to produce the equivalent of 4%, 3.2%, 3% and 2% thickness change, respectively. In addition, three aluminum wires, 2.5 mm in diameter, were inserted inside the sample, producing a density change of about 20%. The radiograph obtained with a medium-speed film (Kodak Industrex M) is given in Figure 3, showing all the drill bits and the aluminum inserts. This proves that a reasonable image quality was attained with this source-film arrangement. However, the structural features of the sediment were not quite visible, likely due to the metallic enclosure, which meant to emulate the structural material of the device.

In order to study the effect of this metal covering, 2 mm thick strips, made of stainless steel, mild steel and aluminum were placed on the front and back surfaces of a sediment sample contained in a cardboard box. The obtained radiograph using a fast film (Agfa D7 DW) is given in Figure 4. The radiograph indicates that the internal structures of sediment are not visible through the stainless steel and mild steel strips, but are visible through the aluminum strip, which demonstrates the suitability of aluminum as a structural material, but excludes the use of steel.

The major difference between this *in situ* radiographic system and conventional radiography is the presence of surrounding sediment behind the film and around the entire system. These surroundings can alter the quality of the image by increasing the buildup effect, i.e. by scattering photons towards the film. Although Monte Carlo simulations [5] indicated that this component had a negligible effect on the image quality, the effect was experimentally examined. A sediment sample was surrounded by a volume of sand (the density of unconsolidated sand is equal to that of many naturally occurring sedimentary deposits). Again, the three metallic strips were placed in front and back of the sample. The resulting radiograph is shown in Figure 5, giving an image similar to that provided by Figure 4, with no significant observable difference between the two. This further verifies that the surrounding sediment has an insignificant scattering effect on the quality of the radiographic image.

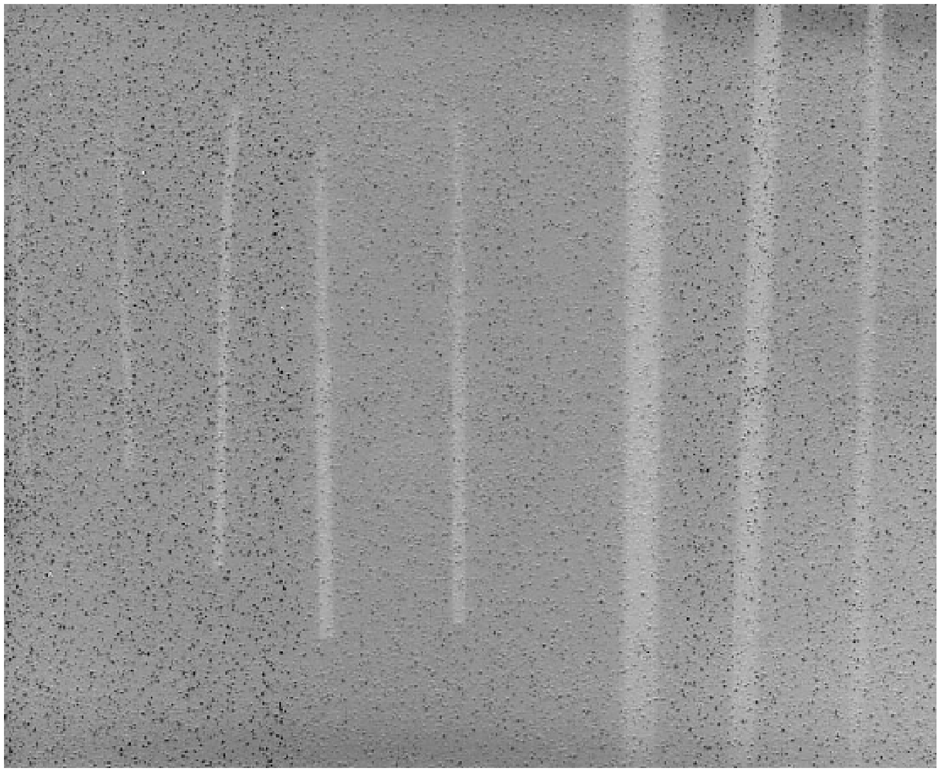

Figure 3: Radiograph of a sediment sample with 4 drill bits (left) and 3 aluminum wires (right).

In order to examine the ability of the system to view fine textural details, an unconsolidated (laminated) sediment, with water-filled pore spaces, was examined. The resulting radiograph is presented in Figure 6, where the laminar structure of sediment sample is clearly visible.

Discussion: The experimental results shown above demonstrated that an ^{241}Am source is capable of producing good quality images of sediment samples, provided that the sample is contained in a casing made of aluminum. However, a lighter material, such as Plexiglas, could be used for constructing the device, if it is to be inserted into soft or unconsolidated sediment.

The radiographic exposure time used in the above experiments was quite long; about 12 hours with a 11.GBq ^{241}Am source and a fast film. The exposure time could be reduced to one hour by increasing the source activity by a factor of 12, i.e. to 133 GBq (3.6 Ci). However, much higher activities can be attained if short-lived sources are employed. Ytterbium-169 and thulium-170, both emit photons at about 60 keV, are well suited for this purpose. These two isotopes are commercially available in very small sizes (0.6 mm to 3 mm) and high activity (3 to 50 Ci) [7]. The short half-lives of ^{169}Yb (32 days) and ^{170}Tm (127 days) will not only enable the acquisition of small size sources with very high activity, but are also environmentally advantageous, as the sources will decay rapidly if lost within the deposition environment. The increased activity can be accommodated in biological shielding with a small amount of lead.

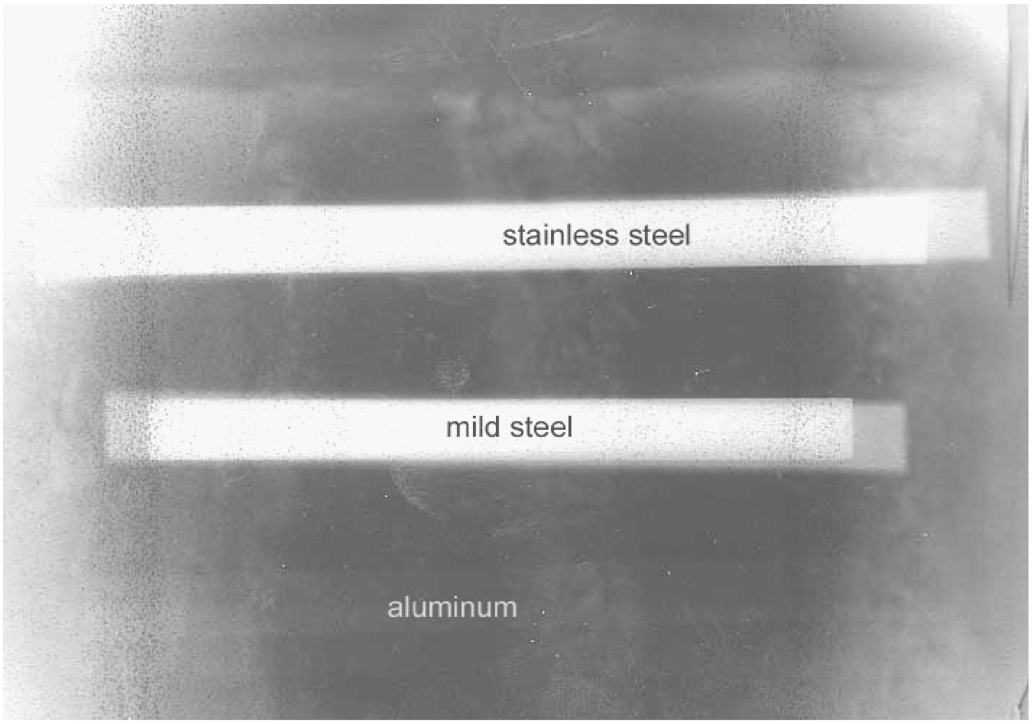

Figure 4: Radiograph of a sediment sample with three different metallic strips.

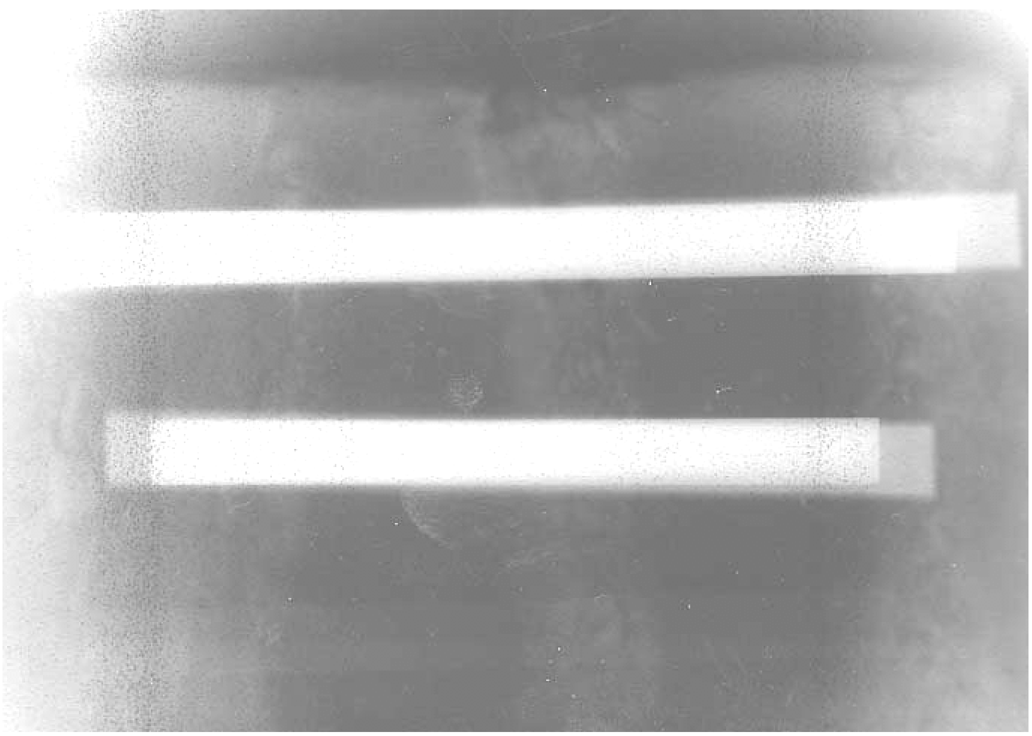

Figure 5: Radiograph of a sediment sample with surroundings.

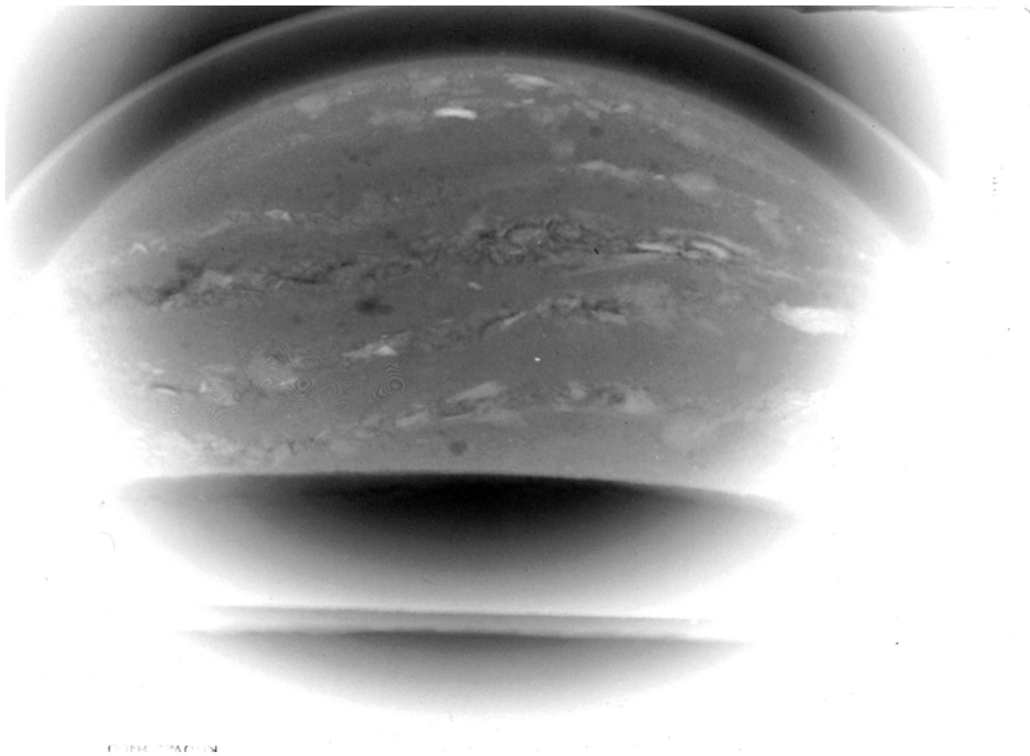

Figure 6: Radiograph of a sediment sample with a fine laminar structure.

Conclusions: This work demonstrated the feasibility of imaging marine sediments *in situ*, using a radioisotopic source. A conceptual system configuration was presented, which involved the introduction of a source and a radiographic film into a device that can be inserted into the sediment. Experiments with an ^{241}Am source showed that variations in thickness and density were observable, and the layered (laminated) features of sediment structures was visible. However, the structural material of the device is to be made of aluminum or a lighter material. The long exposure time necessitated by the low specific activity of ^{241}Am can be overcome if a short-lived isotopic source, such as ^{170}Th or ^{169}Yb, are used. Further field testing of the system is needed to identify and overcome any possible practical difficulties.

References:

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