MODEL OF THE ARAL SEA SEDIMENTARY CYCLES

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ABSTRACT

The goal of this project was to create a detailed model of the Aral Sea sedimentary cycles. Modern methods of image processing and wavelet analysis were used to reveal the nature of lamination and determine the average and interval sedimentation rates. The results obtained were then compared with those from the radiocarbon dating.

The images used in this project are photographs of core (sediment) samples taken with hollow plastic tubes. The samples were removed from the tubes by cutting them in half lengthwise, and then photographed. The image resolution was 0.34 mm.

The task of identifying the periodic components and determining the quantitative characteristics of individual cycles and microcycles was accomplished through the wavelet analysis of the "brightness" curve.

The cycles that make up the sedimentation model have periods of 1, ≈2, ≈5, ≈13, ≈50 and ≈200 years (i.e. they are well aligned with the common climatic cycles).

The average sedimentation rate is estimated at 2-3 mm/year.

The model shows that a 50 cm thick sediment forms in ~160 years. The radiocarbon dating, however, produced a different outcome – 440 ± 100 years. Obviously, the differences in the results are not trivial even if the likely level of error is taken into account.

Keywords: annual laminations, depositional cycle, thin-laminated clays, image processing, wavelet

INTRODUCTION

The most common method used for determining the absolute ages of rocks is the radiocarbon dating [1]. However, under certain circumstances, the radiocarbon dating can be highly inaccurate [2]. For this reason, an alternative (non-isotopic) method is usually used for sediments with seasonal (annual) layering [3,4]. The seasonal nature of layering, if proved, is sufficient for sedimentation rate evaluation and study of other time-related characteristics like periodic changes in various geological and geophysical parameters.

The Aral Sea is a unique natural object. On the geological time scale, it is a very young and ever-changing object. It was formed in the Early Holocene [5]. Over the last decade, researches [5,6] have shown that the Aral Sea seems more unstable than stable.

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Current researches have shown [7,8] that thin-laminated sediments can be found in any part of the Aral Sea. However, there is not a single sediment core column in which thin lamination can be observed over the entire length of the column without any interruptions. A large amount of organic matter in the sediments allows safe usage of the radiocarbon dating and comparison of the results with those provided by the sedimentary cycle analysis.

For this project, the results of the sedimentary cycle analysis obtained for thin-laminated bottom sediments of the Aral Sea were compared with the radiocarbon data. The radiocarbon study was carried out by ETH Zurich.

MATERIALS AND METHODS

For the analysis, the core column #23 (Chernyshev Bay, 45°59'574"N 59°13'950"E) was selected. The thin lamination in this column can be observed at a depth of about 4.5–6.5 m.

Bottoms of the northern bays (including Chernyshev Bay) are composed of pelitic sediments called "northern bay clays". It is assumed [7,8] that these clays were formed from the primary deposits, i.e. clays and sands of the Tertiary and Cretaceous.

The newly-sampled (still wet) sediment looks like a dense viscous silt, often dark gray, almost black. Usually it also contains plant remains – seaweed predominantly. In air, the sediment's surface oxidizes rapidly.

The lamination observed in this sediment is the sequencing of light and dark layers, 0.8-2 mm thick (in some cases, they reach 10-40 mm in thickness). The light layers are composed of carbonates and gypsum, the dark ones are represented mainly by clays rich in organic matter.

The nature of laminations is most probably seasonal: lighter layers (chemogenic) formed during dry seasons, while darker ones (consisting of clay and organic matter) accumulated during periods of extreme rainfalls and rapid vegetation growth.

Producing the images. The images used in this project are photographs of sediment core sampled with 3 m hollow plastic tubes. The samples were removed from the tubes by cutting them in half lengthwise, and then photographed. When photographing different parts of the core sample, the same lighting conditions were maintained, and the camera was attached to a tripod. Photographs were taken with an overlap of approximately 10 cm. Because the camera was kept at the same height throughout the whole process, all the images have the same scale and resolution. The image resolution was 0.34 mm.

In the next phase, the images were processed with the use of specialized software: commercial software (ERDAS Imagine and ArcGIS) and original custom-made applications developed in Kazan Federal University for data conversion, wavelet analysis and determination of quantitative characteristics of sedimentary microcycles.

Image processing. Pre-processing was carried out in ERDAS Imagine. It included geometric correction and mosaicing to obtain a complete image of the whole sediment sequence (Fig. 1a). To prevent the background from having an impact on the final result and enhance the contrast, 15x100 mm rectangular areas were cut from each image with an overlap of 10-30 mm (Fig. 2a,b).

The next step was the principal component analysis (Fig. 2b,c) used for data compression and noise reduction. The analysis showed that only the first principal component is relevant. It represents the sequencing of light and dark layers, i.e. the lamination (Fig. 2c).

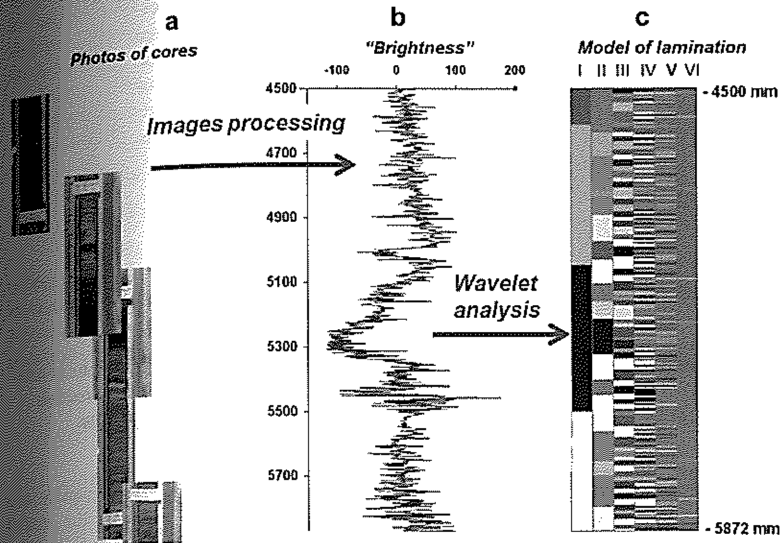

Fig. 1. Image processing and lamination model creation.

The "brightness" curve. The cross-section profile in Figure 2d is basically a graph picturing the first principal component changing with depth, or, in other words, the variation of the layers' "brightness". To obtain a complete picture, the "brightness" curves created for each fragment of the image were combined into a single general curve (Fig. 1b). The lamination reflects sedimentary cycles, which, in turn, depend on many climatic and paleogeographic factors. Thus, by identifying the periodic components of the "brightness" curve, one can reveal periodic changes in those factors.

Quantitative characteristics of sedimentary cycles and creation of the lamination model. Wavelet analysis [9] of the "brightness" curve was used to identify the periodic components and determine the quantitative characteristics of sedimentary cycles and microcycles.

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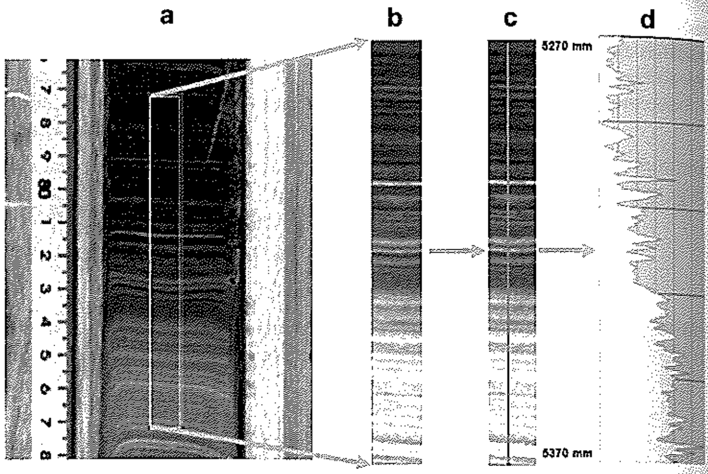

Fig. 2. Image pre-processing: a) original image; b) part of the image without any background content; c) the first principal component and the cross-section profile; d) the first principal component change along the profile.

Wavelet analysis can be used not only to reveal hidden periodicity in signals and decompose them into different order components, but also to determine the spatial positions of layers (or couplets) reflected in these components. As a result, a lamination model can be created for any sedimentary cycle regardless of its scale. The Mexican hat wavelet was used as a template [9]. The "brightness" curve consisted of 4588 points. The relevant scales were determined using wavelet spectra [9]. In this case, the most relevant scales were 237, 38.5, 9.21, 3.32, 1.49, 0.49. They correspond to the periods of 920, 150, 36, 12.8, 5.8, 1.9 mm. A graphical representation of the model was created in ArcGIS (Fig. 1c). The model consists of cycles of six different orders. Each cycle is represented by a couplet: one light layer and one dark layer. For each order, a grayscale image was created: the darkest layers were colored in black, the lightest ones became white.

RESULTS

Based on the assumption that the lowest order models describe annual cycles, spatial periods can be transformed into temporal by calculating how many annual cycles fit into a larger cycle. One can also calculate the number of years during which the sediment was accumulated, or determine the average and interval sedimentation rates. Figure 3 shows the thickness of couplets representing the sixth order cycle (Fig. 1c). This curve can be interpreted as the sedimentation rate at the studied depth. The average sedimentation rate is estimated at 2-3 mm per year. There is a significant increase in the

sedimentation rate that can be observed at 5–5.15 m (up to 13 mm/year) and 5.5–5.65 m (up to 40 mm/year).

DISCUSSION

Because several samples were taken from the column #23 for the radiocarbon analysis, it was possible to compare the results provided by different methods – radiocarbon dating and lamination modeling (Fig.3). According to the modeling results, a 50 cm thick sediment forms in approximately 160 years. The radiocarbon dating, however, produced a different outcome – 440 ± 100 years. Obviously, the differences in the results are not trivial even if the likely level of error is taken into account. The possible reasons for this are the following:

- inaccuracy of the radiocarbon dating;
- sediment washout (a part of the sequence may be missing);
- incorrect interpretation of the high-frequency component: perhaps the cycles reflected in the sediments are not annual, but represent a much longer time interval. The lamination can be not only of seasonal nature, but also determined by local climate features, geomorphology and other factors. For example, it is possible that rainy seasons occurred once every few years.

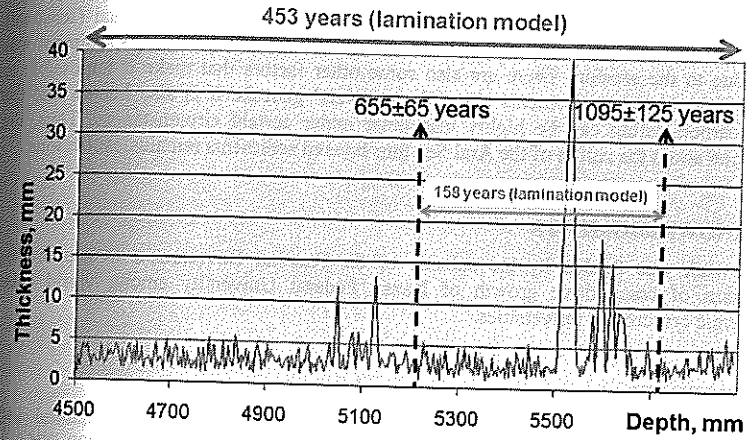

Fig. 3. Comparison of the sedimentation rates: the solid line represents the sedimentation rate calculated from the modeling results, the black dashed lines show sampling points and the corresponding radiocarbon dates.

The most common, simple and reliable way to prove the seasonal nature of laminations is finding a correlation between laminations and climatic changes or solar activity [10].

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Various studies of the microlamination in sedimentary rocks indicate that 11-year solar cycles are most vividly reflected in seasonal microlaminations. These cycles' duration in the Phanerozoic was quite constant: from ≈10 to ≈13 years [10]. This is a fundamental feature in proving the seasonal nature of microlaminations.

The cycles that make up the Aral sea sedimentation model have periods of 1, ≈2, ≈5, ≈13, ≈50 and ≈200 years (i.e. they are well aligned with the common climatic cycles). This supports the idea of seasonal (annual) nature of the sediments under study.

CONCLUSION

The proposed method for studying laminations produced satisfactory results and has a number of advantages:

1) "Brightness" curves are very informative and capture well the sedimentation process in an arid climate. In addition, they are quite easy to create.

2) In contrast to the Fourier analysis, the wavelet analysis allows decomposition of a signal into "natural" periodic components. Thus, no significant component is lost during the analysis, and the model consisting of 6 sedimentation cycles is highly reliable.

There are significantly large differences in the results provided by the radiocarbon dating and the sedimentation model. According to the radiocarbon dating, it takes 2,5 times longer for the sediment to accumulate as compared with the sedimentation model results.

The 11-year sedimentary cycles present in the model indicate the annual (seasonal) nature of laminations. On the other hand, it is possible that a part of the sediment was lost due to the erosion. There are also some other factors that make it impossible to make unambiguous statements about the couplets' genesis. It is also known that the radiocarbon dating can be highly inaccurate under certain circumstances. Thus, the question about the nature of the Aral Sea thin-layered sediments remains contentious.

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