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DISTINGUISHING ICE-RAFTED DEBRIS WHILE ESTIMATING PALEOCURRENT STRENGTH IN SEDIMENTS: REVIEW OF EXISTING METHODS

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The work covers different methods applied to consider presence of the coarse ice-rafted particles in marine sediments subject to current sorting. This is needed while reconstructing the strength of the bottom currents in the past as a main proxy is based on grain size data. Issue of the problem is explained and main methods of estimation paleocurrent activity are described shortly here as well.

Keywords: *ice-rafted debris (detritus), paleocurrent, marine sediments, high latitudes*

Introduction and origin of the issue. One of the most effective ways to reconstruct near-bottom water flow strength is to study fluctuations of the certain fine fraction content, as only sediments of a particular size can be moved by the current. This technique is easy to implement in low latitudes where water flow intensity is the dominating factor of grain size, except for microbiota which can be deleted by dissolution prior to the analysis. In high latitudes, though, sediments carried by the ice are ubiquitous due to the presence of glaciers and sea ice, and the size of particles varies significantly thus interfering with the sediments carried via bottom currents. This poses a problem of considering the ice-rafted debris while using grain size as a proxy for paleocurrents. The present work studies the methods of solving this task which are used nowadays.

Sortable silt mean grain size as a palaeocurrent proxy. One of the proxies for paleocurrent strength is the sortable silt (10-63 µm) mean size (SS mean, $\overline{SS}$) which has been widely used [e. g., *Hoffmann et al., 2019; Thomas et al., 2006; Lamy et al., 2015; Li et al., 2019; McCave et al, 2017*] since the moment of its introduction by McCave et al. in 1995. There are several reasons why specifically this grain size interval is used. Size of 63 µm has been traditionally used as a boundary between sand and mud (the updated Udden-Wentworth classification is used [*Folk and Ward, 1957*]), and sand is considered to be too large and heavy to be transported by currents long-distance; thus, particles larger than 63 µm are excluded from the current-transportable fraction despite that very strong currents can transport them [*Lamy et al., 2015*]. It has been noted that silt particles less than 10 µm in diameter behave like clay: they are cohesive and form aggregates easily [*McCave et al., 1995*]. To detect flow speed, only primary size should be considered, that is why the finest fraction is excluded. Due to these conditions, the size window 10-63 µm is called “sortable silt”.

Definition of the ice-rafted debris. Ice-rafted debris is usually defined as particles larger than 150 µm (the number of grains per gram bulk sediment). Another definition sees IRD as a weight percentage of material coarser than coarse silt (>63 µm). Particles of all grain sizes may potentially be ice-rafted [*Andrews, 2000*], so the precise size range cannot represent all ice-rafted debris. Moreover, fine grains generally constitute the main share of IRD in glacimarine environments [*Harff et al., 2016*]. This overlap in fine fraction makes it complicated to distinguish if the particles were deposited from the ice or rather influenced by the currents.

Correlation of the fractions. Hass, 2002, makes an implication that the sand fraction cannot be transported by currents therefore is represented only by ice-rafted material, and the main factor influencing the silt fraction accumulation is current-sorting. This simple approximation allows distinguishing between IRD and current-sorted material. Therefore, a high correlation between these two fractions can be used as an indicator of the strong IRD influence on the sediments while low correlation means that the dominating factor of sedimentation is the water flow sorting. The presence of some correlation between sand and silt does not allow considering sand to be composed of IRD only, though it can contain such particles [*Hoffmann et al., 2019*]. Moreover, the periods of IRD deposition could coincide with enhanced currents modes. Considering this, the attempts to eliminate the IRD effect by simply taking sand fraction as ice-rafted should be taken with extreme care.

Regression function. The more advanced approach based on the same principle is taking the whole sand fraction as ice-rafted and then using deviations from a regression function created by plotting the sand fraction content against $\overline{SS}$. Hass, 2002, claims that the randomness of the ice-rafted material incorporation and deposition is the key to differentiate the sediments. Indeed, ice-rafted sediments can hardly show some clear pattern while the strong water flow makes the sediments follow steady changes. The regression function ($y = a*x$^b) describes the correlation between the sand fraction and $\overline{SS}$. Samples lying on the regression line were deposited under "average" conditions when IRD variations were low while scattering around the line indicates moved equilibrium with either high IRD input or strong current sorting. Inserting sand content into the equation as x allows calculating potential $\overline{SS}$ ($\overline{SS}_{pot}$) supposedly showing the $\overline{SS}$ record deposited under the IRD main influence. Subtraction of $\overline{SS}_{pot}$ from $\overline{SS}$ gives the so-called delta $\overline{SS}$ – the equivalent of $\overline{SS}$, only without IRD input. The method is applied and interpreted by the authors as valid in the articles by *Jonkers, 2015, Hoffmann et al., 2019*, and others.

Considering that the sand fraction can be current-sorted as well as transported by the ice while in this method all particles larger than 63 μm are considered to be IRD, the results of distinguishing between IRD and current-sorted material require closer study.

End member modeling. Some authors [*Jonkers et al., 2015; Hoffmann et al., 2019; Wu et al., 2018*] use end member decomposition [*Weltje, 1997*] in order to discover the origin of the sediments including ice-rafting. They use the algorithm that derives end-members and considers their contribution. This process – unmixing – does not have one solution, so the choice of the number of end-members is made by the researcher. Three end-members (EMs) are proved to be sufficient to explain the variance in the size data. Two of the EMs are well-sorted unlike the third which represents all qualities of the typical IRD and resembles the pattern of coarse IRD counts. *Jonkers et al., 2015*, propose to use the ratio of EM2/EM1 as an independent indicator of the current sorting degree and therefore current strength.

McCave and Andrews, 2019, though claim this analysis to be ineffective for the ice effect elimination in current-sorted sediments and demonstrate that the new proxy can show the flow changes opposite to $\overline{SS}$. According to them, end member modeling does not divide the sediments on a genetic basis, which would be useful in this case, but only on a statistical basis; this seems to prevent effective usage of the end member decomposition for reflecting the palaeoflow variations.

Conclusion. Considering the methods described above, we can conclude that there are basically two main principles of separation of the ice-rafted material in sediments used nowadays: one is based on bad sorting of IRD, the other tries to discover the origin of the particles and uses the sorting for verification. They do not always indicate the same changes in the bottom water flow strength and IRD input, sometimes they are the opposite, and this leaves the question of the correct method to reduce the IRD influence on the current-sorted sediments open.

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УЧЕТ ПРИСУТСТВИЯ ЧАСТИЦ ЛЕДОВОГО РАЗНОСА В ДОННЫХ ОСАДКАХ ПРИ ОЦЕНКЕ СИЛЫ ПАЛЕОТЕЧЕНИЙ: ОБЗОР ПРИМЕНЯЕМЫХ МЕТОДОВ

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В данной работе описаны методы, применяемые для учёта грубых частиц ледникового разноса в морских донных осадках, подверженных сортировке придонными течениями. Данная тема актуальна, поскольку основной прокси (индикатор) для реконструкции силы палеотечений основан на данных гранулометрического состава. В работе объяснена суть проблемы, а также кратко описаны основные методы оценки активности палеотечений.

Ключевые слова*: ледниковый разнос, палеотечения, морские донные осадки, высокие широты*

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Одним из наиболее эффективных способов реконструирования силы придонного потока воды является изучение колебаний содержания тонкой фракции донных осадков, поскольку течение может перемещать только частицы определенного размера. Этот метод с лёгкостью применяется в низких широтах, где интенсивность потока воды является доминирующим фактором гранулометрического состава осадков, за исключением микробиоты, которая может быть удалена перед анализом. Однако в высоких широтах отложения, переносимые льдом, а не в потоке воды, широко распространены из-за наличия ледников, а следовательно, айсбергов, и морского льда; такие частицы, размер которых значительно варьируется, смешиваются с осадками, переносимыми придонными течениями. Это ставит задачу учёта частиц ледового разноса при использовании размера зёрен в качестве индикатора силы палеотечений.

Метод [*Hass, 2002*] основан на предположении, что все частицы в осадке размером крупнее чем 63 мкм были принесены льдом, поэтому корреляция между грубой и тонкой фракциями используется для уточнения вклада материала ледового разноса. Построение уравнения регрессионной функции, описывающей связь фракций, позволяет уточнить источник осадков. Метод конечных элементов – другой способ выявить происхождение частиц. Он позволяет поделить весь осадок на несколько компонентов в зависимости от источника привноса. Исследования [*Jonkers et al., 2015; Hoffmann et al., 2019; Wu et al., 2018*] показывают выделение материала, предположительно принесённого льдом, в том числе в осадках, сортированных течением.

Некоторые исследования [например, *McCave and Andrews, 2019*] показывают, что рассмотренные выше методы не всегда указывают на одни и те же изменения силы придонного потока воды и поступления материала ледового разноса, иногда результаты противоположны, и это оставляет открытым вопрос о наиболее подходящем методе учёта присутствия материала ледового разноса в осадках, подверженных сортировке течениями.