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Morphology and Genesis of Very Deep Channel Forms ("Deep Scour Holes") in the Arctic River Deltas of the Mackenzie and Kolyma

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1. INTRODUCTION

The lack of systematic observational data means that the dynamics and morphology of distributary channels in Arctic deltas remain poorly understood. This is primarily due to the fact that these areas are covered by ice and snow for most of the year, significantly hindering regular field measurements. Our recent studies have shown that large distributary channels within these deltas may exhibit unusual morphometric characteristics, including locally occurring significant depths. In the Mackenzie and Kolyma deltas, channel forms exceeding 20 meters in depth have been identified, commonly referred to in English-language literature as scour holes or deep scour holes (Beltaos et al. 2011; Lapointe 1986; Fassnacht and Conly 2000). Field measurements conducted over the past four years confirm that these forms exhibit diverse morphologies — they occur as kettles, craters, and trenches. The presence of permafrost in these regions suggests that one of the factors contributing to their formation may be thermo-erosion.

The aim of this study is to provide a detailed morphometric characterization of 43 identified deep scour holes occurring within distributary channels of the Mackenzie and Kolyma deltas. These investigations seek to better understand the mechanisms responsible for their formation and their role in sediment dynamics and geomorphological transformation of Arctic deltas.

2. METHODS

During the summer seasons of 2021, 2023, and 2025, depth mapping of selected channel sections in the Mackenzie and Kolyma deltas was carried out. Measurements were conducted using the infrastructure of two research stations: the North-East Science Station in Chersky (Russia) for the Kolyma, and the Aurora Research Institute, Western Arctic Research Centre in Inuvik (Canada) for the Mackenzie.

Fieldwork on water was carried out using 200 kHz single-beam echo sounders mounted on motorboats and geodetic-grade GNSS receivers. Surveys were conducted along pre-established

cross sections spaced every 100 meters. In regions where significant depths were detected, the measurement coverage was densified.

3. STUDY AREA

The Mackenzie River is the fourth largest Arctic river in terms of average annual discharge (approx. 316 km³/year), while the Kolyma ranks sixth (approx. 136 km³/year). In the Kolyma basin (Yakutia, Russia), permafrost covers 100% of the surface and is classified as continuous permafrost. In contrast, the Mackenzie River basin (Northwest Territories, Canada) is approximately 82% underlain by permafrost.

Both deltaic plains are characterized by high lake density — with approximately 49,000 lakes in the Mackenzie Delta region (Burn 2010). The Kolyma River stands out for its exceptionally long ice-cover period — exceeding 210 days per year — which significantly complicates regular hydrological monitoring.

Both deltas are located north of the Arctic Circle, where the average annual air temperature ranges from –8 to –4 °C (Sakai et al. 2016; Emmerton et al. 2007). Ice breakup usually occurs rapidly at the end of May. During its degradation, river discharges may increase abruptly — from 2,000–3,000 m³/s up to as much as 30,000 m³/s.

4. RESULTS

Along a 40-kilometer section of the main distributary channel in the Kolyma Delta, 7 deep scour holes were identified. Notably, all of these features exhibited very similar maximum depths in the range of 25–27 m, differing only in length and width (with an average length of 500 m and width of 300 m).

In the eastern part of the Mackenzie Delta, 36 deep channel forms were identified. In the Middle Channel, 11 such forms were mapped, with a maximum depth reaching up to 48 m. In the Inuvik region, within the East Channel, 21 forms were identified with more varied depths — ranging from 22 to 36.8 m (Fig. 1).

Identified forms were classified based on their basic morphometric parameters, morphogenetic characteristics, ice dynamics associations, and sediment transport characteristics. A common feature of deep scour holes in both the Kolyma and Mackenzie deltas is the presence of very steep side slopes, ranging from 50° to 85°. In the Mackenzie, most forms resemble kettles, while in the Kolyma they are more trench-shaped.

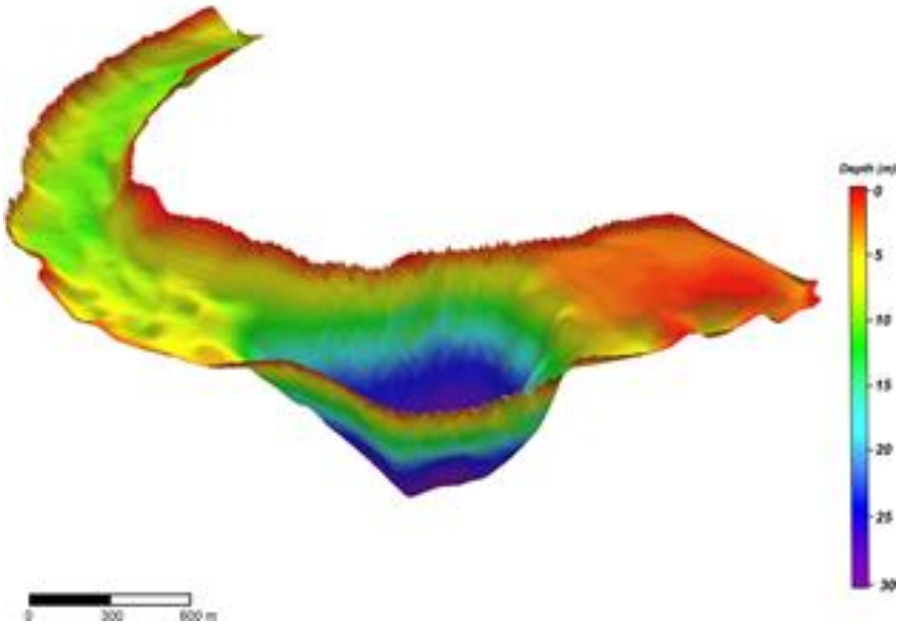

Fig. 1. One of the "deep scour holes" mapped in August 2023 within the East Channel of the Mackenzie River. Maximum depth during low flows: 29 m.

5. CONCLUSIONS

The occurrence of deep channel forms known as deep scour holes in Arctic deltas is not a marginal phenomenon, as evidenced by their high density along the randomly selected distributary channel sections analyzed. Numerous forms of considerable depth (up to 48 m), large spatial extent, and exceptionally steep side slopes have been identified in both the Kolyma and Mackenzie deltas. All analyzed deep scour holes create unique morphological conditions for flowing water, confirming their significant impact on sediment transport dynamics within Arctic deltas.

Not all identified forms occur within tidal delta channels, which allows the exclusion of contemporary marine processes as a major factor in their formation. The characteristic abundance of lakes in the studied deltas suggests that their capture by river channels may represent a key mechanism initiating the development of these features.

Preliminary analysis indicates that their genesis results from the interaction of multiple factors. The most important include: incision-related erosion linked to ice dynamics (e.g., ice jams and sudden meltwater surges), the presence of Holocene lacustrine sediments and organic-rich dendritic material, and thermoerosional processes triggered by permafrost degradation.

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