

Clim. Past Discuss., referee comment RC1
<https://doi.org/10.5194/cp-2021-111-RC1>, 2021
© Author(s) 2021. This work is distributed under
the Creative Commons Attribution 4.0 License.

Comment on cp-2021-111

Ruediger Stein (Referee)

Referee comment on "Heavy mineral assemblages of the De Long Trough and southern Lomonosov Ridge glacigenic deposits: implications for the East Siberian Ice Sheet extent" by Raisa Alatarvas et al., Clim. Past Discuss., <https://doi.org/10.5194/cp-2021-111-RC1>, 2021

Review by Ruediger Stein (11 October 2021)

(for complete review including figures see supplement)

Whereas quite detailed information about the existence, timing and extent of the North American and Eurasian ice sheets during the Pleistocene glaciations is available, the data base for the existence, timing and extent of an East Siberian Ice Sheet is very limited and based on sparse geophysical and marine geological data (e.g., Jakobsson et al., 2010; Niessen et al., 2013; Jakobsson et al., 2014). In order to get more detailed information about the history of this ice sheet, Alatarvas et al. present new mineralogical data from marine sediment cores recovered from the East Siberian shelf and slope, especially from a glacial trough and related trough mouth fan setting, focusing on heavy mineral assemblages. That means, heavy minerals in the coarse fraction have been used to reconstruct provenance and source areas and plausible transport mechanisms of the terrigenous sediment fractions. These data are the basis for far field reconstructions of ice sheet activity on the east Siberian Margin during the late Quaternary. For lithostratigraphy and chronology of the studied sediment cores, an important and fundamental prerequisite for any paleo-reconstructions, the authors refer to O`Regan et al. (2017, 2020) as well as Jakobsson et al. (2016). This very well written paper is certainly of interest and an important puzzle piece for the still needed more detailed reconstruction of the history of the East Siberian Ice Sheet, especially in context and relationship to the other major circum-Arctic ice sheets. The new heavy-mineral data give evidence for an extensive ice sheet growth from the East Siberian shelf but also from the New Siberian Islands and westerly sources, probably during MIS 6 (although a deposition during a stadial in MIS 5 or the glacial period of MIS 4 might also be possible as stated by the authors). In general, I have a very positive opinion about the outcome of this study and would like to see the paper published. However, I have some points that should be considered before publication (see below). Thus, at its present stage I recommend **"publication after minor revision"**.

Several Polarstern expeditions have been carried out in the area across and around southern Lomonosov Ridge close to the Siberian continental margin (e.g., Rachor, 1997; Stein, 2015, 2019), and a large number of sediment cores have been recovered (Fig. 1). Most of these sediment cores can be correlated very well based on their lithology, and a very clear lithostratigraphic concept has been developed (Fig. 1a) that is further supported by physical property data (see Marine Geology subchapters in the cruise reports Rachor, 1997; Stein, 2015, 2019). Based the lithostratigraphy and physical property records as well as some micropaleontological data and preliminary interpretation of paleomag data from Core PS2757-8, a tentative (!) age model had been proposed in our early studies (cf., Behrends, 1999; Stein et al., 2001), an age model that is still be used (cf., Stein et al., 2017) although it's still tentative. Based on this age model, the prominent dark gray sandy silty clay unit in the lower part of the cores seems to be of MIS 6 age (Fig.1a). The lithologies of the key cores of this study can also be correlated to the Polarstern cores, and their age model based on the new findings of O'Regan et al. (2020) seems to support the old tentative age model we have used for our Polarstern cores.

From several of these Polarstern cores (including key cores PS2757 and 2761) detailed mineralogical and geochemical data have been produced within three PhD studies (Behrends, 1999; Müller, 1999; Schoster, 2005; part of the data is published in Behrends et al., 1999; Müller and Stein, 2000; Schoster et al., 2000). These data including heavy minerals, clay minerals, and major & minor elements, have been used to reconstruct (1) the provenance, source areas and transport mechanisms of the terrigenous sediment fractions and, based on these data sets, (2) the history of the Eurasian and East Siberian ice sheets (Fig. 2). The extent and timing of proposed ice sheets in northern Siberian during MIS 4 and/or MIS 6 are discussed (Fig. 2b; cf., Arkhipov et al., 1986,1995; Müller, 1999). As one example, the heavy mineral record from Core PS2757 is shown in Figure 2c. I recommend that some of these data should be considered and discussed in the present paper.

Finally, I would like to highlight that the reconstruction of provenance, source areas and transport mechanisms of the terrigenous sediment fractions as well as the history of the Pliocene-Pleistocene Eurasian and East Siberian ice sheets is one of the key objectives of the IODP Expedition 377 (ArcticOcean Paleoceanography – ArcOP) scheduled for autumn 2022 (Stein et al., 2021). The locations of the potential IODP sites are in the neighbourhood of the cores discussed here (Fig. 1b). Thus, the results of the studies by Alatarvas et al. as well as our own previous studies on Polarstern material may give ground truth information that is important and helpful for the interpretation of the coming IODP data.

References

Arkhipov, S.A., Bespaly, V.G., Faustova, M.A., Glushkova, O., Isayeva, L.L., Velichko, A.A., 1986. Ice-sheet reconstructions. *Quaternary Science Reviews* 5, 475-483.

Arkhipov, S.A., Ehlers, J., Johnson, R.G., Wright, H.E., 1995. Glacial drainage towards the Mediterranean during the Middle and Late Pleistocene. *Boreas* 24, 196-206.

Behrends, M., 1999. Reconstruction of sea-ice drift and terrigenous sediment supply in the Late Quaternary: Heavy-mineral associations in sediments of the Laptev-Sea continental margin and the central Arctic Ocean. *Reports on Polar Research* 310, 167 pp. (PhD Thesis University of Bremen; in German).

<https://epic.awi.de/id/eprint/26490/1/BerPolarforsch1999310.pdf>

Behrends, M., Hoops, E., Peregovich, B., 1999. **Distribution patterns of heavy minerals in Siberian rivers, the Laptev Sea and the eastern Arctic Ocean: an approach to identify sources, transport and pathways of terrigenous matter.** In: H. Kassens, et al. (Eds.), *Land-Ocean Systems in the Siberian Arctic: Dynamics and History*, Springer, Berlin (1999), pp. 265-286.

Jakobsson, M., Polyak, L., Edwards, M., Kleman, J., Coakley, B., 2008. Glacial geomorphology of the Central Arctic Ocean: the Chukchi Borderland and the Lomonosov Ridge. *Earth Surf. Process. Landforms* 33, 526–545.

Jakobsson, M., Andreassen, K., Bjarnadóttir, L. R., Dove, D., Dowdeswell, J. A., England, J. H., Funder, S., Hogan, K., Ingólfsson, Ó., Jennings, A., Larsen, N. K., Kirchner, N., Landvik, J. Y., Mayer, L., Mikkelsen, N., Möller, P., Niessen, F., Nilsson, J., O'Regan, M., Polyak, L., Nørgaard-Pedersen, N., and Stein, R. 2014. Arctic Ocean glacial history, *Quaternary Sci. Rev.* 92, 40–67, <https://doi.org/10.1016/j.quascirev.2013.07.033> .

Jakobsson, M., Nilsson, J., Anderson, L., Backman, J., Björk, G., Cronin, T.M., Kirchner, N., Koshurnikov, A., Mayer, L., Noormets, R., O'Regan, M., Stranne, C., Ananiev, R., Barrientos Macho, N., Cherniykh, D., Coxall, H., Eriksson, B., Flodén, T., Gemery, L., Gustafsson, Ö., Jerram, K., Johansson, C., Khortov, A., Mohammad, R., Semiletov, I.: Evidence for an ice shelf covering the central Arctic Ocean during the penultimate glaciation. *Nature Communications* 7, 10365,

<https://doi.org/10.1038/ncomms10365>

Jakobsson, M., Nilsson, J., O'Regan, M., Backman, J., Löwemark, L., Dowdeswell, J.A., Mayer, L., Polyak, L., Colleoni, F., Anderson, L.G., Björk, G., Darby, D., Eriksson, B., Hanslik, D., Hell, B., Marcussen, C., Sellén E., and Wallin, Å., 2010. An Arctic Ocean ice shelf during MIS 6 constrained by new geophysical and geological data, *Quaternary Sci. Rev.* 29, 3505–3517, <https://doi.org/10.1016/j.quascirev.2010.03.015>

Müller, C., 1999. Reconstruction of paleoenvironmental conditions at the Laptev Sea continental margin during the last two glacial/interglacial cycles based on sedimentological and mineralogical investigations. Reports on Polar 328, 146 pp. (PhD Thesis University of Bremen; in German). <https://epic.awi.de/id/eprint/26507/1/BerPolarforsch1999328.pdf>

Müller, C. and Stein, R., 2000. Variability of fluvial sediment supply to the Laptev Sea continental margin during Late Weichselian to Holocene times: Implications from clay-mineral records. *Int. Journ. Earth Sci.* 89, 592-604.

<https://link.springer.com/content/pdf/10.1007/s005310000112.pdf>

Niessen, F., Hong, J. K., Hegewald, A., Matthiessen, J., Stein, R., Kim, H., Kim, S., Jensen, L., Jokat, W., Nam, S., 2013. Repeated Pleistocene glaciation of the East Siberian continental margin, *Nature Geosci.*, 6, 842–846, <https://doi.org/10.1038/ngeo1904>,

O'Regan, M., Backman, J., Barrientos, N., Cronin, T.M., Gemery, L., Kirchner, N., Mayer, L.A., Nilsson, J., Noormets, R., Pearce, C., Semiletov, I., Stranne, C., Jakobsson, M., 2017. The De Long Trough: a newly discovered glacial trough on the East Siberian continental margin. *Climate of the Past* 13, 1269–1284, <https://doi.org/10.5194/cp-13-1269-2017>

O'Regan, M., Backman, J., Fornaciari, E., Jakobsson, M., West, G., 2020. Calcareous nannofossils anchor chronologies for Arctic Ocean sediments back to 500 ka. *Geology*, 48 (11), p. 1115–1119. <http://doi.org/10.1130/G47479.1>

Rachor, E (Ed.), 1997. Scientific cruise report of the Arctic Expedition ARK-XI/1 of RV „Polarstern“ in

- Rep. Pol. Res. 226, 157 pp.
<https://epic.awi.de/id/eprint/26404/1/BerPolarforsch1997226.pdf>

Schoster, F., 2005. Terrigenous sediment supply and paleoenvironment in the Arctic Ocean during the late Quaternary - Reconstructions from major and trace elements. Reports on Polar and Marine Research 498, 149 pp. (PhD Thesis University of Bremen; in German). <https://epic.awi.de/id/eprint/26677/1/BerPolarforsch2005498.pdf>

Schoster, F., Behrends, M., Müller, C., Stein, R., Wahsner, M., 2000. Modern river discharge in the Eurasian Arctic Ocean: Evidence from mineral assemblages and major and minor element distributions. Int. Journ. Earth Sci. 89, 486-495.
<https://link.springer.com/content/pdf/10.1007/s005310000120.pdf>

Stein, R. (Ed.), 2015. The Expedition PS87 of the Research Vessel *Polarstern* to the Arctic Ocean in 2014. Reports on Polar and Marine Research 688, 273 pp
(http://epic.awi.de/37728/1/BzPM_0688_2015.pdf).

Stein, R. (Ed.), 2019. The Expedition PS115/2 of the Research Vessel POLARSTERN to the Arctic Ocean in 2018. Reports on Polar and Marine Research 728, 249 p.;
(https://epic.awi.de/id/eprint/49226/1/BzPM_0728_2019.pdf).

Stein, R., Fahl, K., Gierz, P., Niessen, F., Lohmann, G., 2017. Arctic Ocean sea ice cover during the penultimate glacial and the last interglacial. Nature Communications 8: 373.
<https://www.nature.com/articles/s41467-017-00552-1>

Stein, R., Fahl, K., and Müller, J., 2012. Proxy reconstruction of Arctic Ocean sea ice history: „From IRD to IP₂₅“. Polarforschung 82, 37-71,
https://epic.awi.de/id/eprint/31715/1/Polarforschung_82-1_37-71.pdf

Stein, R., Matthiessen, J., Niessen, F., Krylov, R., Nam, S., Bazhenova, E., 2010. Towards a Better (Litho-) Stratigraphy and Reconstruction of Quaternary Paleoenvironment in the Amerasian Basin (Arctic Ocean). *Polarforschung* 79 (2), 97-121.
<https://epic.awi.de/id/eprint/22435/1/Ste2010b.pdf>

Stein, R., St. John, K., and Everest, J., 2021. Expedition 377 Scientific Prospectus: Arctic Ocean Paleoceanography (ArcOP). International Ocean Discovery Program.
<https://doi.org/10.14379/iodp.sp.377.2021>

Figure Caption

Fig. 1

(a) Transect of selected sediment cores recovered across the southern Lomonosov Ridge during Polarstern expeditions in 1995, 2014, and 2018 showing main lithologies, lithostratigraphy, and still tentative age model (MIS 6 to 1) based on shipboard data and core correlation (Rachor, 1997; Stein, 2015, 2019 and further references therein). Core PS115/2-14-3 was recovered at the location of proposed IODP Site LR-06A. **(b)** Map shows locations of Polarstern cores (white circles: 1995; blue circles: 2014; black circles: 2018) and eight of the proposed ArcOP sites (large yellow circles). Location of Core 29-GC-1 shown as black rhomb. Figure from Stein et al. (2021), supplemented.

Fig. 2

(a) Bathymetric map of the Arctic Ocean modified to showing lowered sea level of 120 m during maximum glaciation and ice streams (blue and red arrows), projected flow lines of ice shelves and limits of ice rises (from Jakobsson et al., 2008, supplemented). Main source areas of specific minerals are shown (from Stein et al., 2010, 2012 and references therein): qua = quartz; dol = dolomite; ill = illite; sme = smectite; chl = chlorite; kao = kaolinite; am = amphibole; cli = clinopyroxene. Colour codes mark source region: green = western Laptev Sea, Kara Sea, Barents Sea; blue = eastern Laptev Sea, East Siberian Sea; orange = Bering Strait; pink = Canada, northern Greenland; white = no specific

source area. Tentative extent of East Siberian Ice Sheet has been added (cf., Niessen et al., 2013). (Figure from Stein et al., 2012, supplemented). **(b)** Siberian shelves and proposed ice sheets in northern Siberia during MIS 4 and MIS 6. Figure from Müller (1999) based on Arkhipov et al. (1986, 1995) and own data from her PhD thesis work. Core locations are indicated by black circles. **(c)** Distribution of heavy minerals in Core PS2757. MIS boundaries 5/6, 4/5, 3/4, and 1/2 are marked as dashed intervals based on a preliminary age model (Behrends, 1999).

Please also note the supplement to this comment:

<https://cp.copernicus.org/preprints/cp-2021-111/cp-2021-111-RC1-supplement.pdf>