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Interactive comment on "The 3.6 ka Aniakchak tephra in the Arctic Ocean: a constraint on the Holocene radiocarbon reservoir age in the Chukchi Sea" *by* Christof Pearce et al.

Christof Pearce et al.

christof.pearce@geo.au.dk

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Author replies are in red.

Tephra and cryptotephra studies are being successfully used in various kinds of paleoenvironmental research, mainly for synchronization of various marine, terrestrial and ice records. Last decades see a real boom in global tephra and cryptotephra studies, however, in many large geographical areas this technique still has not been employed. One of such areas, surprisingly, is the Arctic Ocean where no tephra research has been performed until very recently although cryptotephra has been reported from the Fram Strait connecting the Arctic Ocean with the Nordic seas (Zamelczyk et al., 2012).

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Discussion paper

This reference (Zamelczyk et al 2012) will be added to the introduction.

The paper under review presents the first documentation of a cryptotephra from an Arctic core providing an account on particle concentrations, composition of volcanic glass, and grain size distribution in the sediments. The paper is well articulated, based on solid data, and is accompanied with detailed supplementary tables. This paper definitely deserves publication after only a minor revision because it opens a discussion on the applicability of tephra for dating and correlation of the Arctic Ocean sediments as well as for understanding of sediment transport and deposition patterns. The authors focus on one specific goal - identification of the Holocene reservoir age in the Chukchi Sea based on correlation of a cryptotephra horizon between dated marine and terrestrial/ice sequences. This task requires an accurate and reliable positioning of a tephra isochron relative to the dated core levels. The authors were lucky to find geochemically distinct and well dated Aniakchak II tephra, which links their core to many 14C-dated terrestrial sites and, more important, to two Greenland ice cores where the age of this tephra is estimated with a precision of ± 3 yrs. At the same time, some issues related to tephra distribution in the Chukchi Sea sediments (and thus to the position of the Aniakchak II isochron in the core) deserve further discussion. The authors document a >1.5 m thick zone of high glass concentrations accumulated within >700 yrs. As the upper part of the core has not yet been explored we cannot tell whether this tephra zone fades away at 550 cm or extends up core. Based on geochemical data, at least the lower 90 cm interval of this zone contains rhyolitic Aniakchak II glasses with no admixture of any other glass populations. To my knowledge this is the first reported case where geochemically identical glasses are continuously present over such a broad interval of a marine core. Bredryan et al. (2010) also reported tephra zones accumulated during 1000 yrs, however, first, in their core 1000 yrs correspond to only few cm of sediments, and second, in some cases such zones in fact may contain different tephras from the same or different volcanic systems (e.g., Bourne et al., 2013; Davies et al., 2014).

The upper part of the core was not explored because of the apparent continued variable input of Aniakchak tephra, at least 1 meter following the original eruption. Based on shard counting alone, it would thus not be possible to distinguish any following eruption. Reworking of primary tephra deposits by ocean current and sea ice transport apparently play a very large role here. Your observation that this is probably the first reported case of a marine core containing more than 1 m of geochemically identical glass will be added to the revised manuscript in the discussion.

Some authors suggest placing a tephra isochron at the first shard occurrence in the core (e.g., Austin et al., 1995; Brendryen et al., 2010) while others demonstrate a complex structure of the lower boundary of a tephra layer, and suggest placing an isochron at the maximum glass concentrations (e.g., Abbott et al., 2014; Davies et al., 2014; Griggs et al., 2014, 2015). The authors of the paper under consideration try to find a balance between these two suggestions putting an isochron either at 711.5 (a major increase in glass contents and the first analyzed level) or at 696.5 cm (15 cm higher). I am not sure if any unambiguous decision about correct position of the isochron can be reached at this stage, however, I think this section requires more elaboration involving further ideas on mechanism of the emplacement of these glasses.

The two options of either placing the isochron at first shard occurrence or at maximum shard concentration are all based on studies where the ash occurs in a much shorter section of the core. As stated in the previous comment, our record, however, contains >1 m of the same ash instead of a few centimeters. This will be added in the discussion.

The reasoning behind our proposed depth range for the isochron is the following. Downward mixing of tephra of 0.5 – 1 m by bioturbation is simply unrealistic and therefore the placement of the isochron was based on the principle of first shard occurrence. However, we cannot rule out bioturbation as a mixing mechanism entirely and therefore we add a coarse estimate of 15 cm of possible mixing and end up with a depth range estimate of 696.5 – 711.5 cm.

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Discussion paper

Brendryen et al (2010) and others describe centuries to millennia long lags between the initial airfall and the delivery of tephra to the ocean floor and they explain such delays by distribution of a tephra over an ice sheet, slow movement of the ice towards the sea "where it subsequently calves off tephra-laden icebergs". In the case of the Chukchi Sea, as far as I understand, the main transport mechanisms in mid-Holocene times likely are sea ice and currents rather than icebergs (which is further supported by homogeneous glass compositions). So why does the Aniakchak signal peak >58 cm above the lowermost analyzed level? Could bottom currents in the Herald canyon or redeposition from the canyon walls play a role in an unusually long vertical dispersal of identical glasses? Could a tsunami wave associated with the caldera-forming eruption (Waythomas and Neal, 1998) contribute to wide spread of the Aniakchak glasses?

We observed that the highest concentrations of tephra coincide with increased input of coarse material. This would indicate sea ice transport to play a major role in the secondary deposition of the tephra grains. Larger scale remobilization of sediments from canyon wall failure or a tsunami wave is not likely, based on the continuous sediment accumulation rate indicated by the radiocarbon dates.

The authors do not mention that the Aniakchak II glasses from airborne tephra have both andesitic and rhyolitic populations (e.g., Kaufman et al., 2012; Davies et al., 2016). Were andesitic glasses (if present in the Chukchi Sea sediments) separated into the >2.5 g/cm3 fraction? If not - why aren't they present in the larger glass concentration peaks? It is true that in some of distal airfall deposits only rhyolitic shards have been analyzed (e.g., Blackford et al., 2014) but if the authors suggest that the larger glass concentration peaks are explained by reworking of primary tephra deposits and transported to the core site by currents or sea ice (from the Bering Sea?) we would probably expect to see also andesitic shards and admixture of some other glass populations.

This study solely focused on the rhyolitic fraction (<2.5 g/cm3) and the denser fraction was not studied. Yes, most likely, andesitic shards would also be present, but we have no data to show this.

Considering the admixture of other glass populations: every single microprobe analysis on one of our tephra shards returned the same geochemistry matching that of Aniakchak CFE II.

Neal and others (2001, p. 4), referring to Riehle and others (1999), suggest that at least 20 explosive eruptions occurred at Aniakchak in postglacial time before the Aniakchak II eruption (cited from Bacon et al., 2014). The Aniakchak II proximal pyroclastic package as well as the sequence at the Bering Sea coast includes several units (Bacon et al., 2014; Riehle et al., 2014). I wonder if this proximal record can be resolved on centennial scale because of slow paleosol accumulation over a thick pyroclastic cover. Kaufman et al (2012) reported two closely spaced visible Aniakchak tephra layers in Alaska. Could different but closely spaced in time Aniakchak eruptions contribute to a long Aniakchak signal in the Chukchi Sea core?

Kaufman et al (2012) concluded that it was not possible to distinguish whether the second layer was another eruption, or reworking of the primary deposit of Aniakchak II. The same is true for our record since it is so dominated by highly variable secondary input of the ash.

Hope that some of these issues could be further discussed in this paper. Please find my minor comments and additional references in the attached file Please also note the supplement to this comment: http://www.clim-past-discuss.net/cp-2016-112/cp-2016-112-RC2-supplement.pdf Interactive comment on Clim. Past Discuss., doi:10.5194/cp-2016-112, 2016.

We will address all of the minor remarks mentioned in the supplementary document when submitting the revised manuscript.

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