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Interactive comment on "Strategy of valid ¹⁴C dates choice in syngenetic permafrost" *by* Y. K. Vasil'chuk and A. C. Vasil'chuk

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Referee #2: This paper is mostly a review of 14C chronologies from permafrost regions, with a special emphasis on a few sites from Arctic Siberia. I've read through the paper twice now, and I have to admit as a series of brief case studies, I remain unconvinced that an overall strategy is forthcoming from what the author's present. The paper needs substantive editing and reorganization along with a consideration of perhaps focusing on more detail on fewer examples that may have a simpler message in terms of the overall strategies of 14C selection (which is the main focus of this paper). General points The authors seem to accept all dates that have been published as being reliable

indicators of when that organism died They mention a couple exceptions related to thermokarst lakes in Alaska, but overall they accept that most dates are reliable and the problems lie with remobilization of older (or curiously younger- which I return to below since I don't follow their point) organic material.

Authors reply: We accept published data, however discussed that samples which had been collected by cutting from syngenetic permafrost deposit or from the ice wedge. Every sample of frozen ground or ice was scraped off with clean chisels to remove surface contamination.

Referee #2: At no point is there any discussion of the mechanics of 14C, importance (and sensitivity) of pre-treatment protocols and dating specific fractions (fulvic, humic acids, high temp/low temp combustion etc- a rich literature- see Brock et al. 2011 Quat. Geoch, 5, 625-630), or the problems that can creep into datasets.

Authors reply: The problem of allochtonous peat 14C dating is considered by F. Brock et al (2011) when peat is composed of a heterogeneous mix of organic materials of different radiocarbon ages and at different stages of humification. Different chemical fractions (most frequently humin and humic acid) have been observed to yield significantly different radiocarbon ages from some peat deposits.

Referee #2: Certainly there are many very important points of 14C dating such as importance (and sensitivity) of pre-treatment protocols and dating specific fractions (fulvic, humic acids, high temp/low temp combustion, background detection limits etc. For example, Bird and co-workers have clearly demonstrated that 14C ages of old samples that are obtained using standard chemical and extraction techniques often underestimate true 14C ages by 8–10 ka or more (Bird, et al., 1999) There are at least four primary sources of uncertainty or error that combine to set the practical upper limit of 14C dating of terrestrial samples: (1) lack of sample integrity (i.e., complete in situ replacement of primary C via chemical or isotopic exchange), (2) incomplete removal of secondary (contaminant) C species during chemical pretreatment, (3) atmospheric

C that is introduced to the original sample C during extraction, graphitization, and/or storage, and (4) uncertainties associated with AMS measurements.

Authors reply: The focus of the paper is the 14C dating aspects of syngenetic permafrost. The other very important points we would like to discuss applying to the problems appeared in 14C dating of permafrost syngenetic sediments with ice wedges (yedoma)"

Referee #2: For example, in the last 14C intercomparison something like 10% of 14C dates were simply wrong for a myriad of reasons from incomplete pre-treatment, sample labeling and errors in the lab, changing, etc. I suspect many of the ages that are reported in this paper are actually non-finite with some young 14C contamination.

Authors reply: We discussed our data only that samples which we collected by cutting from the ice and permafrost sediments, after sampling the ice and peaty sediment were isolated up to treatment. So the contamination at the sampling stage was reduced.

Referee #2: This has certainly been our experience, that dates that are ca. 35,000-45,000 14C years BP are in fact non-finite and have some younger contamination because of poor handling of samples and microbial growth, poor background estimation (and thus subtraction of the blank) or the fact that blanks are still not known from most laboratories that service users. Almost no papers report background values of the blanks which is critical to understanding the reliability of 14C dates, especially as you approach 14C background (which again is not discussed).

Authors reply: However we would like to discuss the problem appeared in 14C dating of permafrost syngenetic sediments with ice wedges (yedoma)", background values of the blank is very important however this problem is general for 14C dating not only for syngenetic permafrost.

Referee #2: Keep in mind that as little as 1% young carbon contamination in a non-finite sample results in an age of ca. 38,000 14C years BP. This is a huge problem

and most studies do not report background values for their blanks or mass-dependent background. With small sample masses blanks (and thus non-finite samples) can be reported in the 20,000 year range. If you don't known the blank this will seem as a solid date. The paper by Kennedy et al. (QSR, 29, 217-225) has some discussion of this problem.

Authors reply: (p.4, lines 73-10) At first, it was assumed that 14C ages from permafrost usually rejuvenated as it took place in the non-permafrost areas. Even small amounts of modern carbon (which is everywhere) very easily create apparently finite ages when one is near the limit of the technique. Graphic and dramatic example of this can be seen in Pigati et al. (2007). Bird and co-workers have clearly demonstrated that 14C ages of old samples that are obtained using standard chemical and extraction techniques often underestimate true 14C ages by 8–10 kyr or more (Bird, et al., 1999). As it was shown by Nilsson et al. (2001) and Turetsky et al. (2004), the main sources of carbon which are likely to contaminate contemporaneous carbon pools with modern carbon are assumed to be young roots, rootlets and rhizomes penetrating down into older, underlying peat, and humic acids and other dissolved organic carbon which leach downwards in percolating ground-waters (Brock et al., 2011). According to Wallén (1984), up to 90% of photosynthetically fixed CO2 is allocated to roots; they transfer current atmospheric carbon dioxide to deeper layers and may be observed to penetrate up to 2 m in certain environments (Saarinen, 1996). Nilsson et al. (2001) reported that most root biomass does not penetrate deep enough into older peat to affect significantly radiocarbon ages. As to permafrost area, young roots may to grow within active layer. Dissolved organic carbon, in particular humic and fulvic acids, may originate either from decomposition of plant matter or from root exudation. But this young organic material does not penetrate into the underlying permafrost, and even more so in the ice wedges. Younger organic materials may be incorporated in older sediments in syngenetic permafrost within active layer only. In rare cases, younger organic materials may be incorporated in older sediments in syngenetic permafrost. This could happen, and does happen with pore waters through the active layer that accumulate at the top of the permafrost table, but for the most part these waters would not be able to carry organic material with it or through cryoturbation, or when macrofossils (wood, seeds, bones etc.) submerged into semi-liquid sediments of the lakes or ponds. Rejuvenation can take place if there are conditions for microbial processing of modern fluids such as carbon, methane or carbon dioxide. It is possible to evaluate the probable rejuvenation of the 14C age based on tritium concentrations. Our data show that usually the tritium concentration in syncryogenic sediments is very low less than 1-10 TU (Vasil'chuk et al., 2000b).

Referee #2: That paper also has quite an extensive discussion of the importance of choice of material for dating, such that fragile macros and those that are ecologically coherent with the environment that one is dating are typically younger and well-preserved and robust macros (including spruce needles and wood) tend to be older and reworked. Non-finite and mixed ages underscore the significant problem of reworked, well-preserved macrofossils in Arctic environments and the need for careful selection of both fragile and ecologically-representative macrofossils to establish reliable chronologies.

Authors reply: (p.7, lines 207-221). According to Kennedy et al Radiocarbon ages from study of Eagle River meltwater channel and braid delta, northern Yukon have demonstrated that coarse, woody materials consistently over-estimate the ages of the sediments they are used to date. All sediments occur in rapidly aggrading forms with no evidence for a significant hiatus in deposition. Radiocarbon ages on woody plant macrofossils and spruce needles are non-finite, while radiocarbon ages on macrofossils from herbaceous plant taxa and insects with 'steppe-tundra' ecological affinity from the upper part of the delta range from 15,840 $\pm$ 90 to 21,600 $\pm$ 1300 14C yr BP. It was stressed that these ages must be considered within the context for potential depositional histories including extensive preservation and reworking. Bulk samples from the region could yield artificially old 14C ages by containing any number of well-preserved macrofossils of varying age. The composite samples potentially contain macrofossils

of differing ages that will produce a composite age older than the youngest component (Kennedy, 2009, Kennedy et al., 2010). Thus, permafrost syngenetic sediments and ice wedges are characterized by significant 'reservoir' effects, the magnitude of which is likely to be highly variable and not easily and independently constrained for ancient permafrost. The youngest age from this point may be maximum limiting age for the syngenetic sediment or ice.

Referee #2: The authors also enter into some discussion of bone dating – which is another complete literature on the importance of things such as bulk methods of collagen extraction (Longin method) vs. ultrafiltration (Brown et al. 1988; Stafford, 1996), vs. single amino acids, etc. that can lead erroneous dates. I'm not suggesting the authors be exhaustive, but rather define their scope early- at present the paper tackles far too much driftwood, marine sediments and modern reworking, etc. etc. . .

Authors reply: There are many specific problems in 14C dating of bones, some of them we have discussed in the papers Vasil'chuk Yu.K., Vasil'chuk A.C., Long A., Jull T., Donahue D.J. 2000. AMS dating of mammoth bones: comparison with conventional dating. Radiocarbon. Vol.42. âĎŰ2. P. 281 – 284. Vasil'chuk Yu.K., Punning M.-K., Vasil'chuk A.C. 1997. Radiocarbon ages of mammoth in Northern Eurasia: implications for population development and Late Quaternary Environment. Radiocarbon. Vol.39. N 1. P. 1 – 18. The age of the bone corresponds to the time of animal life, but not always the age of the host sediment. So even whole carcasses may be re-transported as the case with baby mammoth Dima found in the Holocene sediments of Dima Crick in Kirgilyakh River valley, and aged about 40 kyr BP. If the bone is the youngest from the age set of the layer in yedoma, hence the age of the bone corresponds to maximum limiting age of the layer. Reworking bones are found more often than "in situ" ones. (p.6, Line 202-206) Successful method of 14C dating in permafrost-affected areas demonstrated by Zazula et al. (2004, 2007). Representative of their depositional context fragile macrofossils (flowers, seeds, leaves and seed capsules) and formation of coherent ecological assemblages herbaceous xerophilic taxa from glacial environments), are selected for the purposes 14C dating achieving duplication and assessing different types of material (needles, beetles and seeds).

Referee #2: 2. In the abstract it is stated: 'due to the very good preservation of organic materials in permafrost conditions and numerous re-burieals of the fossils from ancient deposits into younger ones the dates could be both younger and older than the true age of the dated material'. I'm afraid I don't follow this point. How could younger organic materials be incorporated in older sediments in syngenetic permafrost? This could happen, and does happen with pore waters through the active layer that accumulate at the top of the permafrost table, but for the most part these waters would not be able to carry organic material with it (that isn't DOC I suppose) or through cryoturbation this could happen with active layer mixing. Is this what the authors mean? This point is made on p5590, L5, and p5594, L3. Without some explanation, this is a strange point to make.

Authors reply: The sentence removed from abstract. Referee #2: How could younger organic materials be incorporated in older sediments in syngenetic permafrost . This could happen, and does happen with pore waters through the active layer that accumulate at the top of the permafrost table, but for the most part these waters would not be able to carry organic material with it (that isn't DOC I suppose) or through cryoturbation this could happen with active layer mixing. And also Is this what the authors mean? This point is made on p5590, L5, and p5594, L3. Without some explanation, this is a strange point to make.

Authors reply: (P.3-4 Line 94-107) As to permafrost area, young roots may to grow within active layer. Dissolved organic carbon, in particular humic and fulvic acids, may originate either from decomposition of plant matter or from root exudation. But this young organic material does not penetrate into the underlying permafrost, and even more so in the ice wedges. Younger organic materials may be incorporated in older sediments in syngenetic permafrost within active layer only. In rare cases, younger organic materials may be incorporated in older sediments in syngenetic permafrost.

This could happen, and does happen with pore waters through the active layer that accumulate at the top of the permafrost table, but for the most part these waters would not be able to carry organic material with it or through cryoturbation, or when macrofossils (wood, seeds, bones etc.) submerged into semi-liquid sediments of the lakes or ponds. Rejuvenation can take place if there are conditions for microbial processing of modern fluids such as carbon, methane or carbon dioxide. It is possible to evaluate the probable rejuvenation of the 14C age based on tritium concentrations. Our data show that usually the tritium concentration in syncryogenic sediments is very low less than 1-10 TU (Vasil'chuk et al., 2000b).

Referee #2: 3. 'subaerial-subaqueous deposition'. What do the authors mean by subaqueous deposition? The authors appear to follow the loessal origin of yedoma in Siberia (p5590,L23) such that I don't follow what they mean by subaqueous. By definition it means 'underwater'. And if that's what they mean, how does permafrost survive under a body of water? Please clarify this point through the text. There are many ways that syngenetic permafrost can aggrade- due to loessal inputs (the main North American model for syngenetic permafrost in eastern Beringia- see Schirrmeister et al. 2014 Encylopedia of Quaternary Science), colluvial inputs, aggradation of peat and vegetation, or perhaps fluvial inputs. Each of these has their own setting and challenges.

Authors reply: We do not exlude the aeolian intuts, but in yedoma cross-sections are fixed fluvial inputs, and colluvial inputs and also Aeolian inputs which corresponds to subaqueous stage, and aggradation of peat, soil formation and also Aeolian inputs occurs at subaerial stages. (see Fig 2 – Model and p.8 lines 264-266)

Referee #2: 4. Case studies not especially clear. Many of the case studies simply refer to a series of ages and accept that the youngest ages are correct and therefore reliable. See point 1, but there are many ways for 14C dates to be wrong and it's only through rigorous laboratory methods coupled with excellent sample selection (and ideally understanding the ecology of the samples that are being selected) such that they form a coherent set of samples with robust ages that one can move toward confidence in the dating. I would prefer to see a couple of case studies with stratigraphic logs and more clear discussion of why the dates are reliable rather than many paragraphs that are difficult to follow without going back to the earlier papers.

Authors reply: Attempts to identify the yedoma age at Duvanny Yar and Mamontova Khayata have usually resulted in a recognition of the impossibility of exact dating amidst the apparent chaos of ages. However, the principle of the choice of the youngest 14C age from the data set in the particular horizon allows us to obtain an adequate un-inversion maximum limiting age series of these complicated heterochronous complexes. Of course in addition to the choice of the youngest dating should take into account the environmental compatibility of organic residues, the ability to rejuvenate sampling, processing and measurements.

Referee #2: Perhaps focus on Duvanny Yar and the problems that site still presents (you might look at the dates reported in Willerslev et al. for that site in addition to what is presented here). I would assume there are 50+ dates for Duvanny Yar, while only 4 are reported on Table 2. That site could well warrant a serious discussion of the issues of true 14C background, reworking of old material, importance of macrofossil selection (i.e. ground squirrel nests vs detrital material), etc. As it stands, one would think the site only has a brief handful of ages available.

Authors reply: In Table 2 there are 14C ages of different fractions from the same samples (p.17, lines 562-569) The 14C ages yielded in the last time in Duvanny Yar assigned to another temporal section. It is not correct to compare the previous data set with the last. Duvanny Yar is very complicate sequence. It has dome shape and within its body there are paleoalases, which age is distinguished from the ages of the main body (Vasil'chuk, 2013). This interpretation of 14C data is touched upon that fragment of Duvanny Yar yedoma, which was available for sampling in 70-90th of XX century. Considering non-horizontal bedding of the yedoma sediments and clay dome in the central part in the context of further erosion more ancient yedoma fragments may be-

come revealed.

Referee #2: Maybe the Fox permafrost tunnel- which is still a challenge- but also see the paper by Lachniet et al. and maybe Wooller et al. in addition to those noted. Overall, the paper has some merit and with considerable reorganization and perhaps a better framework for the discussion could be an addition to the literature, but as it stands, it needs considerable re-thinking before it can be published.

Authors reply: (P13, Lines 426- 439) . . .as has been shown by Lachniet et al. (2012) in the CRREL Permafrost Tunnel in Fox, Alaska. 14C ages both the carbon dioxide (CO_2) in air bubbles and the dissolved organic carbon within the ice to 11,170 yr younger than the particulate organic carbon contained within the same wedge. This indicates that the POC is detrital in origin. A buried ice wedge system and the sediments enclosing a permafrost ice wedge were studied in the tunnel near Barrow (Meyer et al., 2010). The Late Pleistocene age of the site is indicated by AMS ages in the surrounding sediments of 21.7 kyr BP at the lateral contact of the ice wedge system, as well as 39.5 kyr BP below the ice wedge system. Here we would like to discuss the problem appeared in 14C dating of permafrost syngenetic sediments with ice wedges (yedoma)" but we take into account that there are many sources of uncertainty or error that combine to set the practical upper limit of 14C dating of terrestrial samples, such as: incomplete removal of secondary (contaminant) C species during chemical pretreatment, atmospheric C that is introduced to the original sample C during extraction, graphitization, and/or storage, and uncertainties associated with AMS measurements.

Added Figure 1 (in the paper this is Figure #2). The scheme of cyclic model of thick syngenetic ice wedge formation: 1 – peat; 2 – peaty silt; 3 – low content of old organic matters; 4 – high content of old organic matters.

Please also note the supplement to this comment:
http://www.the-cryosphere-discuss.net/8/C2986/2015/tcd-8-C2986-2015-supplement.pdf

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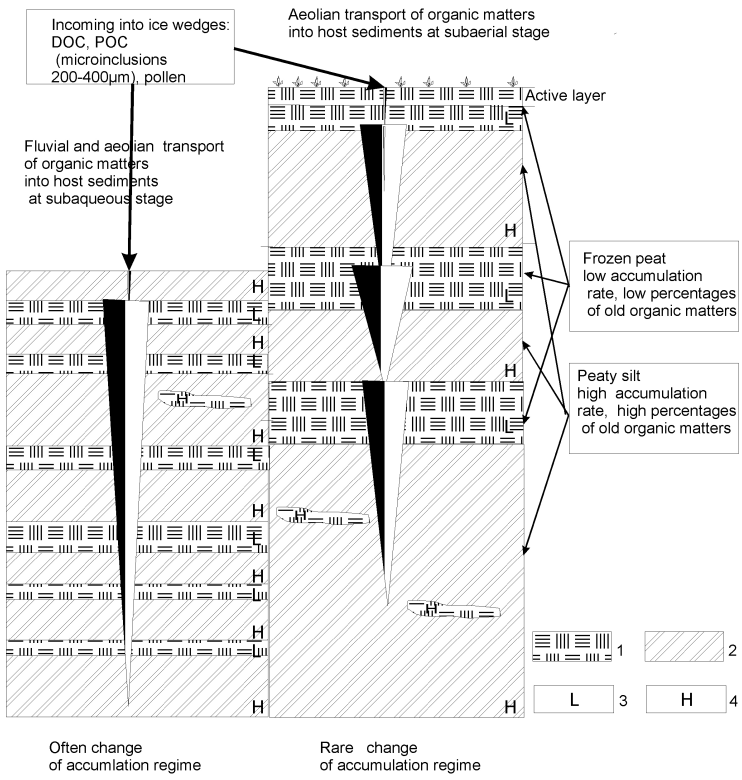

Fig. 1.