We thank the anonymous reviewer for their time, expertise, and their insightful and helpful suggestions to make the manuscript more accessible, accurate, and impactful.

Anonymous Referee #1 Received and published: 26 June 2019 Summary:

Reviewer Comment 1:
This article looks at a rock glacier in Taylor Valley and concludes that observed glacial successions are useful for studying past climates in the MDV. Overall, I think the article is well described and written, but I do have issues with their age estimate based on pond salts, as well as the description of the pond samples. Unfortunately, this is a key argument in the paper, so the lack of an age constraint requires changes to the discussion and conclusions. However, I don't think this greatly impacts the overall point.
Reply to Comment 1:
We have replied to the reviewer's specific comments about the lake samples and the age estimate below.

Detailed comments:

Reviewer Comment 2:
Figure 2: I know that you can tell what is downhill from the contours, but at first glance the figure seems turned around and was quite confusing, until I realized it was oriented differently from Fig. 1. I recommend including a big bold arrow and 'downhill' text, so that this is immediately clear.
Reply to Comment 2:
We agree that the orientation was probably confusing because North was down.
Author changes in manuscript:
We will flip the Figure around so that North is up.

Reviewer Comment 3:
Section 3.2: I'm a little confused as to exactly what samples were collected from the ponds, so more clarity is needed. Were all the ponds frozen during sampling? If so, where were the samples taken? From the upper surface, from the margins? I'm particularly curious because some of the pond samples have remarkably high salt concentrations, which is difficult to reconcile with samples of surface ice, which I'd expect to have low concentrations.
Reply to Comment 3:
Thank you for pointing out our lack of detail in describing the lake samples.
All but one of the lakes were completely frozen during sampling. All samples were taken from the 3–5 cm depth in the center of the lake ice, after manually removing the upper 3 cm of the ice. One lake, L3, was not frozen solid, but was starting to thaw and to become slushy. However, it was not fully thawed and the person sampling could still walk out onto the lake slush. The ice below 10 cm depth was more solid. We were monitoring air temperatures at the time, because we were also ice coring, and air temperatures were consistently $< -8^{o}$ C. The pond was shaded by the steep hill to the north and so the early surface slush was likely the result of its high salinity and early top-down melting.

Author changes in manuscript:
In the Methods section, we will include information on pond sampling depths and locations, as well as the information regarding the frozen/slushy nature of the surface ice in pond L3.

Reviewer Comment 4:
Table 3: The authors should fully list all of the ions analyzed and their concentrations, as well as the listed total salt content. Assuming that the isotopes were analyzed for the same samples, these values should also be listed. I also recommend adding in the elevation to the table for easy reference.
Reply to Comment 4:
We do need to include all data with this paper (isotopes and ions). It was a definite oversight that we did not include the data with the original manuscript.
Author changes in manuscript:
In the Supplementary Data, we will include tables for: (1) ion concentrations for the lake cores, (2) ion concentrations for the lake near-surface samples, and (3) stable isotopic data for all samples: lake, buried ice and glacier ice.

Reviewer Comment 5:
Section 4.3: It's worth mentioning here that samples falling below the local water line suggest either evaporation or sublimation.
Author changes in manuscript:
We will mention evaporation / sublimation earlier in the text at this point as an explanation for stable isotopic data falling below the local meteoric water line, and not just in the Discussion section.

Reviewer Comment 6:
Section 5.3: The major source of ions to these ponds is likely dissolution and aeolian transport of salts from nearby soils, as well as inputs of snow and ice melt, and probably a small component due to direct weathering or atmospheric inputs. See the following references on Taylor Valley salts: Keys, J. R. H. and K. Williams (1981). "Origin of crystalline, cold desert salts in the McMurdo region, Antarctica." Geochimica et Cosmochimica Acta 45(12): 2299-2309. Toner, J. D., et al. (2013). "Soluble salt accumulations in Taylor Valley, Antarctica: Implications for paleolakes and Ross Sea Ice Sheet dynamics." Journal of Geophysical Research 118(1): 198-215. In general, this section needs improvement. Part of the difficulty I'm having with it is that I don't know exactly what was sampled, and if only a surface ice sample was collected, then the measured chemistry would have little relation to the bulk pond composition/salinity. Also, the age analysis using Cl- accumulation is poorly justified. First, only a snowfall source is invoked, but as I mention, this is probably minor relative to Cl- fluxes from surrounding soils. Also, this assumes that the pond is a closed system, so that all the Cl- that goes in does not come out, but this seems unlikely for a pond perched on a valley slope. Throw in the aforementioned uncertainty about how representative the samples are. Basically, I don't think you can come up a with an age using snowfall. I recommend just removing this paragraph. However, given that the age of these ponds is a major point in the article, this would involve some general restructuring of the later discussion and conclusions. On the whole, I find the argument for glacial successions is robust, but not the age estimate based on salt accumulation.

Reply to Reviewer Comment 6:
The age of the ponds is not the point of the article, and we agree with the reviewer that our estimate is rough (as stated in the article) and based on a series of assumptions. If we removed this section entirely, it would not compromise the main conclusions or the scientific impact of the article.

As suggested by the reviewer, we will remove the absolute age estimate (40,000 years) from the text. That estimate is based on a series of assumptions and therefore likely has significant error. However, the high salinity of pond L3 does have implications for surface processes and the potential pre-Holocene age for the lower rock glacier. Therefore, we propose to replace the ***quantitative*** *discussion of pond age in sections 5.3 and 5.4 with a* ***qualitative*** *discussion.*

As stated by the reviewer, if there is a soil-weathering source of Cl-, then our calculated age would be an overestimate. Notably, several of the issues raised by the reviewer actually highlight the fact that our age might be an underestimation:

a. *If the bulk chemistry of the ponds is significantly different from the near-surface ice, this would imply occasionally stratified waters where the saltier waters (ice) are at the bottom. Thus, the surface ion concentrations could be a minimum average composition for the ponds, and our rough age estimate would err toward the young.*

b. *Witherow et al. (2006), examined the ion flux to this part of Taylor Valley, and found that most ion sources were from marine aerosols contained within snow blown in from the coast. We concur that a soil source of major ions, especially Cl-, would decrease the estimated age of L3. However, our conclusion that the lower rock glacier predates the Holocene based on L3 salinity is only compromised if the soil source of Cl- is four times that of the aerosol contribution from snow. This condition also demands that all Cl- is delivered from the soils to the pond and that the pond does not lose ions.*

   Nearly all local bedrock and rock glacier clasts are granitic, containing low concentrations of Cl-. Small, nearby cinder cones have produced slopes with scoria granules and cobbles, which have much higher concentrations of Cl-. It is certainly possible that some of the Cl- in the ponds originates from these cinder slopes. For instance, we observed two categories of salt crusts at/near the surface of the study area. First, we noted thin layers of salt marking previous extents of existing snowbanks. Second, salt efflorescence is present on the underside of some mafic cinder clasts on the cinder slopes. This supports a case that both snow and wind-blown local sources are possible contributors to the ponds.

c. *If the Cl- is percolating out of the system, we are again left with a conservative estimate of Cl- accumulation in the depression and therefore of the pond age. Our major ion ratios do not support a strong migration trend: migration of ions during freeze-thaw cycles preferentially concentrates the least soluble ions (e.g., Mg++) in upslope areas, while the more soluble ions (e.g., Na+) travel downslope. However, our Mg++:Na+ is highest in the most downslope, saline pond, L3, indicating that* *preferential removal of ions is not responsible for the overall trend in salinity. Because the pond does completely dessicate on occasion, windblown loss of ions from surface sediments is a likely process through which Cl- could be removed from the depression and the pond.*

Author changes in manuscript:
In the final manuscript, we propose to revise the Discussion and Conclusion sections as follows:

1) *We will remove the final paragraph of Section 5.3 (page 11, lines 1–14).*
2) *In place of this paragraph, we will include a discussion of the high salinity of pond L3 and how that might indicate long surface age for the lower rock glacier. We will keep this discussion qualitative rather than providing an absolute age estimate for the pond. This new paragraph will include:*

    (a) *A discussion of the various sources of ions (and specifically Cl-) to central Taylor Valley as outlined by Witherow et al. (2006), Keys & Williams (1981) and Toner et al. (2013).*
    (b) *How ions might be transported to and removed from the pond to highlight what high salinity of L3 might mean for surface processes and pond antiquity. We will include increased wind-blown snow accumulation to the depression, transport of ions to the pond by near-surface water flow, removal of ions by wind especially during dessication events, and the fact that some ions will not be transported to the pond but rather stored in surrounding soils.*
    (c) *We will state that the high salinity of the pond (and possibly of the surrounding soils – unfortunately we did not measure soil salinity) supports the potential antiquity of the lower rock glacier because both aerosol and weathering sources for ions require time to accumulate. These data supplement other data that indicate a long, complex history for the rock glacier (weathering, grussification and GPR analyses).*

3) *We will edit Section 5.4 to remove text that mentions absolute ages based on pond L3 (MIS 3 and MIS 5). We will instead focus on the evidence for multiple glacial advances that are contained in one large rock glacier (1-km long) that is sourced from a relatively small cold-based alpine glacier (3-km long). We will also highlight the potential pre-Holocene antiquity of the lower rock glacier as evidenced by grussification, clast weathering, thick sediment cover, and a high salinity pond in the lower rock glacier, coupled with GPR evidence that supports >4 episodic advances and retreats of the source glacier.*
4) *We will delete the Cl- age estimate from the Conclusions section, which is presently only one sentence. This will not compromise the main Conclusions of the article: (a) the buried ice is sourced from the local alpine glacier, (b) that the rock glacier records multiple glacier advances that likely extend from the present to pre-Holocene, and (c) that rock glaciers and ice-cored drift could be used elsewhere in Antarctica to map and record glacier advance, especially where debris-starved cold-based glacier ice occurs.*