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Reply

Reply to comment received from J. Shulmeister et al. regarding “Reconciling the onset of deglaciation in the upper Rangitata valley, Southern Alps, New Zealand” (Quaternary Science Reviews 203 (2019), 141–150.)

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Here we discuss issues raised by Shulmeister et al. (2019a) in relation to our recent paper (Barrell et al., 2019), which in turn addresses some aspects of their earlier paper (Shulmeister et al., 2018). We first comment on the puzzle of sample elevation errors, then address geomorphological interpretations and end by evaluating dating results and their interpretation.

1. GPS elevation errors

Shulmeister et al. (2019a,b) report that their incorrect elevations were measured on the afternoon of 26 January 2016 New Zealand Daylight Time (NZDT). It turns out their measurements coincided with a c. 11-hour duration error in the Coordinated Universal Time (UTC) offset parameters broadcast by some of the Global Positioning System (GPS) satellites, which caused a −13 μs error in clocks controlled by GPS satellite time broadcasts (Yao et al., 2017). Shulmeister et al. (2019b) attribute their elevation inaccuracies to the UTC timing error, yet Kovach et al. (2016) found that the GPS broadcast error had no impact on GPS positioning. Coincidentally that same afternoon, one of us (AEP) was collecting surface exposure dating (SED) samples near Lake Tekapo, c. 47 km southwest of the Butler Downs sampling site. At Tekapo, seven samples were collected over a c. 5-hour period from midday and their locations determined by GPS (Table 1). Alerted by Shulmeister et al. (2019a,b) to the UTC timing error, we independently estimated ground elevation at the Tekapo sites using 20-metre-interval topographic contours and the Satellite Radar Tracking Mission (SRTM) digital elevation model (Table 1), using the method of Barrell et al. (2019).

Considering just the uncorrected Tekapo GPS data to avoid any possible remedial effect due to differential correction, the GPS elevations are within 10 m of the SRTM elevations (Table 1), approximating the SRTM/GPS elevation relationship found at Butler Downs in March 2018 by Barrell et al. (2019). We conclude that no identifiable positioning errors arose using a Trimble receiver at Tekapo on 26 January 2016. We have no reason to think the Garmin hand-held GPS receiver used for the Shulmeister et al. (2018) measurements calculates positions in a different way from that of a Trimble receiver. The alignment of Tekapo GPS data with independent assessment that GPS positioning was unaffected by the UTC timing error (Kovach et al., 2016) leads us to the view that GPS elevation errors reported from Butler Downs on 26 January 2016 NZDT await satisfactory explanation.

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Table 1
GPS survey data for SED samples from the Lake Tekapo area, measured on 26 January 2016 (NZDT) using a Trimble Geo7x GPS receiver. Latitude (lat) and longitude (long) are in decimal degrees relative to the WGS 1984 datum. Date and time (24-hr format) of measurement is in both UTC and NZDT. Sample site elevations (Elev) comprise the uncorrected (Uncorr) GPS field measurement and the corrected (Corr) value following differential correction (dGPS) against data collected at the Mount John Observatory geodetic base station, c. 6 km southeast of the sampling area. The dGPS elevations are referenced to mean sea level and calculated uncertainty of the corrected values (dGPS error Corr) is mostly ±0.1 m. Other elevations comprise Elev TC estimated from topographic contours and Elev SRTM estimated from the Satellite Radar Tracking Mission digital elevation model. Elev TC is referenced to sea level and Elev SRTM is referenced to the WGS84 Earth Gravitational Model (EGM 96). The uncorrected GPS elevations approximate those that would be obtained by a hand-held receiver. The differentially corrected values (bold) are the ones we would rely on for age calculation. In the text, we discuss the uncorrected GPS elevations in relation to the SRTM values.

Sample ID	Lat (dd)	Long (dd)	Date UTC	Time UTC	Date NZDT	Time NZDT	Elev GPS Uncorr (m)	Elev dGPS Corr (m)	dGPS error Corr (m)	Elev TC (m)	Elev SRTM (m)
TEK-16-10	−43.961143	170.427931	25-Jan	23:11	26-Jan	12:11	843.03	**840.12**	0.1	820–840	834
TEK-16-11	−43.960989	170.427931	25-Jan	23:57	26-Jan	12:57	841.29	**841.35**	0.1	820–840	834
TEK-16-12	−43.960470	170.427615	26-Jan	00:21	26-Jan	13:21	843.16	**843.43**	0.1	820–840	838
TEK-16-13	−43.950602	170.425322	26-Jan	01:36	26-Jan	14:36	858.24	**859.78**	0.8	840–860	859
TEK-16-14	−43.950064	170.425127	26-Jan	02:37	26-Jan	15:37	860.86	**860.70**	0.7	840–860	859
TEK-16-15	−43.948671	170.424708	26-Jan	03:14	26-Jan	16:14	861.53	**861.83**	0.1	840–860	858
TEK-16-16	−43.948366	170.424593	26-Jan	03:57	26-Jan	16:57	863.59	**861.54**	0.1	840–860	858

2. Geomorphological interpretation

Sandstone is by far the dominant lithology of the 'greywacke' basement rock that forms the Rangitata catchment (Cox and Barrell, 2007) and we agree that most moraine boulders are of that composition, with occasional examples of other lithologies. Thus, sandstone lithology in boulders on the high-level sampling area of Butler Downs is not unexpected and needs no special explanation, such as derivation from single-source rockfall. The descriptor 'boulder cluster' is incompatible with multi-directional views (Fig. 1b–e in Shulmeister et al., 2019a) showing very few large boulders.

Extended discussion of the post-glacial lake introduces no new data and it is not explained how the 'low elevation of the lateral moraines on the Downs' is relevant to lake extent or depth. We have nothing to alter or add to the lake discussion in our paper.

The map in our paper is sourced from a 1:100,000-scale geomorphological map (Barrell et al., 2011, 2013) which covers a land area of c. 31,000 km^2 across the central part of the South Island, including the Rangitata valley, and provides a uniform regional characterisation of glacial landforms on both sides of the Southern Alps. Generalizations necessary for regional-scale cartographic legibility on the Barrell et al. (2011, 2013) map include exaggerated widths for some relatively prominent moraine ridges, while most small moraine ridges are each depicted as a single line ('ice-contact slope') within a moraine map unit. We regard the Barrell et al. (2011, 2013) map as giving satisfactory scale-appropriate characterisation of the Rangitata landforms. The objection to some kame terrace margins being mapped as lateral moraines misses the point that kame terraces are ice-marginal landforms and their valley-ward edges, where not modified by later erosion, approximate the edge of the glacier that constrained the marginal meltwater streams. Figure 1f in Shulmeister et al. (2019a) shows small irregularities on many of the narrow terrace surfaces, which led Barrell et al. (2011, 2013) to classify those benches as moraines. Nevertheless, whether moraines or kame terraces, their valley-ward edges approximate ice-contact slopes. That same photograph shows good detail of the prominent lateral moraine wall referred to in our paper, that starts at the bench just above the arrowed minor terrace. The moraine wall comprises a generally featureless and slightly gullied ice-contact slope, steepest at the top, that descends to at least the forested middle ground. It is a classic Southern Alps example of a landform typically produced during sustained ice downwasting (Barrell et al., 2011).

The so-called 'kettle landscape' or 'dead-ice topography', said to be 'entirely missing', is shown on our map but classified simply as 'moraine'. Long views in several directions across this landform (Fig. 1b–e in Shulmeister et al., 2019a) show undulating to slightly hummocky terrain with one broad depression, rather than a glaciokarst terrain as implied by the nomenclature of Shulmeister et al. (2018, 2019a). Although our March 2018 fieldwork confirmed several large, widely-scattered, broad topographic depressions in that area, these are common features of general moraine topography in Southern Alps valleys.

Quaternary-age strata in the Southern Alps are generally seen only in patchy, discontinuous, exposures in eroded gully or valley walls, or vehicle-track cuttings. We estimate that stratigraphic exposure comprises of the order of 1% by area of the landscape and renders inaccurate the descriptor 'abundant' applied by Shulmeister et al. (2019a). Exposures within glacial troughs commonly contain remnants of relatively old sediments, as Shulmeister et al. (2010a) show in the nearby Rakaia valley. Southern Alps glacial and fluvioglacial land surfaces reflect the most recent geomorphic activity and the underlying stratigraphic units commonly reflect earlier erosional/depositional events unrelated to the present topography. Studies of the available scattered exposures provide useful stratigraphic insights but have little if any bearing on exposure dating of glacial landforms in the Rangitata valley.

We appreciate the differences in the scales and approaches of the landform mapping discussed above, but do not see them materially influencing the question of timing of deglaciation, which depends on direct chronological data. We reiterate the similarity of the Butler Downs/Brabazon Downs landform signatures to those of the well-dated deglacial landform sequences of the Ohau and upper Rakaia valleys mentioned in our paper.

3. Dating results

With the recalculations based on corrected sample elevations, general agreement has been achieved on the boulder age calculations. However, difference remains regarding the age interpretations, not aided by conflicting information whereby Shulmeister et al. (2019b) infer a c. 2 ky duration of ice recession from the mean age $\pm 1\sigma$ standard deviation (17.8 ± 0.9 ka) of their dataset, but Shulmeister et al. (2019a) base their c. 2 ky gradual ice recession on the oldest age of a sample set as representing the time of moraine deposition. The latter estimation goes against the guidance of Applegate et al. (2012) that reduced chi-squared values of the order of 1 (e.g. 1.7; Shulmeister et al., 2019b) call for the use of mean SED age to estimate the time of moraine deposition.

We note that the Shulmeister et al. (2019a) landform age interpretation refers only to the Butler Downs. Using the oldest age (c. 19.5 ka) from the morphostratigraphically-oldest dated moraine and the oldest age from the morphostratigraphically-youngest dated moraine (c. 17.6 ka), they conclude that ice recession took c. 1900 years. This evaluation neglects their Brabazon Downs sampling area, where they obtained four ages from the morphostratigraphically-youngest moraines of their study area (Fig. 3 of Barrell et al., 2019, also the ice limit lines in Figure 1a of Shulmeister et al., 2019a). Three of those four samples returned ages of c. 18.6 ka. Properly applied, their approach should compare the morphostratigraphically-oldest and youngest moraines of their whole study area, with respective oldest ages of c. 19.5 and 18.6 ka and find that c. 300 m of ice downwasting (Fig. 3 of Barrell et al., 2019) occurred in c. 900 years. This is just a hypothetical comment, because we disagree with the approach of considering only the oldest ages of the upper Rangitata dataset.

The approach to age interpretation applied by Shulmeister et al. (2018, 2019a) contrasts with previous SED studies by the Shulmeister group in the Southern Alps (e.g. Shulmeister et al., 2010b; Rother et al., 2014, 2015) and in recent compilations (e.g. Shulmeister et al., 2019c) which employed mean age calculations, an approach with which we agree. We consider that Shulmeister et al. (2018, 2019a) have not made a convincing case for slow ice recession near the end of the last glaciation in the upper Rangitata valley. In our view, the application of statistics to morphostratigraphically-grouped ages indicates that rapid ice recession was in progress in the upper Rangitata valley at c. 18 ka.

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