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Revised Quaternary glacial succession and post-LGM recession, southern Wind River Range, Wyoming, USA

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ABSTRACT

We present here a more complete cosmogenic chronology of Pleistocene glacial deposits for the Wind River Range, Wyoming, USA. Fifty-one new and thirty-nine re-calculated ^{10}Be and ^{26}Al exposure ages from Sinks and North Fork canyons, Stough Basin, Cirque of the Towers and the Temple Lake valley allow us to more tightly constrain the timing and sequence of glacial alloformations in the southern portion of the range.

Moraines, diamicts and bedrock exposures here have previously been correlated with as many as five Pleistocene and four Holocene glacial events. Exposure ages from Pleistocene alloformations associated with trunk glaciers in Sinks Canyon and North Fork Canyon generally confirm earlier age estimates. Cosmogenic radionuclide (CRN, ^{10}Be and ^{26}Al) ages from moraines and striated bedrock surfaces previously mapped as Pinedale correspond to MIS2, while boulder exposure ages from moraines mapped as Bull Lake correspond generally to MIS5-MIS6. Geomorphic data from a moraine previously mapped as Younger pre-Sacagawea Ridge appears to correspond most closely to the Sacagawea Ridge glacial episode (MIS-16), but the uncertainty of a single ^{10}Be exposure age suggests the unit could be as young as MIS-10 or as old as MIS-18. Boulders from a diamict on Table Mountain previously reported as Older pre-Sacagawea Ridge yield two ^{10}Be exposure ages that suggest the presence of Early Pleistocene glacial activity here possibly older than 1–2 Ma (>MIS-30).

Bedrock exposure ages within Sinks Canyon suggest the Pinedale valley glacier had retreated from the floor of Sinks Canyon to above PopoAgie Falls by ca. 15.3 ka. Cirque glaciers in Stough Basin appear to have retreated behind their riegels by ca. 16 ka, which suggests the cirque glaciers were decoupling across their riegels from the valley glaciers below at this time, prior to their readvance to form Lateglacial moraines.

New ^{10}Be boulder exposure ages from moraines previously correlated to the Temple Lake and Alice Lake allostratigraphic units in the cirques of Stough Basin and Cirque of the Towers show general equivalence to the stadial event just prior to the onset of the Bølling interstadial (17.5–14.7 ka) and to the Intra-Allerød Cold Period-Younger Dryas stadial phase (13.9–11.7 ka), respectively. From this evidence, the Temple Lake Alloformation of the Wind River Mountains now should correspond to the INTIMATE GS-2.1a (Oldest Dryas) stadial event while the Alice Lake Alloformation should correspond to the INTIMATE GS-2 stadial (IACP-Younger Dryas). Thus, we consider that evidence no longer exists for early-to mid-Holocene glacial events in the southern Wind River Range.

1. Introduction

The U.S. Rocky Mountains contain numerous ranges with records of multiple Pleistocene glacial episodes (Richmond, 1986;

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Dahms, 2004b; Locke, 1990; Locke and Smith, 2004; Osborn and Gerloff, 1997; Pierce, 2004; Pierce et al., 2018). The Greater Yellowstone Ecosystem of Wyoming-Montana-Idaho plays a central role in our understanding of North American alpine glacial history as it contains many of the type localities used for our present understanding of the Pleistocene-Holocene glacial succession in this region of the Rockies (e.g., Richmond, 1986; Dahms, 2004b; Dahms et al., 2010; Pierce, 2004). The Wind River Range (WRR) occupies the southern-most portion of the Greater Yellowstone Geoecosystem and, along with Yellowstone Park itself, is the focus of much past and continuing research into the regional Pleistocene glacial succession (Blackwelder, 1915; Richmond, 1948, 1964, 1965, 1973, 1986; Richmond and Murphy, 1965, 1989; Murphy and Richmond, 1965; Mears, 1974; Dahms, 2004a; b; Dahms et al., 2010).

1.1. Pleistocene succession of the WRR

Glaciers in the Wind River Mountains have occupied all of the range's major alpine valleys. Using the seminal works of Blackwelder (1915) and Love (Mears, 1974), Richmond (1965, 1986 and references therein) presented morphostratigraphic evidence from the Bull Lake Type Area (BLTA) that identified a series of moraine, outwash and lake deposits at Cedar Ridge corresponding to five purported early-to-late Pleistocene glacial periods [from youngest: Pinedale - Bull Lake - Sacagawea Ridge - Cedar Ridge - Washakie Point]. Hall and Jaworowski (1999) reevaluation of the Cedar Ridge section showed that all of the Pleistocene allostratigraphic units (NACSN , 1983) above the Tertiary beds at Cedar Ridge should be correlated to Sacagawea Ridge-and-younger deposits and are paleomagnetic-normal (no older than the Gauss-Matuyama boundary of 781 ka). Thus, no evidence exists at this locality for Richmond's purported Cedar Ridge and Washakie Point deposits. Likewise, recent ^{10}Be and ^{36}Cl exposure age-analyses from moraine boulders at the BLTA (Hall and Jaworowski, 1999; Chadwick et al., 1997) also found no evidence for pre-Sacagawea Ridge units. Thus, since 1999, the oldest two of Richmond's three 'pre-Bull Lake' units are no longer viable allostratigraphic units in the WRR, and that only the Sacagawea Ridge, Bull Lake, and Pinedale remain as widely recognized units.

Dahms (2004a) used morphostratigraphy and soil development at Sinks Canyon to identify a succession of allostratigraphic units (moraines) corresponding to the Pinedale (MIS2; Cohen and Gibbard, 2011), Early Wisconsin (MIS4), Bull Lake (MIS6), Sacagawea Ridge (MIS16?) glaciations as well as two stratigraphically older diamictons above/outside the canyon that suggested that two older (undated) glacial advances were represented here. These were provisionally termed Older and Younger pre-Sacagawea Ridge (Dahms, 2004a).

The previous model for the Lateglacial/Holocene (post-LGM) succession of the WRR (Dahms et al., 2010) was based on cumulative relative and numeric age data gathered by numerous workers from alpine valleys along the range (Holmes and Moss, 1955; Currey, 1974; Dahms, 2002; Gosse et al., 1995a; b; 1999; Mears, 1974; Miller and Birkeland, 1974; Mahaney, 1978, 1984a; b; Zielinski and Davis, 1987). The main points of contention in this work have been (a) the age of those deposits previously associated with the Younger Dryas (YD) and (b) the number and age(s) of post-YD events preserved here. Early interpretations of the post-LGM succession focused chiefly on the age of the type Temple Lake moraine in the Temple Lake Valley. Hack (1943) and Moss (1949, 1951; Holmes and Moss, 1955) identified deposits corresponding to two late Pleistocene – Holocene glacial advances here. Their work identified the Type Temple Lake moraine as a pre-Altithermal unit and younger moraines corresponding to the 'Little Glaciation' (Little Ice Age). Richmond (1965) later revised the interpretations of Holmes and Moss in the Temple Lake valley, suggesting that two Temple Lake moraines were preserved here ("*a*" and "*b*") that represented the oldest two of three neoglacial (post-Altithermal) advances. Richmond also revised the name of the Little Glaciation to Gannett Peak (Richmond, 1965; Benedict, 1968; Birkeland et al., 1971). Miller and Birkeland (1974) later re-interpreted these deposits, using significant differences in moraine and boulder weathering characteristics and soil development to suggest four YD-to-Holocene glacial events are preserved here [Temple Lake, Early Neoglacial, Audubon equivalent (Benedict, 1973; Miller and Birkeland, 1974), Gannett Peak]. Most recently, Dahms (2002) and Dahms et al. (2010) presented a revised post-LGM stratigraphy for the WRR that essentially mirrored Birkeland and Miller's correlations with suggested ages: Gannett Peak (LIA), Black Joe (1–2 ka), Alice Lake (~5500-4000 yr), Temple Lake (YD-equivalent).

In this paper, we use a combination of new and recalculated ^{10}Be and ^{26}Al exposure ages from successions of moraines, diamictons, and bedrock surfaces previously described by Dahms (2002, 2004a) and Fabel et al. (2004) from Table Mountain, Sinks Canyon-Stough Basin, and North Fork Canyon-Cirque of the Towers to more tightly constrain the Pleistocene glacial succession for the southern WRR (Fig. 2). As the WRR is the type locality for most of the Rocky Mountain glacial sequence, an updated chronology here adds to a more complete understanding of the alpine glacial succession in North America. Additionally, we present evidence for rates of ice retreat along the Middle and North Forks of the PopoAgie (Po-po'-zhuh) Basin from the maximum positions of Pinedale ice (MIS2) in Sinks and North Fork canyons at/near the Last Glacial Maximum (LGM) to the Lateglacial positions of the cirque glaciers as represented by moraines in Stough Basin and Cirque of the Towers.

2. Study area

The Wind River Range (WRR) is located in the Middle Rocky Mountains of west-central Wyoming, with the PopoAgie River basin on the range's southeastern flank (Fig. 1). Table Mountain, Sinks Canyon and Stough Basin are parts of the Middle PopoAgie Basin while North Fork Canyon and the Cirque of the Towers occupy most of the basin of the North Fork of the PopoAgie (Fig. 2). Table Mountain and the mouth of Sinks Canyon are located ca. 15 km southwest of the city of Lander, Wyoming. Sinks Canyon was the single outlet for the trunk glacier in the Middle PopoAgie Basin and is the most southerly of the four major canyons along the eastern slope of the WRR (Fig. 1) where Pleistocene glacial deposits previously were described (Richmond, 1957, 1986; Richmond and Murphy, 1965, 1989; Murphy and Richmond, 1965; Shroba, 1989; Chadwick et al., 1997; Phillips et al., 1997; Applegarth and Dahms, 2001; Dahms, 2004a). The mouth of North Fork Canyon lies ca. 13 km northwest of Lander (Fig. 2). North Fork Canyon was the single outlet for the North Fork Basin trunk glacier. Post-LGM glacial deposits were previously reported from Stough Basin and Cirque of the Towers by Dahms and his colleagues (Dahms, 2002; Dahms et al., 2010). Glacial deposits have not previously been described from the North Fork Canyon, downvalley from Cirque of the Towers.

Bedrock of the areas sampled for this study is Archaean granite and granodiorite of the Louis Lake Formation (Love and Christianson, 1985; Frost et al., 2000). Although Sinks and North Fork canyons are carved into a nearly complete section of the Paleozoic limestones, dolomites, and sandstones described for this region of Wyoming (Love et al., 1992), only granitic boulders and bedrock exposures were sampled for this study.