



## Moraine formation during an advance/retreat cycle at a temperate alpine glacier

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Mountain glaciers are highly sensitive to variations in temperature and precipitation, and so moraine records from such systems are strong indicators of climate change. Due to the prevailing trend of retreat of the majority of mountain glaciers globally over the last few decades, there are limited opportunities to observe moraine formation, especially at temperate alpine glaciers. In the Southern Alps of New Zealand, while glaciers have all experienced a major retreat since the late 19th century, within this loss of ice mass, there has been a distinct variance in individual glacier response. Indeed, while Tasman Glacier, the longest glacier in the Southern Alps has thinned and entered into the current phase of calving retreat in the early 1990s, the steeper, more responsive glaciers to the west of the Main Divide, such as Franz Josef and Fox Glacier have experienced more elaborate advance/retreat phases. We focus on moraine formation at Fox Glacier, a c. 12.5 km long valley glacier terminating at 300 m above sea level. Fox Glacier retreated substantially since the 1930s, before advancing 800 m between the mid-1980s and 1999. A minor retreat then followed until 2005, succeeded by a 300 m re-advance until 2007-8. Continued retreat and down-wasting has since followed. Superimposed on this alternating advance/retreat cycle, have been minor winter re-advances. Sedimentological and morphological information were combined with detailed observations, historical photos and recent time-lapse photography of the terminus. Characteristics of several modes of moraine formation have been observed: (1) the late 20th century advance culminated in a broad <5 m high terminal moraine, formed by an admixture of “bulldozed” proglacial sediments and dumping of supraglacial material; (2) the 21st century short-lived advances were characterized by 1-2 m high (often multi-crested) ridges with a “saw-tooth” plan-form controlled by longitudinal crevasses outcropping at the terminus; (3) time-lapse imagery identified thrusting and subsequent melt-out of fine-grained englacial material along reverse faults intersecting the terminal face as a significant contributor to the subdued terminal moraines forming during the most recent phase of recent recession; (4) collapse of lateral moraines due to post-2008 down-wasting is now proceeding. Overall, even short-term preservation of glacigenic sediment-landform associations on the Fox Glacier sandur is limited by the glacial meltwater regime, with lateral migration of the proglacial river continually reworking morainic material.