Effects of the M7.9 Denali Fault Earthquake on glaciers in the Alaska Range

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ABSTRACT
Glaciers are present in many valleys aligned with the Denali fault. As a result, more than 40% of the surface rupture resulting from the November 3, 2002 M7.9 event is on glaciers. Surface rupture was observed on the Susitna, Black Rapids, Canwell, Gakona, and Chistochina Glaciers. In addition, offset glacier ice was observed near the terminus of the West Fork Glacier where the Susitna Glacier fault (SGF), a newly discovered fault, intersects the glacier.

Offsets resulting from the Denali Fault earthquake in glacial ice have variable morphologies. The earthquake epicenter was located near an icefall in a tributary of the West Fork Glacier. Almost all seracs in the icefall toppled during the event. The Denali fault laterally offset pre-existing crevasses on the north side of the Canwell Glacier and vertical offset was observed at many localities. At some locations, one or more long linear cracks can be traced along the glacier surface, often following moraines that presumably form areas of weakness. The SGF appears to make a sharp turn to the west where it follows a looped moraine across the glacier. At some locations along the Denali fault cracks in the ice are oriented perpendicular to the fault trace. These observations suggest that careful examination of glacier morphology must be considered while delineating fault traces in glaciers.

The most dramatic changes to glaciers resulted from rock, ice and snow avalanches released by the earthquake. Three rock falls from the south wall of the Black Rapids Glacier cover about 13 km^2 of the ablation area or about 5% of the total glacier area. The blanketing effect of these rock falls will increase the glacier's mass balance by about 0.2 m a^{-1} by insulating the ice from warm summer temperatures. A large rock and ice fall also occurred on the upper Gakona Glacier. The rock and ice fall will not affect the glacier's mass balance immediately, because it was deposited onto the glacier's accumulation area. These rock falls will be a readily visible surface feature for the next 200 to 400 or more years. Prior to the November 3 event, large rock and ice fall debris cover was not evident on the glaciers of the region. This suggests that an event of similar consequences has not occurred in the recent past.

Cracks

The surface rupture is visible on many of the glaciers (Figs. 1,3,4, 6, 8, 10, 11) along the fault (Susitna, Black Rapids, Canwell, Gakona, West Fork Chistochina, and Chistochina), but not on the West Fork Glacier, which is closest to the epicenter. On an icefall close to the epicenter most of the seracs have fallen over, giving it a very unusual appearance (Fig. 2). On the Canwell Glacier the fault cut through transverse crevasses, making it possible to measure offset (Figs. 6, 8). Surface rupture often follows along moraines, which presumably form places of weakness. Because these moraines don't always follow the fault trace, it can result in jumps with an echelon structure (Fig. 10). On the Chistochina Glacier there are places where the surface rupture takes the form of two or multiple sub-parallel linear cracks (Fig. 11).
On many glaciers newly formed cracks perpendicular to the fault trace were observed (Fig. 4), indicating failure under compression or tension.
Thrust faulting was documented on the lower Susitna Glacier, along the newly discovered Susitna Glacier Fault (Fig. 3).

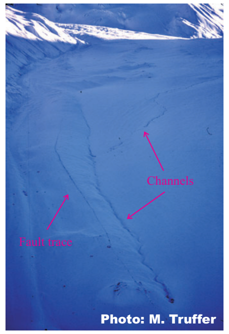


Fig. 1: Susitna Glacier

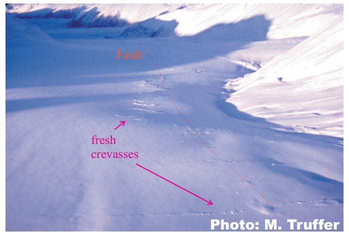


Fig. 4: Black Rapids Glacier

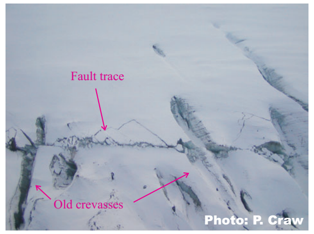


Fig. 6: Canwell Glacier

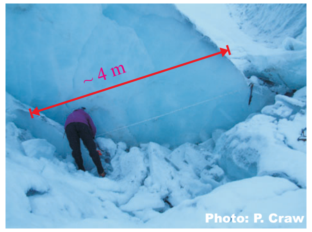


Fig. 8: Canwell Glacier

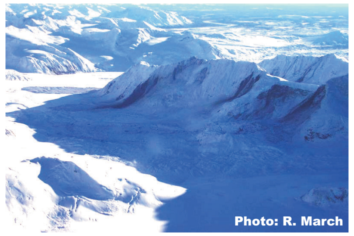
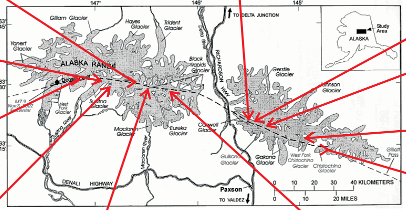


Fig. 9: Gakona Glacier



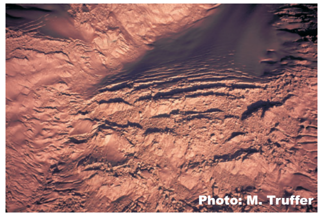


Fig. 2: West Fork Glacier

Fig. 10: West Fork Chistochina Glacier

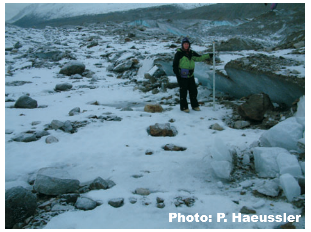


Fig. 3: Susitna Glacier

Fig. 5: Black Rapids Glacier

Fig. 7: Black Rapids Glacier

Fig. 11: West Fork Chistochina Glacier

Rock slides and avalanches
Avalanching and rock slides are very widespread along the entire rupture zone. The most impressive ones are a series of three slides on the lower Black Rapids Glacier (Fig. 7). This rock fall originated from the south walls of the glacier, crossed a medial moraine (~30 m high), and continued across the entire glacier valley (> 2 km). The rock blanket covers an estimated 13 km^2 of the glacier's ablation area. A very crude estimate suggests that the total volume exceeds 10 Mio m^3. Typical ablation rates at that altitude are about 4 ma^{-1}. The insulationg effect of the fresh rock cover will increase the glacier-wide mass balance by about 0.2 ma^{-1}.
Another massive rock fall occurred on the upper Gakona Glacier (Fig. 9). It will not affect the glacier's mass balance in the near future, because of its location in the accumulation area.

Blow outs
Perhaps the most curious features are the blow-out holes and crevasses (Fig. 5) observed on Black Rapids Glacier. No direct surface observations were made, but there is no evidence of water in the pictures. Possibly a pressure pulse in the sub- and englacial water system created an air pressure wave in holes connected to the surface that was strong enough to blow out snow bridges.
On the other hand, the ice covers of glacier lakes in the nearby potholes area were undisturbed.

Long term effects
The glacier cracks are likely to heal quickly and not result in any long term effects. Although the earthquake hypothesis for surge initiation has long been discredited, this earthquake does provide a good definite test for it, because many of the Denali Fault glaciers or of surge-type, and the Susitna and Black Rapids have not surged since 1952 and 1937 respectively. Currently no surge activity has been reported.
The massive rock falls on Black Rapids Glacier will affect its mass balance in the coming century or more. The Gakona Glacier rock fall will get buried by snow in the coming years and only have an effect on the glacier when it re-emerges in a few hundred years.
It is interesting to note that no rock falls of similar size have been present on any of these glaciers before the November 3 event. These recent slides will be a prominent feature for up to the next 400 years. This suggests that no event of similar magnitude has occurred in the last 400 years or so.

Other earthquakes
A big rock fall also occurred on the Sherman Glacier in the Chugach Mountains, Alaska, as a result of the 1964 Good Friday earthquake. Although earthquakes of such large magnitude do not frequently occur in glaciated areas, the erosion caused by the rockslides could be an important geomorphic agent.
Surface rupture was also observed after the 1958 Fairweather Fault earthquake (Austin Post, pers. comm.), but it was not found to have a lasting effect on the glaciers.

More info and pictures
http://wwwdggs.dnr.state.ak.us/earthquake.html
http://ak.water.usgs.gov/glaciology/m7.9_quake/