

## **Glacial-Marine Sedimentation as a Recorder of Tectonic, Climatic and Sea-Level Dynamics on Active Continental Margins**

Charles A. Nittrouer and Bernard Hallet

School of Oceanography and Department of Earth & Space Sciences

University of Washington, Seattle, WA 98195

[nittroue@ocean.washington.edu](mailto:nittroue@ocean.washington.edu), [hallet@u.washington.edu](mailto:hallet@u.washington.edu)

*Submitted in regard to "Sediment Transfer and Feedbacks"*

Keywords: tidewater glaciers, fjords, sediments, tectonics, climate, sea level, continental margin

### *a) Overview Statement*

Glacial-marine sedimentation responds to and provides sedimentary archives for a diversity of important processes associated with continental-margin dynamics. Tectonic convergence and subduction on active margins lead to uplift and volcanism that commonly (in temperate and high latitudes) create coastal mountain ranges with sufficient elevation to be ice covered. Glaciers are extremely effective in eroding mountains, transferring much ice and sediment to the sea, and aiding continued uplift. In areas with high coastal mountains, the ice commonly extends to sea level as tidewater glaciers (e.g.: southern Alaska; Patagonia; south island New Zealand; Antarctic Peninsula). Today, in these settings, the glacial sediments are typically released into a fjord (Fig. 1) with nearly complete entrapment of erosion products, forming a well-preserved sedimentary record of uplift, ice build-up, associated climatic variations, erosion, and transfer events. These under-studied coastal glaciers and sedimentary settings are also gaining attention for their control over sea-level rise (e.g., Overpeck et al. 2006), which is one of the largest potential threats of future climate change. On a global scale, the complex behavior of outlet glaciers and rapid ice-marginal changes are prime factors limiting confidence in predictions of impending sea-level rise. So, in these sites, the record of recent history and the prediction of future events (e.g., next century) have great scientific, environmental and human value. Our understanding of the linkages between glacial erosion and tidewater sedimentation would benefit greatly from an integrated investigation.

### *b) Tectonics, Subduction and Uplift*

On active margins, ocean crust collides with and is subducted beneath continental crust. Spectacular coastal mountain ranges, including the St. Elias mountains in the NE Pacific, can form where continental terranes coupled to oceanic crust converge with continental plates. Based on much work in this area, Berger et al. (2008) hypothesize that "alpine glaciation in late Cenozoic time modified denudation and deformation within numerous mountain belts worldwide. This is consistent with climate as the driver of observed changes in exhumation rates, sedimentation rates and relief within many orogenic systems over the past few million years. Where present, glaciation may thus have a significant role in the internal processes of mountain building, empirically supporting the paradigm that orogenic architecture, kinematics and evolution may be heavily influenced by external climatic processes."

*c) Glacial Erosion*

Glacial erosion is receiving increased attention due to: 1) the high erosion rates documented for many active glaciers (e.g., Hallet et al., 1996; Delmas et al., 2009); 2) its role in curtailing the height of mountain ranges, the “glacier buzzsaw” (see Fig. 2; Egholm et al., 2009); and 3) alpine glaciers being widespread during Plio-Pleistocene climate (e.g., Berger et al., 2008). Many active orogens have been extensively glaciated in the past (e.g., Himalayas, Andes, European Alps, Southern Alps in New Zealand, northwestern Cordillera of North America), but most of these regions currently contain only small alpine glaciers and remnants of larger ice fields. Consequently, the studies of coupling between glacial erosion and tectonic processes are based on the geomorphic studies of formerly glaciated landscapes and on conceptual, analytical, and numerical models (Tomkin and Roe, 2007). Direct field investigations of tectonically active regions that are currently glacier covered have only recently gained attention (e.g., Enkelmann et al., 2009).

*d) Tidewater Glacial-Marine Sedimentation*

Sedimentation proximal to the calving ice front impacts glacial advance and retreat, and the distal sedimentation records their history. Many tidewater glaciers advance slowly into deep water over a period of centuries with little sensitivity to climate variability, by keeping before them a moraine shoal that drastically reduces ice loss by calving (Meier and Post, 1987). This shoal, which can buttress not only a tidewater glacier but the massive ice sheet behind it, is slowly moved forward by erosion on the glacier side and deposition on the far side. Sedimentation in proglacial portions of fjords is complicated by englacial and subglacial discharge and by oceanographic factors (temperature, salinity and bathymetry), which impact melting of glacial ice and mixing in fjord water. Sediment supply and accumulation on the seabed decrease with distance from the ice front (Syvitski, 1989; Cowan and Powell, 1991; Domack and Ishman, 1993; Jaeger and Nittrouer, 1999). The gradient of decrease and the detailed sedimentary signatures record assorted histories of ice and sediment supply and release.

*e) Sea-Level Rise*

Glacial retreat around the world has been used as dramatic and visible evidence of climate change, and has considerable practical importance because it directly contributes to global sea-level rise. However, the controls on the fluctuations of some of the most important outlet glaciers are only partly related to climate variability (Fig. 1), and these controls remain poorly understood. An innovative merger of glaciology and oceanography could provide a valuable understanding of retreat by tidewater glaciers.

*f) Concluding Statement*

The linkages described in this white paper are very common, and are found on many margins surrounding the Pacific Ocean. Therefore, gains in knowledge about the intrinsic processes will significantly improve our understanding of active continental margins. The writers’ expertises are centered in glacial erosion, tectonics and marine sedimentation, however, they have tried to demonstrate the broader linkages to other aspects of the MARGINS initiative. As mentioned in the overview, relevant study areas abound (e.g.: southern Alaska; Patagonia; south island New Zealand; Antarctic Peninsula). In addition, this research lends itself to numerical modeling, and can be readily integrated with diverse Earth system studies ranging from orogenesis to ice-sheet stability and their impact on continental-margin sedimentation and sea-level rise.

## References

- Berger, A.L., et al. 2008. Quaternary tectonic response to intensified glacial erosion in an orogenic wedge. *Nature Geosci.*, 1, 793-802.
- Cowan, E.A. and R.D. Powell 1991. Ice-proximal sediment accumulation rates in a temperate glacial fjord, southeastern Alaska. In *GSA special paper 261*, 61-73.
- Delmas, M., et al. 2009. Variability of Quaternary glacial erosion rates – A global perspective with special reference to the eastern Pyrenees. *Quat. Sci. Rev.*, 28, 484-498.
- Domack, E.W. and S.E. Ishman 1993. Oceanographic and physiographic controls on modern sedimentation within Antarctic fjords. *GSA Bull.*, 105, 1175-1189.
- Egholm, D.L., et al. 2009. Glacial effects limiting mountain height. *Nature*, 460, 884-887.
- Enkelmann, E., et al. 2009. Intense localized rock uplift and erosion in the St. Elias orogen of Alaska. *Nature Geosci.*, 2, 360-363.
- Hallet, B., et al. 1996. Rates of erosion and sediment evacuation by glaciers: a review of field data and their implications. *Global Planet. Change*, 12, 213-235.
- Jaeger, J.M. and C.A. Nittrouer 1996. Sediment deposition in an Alaskan fjord: controls on the formation and preservation of sedimentary structures in Icy Bay. *Jour. Sed. Res.*, 69, 1011-1026.
- Meier, M.F. and A. Post 1987. Fast tidewater glaciers. *Jour. Geophys. Res.*, 92, 9051-9058.
- Overpeck, J.T., et al. 2006. Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise. *Science*, 311, 1747.
- Pfeffer, W.T., et al. 2007. The opening of a new landscape: Columbia Glacier at mid-retreat. *Am. Geophys. Union Spec. Pub. Series*, 59, 108 p.
- Tomkin, J.T. and G.H. Roe 2007. The response of a glaciated critical wedge orogen to changes in climate. *Earth Planet. Sci. Lett.*, 262, 385-397.
- Syvitski, J.P.M. 1989. On the deposition of sediment within glacier-influenced fjords: oceanographic controls. *Mar. Geol.*, 85, 301-329.

