Examining Tectonic-Climatic Interactions in Alaska and the Northeastern Pacific

Southeastern Alaska, encompassing the glaciated Chugach-St. Elias range (Figure 1), is one of the premier locations where tectonics, orogenesis, glacial erosion, landscape modification, and continental margin sedimentation can be studied in unison, allowing for quantitative models to be developed linking this suite of processes [e.g., Jaeger et al., 2001]. This area is an exceptional natural laboratory for studying a range of geologic problems (Figures 2 and 3), including the links between orogenic processes and continental accretion, glacial landscape modification, and sedimentation.

Geologic processes operate at rapid rates along the margin, which allows concurrent data collection on tectonic deformation, uplift, erosion, and sedimentation and development of comprehensive geodynamic models connecting these diverse processes. The active processes in southeastern Alaska are comparable or significantly greater than those studied in the Himalayan orogeny and include extremely high sediment yields, active faults associated with mountains and valley glaciers, and orogeny coinciding with extensive glacial cover.

An important advantage of Alaska is the proximity of the highest coastal mountain range on Earth to an energetic ocean with essentially no intervening basins to trap sediment. Tectonic signals are therefore quickly recorded in offshore basins with little signal modification resulting from long transport in rivers or temporary storage.

Due to the variety of climatic and tectonic processes that interact through the orogenesis of a glacially dominated coastal mountain belt such as the St. Elias range, a wide scope of expertise and techniques are required to produce a fundamental leap forward in our understanding of such systems.

To that end, a science plan has been assembled by attendees of a workshop, funded jointly by the U.S. National Science Foundation-Continental Dynamics program and the Joint Oceanographic Institutions-U.S. Science Support Program, which was held in Austin, Texas, 4–6 May 2003. This plan (which can be downloaded from: http://web. clas.ufl.edu/users/jaeger/JOI_CD/index2.htm) stems from the advice of the 57 workshop attendees, plus additional researchers interested in using the southeastern Alaska region (i.e., coastal mountains, continental margin, Gulf of Alaska abyssal plain) as a natural laboratory to study tectonic-climatic interactions in a glacial environment.

The science plan—written by members of the diverse communities of ocean drilling, glaciology, tectonophysics, and climate dynamics—summarizes the state of knowledge of relevant topics, provides a list of detailed scientific questions, and contains suggestions for implementation. By bringing together such a diverse group of Earth scientists, it was possible for the first time to outline the issues associated with gaps in our understanding of the linkages between late Cenozoic collisional tectonics and climate in Alaska and the northeastern Pacific Ocean.

This article summarizes the science plan.

Scientific Questions

The science plan organizes important goals in the Gulf of Alaska for evaluating tectonic-climatic cooperation into four broad topical research questions of potentially global importance:

1. What are the three-dimensional kinematic and dynamic processes of oblique microplate accretion/plateau subduction, and what are the implications for continental growth?

2. What have been the critical Neogene climatic shifts in the high-latitude Pacific, and what were the consequences for northern hemisphere climate, glaciation, and environmental change?

3. At what temporal and spatial scales does orogenesis influence global climate, and how do major glacial fluctuations shape orogenesis?

4. How can this natural laboratory with its active tectonics, abundant geologic hazards, aggressive glacial processes, and dramatic landscape be used for geoscience education and outreach?

Fig. 1. Photograph taken from Icy Bay showing Mount St. Elias towering 5.5 km above the coastline of the Gulf of Alaska with a tidewater glacier reaching the bay in the foreground.
Why Southeastern Alaska?

Several key points are raised as to why southeastern Alaska provides such an excellent setting for insight into these four global questions. Tectonically, it can serve as a modern analog for processes that have constructed much of the continental crust through terrane accretion. The margin encompasses a subduction to strike-slip transition that is observable both onshore and offshore, allowing imaging of crust-mantle interaction at such transitions. This plate boundary has generated the second-largest historical earthquake (1964), the largest historical tsunami (1958), the largest area of coseismic uplift (1964), and the greatest documented coseismic uplift (14.2 m in 1899). Present tectonic convergence rates are 2–3 times as high as in the Himalaya and are comparable to the total convergence between India and Eurasia.

Climatically, the area includes the oldest and thickest northern hemisphere Cenozoic glacial record, and studies in this region can illuminate the currently poorly constrained history of the Cordilleran ice sheet, potentially including its initiation, and its significance for global climate dynamics. The expanded Neogene marine and glacial sedimentary record within the North Pacific can enhance other high-latitude climate records. The Gulf of Alaska is a prime site for assessing the history of Holocene (or longer) decadal-scale (e.g., Pacific Interdecadal Oscillation or PDO) climate change, both geographically and due to high sediment volumes producing very high resolution paleoclimate records. Finally, there is an opportunity to constrain the Late Quaternary marginal marine environment to assess the feasibility of prehistoric human coastal migration routes.

The Chugach-St. Elias range is a mini-orogeny where tectonic and climatic processes and their interactions may be studied at a tractable scale. The landscape is sculpted primarily by glacial processes that produce the highest global glacial denudation rates (over 10^4 mm a^-1) and in turn provide record high sediment accumulation rates allowing for very high resolution proxy sedimentary records. This margin is the type location for temperate glacimarine systems and their models, and a unique ~5-km-thick sedimentary record of deposition recording at least 6 Ma of tectonic and climatic interaction is present. Because of the relatively confined and closed source-to-sink depositional system, there may be little lag between sediment production and marine accumulation. Tectonically observable deformation patterns in oblique convergent settings may reflect climatic influences. The tectonic setting, Neogene stratigraphy and sedimentary processes, glacial mass-balance, and structural and metamorphic history are reasonably well characterized, which allows for development of integrated experiments in tectonic and climatic interaction.

Implementation Phases

Because of the far-reaching scope of the issues raised in this science plan, it is not possible to create a comprehensive implementation plan. Instead, a general list of recommended tasks have been grouped into three implementation phases that reflect logistical concerns and the need to address the most glaring gaps in knowledge and data.

Phase 1

Developing and maintaining a Gulf of Alaska research Web site and an Alaska GIS database for integration of emerging interdisciplinary data sets is a high priority. Because of the outreach potential, all future field and laboratory projects should have a strong outreach component from the beginning of the program with Web sites identified and accessible to K-12 education.

Particular Phase 1 experiments should include the acquisition of both high-resolution and regional marine seismic reflection surveys to adequately understand the regional sedimentary budget, examine the offshore tectonic deformation, and plan for future IODP drilling.

A comprehensive suite of very high resolution paleoclimatic, paleoceanographic, and paleoecological studies on cores from the margin will establish proper chronometers and a series of climate proxies leading to an understanding of the Quaternary climatic history that can be later extended into the Neogene through ocean drilling and terrestrial outcrop sampling.

A GPS array should be installed rapidly to ensure a sufficiently long period of observation to exceed 1 mm a^-1 vertical precision. Existing monitoring surveys of glacial and fluvial mass fluxes should be maintained and expanded to ensure continuity of records in an aim to capture transients in mass flux.

Expansion of modern automated meteorological arrays is important for constructing sufficiently long climate time series that permit integration of records from high-altitude ice core sites to sea level marine records. Establishment of a passive seismic monitoring array will be necessary for imaging crustal and upper mantle velocity structure and evaluating seismic hazards. A modeling program should be initiated to aid in sampling strategies, to integrate core and paleoceanographic data sets, and to develop numerical strategies for handling the nonlinear interactions in the climatic-tectonic system.

Phase 2

The collection of the initial data sets in Phase 1 will allow for the refinement of experiments that can investigate stratigraphic, structural, and petrologic processes and relationships to...
examine orogenic history, mass flux, and climate interactions through the system. A geochronological framework should be developed early in Phase 2 to identify trends in local kinematics using low- and high-temperature thermochronology, cosmogenic dating, detrital thermochronology, fluid inclusion, and geological studies. To constrain the spatially varying tectonic geometry, an active seismic study of crustal architecture should be conducted onshore and offshore to collect two-dimensional and three-dimensional tomography. Aerogeophysical, marine geophysical, and remote sensing programs need to be initiated to determine the gravity field, ice thickness, and integrated topographic-bathymetric surface to serve as baseline data for repeat surveys that monitor temporal changes. Geometric information from seismic studies and mass flux data should be used to condition, test, and develop the numerical models focused on kinematics, denudation, sediment transport, and storage.

**Phase 3**

Repeat marine and aerogeophysical, and satellite-based remotely sensed surveys to examine landscape evolution should be acquired. Repeat surveys of GPS arrays would provide additional information on local velocity fields. Offshore IODP drilling from fjords to deep-sea fans will examine the integrated tectonic-climatic history of the margin. Drilling builds on all previous geophysical, geological, ecological, climatic, and modeling efforts to enhance an integrated picture of the cooperation between climate and tectonic processes.

**Conclusion**

While these recommendations are wide-ranging and ambitious, it is through the proposed targeting of the southeastern Alaska natural laboratory with a broad range of techniques to study a series of dynamic but interrelated processes that will allow significant advancement in our understanding of continental dynamics, glacial-interglacial climate, and their interactions. The process has already begun, as some of these recommended studies have been proposed and recommended for funding by NSF.

**Acknowledgments**

The authors thank the attendees of the Tectonics and Climate in Alaska workshop in Austin, Texas, and the contributors to the science plan. This workshop, which the science plan and this article grew out of, was sponsored by NSF Continental Dynamics and Joint Oceanographic Institutions, Inc. The efforts of Judy Jacobs and an anonymous reviewer are appreciated. This article is UTIG Contribution 1705.

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