Varying Neogene Impact of Glacial Sediment Flux from Source to Sink on Tectonics and Stratigraphy in the Gulf of Alaska

Sean P. S. Gulick[1], John M. Jarger[2], Robert S. Reece[1], Lindsay L. Worthington[1], Aaron L. Berger[3], James M. Spotila[3], Kenneth D. Ridgway[4], Terry L. Pavlis[5], Gail L. Christeson[1]

1 The University of Texas at Austin, Jackson School of Geosciences; 2 University of Florida; 3 Purdue University; 4 UTEP; 5

SUMMARY

The combination of highly erosive temperate glaciers in an active convergent tectonic setting in southern Alaska allows for the study of the long-term impact of climate and tectonics on source-to-sink sediment production and accumulation (Fig. 1). For the majority of the last 6 Myr, glaciers have been the dominant force of erosion and mass redistribution in southeast Alaska. Flat-slab subduction and collision of an oceanic plateau, the Yakutat Terrane, has been ongoing in the Gulf of Alaska for at least 10 Myr, but possibly as much as 20 Myr, resulting in the highest coastal mountains (the St. Elias) in the world (Fig. 2,3). Temperate glaciation has varied with climatic events and includes tidewater glaciation from 6-4 Ma, a period of limited glaciation in the Mid-Pliocene Warm Interval, re-advance of glaciers and formation of the Cordilleran Ice Sheet starting around 3 Ma, and intensification of glacial-interglacial cycles since 1 Ma (Fig. 4). Sediment flux from the orogen onshore to the continental shelf offshore and the deep-sea Surveyor Fan has therefore varied temporally and spatially owing to changes in glaciation and Yakutat terrane collision (Fig. 5,6). Seismic reflection and refraction data, structural and stratigraphic field mapping, thermo-chronology, and piston coring have determined the magnitude and resolution of the sedimentary record and highlighted the importance of interplay between tectonic and climatic processes (Fig. 7). Specifically, up to ~15 km of sediment on the continental shelf (Fig. 8) reveals the increasing influence of glaciation on the sequence architecture, with glaciomarine sediments and glacial erosion first observed near the coast and then later in sea valleys (Fig. 9,10,6). The influence of erosion and redeposition by glaciers control Late Pleistocene deformation in the Pamplona Zone fold and thrust belt are coeval with increased tectonic shortening onshore (Fig. 4,8,11). The Surveyor deep-sea Fan contains strata up to 4 km thick that were deposited throughout the glacial periods but appear to be dominated by sediment deposited since the mid-Pleistocene, in agreement with the shelf record of increasing glacial influence (Fig. 10). These sedimentary depocenters therefore record mass flux from source (orogenesis) to sink (shelf and fan deposition) that is modulated by climate, in particular the Mid-Pleistocene Transition.

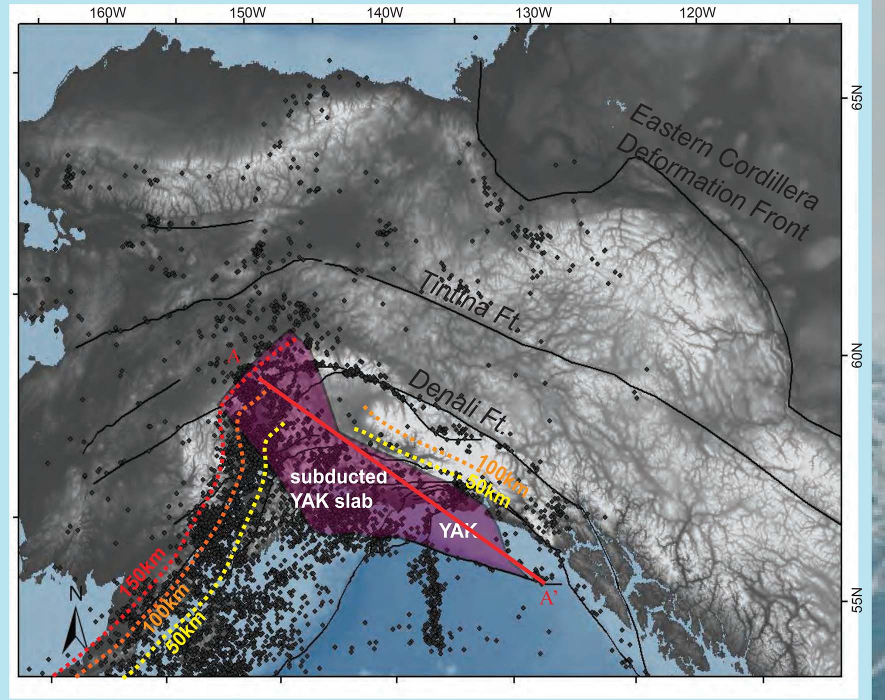


Figure 1. Alaska seismicity map and projected image of subducted YAK block. 50 km, 100 km, 150 km Benioff zone contours illustrate distinct shallowing of subduction zone earthquakes in vicinity of YAK subduction. Most Alaskan seismicity is focused in the southern region of the state, and is associated with the PAC-NA subduction zone. However, some shallow seismicity occurs near the Brooks range and along interior fault zones. These events indicate that crustal deformation occurs away from the subduction driver. (modified from Eberhart-Phillips et al., *JGR*, 2006)

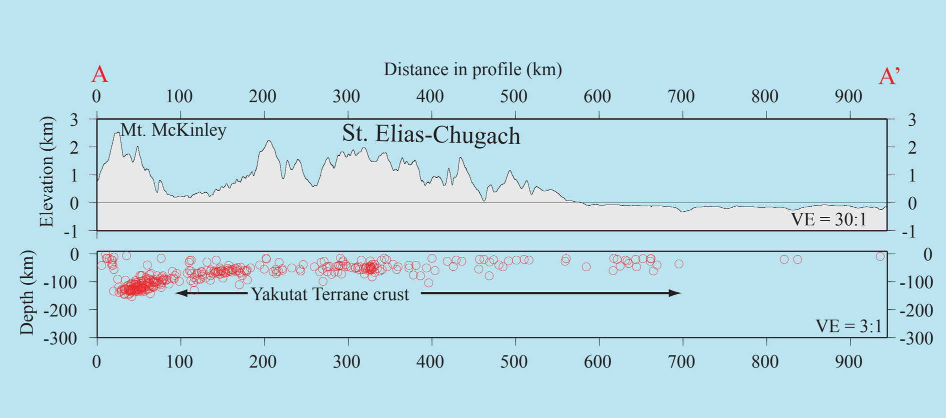


Figure 2. Topography profile plotted versus earthquake depth cross-section is taken across bend in Benioff zone illustrated in Figure 4. Subduction of the Yakutat block beneath North America initiates at the Pamplona zone deformation front, giving a subducted slab that reaches 150 km depth over ~700 km horizontal distance. The angle of subduction is ~12 degrees, comparable to flat-slab subduction regimes observed along segments of the Andean subduction zone and Cascadia. (modified from Gulick et al., *Geology*, 2007)

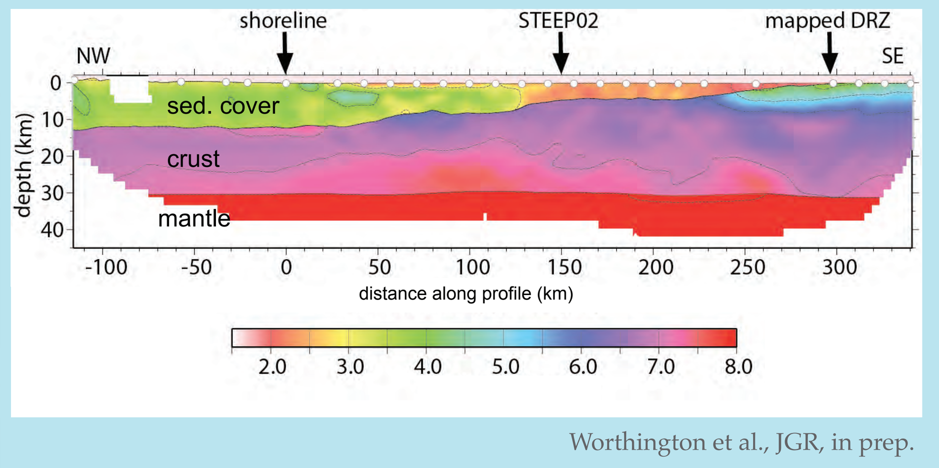


Figure 2. Crustal scale refraction model from based from an onshore-offshore profile along the subduction direction of the Yakutat Block. Note the wedge shaped block results accommodation space that is now filled with up to 15 km of Neogene sediments. Position of ocean bottom and land seismometers used are shown across the top as white circles. Location of the shoreline (near the Bering Glacier) is marked. Exact position of this profiles is shown in Figure 6 (profile STEEP01).

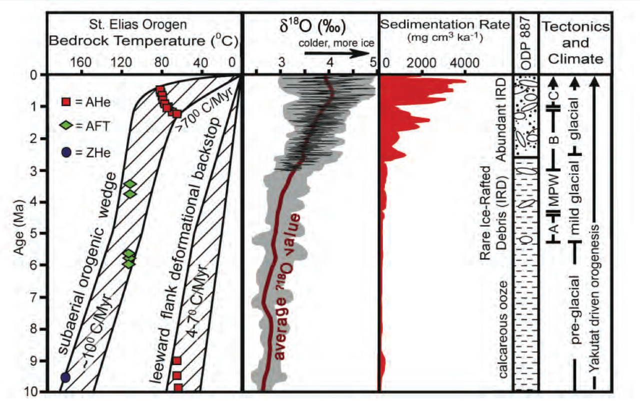
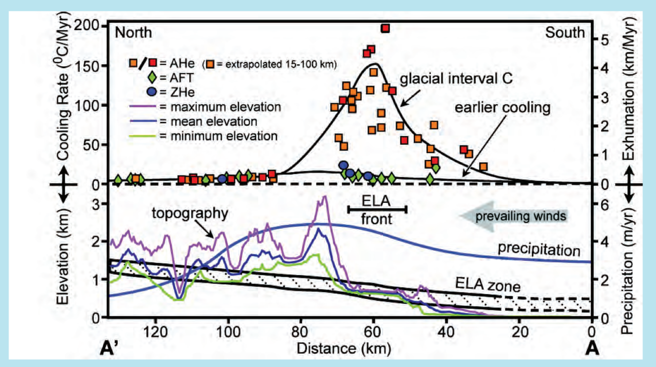


Figure 4. ABOVE: Summary of climatic effects, SE Alaska. (Berger et al., 2008). From left to right, thermochronology demonstrates are significant change in exhumation rate since the Mid-Pleistocene Transition (MPT, ~1 Ma). O-18 record shows the coincident transition from 41 kyr to 100 kyr glacial-interglacial cycles. Terrigenous flux at ODP Site 887 in distal Gulf of Alaska shows a doubling of accumulation at onset of Northern Hemisphere glaciation (locally called Glacial Interval B) and again since the MPT (locally called Glacial Interval C). The influence of tidewater glaciation on these sediment fluxes is inherent in the abundance of ice-rafted debris in the cores.

BELOW: Increased exhumation rates since 1 Ma correlate glacial equilibrium line altitude on the windward side of the St. Elias orogen. Earlier effects of cooling did not produce such a significant erosional signal suggesting the enhanced glacial flux since the MPT provided the necessary tipping point for a positive feedback loop.



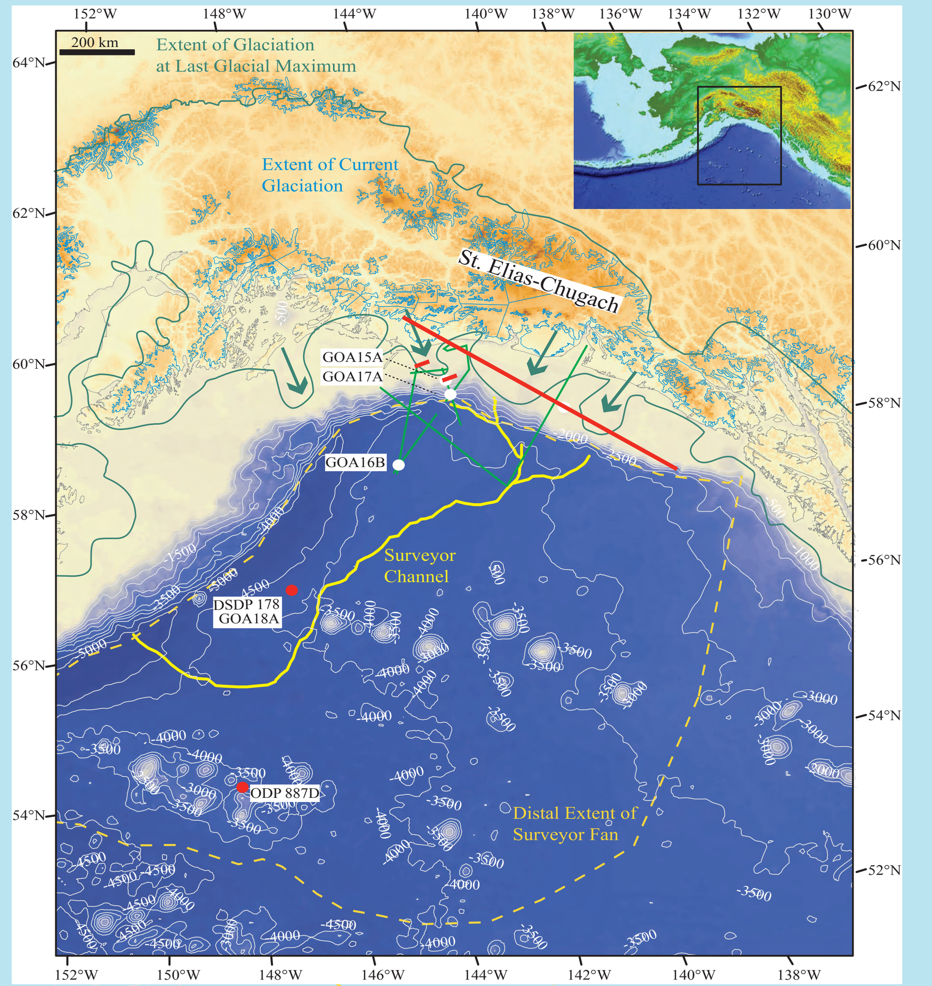


Figure 5. Erosional products of the Yakutat collision are located on the Shelf and in the Surveyor Fan. During interglacial times (blue outline shows extent of glaciers during modern interglacial) the southern Alaskan temperate glaciers produce sediment that is deposited within the fjords and on th shelf. During glacial times (green outline shows extent of glaciers during the last glacial maximum) the glaciers advance out into sea valleys and the eroded sediments from the orogen are deposited off the shelf edge onto the slope and in the Surveyor Fan. Outline of the Surveyor Fan is shown in yellow. Surveyor Fan sediment delivery system is dominated by the Surveyor Channel system.

In order to determine the potential feedbacks between tectonics and climate, proposal 686 to the Integrated Ocean Drilling program targets the shelf and fan record sedimentary record. Key climatic events to be sought within these sediments include onset of tidewater glaciation ~6 Ma (Glacial Interval A), onset of Northern Hemisphere glaciaation (Glacial Interval B), and the Mid-Pleistocene climate transition (Glacial Interval C). DSDP and ODP sites are shown in Red and the proposed IODP sites are shown in White with the addition of a proposed re-drill of Site 178.

STEEP seismic lines are shown for reference in Green and those lines displayed on this poster are shown in Red where ST stands for STEEP.

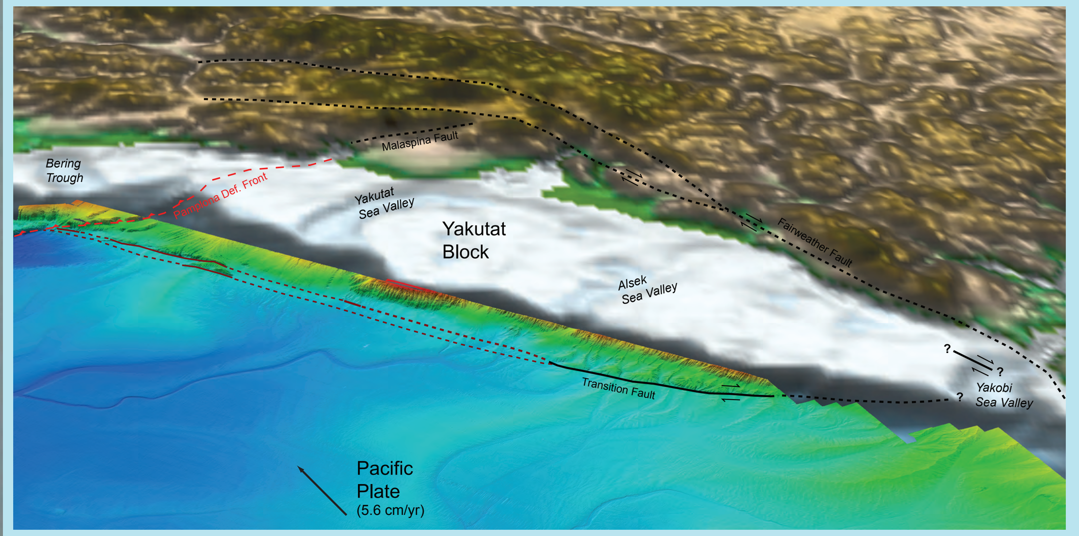


Figure 6. Perspective view of Yakutat collision and St. Elias orogen (modified from Gulick et al., *Geology,* 2007). Yaakutat shelf is crossed by glacial sea valleys that allow efficient cross-shelf flux of sediment during lowstands and are depocenters during highstands. The Surveyor Channel system segments have their heads at these sea valleys and thus further the distribution of sediment into the large Surveyor Fan. For more detials see poster by Reece et al (this session).

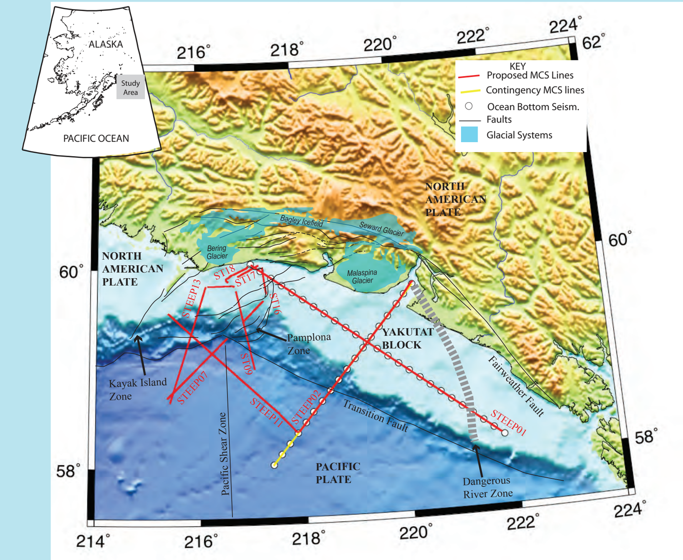
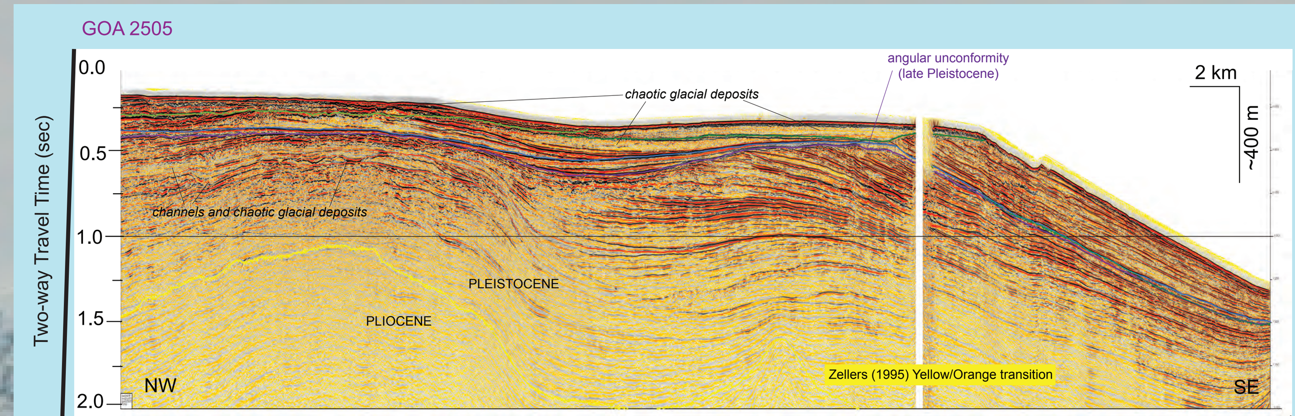


Figure 7. The NSF Continental Dynamics funded STEEP project included the acquisition of ~1250 km of multichannel seismic (MCS) data imaging the Dangerous River Zone, the Transition Fault, the Pamplona Zone, and the sedimentary record contained on the shelf and in the Surveyor Fan. Data were collected using the R/V *Marcus G. Langseth*'s 8 km solid streamer with 640 channels (receivers every 12.5 m for depth point spacing of 6.25 m) and 36 Bolt airguns totaling 6600 cubic inches in volume fired every 50 m. Ocean Bottom Seismometers (OBSs) were deployed at a spacing of 15 km along two wideangle profiles. 25 OBSs were deployed on STEEP01, with 23 of these instruments recovered.18 OBSs were deployed on STEEP02, with 17 instruments recovered.The STEEP profiles are shown in Red and Yellow and the OBS are in white.

An earlier, 2004, NSF high-resolution and coring study acquired numerous line crossngs using a 0.75-1.5 km streamer and dual GI guns with a depth spacing of 12.5 m but a vertical resolution of 3-5 m. The profiles from that survey from the Bering Trough region that are shown on this poster are Green.



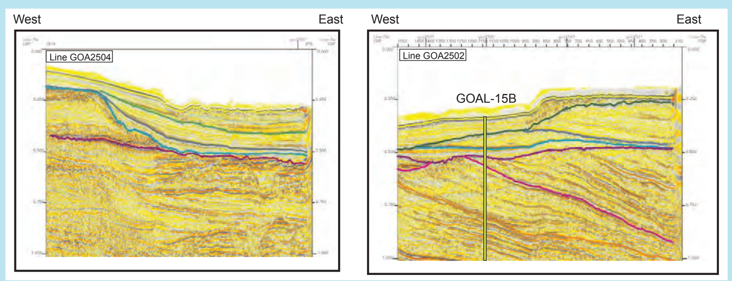


Figure 9. LEFT: High-resolution seismic line GOA2505 in the Bering Trough showing timing of shutdown of shelf anticlines within the glacial sea valley is approximately mid-Pleistocene. Plio-Pleistocene bounary is based on last appearance of *N. asanoi* within nearby industry wells. RIGHT: High-resolution profiles crossing two flanks (in different locations of the Bering Trough. These suggest the sea valleys and thus cross-shelf glacial sediment delivery system developed since the Mid-Pleistoce Transition (Berger et al., 2008).

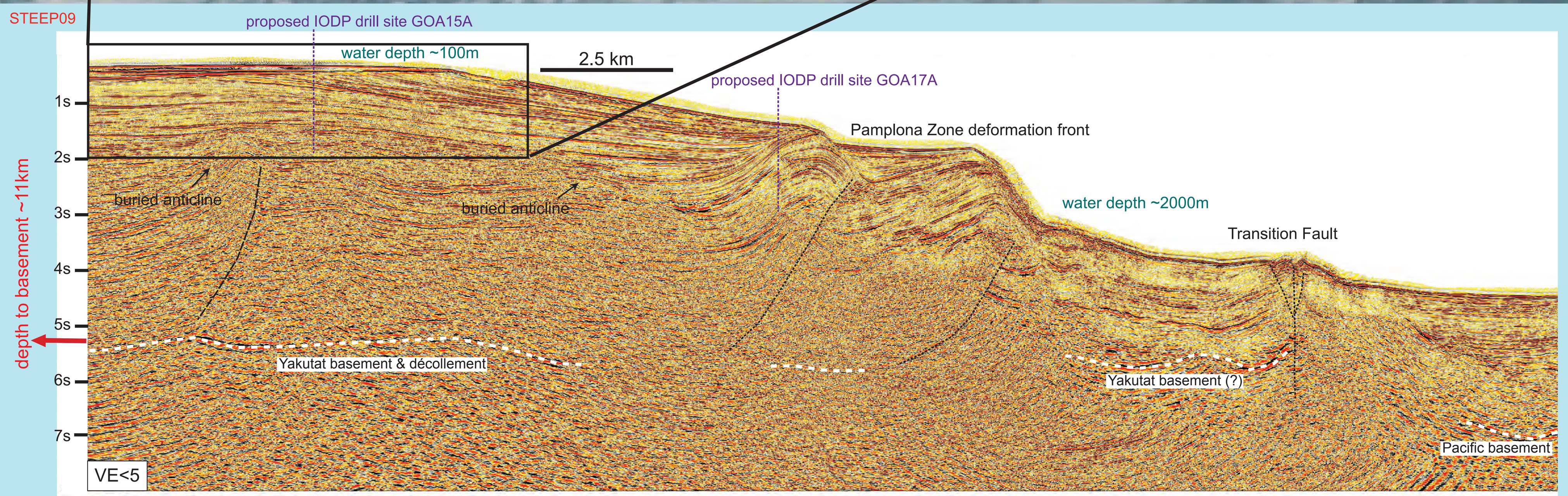


Figure 8. STEEP09 crustal scale MCS profile (see Figures 5 and 7 for location) showing deformation front of the Pamplona Zone on the slope which is active, buried and inactive anticlines beneath the shelf, and the Transition Fault which separates the Pacific from the Yakutat crust. Also shown are two proposed IODP drill sites to test the timing of change in deformation to test correlation with glacial erosion events.

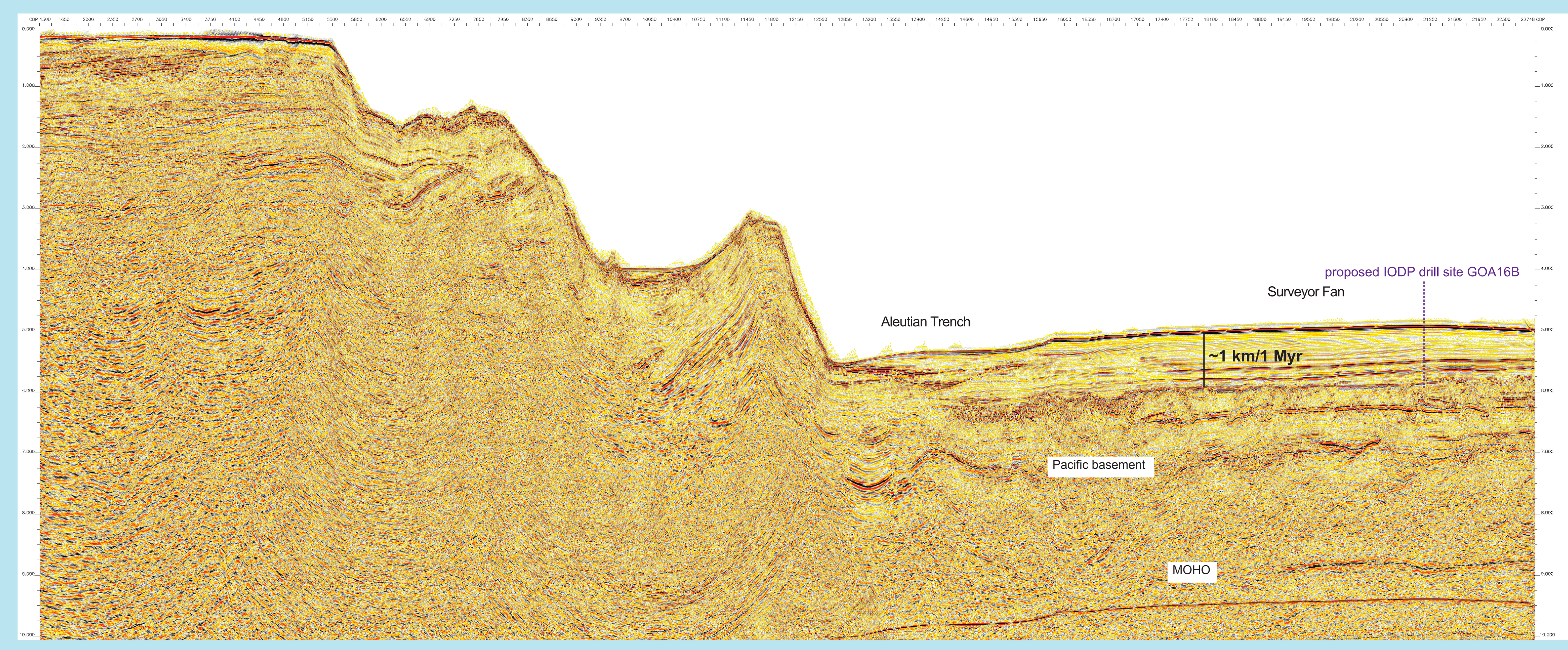


Figure 10. STEEP seismic line 13 from shelf to Surveyor Fan. Sediment eroded from the shelf by glacial advances both ends up in the Surveyor Fan and in the Aluetian Trench. We estimate approximately one-half of the sediment within the Fan may date since the Mid-Pleistocene climate transition.

WHAT'S NEXT?

The hypothesis of tectonic climate interactions and the importance of the Mid-Pleistocene Transition is the focus of an upcoming IODP expedition to the Gulf of Alaska. Drilling is likely to be schedule August to September, 2012 and applications to sail or be on the shore-based Science Party will be widely advertised. Location of the proposed transect of sites are shown on Figure 5. These include drilling through the angular unconformity on the Yakutat shelf thought to be the first cross-shelf glaciation, drilling the Upper Surveyor Fan sequence thought to have accumulated since this time, and re-drilling DSDP Site 178 in the distal Surveyor Fan for the complete 10 Myr of sedimentary history. This expedition is designed to specifically test whether the timing of cross-shelf glaciation and the bulk of the Surveyor Fan sediments support the importance of the Mid-Pleistocene Transition for tectonic-climate interactions.

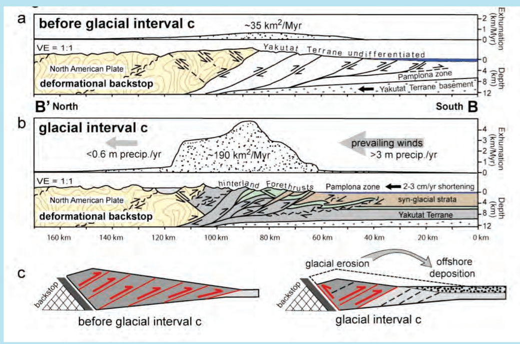


Figure 11. Critical wedge model presented in Berger et al., Nature Geosciences, 2008 which suggests that glacial erosion can result in concentration of deformation within the core of the orogen in order to re-attain critical taper. Model predicts significant greater mass flux during Glacial Interval C which can be tested by examination of the record in the Surveyor Fan.

CONCLUSIONS

Transport of sediment across shelf in glaciated margins may have fundamentally changed with the onset of the 100 kyr glacial-interglacial cycles ~1 Ma.

Tectonics can be directly effected by enhanced erosion in the highlands and deposition in the lowlands.

Sediment flux to the Surveyor deep sea fan and adjacent Aluetian subduction zone within the Gulf of Alaska appears to undergone a significant increase due to the Mid-Pleistocene climate transition. This increased flux may directly effect the Pacific-North American suduction dynamics.