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Single grain heavy mineral provenance of garnet and amphibole in the Surveyor fan and precursor sediments on the Gulf of Alaska abyssal plain — Implications for climate-tectonic interactions in the St. Elias orogen

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ABSTRACT

The St. Elias orogen formed as a result of the northwestward drift of the Yakutat terrane along and final collision with the Alaska margin in the Miocene. Its exhumation coincided with changing glacial conditions that are considered to have strongly interacted with mountain building processes. A significant part of the record of these tectonic-climatic interactions is stored in sediments on the Gulf of Alaska abyssal plain including the Surveyor fan. Our study examines temporal provenance changes of Miocene through Pleistocene sediments of the Surveyor fan, Gulf of Alaska, to constrain the dynamics of exhumation and mass transfer from the evolving St. Elias orogen to the adjacent Surveyor deep sea fan. We present single grain geochemical data of amphibole and garnet and $^{40}Ar/^{39}Ar$ cooling ages of biotite and amphibole together with point counting data of heavy minerals from sands and silts from two sites in the distal and proximal fan, drilled by IODP expedition 341 in 2013 (sites U1417 and U1418, respectively).

A shift in heavy mineral composition during the Miocene, predating the onset of glaciation, points to a tectonically-induced change in erosion centers and sediment transport, probably caused by the rise of the St. Elias Mountains. Garnet and amphibole data suggest the Chugach metamorphic complex is the main sediment source, implying input to the Surveyor fan from sources relatively far in the north during the Miocene. Changing provenance signals from the Miocene to Pliocene suggest rising input from the lower grade metamorphic areas at the southern flanks of the orogen, indicating the advance of glaciers to the tidewater line, providing material from this flanking region. Higher input from the Chugach metamorphic complex in all Pleistocene sediments suggests the Northern Hemisphere glaciation at the Plio-Pleistocene boundary caused erosion and sediment yield from the interior of the orogen. Climatic changes at the mid-Pleistocene transition did not cause significant changes in the provenance signal.

1. Introduction

In active orogens, tectonically-driven deformation and climate-induced removal and redistribution of mass show complex interactions (e.g., Molnar and England, 1990; Meigs et al., 2008; Adlakha et al., 2013). The style of feedback between and coupling of climate and tectonics continues to be controversially discussed (e.g., Molnar and England, 1990; Raymo and Ruddiman, 1992; Meigs and Sauber, 2000; Peizhen et al., 2001; Molnar, 2004; Clift, 2006; Huntington et al., 2006; Clift et al., 2008; Gulick et al., 2015; Enkelmann et al., 2015a; Worthington et al., 2018). The evolution of the St. Elias orogen at the southern Alaska continental margin (Fig. 1A) is connected to subduction of the Yakutat plate under the North American Plate, and coincides with pronounced climatic changes. The relative contribution of climate and tectonics to exhumation is the subject of ongoing research (e.g., Spotila et al., 2004; Berger and Spotila, 2008; Meigs et al., 2008; Berger et al., 2008a,b; Enkelmann et al., 2009, 2010, 2015b, 2017; McAleer et al., 2009; Headley et al., 2012, 2013; Pavlis et al., 2012; Gulick et al., 2015). Onshore studies in the St. Elias Mountains are hampered by the ongoing glaciation (Fig. 1B). Most of the orogenic detritus has been delivered to the Gulf of Alaska forearc, shelf and abyssal plain including the Surveyor deep sea fan, potentially storing information on the evolving orogen and sediment routing into the ocean (Jaeger et al., 1998; Expedition 341 Scientists, 2014).

Provenance research on offshore sediments in other regions has demonstrated its usefulness in deciphering regional changes in tectonics and sediment dispersal mechanisms and pathways (e.g., Usman et al., 2014; Pandey et al., 2016). Zircon U-Pb ages and Hf-isotope data obtained for IODP sites U1417 and U1418 drilled in the Surveyor fan (Huber et al., unpublished manuscript) identify the Chugach-Prince William and Yakutat terranes and the Chugach metamorphic complex

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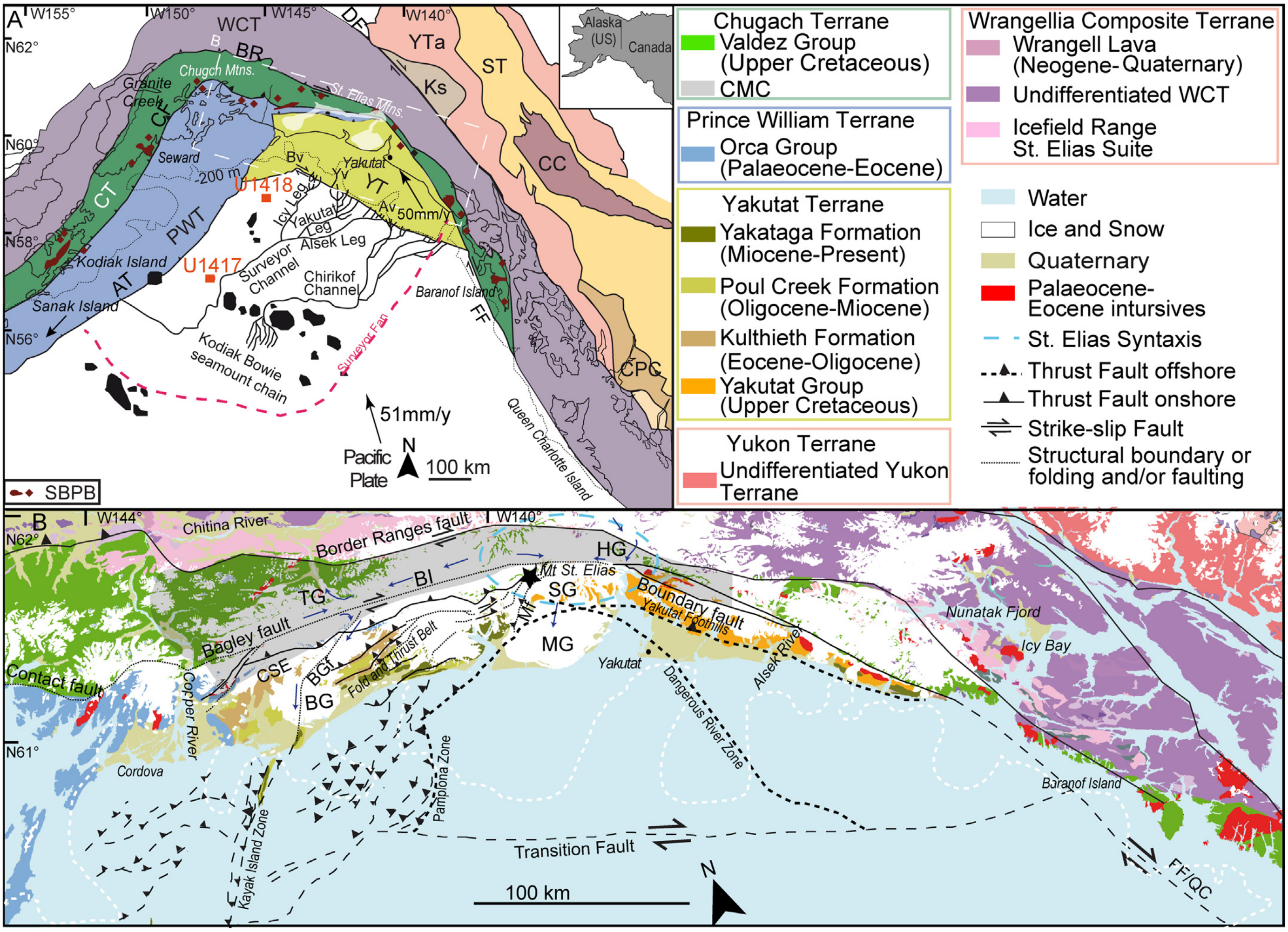

Fig. 1. (A) Terrane map of the southern Alaska continental margin (modified after Plafker, 1987; Carlson et al., 1996; Colpron and Nelson, 2011; Reece et al., 2011; Gasser et al., 2012). Plate velocity vectors after Elliott et al. (2010). AT = Aleutian trench; Av = Alsek valley; BR = Border Ranges fault; Bv = Bering valley; CC = Cache Creek terrane; CF = Contact fault; CPC = Coast Plutonic Complex; CT = Chugach terrane; KS = Kluane Schist; FF = Fairweather Fault; PWT = Prince William terrane; SBPB = Sanak Baranof Plutonic Belt; ST = Stikinia terrane; WCT = Wrangellia composite terrane; YT = Yakutat terrane, YTa = Yukon-Tana terrane; Yv = Yakutat valley. Red dots mark the distal (U1417) and proximal (U1418) sites of IODP Expedition 341. (B) Simplified geological map of the southern Alaska continental margin. BG = Bering Glacier, BGf = Bering Glacier fault, BI=Bagley Icefield, FF/QC = Queen Charlotte - Fairweather Fault System; CSE = Chugach-St. Elias Fault, HG = Hubbard Glacier, Mf = Malaspina fault, MG = Malaspina Glacier, SG = Seward Glacier, TG = Tana Glacier. Map data from: Bruhn et al. (2004, 2012), Colpron and Nelson (2011), Wilson et al. (2015), Lipovsky and Bond (2014) and Cui et al. (2015). Glacial flow directions are indicated by dark blue arrows after Post (1972). White line indicates glacier extent during LGM (Last Glacial Maximum) after Manley and Kaufman (2002). Gray shaded area marks the extent of the Chugach metamorphic complex (CMC).

(CMC) in particular as important sources, and suggest a change in provenance at the Miocene/Pliocene boundary. Zircon and apatite fission-track ages reveal input to the Surveyor fan from the rapidly exhuming St. Elias Syntaxis from the Miocene onwards (Dunn et al., 2017). If and how climatic change at the mid-Pleistocene transition affected the provenance signal still remains unresolved (Dunn et al., 2017; Huber et al., unpublished manuscript).

In this contribution, we attempt to further constrain the mass transfer from the St. Elias orogen into the Surveyor fan as a function of the evolving orogen's exhumation by application of single grain geochemical methods to heavy minerals. We present results of a provenance study focusing on the geochemistry of detrital amphibole and garnet and $^{40}Ar/^{39}Ar$ dating of amphiboles and mica, along with a quantification of the heavy mineral spectra by point counting of Miocene to Holocene sediments from IODP 341 sites U1417 and U1418 (distal and proximal Surveyor fan, Fig. 1B). Single grain geochemical analyses are less affected by chemical and physical fractionation compared to bulk methods, and have been used successfully in provenance analysis given that the source rocks show heterogeneous compositions for certain minerals (Mange and Morton, 2007; Andò et al., 2014; Aliazi et al., 2016; Garzanti, 2016). Amphibole and garnet in particular constrain information on the metamorphic grade of the source lithologies (Morton, 1984; Andò et al., 2014; Aliazi et al., 2016) that varies along the southern Alaska continental margin (Plafker, 1987; Gasser et al., 2011; Bruand et al., 2014).

2. Background

2.1. Geological setting

The St. Elias Mountain range is characterized by a high local relief of over 5000 m (e.g., Mt. St. Elias, 5489 m), rising from sea level to high peaks over a short distance of 55 km. Ongoing flat slab subduction of the Yakutat terrane under the North American Plate since the Oligocene and final oblique collision with the North American Plate in the Miocene led to the rise of the mountain range (Plafker et al., 1994; Bruhn et al., 2004; Enkelmann et al., 2008; Finzel et al., 2011; Falkowski et al., 2014; Finzel et al., 2015). The Yakutat terrane sits at the termination of the Aleutian trench, in the gap between the North American continent to the north and the Pacific Plate to the south (Fig. 1A). To the west, it is bordered by the Kayak Island zone, to the south by the Transition fault and to the north and east by the Chugach-St. Elias fault and