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Micromorphological changes as an indicator of the transition from glacial to glaciofluvial quartz grains: Evidence from Svalbard

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ABSTRACT

The micromorphology of quartz grains in a sedimentary environment is determined by the transport mechanism and the nature of weathering. Both these aspects change during the transport history of grains. Thus important questions include how are quartz grains affected by possible changes in the transport medium, and how quickly do the different micromorphological features develop or disappear. The main goal of this study was to characterize the changes in the micromorphological features of quartz grains during the transition from a glacial to a glaciofluvial environment, and to identify a set of diagnostic microtextures that can be used to distinguish between glacial and glaciofluvial quartz grains. The samples came from the moraines of the Bertilbreen and Hørbyebreen glaciers (Svalbard) and from the sediments of glacier-fed rivers in the forelands of these glaciers. A total of 30 different micromorphological features was observed on 800 different quartz grains from 13 samples of glaciofluvial sediment and 3 samples of glacial sediment. It was found that the frequency of rounded grains, V-shaped pits, meandering ridges and cemented microblocks on glaciofluvial grains increased significantly with increasing length of fluvial transport, whereas the frequency of angular grains, straight steps, straight and curved grooves, adhering particles, pitting and oriented etch pits decreased significantly. Different types of micromorphological features of quartz grains change with fluvial transport at different rates. Adhering particles (after the first kilometer of fluvial transport), straight steps and meandering ridges (after the second kilometer of fluvial transport), and V-shape pits, angular shape and straight grooves (after the third kilometer of fluvial transport) are reliable mechanical micromorphological features for distinguishing between glacial and glaciofluvial quartz grains.

1. Introduction

Glaciofluvial sediments are deposited by glacier-fed rivers in either ice-contact or proglacial settings (Benn and Evans, 1998). Glaciofluvial sediments initially develop as glacial sediments and are then subsequently transported by streams. Quartz grains in glacial sediments are characterized by the greatest range of microtexture types (Mahaney, 2002). Typical mechanical microtextures include parallel striations, curved grooves, straight grooves, conchoidal fractures, crescent-shaped features, straight and arcuate steps and adhering particles (e.g., Krinsley and Doornkamp, 1973; Cremer and Legigan, 1989; Helland et al., 1997; Mahaney et al., 2001; Mahaney, 2002; Strand et al., 2003; Alekseeva, 2005; Křížová et al., 2011; Immonen et al., 2014; St John et al., 2015; Woronko, 2016). The shape of glacial grains is often angular, with edge abrasion and a high relief (Mahaney, 2002), but not all broken grains in tills result from crushing in glacial environments (Woronko, 2016). Silica pellicles and silica precipitation, formed during diagenesis, may occur on some glacial grains (Mahaney et al., 2001). The frequency of the constituent micromorphological features developed on quartz grains in fluvial environments depends primarily on transport length, stream energy and sediment concentration (Mahaney, 2002). If the transport length is short or the stream energy is low, quartz grains are not influenced by the fluvial environment and pass through it almost intact (Mahaney and Kalm, 2000). Quartz grains transported by running water often have a rounded shape with V-shaped pits, straight and curved grooves and other impact features (Krinsley and Donahue, 1968; Kleesment, 2009; Longhinos, 2009; Madhavaraju et al., 2009). Various chemical microtextures, such as silica precipitation, and various forms of etching and quartz crystal overgrowths, have also been observed on fluvial quartz grains (Manker and Ponder, 1978; Manickam and Barbaroux, 1987; Cremer and Legigan, 1989). However, Manker and Ponder (1978) noted that these microtextures occur in other environments and that investigators should be wary of using these features alone as environmental indicators.

Glacier-fed rivers have considerable energy and transport large quantities of sediment eroded by glaciers (Bogen and Bønsnes, 2003;

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Zajączkowski and Włodarska-Kowalczuk, 2007). On the other hand, glacier-fed rivers are characterized by seasonal and diurnal changes in flow regime leading to formation of braided and anastomosing networks (Goudie, 2004). Thus, glaciofluvial sediments can be alternately exposed to subaquatic and also subaerial environments. In the literature, the micromorphological features of glaciofluvial quartz grains have merely been listed and not related to the length of fluvial transport. Mahaney and Kalm (2000) reported that the quartz grains of glaciofluvial sediments are rounded and exhibit edge abrasion and that the surface of the quartz grains is largely covered with percussion cracks and microtextures, bearing evidence of glacial transport. According to Bull and Morgan (2006), subangular to subrounded grains, with traces of mechanical abrasion in the form of V-shaped pits and precipitation and dissolution features are typical of glaciofluvial grains.

From these observations, it is clear that micromorphological features typical of both glacial and fluvial transport should be present on glaciofluvial quartz grains. The frequency of fluvial micromorphological features should grow with increasing length of fluvial transport; conversely, glacial micromorphological features should gradually disappear. This allows us, on the one hand, to study the rate of formation of some types of micromorphological features and, on the other hand, the resistance of other micromorphological features at interfaces between glacial and glaciofluvial environments. In terms of the micromorphological analysis of quartz grains and its interpretation, it is essential to ask questions regarding the rates of formation of different micromorphological features and how resistant these features are. However, few authors have pursued this topic (e.g., Mahaney, 2002; Górska-Zabielska, 2015; Woronko and Pisarska-Jamroży, 2015). The main goal of this work is to characterize the frequency change of micromorphological features of quartz grains as they move from a glacial to a glaciofluvial environment over the first 4 kilometers of fluvial transport (i.e., to express how quickly micromorphological features respond to changes in the transport medium), and to identify a suitable set of micromorphological features for distinguishing between glacial and glaciofluvial quartz grains.

2. Study area

The samples come from moraines situated near the terminus of Bertilbreen and Hørbyebreen and from recent fluvial sediments of their glacier-fed rivers from the northern Billefjorden area, central Svalbard (Fig. 1).

Bertilbreen and Hørbyebreen are polythermal valley glaciers (Evans et al., 2012). In 2002, the total area of Bertilbreen (ca 640–240 m a.s.l.) was 3.91 km^2, and its total length was 4.69 km (Rachlewicz et al., 2007). Its width in 2013 was approximately 100 m (Hanáček et al., 2013), and its thickness in the 1980s reached 73 m (Zhuravlev, 1981). In 2002, the total length of Hørbyebreen (ca 450–75 m a.s.l.) was 6.75 km (Rachlewicz, 2003), and its total area was 13.9 km^2 (Rachlewicz et al., 2007), with a maximum width of 1 km (Hanáček et al., 2013). Since the Little Ice Age, both glaciers have retreated (Rachlewicz et al., 2007).

Unconsolidated sediments forming the moraines (Fig. 2) of both glaciers are rich in quartz grains because the underlying rocks are mainly composed of sandstone and orthogneiss, with subordinate amphibolite, conglomerates, siltstones and claystones (Fig. 3), in which there are rare layers of coal (Dallmann et al., 2004). Svalbard features an arctic climate, with an average annual temperature of −6.5 °C for the period 1961–1990 (Rachlewicz, 2003). The warmest months are July and August, with an average annual temperature of 5–6 °C for the period 1961–1990 (Rachlewicz, 2003). The coldest months are January, February and March (Gibas et al., 2005). The average annual

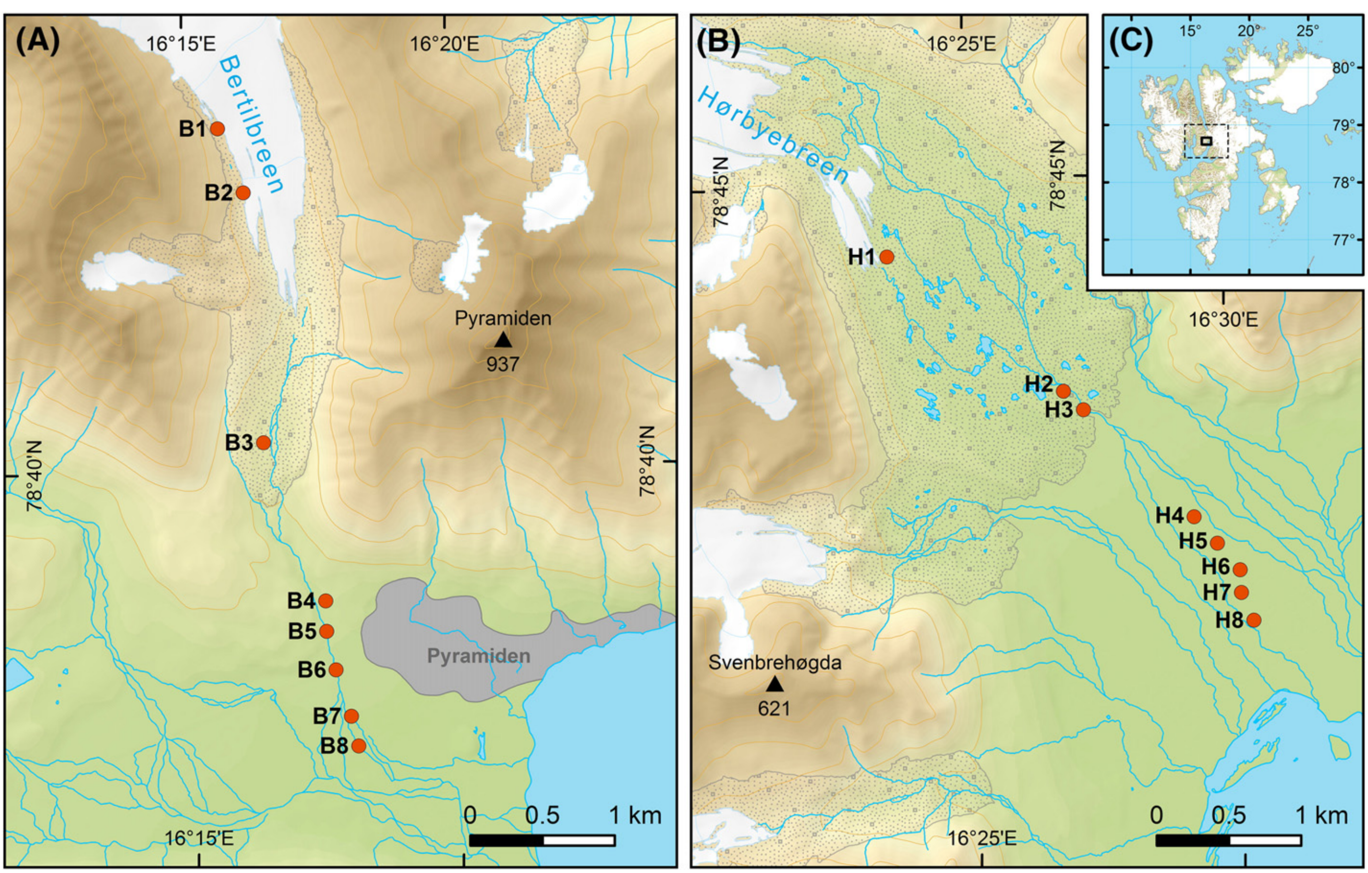

Fig. 1. Study area: (A) the Bertilbreen area with location of glacial (B1, B2) and glaciofluvial (B3–B8) sample sites; (B) the Hørbyebreen area with location of glacial (H1) and glaciofluvial (H2–H8) sample sites; (C) Svalbard archipelago. Contour interval is 100 m. Topography basemap: TopoSvalbard by Norwegian Polar Institute, 2017.