

GPR-Derived Architecture of Large-Scale Icelandic Jökulhlaup Deposits, North-East Iceland

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Abstract— Jökulhlaups (glacial outburst floods) occur frequently throughout Iceland and across most of the glaciated regions of the world. The largest of these jökulhlaups are known to have occurred along the northern margin of the Vatnajökull Icecap and drained down the Jökulsá á Fjöllum river during the Holocene. Unfortunately, little is known about the number, frequency, age and flow characteristics of the Jökulsá á Fjöllum jökulhlaups and the relationship between their deposit architectures and the underlying volcanic lavas. During the summer of 2003, a total of over 20 km of GPR data was collected from a variety of jökulhlaup outwash sediments across the Jökulsá á Fjöllum flood plain. GPR results and corresponding facies interpretations are presented for the outwash deposits at two locations: Kverkfjöll, (approximately 20 Km from the jökulhlaup source) and Möðrudalur (approximately 100 Km downstream from the glacial margin). By combining the GPR data with ground surveying, photogrammetry and detailed sedimentary outcrop evidence, this study adds new perspectives to the sedimentary analysis of high-magnitude jökulhlaup events and their large-scale bars and bedforms. The results indicate that sedimentary architectures are controlled by the topographic nature of the underlying lavas and the flow conditions in each region. By analysing the GPR derived facies in detail, it is also possible to identify different phases of jökulhlaup deposition. This information is vital for the assessment of jökulhlaup magnitudes, frequencies, and pathways and can be used for the prediction of future jökulhlaup impacts.

Keywords- Jökulhlaup; Outburst floods; Iceland; Sedimentary architecture; GPR facies; Glacial margins.

I. INTRODUCTION

Large Jökulhlaups (glacial outburst floods) are common events in Iceland and have serious implications for the hazard management of transportation routes, agriculture, land usage and tourism. Some of the largest jökulhlaups are known to have occurred along the northern margin of the Vatnajökull Icecap and drained down the Jökulsá á Fjöllum river (Iceland's largest river - figure 1) during the Holocene period [1]. Hydrological, geomorphological and sedimentological reconstructions indicate that some of the most extreme events are likely to have had average peak discharges of up to $1,000,000 \text{ m}^3 \text{ s}^{-1}$ with little attenuation over tens of kilometers [2][3]. This flow/discharge magnitude can result in the deposition of up to twenty metres of coarse sediment across vast areas, destroying roads, farmland and property. Unfortunately, little is known

about the number, frequency, age and flow characteristics of these events and the relationship between their deposit architectures and the underlying volcanic lavas. Therefore, it is vital that jökulhlaup magnitudes, frequencies, pathways and sedimentary architectures are understood in order to assess the nature of future jökulhlaup events and their impact on the surrounding landscape.



Figure 1. Location of the Vatnajökull Icecap, Jökulsá á Fjöllum river, and Möðrudalur/Kverkfjöll sites in northeastern Iceland.

II. SITE LOCALITIES

During the summer of 2003, a total of over 20 km of GPR data was collected from a variety of jökulhlaup outwash sediments across the Jökulsá á Fjöllum flood plain (in the form of 2D and pseudo-3D sections at frequencies of 50 & 100 MHz). GPR results and their corresponding facies interpretations are presented for the outwash deposits from two locations: Kverkfjöll, (approximately 20 Km from the jökulhlaup source) and Möðrudalur (approximately 100 Km downstream from the glacial margin). The first site is associated with 'slackwater' deposits from a relatively low-energy zone of reduced flows and restricted discharge areas, whereas the second site consists of deposits from higher-energy, mixed velocity flows in a region of expanding discharge area and reducing water depths (figure 2).

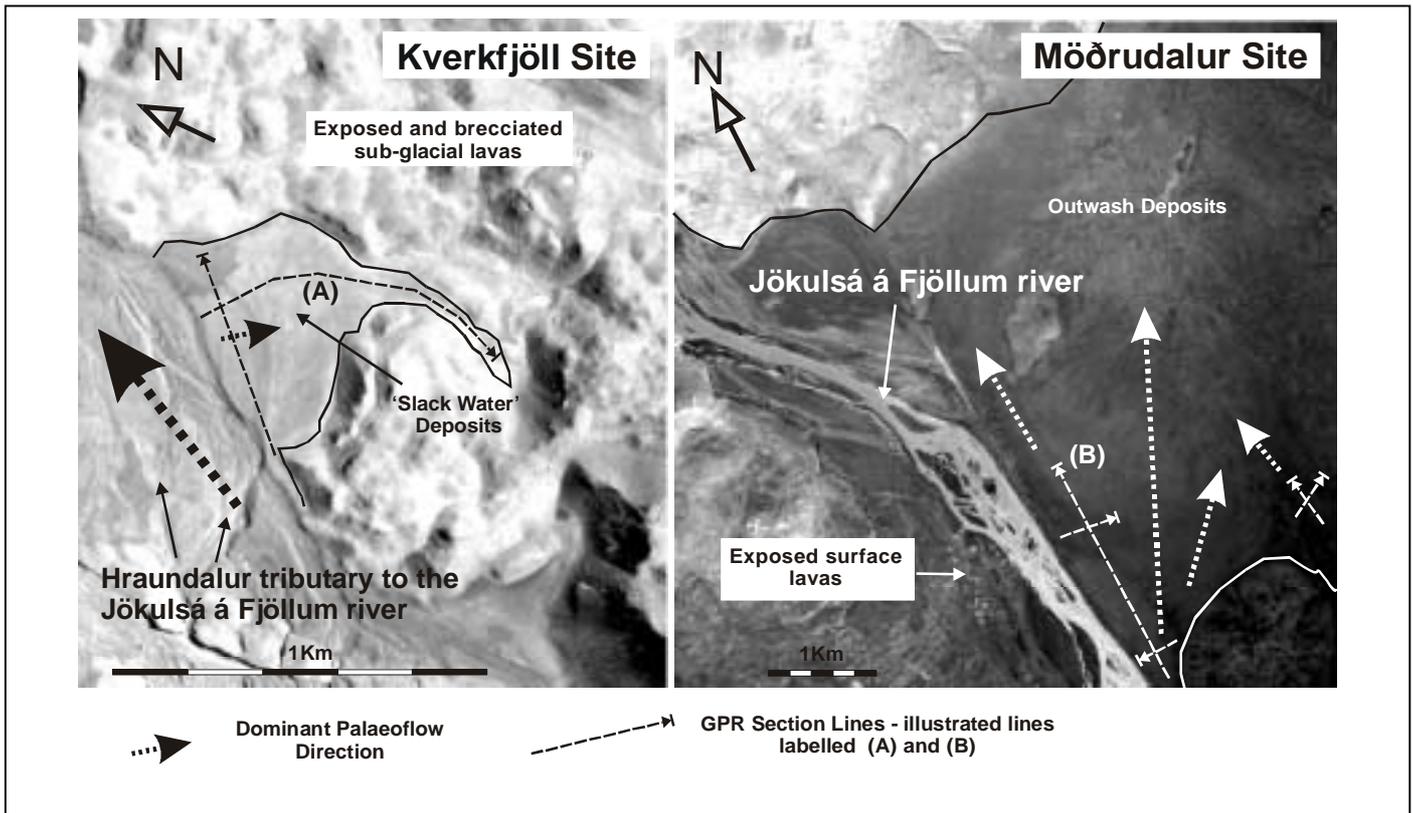


Figure 2. Location of the illustrated GPR section lines at the Möðrudalur and Kverkfjöll sites.

III. DATA ACQUISITION AND PROCESSING.

For each section, data was collected with a Sensors and Software PulseEKKO 100™ GPR unit (50 & 100MHz antennae) in co-planar, constant separation, reflection mode (figure 3). Sections were orientated either parallel or perpendicular to the dominant palaeoflow direction and extended across the main depositional fan units. A number of common mid point (CMP) velocity profiles were collected at convenient points across the site and inverted to provide a velocity-depth estimate for each section line.

Post-acquisition data processing steps included (where necessary):

- Trace sorting, editing and interpolation (typically less than 0.2% of traces edited)
- Dewow and trace normalization
- Time zero correction
- Bandpass filtering (primarily to reduce high-frequency noise above 200MHz).
- 2D Background filtering (to remove signal 'ringing').

- Topographic correction (sections surveyed with a total station at ~10m intervals or less).
- Diffraction/reflection hyperbolae matching for improved velocity-depth analysis.
- Attribute analysis (instantaneous frequency, phase and amplitude to assist in section interpretation and reflector 'tracing').



Figure 3. Data acquisition across the 'slackwater' sediments at Kverkfjöll (50MHz Pulse EKKO GPR unit in co-planar reflection mode).

IV. GPR SECTIONS AND FACIES INTERPRETION .

Figure 4 illustrates representative regions of the 50MHz GPR section lines (A – Kverkfjöll, flow-parallel, ‘slackwater’ deposits; B – Möðrudalur, flow-parallel, high-energy deposits) and their associated GPR facies interpretations. Note that the sections are unmigrated and that depth estimates are based on a near uniform velocity profile of approximately 0.1 m/ns for Kverkfjöll and 0.08 m/ns for Möðrudalur.

A. Facies interpretation – Kverkfjöll ‘slackwater’ deposits

At this site, the deeper deposits (2-7m deep) form laterally restricted, prograding units of coarse-to-fine sands and gravels that gradually in-fill the existing topography with limited basal erosion and scour. Being an ‘eddy zone’ away from the main outwash flow, velocities are significantly lower than in the main channel and a spatially confined ‘slackwater’ environment quickly develops during a flood. Sediment rapidly in-fills the available accommodation space and the deeper, moderately dipping foreset units gradually evolve into shallow, laterally continuous horizontal beds of finer material (0-2m deep). There is little evidence of basal erosion and scour, even though the sub-glacial lavas are brecciated and fissile when compared to the surface lavas at Möðrudalur. This indicates that, in this ‘slackwater’ region, flow velocities and stream powers are not high enough to produce significant modification to the basal topography. As a result, the distribution and spatial variation in the sedimentary architecture is primarily controlled by the form and geometry of the underlying lava surface.

B. Facies interpretation – Möðrudalur high energy deposits

In contrast to Kverkfjöll site, the deposits at Möðrudalur tend to form more coherent units of laterally continuous, coarse-to-fine sand and gravel beds (approximately 8-10m deep). Moderately dipping foreset units can be observed in areas where the basal topography is varied but, in general, the form of the sedimentary architecture is less dependent on the nature of the basal surface. Two distinct GPR derived facies can be identified: an upper unit (0-4m deep) dominated by sub-horizontal, laterally extensive beds and broad channels, and a lower unit (6-10m deep) of laterally restricted bedforms exhibiting erosional toplap on their upper surfaces. Flow velocities and stream powers are much higher at this site and the whole area forms a flood plain of expanding discharge area, mixed velocity flow and reducing water depth. Adjacent exposures of the underlying lavas reveal a relatively flat, plucked and scoured surface of blocky, columnar jointed flood basalts crosscut by deep erosional channels (figure 5). This is consistent with the nature of the basal surface in the sections and implies that flow conditions and sediment loads are the primary influence on sedimentary morphology and architecture geometry.

C. Event Phases

Sedimentary evidence from the middle reaches of the Jökulsá á Fjöllum river suggests that there have been two phases of major jökulhlaup deposition during the Holocene [1],

although the exact source, nature and extent of the events is unknown. The GPR derived interpretation of the Möðrudalur data is consistent with this hypothesis as two distinct facies units can be observed in the section. In contrast, the Kverkfjöll deposits appear to form a single facies unit that gradually evolves in morphology as the deposit shallows. This is consistent with deposition during one jökulhlaup only and shallow reworking and/or minor deposition during subsequent events.



Figure 5. Plucked and scoured flood basalts exposed at Kverkfjöll.

CONCLUSION

By combining the GPR survey data with ground surveying, photogrammetry and detailed sedimentary outcrop evidence, this study adds new perspectives to the sedimentary analysis of high-magnitude events and their bedform morphologies. The results indicate that ‘local scale’ deposit architecture is controlled by the topographic nature of the underlying lavas, or alternatively, by the flow conditions and sediment loads. By analysing the GPR derived facies interpretations in detail, it is possible to identify different phases of jökulhlaup deposition which has important connotations for the study of event magnitudes and frequency.

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