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Assessing the performance of geophysical survey techniques for characterising the subsurface around glacier margins

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Glacier forelands contain valuable information on past glacier dynamics and associated climatic conditions, particularly at small mountain glaciers where responses to climate change are rapid. To maximize the potential of glacial landforms as palaeoclimate indicators, a thorough understanding of the controls on landform genesis and subsequent evolution is required. Traditionally, such landforms have been studied using glacial geological techniques such as sedimentary logging. While these provide valuable in situ information they have numerous limitations, namely poor availability and spatial extent of exposures. Near-surface geophysics provides an efficient and non-invasive means of studying subsurface conditions in numerous sedimentary settings, offering spatially extensive information on substrate material properties and architecture. However, the logistically challenging terrain, remote location and complex structure of proglacial environments has limited the development of geophysical techniques for studying the internal architecture of glacial landforms.

Here, we explore the application of three geophysical methods to investigate proglacial substrates: ground penetrating radar (GPR), seismic refraction and multi-channel analysis of surface waves (MASW). Three sites with contrasting sediment properties were surveyed at the foreland of Midtdalsbreen glacier in southern Norway; (a) a 100 m^2 area of glaciotectonised sandy sediments, (b) a ~2 m high lateral moraine ridge containing stratified silts, sands, and gravel and (c) a terminal moraine ridge with a peak crest height of ~5 m and an open blockwork of cobbles and boulders at its surface. At all sites, we deployed 25 MHz and 100 MHz GPR antennas and undertook seismic surveys with 50−75 m long geophone spreads and a sledge-hammer source to sample to target depths of around 10−15 m. Through comparing the results from sites (a) to (c), we assess the capabilities and limitations of each of the aforementioned techniques for proglacial substrate imaging and characterisation, we analyse how their performances vary across these settings and outline factors that contribute to a successful geophysical investigation.

The ease of analysis and achievable investigation depths of the geophysical data and the applicability of seismic interpretation methods varied considerably depending on the surface terrain and structural complexity of the site. Our results show how the combination of GPR and

seismic data can assist with the internal characterisation of glacial moraines when a relatively simple subsurface structure is present. However, basic seismic inversions likely lack the sophistication to resolve seismic structure in all but the simplest of layered models. We offer suggestions on how to optimise field time in more complex settings, where more sophisticated seismic inversion algorithms (e.g. tomography) or 3-D GPR surveys could be better-suited.

Our experience should help advance the use of geophysics in proglacial studies. It should serve as a guide for future survey planning, and help avoid typical pitfalls such that field time can be optimised. It is hoped that geophysical survey methods will play an increasing role in the understanding of proglacial sedimentary landforms and their associated palaeoenvironments.