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Subglacial processes, deposits and landforms—introduction

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The nature of the subglacial interface is instrumental for major glacial processes such as erosion, transport, deposition and formation of various active-ice landforms. Interactions between basal ice and its bed impact the dynamics and stability of glaciers, which is relevant to predicting the future fate of ice sheets. Warm-based glaciers resting on soft, deformable and poorly drainable sediments have a high potential of developing instabilities, potentially leading to surges and ice streaming that may result in significant discharges of ice masses into oceans. Of particular importance here is that the subglacial meltwater not only lubricates the bed but also facilitates sediment deformation and erosion, and—when sufficiently pressurized—may lift the glacier from the bed, initiating its collapse.

Deciphering the processes operating under ice sheets and glaciers has been attempted in both modern and past environments (e.g. Menzies 2002). Investigating present-day systems has the advantage of monitoring the glacial environment in real time, but it is limited by the poor accessibility of the bed, often through ice hundreds of metres thick. Studying the geological record left by past glaciations gives the advantage of direct access to the past ice/bed interface and the deposits and landforms created there, but the palaeoglaciological conditions remain poorly constrained and largely speculative. Ideally, both approaches should be complementary and supported by numerical modelling and analogue experiments to better inform and parameterize the relevant processes. As long as our knowledge of the subglacial environment remains fragmentary, predicting the future of large continental ice sheets is largely uncertain.

This collection of 12 papers presents original research recently conducted in Europe, North America and Antarctica on both past and modern glacial systems and addresses the signatures of subglacial processes preserved in landforms and deposits. It plays into the growing interest of a still poorly explored environment (e.g. Benn & Evans 2010) and hopes to contribute to better illuminating some of its aspects.

Methodological progress in automated mapping and analysing subglacial bedforms is reflected in two articles using Python software. Abrahams *et al.* (2025) present a new tool utilizing machine learning trained on over 600 000 data points from the Northern Hemisphere to automatically identify streamlined features. Successfully tested on a selected area in the United States, the tool allows rapid delineation of past ice flow directions based on bedform elongation characteristics. This innovative method has already generated scientific interest and debate (Li *et al.* 2025; McKenzie *et al.* 2025), showing its relevance and potential for subglacial research. Another Python-based automated tool to delineate and morphometrically analyse subglacial bedforms is developed by Hesni *et al.* (2025). Their method is innovative in treating bedforms as continuously varying in morphology rather than just fitting them into the traditional named classifications. Tested on a portion of the former Laurentide Ice Sheet in northern Canada, the method revealed a high (75%) correspondence with reference maps manually digitized by independent experts, which demonstrates its high reliability and possible applicability to other previously glaciated areas while offering a great efficiency of the analytical time involved.

Several articles address the characteristics and origin of subglacial landforms and landform systems using geological, geophysical and remotely sensed data to inform about the nature of ice/bed interactions. Gegg *et al.* (2025) construct an inventory of over 100 spectacular overdeepenings in southern Germany and Austria. These overdeepenings are incised up to about 1000 m below ground surface and are up to about 100 km long, making them one of the most prominent features of glacial erosion. Their depths correlate with modelled ice thicknesses and flow velocities, and the formation of individual basins is believed to have been rapid, lasting up to a few millennia only. A counterpart to these overdeepenings are tunnel valleys in the North German Basin studied by Lang *et al.* (2025), who examined a possible causal relationship between the geological characteristics of the deep substratum and the distribution and orientation of these valleys. It is shown that deep tunnel valleys occur exclusively in areas of thick erodible Cenozoic deposits, while no correlation is evident between the occurrence and orientation of the valleys and tectonic elements such as faults and salt structures. The absence of such a correlation makes predictions of possible future tunnel valley locations in northern Germany difficult, which is relevant to planning radioactive waste repository sites that should withstand a deep-time impact of ice overriding and erosion. Smaller, previously unrecog-

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nized relict glacial channels are studied by Fisher *et al*. (2025) in an area formerly covered by the Laurentide Ice Sheet in Ohio, USA. These low-relief dry channels are found in a karstic terrain, which opens several formation hypotheses including fluviokarst processes and collapse of dolines, but the most significant erosional agent has likely been subglacial meltwater erosion. The latter is also considered by Sharpe & Smart (2025) as the major shaping mechanism of landscapes in southern Ontario, Canada. Using high-resolution LiDAR images, these authors investigate a streamlined glacial flow tract hosting eskers, channels, boulder lags, and drumlinized surfaces and suggest that this landform system has been primarily generated by subglacial sheet flow collapsing into channelized flow. They envisage a rapid release of large volumes of meltwater along the ice/bed interface that scoured a regional unconformity recognized in the geological record. Another area in Canada, the Fraser Plateau in British Columbia, is studied by Sodeman & Brennand (2025), who document the characteristics of terrain resembling murtoos, enigmatic landforms recently identified in Finland and Sweden. This is the first occurrence of such features in association with the Cordilleran Ice Sheet and possibly in the whole of North America. The area, referred to as 'murtooized terrain', consists of steep slopes several metres high and up to 2 km long, imprinted with a distinct zig-zag topographic pattern. Contrary to the Scandinavian murtoos, this terrain is interpreted as having been created by a sequence of processes involving basal ice regelation, channelized subglacial outburst floods, glaciotectonism and deposition of till, which suggests that the relief similarity there and in Europe may result from a formational equifinality.

Two articles investigate large-scale ice flow patterns using streamlined and ice-marginal landforms and relate these to past and modern glaciological conditions. Kurjanski *et al*. (2025) examine marine-based ice-sheet deglaciation in the central Barents Sea with a focus on a shallow bank (Storbanken) that acted as a pinning point for the ice sheet. During deglaciation, the marine ice dome located there likely detached from the Svalbard-Barents Ice Sheet and generated multiple small ice streams characterized by flow directions actively switching in time and space in response to dynamic changes in the driving stress of the ice dome. This study

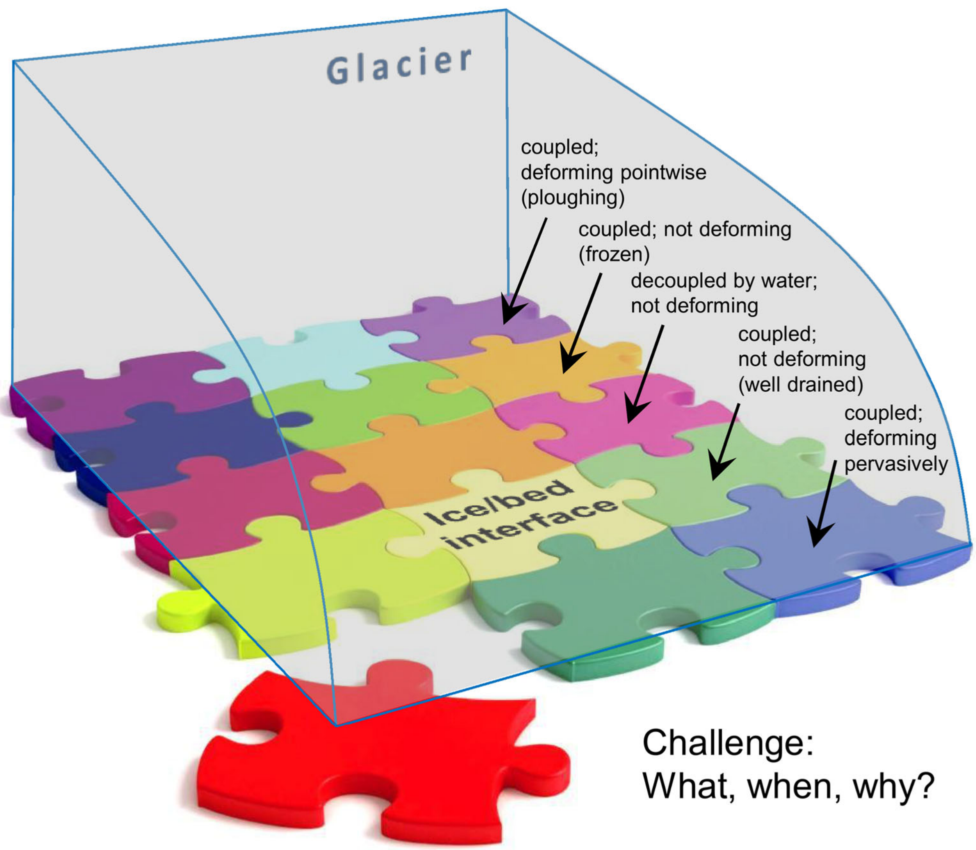

Fig. 1. Conceptual representation of the ice/bed interface as a mosaic of various processes depicted in the context of the strength of the basal coupling.

emphasizes the importance of shallow bathymetric banks for the behaviour of marine-based ice sheets, which is relevant for predicting the fate of modern glacial systems such as the West Antarctic Ice Sheet. The only article in this collection addressing a modern ice-sheet system is one by Schlegel *et al*. (2025), who study the formation of the subglacial landscape under the Rutford Ice Stream in West Antarctica. Use of novel high-resolution 3D radar data allowed for deciphering of basal conditions and relating them to the dimensions and spacing of streamlined bedforms. The results show no significant correlation between the dimensions of these bedforms and the ice flow velocity or (surface or basal) topography. In the proposed genetic model, the variations in bedform dimensions are mainly modulated by sediment properties and effective pressure of the ice above, which is important for parameterization of subglacial conditions in numerical modelling of ice stream dynamics.

(Sub)glacial deposits, mainly tills, are the focus of three articles that all reaffirm the complexity of till properties and processes of its formation (cf. Evans 2018). Rivers *et al*. (2025) use sedimentological and ground penetrating radar data to document the internal composition of De Geer moraines in southwest Finland. Multiple deposits occurring there are interpreted as subglacial traction tills and ice-marginal diamicts truncated by heavily deformed deposits, all characterized by distinctly different ice-proximal and distal distributions and properties. A landform assemblage classification and a conceptual model of formation is proposed in which "De Geer terrain" results from seasonal variations in ice-marginal deposition (summer) and glaciotectonic thrusting (winter). Glacial deposits are also studied by Hermanowski & Piotrowski (2025) at the margin of the former Scandinavian Ice Sheet in Poland using a combination of outcrop-scale observations and micromorphological data. A time-transgressive succession of ice-marginal deposition, subglacial deposition and deformation, and material release from stagnant ice are inferred, which generated hybrid diamicts hosting signatures of various superposed processes. Evidence of basal decoupling and small subglacial channels suggest that meltwater pressure was in the vicinity of the ice flotation point, facilitating basal sliding and thin-skinned bed deformation. One of the oldest glacial deposits in the northern Alpine foreland is investigated by Bamford *et al*. (2025), using a combination of sedimentological and geotechnical approaches. The exposed part of the infill of an Early Pleistocene overdeepened basin consists of two glacial diamicts, the lower one affected by subglacial shear and the upper one undeformed, showing a succession of different basal processes over time. The study emphasizes the advantages of combining geotechnical testing with CT-based microtomography to inform about the properties and origin of glacial diamicts.

Although this small collection of articles cannot be considered representative of modern subglacial research trends, it demonstrates the complexity of the interface between ice sheets and their beds addressed by the "What, where, why?" questions envisaging the subglacial environment as a system of diverse processes transient in time and space (Fig. 1).

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