

## USING SEDIMENTOLOGY & GROUND PENETRATING RADAR TO INVESTIGATE THE INTERNAL ARCHITECTURE OF DE GEER MORAINES

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### Abstract

Spatiotemporal resolution of palaeo-ice sheet terrain is critical to the quality of ice sheet reconstructions. De Geer moraines (DGMs), may be a candidate landform that can increase such resolutions to a potentially unprecedented (e.g. annual) rate of retreat, however, prior to reconstruction development, accurate formational properties must be established.

The aim of this project/fieldwork campaign is to investigate the internal architecture of DGMs and establish a more accurate mode of formation. Fieldwork involved investigating DGMs at four key sites across southwest Finland employing a combination of sedimentological and ground penetrating radar (GPR) methods.

We present preliminary findings describing the internal architecture of one DGM from southwest Finland. Key findings include: a vertical variability in lithological units indicating diachronous formation, thrusting structures located within the proximal parts of the ridge suggesting unidirectional pushing processes, and evidence of shearing stresses within upper units of the ridge indicating movement from overriding ice.

We suggest that, whilst deposits situated at the base of the ridge may have been deposited behind the grounding line, possibly in shallow subglacial canals and/or crevasse cavities, the main DGM ridge was formed via push processes at the grounding line of a water terminating ice margin. The preliminary findings

provide merit to support the idea that DGMs may be used to refine ice marginal reconstructions, however, further work must be undertaken to constrain the timescales at which they form.

### Background and Rationale

Palaeo-ice sheet reconstructions provide valuable information regarding the extent and evolution of past ice sheets (Clark et al., 2022; Gowan et al., 2021; Hughes et al., 2016; Stroeve et al., 2016), thereby enabling us to better understand how the cryosphere responds to global climate and environmental change. Ice sheet reconstructions are typically produced by a 'glacial inversion model', allowing glaciological inferences to be made from the integration between geomorphological evidence and numerical dating (Clark, 1997; Dalton et al., 2023; Gowan et al., 2021; Pearce et al., 2017). Modern palaeo-ice sheet reconstructions provide time-slice resolutions of between 1,000 – 100 years (Clark et al., 2022; Hughes et al., 2016; Stroeve et al., 2016), however, as high-resolution digital elevation models (DEM), (derived from LiDAR, for example) become more widely available, it is possible that lower-relief geomorphology may be identified and used to refine these resolutions.

De Geer moraines (DGMs) are lower-relief ridges, typically elongated, narrow and orientated transverse to former ice flow direction. Since first observations, several models of formation have been conceptualised, with two overarching ideas commonly debated.

The first constitutes a sub-aqueous ice marginal environment whereby sediments are deposited at the grounding line of water terminating glaciers. This model infers that ridges are formed asynchronously, potentially annually, at the ice margin thereby illuminating DGMs as a good landform candidate for ice marginal reconstructions. The second model constitutes a crevasse infilling method whereby saturated and deformable sediments are squeezed up into basal crevasse cavities. This model suggests that ridges are formed synchronously, behind the ice margin, and do not pertain any temporal qualities that would be useful for ice marginal reconstructions (Rivers et al., 2023). The two opposing models present different spatiotemporal implications for ice marginal reconstructions and highlight the importance of establishing a more accurate understanding of genetic properties for ice-marginal and sub-marginal ridges.

## Methods

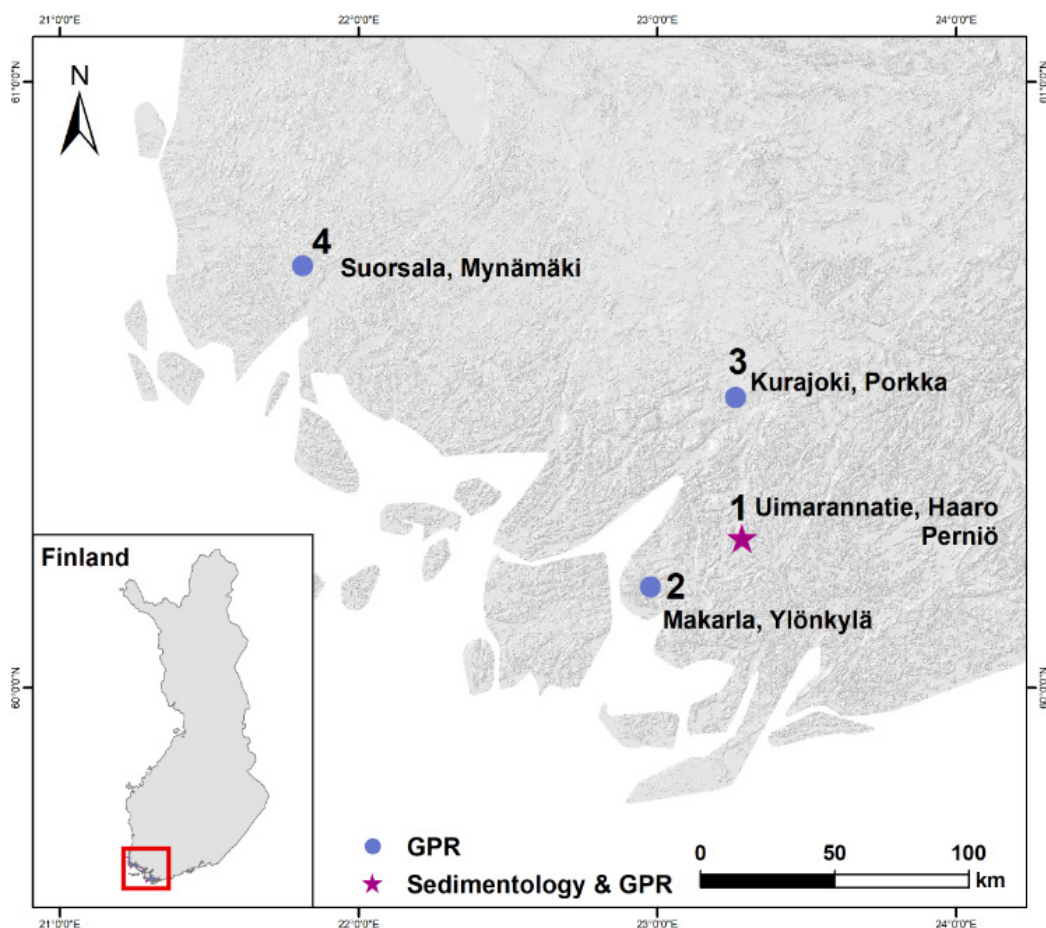
Field investigations were undertaken at four key sites distributed across southwest Finland (FIGURE 1). Sedimentological and ground penetrating radar (GPR) methods were undertaken to investigate the internal architecture of DGMs.

## 1. Sedimentological Investigations

Sediment exposures across the mid-sections of one prominent (*UT1*) and one intermediate (*UT2*) DGM were excavated at right angles to the ridge crestlines to investigate the internal architecture of these DGMs (FIGURE 2). For each exposure: physical characteristics of sediment profiles were described and logged, lithological units were identified based on: grain size, degree of sorting, matrix composition and clast lithology (Benn & Evans, 2013; Evans, 2004).

## 2. Ground Penetrating Radar Investigations

GPR data were collected using 32-bit Mala GroundExplorer (GX) 160- and 450-MHz shielded antennas mounted on rough terrain skid plates and connected to a Mala GX controller. Multiple GPR datasets were acquired for each sampled DGM, acquiring both cross-sectional and along-crestline profiles where possible. Radar facies were determined by variations in reflector motif (e.g. reflector strength, length, shape, amplitude, and pattern). These were then corroborated with lithofacies identified from the excavated sediment exposures.



**Figure 1:** Location map indicating selected sites across SW Finland for data acquisition: 1) Uimarannatie, Haaro, Perniö – sedimentology & GPR; 2) Makarla, Salo – GPR; 3) Kurajoki, Salo – GPR; 4) Suorsala, Mynämäki - GPR.





**Figure 2:** Photos of UT1 excavated sediment exposure. A) drone captured aerial photograph showing plan view of excavated trench; B) oblique photograph (view toward distal side); C) oblique photograph (view toward proximal side); D) oblique photograph (view toward proximal side).

## Results

Preliminary data from one investigated DGM (*UT1*) located at sample site 1 are presented. Sedimentological investigations revealed five different lithological units showing variable compositions of diamicton, interspersed in some locations with finer sands, silts and clays (FIGURE 3a). Evidence of thrust planes located proximally within the ridge indicate a unidirectional push movement involved during formation (Units 3a & 4). Shearing structures and stratification within the upper facies provide evidence of overriding ice (Unit 5). These are supported by evidence within the GPR radargrams showing long and continuous reflectors within the proximal parts of the ridge (RF2) (FIGURE 3b). These units are interpreted as being derived from an ice marginal push environment. Within the lower sectors of the ridge, however, sediments are more varied in grain size and interspersed with finer silts, sands, and gravel streaks. These units are interpreted as crevasse infill, possibly deposited behind the ice margin.

## Significance

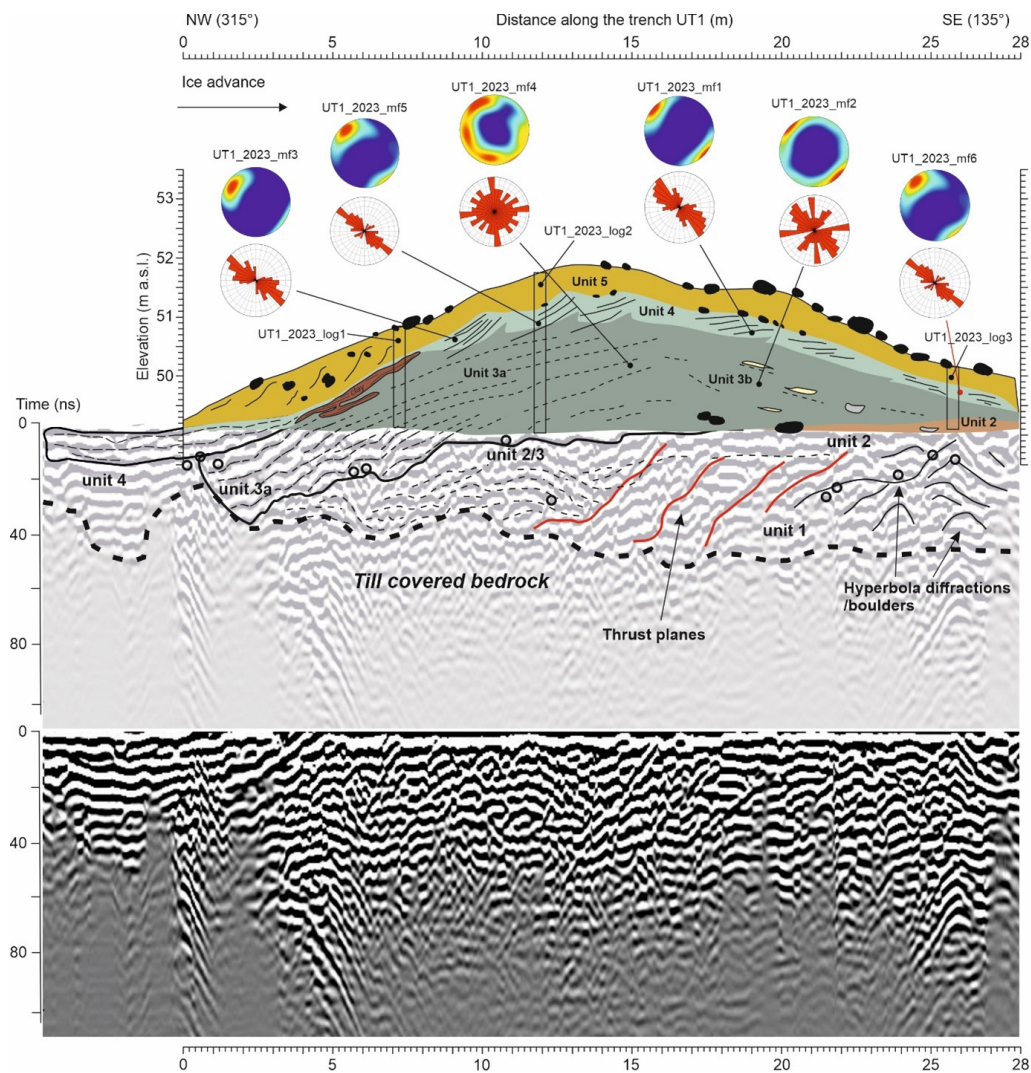
Differences in derivation between some of the units, particularly when assessing the ridges using litho- and seismostratigraphic approaches, infer diachronous formation. For example, it may be that

lower sediment units were initially deposited in shallow subglacial canals and/or crevasse cavities situated behind the grounding line and then at a later stage these deposits were overridden, deformed, and aggregated by ice marginal push dynamics that formed more distinctive grounding line DGM ridges. This presents important implications for DGM utility within ice marginal reconstructions as it suggests that an annual ice marginal signal is likely, however, must be accurately distinguished within wider DGM fields. As such, the next steps of the project are to test this idea, attempting to develop a refined reconstruction of the Finnish sector of the Fennoscandian Ice Sheet margin using DGMs as geochronometric indicators.

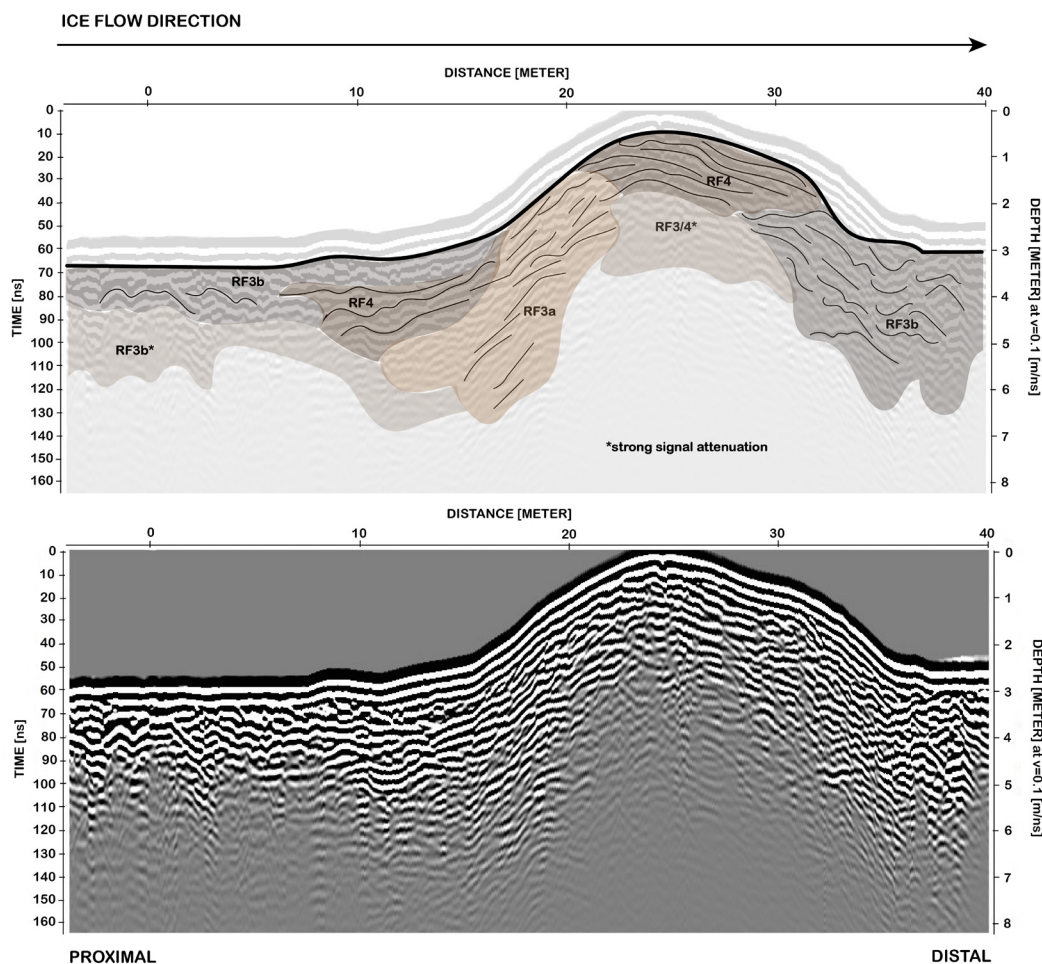
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**Figure 3a:** Exposure sketch of UT1 with subsurface GPR data. GPR data was acquired along the excavation bottom to allow subsurface investigations.



**Figure 3b:** Radargram for UT1 at sample site 1 (GPR #1), Uimarannatie, Haaro, Perniö.

## References

- Adobe Inc. (2019). Adobe Illustrator. Retrieved from: <https://adobe.com/products/illustrator>
- Agisoft - Metashape (version 1.8.1). (2022). Retrieved from: <https://agisoft.com/downloads/installer/>
- Benn, D., & Evans, D. J.A. (2013). *Glaciers and glaciation* (Second edition.). Routledge.
- Clark, C.D. (1997). Reconstructing the evolutionary dynamics of former ice sheets using multi-temporal evidence, remote sensing and GIS. *Quaternary Science Reviews*, vol. 16, pp. 1067-1092. DOI: [https://doi.org/10.1016/S0277-3791\(97\)00037-1](https://doi.org/10.1016/S0277-3791(97)00037-1)
- Clark, C.D., Ely, J.C., Hindmarsh, R.C.A., Bradley, S., Ignéczi, A., Fabel, D., Ó Cofaigh, C., Chiverrell, R.C., Scourse, J., Benetti, S., Bradwell, T., Evans, D.J.A., Roberts, D.H., Burke, M.S., Callard, L., Medialdea, A., Saher, M., Small, D., Smedley, R.K., Gasson, E., Gregoire, L., Gandy, N., Hughes, A.L.C., Ballantyne, C., Bateman, M.D., Bigg, G.R., Doole, J., Dove, D., Duller, G.A.T., Jenkins, G.T.H., Livingstone, S.L., McCarron, D., Moreton, S., Pollard, D., Praeg, D., Sejrup, H.P., Van Landeghem, K.J.J., Wilson, P. (2022). Growth and retreat of the last British-Irish Ice Sheet, 31 000 to 15 000 years ago: the BRITICH-CHRONO reconstruction. *Boreas*, vol. 51(4), pp. 699-758. DOI: <https://doi.org/10.1111/bor.12594>
- Dalton, A.S., Dulfer, H.E., Margold, M., Heyman, J., Clague, J.J., Froese, D.G., Gauthier, M.S., Hughes, A.L.C., Jennings, C.E., Norris, S.L. & Stoker, B.J. (2023). Deglaciation of the north American ice sheet complex in calendar years based on a comprehensive database of chronological data: NADI-1. *Quaternary Science Reviews*, vol. 321, 108345. ISSN: 0277-3791. DOI: <https://doi.org/10.1016/j.quascirev.2023.108345>
- De Geer, G. (1889). Ändmoränerna I trakten mellan Spånga och Sundbyberg. *Geologiska Föreningens I Stockholm Förhandlingar*, vol. 11(126), pp. 395-396
- Evans, D. (2004). *Practical guide to the study of glacial sediments*. Taylor & Francis Group.
- Golledge, N.R., Phillips, E., 2008. Sedimentology and architecture of De Geer moraines in the western Scottish Highlands, and implications for grounding-line glacier dynamics. *Sediment. Geol.* 208 (1–2), 1–14. <https://doi.org/10.1016/j.sedgeo.2008.03.009>.
- Gowan, E.J., Zhang, X., Khosravi, S., Rovere, A., Stocchi, P., Hughes, A.L.C., Gyllencreutz, R., Mangerud, J., Svendsen, J-I. & Lohmann, G. (2021). A new global ice sheet reconstruction for the past 80 000 years. *Nature Communications*, vol. 12(1199). DOI: <https://doi.org/10.1038/s41467-021-21469-w>
- Hoppe, G., 1959. Glacial morphology and inland ice recession in northern Sweden. *Geogr. Ann.* 41, 193–212.
- ®National Land Survey of Finland, LiDAR digital elevation model, 2/2023.
- Ojala, A.E.K. (2016). Appearance of De Geer moraines in southern and western Finland – Implications for reconstructing glacier retreat dynamics. *Geomorphology* 255, 16–25. <https://doi.org/10.1016/j.geomorph.2015.12.005>.
- Ojala, A.E.K., Putkinen, N., Palmu, J.P., Nenonen, K., (2015). Characterization of De Geer moraines in Finland based on LiDAR DEM mapping. *GFF* 137 (4), 304–318. <https://doi.org/10.1080/11035897.2015.1050449>.
- Pearce, D., Ely, J., Barr, I.D. & Boston, C.M. (2017). Glacier Reconstruction. In: *Geomorphological Techniques. British Society for Geomorphology*, pp. 1-16. Retrieved from <https://e-space.mmu.ac.uk/619301/>
- Rivers, G.E., Storrar, R.D., Jones, A.H. & Ojala, A.E.K. (2023). 3D morphometry of De Geer Moraines and Crevasse-Squeeze Ridges: Differentiating between pushing and squeezing mechanisms from remotely sensed data. *Quaternary Science Reviews*: 321C(1). DOI: <https://doi.org/10.1016/j.quascirev.2023.108383>