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Spatial domains of the trimline, nunatak and frozen-bed concepts

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Relict upland morphology has been reported from most glaciated areas, typically forming a dramatic contrast to conventional glacial morphology at lower elevations. The topographical and geographical setting is diverse, ranging from fjord landscapes, such as in Greenland, Norway and Canada, to the hilly hinterland landscapes of, for example, Sweden, Scotland and Baffin Island. The morphological boundary between glacial landscapes and relict landscapes is often so distinct that it has been interpreted to mark a former *trimline* which, by definition, marks the upper ice-sheet surface. The inference of trimlines, therefore, forms the basis for pinpointing specific uplands and summits as *nunataks*, and inferring maximum ice sheet elevations. In a different school of thought the same morphological contrast is interpreted to represent topographically-induced subglacial thermal boundaries, i.e *frozen-bed conditions* under the thinner ice over uplands and *thawed-bed* basal sliding conditions across intervening lowlands.

We review key relationships related to the concepts of trimlines, nunataks, and frozen-bed patches. We pay particular attention to (i) the glaciological environment in which trimlines form, (ii) how uplands can be demonstrated to have been nunataks, and (iii) how relict surfaces can be demonstrated to have been ice-overriden, thus justifying a frozen-bed interpretation.

We find that "trimline-and-nunatak" interpretations *may* be valid in coastal high-relief domains, but that it is exceedingly difficult to reliably demonstrate that a certain upland has remained uninterruptedly ice free. The "frozen-bed" interpretations are valid primarily for hinterland domains, where direct evidence (erratics, slight glacial modifications) or circumstantial evidence (isostatic uplift patterns, numerical ice sheet modelling) irrefutably indicate complete ice overriding.

The application of terrestrial cosmogenic nuclide studies has recently revived studies of relict surfaces and glacial landscapes. Whereas such studies have convincingly shown the antiquity and subglacial preservation of relict hinterland domains (through studies of bedrock-erratic pairs), it has been impossible to convincingly demonstrate subglacial preservation for some coastal domains in the absence of erratics. It has been equally difficult to demonstrate the presence of nunataks in the coastal domain during maximum glaciation, primarily because the effect of relatively short-lived ($<$ 10,000 years) overriding events are undetectable given current analytical and systematic uncertainties in the cosmogenic nuclide method, and can therefore not be distinguished from a full-exposure scenario.