A method of quantifying subglacial sediment transport / deformation

M J Smith[1], J Rose[2] and M B Gousie[3]
Contact: michael.smith@kingston.ac.uk

Institutions
[1]School of Earth Sciences and Geography, Kingston University
[2]Department of Geography, Royal Holloway University of London
[3]Department of Mathematics and Computer Science, Wheaton College, MA, USA

1. Introduction

Glacial lineaments are part of a continuum of bedforms generated beneath ice sheets and are commonly observed in previously glaciated terrain. Typically they are known as drumlins, flutes, streamlined hills, whalebacks, megadrumlins, megaflutes, ribbed / Rogen moraine. They are formed in both deformable substrates (i.e. drumlins) and bedrock (i.e. whalebacks) and typically display a linear shape with relatively high elongation ratios.

Further understanding of these processes, operating at the glacier-bed interface, can come from detailed knowledge of the stress patterns involved during formation, in addition to the volume of sediment deposited during different phases of landform genesis. The latter can be recorded through the use of any one of a number of different survey techniques (Figure 1).

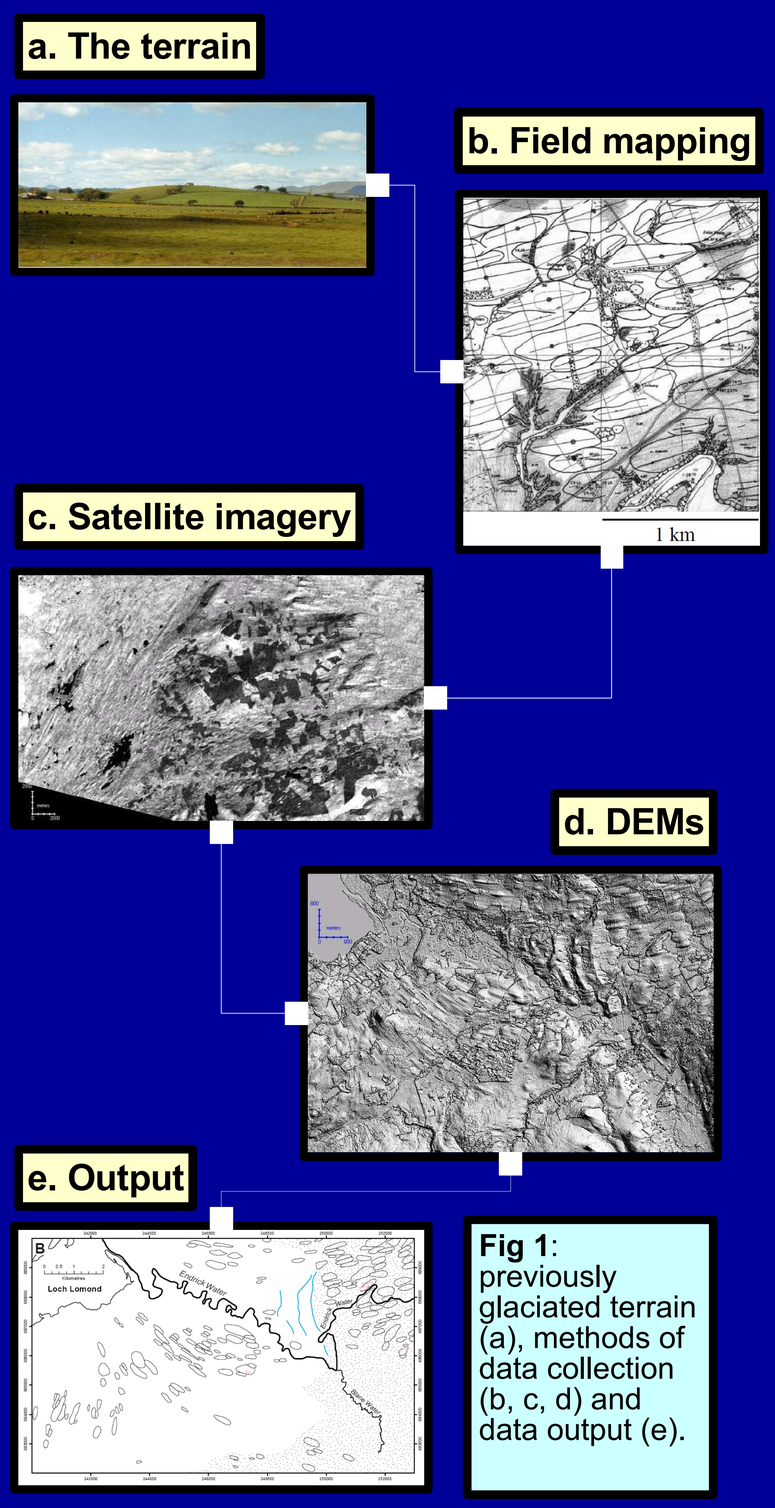


Fig 1: previously glaciated terrain (a), methods of data collection (b, c, d) and data output (e).

2. Quantitative Output

- Measurement of landform dimensions such as length, width, orientation (e.g. Rose and Letzer, 1977)
- Statistical summaries of glacial landform distributions (e.g. Rose and Letzer, 1977)
- Identification and characterisation of glacial events (e.g. Rose and Letzer, 1977)
- Research has focused upon 2D (planimetric) lineament characterisation
- Potential for 3D characterisation and therefore volume estimates (Rose, 1989; Evans, 1987); enabled through the availability of high resolution (sub-5m) digital elevation models (DEMs)

3. Cookie Cutter

In order to calculate volume, it is necessary to extract ("cut out") individual lineaments (aka "Cookie Cutter"). The criteria for a cookie cutter are:

- template cutter► **lineament outline**
- medium to cut extracts from► **DEM**

There are two outputs from this technique:

- individual lineament DEMs
- DEM with "holes"

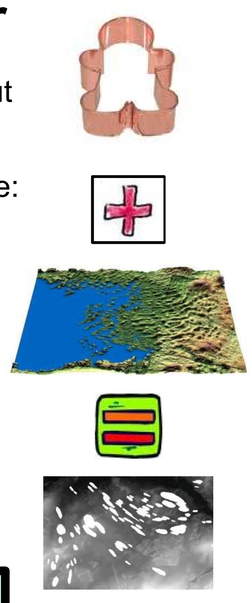


Fig 2: Illustration of "cookie cutter" technique

4. Model Inputs

1) Lineament Outline: lineaments mapped from DEMs (Smith and Clark, 2005) meet this criterion.

2) DEM: resolution (vertical/horizontal) is crucial to volumetric calculations in order to:
- to maximise the inclusion of landforms
- to minimise error

5. Volume Calculation

In order to calculate volume, we need to subtract "interpolated terrain" from the original DEM. This leaves a "DEM" of individual drumlins.

Relative Elevation:
The cookie cutter output is comprised of terrain with "holes". In order to produce volumetric calculations, we actually need terrain **without** lineaments. We define this as *relative elevation* and is the difference in the landscape from pre- to post- lineament formation

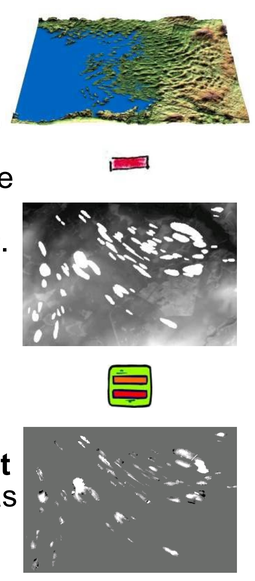


Fig 3: Calculation of lineament volume

6. Interpolator

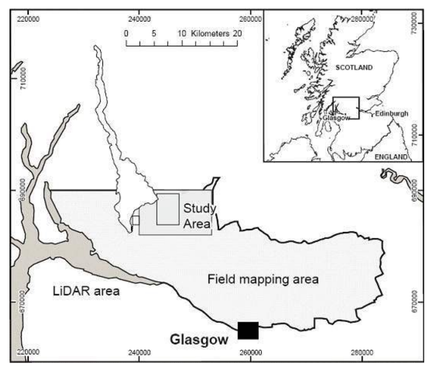
Initial testing has incorporated two interpolation techniques:
- inverse distance weighting (IDW)
- thin-plate method, possibly including a tension parameter

As areas of relative elevation are generally small, it may be sufficient to use the simple IDW interpolator. In either case, care must be taken so that artefacts on the edges of the drumlin are not part of the interpolation.

7. Study Area

The study site (Figure 4) is located in an area of central Scotland last glaciated during the Last Glacial Maximum (LGM) and Younger Dryas (YD). Detailed geomorphological mapping has been performed from NEXTMap DEM data (5m resolution; after Smith et al, in press).

Fig 4: Location of study area



8. Initial Results

Initial results for the study area show relative elevation for each 5x5m pixel:
Mean: 3.7 m
Min: -14 m
Max: 57 m
SD: 4.7 m

Total Relative Elevation: 15,264,016 m
Total Volume: 381,600,100 m^3
= 3,816,001 m^3 / km^2
Clearly -14m is an error as we cannot have negative relative elevation

9. Sources of Error

The following have been identified as potential sources of error and are being investigated further:

- accuracy of digital lineament boundaries
- lineament adjacency (shared boundaries)
- DEM resolution/lineament size
- surface clutter
- landform degradation (change since formation)

10. Conclusions

Few studies have quantitatively assessed sub-glacial sediment volumes and, of those completed, none have been performed regionally. Estimation of landform volume allows an estimate of sediment quantity and therefore provides a basis from which a first estimation of sediment flux at the base of a glacier can be performed. In addition to the caution implied above, caution should be applied to the interpretation caused by net changes in the total landscape between bedform formation, and the present time.

References

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