LANDSCAPE-ANALYSIS BASED VISUALIZATION OF DRUMLINS

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1 ABSTRACT

Drumlins are elongate, streamlined, hills that form sub-glacially, parallel to ice flow [Benn & Evans, 1998]. Their number, size, orientation and distribution contain information about ice sheet conditions during their formation such as flow direction and velocity. Objective and consistent mapping of drumlins is therefore paramount for reconstructing ice sheet dynamics from palaeo evidence [Clark, 1997].

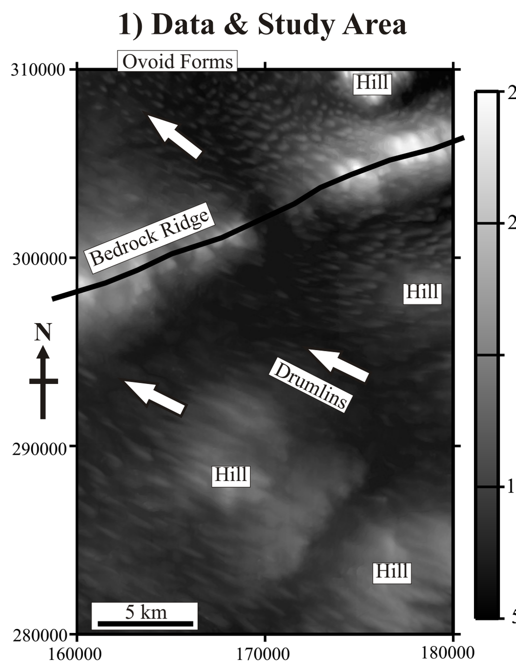
Drumlins can be mapped in the field or from remotely sensed data, for instance digital elevation models (DEMs). Whilst automated techniques are reproducible, their accuracy rates are currently inadequate and manual mapping techniques remain prevalent [e.g. Vencatasawmy, 1997].

Manual techniques involve the use of visualization-based methods; for example, *relief-shading*, *gradient*, and *curvature* [e.g. Smith & Clark, 2005]. Here, we develop a technique that assists visualization by isolating drumlins from other components of the landscape. As in Smith & Clark [2005], we use the region surrounding Lough Gara, Ireland, as a study area. Using a sliding 1 km wide median filter, the hills underneath the drumlins (~200 m wide) are removed. An envelope, varying laterally on a scale of ~1 km, is placed around the upper and lower bounds of the drumlins' topography. Drumlins of ~2 m to >10 m high are then displayed on a coloured scale stretched (from black to white) between these limits. The 1x1 km box was chosen to exploit the difference in size-scale between the hills and drumlins, following the former whilst averaging out the latter, in order to optimally separate them. In terms of landforms identified, the technique is similar to *curvature* and *orthogonal relief shading*, but exceeds others. It is important to note that, in contrast to relief shading, the landscape-analysis technique is not biased by the azimuth of illumination.

INTRODUCTION

.Fig. 1 is a greyscale image of topography data in the Lough Gara region of Ireland (53.94°N,8.44°W). Light grey shades indicate topography highs on the DEM, whilst dark shades are lower areas. Heights range from 53 to 264 m. Hills and the bedrock ridges are ~5-10 km wide, compared to a few 100 m for the drumlins and ovoid forms (little preferred orientation).

Drumlins, are commonly topographically subtle, namely low amplitude (up to ~20m). So, when draped over higher amplitude bedrock hills (~200m), drumlins are often hard to see. Visualization techniques are used to emphasize them prior to mapping.



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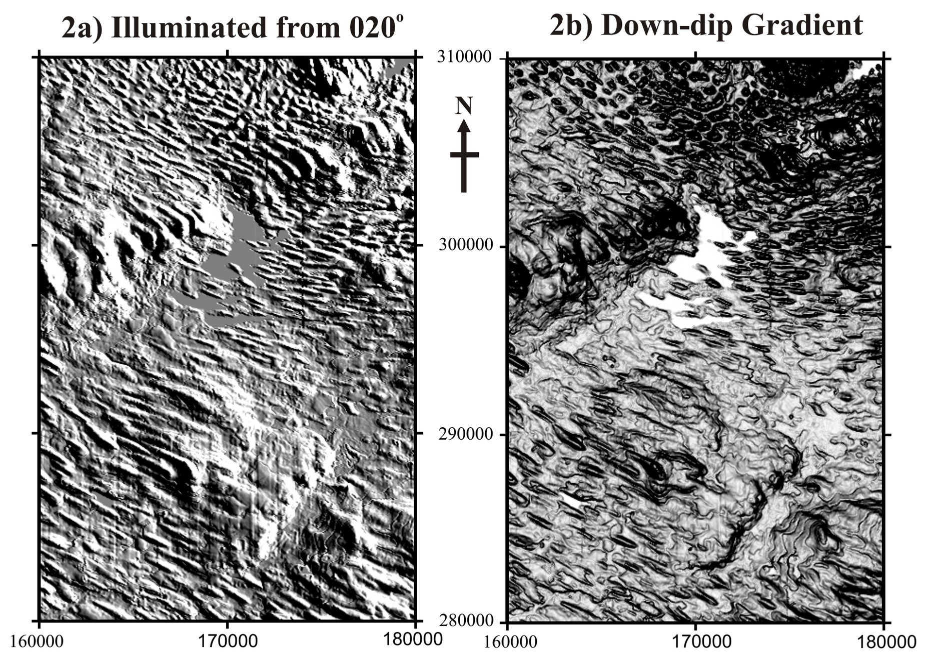


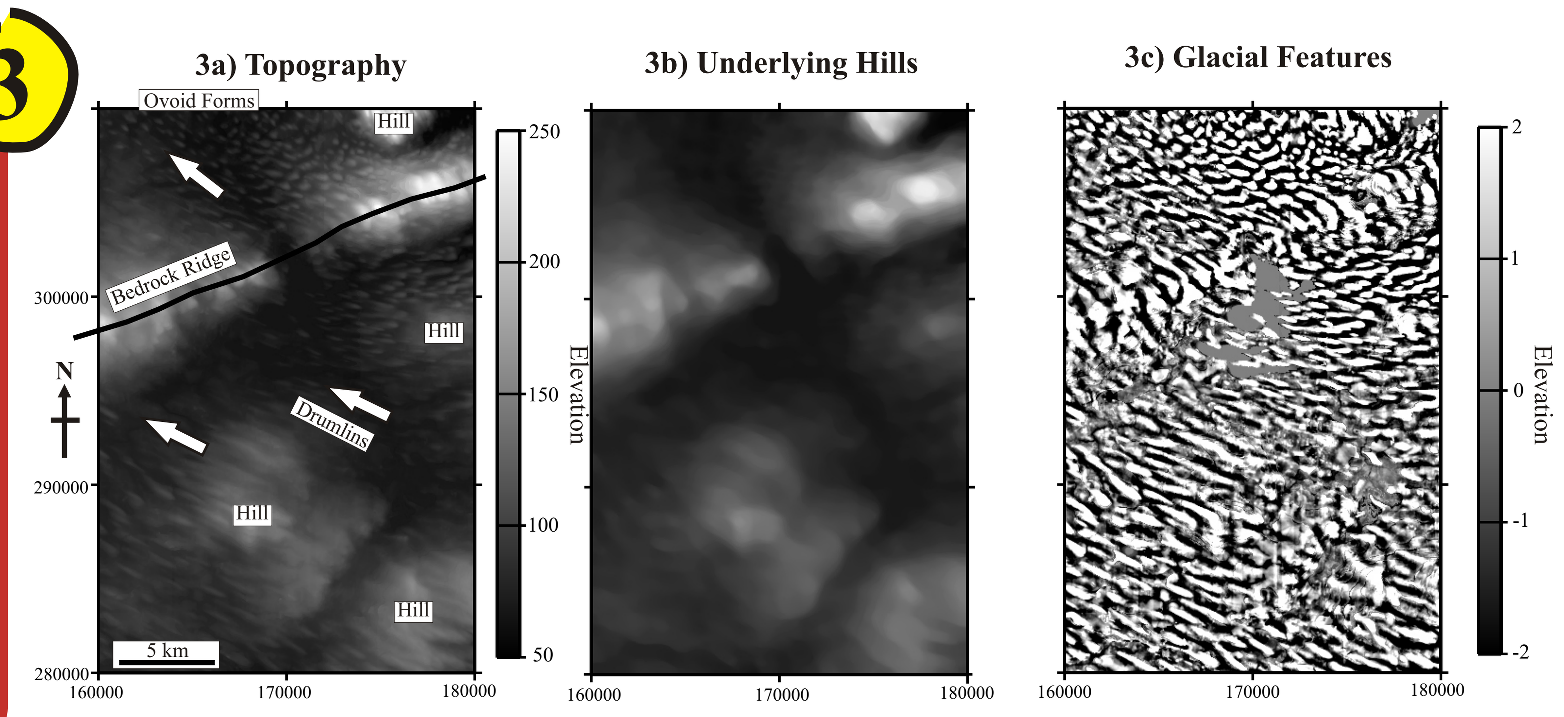
Fig. 2 shows examples of two commonly used visualization techniques applied to the topography in Fig. 1. Both utilize topographic slope, distinguishing relatively steep-sided drumlins from the rolling bedrock hills underneath. a) shows 'relief shading' of topography [e.g. Onorati et al, 1992; Pike, 1992], which is notably simple and effective. The illumination is from 020°, orthogonal to the main drumlin orientation [Smith & Clark, 2005]. Illuminations here are simply directional derivatives of the DEM. Gradients down to the SW are dark shades, whilst gradients down to the NE are light shades. Fewer drumlins will be visible with shading from other azimuths [e.g. Lidmar-Bergstrom, 1991; Bonham-Carter, 1994], a problem dubbed 'azimuthal bias' by Smith & Clark [2005]. b) plots the down-dip magnitude of topographic slope or 'gradient'. High gradients are black, whilst horizontal planes are white. As gradient images are not illuminated, there is no azimuthal bias, but sometimes it is difficult to see how the image relates to the DEM (i.e. not one-to-one relationship between intensity and height).

So, a method is needed that is without azimuthal bias and produces images directly resembling topography. One such method is now described.

3 LANDSCAPE PROCESSING 1

Fig. 3 illustrates the first stage of a landscape analysis based on spatial scale, not slope (traditional techniques). Relatively steep sides are not the only characteristic differentiating drumlins from bedrock hill. Respective width-scales are also different. The hills are ~5-10 km wide, whilst the drumlins span a few 100 metres.

Fig. 3a is the topography. The large-scale hills in b) are isolated by approximating them with a 1 km x 1 km 'sliding window' applied to the DEM. The median height is returned to a central point (i.e. median filter) (grdfilter GMT software [Wessel & Smith 1998]). Subtracting the hills from the topography leaves the drumlins, shown in c). Note that a different, ±2 m, greyscale is used in c) as drumlins in the north are higher amplitude than in the south.

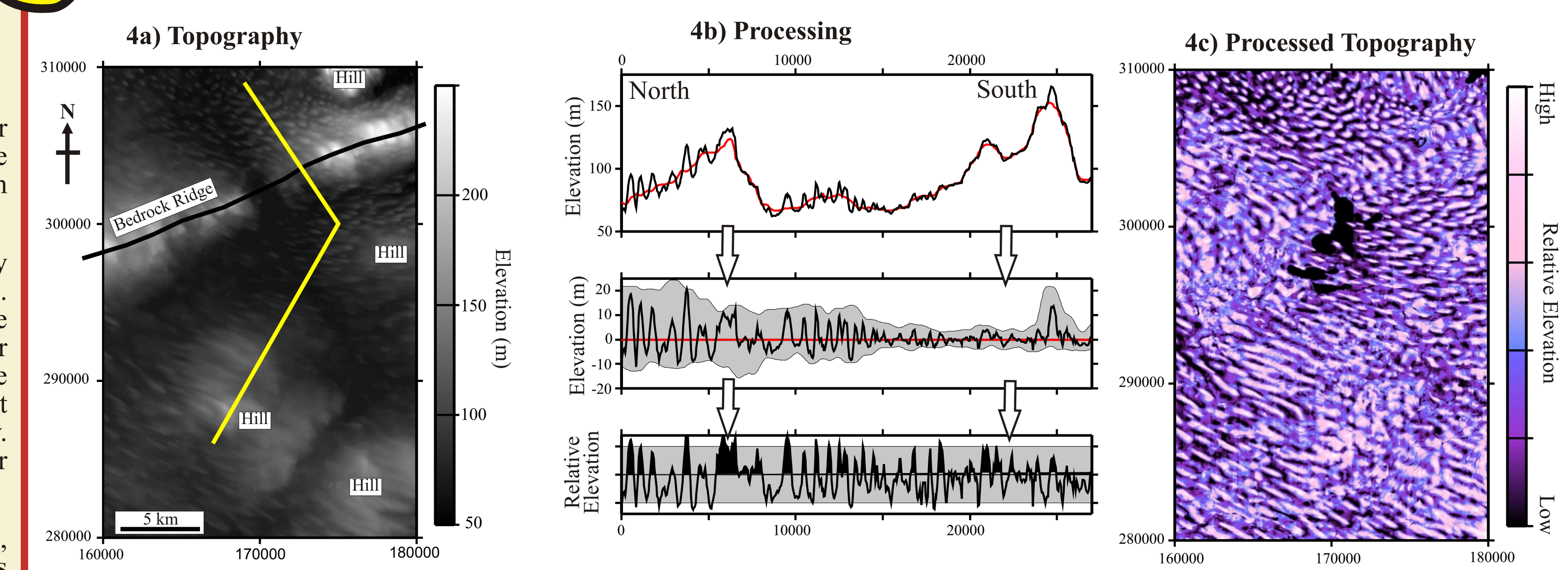


4 LANDSCAPE PROCESSING 2

A second processing stage (adapted from Hillier et al [2007]), corrects for the spatially variable amplitude of the drumlins (>10 m in north, ~2m in south), again using sliding windows.

The top panel of Fig. 4b shows topography (black line) along a profile (yellow line in 4a). The median filter (red line) is subtracted to give 'drumlins' in the middle panel. Locally, upper and lower envelopes are evaluated around the drumlin height data using 1x1 km windows that return highest and lowest values respectively. Smoothing these with a 0.5 x 0.5 km boxcar filter gives the grey zone.

'Relative elevation', in c) and bottom panel of b), between the envelopes is then calculated as $h_{relative} = (h - h_{min})/(h_{max} - h_{min})$, where h is height.



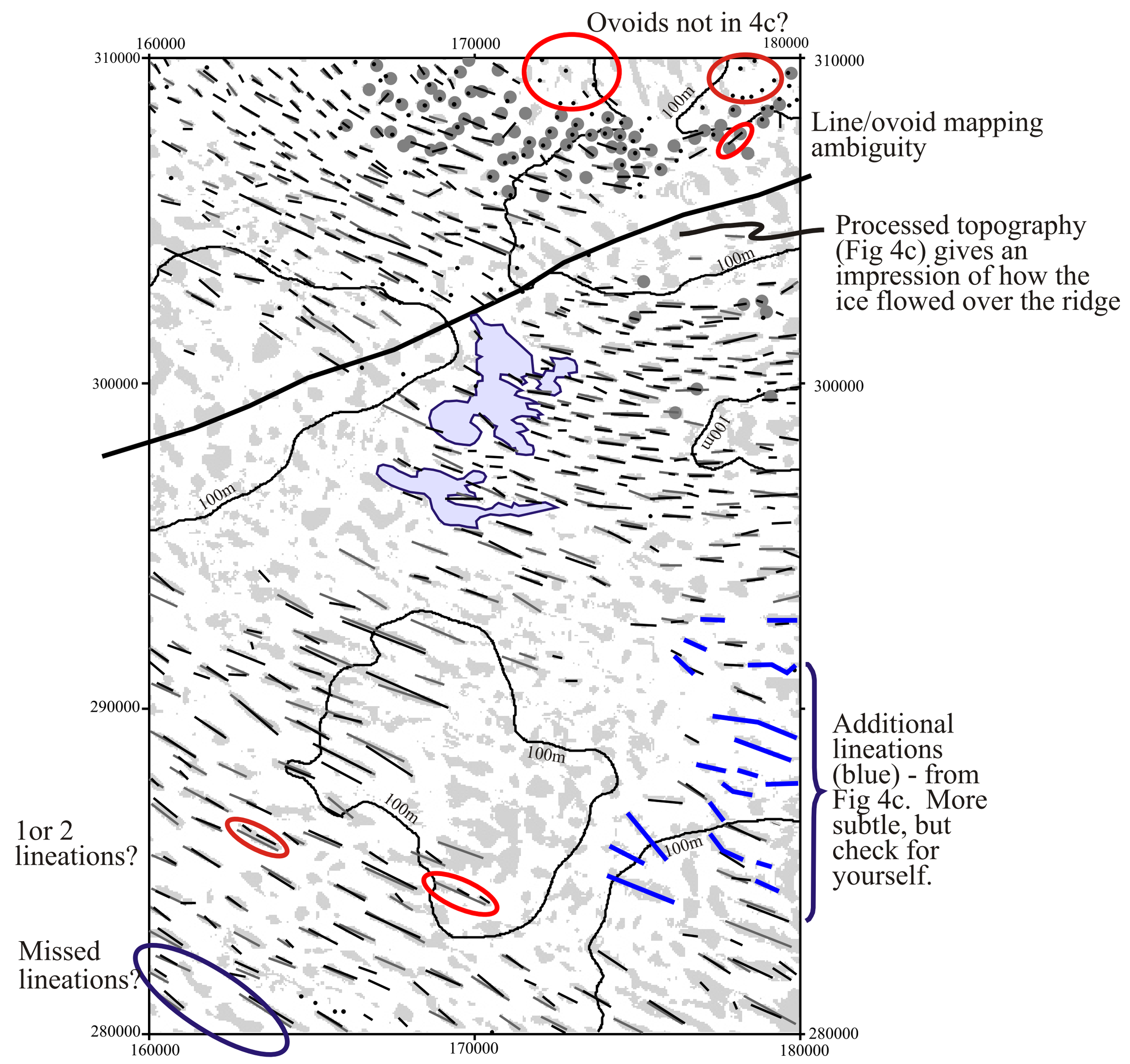
5 MAPPING RESULTS

Fig. 5 is a generalized lineament map of the Lough Gara region. Lineations mapped from the processed landscape (Fig. 4c) are grey lines, whilst a 'ground-truth' data set collated by multi-azimuth illumination mapping [Smith & Clark, 2005] are black. Likewise filled circles are ovoid forms. Light grey areas have relative heights of > 0.6 (Fig. 4c). The 100 m topographic contour locates hills, the prominent WSW-ENE ridge is a thick black line, and flat areas in and around the lake are shown in blue.

Visual agreement between the data sets is good (All mapping by M. J. Smith).

Numerically, however, of 442 lineaments and 109 ovoid forms in the ground-truth data, 371 and 101 were mapped from orthogonally illuminated data [Smith & Clark, 2005], but 340 and 84 from the landscape processed here. This is somewhat disappointing, but cumulative lineament lengths of 263, 289 and 271 km respectively are comparable and indicate that variability of mapping may explain a large amount of this difference.

In Fig. 5 areas highlighted with red circles illustrate this variability. Importantly, some areas showing lineations/ovoids in the relative elevation data are not mapped at all. By inspection of Figure 4c, one author (Hillier) has added some plausible extra lineations (blue) in a sample area. Care, however, must be taken to avoid 'false positive' identifications such as anthropogenic modifications [Smith & Wise, 2007]. This illustrates the need for a drumlin-detection algorithm, but we feel able to argue that this landscape analysis performs as well as the best of other techniques.

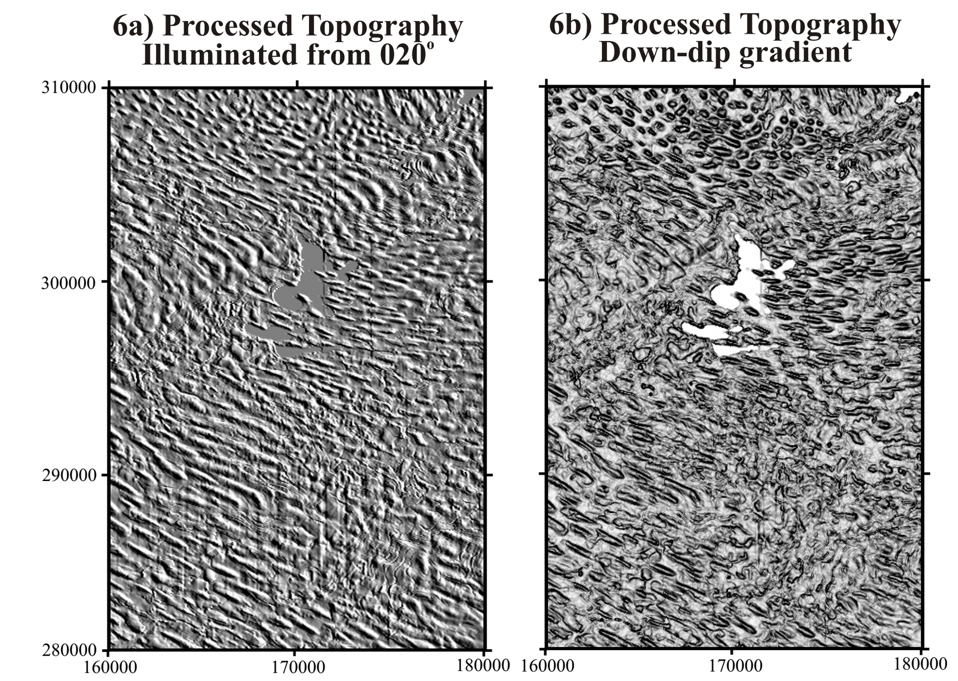


6 DISCUSSION

To map subtle glacial morphologies such as drumlins, techniques are required to emphasize them over other, higher amplitude, bedrock hills. Characteristics distinctive to drumlins such as magnitude of topographic slope, width-scale, or an elongate morphology may be used to achieve this. Traditional techniques (e.g. *gradient*, *curvature*, *relief shading*) use the first, distinguishing relatively steep-sided drumlins from rolling hills. A technique using width-scale, distinguishing narrow drumlins from wide hills, has been successfully implemented here. A map coloured for 'relative height', or height with respect to the immediate surroundings, was produced (Figure 4c).

'Relative height' has several advantages. It is simple and quick to calculate on freely available software (GMT [Wessel & Smith, 1998]). It is independent of 'pixel' size in the data, robust to significant noise in the data, and highlights data artefacts less than surface derivatives. It is not illuminated, so has no 'azimuthal bias' [Smith & Clark, 2005]. Relative height also directly reflects the original topography. Namely, high drumlins are white, separated by black unlike, curvature for instance.

Note, processing here in no way precludes use of any traditional visualization techniques after either stage. Drumlins are simply more obvious. Figure 6, for instance, is the processed topography (Fig 4c) illuminated from 020° and as a gradient.



7 CONCLUSIONS

- Manipulating a landscape (i.e. heights in a DEM) with spatially localized statistical operations is a useful complement to existing drumlin visualization methods. We dub this 'landscape analysis'.
- Width-scale, instead of slope, can separate landscapes into geomorphological components (e.g. bedrock hills & drumlins).
- Landscape analysis produces an image closely resembling the glacial part of terrain without 'azimuthal bias'.
- Landscape analysis enhances existing methods if it is used as a pre-processor.

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