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The impact of Quaternary glaciations on inselbergs in northern Sweden

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ABSTRACT

We investigate the glacial modification of inselbergs (large, isolated bedrock hills) in northern Sweden. Inselbergs are generally regarded as products of deep weathering (etching) and stripping under warm and humid climates. Unlike inselbergs found in the tropics, the inselbergs in northern Sweden were exposed to ice sheet glaciation for long periods of the Quaternary. We used DEMs to examine 794 inselbergs in our study area and they were classified according to their degree of glacial modification. Bedrock structural control was assessed using GIS data on the regional geology. Clusters of inselbergs were mapped in the field for features indicative of glacial erosion, such as glacial cliffs and stripped bedrock surfaces, and for features indicative of limited erosion, such as tors and blockfields. The results of the study indicate that inselbergs in the area were mostly modified by Quaternary ice sheets only to a low or moderate extent and that the degree of glacial erosion is dependent on their relief and location. Inselbergs with a relative relief of <100 m and in areas of lower absolute relief experienced the strongest glacial modification, where the strongest glacial modification can result in lateral erosion of the inselberg flanks. Inselberg summits often display signs of minimal glacial erosion, such as torlike bedrock outcrops with signs of strong weathering. In summary, we argue that inselbergs in northern Sweden have largely retained their pre-Quaternary shape despite long periods of ice sheet cover.

1. Introduction

Inselbergs may evolve through etching and stripping (e.g., Büdel, 1978; Thomas, 1978, 1994) or slope retreat (King, 1948). Inselberg development is often associated with tropical climates, with alternating phases of weathering during wet periods and stripping during semi-arid periods (e.g., Büdel, 1978; Thomas, 1978, 1994). Bedrock structural control is widely regarded as essential for inselberg development (e.g., Thomas, 1994; Migoń 1997, 2006). Inselbergs have been studied most frequently in tropical, mostly African, regions (e.g., Willis, 1934; Twidale, 1978; Ollier, 1978; Büdel, 1978; Thomas, 1978, 1994; Römer, 2005, 2007) but inselbergs have been described also for non-tropical areas such as central Europe (e.g., Büdel, 1957, 1977; Migoń, 1997), Scotland (Godard, 1965; Hall, 1991) and Sweden and Finland (Schrepfer, 1933; Büdel, 1978; Kaitanen, 1985; Rudberg, 1988).

In the present article, we investigate inselbergs in a glaciated area. These inselbergs rise above plains in northeastern Sweden. These plains, the Muddus plains, are one of six palaeosurface generations in northern Sweden identified by Wråk (1908). The Muddus plains are considered to have formed after etching (deep weathering) and stripping during the Mesozoic (Lidmar-Bergström, 1995; Lidmar-Bergström et al., 2007). The inselbergs in northern Sweden are consequently regarded as remnants after the stripping process of the area and possibly subsequent further weathering and slope retreat during the Tertiary (Lidmar-Bergström, 1995; Lidmar-Bergström et al., 2007). Up to this point in time, the inselbergs of northern Sweden probably developed along similar pathways to inselbergs found today in locations like Zimbabwe and Namibia (cf. Lidmar-Bergström, 1995).

The onset of cooling in the Neogene culminating in the onset of glaciation 2.6 million years ago (Shackleton et al., 1984) led to fundamental changes in boundary conditions for landscape development. Initially, the inselbergs may have continued to develop by weathering and erosion operating under humid temperate conditions, but the first extensive glaciations that covered the study area around 2 million years ago (inferred from Shackleton et al., 1984; Mangerud et al., 1996; Kleman et al., 2008) likely brought a halt to the operation of the preexisting inselberg-shaping processes and the onset of a period of glacial modification. This modification may have included inselbergs being glacially reshaped to different degrees, saprolites being partly removed, and glacial sediment accumulated on the inselberg surfaces and in their surroundings. However, the glacial effect on the north Swedish preglacial landscape has been shown to be highly heterogeneous as a result of a patchy distribution of warm-based erosional/depositional zones and cold-based nonerosive zones under the ice sheets (Kleman, 1992; Kleman and Stroeven, 1997; Kleman et al., 1999; Kleman and Hättestrand, 1999). Some areas have been heavily eroded throughout numerous glaciations, as witnessed by bedrock hills being integrated in glacial erosional and depositional streamlined features such as drumlins and crag-and-tails

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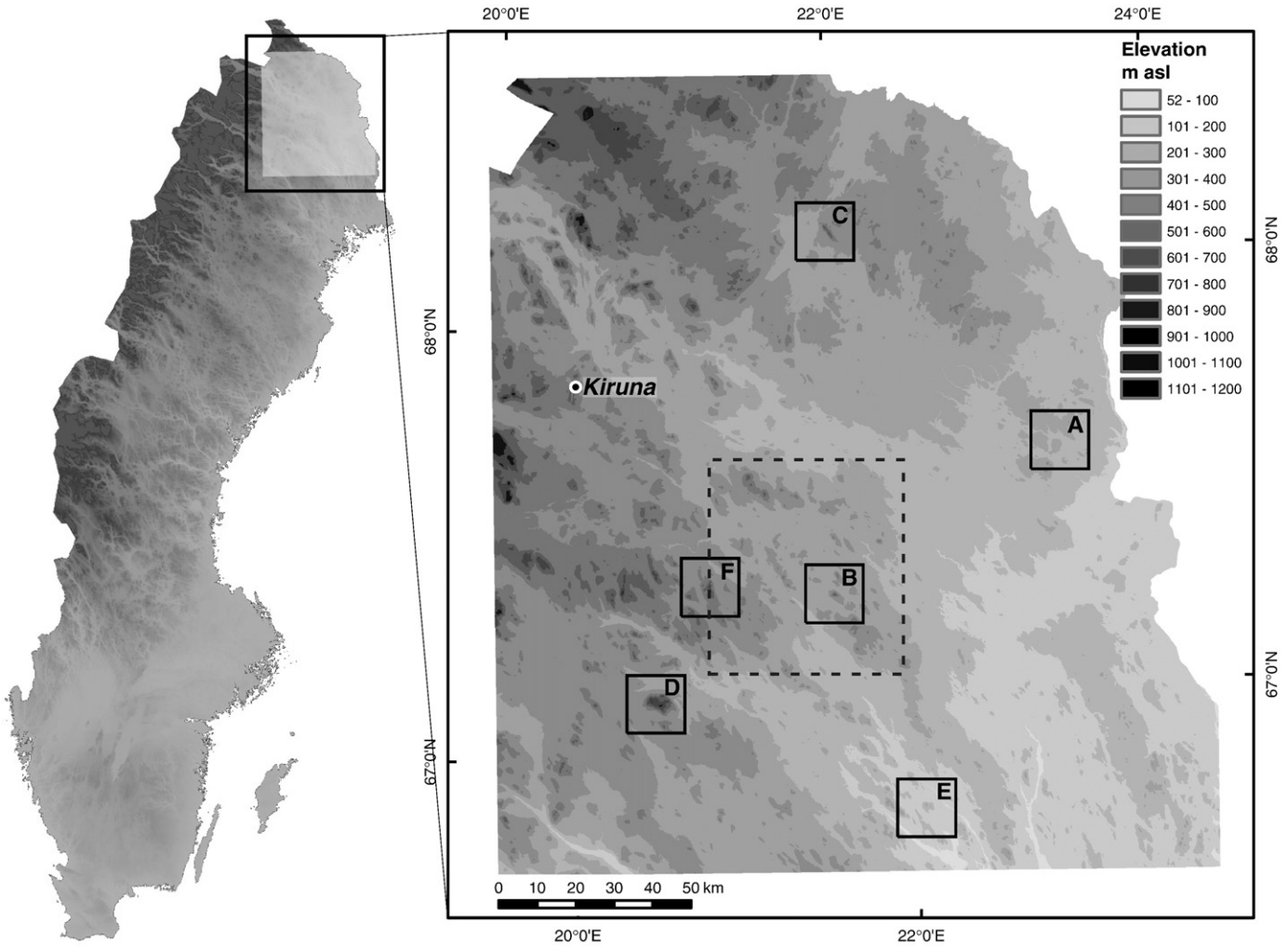

Fig. 1. Elevation map of the study area in northern Sweden east of the northern Scandes. Rectangles indicate locations of areas in Fig. 3; rectangle with dashed line shows location of area in Fig. 6.

(Hättestrand et al., 1999, 2004), while other areas display what appears to be an essentially unmodified landscape including tors and other relict weathering remnants (Lagerbäck, 1988; Hättestrand and Stroeven, 2002; André, 2004; Darmody et al., 2008).

The degree of glacial modification of large bedrock obstacles has previously been studied from a glaciogeomorphological perspective, for example where the bedrock obstacles were described as large roche mountonées (Sugden et al., 1992), the crags of crag-and-tails (Jansson and Kleman, 1999), or from one case study (Stroeven and Kleman, 1999). A few studies have focused specifically on the effect of the Quaternary glaciations on pre-Quaternary large-scale landforms from a Swedish perspective. For example, Rudberg (1954, 1988) described a characteristic feature of hills in northern and central Sweden, which had one side cut off by glacial erosion, and called these features "flyggbergs". In other studies, focus was put on palaeosurfaces identified as essentially preglacial and on the degree to which these still retained their preglacial appearance (Lidmar-Bergström, 1997; Kleman and Stroeven, 1997; Olvmo et al., 1999; Lidmar-Bergström et al., 2007). These studies have in common that they primarily describe the preservation of these surfaces during Quaternary glaciation.

Studies focusing on the complete pre-Quaternary (preglacial) and Quaternary (glacial) landscape development are rare. In this paper we show that a combined view on a pre-Quaternary large-scale bedrock landform type, the inselbergs of northern Sweden, provides an excellent possibility to study the Quaternary glacial impact on the landscape of northern Sweden.

As inselbergs are preglacial landforms, the degree of glacial reshaping of inselbergs in northern Sweden can tell us more about i) the accumulated effects of the Quaternary glaciations on the large-scale landscape east of the northern Scandes as recognized from inselberg glacial modification, and ii) ice sheet effects on large-scale obstacles.

2. Study area

The study area is situated east of the northern Scandes (Fig. 1) and covers an area of c. 30,000 km^2. It predominantly embraces a landscape type characterised by plains with residual hills (Lidmar-Bergström,

Table 1
Number and percentage of inselbergs compared to bedrock type area (bedrock from national geological bedrock database 1:1 million of the Swedish Geological Survey, SGU).

Bedrock	Inselbergs (count)	Inselbergs (%)	Area (%)
Granitic and granodiorite rocks	515	64.86	70.81
Volcanic and metavolcanic rocks	83	10.45	9.06
Meta sediments, schist, gneiss	78	9.62	7.33
Dolerite, gabbro, metagabbro	36	4.53	4.77
Quartzite	28	3.53	1.84
Basalt	21	2.65	1.88
Sedimentary and volcanic rocks	31	3.90	2.95
Other	2	0.26	1.68
Total	794	100	100