IMAGING PERIGLACIAL STRIPES USING GROUND PENETRATING RADAR AT THE 'GRIM' TRAINING SITE, GRIME'S GRAVES, BRECKLAND, NORFOLK

Steve Boreham and Christopher J. Rolfe*

Department of Geography, University of Cambridge,
Downing Place, Cambridge CB2 3EN
*e-mail: sb139@cam.ac.uk

ABSTRACT

The geological structure of periglacial patterned ground made visible by heather 'tiger' stripes at the GRIM Military Training Site, Breckland, Norfolk was investigated using Ground Penetrating Radar. A tripartite deposit model comprising an upper pellet chalk, a gravelly diamicton and a lower chalk rubble, overlying bedrock Upper Chalk is proposed. Frost cracks active during the Devensian Stage appear to have allowed the diamicton to 'heave' to the surface during solifluction. Coversand has been deposited in the gullies formed by the frostcracks during the Devensian. It is the acidic coversand that supports the growth of heather and makes this site of both geological and ecological interest.

INTRODUCTION

The area known as Breckland is centred on Thetford, and covers about 1000 km^2 of East Anglia in southwest Norfolk and northwest Suffolk. It one of the driest areas in England, with an annual precipitation of around 530 mm; its climate is almost continental compared to the oceanic climate experienced over much of the British Isles. Breckland comprises an area of somewhat infertile sandy soil developed on relatively thin coversand overlying various glacial deposits and Upper Cretaceous Chalk (Holywell Nodular Chalk Formation and New Pit Chalk Formation; Moorlock et al., 2003) bedrock, which forms a plateau about 30-45 mOD. The weathered surface of the chalk bedrock is often mantled by a unit of periglacially disturbed chalk pellets in a matrix of chalk putty described

---

Bull. geol Soc. Norfolk (2016-17), **66**, 31-43.

herein as ‘pellet chalk’. Angular frost-shattered chalk clasts in contact with the rockhead often form a unit of ‘brecciated chalk’, which sometimes passes upwards into ‘pellet chalk’. The surface of the underlying weathered pellet chalk is rarely flat, and often exhibits troughs and ridges (patterned ground) that are thought to be the product of periglacial activity during the last glacial period (Devensian) (Bateman et al. 2014).

It appears that the well-rounded and well-sorted coversands, with a mean particle size of c. 175 μm, blew into Breckland from the glacial margin towards the end of the Devensian, between the Last Glacial Maximum (LGM) *c*. 18,000 years BP and the start of the Holocene c.11500 years BP (Chorley *et al*., 1966). Indeed, inland dune fields were active in Breckland not only during the last glacial period, but from mid-Holocene times onwards (Bateman & Godby, 2004).

During the Devensian, the proximity of the North Sea ice sheet at Hunstanton on the present Norfolk coast would have brought intense periglacial activity to Breckland, leading to brecciation of Chalk bedrock, and heaving of the permafrost active layer resulting in the formation of patterned ground (polygons and stripes) (Nicholson 1976; Ballantyne & Harris 1994). The Breckland coversand is of variable thickness, and analyses by the authors show that the sandy soils formed upon it have pH values that vary from >pH 8 where influenced by cryoturbated pellet chalk, to <pH 4 where developed on deep coversand. Today much of the region is dominated by commercial forestry, but in un-forested localities such as Military Training Areas, deeper patches of coversand usually support heather (*Calluna vulgaris*) and acid tolerant grassland. However, in closely adjacent areas with brecciated pellet chalk close to the surface, bio-diverse calcareous grassland is supported (Watt *et al*. 1966). The flora and vegetation patterns of this heathland can vary over small distances (<10 m) as a consequence of these diverse soil characteristics. Lowland heath is one of the most threatened habitats in England. Breckland is designated as an Environmentally Sensitive Area, and contains several Sites of Special Scientific Interest (Marrs & Britton, 2000).

STUDY SITE

The GRIM Military Training Area (a Danger Area with severely restricted access due to the possible presence of unexploded munitions), exhibits closely juxtaposed acid heath and calcareous grassland (c. 30 – c. 20 mOD) arranged in ‘tiger’ stripes extending down

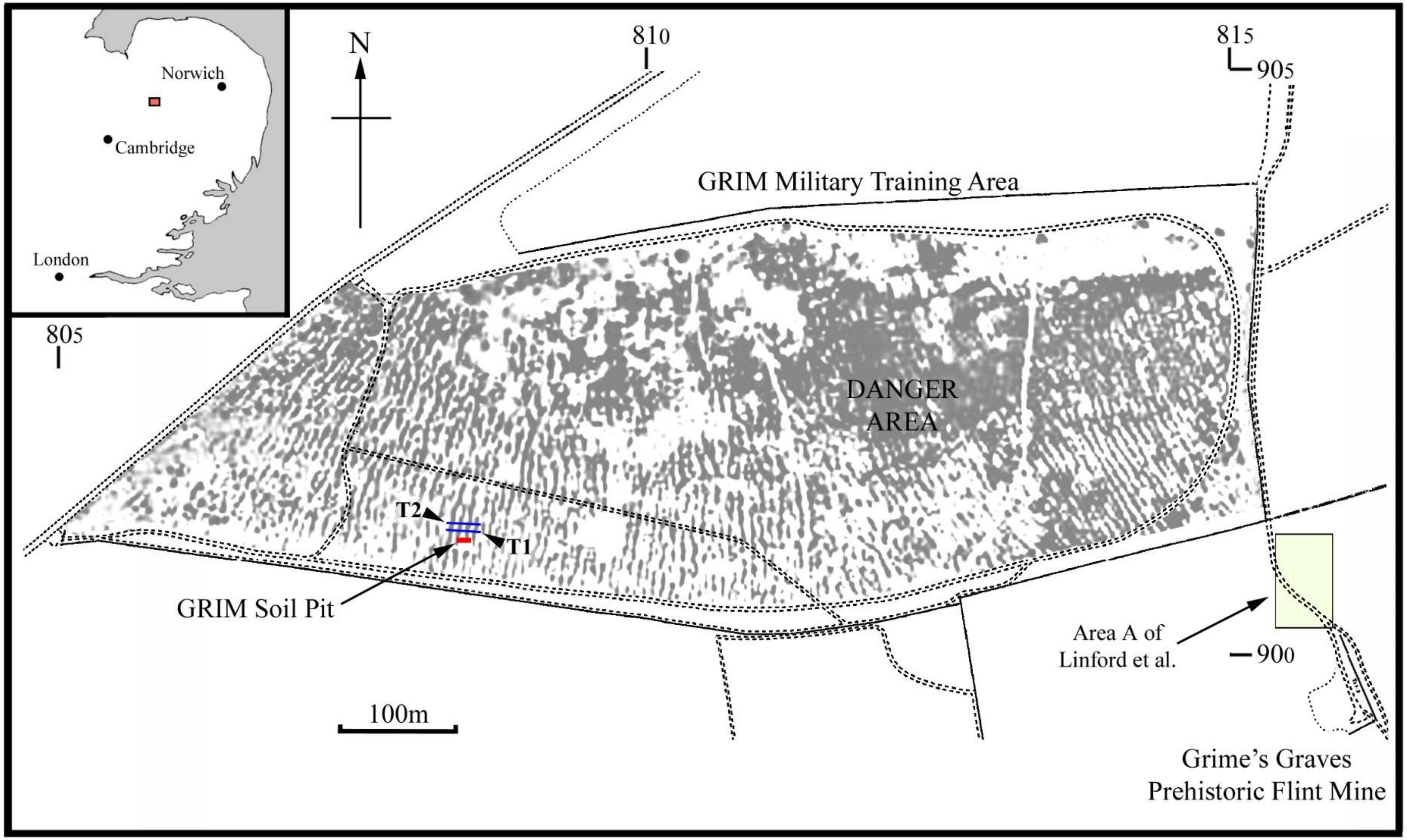

Fig. 1. GRIM Military Training Area showing distribution of heather stripes from aerial photography, location of the GRIM Soil Pit and GPR transects (T1 & T2). The location of the Grime's Graves Prehistoric Flint Mine is also shown with the position of 'Area A' from the GPR survey of Linford *et al*. (2009). Aerial image © Cambridge University Collection of Aerial Photography.

a gentle slope (2-3º) towards the floor of a small dry valley opposite the Grime's Graves Prehistoric Flint Mine (see Fig. 1). The vegetation stripes closely follow periglacial patterned ground, a section through which is visible at the GRIM Soil Pit (NGR TL 80845 90105; Fig. 2). A description of the sediments exposed in the soil pit section is shown in Figure 3. Although red/brown coversand can be clearly seen to rest in a gully between flanks of contorted brecciated pellet chalk, it is underlain by a brown diamicton comprising contorted gravel, sand and pellet chalk. Boreholes by the authors along the heather stripes have shown that coversand is rarely deeper than c.1 m, and that pellet chalk is usually encountered after only c. 30 cm in the intervening grassy swards. Large flints, often vertically aligned, often occur associated with the coversand. The nature of these and other periglacial stripes has been the subject of investigation and debate over many years.

Fig. 2. Field photograph of the GRIM Soil Pit looking NE, showing the position of a heather stripe above a gully filled by coversand and flanked by brecciated pellet chalk.

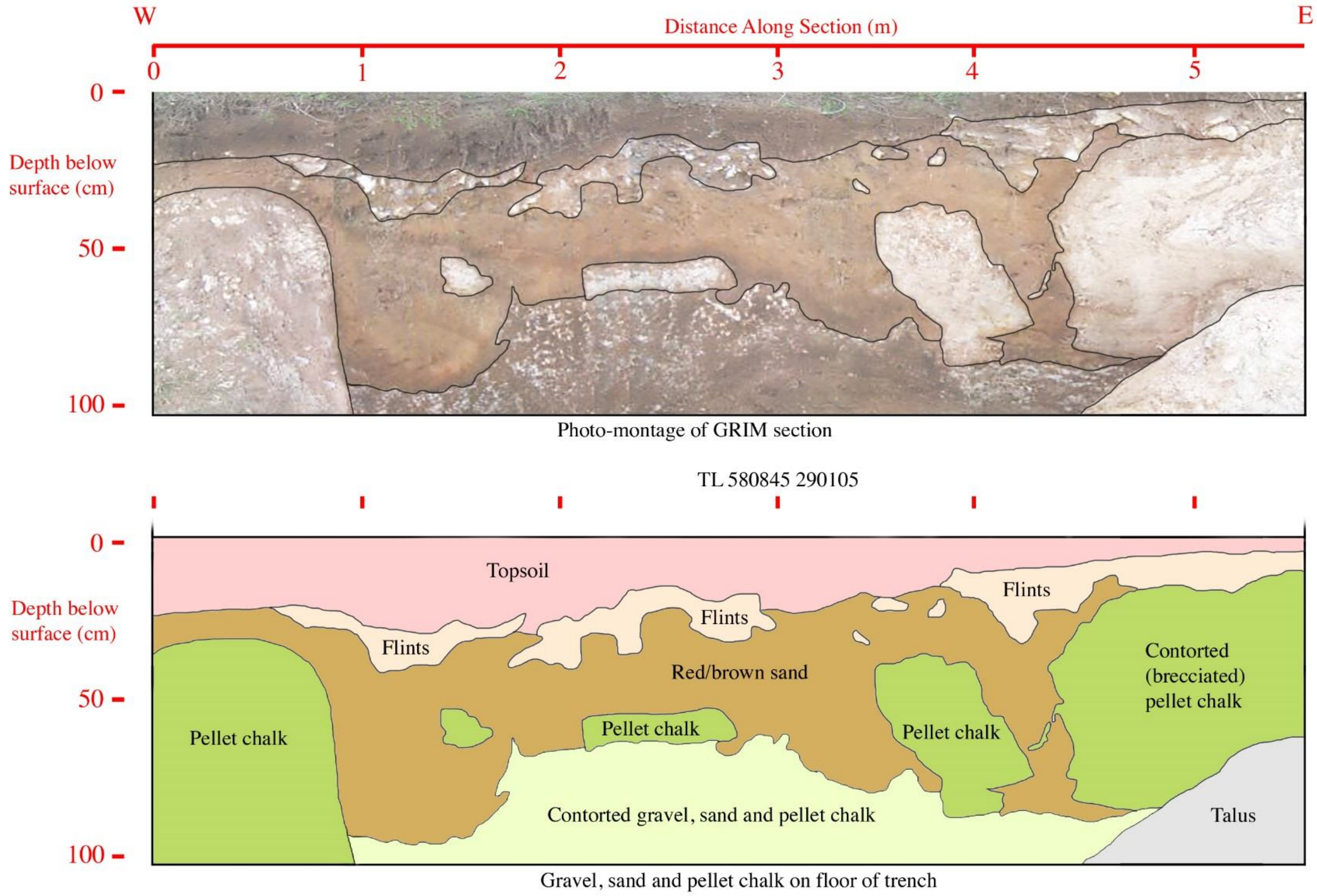

Fig. 3. Field photograph of the GRIM Soil Pit section and description of the exposed sediments.

Table 1. Radar surfaces and facies identified in this study and their interpretation.

	Description	*Interpretation*
Radar facies RF5	Moderate to high amplitude, planar, sub-parallel, continuous reflectors, truncated by RS4	Topsoil and regolith with flints
Radar surface RS4	Sub-horizontal, gently undulating surface	Unconformity
Radar facies RF4	Low amplitude, horizontal and dipping fragmented or discontinuous reflectors, truncated by RS3	Periglacially disturbed pellet (brecciated) chalk and/or coversand
Radar surface RS3	Sub-horizontal, complex sinuous, wavy or inverted, undulating surface	Unconformity
Radar facies RF3	Moderate to high amplitude, sub-horizontal, dipping, sub-parallel, sometimes discontinuous reflectors, truncated by RS2	Contorted gravel, sand and pellet chalk - diamicton
Radar surface RS2	Sub-horizontal complex sinuous or wavy, undulating surface	Unconformity
Radar facies RF2	Low amplitude, horizontal and dipping fragmented or discontinuous reflectors, truncated by RS1	Periglacially disturbed (brecciated) chalk rubble
Radar surface RS1	Sub-horizontal sinuous or wavy, undulating surface	Bedrock surface (rockhead)
Radar facies RF1	Medium to high amplitude, sub-parallel horizontal and dipping, continuous and discontinuous reflectors	Chalk bedrock

GROUND PENETRATING RADAR

The internal structure of the periglacial stripes immediately upslope of the GRIM Soil Pit has been investigated using a ground-penetrating radar (GPR) GSSI 200 MHz shielded antennae (Annan & Davis, 1976 and Davis & Annan, 1989), which offers acceptable depth penetration and excellent acuity. The GPR data has been truthed and interpreted using hand-augered boreholes. The location and altitude of the two GPR transects (T1 & T2) were determined using a Leica GNSS SmartNet system. The GPR transects presented here show the architecture of deposits associated with the periglacial landforms (Figs 4 & 5). An average relative dielectric value (er) of 8, used for initial depth conversion, was estimated from the literature (Davis & Annan 1989; Hänninen 1991; Neal 2004). Post-processing of raw data was accomplished using Radan software. The radar stratigraphy here is based on the recognition and interpretation of radar surfaces (bounding surfaces) and radar facies (bed assemblages). Five radar facies (RF1-RF5) and four radar surfaces have been identified (RS1-RS4). The radar facies are summarised in Table 1.

Figures 4 and 5 both show c. 30 m long GPR transects (T1 & T2) about 5 m apart, each crossing four heather stripes. The plots show that the area between the stripes is composed of periglacially disturbed brecciated chalk (RF4). Note that the coversand in the gullies cannot be easily differentiated by the GPR and thus must have a similar dielectric value to the surrounding pellet chalk. Beneath each stripe is a column of diamicton, comprising gravel, sand and pellet chalk (RF3). Note that this material extends down to c. 2 m depth where it joins laterally to form a stratum that underlies the upper pellet chalk. Beneath this is a separate body of material interpreted here as brecciated chalk rubble (RF2). Although this material lies in contact with the bedrock chalk (RF1) with a rockhead at 3.5- 4.5 m, it is punctuated in places by the overlying columns of gravelly diamicton (RF3).

DISCUSSION

In 2007 Ground Penetrating Radar investigations took place at Grime's Graves Prehistoric Flint Mine (Linford et al. 2009). The area of study was opposite the GRIM Military Training Area (see Figure 1), and although mainly directed at discovering hidden archaeology, some details of periglacial features were also uncovered. The 2007 GPR investigation showed the Chalk rockhead to be present at between 1 and 3 m depth, sometimes with regularly spaced deeper areas. In the present study at GRIM there is superficial coincidence between slightly higher points on the chalk bedrock reflector and the heather stripes (Figs 4 and 5). This is almost certainly caused by periglacial heaving beneath each column of diamicton. Boreholes at Grime's Graves in 2007 discovered a

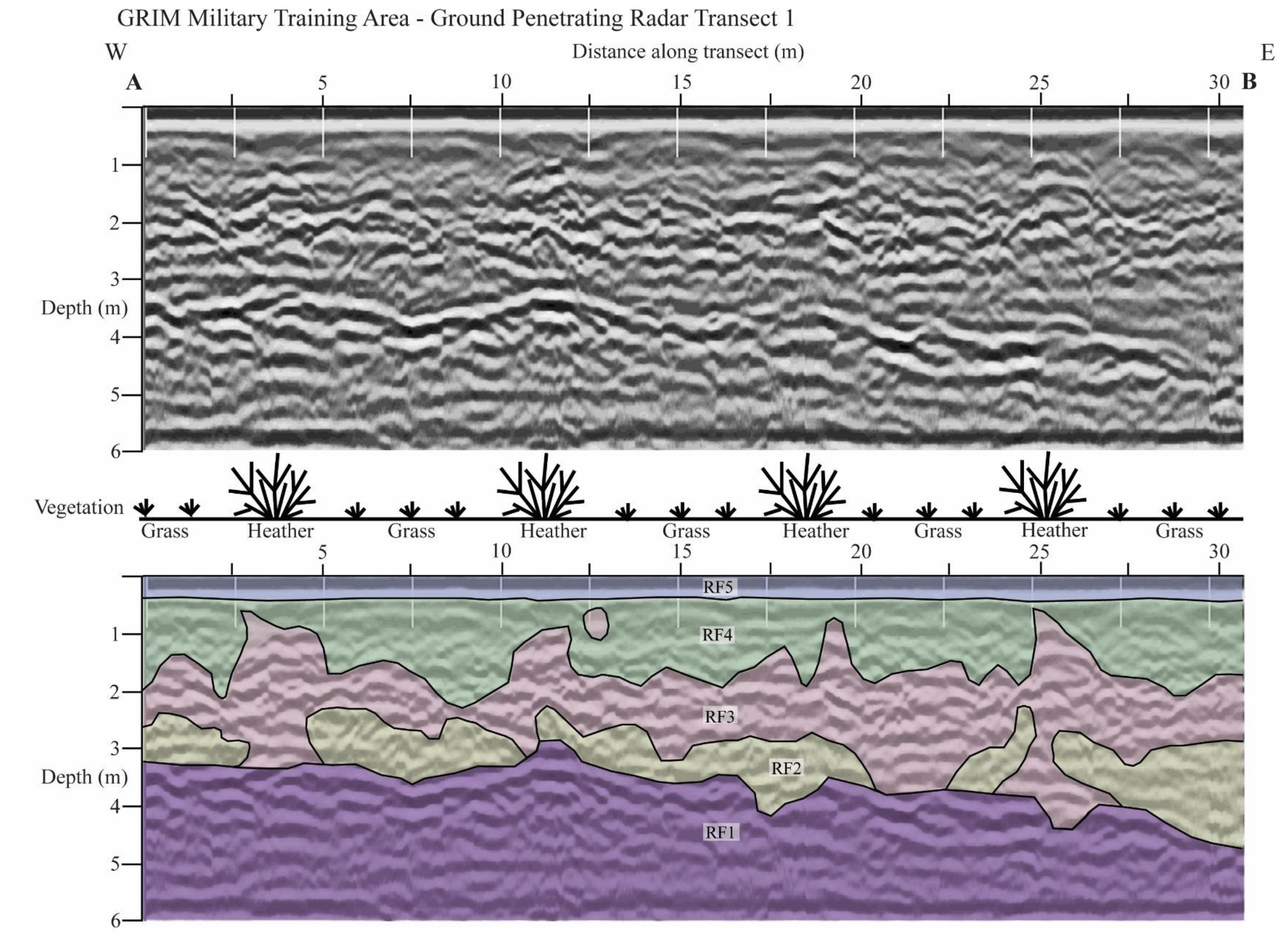

Fig. 4. Ground Penetrating Radar plot for transect T1 showing interpretation of the reflectors and the position of heather stripes.

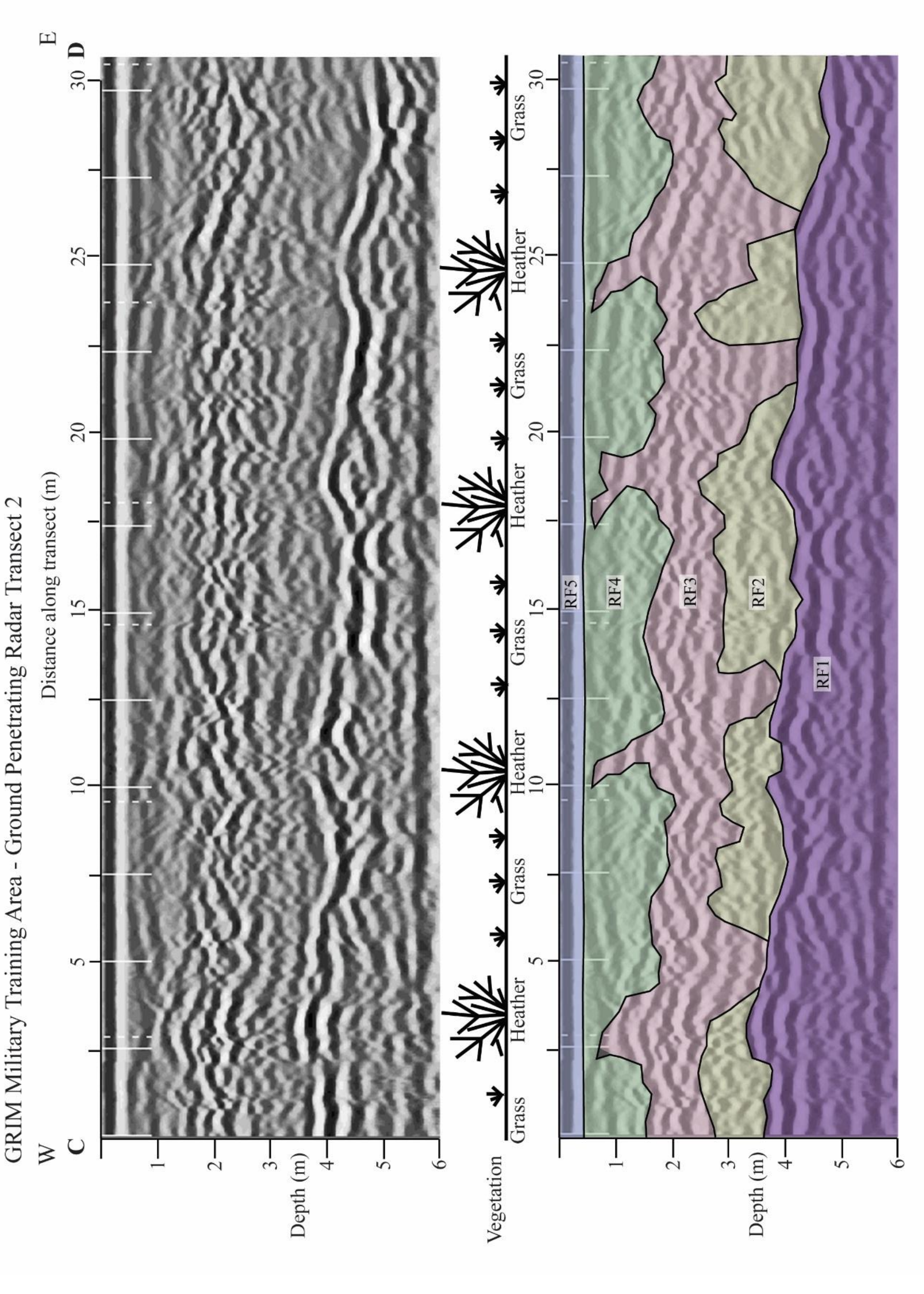

Fig. 5. Ground Penetrating Radar plot for transect T2 showing interpretation of the reflectors and the position of heather stripes.

sequence of chalk rubble and sand more than a metre thick, resting on Chalk bedrock at c. 2.5 m depth. Above this was a stratum (c. 40 cm thick) of brecciated pellet chalk, in turn overlain by c. 50 cm of coversand and finally thin topsoil. Although this sequence seems superficially similar to that at the GRIM Military Training Ground, it appears that there is an absence of gravelly diamicton at this site between the basal chalk rubble and the overlying pellet chalk. The block sections of Breckland stone stripes created by Nicholson (1976), and reproduced in Ballantyne & Harris (1994; p.97 fig 6.15) closely represents the situation seen at Grime’s Graves. In contrast, several sites in Breckland with periglacial stripes and OSL dated by Bateman et al. (2014) were formed by coversand overlying a chalk diamicton. This seems to suggest a far simpler genesis of periglacial features, and indeed Bateman et al. (ibid) conclude that these features resulted from repeated periglacial activity within the Devensian Stage.

A summary interpretation of the GPR reflectors and deposits beneath heather stripes at the GRIM Military Training Area is shown in Figure 6. The heather stripes at the GRIM Military Training Site appear to be closely associated with c. 1 m thick accumulations of acidic (<pH 4.5) coversand that occupy deep gullies developed in frost cracks on top of heaved columns of gravelly diamicton extending down 3 – 4 m to the Chalk bedrock. Note that the frost cracks aligned with the heather stripes appear to have allowed the gravelly diamict to ‘heave’ or ‘boil’ to the surface between ‘rafts’ of upper pellet chalk. There do not seem to be ice wedge casts associated with the frost cracks. The tripartite nature of the deposits overlying the Chalk implies that solifluction must have brought regolith material with different compositions into the area at different times. This strongly implies a polycyclic origin for the chalk rubble, pellet chalk and the intervening gravelly diamicton, either within the Devensian Stage, or potentially encompassing several Pleistocene glacial periods. The basal brecciated chalk rubble must presumably be the product of the original sub-aerial exposure of the Chalk bedrock to periglacial conditions. The overlying gravelly diamicton must have come from a source upslope to the north. It appears to comprise an admixture of flints, coversand and pellet chalk. The upper pellet chalk must also come from a location upslope, presumably from an exposure of Chalk bedrock.

During the last glacial period, the periglacial regolith at the GRIM training site must have been progressing down the low-angle slope through repeated cycles of

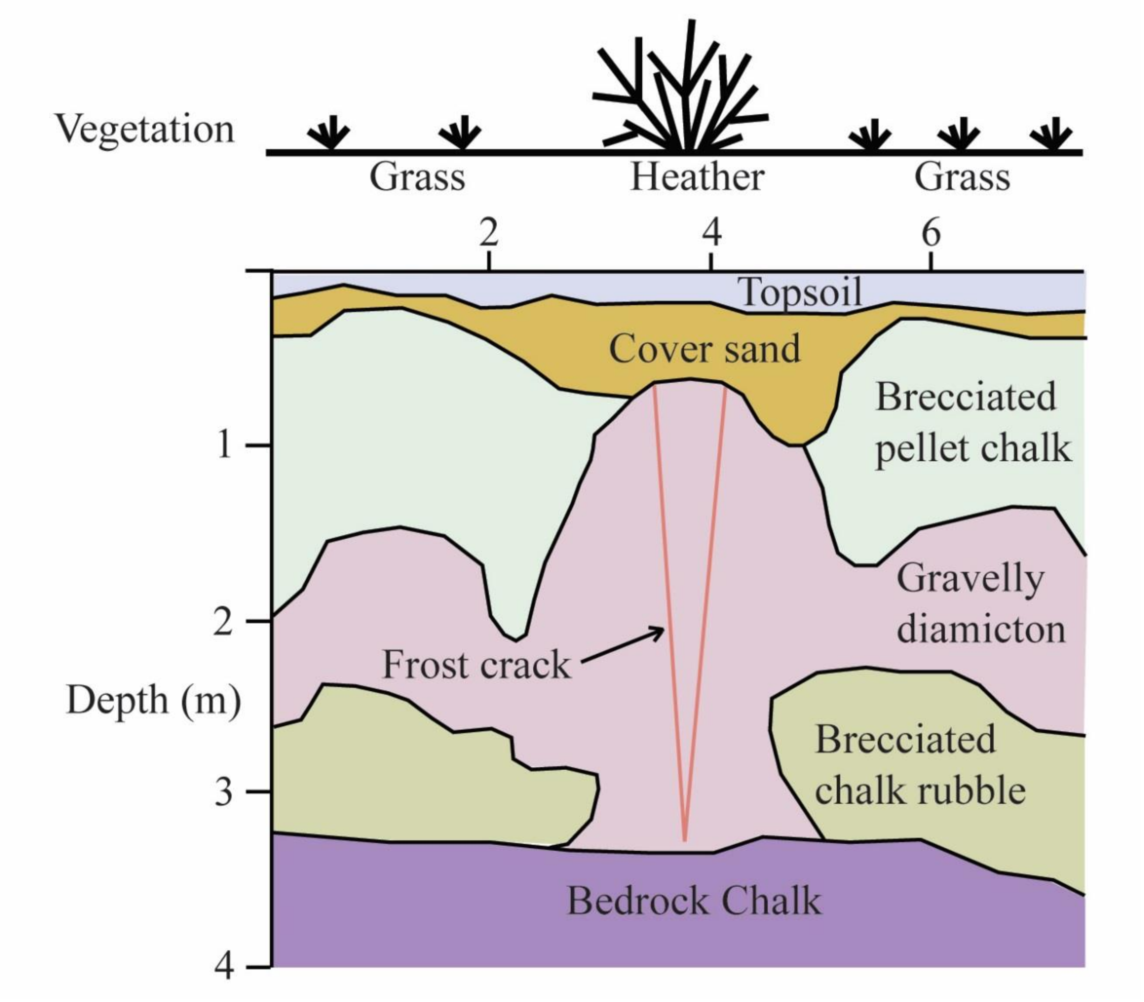

Fig. 6. Summary interpretation of the GPR reflectors and deposits beneath heather stripes at the GRIM Military Training Area.

freezing and thawing, rather like a slow-moving conveyor belt. Polygonal frost cracks appear to have been elongated by the down-slope movement of the regolith to form a ‘stretched reticulum’ and ultimately the ‘tiger stripes’ that we see today. Coversand must have been deposited into the gullies formed by the frost cracks as aeolian sediment and potentially reworked by colluvial processes. It seems likely that drainage was once active in the small valley at the foot of the slope in order to remove the regolith material delivered by solifluction processes.

In this study, a combination of boreholes, sediment descriptions from the GRIM Soil Pit and Ground Penetrating Radar have been used to image and understand complex periglacial structures beneath heather stripes that form above gullies filled by coversand.

The impetus to publish this short account was the perceived fragility of the site. The delicate nature of the heather stripes is maintained by carefully managed grazing, but the constant issue of encroachment by both scrub and bracken threatens to obscure these once impressive features. The GRIM Soil Pit is also becoming overgrown and degraded. However, the periglacial features at GRIM have survived the entire Holocene with its attendant changes in climate and vegetation, and they will undoubtedly continue to offer geological and ecological interest for those lucky enough to visit them. Access to the GRIM Military Training Site is tightly controlled, being a Danger Area, with the possibility of unexploded munitions. Today, the heather stripes are best viewed by looking north from the Grimes Graves Prehistoric Flint Mine.

ACKNOWLEDGEMENTS

The authors wish to thank military personnel at the STANTA Training Area for providing access to the GRIM Military Training Area, and also thank Prof Richard West for his help and advice with the manuscript. Figure 1 was created using an Ordnance Survey data licence and contains Ordnance Survey data © Crown copyright and database 2016.

REFERENCES

ANNAN, A. P. & DAVIS, J. L. 1976. Impulse radar sounding in permafrost. *Radio Science*, **11**, 383-394.

BALLANTYNE, C.K. & HARRIS, C. 1994. The Periglaciation of Great Britain, Cambridge University Press, Cambridge.

BATEMAN, M. D. 1995. Thermoluminescence dating of British coversand deposits *Quaternary Science Reviews*, 14, 791-798.

BATEMAN, M. D. & GODBY, S. 2004. Late-Holocene inland dune activity in the UK: a case study from Breckland, East Anglia. *The Holocene*, 14, 579-588.

BATEMAN, M. D., HITCHES, S., MURTON, J. B., LEE, J. R & GIBBARD, P. L. 2014. *The evolution of periglacial patterned ground in East Anglia, UK.* Journal of Quaternary Science, 29 (4). pp. 301-317.

CHORLEY, R.J., STODDART, D.R., HAGGETT, P. & SLAYMAKER, H.O. 1966. Regional and local components in the aerial distribution of surface sand facies in the Breckland, *Journal of Sedimentary Petrology*, **36**, 209-220.

DAVIS, J. L. & ANNAN, A. P. 1989. Ground-penetrating radar for high resolution mapping of soil and rock stratigraphy. *Geophysical Prospecting*, **37**, 531–551.

HÄNNINEN, P. 1991. Maatutkaluotaus maaperä geologisissa tutkimuksissa. 23 Tutkimusraportti 103, Geologinen Tutkimuskeskus (Espoo), 37 pp.

LINFORD, N., MARTIN, L. & HOLMES, J. 2009. Grimes Graves, Norfolk. Report on Geophysical Survey October 2007. English Heritage Research Department Report Series No. **64**-2009.

MARRS, R. & BRITTON, A. 2000. Conservation problems on Breckland heaths: from theory to practice *Biological* Conservation, **95**, 143-151.

MOORLOCK, B. S. P., BOREHAM, S., WOODS, M. A. & SUMBLER, M. G. 2003. Geology of the Saffron Walden district. British Geological Survey. NERC.

NEAL, A., 2004. Ground-penetrating radar and its use in sedimentology: principles, problems and progress. *Earth Science Reviews*, **66**, 261-330.

NICHOLSON, F. H. 1976. Patterned ground formation and description as suggested by low arctic and subarctic examples. *Arctic and Alpine Research*, **8**, 329-342.

WATT, A. S., PERRIN, R. M. S. & WEST, R. G. 1966. Patterned ground in Breckland - structure and composition. *Journal of Ecology*, **54**, 239-258.

[Manuscript received 8 December 2016; revision accepted 9 January 2017]

BACK ISSUES OF THE BULLETIN OF THE GEOLOGICAL SOCIETY

OF NORFOLK AND 50th JUBILEE VOLUME

The Geological Society of Norfolk (GSN) has back issues of the Bulletin available for purchase as outlined below. The Bulletin may not be easily available at some institutions - except through Inter-Library Loan – so individuals might consider a recommendation for purchase by institution libraries.

At present we can supply all issues except volumes 19, 32 and 42. Volumes 23, 27 and 28 are in short supply (less than 10 remaining). Volumes 1-10 and 11-18 are only available as reprint volumes 38A and 39A.

There are plenty of copies of the now famous 'East Anglian Geology' issue, volume 34.

Back issues of the Bulletin are available at £3-50 per issue to GSN members and £10-00 per issue to non-members. For purchase of two or more issues it is cheaper for non-members to join the society (£10-00 per year) and buy at member price.

In addition, the society published a special Jubilee volume (edited by Roger Dixon) to commemorate its 50th anniversary. This volume is dedicated to Prof. Brian Funnell and contains a number of articles about Prof. Funnell, his research and the early days of the Society. The Jubilee Volume is free to GSN members. The remainder are available at cost (£8-50).

If you would like to place an order please discuss your requirements with Julian Andrews at UEA, preferably on the following e-mail address: j.andrews@uea.ac.uk

Or by post to: Prof. Julian Andrews, School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ.