ENGINEERING GEOMORPHOLOGICAL MAPPING OF THE UPPER GREENSAND ESCARPMENT NEAR HONITON, DEVON.

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Engineering geomorphological mapping has being used quite extensively as a reconnaissance technique in preliminary site investigations in the UK for over 20 years. The technique is particularly suitable for investigating route corridors for roads, railways and pipelines when potential hazards to alignments can be identified very early in the design process and minor alternations to alignments can be made without significant cost implications. In this paper an engineering geomorphological map of the Upper Greensand escarpment north of Honiton is presented that follows the alignment of the existing single carriageway of the A30 trunk road. The map forms the basis for an engineering hazard interpretation that highlights the extensive and varied nature of the instability along the escarpment that has developed in both unconsolidated head deposits and the weakly cemented sandstones and calcareous mudstones that make up the scarp slope. The extent of the instability suggests that detailed landslide treatment measures will be needed in any future road improvements for this area. Geomorphological maps often form the basis of qualitative landslide hazard maps that are now being used quite widely as a planning tool. These constitute part of the suite of applied and environmental earth science maps that present a much broader range of information than the more widely recognised bedrock and drift geology maps, and are now an important part of development planning in the United Kingdom.

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INTRODUCTION

Smith & Ellison (1999) present a review of UK examples of applied geological mapping for planning and development. Their review provides examples of good practice and illustrates the way a range of earth science information, beyond just bedrock and drift geology, can be compiled to guide and inform planning development decisions. Most applied geological mapping studies in the UK were initiated by the former Department of the Environment and carried out at scales between 1:10,000 and 1:50,000. Maps at this scale, whilst ideal for planning development, are too small for the actual design of ground investigations and engineering works and more detailed larger-scale reconnaissance maps are needed for the investigation of route corridors for roads, railways and pipelines. In these situations identifying potential hazards early in the design process allows minor alternations to alignments to be made without significant cost implications. A mapping technique that has found widespread application over the past 20 years for hazard identification is engineering geomorphological mapping. Examples of the use of the technique for engineering projects both in the UK and overseas are well documented (Brunsden, 1998/9; Doornkamp, 1994; Griffiths *et al*, 1995). In this paper an application of engineering geomorphological mapping linked to a hazard assessment is provided for a section of the Greensand Escarpment in East Devon near Honiton.

THE STUDY AREA

Location and Topography

The study area lies to the north-east of Honiton covering an area of approximately 6 km^2, and follows the alignment of the present A30 Trunk Road. The area represents a section of the middle part of the River Otter valley that rises in the Blackdown Hills and discharges on the south Devon coast near Budleigh Salterton. The study area is centred on the village of Monkton (figure 1). Along the southern part of the valley the present A30 Trunk Road is located on a river terrace just above the contemporary floodplain of the River Otter. Approximately 1 km northeast of Monkton the Trunk Road climbs some 50 metres up an escarpment at Reddicks Hill in cut-and-fill earthworks over sidelong ground to emerge on top of a flat plateau.

Geology and Geomorphology

The bedrock geology of the area is relatively straightforward. Forming the base of the exposed sequence is the Triassic Mercia Mudstone Group. These are predominantly red mudstones with a few local sandstones and some evaporites, consistent with semiarid sedimentation in ephemeral lakes (Durrance & Laming, 1985).

According to the British Geological Survey map, the study area appears to be beyond the western limit of the Upper Cretaceous Gault Clay. The interpretation of the geology based on the existing geological mapping indicates, therefore, that unconformably overlying the Mercia Mudstone Group is the Cretaceous (Albian) 'Blackdown facies of the Upper Greensand' (Edmonds *et al*, 1985). However, the occurrence of the Gault Clay in the eastern portal of the Honiton tunnel suggests that the Gault Clay could lie close to the eastern side of the River Otter valley and may actually be found in some localities separating the Greensand from the mudstones. The Upper Greensand is described as a 30metre + sequence of decalcified sands with layers of cherry sandstone concretions (Treisise, 1960, 1961; Taylor *et al* 1983). A detailed sedimentological and biostratigraphic description of a temporary exposure of the Blackdown Greensand in the Blackdown Hills approximately 15 kms north of the study area is provided by Woods & Jones (1996). On the basis of the sedimentological and faunal evidence they infer that the material was deposited as a shallow-marine sand-bar complex that was influenced by weak tides and periodic storms.

The superficial geology comprises clay-with-flints, river terraces, head deposits, landslide debris and alluvium. The oldest of the superficial deposits is the 'clay-with-flints' and cherts that cap the surface of the Upper Greensand plateau. This is a brown or red-brown clay or sandy clay with flint and chert fragments. The widely accepted interpretation, that this is a Tertiary residual deposit left after erosion of the overlying Chalk, has been questioned in recent years (Wilson, 1995). In a study of these deposits in the Sidmouth area, Issac (1979) recognised two unconsolidated deposits overlying the Upper Greensand. The lower unit (Peak Hill Gravel), Issac (op.cit.) regarded as a residual deposit produced by the lateritic weathering of Chalk during the semi-arid condition in the Tertiary. The thicker succeeding unit (Mutters Moor Gravel), contains a lateritic weathering profile at the base and a silcrete horizon, that Issac (op. cit.) described as typical of arid and semi-arid weathering conditions. Durrance & Laming (1985), however, note that the Mutters Moor Gravel is believed to be early Pleistocene in age, a period when climatic conditions would have been deteriorating prior to the onset of full glacial periods. In the study area the clay-with-flints have not been investigated in detail and the general consensus, as indicated on the BGS geological map, is that they are Eocene in age.

Although not indicated on the BGS geological maps of the area, the valley-side slopes have been disturbed by mass movement processes. These mass movements are of two main forms, those that have affected the bedrock of the Greensand and Mercia Mudstones, and those associated with the superficial head deposits. The bedrock failures will have created landslide debris made up of mixed Greensand and Mercia Mudstone blocks and fragments. The age of the landslide debris is not known. The head cover can be detected on the mid- and lower valley-side slopes where there are clearly defined lobate features in the landscape indicative of solifluction or gelifluction. These head deposits comprise reworked sands and clays with chert gravel and cobbles. South of Honiton (ST 162006), head is described as ovelying an interglacial deposit containing extensive mammalian remains that have been dated as Ipswichian (Turner, 1975). The head, therefore, appears to be fairly ubiquitous and it is likely to be of Devensian age.

Above the contemporary floodplain well-developed river terraces are located in a number of places, and such terraces can be found throughout the River Otter catchment (Gregory, 1971). These terraces typically comprise rounded gravels and cobbles although they can be rich in fines. The ages of the terraces have not been ascertained with any accuracy and their relationship with the Devensian head deposits is uncertain. The difficulties in ascribing origin and age to river terraces is addressed by Goudie (1990) but there is increasing evidence to suggest these features are a result of periglacial conditions and, therefore, in the Otter valley they are also likely to be Devensian in age.

The River Otter meanders across a contemporary alluvial flood plain that has been subject to extensive flooding on a number of occasions over the past thirty years. The depth of the alluvial infill within the flood plain is not known although a buried valley that graded down to a lower interglacial sea level would be suspected. The nature of the alluvium is very variable and ranges from 2-3 metres of silty clay to lenses of well-rounded gravels and cobbles.

ENGINEERING GEOMORPHOLOGICAL MAPPING

The Technique

Doornkamp, (1994) states that the technique of geomorphological mapping requires considerable understanding of:

- the theories of landform evolution;
- the history of landscape development
- the nature of the historic and dynamic land-forming processes;
- the nature of landscape modification which has been brought about throughout the period of human occupancy;
- the role of underlying bedrock and soil materials in landform creation.

There are two stages in the production of a geomorphological map: the initial factual mapping of surface morphology, and the subsequent interpretation of morphology in terms of geomorphological processes and landforms. The conversion from the initial morphological mapping to showing an interpretation of the genetic, dynamic and temporal related elements of landforms involves a subjective process that is heavily dependent on the skill and experience of the mapper. The next stage requires the geomorphological map to be adapted to meet the specific needs of the civil engineering industry. The technique of engineering geomorphological mapping is well-documented (Griffiths & Hearn, 1990; Cooke & Doornkamp, 1990) and is now recognised as a legitimate part of ground investigation practice in civil engineering. Griffiths & Marsh (1986) present an example of such mapping in a preliminary site investigation for the Axminster By-pass in East Devon.

Hazard Assessment

The geomorphological map of the study area is presented in figure 1. A close relationship between the bedrock geology and topography can be seen with the scarp slopes developed in the Upper Greensand contrasting with the flatter valley side slopes developed in the Mercia Mudstones. The flattest land is associated with the alluvial infilled River Otter flood plain, the river terraces and the higher level plateau surface developed in the Greensand overlain by clay-with-flints.

From an engineering perspective there are a number of natural hazards that need to be taken into account and these are summarised in Table 1. Probably the most important are the range of landslides that have formed in the upper parts of the valleyside slopes developed primarily in the Mercia Mudstones. In general there appears to be widespread undulating ground, often with well-defined lobate distal limits, indicative of shallow solifluction mass movements associated with periglacial conditions (i.e gelifluction). These features are composed of the reworked clay-with-flints, unconsolidated sands and mudstones that constitute the head deposits in this area. In addition to the ubiquitous solifluction sheets, in the upper parts of the slope there are some later less extensive mass movement features that appear to rework some of the head deposits although probably also involve the in situ Mercia Mudstones. Interestingly the Mercia Mudstone is not a stratigraphic sequence with a high incidence of failures and the normal density on this sequence is 3.9/100km^2 (Jones & Lee, 1994)

In addition to the shallow solifluction failures, at Reddicks Hill there is evidence of deeper-seated landslide movements, possibly of a multiple rotational form, involving the full height of the scarp slope, and, therefore, involving both the Upper Greensand and the Mercia Mudstone bedrock. At one point the existing A30 has suffered damage associated with movements in these landslides. These larger scale movements can be traced north of the study area where, in places, the debris runout has reached down almost to the contemporary floodplain of the River Otter. Although not identified to date, it is possible that the Gault Clay may subcrop in the vicinity of these deeper-seated failures, to account for their extent and location, but it has been obscured by landslide debris. Elsewhere in the UK, large-scale landsliding has often been associated with the outcrop of the Gault Clay and the combination of Upper Greensand overlying Gault Clay has a landslide density in the UK of 14.6/100km^2 (Jones & Lee, 1994).

Jones *et al* (1988) note that the work of Fakhraee (1979) and Wison *et al* (1958) identified the East Devon, West Dorset and South Somerset plateau as having a high incidence of landsliding. As a result valley-side slopes in this region mantled by degraded landslide should be regarded as a hazard to all forms of construction. This was identified by Conway & Denness (1972), in relation to a new building development in Lyme Regis, and by Griffiths & Marsh (1986) during the planning for the recently constructed A35 Axminister By-pass. From an engineering perspective the presence of pre-existing failures along the scarp slope in the study area constitutes a significant engineering problem. Any upgrades to the existing A30 that crossed these failures would have to incorporate foundation designs that allowed for residual strengths in the deposits. Typical values of for the Mercia Mudstone are 18-30° (Chandler, 1969), although it is important to note that the existing slopes in the head deposits and Mercia Mudstones are usually less than

Geomorphological Unit	Natural Hazard
Plateau developed in Upper Greensand overlain by variable cover of Clay-with-Flints	Variable depth to suitable foundations
Scarp slope developed in Upper Greensand	Shallow slumping, sand runs and rilling in the weathered upper zone of the weakly cemented sandstone
Valley-side slopes developed in Upper Greensand overlying Mercia Mudstones (or possibly Gault Clay)	Deep-seated landslides in state of marginal stability with well-defined shear surfaces
Valley-side slopes developed in head deposits overlying Mercia Mudstone	Widespread shallow solifluction features possibly with identifiable shear surfaces
Valley-side slopes developed in Mercia Mudstones	Variable depth of weathering and possibility of periglacial disturbance including the development of fossil frost wedges
River terraces	Possible periglacial disturbance
River Otter floodplain	High flood risk; depth of soft alluvial infill unknown; possibility of a buried valley

Table 1. *Natural hazards in the study area*

usually less than 10°, implying that the slope failures must have occurred under conditions of high pore-water pressures. However, should the Gault Clay be identified in the area, particularly in the vicinity of Reddicks Hill, then the design parameters will be significantly different as Hutchinson (1969) gives Ø'$_r$ values for the Gault Clay of 12° and lower values have been postulated.

Apart from the hazards associated with instability, the other natural hazards in the area are:

- the possibility of flooding in the River Otter valley;
- the possibility of a buried channel in the floor of the river valley that might affect the design of any bridge foundations;
- soil erosion and rilling in the weathered areas of Upper Greensand;
- general periglacial disturbance in the valleyside slopes developed in the Mercia Mudstone and the river terrace gravels.
- possibility of deep weathering zones in the Mercia Mudstone
- with significant reductions in undrained shear strength (Marsland, 1977) and modulus of elasticity (Davis, 1971).

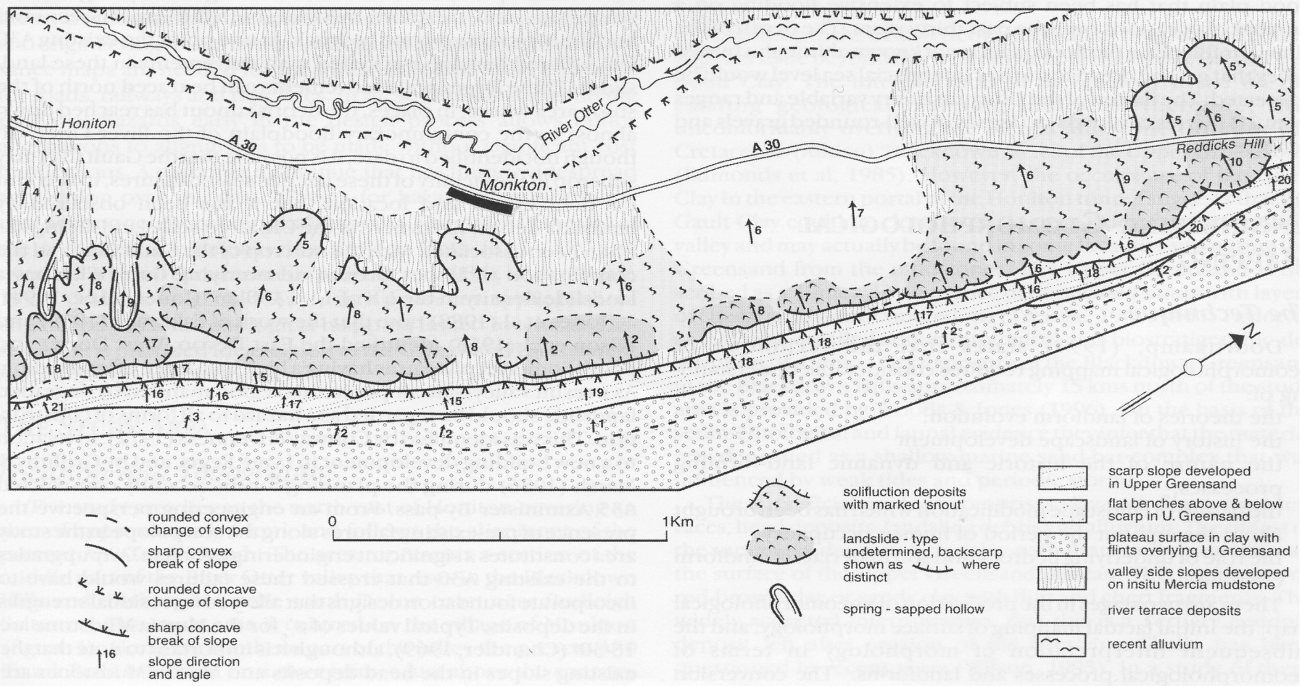
These are standard ground condition issues that can be dealt with during design. They do, however, need detailed desk studies and careful ground investigation to ascertain the nature and extent of the problems.

CONCLUSIONS

In the UK engineering geomorphological mapping was developed during the 1970's initially for preliminary studies of road alignments in South Wales and Nepal (Brunsden *et al*, 1975) and represented a subset of the general field of geotechnical mapping for engineering

Figure 1

Geomorphological Map of the Upper Greensand Escarpment, north of Honiton, East Devon



purposes (Clark & Johnson, 1975). Since then, its history of application has been rather varied (Griffiths & Hearn, 1990), although some of the detailed work undertaken by Hearn (1995, 1997) for the mining industry and mountain roads has demonstrated both its cost-effectiveness and enormous potential. The technique provides an excellent reconnaissance tool giving both guidance for the alignment of linear constructions and the framework for designing and interpreting site investigations.

The engineering geomorphological mapping of the Upper Greensand/Mercia Mudstone escarpment north of Honiton identified a number of potential hazards to any engineering works in the area, in particular the widespread occurrence of shallow mass movement features. In addition, mapping of larger-scale mass movements, of a type found elsewhere in the UK when the Upper Greensand overlies Gault Clay, suggested there was a possibility that the Gault Clay may subcrop further west than presently thought but is obscured by landslide debris. Such anomalies cannot be confirmed without actual ground investigations, however, the mapping can identify the best locations for exploratory holes to allow such hypotheses to be explored. Once the data from such investigations are available, the geomorphological map will allow the results from exploratory holes to be interpolated and extrapolated to allow a full three- or even four-dimensional model of the landscape to be developed. This can continue to be refined during subsequent construction works but always remains as a model against which the results of excavations can be tested to ensure any anomalies are identified and incorporated into on-site design alterations.

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