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Until fairly recently the extent of landslide activity in the central Pennines and adjacent moorland areas had not been fully appreciated. Recent resurvey work by the BGS around Huddersfield had, however, highlighted the problem. Consequently, we undertook an integrated programme of geological field mapping, aerial photograph interpretation and research into archival material in the Rossendale Forest area of East Lancashire. Photographic interpretation, carried out prior to fieldwork, enabled field

- Landslides associated with glacially over-deepened valleys.
- Landslides associated with Drift filled valleys.
- Landslides associated with faulting.

This integrated approach has identified a large number of landslides throughout the survey area, particularly in the area immediately to the north of Rochdale, Bury and Bolton, and around Todmorden in West Yorkshire. Overall,

Lancashire landslides

Integrated mapping of potential geological hazards

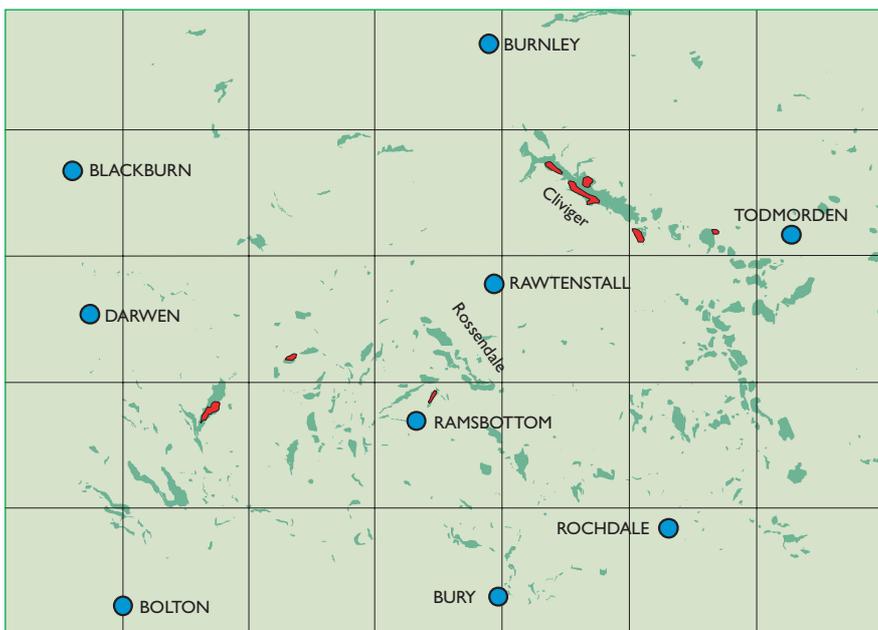
by Dick Crofts

geologists to identify target areas of landslides. Follow-up fieldwork identified additional evidence, particularly in wooded valleys, and placed the landslides in a geological context. Three major groupings of landslides were identified:

the resurvey will provide fit-for-purpose geological maps. The previous survey in the early 1920s identified only eight areas of landslide over the 600 square kilometres of the Rochdale Sheet. Following our recent survey the number of individual landslides identified has increased to over 300 (see map, *left*). The area affected by an individual slide can range enormously in scale from less than five hundred square metres to over three square kilometres. Many occur close to urban areas and may have a bearing on future development.

The majority of these landslides have occurred since the end of the last ice age some 13 000 years ago. While the majority have remained stable for over 10 000 years, reactivation may occur at any time. Landslides can be reactivated naturally as the initiating process continues to act or by the ingress of water, for example during a wet winter. Although reactivation is uncommon, it can disrupt local life as seen by the long-term closure of Calderbrook Road at Summit. Many of the landslides recognised can be classified as multiple or successive rotational slides and flows, but a significant number can be shown to be rock falls and topples.

Until about 13 000 years ago the Rochdale area was covered by up to



Map of east Lancashire indicating over three hundred individual landslides which have been identified following the recent resurvey (dark green areas). The previous survey in the early 1920s identified only eight areas of landslide over the same area (red areas). The survey was supported by archival research and the interpretation of aerial photographs.

1000 metres of ice, rather like Greenland today. As the ice melted, the pressure on the underlying rock was released while, at the same time, large volumes of water were freed. Over-steepened valleys were produced by the ice and escaping waters as, for example, in the Walsden and Rossendale valleys, and most spectacularly in Cheesden Brook and Cliviger. With the supporting ice removed, the valley sides collapsed, often quite catastrophically. Material cascaded down the steep slopes, leaving a rock scar at the highest point and a mix of sandstone and mudstone blocks in a jumbled mass to the valley floor. Many of these areas quickly stabilised and have generally not moved in the past 10 000 years.

Where the rock scar is formed of sandstone, any fractured blocks are often unstable. If the dip is into the valley, further extreme events may cause the blocks to topple into the valley. However, roads are commonly built across these areas and remain stable. In both the Cliviger and Walsden valleys, railway tunnels have been driven through the slipped material with no significant problems.

Further problems can arise where glacial meltwater channels cut across moderately steep sandstone dip slopes. The lack of support in the channel can cause 'bedding plane slides' on the upslope side of the channel. The slide may only be shallow but the area affected can be large. An impressive example of this is the Rushy Hill slide on the northern edge of Rochdale, where a 5 metre cut 500 metres long has caused an area of approximately 500 000 square metres to fail.

Other glacially deepened valleys were dammed by ice and flooded, eventually becoming filled with a complex deposit of sand and clay. As the ice retreated, the ponded water was released, initiating the erosion. Soon after, modern drainage established quickly within these valleys full of soft sediment. Examples within the area occur at Belmont, Edenfield and Rawtenstall. Down-cutting led to progressive failure of the soft sediment, as the stream eroded deeper into the fill. The slides are often complex in nature, with rotational slides and flows, the remnants of which now drape the valley as a series of lumpy mounds.

These areas potentially remain significantly unstable, not only because down-cutting may continue, but because the sediment is often saturated with water which lubricates further movement. Any interference with these areas by cutting or loading can lead to major disruption and unexpected costs. For example, a serious problem was encountered at Ewood Bridge in the upper Irwell Valley. On the west side of the valley, a housing development had to be abandoned while, on the east side, preventive measures were needed to ensure the stability of the A56 trunk road.

The Rochdale area is also affected by a number of large geological faults which are of ancient origin, being initiated more than 250 million years ago. Any movement on these faults in the past two million years will have been insignificant. However, they remain as possible lines of weakness and conduits for water movement.

During the last ice age, these faults would have been subject to pressure from the overlying ice. As the pressure was released the partially unsupported footwall often collapsed in large rotational failures. This action has initiated some of the slides in the northern part of the Cliviger Valley and, to a lesser extent, in the Naden Valley north-west of Rochdale.

As pressure builds on most of our urban areas to expand or improve their transport infrastructure, it is vitally important to consider the geological setting. An appreciation of the geology and, significantly, the recent geological history should always be taken into account during an early stage of planning new developments. Our newly released maps for north-west England will provide a much-needed modern database on which to base these decisions. ■



Landslides in the Cliviger Valley near Cornholme.



Landslides on the south side of the Rossendale Valley.

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