# THE GEOLOGY, HYDROLOGY AND STABILITY OF THE LANDSLIPS BETWEEN OTLEY AND OLD POOL BANK, WEST YORKSHIRE

by

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## I Summary

The area between the eastern side of Otley and Old Pool Bank, adjacent to the A660 main road, consists mainly of landslipped ground. The landslips are of two types: those high on the valley slopes are rotational, and those lower on the slopes are mud-flows. Many springs are present and are associated with the bases of the rotational landslips and the fronts of the mud-flows. Four active landslip areas affect the A660.

## II Introduction

Between Old Pool Bank and the eastern outskirts of Otley the A660 Leeds-Otley road crosses a tract of landslipped ground, which has a long history of stability problems. Numerous small site investigations have been carried out to rectify local failures, but no overview of the entire area has previously been attempted. As an initial step to stabilising the road West Yorkshire Metropolitan County Council Directorate of Traffic Highways and Engineering commissioned a new geological survey of the area by the British Geological Survey. This report summarises the results of the survey.

The geological survey was carried out in late December 1983 and early January 1984. Initially a desk study of three different flights of aerial photographs of the area was undertaken, during which most of the landslip and mud-flow features were outlined. This was followed by fieldwork to check and map identified features, to look for signs of landslips movement, and to plot the locations of springs and other drainage.

## III Geology, landslips and mud-flows

The area lies on the northern edge of the Yorkshire Coalfield. The rocks forming the north-facing scarp of Caley Crags are largely siltstones and mudstones, with some thinly bedded sandstones of Namurian ($R_1$) age. These are capped by the Caley Crags Grit closely overlain by the Bramhope Grit, both coarse-grained sandstones which form sub-parallel escarpments with beds dipping generally at 5 to 10 degrees to the south. Cambering along much of the crop of the Caley

Crags Grit, however, has caused beds on the crest of the escarpment to dip gently northwards. The structure (Fig. 1) is similar to, but less steeply dipping than, that of Otley Chevin (Stephens and others, 1953). The area is partly covered by glacial till (boulder clay), which is thick low on the valley slopes, but thins to a feather edge against the escarpment, not extending much above 122m (400 ft) A.O.D.

Landslips have extensively affected all strata on the escarpment up to the level of the Caley Crags Grit. The gritstone edge also appears to have been affected by landslips in a few places and has morphological features which Edwards (1954) considered to be the expression of numerous small faults cutting the escarpment, but which can be better explained as the results from landslips. These landslip movements affect the glacial till, and it seems probably that they were initiated some 12-15,000 years ago in late glacial and early post-glacial times; movement persists to the present day.

The disturbed area may be divided into two main parts. The upper of these, generally lying above the 122m (400 ft) contour, consists mainly of deep-seated large rotational slip complexes affecting the solid rocks of the escarpment, interspersed with areas of small rotational slip complexes and mud-flows. The lower ground is largely occupied by comparatively superficial mud-flows, emanating from the higher rotational slips, but incorporating also the overlying glacial till. In the account describing the individual landslips (Section V) the area is further subdivided into smaller tracts, each, as far as possible, representing one major phase of slipping with its resulting mud-flows (Fig. 3). Of necessity the boundaries between these tracts are in many places arbitrary, as repeated slip and flow has blurred the distinction between individual episodes, and in places flows overlie one another, forming complex tongues. The age relationships between some of the flows can be determined, as the more recent ones usually have a very undulating morphology and more marked margins.

## IV Hydrology

The survey was carried out in late December 1983 and early January 1984. The weather was generally wet and a light covering of snow was present on several occasions. The streams and springs were all running well and water seepages were commonly easy to pick out where they had melted the thin snow. In Figure 4 a distinction has been attempted between springs and water issues at drainage pipes. In such a landslipped area, however, land drains often break, apparently giving rise to springs; conversely, some springs are tapped into pipes. Allowance should be made for these factors when using Figure 4.

In general, small seepages occur throughout the landslipped area. There is, however, a concentration of springs between about 107m (350 ft) and 130m (425 ft) A.O.D., approximating to the bases of the main rotational landslips. On the lower ground, most of the large mud-flow lobes expecially the active ones have springs at their bases. This suggests that the movement planes are well lubricated.

## (V) Geological and hydrological descriptions, and stability observations of the landslip areas (Figs. 3 & 4)

### 1. The Birches

The Birches stands near the top of a number of small rotational landslips (Fig. 3, 1-S). These have formed in strata immediately below the Caley Crags Grit, and in glacial till (boulder clay) at the northern side of sub-area 1-S. Well defined mud-flow lobes with a few minor rotational landslips (1-M) project northwards from the main rotational landslips and form a series of marked mud-flow lobe features to the south of the Leeds-Otley road. In addition subdued mud-flow lobes, which appear ancient and degraded are present north of the main road.

Adjacent to, and south of, the road the residence called "The Old Orchard" has been constructed in an excavation cut in an area of mud-flow. (Burgess, 1976). During 1982-83 a minor landslip and mud-flow (1-A) occurred in the bank at the southern edge of the excavation. This flow, which carried away the hedge and some trees is currently advancing towards the house. There is a water trough fed by a land drain (possibly with a spring in close proximity) about 40m south of this slip. A boggy patch of ground extends north from the water-trough to the slip, and water from this source may have contributed to the formation of this minor landslip.

## 2. Danefield Wood

Danefield Wood is the site of several of large rotational landslips which cut back southwards deeply into the gritstone escarpment as far as Springfield Farm (2-L). The effect of these landslips has been to lower slightly the crest of the escarpment along an east-west line passing about 150m north of Springfield Farm. The northern edge of the main rotational slips (2-L) is marked by a line of springs (Fig. 4, Springs 11, 12, 19, 20, 22, 23). Well developed mud-flow lobes (2-M) with sharp features emanate northwards from the edge of the main rotational slip. These mud-flow lobes on the south side of the Leeds-Otley road have numerous small rotational slips and tension features within them. Many of the landslip scars and mud-flow lobes in sub-area 2-M have very steep sharp features and appear to be comparatively recent, but they obviously pre-date the housing and the railway.

Slight active movement appears to be taking place at sub-area 2-A where a small scar and mud-flow lobe have developed just to the north of the house called "Hawes". This landslip poses a potential threat to both the house and the Leeds-Otley road. Water from Springs 5 & 6 (Fig. 4) may be partly responsible for this slip. In addition, water which overflows from Drain 10 (Fig. 4) in wet weather runs downhill past "Hawes" and also soaks under the house, to spill onto the landslip and also to run down the track on to the Leeds-Otley road. Drain 10 (Fig 4) feeds Silver Mill reservoirs and was installed as a conduit for the Otley Water Works at some time prior to 1847, as shown on the 1:10,560 scale Ordnance Survey map of that date. Recent improvements in the drainage of Danefield Wood and the installation of new tributary culverts leading to Drain 10 appear to have increased the run-off rate to such an extent that the drain can no longer cope with the flow. Consequently, it overflows at times and water cascades downhill soaking in to the landslips and mud-flows and probably rising again at Spring 14 (Fig. 4) north of the main road. The drainage problems in this area can not contribute to the stability of this tract.

About 100m east of "Hawes" a small rotational landslip and mud-flow form marked features which are currently being levelled and landscaped by the landowner. This operation, which involves excavating landslip material and tipping it elsewhere on the slip, could cause future problems.

## 3. Water Trough Bend

The formation of numerous small to moderate-sized rotational landslips south of Water Trough Bend (Sub-area 3-S) has resulted in loss of support along the gritstone escarpment producing cambered strata (3-C). Morphological features in Sub-area 3-C suggest that this cambering has tilted the beds gently northwards. Small camber gulls (shallow linear depressions over tension gashes) are present near the crest of the Caley Crags escarpment where large blocks have tilted to the north. Northwards from this area, massive gritstone blocks litter the slope, and mud-flow lobes supporting blocks of gritstone fan out over the landslipped area.

Springs 38 and 46 lie near the northern edge of the rotational slips, and mud-flow lobes (3-M) spread out northwards. Within sub-area 3-M many of the features are very fresh; there are two active ($3\text{-}A_1$ and $3\text{-}A_2$) and two recent ($3\text{-}R_1$ and $3\text{-}R_2$) areas of landslip and mud-flow. Sub-area $3\text{-}R_1$ is a marked, but minor rotational slip with a well developed mud-flow lobe. It obviously pre-dates the railway, but appears comparatively recent from its morphology; Sub-area $3\text{-}R_2$ is similar in appearance.

Active movement is obvious in Sub-area $3\text{-}A_1$ and this stretch of road - known as "Water Trough Bend" - has been the location of several site investigations and some remedial work. South of the road there is a small landslip scar; north of the road mud-flow lobes spread out along a 150m front. These lobes are active and have steep sides with signs of caving. The footpath and retaining walls are damaged in several places, and water issues from three springs (36, 37, 40; Fig. 4) just north of the road. The most severe damage to the road has occurred where Spring 38, south of the road, flows to a water-trough in a field then sinks under the road at 39 (Fig. 4), and issues again at Spring 40. The flow of water is considerable and the walls on both sides of the road have subsided. The other springs (36 and 37) are of less clear origin than Spring 40, but it is possible that they are linked to Spring 38 by the failure plane of the landslip and mud-flow. Immediately west of, and slightly lower than, Spring 38 there is a boggy hollow coincidental with the back scar of the slip. It may be that water is soaking in here to lubricate the landslip and mud-flow, finally emerging at Springs 36 and 37. This tract was the subject of Site Investigation Report No. WY/ES/F/660/2/AC.

Some remedial work was carried out on the eastern lobe of mud-flow 3-$A_1$ during 1964-66. This consisted of a fan of near-horizontal boreholes most with porous concrete filters surrounding the pipes. This system now appears to have clogged with silt or slime, and only one of the eight boreholes still yields a considerable flow of water. This factor, coupled with the spring-water problems outlined above, suggests that further movement in the area may occur.

On the southern side of the road, about 100m east of Landslip 3-$A_1$, is the water-trough of Water Trough Bend. The water feeding this trough issues from Spring 46 (Fig. 4) and feeds a manhole for the farm supply. From here it issues into a trough, then partly drains to the roadside trough and partly overflows and soaks away into the field. Water emerges north of the Leeds-Otley road as a boggy spring alongside a disused drain. Soil is creeping and banking up against the wall south of the road; this coupled with water flow under the road at this point is a potential cause of instability.

Sub-area 3-$A_2$ shows slight movement of the retaining wall to the northern side of the road on the eastern side of the mud-flow lobe. The morphological features of the area are very marked, and Springs 26, 27 and 28 (Fig. 4) issue from the central part of the landslip; water also sinks into the landslip at 30.

It is not clear to where the water from these springs flows; it may sink into drains emerging at 32 near the bottom of the hill, or it may soak away under the road. Movement of the roadside wall, the freshness of the morphology and the presence of abundant water make the future stability of this landslip and mud-flow area suspect.

## 4. Poolscar Wood

There are several large rotational landslips in Poolscar Wood (4-L). They have left the gritstone edge unsupported and caused it to camber (4-C). Springs (52 & 63) within sub-area 4-L have newly dug culverts leading northwards from them. Much of the water in the culvert from Spring 52, however, sinks into the ground at 53 and apparently re-emerges north of the road at Drain 54 and Spring 56. This escaping water from the culvert might in future undermine the road nearby. North of the Leeds-Otley road, most of the area (4-M) is composed of mud-flow lobes with numerous small rotational landslips and abundant springs.

## 5. Pools Carr

South of the Leeds-Otley road at Pools Carr (5-L), the ground consists of a series of large rotational landslips which extend southwards well into the gritstone edge, a semi-circular piece of which has subsided slightly. North of the road (5-M) numerous mud-flow lobes are present in Pools Carr associated with abundant springs. West of Pools Carr is an active landslip and mud-flow (5-A). Northwards movement of this active area is indicated by a displacement of up to 1m to the road retaining wall over a length of about 120m. The scars and mud-flow features of this tract indicate it is a complex of rotational slips with associated mud-flow lobes. South of the road the land is undulating with gritstone blocks. Apart from water flowing from Spring 73, the area appears dry at the surface, but immediately north of the road abundant springs (71, 72, 75, 76) issue from near the foot of the retaining wall. There are more springs (79, 80, 81, 82) near the front edge of the mud-flows. The presence of springs emerging from near the foot of the retaining wall may be detrimental to its stability, and the presence of abundant springs with signs of land movement make the stability of area 5-A suspect. In addition, the tipping of waste over the scar at the southern end of the landslip by forestry workers may further threaten stability.

6. Caley Crags

To the north of Caley Crags the land falls away steeply in several large rotational landslips (6-L). The gritstone edge is cambered (6-C) and massive gritstone block debris from Caley Crags has slid downhill to litter the slopes of the rotational landslips below. Numerous springs (97, 98, 101, 105, 108, 109) emerge near the northern edge of the rotational landslips, and abundant mud-flow lobes (6-M) fan out from this line. Within the mud-flows a small active landslip (6-A) has been initiated by making a large excavation for farm buildings.

7. Pool Bank Quarry

Pool Bank Quarry was excavated in the Caley Crags-Grit at some time between 1800 and 1930; when it closed it had a maximum depth of about 25m. The waste from the quarry was mainly tipped onto the steep slope north of the quarry, which is also an area of rotational landslips (7-S). Extensive quarry waste was also tipped north of the Leeds-Otley road as a large steep-sided fan. The loading produced by this fan may have contributed to the mobilisation of the active landslip ($7\text{-}A_1$) on which it was tipped. Documentary proof that this area has moved is given by a comparison of O.S. maps surveyed in 1847, 1933-34 and 1966 (Fig. 2). In 1847 the track crossing the toe of the landslip was straight and Pool Bank Quarry had not been extensively excavated. By 1934 several walls across the middle of the landslip had been displaced, and the track at the bottom had been kinked and moved northwards. The survey of 1966 showed that the walls crossing the slip had been demolished. The track at the bottom, however, appears not to have moved much after 1934. Field observations of this landslip reveal it to have a very marked hummocky form with very sharp marginal features and numerous springs (119, 120, 121, 123, 124, 125, 126, 127; Fig. 4) around the northern edge. Active movement is illustrated by the kinked and broken nature of the wall abutting the track at the toe of the slip. Comparison of the maps (Fig. 2) indicates a northward surface movement of up to 20m at the track. The northern edges of the mud-flow form a bank 3-4m high; to produce these features whilst retaining the track and the wall appears to require the movement of sub-soil material in a semi-fluid waterlogged state.

Adjacent to the Leeds-Otley road there is a small active landslip (7-$A_2$) on the back scar of the major landslip (7-$A_1$). Movement on landslip 7-$A_2$ has demolished some small trees, and may eventually threaten a small section of the road retaining wall.

During the past eighteen years Pool Bank Quarry (7-G) has been filled with refuse and is currently being reclaimed and finished with excavation material. The quarry has been filled to, and possibly beyond and above, its original lip. Several problems may result from the landfill project. The first concerns surface run-off. Currently, during wet weather, water cascades from the tip surface at 116 (Fig. 4), forming a steam which sinks between 117 and 118. This water has triggered off a small mud-flow from the edge of the tip which has demolished the fence. It is advisable to prevent further mud-flows from the tip on to the landslip areas. Furthermore, there is a possibility that water entering the landslip between 117 and 118 (Fig. 4) may accentuate landslipping further downhill. It would be prudent to investigate the possibility of installing adequate drainage, and controlling water run-off in the vicinity of the access road and along the northern side of the tip.

The effects resulting from this landfill (ie. changes in loading near a landslip caused by the additional weight of fill and possible resultant changes in water table level and groundwater flow) cannot be easily estimated. Figure 3 shows that Landslip areas 2-L and 5-L extend back considerably into the gritstone edge, almost as far back as Pool Bank Quarry (7-G). It is possible that cutting the quarry down through the Caley Crag Grit has produced a line of weakness which might, under suitable conditions, form a future slip plane. It is also possible that the lack of support to the north of the escarpment due to

Landslip 7-A, the weight of the fill in Pool Bank Quarry, and possible increases in water-table level and groundwater flow, could combine to produce conditions favourable for the triggering off of a major landslip. It is recommended that the Pool Bank Quarry landfill-site should be fully investigated; that the surface drainage should be carefully controlled and monitored; that the water table and groundwater flow in and around the tip should be monitored; and that calculations should be made of the stresses involved in, and the stability of, the Pool Bank Quarry and landslip area.

8. Low Bank Plantation

The Caley Crag Grit exposed in the Leeds-Otley road cutting is cambered (8-C), with the dip changing from gently southwards to gently northwards near the junction with the Old Pool Bank road. The jointing in the rock becomes more open northwards towards the edge of the escarpment. Below the escarpment there are several small rotational landslips ($8\text{-}S_1$) but some of these are partly concealed by quarry waste ($8\text{-}S_2$) from Pool Bank Quarry. The lower part of the slope (8-M) consists of numerous well developed mud-flow lobes.

## VI Recommendations

It is recommended that within the landslip area particular attention should be paid to the movement of surface and underground drainage. Where water emerges at the surface it should be prevented from soaking back into the landslips and causing instability problems lower down the slopes. The following areas of active landslip 2-A, $3\text{-}A_1$, $3\text{-}A_2$, 5-A, $7\text{-}A_1$, $7\text{-}A_2$, which affect the main A660 road have been identified, and these in particular should be examined in more detail. The geological situation of Pool Bank Quarry suggests that this area should be investigated to ensure its long term stability.

## VII References

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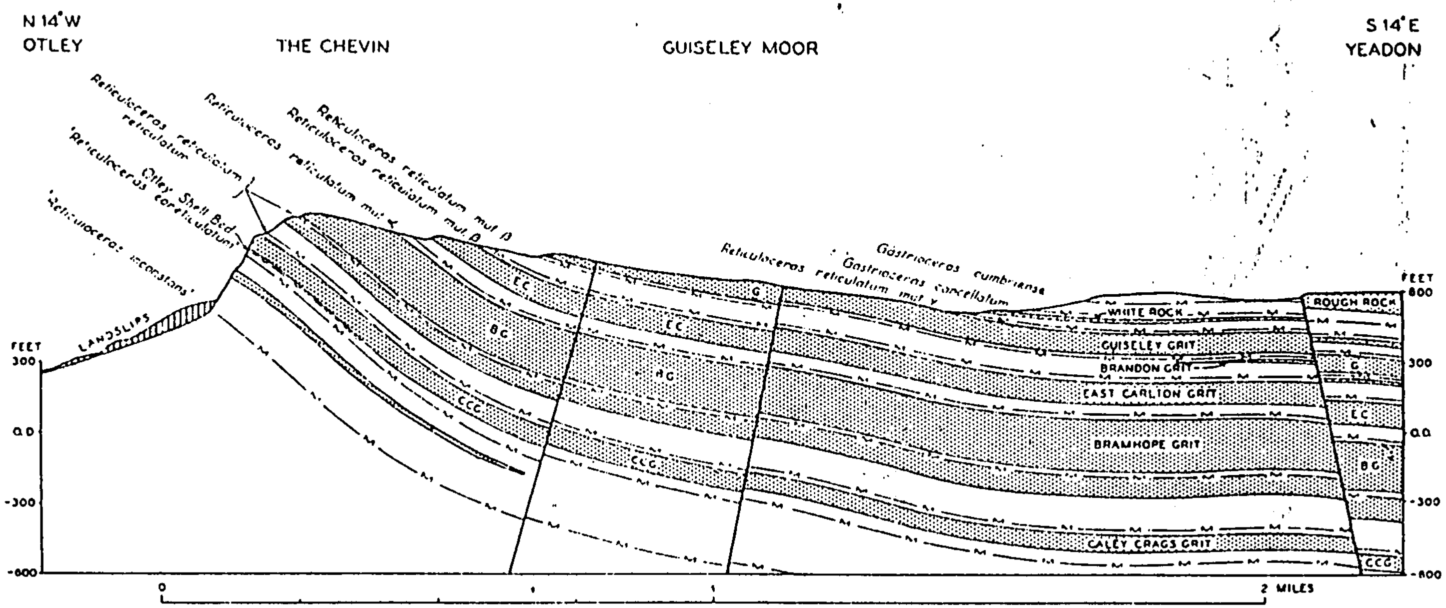


Fig. 1. Section from Otley to Yeadon showing the higher beds ($R_1$ and $R_2$ stages) of the Millstone Grit

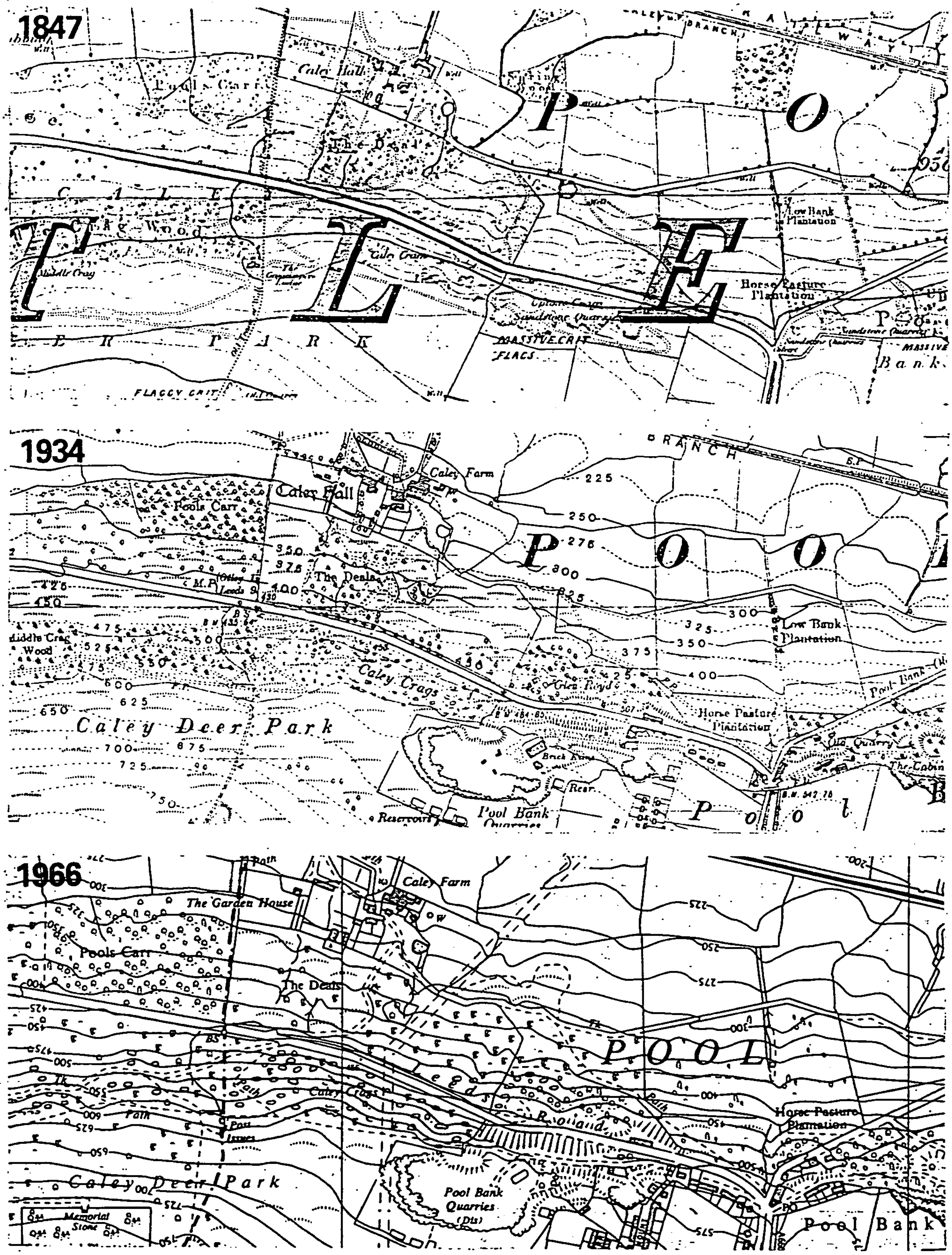


Fig. 2. 1:10,560 and 1:10,000 scale O.S. maps showing the changes in the walls and tracks over the Pool Bank Quarry landslip between 1847 & 1966.

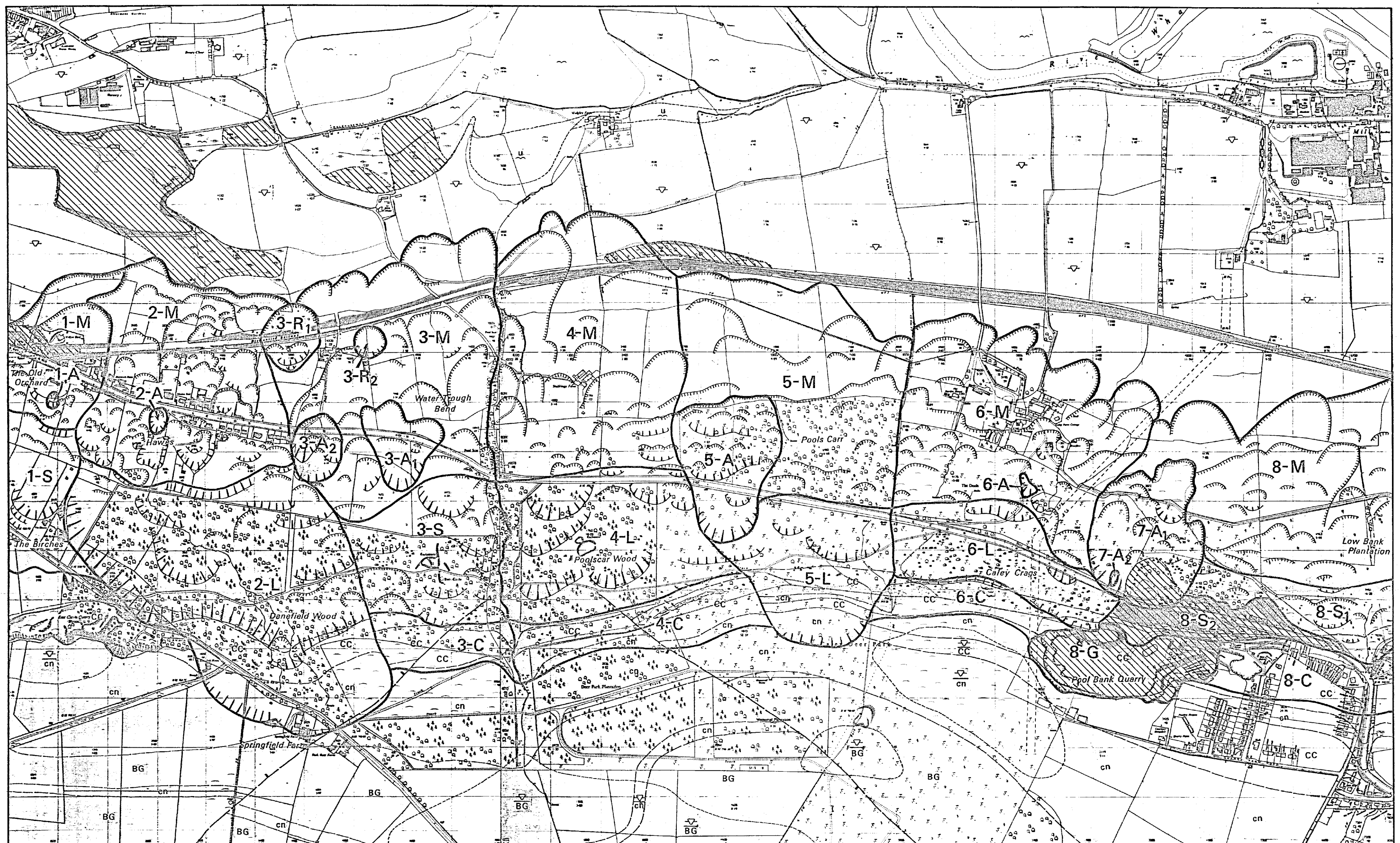


**FIGURE 3: GEOLOGICAL MAP OF THE POOL BANK TO OTLEY LANDSLIPS.** COMMERCIAL IN CONFIDENCE *Surveyed by A.H.Cooper, British Geological Survey, © N.E.R.C. 1984.* **SCALE 1:5 000**

INDEX AND EXPLANATION

| | | | | |
|---|---|---|---|---|
| -A | Actively moving landslips and mud-flow complexes | | Made ground | Edge of landslip sub-area |
| -R | Well defined, recent landslips and associated mudflows. | | Alluvium | Feature marking limit of mud-flow lobe |
| -L | Complexes of large rotational landslips | | River terrace deposits, undivided | Scarp feature related to landslips |
| -S | Complexes of small rotational landslips | | Glacial Till (Boulder clay) | Geological boundary, Drift. |
| -M | Complex mud-flows derived from till and rock, with minor rotational landslips | cn | Namurian, undivided (mainly siltstones & mudstones) | Geological boundary, Solid |
| -C | Cambered strata | BG | Bramhope Grit | Fault at surface; cross-mark indicates downthrow side |
| -G | Made ground in Pool Bank Quarry | CC | Caley Crags Grit | |

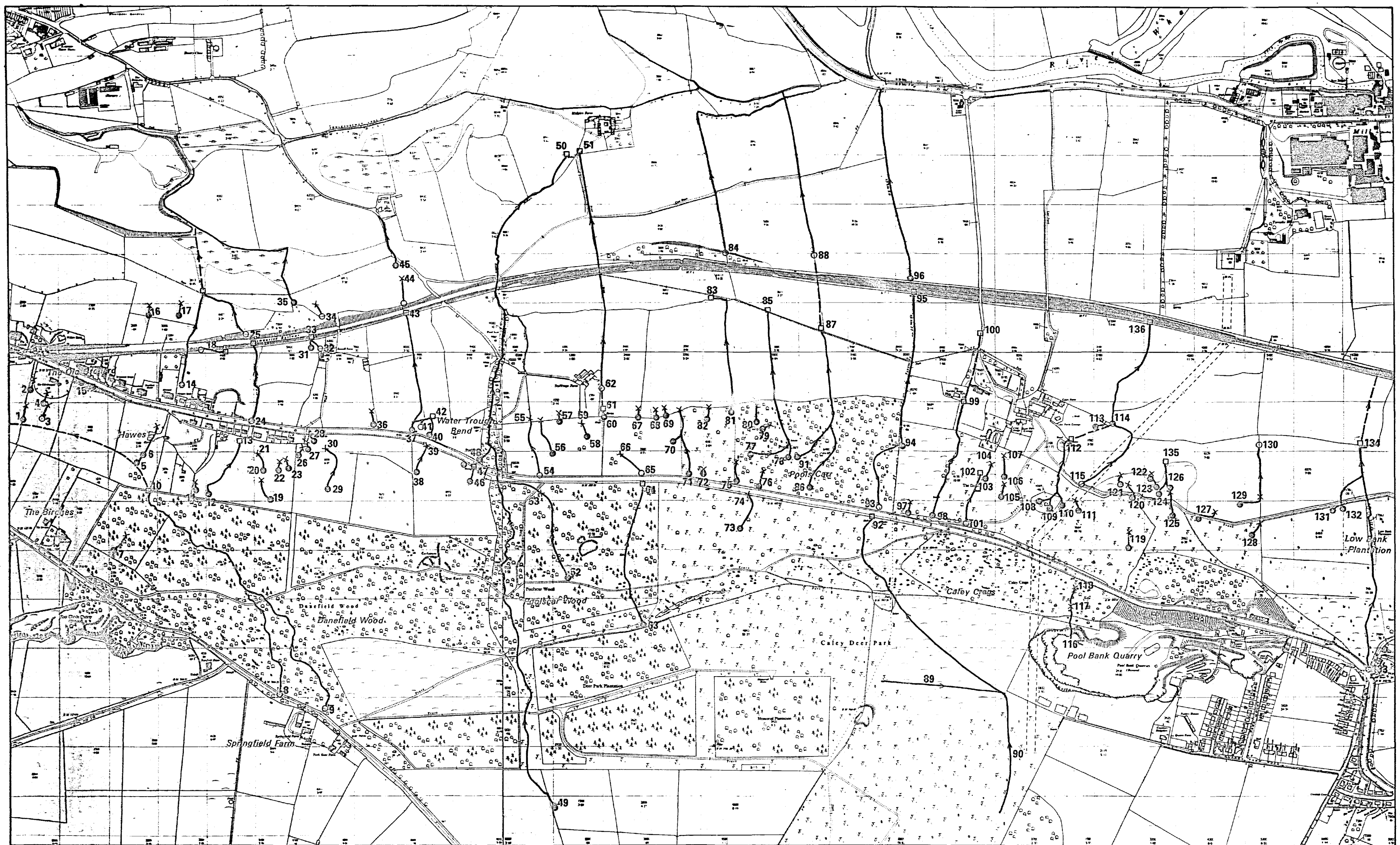


**FIGURE 4: HYDROLOGY OF THE POOL BANK TO OTLEY AREA.**

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**SCALE 1: 5 000**

INDEX AND EXPLANATION

- Spring
- Water issues (springs or drains)
- Drain
- Areas where water sinks
- Water course
- Water pipe