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Desk study and walk-over survey of Rhiw Landslip, Lleyn Peninsula

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BRITISH GEOLOGICAL SURVEY

RESEARCH REPORT CR/03/199N

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A. D. Gibson, A. Forster, M. G Culshaw

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Front cover

View of the Rhiw Landslide at the western end of Porth Neigwl

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Foreword

This report describes the results of a desk study and walk over survey commissioned by Gwynedd Council to investigate the landslide complex at Plas yn Rhiw in Gwynedd and comment upon proposals to mitigate landslide damage to the Class III road at that location.

Acknowledgements

Mr Ian Williamson of Gwynedd Council, Dr Adrian Humpage (BGS) and Dr Richard Water are greatly thanked for his assistance and guidance during the carrying out of this survey. In addition, Ove Arup & Partners and particularly Ian Statham are thanked for the provision of data and comments during the preparation of this report. Lee Jones is thanked for the programming and processing of GPS data collected during the field survey.

Contents

Summary

This report describes the findings of a walkover survey and desk study commissioned by Gwynedd Council. BGS were asked to investigate the geology and geomorphology in the area around Plas yn Rhiw, Gwynedd where landslide activity has led to the closure of an important road. BGS were also asked to comment upon the findings of an existing ground investigation by the consultants Ove Arup & Partners and upon a proposed re-routing of the road.

This survey is in general agreement with the findings of the Ove Arup report that the landslide activity at Plas yn Rhiw occurs within heterogeneous glacial outwash deposits overlying relatively stiff units of glacial till. Although the prediction of future landslide activity is difficult due to the nature of the geology and the effect of previous remediation work on the landslide it is thought likely that, providing care is taken with the disposal of ground and surface water from the site, Route E1A is a viable long-term route for the road.

1 Introduction

1.1 BACKGROUND

The road between Rhiw to Mynytho has long been affected by landsliding. Severe landslide activity in January 2001 resulted in disruption of the road and a section was closed to traffic. This stretch of road which runs between Bryn Foulk [233730 328180] and Sarn y Plas [223860 328330] remains closed at the time of writing. Gwynedd Council has made proposals to mitigate the effects of landsliding, with options that include supporting the current alignment and a complete re-routing of the road such that it will be not be affected by future landsliding. A report has been commissioned from Ove Arup & Partners to examine the area and assess which of the proposed routes would be the best long-term option. This report recommended that the best option for the long-term management of the road (taking into account all construction costs and environmental concerns) is to re-align the road. However, this option requires that the road be constructed in an area that is within the grounds of a National Trust property and will traverse a significant length of difficult terrain.

The British Geological Survey (BGS) was commissioned by Gwynedd Council to prepare an independent report with the following brief:

- Comment on the geotechnical report on the Rhiw landslide by Ove Arup & Partners.
- Undertake a desk study of the landslide area to include the Ove Arup report, the seismic investigation prepared by Terradat (UK) Ltd and other sources of information.
- Produce a report on the long-term stability of the proposed road as shown on drawing 784/GA/1E.

This report presents the findings of this research and is structured in the following way:

- Examination of available data with regard to the site including the results of a desk study and a walkover survey of the survey area which includes discussion of the Ove Arup & Partners Report.
- An assessment of the long-term stability of route 1E.

1.2 SURVEY AREA

The 'Plas yn Rhiw Landslide Complex', (National Landslide Database entry 2788 attached as Appendix 1) lies at the western end of Porth Neigwl on the Lleyn Peninsula in Gwynedd. The area studied to investigate this landslide complex included he coastal slopes beneath Mynydd Rhiw to the foreshore and the grounds of Plas yn Rhiw, Bryn Foulk, Sarn y Plas and Treheli (Figure 1).

1.3 PROCEDURE

This study considered data primarily from three sources,

- The report by Ove Arup & Partners
- Other data and information, including data held in the National Geological Data Centre at the Keyworth office of the BGS
- A walkover survey of the site.

The walkover survey was carried out in order to place information in its correct context and to make a proper assessment of the site. All spatial observations made during the survey were recorded using a Leica GS50 reconnaissance GPS system with a nominal accuracy of 0.4 m in the horizontal plane and 0.7 m in elevation. GPS measurements were registered to Ordnance Survey Grid Coordinates by reference to the Ordnance Survey Static Station located on Mynydd Rhiw.

2 Geology of the survey area

2.1 STRATIGRAPHY

The area around Plas yn Rhiw forms part of Sheet 134 (Pwllheli) of the BGS 1:50 000 map geological map series and Sheet SH 22 NW of the BGS 1: 10 000 geological map series. Detailed descriptions of the local geology are provided in the Pwllheli memoir (Young et al. 2002) and in the memoir of the adjoining Sheet 133 (Aberdaron and Bardsey Island) by Gibbons and McCarroll (1993). The bedrock formations in the survey area consist either of sedimentary rocks of Ordovician age or igneous rocks which intruded into these sediments during the Ordovician (Figure 2a). Over most of the survey area, bedrock is covered by up to 80 m of superficial deposits, deposited during and since the last glaciation approximately 16 000 years ago (Figure 2b).

2.1.1 Bedrock Formations

Ordovician rocks in the survey area belong entirely to a suite of rocks termed the Gwynedd Supergroup. Although the detailed stratigraphy of this supergroup is complex, it may be considered to represent basinal and margin-basinal sedimentation (Ogwen Group) locally interrupted by a series of volcanic events.

In the area around Rhiw only the lower part of the Ogwen Group is present, this is divided stratigraphically into the Nant Ffrancon Subgroup, Trygarn, Wig Bach and Llanengan/St Tudwals (undivided) Formations (Figure 2). Each formation is the result of varying depositional environments during the development of the district.

The oldest rocks in the Rhiw area are the marine sandstones, siltstones and mudstones of the Wig Bach Formation. These were deposited within, and either side of, a marine basin that extended northeastwards across the Pwllheli district in the early Arenig period around 485 millions years ago (485 Ma). Towards the late Arenig (470 Ma) this marine basin had expanded, depositing sediments of the St Tudwals Formation within the basin and over its southeast margin. Around this time sea level dropped, and then rose again in the early Llanvirn. Changing sea level and uplift of faulted rocks in the earliest Llanvirn (470 Ma) led to the introduction of coarse-grained materials interbedded with volcaniclastic sediments of the Trygarn Formation. Volcanic activity around this time led to the emplacement of a welded ashflow[1] and the injection of basic sills[2], seen as the Mynydd Rhiw Rhyolitic Tuff Member and the intrusion of basic doleritic sills into the Wig Bach and Trygarn Formations. Later, gabbroic sills, emplaced during the Caradoc (458-449 Ma) complete the bedrock sequence. Historically, all of the intrusive sills on and around Mynydd Rhiw were thought to be the same unit and represent the same process and time of emplacement (Woodcock 1980). More recent studies have shown that there are two suites of igneous intrusions in the Rhiw area (Figure 3).

2.1.1.1 Wig Bach Formation (WGB)

The Wig Bach Formation is described as a mudstone and sandstone of which the upper part is predominantly grey siltstones and bioturbated mudstones. Poor exposures exist in the quarry near Hen-Felin, which is part of an outcrop that is thought to pass north-easterly, through the quarry at Ty'r-felin to Bryn Foulk where its terminated by a fault The presence of the Wig Bach Formation on Mynydd Rhiw was proven in a borehole at [229 295] by Brown and Evans (1989).

2.1.1.2 Llanengan Formation and St Tudwals Formation -undivided (LGST)

The St Tudwals Formation is characterised by alternations of intensely bioturbated muddy sandstones, and well-bedded units of coarse to medium grained sandstone. In contrast to the disturbed structure of the St Tudwals Formation, the Llanengan Formation is typically dark grey mudstones with thin, pale grey siltstones or very fine-grained sandstone laminae. In the area around Rhiw these rocks are entirely covered by superficial deposits and not divided. The formations do not outcrop in the area but form the bedrock sequence east of the Cefnamwlch-Rhiw Fault.

2.1.1.3 Trygarn Formation (TGN)

The Trygarn Formation forms a succession of mudstones and siltstones with coarse-grained sandstone interbeds containing spherical ferruginous particles (ooids) immediately to the west of the Cefnamwlch-Rhiw Fault. Its base is considered to be an ironstone found beneath a sill in a borehole drilled on Mynydd Rhiw by Brown and Evans (1989). Above this sill lie 32 m of ferruginous siltstones with brachiopods, 2 m of ferruginous siltstones and conglomeratic sandstones with mylonitic detritus and ferruginous ooids over which lie 20-30 m of fine-grained volcanic beds. The upper part of the Trygarn Formation is a succession of finely bedded (5-20 mm) silt and sandstones. The sandstone beds contain many clasts of deep basement

[1] In this case probably a product of an ancient pyroclastic flow materials

[2] a sheet-like volcanic deposit emplaced between existing beds of sedimentary rocks

rock, and detrital white mica and in many places contain a significant proportion of ferruginous ooids. Sideritic cement and chlorite also occur. Phosphatic concretions are locally abundant, especially near the top of the formation, which grades from the thinly bedded ferruginous sandstones and siltstones to micaceous siltstones of the undivided Nant Ffrancon Subgroup. In the area around Mynydd Rhiw, cherts have also been found within the Trygarn. The proximity of intrusive igneous rocks in the Rhiw area means that it is very likely that the Trygarn has been locally metamorphosed.

2.1.1.4 Nant Ffrancon Subgroup (NFR)

Although regionally important and appearing on the geological map (Figure 2a), the marine mudstones, sandstones and volcanic units of the Nant Ffrancon subgroup are not thought to occur in the survey area.

2.1.1.5 Basic and Doleritic Sills (MRRT)/ USO)

These sills tend to be fine to medium grained, heavily altered dolerites. Mineralogically they comprise albitised plagioclase laths, locally up to 2 mm long, anhedral clinopyroxene up to 0.5 mm and secondary minerals of chlorite, actinolite, sphene, calcite and quartz with abundant amygdales of chlorite, calcite and quartz. At least one of these sills intruded into the Wig Bach Formation and four into the Trygarn Formation. Features at the junction between many of these sills and the surrounding sediments indicate that intrusion occurred whilst the sediments were still wet.

2.1.1.6 Mynydd Penarfynydd Layered Intrusion

This is an easterly dipping gabbroic sill consisting of textured brown intercumulus hornblende, commonly enclosing augitic clinopyroxene. Locally the texture is commonly pegmatitic (very coarse-grained).

2.1.2 Superficial Deposits

The superficial deposits around Rhiw represent the westernmost boundary of the thick superficial deposits that fill the valley behind Porth Neigwl. The origins of Quaternary sediments in the Pwllheli district are a contentious issue with some researchers supporting a glacio-marine origin (Eyles & McCabe 1989, 1991) whilst others propose an entirely terrestrial process (McCarroll & Harris 1992). It is the latter of these two models that was adopted by Young et al. (2002) in their interpretation for the current BGS maps and memoir and it is this model that is adopted for this report.

The lowest deposits were lain by glaciers moving from the Irish Sea which moved over (and entirely covered) Lleyn around 18 000 years ago, depositing till against the bedrock of the area. This glacial advance was probably wet based, meaning that the glaciers were so thick that pressure built up at their bases, causing the glacier bottoms to melt. This led to the deposition of fluvial materials from streams flowing at the base of the glacier. When the Irish ice melted, the front section detached and melted in-situ, depositing outwash materials in the area. As the influence of the Irish glacier diminished, glaciers from the Welsh hills advanced and deposited tills on top of the Irish Ice Till. When the Welsh glaciers melted around 14 500 years ago they deposited a series of glacial outwash deposits – a heterogeneous mixture of sands, gravels and silts. Few if any of these sediments are 'in-situ', most having been re-worked by meltwater or having moved downslope under periglacial conditions between and after the ice advances. Therefore a generalised superficial succession in the field area may be a lodgement till emplaced by the Irish Sea Ice, above which lie at least one or more tills (possibly melt out tills from the Irish Sea Ice or Welsh Ice) above which sit pro-glacial sands, gravels and silts. This means there is a basal till (likely to be a stiff to very stiff) above which lie a succession of one or more tills and pro-glacial deposits, becoming weaker and more heterogeneous with reducing depth.

The removal of much of these materials by subsequent erosion and the lack of good exposures of what remains means that the model is based upon a limited number of observations and it is likely that this model will be refined in the light of future evidence. Seismic reflection studies carried out in the foreshore at Rhiw (Brabham et al. 1999, Young et al. 2002) revealed an upper layer of sediment, interpreted as glaciogenic deposits with seismic velocities of 1600-1780 m/s overlying a second refractor with velocities around 3200-3950 m/s which was interpreted, at the time, as bedrock. The glaciogenic sediments were divided into three separate velocity suites (Figure 4). These were thought to correlate with the Upper and Lower Irish Sea tills separated by a sand and gravel described by Jehu (1909).

Quaternary sediments within the bay display wide vertical and lateral heterogeneity, reflecting the variable environment of deposition. Deposits are described in the literature as: clay-rich diamicton characterised by a muddy matrix with scattered, commonly striated clasts of mixed lithology including broken shell fragments and compressed wood, in places with crude stratification and lenses of sand and gravel. The total thickness of Quaternary sediments on the Rhiw foreshore is estimated at around 80 m.

2.1.3 Walkover geological survey

Exposures of bedrock were found at only three locations in the survey area, at quarries near Treheli and Bryn Foulk and at the coast near Bryn Foulk. The coastal exposure near Bryn Foulk (Figure 5) also showed the nature of materials near the bedrock-superficial contact at the margin of the bay. Above a sharp contact lies a stiff to very stiff, light brown diamicton comprising silt/clay with abundant gravel sized clasts of locally derived bedrock. The orientation of larger clasts in a broadly downslope direction indicates that they have been subject to downslope movement, possibly prior to the deposition of further sediments on top. Their generally sharp 'fresh' appearance indicates that they have not travelled very far from their origin.

Upslope from this location, within the embayment that leads to Bryn Foulk two Quaternary facies were exposed in the near vertical scarp of a recent landslide (Figure 6) at [223774, 328146, z30.5]. Facies 1 was described as a stiff to very soft (where wet) light to medium brown silt/clay containing many angular and subangular gravel to boulder sized clasts of very hard, dark grey igneous rock, possibly mottled gabbro – [Till]. Facies 2 was described as very stiff to soft (where wet) light to medium brown silt/clay with many fragments of fine to coarse mainly angular fragments of dark grey to black very hard rock fragments of fine to coarse gravel size and sub-angular fragments of dark grey to grey lithofragments of medium gravel size - [Till].

At the same elevation and 10 m further to the West, recent movements had exposed a section that appeared to consist of a soft, dark grey to dark brown poorly laminated silts. (Figure 7). Further upslope from here, in the cliffs immediately to the East of Bryn Foulk were exposed light brown, irregularly bedded sandy, gravelly diamictons (observed from a distance) which were thought to be of a fluvial/ fluvio-glacial origin. Although it is difficult to make an interpretation based upon so few exposures and it seems reasonable to suggest that these exposures represent the depositional margin of Porth Neigwl where a sloping bedrock surface is overlain by at least one till which in turn is overlain by glacio-fluvial derived deposits.

Cliff top and coastal exposures of material elsewhere in the survey to the east of this location showed the variability of the glacially derived deposits in this part of Porth Neigwl. These included units of soft, light brown, laminated fine sands (Figure 8), soft to stiff sandy clays (Figure 9) and light brown gravelly sandy units (Figure 10).

An isolated exposure of fissured, purplish light brown, clay with silt (interpreted by its colour as Irish Ice Till) was observed on the foreshore around 36 m seaward of the foreshore (Figure 11). This unit, with apparent fissuring running parallel to the coastline was thought (in agreement with the Arup report) to represent the toe of a rotational landslide. No purple clay was exposed in the coastal slope section, indicating either that the material must be in-situ below the current beach level and was heaved into its current position by a deep-seated rotational movement or that the clay is present but unexposed in the cliff and had been involved in a fairly shallow rotation. Whichever of these processes is correct the fact remains that there is evidence of an active shear surface beneath beach level.

2.1.4 Depth to bedrock and seismic investigation

Bedrock occurs at surface at the foot of the coastal slope south of Bryn Foulk and is near to surface at elevations of around 45 m at the east and west margins of the survey area. Elsewhere within the survey area it is likely that the top surface of bedrock occurs at elevations around 30 m (behind Treheli (Arup Borehole B[3], 10/04/03[4]) to approximately 20 m below beach level at the coast indicating a gradient of 1 in 5. This is supported by the apparent slope of the ‘bedrock’ reflector in the second series of seismic tests carried out by Terradata. It is likely that this bedrock surface is irregular and depressions can be expected both parallel and especially perpendicular to the coast.

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[3] Bedrock recorded (in draft core-log) as ANDESITE, a classification presumably based upon local geochemical knowledge of lithological conditions, otherwise GABBRO or DOLERITE would be expected. Andesite is not likely to occur in the survey area.

[4] Exact position of borehole unknown at the time of writing.

3 Geomorphology of the survey area

3.1 GEOMORPHOLOGY

The evolution and resultant morphology of the coastal slopes in the survey area have been influenced strongly by the underlying geological succession. The gabbroic intrusions that now form Mynydd Rhiw and Mynydd y Graig constrained the movement and resultant deposition of glaciers at the end of the last ice age and since then have probably exerted a significant influence upon terrestrial drainage characteristics and offshore coastal-dynamics. These peaks form the western margin of a wide embayment now known as Porth Neigwl. This embayment is partially filled by outwash sediments that form a flat plane across the bay. It is not known what the original depth or lateral extent of these sediments was but it is almost certain that a significant amount of them has been washed away, leaving the low lying plain of sediments. Glacial and fluvio-glacial materials at the margins of this embayment (as those in the survey area) are likely to have been subject to slope movement during periglacial conditions. In historical times the slopes have been further affected by anthropogenic activity (woodland clearance, agricultural practice, mineral exploitation, construction etc) and by natural processes such as coastal erosion and weathering.

The most up to date geomorphological assessment of the survey area is that shown in the Arup report as Figure 2. The mapping carried out for that research demonstrated that the coastal slopes are bounded to the north by a steep rear scarp, varying in height between 1 m (south of Treheli) to greater than 5 m east of Bryn Foulk. Downslope of this scarp the ground surface forms a series of disturbed, hummocky benches characteristic of deep-seated rotational landsliding. Smaller landslide features, including mudslides, flows and shallow rotations are found over much of the landslide area.

3.1.1 Walkover geomorphological survey

Although detailed mapping was not done during this survey, the findings of this walkover survey support the interpretation of the mapping by Arup (2002). The general morphology of the coastal slopes was of a series of two or three back-tilted benches, disturbed by many smaller landslide features (Figure 12). Recent and probably active, was indicated by the presence of fresh tension cracks and small landslides over much of the coastal slopes. The rear scarp, for most of its width, was un-vegetated and appeared to be recently exposed (for instance Figure 10). Many springs were observed to be flowing on the coastal slopes (Figure 13), most notable of these (with observed flow rates estimated at over 600 litres per hour) were the ones emanating near the bedrock-superficial contact at [223846 328091] and at the foot of the slope immediately south of Treheli near [224043 328276]. The latter of these is indicated on the Arup Report-Figure 2 as the issue from what has, in the past been an engineered drainage route.

Upslope of the existing road the ground was examined for features such as tension cracks, lobate features and irregularities that may indicate a history of ground movement in that area. As indicated in the Arup report the terrain in this area is very difficult to interpret. Where land has not been cleared and landscaped it is covered with thick superficial deposits included in which are many large boulders. The area is also densely wooded.

The presence of displaced diamicton exposed at the coastal section (Figure 5), the general steepness of the slopes in the survey area and reduction in depth of the superficial materials upslope indicate that all superficial deposits in the survey area have been subject to some form of downslope movement since deposition. No evidence to suggest that there had been any recent slope movement was found in the area upslope of the existing road.

Estimates of the scale of movement in the area can only be made by reference to archive data in the form of maps and photographs. In the case of Rhiw, the oldest records used in this survey are the Ordnance Survey maps of 1888. These were compared with the maps published in 1901, 1920 and 2002. All maps were corrected for distortions and geo-rectified to the present Ordnance Survey Grid and Datum. Each of these was compared to the current position of the cliff and coastlines as determined by GPS survey during the walkover.

Changes between the maps of 1888 (Figure 14) and 1901 (Figure 15) are largely cosmetic and unlikely to constitute a re-mapping. The majority of linework remains constant and only the use of symbology, such as the ornamentation for different land-use is changed. The only significant changes to the cliffline between 1888 and 1920 (Figure 16) occur south and southwest of Treheli [221450 328500] to [224280 328520] where both the coastline and cliffline have retreated by up to 15 m. Greater changes are apparent at the foreshore, an embayment absent on the 1888 map is indicated near the mouth of the gulley at Bryn-Foulk. There are significant changes to the foreshore between Bryn-Foulk and Treheli, a beach has formed in the upper foreshore immediately at the foot of the coastal slope which indicate an accretion of beach deposits. There is also a significant reduction in the extent of the foreshore itself. Between 1920 and the 2002 (Figure 17) the changes are more dramatic with virtually the entire cliff line west of [223900 328380], SW of Treheli receding by 12-25 m. Over the same period the gulley at Bryn Foulk has widened and extended northeasterly by up to 22.5 m. In variance with this general pattern of retreat, the coastline immediately downslope of Sarn y Plas has remained constant since 1888 and in some sections has actually prograded. In the area of Sarn y Plas itself there appears to be little change in the location of the landslide rear scarp and movements do not appear to have exceeded 10 m since the earliest map. This may, in part, be attributed to the changing detail of attribution, for example the ‘cliff line’ on the 2002 map is actually 150 m seaward of the true cliff line and that of the 1920 map, not because of a change in cliff location but a change in cartographic style. It must also be recognised that the cliff in this area has been subject to remedial works for over 40 years and may not represent the natural cliff line as required for proper comparisons with historical data. The current cliff line (Figure 18) should be regarded as the rear scarp of the landslide complex at the present time. Recession of the cliff and coastlines is summarised on Figure 18.

Observations of damage to built structures were made during the walkover survey. None of the habitable buildings within the survey area appeared to be suffering structural distress as a result of slope instability. The northern wall of Sarn y Plas appeared to be in some distress and was not in exact alignment with the rest of the building but this could not be attributed to landsliding directly and could have been a result of processes other than landsliding. All of these buildings are of some antiquity, all appear to be over 100 years old and buildings in their locations appear on the 1888 map of the area. Although this indicates a lack of historic landslide activity in the area it could equally suggest that the rear scarp of the landslide has not yet regressed sufficiently inland to cause disturbance. Cracking was evident in the road immediately in front of Sarn y Plas (Figure 19) with a deep fissure over 10 m in length spanning between [223853 328325] and [223848 328317]. This fissure occurs upslope of a gabion wall constructed in 1988. To the southwest and parallel to that fissure, a recent failure in the rear scarp had resulted in the removal of kerbing and disturbance to the road surface (Figure 20) and fence line (figure 21).

Although there was a considerable length of dry-stone walling within the wooded area surrounding Sarn y Plas it was impossible to establish which sections, if any, had been subject to slope movement. The walled sections were generally in a state of disrepair and may well have been disturbed or re-aligned in the past in accordance with changing land-use requirements or repairs, some of which are indicated in Section 2.2 of the Arup Report.

4 Slope Instability and Route E1A

4.1 SLOPE INSTABILITY

It is not the intention of this report to propose a ground model for the survey area but to comment upon that proposed in Section 5 of the Arup Report. Although it is impossible to confirm the exact landslide mechanism without a very detailed ground investigation there is sufficient evidence to confirm that the slope model put forward by Ove Arup & Partners is the most reasonable interpretation of the slope when considering all presently available information.

4.2 COASTAL EVOLUTION

If the accepted mode of slope movement in the area is correct, the present landslide complex at Rhiw is the result of continuing recession of the coast caused by the erosion of superficial materials which lie above a seaward sloping bedrock surface.

Erosion at the toe of the slope has resulted in a loss of toe weight and support to the entire upper slope. At the coastline this has resulted in a series of non-circular rotational failures, probably within the basal tills (a reasonable degree of cohesion is required to account for toe heave), possibly at, or near, the contact with bedrock. These basal failures removed support from overlying deposits and led to a series of retrogressive landslides that propagated back through the coastal slope (Figure 22), terminating at the current cliff line. It is likely that such processes have been active for a considerable length of time, probably since the cessation of the last ice age at which time the cliffline would have been some distance seawards of its current location. This series of retrogressive rotational slides has continued to the present day and will continue to do so if there is a sufficient supply of superficial materials (as there is towards the centre of Porth Neigwl). However, at Plas yn Rhiw this supply of superficial material is now much reduced and landslide recession has apparently slowed and the style of slope movement is adapting to a relatively shallow depth to bedrock.

It is uncertain how the landslide mechanism will evolve in the future; to a great extent this will depend upon local variations of geotechnical properties, hydrogeology and coastal erosion. Many hypothetical scenarios can be derived for future landslide mechanisms at a site where heterogeneous tills and outwash deposits lie upon an irregular sloping bedrock contact and are subject to removal of toe support. Future landslide patterns will depend upon the nature and geotechnical/ hydrological characteristics of the glaciogenic deposits and the depth and shape of the bedrock contact.

Assuming that coastal erosion continues it must be considered that eventually it is likely that all superficial materials will be removed from the slope at some time in the future. At 'current' rates of erosion the length of the existing road alignment that is directly affected by landslide activity could increase significantly over the next few decades. The nature of landsliding at susceptible locations (including the area around Bryn Foulk, Sarn y Plas and downslope and to the east of Treheli) could alter over time as well. This is in agreement with section 6.3 of the Ove Arup Report. As stated in the Arup Report, the existing cliff line may remain more or less stable for quite some time but equally the slope may become unstable rapidly.

4.3 EVALUATION OF ROUTE E1A

Although it is difficult to assess the long-term stability of Route E1A it is possible to draw some conclusions about the proposed route based upon the findings of this report, those discussed in the main report by Arup and the addendum to that report (Ove Arup and Partners International Ltd 2002, 2003).

- The proposed route is not within the existing boundary of the Plas yn Rhiw landslide complex and is not directly subject to landslide movements at the current time.
- The proposed route is in a location unlikely to be affected by landsliding (either coastal or from upslope) for a considerable period of time. Although it is impossible to predict with certainty what length of time this may involve (see assumptions below and Section 4.2) it is likely that the proposed route E1A will remain a sustainable route for 100 years as suggested by Ove Arup and Partners International Ltd (2003).
- The proposed route is well positioned to allow adaptation to future changes in alignment at the eastern end of the site where the erosion of superficial materials will continue at their present rate.

Route E1A is, with consideration of the available information a reasonable solution (in terms of the medium to long term evolution of the coastal slopes) to the problem of road stability in the area surrounding Plas yn Rhiw. Based upon the current understanding of the landslide complex, the route is likely to be sustainable for the period of 100 years or more as stated by Ove Arup and Partners International Ltd (2003). Over this period of time however it is impossible to discount the possibility of further landslide activity and the road may from time to time be threatened by localised failures depending upon geotechnical conditions. However, re-alignment to route E1A will mean that responses to such potential failures can be better managed than would be the case if the existing alignment was maintained.

Such a conclusion does rely upon a number of assumptions regarding the existing landslide processes:

- Marine erosion rates do not accelerate
- The current rate of cliff recession remains the same (i.e. erosion does not accelerate or that multiple 15 m events do not occur)
- The landslide mechanisms remain the same

It would appear that the proposed construction methodology for route E1A does take account of these assumptions. Ove Arup (2002) take the reasonable position that slope evolution, as can be foreseen at the current time will lead to a reduction in the potential for deep-seated rotational failures in much of the study area.

In light of the complex nature of sediments in the area and other issues such as likely increases in sea level and annual rainfall any re-alignment of the route must adopt a precautionary approach. In this case, the route should seek to remain as close to the bedrock surface as possible. By doing so, the uncertainty over the very long-term stability of the road section is reduced – both in terms of continuing recession and the complexity of future remediation strategies.

Two further issues that are outside the terms of reference of this report may need to be considered:

- The fate of existing remediation works in front of Sarn y Plas – these may at present (Arup report Section 2.2) be restraining rotational failures in the rear scarp and are likely to be exerting a stabilising influence upon materials upslope.
- It was stated in the Arup report that drainage water should be allowed to 'follow its original course' once it had been culverted and diverted beneath the road. Clearly the implications of such a strategy will depend upon the nature of support to the road but such drainage methods do risk creating an unprotected, localised concentration of drainage water, which could encourage a subsequent, localised recession to occur if and when, the drainage pathway was disturbed by future movements.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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Appendix 1 Landslide Database Entry, Plas Yn Rhiw Landslide.

National Landslide Database Report

Landslide 2788, Plas Yn Rhiw

Details

National Landslide Database Number	2788	**National Grid E**	223856
Locality	Plas Yn Rhiw	**National Grid N**	328322
Locality Details	SE of Rhiw, Gwynedd, Lleyn, N Wales	**OS Q/sheet**	Sh22nw
Original Survey	19/08/1985 (council)		
BGS Survey Number	1		
BGS Survey Staff	AGIBSON		

Dimensions

Elevation of Crown	44.35	**Total Slide Length**	-
Elevation of Tip	0	**Centre Line Length**	165
Rupture Width	400	**Disp. Mass Length**	174
Rupture Length	160	**Displ. Mass Max Width**	430
Rupture Depth		**Disp. Mass Depth**	

Landslide Detail

Movement Type	Movement Order	Comments
Flow	1	Rotations degrading into mudflows lower down slope
Rotational slide	1	Probable sequence of deep seated landslides from main scar possibly with base of slide under sea level

Causal Factors

Cause	Nature	Comments
Erosion	Natural	Marine action removing toe support
Water	Natural	Natural drainage patterns focus slope water
Geology	Natural	Superficial sediments overlying a sloping bedrock contact

Slope Detail

Slope Profile	Non Uniform (terracettes)	**Slope Vegetation**	Trees
Slope Height	44	**Slope Water**	Wet/ spring
Slope Angle	Natural	**Slope Water Position**	Total
Slope Aspect	Natural		

Land Use

Land Use	Relative Position	Damage Classification	Comments
Agricultural	Body	Damage recorded	Loss of pasture and coastal erosion
Industrial and commercial	Body	Damage recorded	Caravan park damaged by recession of rear scarp
Transport	Above the landslide	Damage recorded	Damage and re-alignment of trafficked roadway by recession of rear scarp
Wood	Body	Damage recorded	Loss of woodland

National Landslide Database Report

Landslide 2788, Plas Yn Rhiw

Geology

Lithology	Formation	Depth Top	Depth Base	Bedding Direction	Bedding Spacing	Joint Direction	Joint Spacing	Comments
Diamicton	Glacial Deposits Undiff.	-	-	na	na	na	na	Glacial outwas/proglacial deposits in which the majority of landslide deposits occur
Diamicton	Till	-	-	na	na	na	na	Regional geology indicates it is likely that Irish Sea Till underlies deposits formed by the outwash materials
Gabbro	Unnamed Sill, Ordovician	-	-	Out of slope	Wide	na	na	
Gabbroic-Rock	Unnamed Sill, Ordovician	-	-	na	na	na	na	
Sandstone Undiff.	Trygarn Formation	-	-	na	na	na	na	Only exposed at coastal section
Sandstone Undiff.	Llanengan Formation	-	-	na	na	na	na	

References

Reference Number	Reference Type	Title
1	Database	Geomorphological Surveys Ltd 1984 survey - National Landslide Database
2	Report	Pete Wight (1985) Gwynedd County Council records, County Offices, Caernarfon, LL5 1SH (ref 1/21/06 19/8/85)
3	Report	Ove Arup & Partners (2002). Rhiw Landslip, Geotechnical Report. Held By Gwynedd Council
4	Map	Sheet 134 (Pwhelli), BGS 1:50 000 Series Geological Map
5	Map	SH 22 NW BGS 1: 10 000 Series Geological Map

ADDITIONAL COMMENTS

May 2003 - subject to investigation (ref insert) by BGS.
2002-2003 Gwynedd Council have commissioned Arup (I Statham) to carry out ground investigation and assessment of road management strategies.

5 Figures

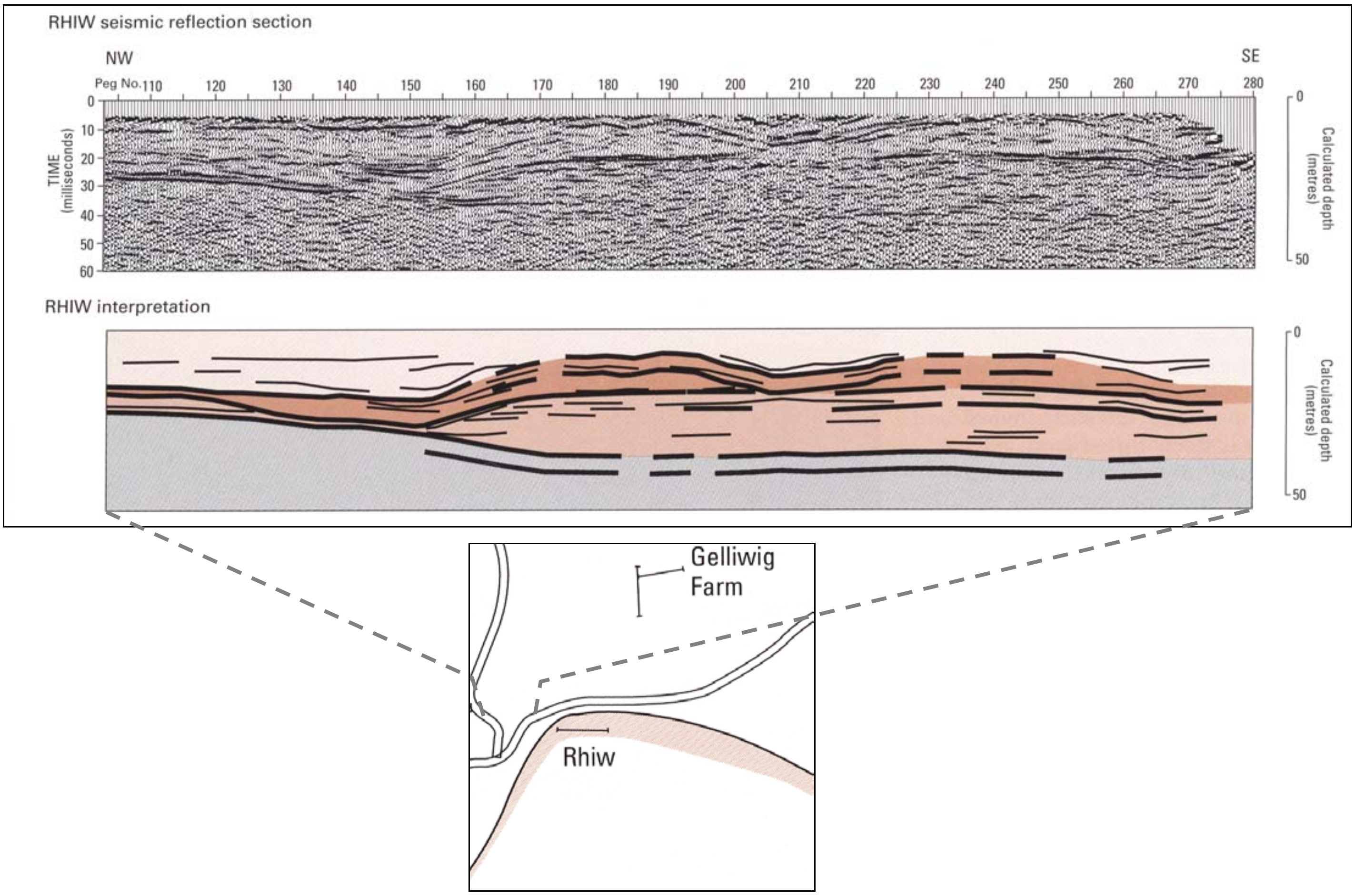

Figure 4. Results of high-resolution shallow seismic reflection surveys at Rhiw beach with location map inset (from Young et al. 2002).

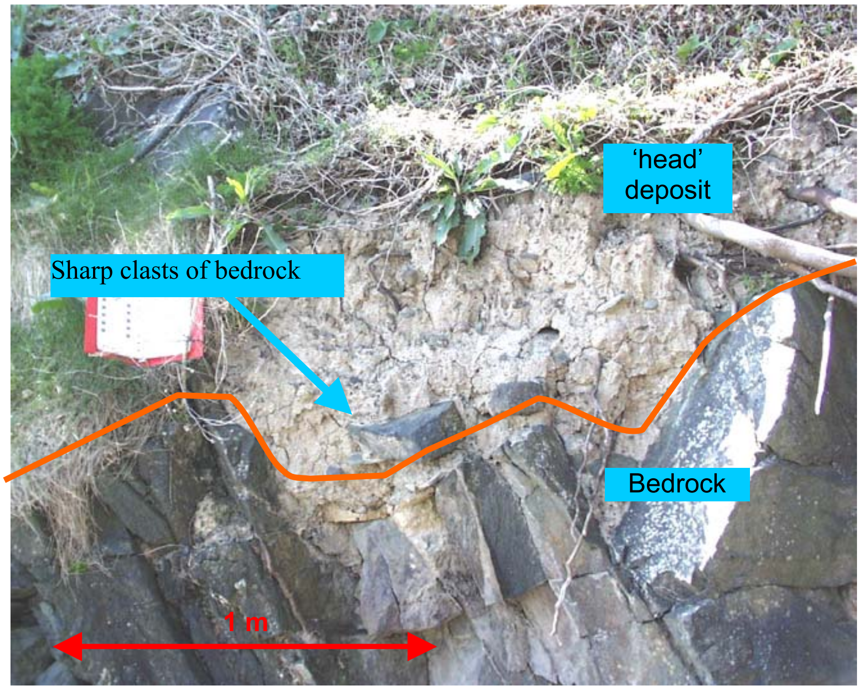

Figure 5. Contact between bedrock and superficial materials in a coastal exposure looking NW at [223848 328127, z3.5]. The size, sharp edges and downslope orientation of the large clasts within the superficial matrix indicate that the material has moved downslope over a short distance.

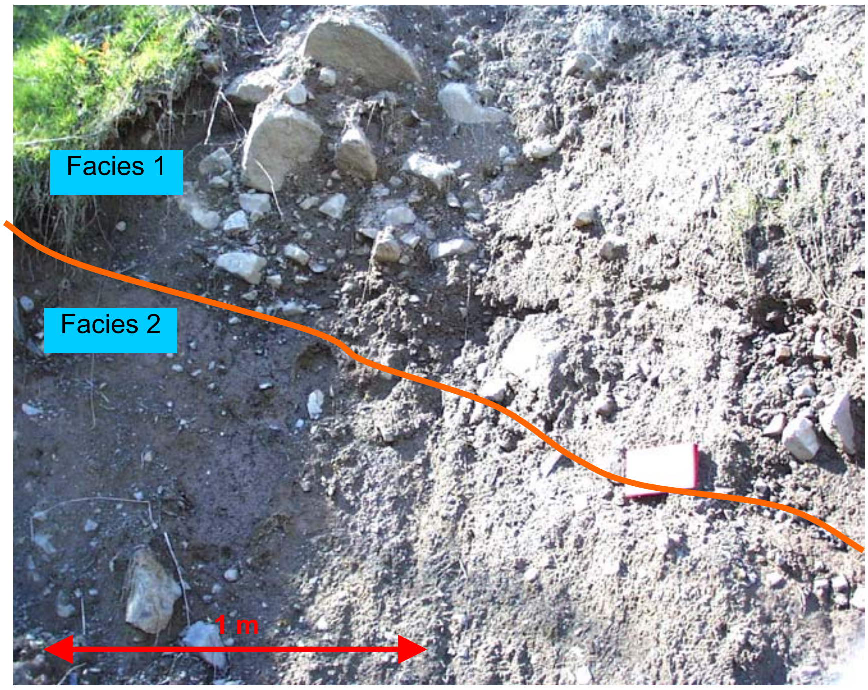

Figure 6. Two till facies observed looking NW at [223774, 328146, z30.5], the upper facies generally contained a coarser clast size and had little bedding structure whilst the lower 'till' contained clasts only up to coarse gravel size and displayed weak signs of bedding or lamination.

Figure 7. A shallow failure within the exposure of poorly laminated gravelly silt 10 m NW of the exposure in Figure 6., (looking NNE at approximate grid reference [223774, 328156, z34].

Figure 8. Exposure of soft, light brown to dark grey laminated, fine grained sands looking NW at [223973 328254, z1.5]. Although intact laminations could be seen in the exposure it is thought that the material had been emplaced as part of a slope movement.

Figure 9. Exposure of disturbed soft to firm, light grey to light brown sandy clays at [224031 328306].

Figure 10. Exposures in the landslide rear-scarp of light brown, gravelly sandy clay diamicton interpreted as fluvio-glacial outwash deposits at the cliff top immediately in front of Treheli at [224131 328518, z35.8].

Figure 11. Remnants of light brown to purple stiff fissured clay on the foreshore in front of Treheli at which is probably the remnants of toe heave resulting from a deep-seated rotational landslide.

Figure 12. A typical profile of the landslide area immediately downslope from Treheli. The photograph was taken from the top of the arcuate back-scarp. Visible are the back-tilted ground surfaces indicating the upper surface of rotated blocks.

Historic Maps on Paper Copy.

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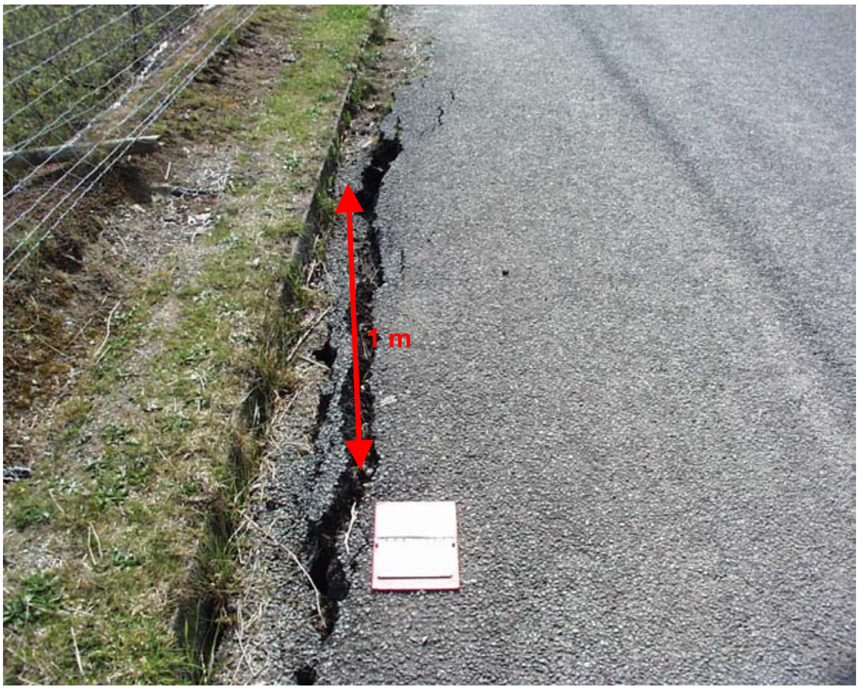

Figure 19. Crack in the road immediately in front of Sarn y Plas.

Figure 20. Loss of kerbing and road surface due to undermining southwest of Sarn y Plas.

Figure 21. Distress to the fencing immediately southeast of Sarn y Plas. This photograph, facing towards the southeast is a further illustration of topography interpreted as the back-tilted blocks of rotational landslides.

Cross Section on Paper Copy.