The Geology and Cliff Stability at Nefyn, North Wales – Interim Report

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The Geology and Cliff Stability at Nefyn, North Wales – Interim Report

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Front Cover

A view looking east towards Y Lôn Gam
from above Porth Nefyn
(Photograph: A.Humpage © NERC 2001)

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CONTENTS

List of Figures

The Geology and Cliff Stability at Nefyn, North Wales – Interim Report

1. Introduction

The cliffs fringing the bay between Penrhyn Nefyn and Penrhyn Bodeilas, within which sits Porth Nefyn, (Figure 1), have been subject to minor landsliding activity for many years. One such slip that occurred on 2 January 2001 resulted in the death of a visitor to the area. Following this incident, the British Geological Survey (BGS) has carried out a number of site visits to the area in order to investigate the geology and to conduct an outline assessment of the causes and mechanisms of landsliding in the area. This report presents the initial findings of ongoing research and considers the area immediately surrounding the location of the slip of 2 January.

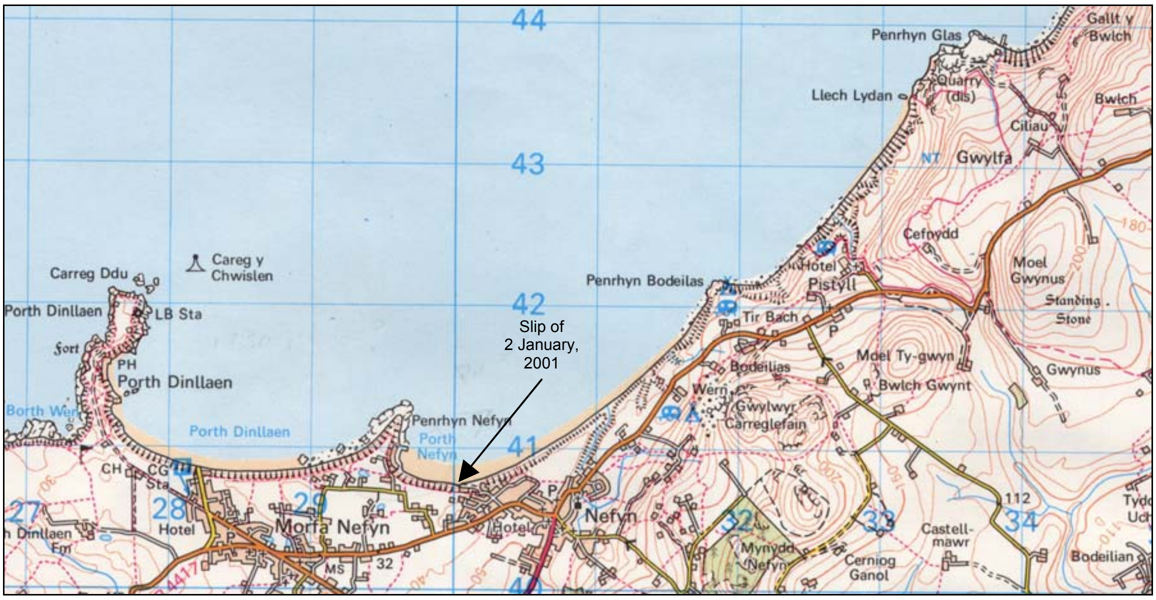


Figure 1: Location of landslide of 2 January 2001 within Nefyn Bay

Ordnance Survey Topography © Crown Copyright

2. Objectives

The objectives of the study (ongoing) are to:

- Investigate the geology of the coastal strip.
- Identify instances of slope instability in the bay.
- Identify the factors that caused these instabilities to occur.
- Define areas of similar hazard from slope instability.
- Indicate the risks to land, property, facilities and infrastructure.
- Carry out a basic analysis of the landslide of 2 January 2001

3. Limitations

This report is presented as work in progress and will be subject to alteration as further field surveying and laboratory testing of samples are carried out.

Fieldwork carried out to support this report was severely disrupted by the national outbreak of foot and mouth disease. Although the area immediately around Nefyn has been unaffected, it was considered by BGS and Gwynedd Council that a precautionary approach to field activity should be maintained, and as a result, fieldwork was suspended until April/May 2001. Fieldwork was restricted to the coastal path, undercliff and beach areas. No attempt was made to gain entry to any inland agricultural areas and contact with livestock grazing on the undercliff was avoided.

Field activity was also constrained by the health and safety issues concerning working in areas of instability. Details of the considerations and constraints upon working procedures and the methodology to ensure safe working are provided in the health and safety plan for this field survey, which is available from BGS.

4. Outline Geology

Nefyn Bay lies within the 1:50,000 scale geological map sheet 118 (Nefyn), which has not yet been subject to a detailed survey by the British Geological Survey at the 1:10,000 scale and there is no current memoir. The mapping carried out as part of this research therefore represents the first modern, large scale mapping (1:10,000) of the Nefyn Bay area by the BGS.

The bay is constrained at either end by two bedrock headlands – Penrhyn Nefyn to the south-west and Penrhyn Bodeilas to the north-east. Both these bedrock headlands are overlain by glacial till deposited by the last (Devensian) ice sheet. Between the two headlands, the entire coastal section is composed of glacial deposits that are indicative of an ice margin outwash environment. These deposits are dominated by glacio-fluvial deposits of sand and gravel, with scattered deposits of silts and clays laid down in lower energy environments.

4.1. Generalised Succession

From Porth Nefyn [2950 4080] to [3055 4095] a distinct succession of glacial outwash deposits can be identified, and with minor variations, this sequence can be recognised in the area of Y Lôn Gam.

The generalised sequence identified in this part of Nefyn Bay is shown schematically in Figure 2. Below beach level, and only observed in trial pits, is a stiff grey silty clay with numerous sub-angular to sub-rounded pebbles which is probably a glacial till (Bed 1). Overlying the till, and seen in the foot of the cliff, is approximately 4m to 5m of loose, bedded, fine- to medium-grained sand with abundant gravel dominated units (up to 1m thick) and thin gravel stringers, which often show evidence of channel deposition (Bed 2). Overlying these sands and gravels, is a distinct, erosive-based coarse cobble gravel bed (Bed 3). Up to 2m in thickness, the matrix between coarse material in this unit is cemented, thus making the upper surface effectively impermeable to water, or else restricting water to flowing within discrete conduits through it.

Overlying Bed 3 is a medium grey laminated silt, up to 1m in thickness, which can be traced around much of the bay (Bed 4). Above this, a stiff, structureless, blocky fractured clayey silt a

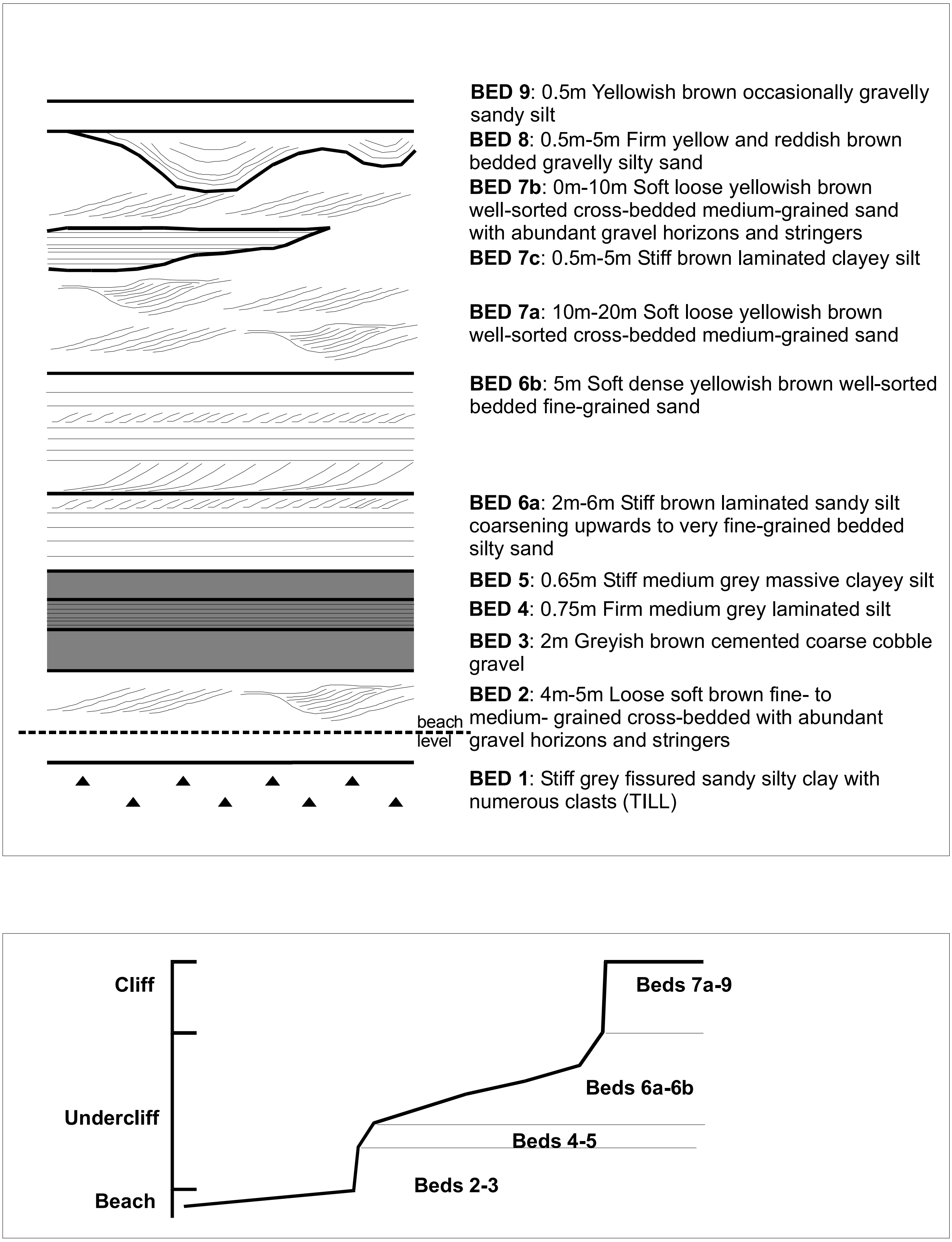


Figure 2: a) generalised geological succession occurring in the cliff sections in the southern half of Nefyn Bay
b) schematic profile showing the relationship with the geological beds and the terminology used in this report

(Bed 5) contains clasts of the underlying laminated silt. This passes rapidly up into a brown sandy silt (Bed 6a) and then into a fine cross-bedded sand (Bed 6b), which gradually coarsens upwards into well-sorted, cross-bedded, medium-grained sand (Bed 7a), which makes up much of the upper half of the cliff in the southern-most third of Nefyn Bay. In some locations, overlying Bed 7a is a variably thick loose, bedded, fine- to medium-grained sand with abundant gravel units and stringers, which often show evidence of channel deposition similar to Bed 2 (Bed 7b in Figure 2). Locally, laminated silt and clay units also occur (Bed 7c). At the top of the cliffs, variably thick, localised, channelised deposits of gravely, silty sand, identified as a possible Head deposits were recorded (Bed 8) and immediately below the top of the cliff, patches of up to 0.5m of wind-blown silt (Bed 9) were identified.

4.2. Geology Adjacent to Road Access to the Beach

Within the area of Y Lôn Gam, the basic succession described above can be identified. However, it is slightly complicated by the presence of small faults at points adjacent to the end of the road ramp and at the upper end of the car park (Figure 3). These small faults have resulted in the observable downward displacement of the cemented cobble gravel bed (Bed 3) from approximately 10m above beach level to only 3m to 4m above beach level. This movement appears to have post-dated the deposition of the gravel, but occurred concurrent with, or immediately prior to, the deposition of the grey laminated silts (Bed 4) and massive silty clays (Bed 5), as these units appear to be thicker in this area compared to elsewhere in the southern part of Nefyn Bay. It should be noted that these faults are postulated, as their position is obscured by surface material.

Further displacement on these faults may have occurred following the deposition of Beds 4 and 5, as a significant thickness of brown laminated silts (Bed 6a) occurs below the toilet block. The toilets are built on a bench at the top of this unit. This unit appears to thin westwards and may be absent behind the demolished chalets above the road. Further evidence of continued syn-depositional movement is shown by a significant thickness of cross-bedded medium-grained sand (Bed 7a) observable behind the demolished chalets. High on the undercliff within the sand, an additional unit is identifiable, which is termed Bed 7c in Figure 3. This is a brown, stiff laminated silty clay that is thickest behind the shop.

Above the sand unit (Bed 7a), deposits of gravelly sandy silt (Bed 8) can be identified in channels locally in the cliff top.

Observations made during fieldwork indicate that the geological succession is close to horizontal, but in the area of Y Lôn Gam may be dipping gently west-south-west, although this could not be directly measured.

Most of the undercliff is covered in a layer of debris comprised of degraded surface materials and deposits from slope movements. In several areas the slopes have been altered by construction and by the tipping of waste material.

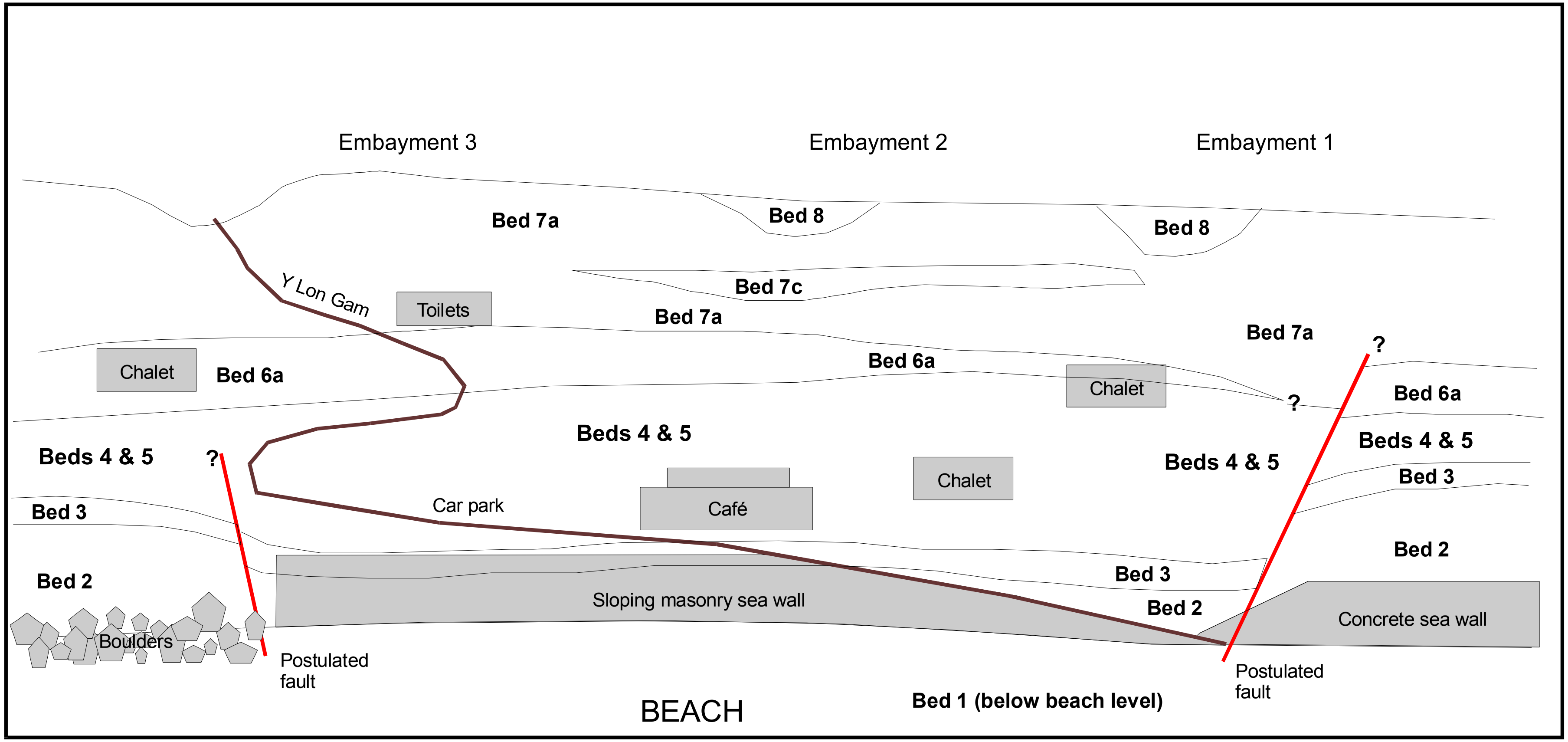


Figure 3: Schematic geological section in the area of Y Lôn Gam showing postulated geological relationships in this area. Note Bed 7b is not present in this area. **NOT TO SCALE**

5. Geomorphology - Landslide Types and Mechanisms

The morphology of slopes between Y Lôn Gam and Penrhyn Nefyn appears to be influenced by the underlying geology. Areas underlain by the lower gravel units (Beds 2 and 3) or sand (Bed 7a) generally have steep slope angles (greater than 50°). Below these areas there is often an apron of loose debris. The form of the cliff edge in the gravel dominated beds tends to be straight in plan, whilst in Bed 7a there is a tendency to develop deep embayments up to 10m in depth, separated by sharp promontories. Areas where the silts and fine-grained sands of Beds 4 to 6a predominate, display a generally lower slope angle, usually in the region of 5-40°.

The cemented gravel (Bed 3) and to a lesser extent, the grey silts and silty clays (Beds 4 and 5) form gently seaward-inclined benches approximately half-way up the undercliff, upon which material transported from higher up the cliff collects. These beds, which are generally less permeable than those immediately above, also form barriers to the downward percolation of water, preventing drainage from the material collected on the bench. This situation may lead to the build up of porewater pressures within this overlying material, contributing to a reduction in strength.

Morphological features, and their associated occurrences of instability can be classified into four groups that broadly correspond to different lithologies.

1. Lateral Failures, Slumps and Flows in the Sands (Bed 7a)

Fresh failures from this steep upper cliff are clearly identified by the removal of vegetation from all, or part of, the length of the failure. Failures tend to occur on the edges of promontories or near the base of the cliff where water seepages occur at the contact with the brown silts (Bed 6a). These movements are usually slumps, with a distinct translational element down the steep cliff face, becoming more rotational as the slipped mass comes into contact with material on the bench below (Figure 4). The size and precise shape of these failures varies widely, from small individual slides less than a metre wide and a few metres long, to coalesced failures several metres wide. Where the slope profile is sufficiently steep and/or there is a sufficient supply of water, debris may cascade down the entire length of the slope. More commonly, debris from these failures tends to accumulate on the benches immediately below the cliff. It is this type of slump that has removed parts of the cliff path in places.

2. Rotational Failures, Slumps and Flows in the Sands and Silts (Beds 4-6a)

The middle elevations of the undercliff are dominated by what appear to be degraded non-circular rotational failures within the silt dominated beds. Sliding probably took place along discrete shear zones a short distance above the cemented gravels (Bed 3) and, to a lesser extent above the tops of both Bed 4 and Bed 5. At the time of investigation, there appeared to be no evidence for active or recent movements of this type. It is probable that the environmental conditions required to cause such failures are not currently present.

Rotational failures can occur at any location where a less permeable geological unit underlies a more permeable unit, or where a unit of low permeability prevents water from readily draining, so giving rise to the possibility that porewater pressures can build up and promote slope instability. In the study area, shallow failures of this type associated with these mechanisms can be expected at the contact between the sands of Beds 6b and 7a and silts of Bed 6a and at the contact between the silts of Beds 4 and the cemented gravels of Bed 3.

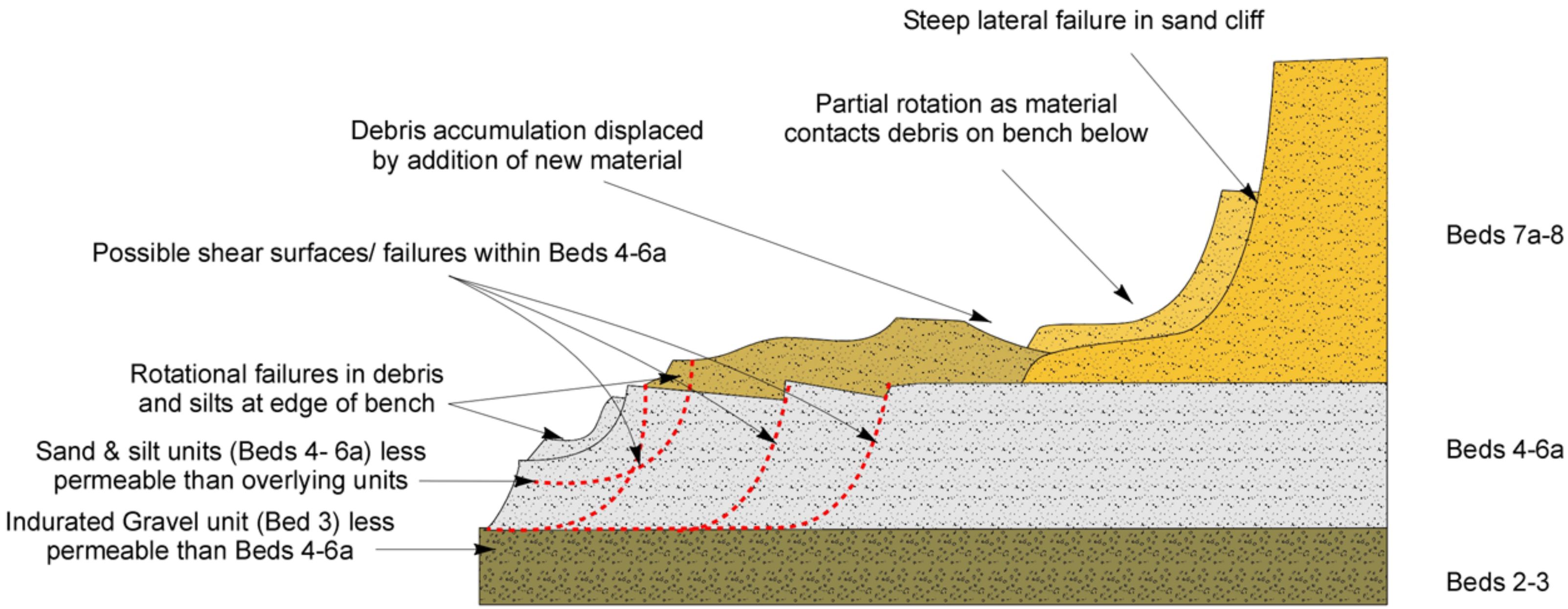


Figure 4: Diagram showing development of slump materials from Beds 7a-8, and rotational failures above Bed 3. For diagrammatic purposes only. **NOT TO SCALE**

Deeper-seated landsliding of this type could occur at the contact between the till of Bed 1 and the sands and gravels of Bed 2. Such a deep-seated failure would involve movement within the entire cliff profile and could trigger smaller movements in the surrounding area. No evidence of recent deep-seated movements was found during field investigations. This could indicate that no such movements have ever taken place or, alternatively, that any evidence has been removed by natural or anthropogenic processes.

3. Talus slopes below gravels
Few failures were observed in the steep slopes comprising the lower gravel-dominated units of Bed 2 and Bed 3. Those present are in the form of small-scale rock-falls which develop talus slopes which tend to be stable and vegetated. However, some parts of these slopes are covered by debris which has moved downslope from failures initiated in the geological units above Bed 3. This material rests upon the backfill for the concrete sea wall and the sea wall itself, occasionally spilling over onto the beach.

4. Shallow failures in the superficial cover
The superficial cover that is present over most of the undercliff is a mixture of weathered debris from landslide processes and other down slope movement of eroded *in situ* material, and organic material derived from decaying vegetation. The depth of such deposits is likely to be highly variable, as are their geotechnical characteristics.

This material generally forms a soft deformable layer, which may fail in a translational, rotational or flow dominated manner depending upon the underlying surface and prevailing groundwater conditions. Generally this material has a higher permeability than the *in situ* material it overlies and in terms of hydro-geological regime may be act as a perched aquifer. The failure of 2 January 2001 occurred in this superficial material.

It should be noted that although different types of landslide have been mapped individually, they rarely occur in isolation. Such failures are more likely to occur in combination with each other.

Although mostly vegetated, virtually the entire surface of the debris accumulation on the bench formed by Beds 4 to 6a was softened, wet and was covered in tension cracks developed near parallel to slope. Such conditions indicate that much of the material accumulated upon the bench is generally poorly drained and unstable.

Evidence for landslide activity within the superficial deposits upon the bench formed by Beds 4 to 6a is greatest in areas where water flow is concentrated by local factors such as channelling by surface gullies or because of subsurface disruption of through flow.

At the leading edge of the bench formed by Beds 4 and 5, this concentration of water can lead to rotational failures in both *in situ* deposits and the superficial cover, with failure depths ranging between 1m and 6m (Figure 4). Water issuing further inland results either in spring sapping, gully erosion or the generation of mudflows, depending upon the amount of loose material and vegetation present, and localised slope morphology. Again such features vary widely in size.

A further consideration in the Nefyn area is the inherent heterogeneity of the geology. The materials are probably the result of deposition in a glacio-fluvial and therefore sedimentary and geotechnical characteristics can be expected to show wide variations in lateral and vertical extent. Consequently landsliding may be controlled to some degree by local lithological and hydrogeological circumstances that make landslide hazard assessment difficult at the local scale.

6. Landslide Activity within the Study Area

In common with many landslide events, it is impossible to be certain of the precise causes and mechanism of the failure after the event, when the topography and groundwater conditions prior to the event are unknown. Following the initial failure of 2 January 2001 slopes in the area were altered by emergency stabilisation works. Slopes may also have been subject to natural erosion and weathering in this period.

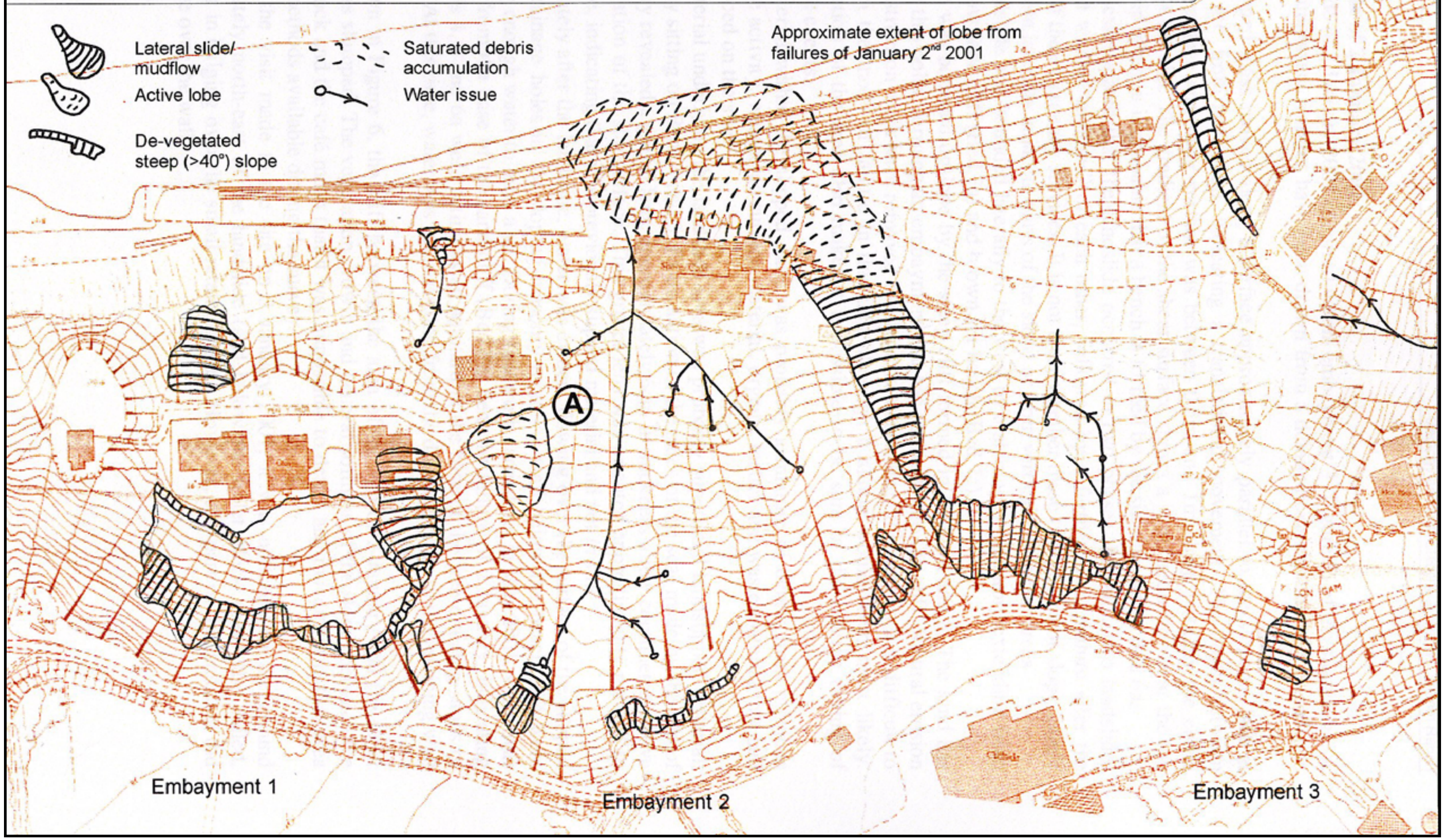
As shown in Figure 5, the area considered by this report is mainly concerned with activity within three embayments defined by the cliff line. Four chalets (two of which have been demolished) lie in the westernmost embayment, the beach café in the central one and toilet block in the easternmost.

Within these embayments it seems likely (Figure 3) that the beach café sits above Bed 3, the chalets which occur at a higher elevation upon the upper surface of either Bed 4 or Bed 5, and the toilet block on top of Bed 6a. In all of these instances, there has been an unknown amount of excavation, fill and re-grading of slopes over time so it is impossible to determine the original, natural morphology of the ground.

Consideration should be given to the stability of lobate feature A in Figure 5 upon the bench formed by Beds 4 and 5. This feature is characteristic of a translational failure within the superficial deposits and appears to be less well-drained than other similar material on this bench. At the time of investigation (14-18 May 2001), this lobe appeared to be wetter than its immediate vicinity and was ‘bulging’ towards the coast. In such a state, it is thought that this feature may be susceptible to failure if porewater pressures increase or the area is in some other way disturbed.

The sloping masonry sea wall immediately north-east of the beach café could be seen both from aerial photographs and field surveying to be bulging towards the sea. This bulging may indicate stresses that are placed on the wall by the movement of material in the area of the café. Such movements could be the result of deep-seated landslide activity.

Figure 5 . Diagram of Geomorphological Features and recent landslide activity in the Lôn Gam area, as of 27/04/01.
For clarity, the diagram only includes features which, during field examination were considered to represent activity which has taken place around the time of or since the landslide of January 2nd. The diagram is not intended to and does not represent all landslide features in the area
Approximate Scale 1:1250



7. Landslide of 2 January 2001

The landslide of 2 January 2001 occurred within embayment 3 (Figure 5) of the study area. A number of important features have been drawn from a detailed examination of the landslide site:

- The slipped mass moved along a surface approximately parallel to the slope surface at around 40° from horizontal, indicating a translational movement. The depth between ground surface and shear surface was between 0.5m and 1m along virtually the entire length of the slip. The gradient of the shear surface shows a slight reduction near the top of the slip where it is probable that a bench is formed by the silt-dominated Bed 6a.
- Eyewitnesses stated that the landslide occurred in two phases. Initially, two landslides occurred within “minutes” of each other, followed by a further small failure after the arrival of the emergency services. It is not clear whether these two phases of slope failure came from laterally adjacent parts of the slope or from vertically adjacent areas.
- The landslide was bounded laterally to the west by a sloping promontory extending from the yellow sand cliff (Bed 7a) and brown silt bench (Bed 7c).
- The slip was bounded upslope by the steep cliff formed in Beds 7a and 8. The sand has failed at this point, forming an embayment that has cut back into the cliff. Natural erosion and construction work have removed much of the debris from this area so it is difficult to ascertain the mode of failure in this unit although a slump would seem most likely. Degradation of the area also makes it impossible to be sure of the relative timing of landslide events.
- The material within the slipped mass was probably a mixture of debris from previous landslide activity, weathered surface material, organic matter and waste material that had been tipped on the site.
- The material underlying the landslide area was probably superficial landslipped material, primarily sitting on Beds 4 and 5. Examination of the sides of the scar made by the slip of 2 January revealed a gravel lens, approximately 6cm in thickness a few centimetres above the elevation of the slip surface. This gravel lens was oriented approximately parallel to the slope, indicating that it is previously slipped material and not *in situ*.
- Immediately after the landslide, water was evident flowing over the surface of the slipped area. Drainage holes in the sloping masonry retaining wall below the beach café were emitting enough water to form a jet. During fieldwork carried out in May 2001, water was issuing from the base of the sand cliff (Bed 7a) near the failure of 2 January, indicating that Beds 4, 5 and 6a were acting as an aquitard at the base of the free-draining sands of Bed 7a. At this time, water was again issuing from the drainage holes in the retaining wall in a jet.
- As shown in Figure 6, the cliff between the area of the slip of 2 January and the toilet block has slumped. The vegetation growth and general softness of the slopes between the toilet block and the café mean that it was impossible to detect any movement in that area by the methods available during the survey.
- During the visit made to the site on 3 January 2001, it was noticed that the ground immediately north-east of the landslide (and below the toilet block road) also failed, resulting in bulging over the small retaining wall. However, this part of the landslide did not move over the wall.

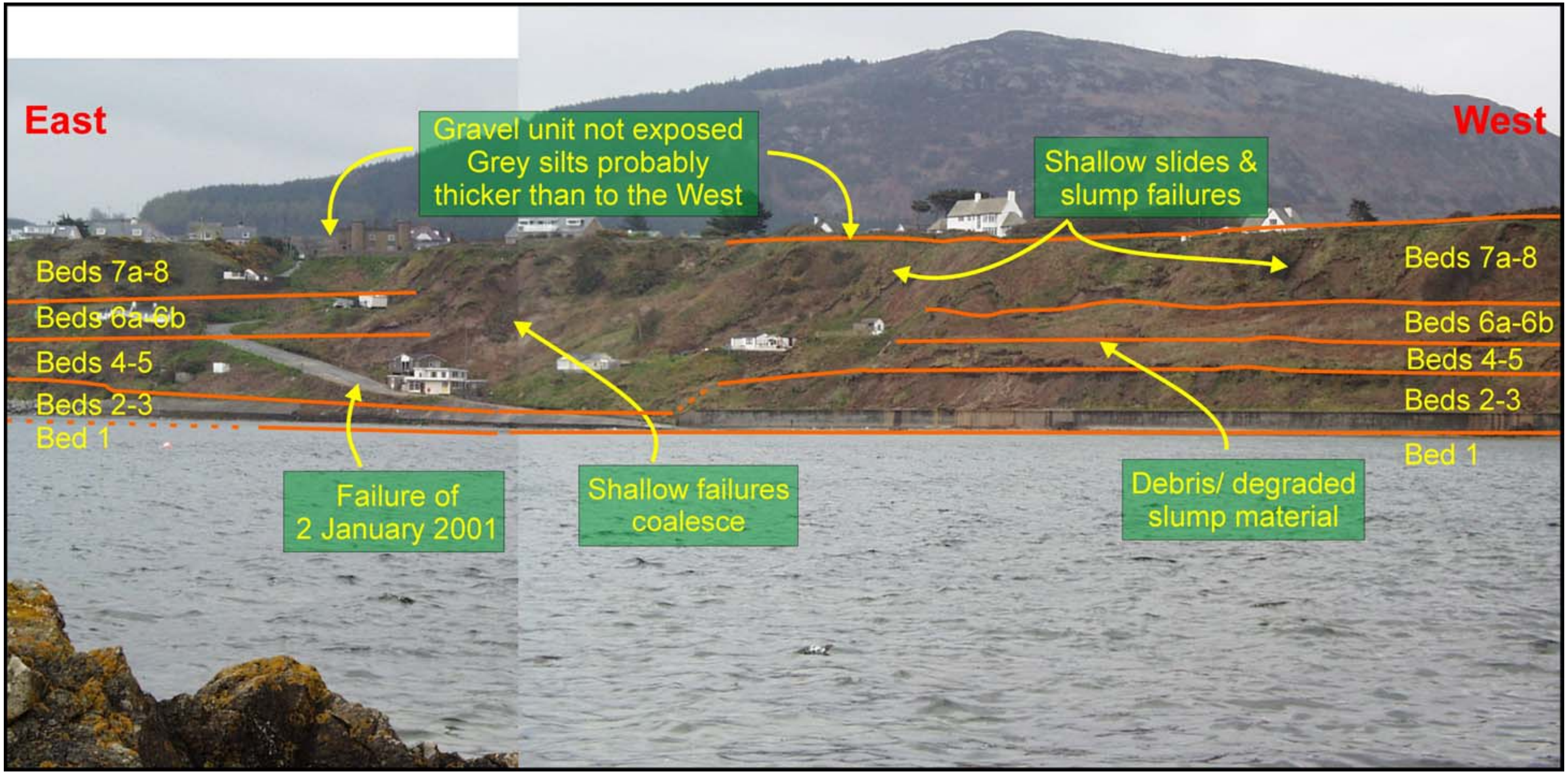


Figure 6: Photo-montage showing the outline geology adjacent to the landslide of 2 January 2001. Highlighted are some of the observed landforms

8. Proposed Interpretation of Events of 2 January 2001

From these investigations, the following interpretation of events has been made:

- It seems likely that water issuing from the base of Bed 7a and possibly at other levels, had been feeding into the debris covering the slope in the vicinity of the slip. This influx of water increased porewater pressures within the debris mass, decreasing its strength to the detriment of its stability and bringing it close to failure.
- The ultimate triggering mechanism of this failure is uncertain and a number of different scenarios could be put forward. Based upon the field evidence available, the most likely scenario in our opinion is that increasing porewater pressures within the mass caused the shear strength of the slope forming material to drop below a critical value that would maintain the slope in a stable condition, leading to a failure within that material.
- Reports of the incident described at least two phases of 'mudflow' movements. This could be accounted for by:
    - An initial failure in the lower slopes immediately above the car park area, this initial failure, which only propagated part of the way up the cliff removed toe support from material remaining above.
    - A second failure occurred within the debris upslope from the original failure, this material moved largely within the 'channel' made by the initial slip.
    - Both of these failures would have resulted in a loss of slope stability further up the cliff and may have triggered the slumps that were observed in the sand cliff at the elevation of the toilet block.
- An alternative interpretation is that the landslide is the result of failure of two blocks of material, lying adjacent to each other, perpendicular to the slope of the ground surface. The movement of one block would have removed some support from the other block above, as well as changed its groundwater conditions. This change in stress and hydrogeological conditions could have triggered the movement of the second block.