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Title:

The 2017 Regent Landslide, Freetown Peninsula, Sierra Leone.

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Abstract:

At 06:50 on Monday 14th August 2017, a hillslope on the Freetown Peninsula, Sierra Leone, collapsed, sending 300,000 m³ of debris into the flooded valley below. As this debris mixed with floodwater it became a sediment-laden flood which entered a drainage channel and travelled 6 km to the coastline. The event destroyed nearly 400 buildings, claimed the lives of an estimated 1,100 people and affected approximately 5,000 people. The mechanism was a two-stage rainfall-triggered landslide followed by a channelised debris-laden flood. The processes were similar to the nearby 1945 event in Charlotte, which killed at least 13 people.

Geomorphological mapping has identified evidence of hundreds of other large landslides that occurred before modern records, providing an appreciation of the slope processes affecting the Freetown Peninsula.

Following the 2017 Regent Landslide, rehabilitation of the affected area involved a risk reduction strategy that centred on reducing population exposure. These events are a reminder that the steep slopes and valleys across the Freetown Peninsula are highly susceptible to rainfall-triggered landslides which, given the topography have a high propensity to generate high intensity landslides and debris-laden floods. Future urbanization must consider whole-catchment management, flooding and slope engineering issues to provide lasting landslide risk reduction.

Main body of paper:

Sierra Leone is situated on the west coast of Africa and shares borders with Guinea to the north and Liberia to the south. The capital city of Sierra Leone, Freetown is located on a mountainous peninsula in the far west of the country on the Atlantic Ocean Coast (Figure 1). The peninsula is approximately 38 km long and 16 km wide, with a topographic relief of over 700 m. Dense forest covers the highest areas of the peninsula, while many of the lower slopes have been deforested leaving a cover of sparse forest, grasslands and urbanised built-up areas. The city of Freetown itself is located at the northern tip of the peninsula, bounded by the Atlantic Ocean to the west and the deep natural harbour at the mouth of the Sierra Leone River to the north and east.

Part of the Freetown Peninsula was declared a forest reserve in 1916. The forest reserve area covers many rainwater catchments which are vital for the drinking water supply to Freetown (including the site of the 2017 Regent Landslide). If protected, the city's reservoirs, which are located across the peninsula, have enough capacity to supply Freetown with clean water.

However, the forest reserve is seriously threatened by deforestation for charcoal burning, farming, quarrying and construction. Rapid urbanisation in Freetown has contributed to the development of informal, unplanned settlements. Internal displacement during the civil war, and migration in search of employment opportunities in Freetown, has further contributed to the growth of the city's population (Arup et al. 2018).

2. Geology, climate and natural hazards

2.1 Geology

Bedrock geology across the Freetown Peninsula is dominated by the Freetown Layered Complex, a 65 km long, 14 km wide, 7 km thick tholeiitic intrusion which intruded the West African Craton during the Early Jurassic ~200 Ma (Callegaro et al 2017; Chalokwu et al. 1995; Chalokwu, 2001). The intrusion has an arcuate outcrop towards the west and extends out under the Atlantic Ocean. It is composed of a layered complex of gabbro, norite, troctolite and anorthosite. The igneous layering dips southwest and is transected by several steeply-dipping late faults, with both NE-SW and WNW-ESE trends (Umeji 1983). The bedrock geology of Sierra Leone is dominated by Archaean basement, formed between 3.5 and 2.8 Ga (Rollinson, 2016). The western margin of that cratonic block, along the coast of Sierra Leone, is marked by Proterozoic terranes that were most probably accreted at the end of the Neoproterozoic (de Waele et al. 2015). The Freetown Layered Complex was intruded into this margin at c. 200 Ma (Callegaro et al. 2017) as part of the voluminous Central Atlantic Magmatic Province (CAMP). Finally, the Bullom Group marine and estuarine sediments were deposited unconformably onto the coastal strip of Sierra Leone during the Cenozoic (Dixey, 1922; Williams, 1978; Morel, 1979; MacFarlane et al., 1979; MacFarlane et al. 1981; Umeji, 1983; Chalokwu, 2001).

The present-day topography is the product of a combination of rock weathering processes during the Quaternary when a thick saprolite soil mantle developed, and periods of erosion of soil and bedrock on slopes by landslides. Laterites consisting of ferricrete surfaces formed at the foot of slopes, with recent marine and river alluvium along the coast and in river tracts (Fookes, 1990).

2.2 Geomorphology

The topography of the central part of the peninsula is dominated by steep hillslopes, ridges and valleys. Valleys in the mountain region are deeply incised and steeply sided, with a dense, though diminishing, tree cover. The drainage pattern is strongly influenced by a series of NE-SW orientated parallel mountain ridges (Dixey 1922) and two main NW-SE orientated valleys, probably associated with major unloading joint systems, and bedrock faults respectively. Rivers and groundwater pathways have exploited the mechanically weaker (more fractured and deeply weathered) materials that occur along these features. Where the rivers reach the coastal platforms or the flat embayments on the peninsula, they become sharply entrenched but the hard lateritic crust confines the rivers to narrow, steep-sided valleys (Wells, 1962). There are several man-made reservoirs (Guma Dam No. 1 and No. 2, Tacugama, Bathurst) that exploit the elevated valleys to supply water and hydropower to Freetown (Williams, 1965). Dixon and Robertson (1970) provide a review of the weathered tropical soils encountered during the construction of the Guma Dam.

2.3 Climate

Sierra Leone has a humid, tropical climate and a seasonal rainfall pattern that peaks between July and September (McSweeney et al., 2010). Recently, periods of drought have occurred due to the delayed onset of the monsoon rains. When the heavy rain has arrived there has often been extensive flooding (Tarawalli, 2012). This rainfall season is largely controlled by

the movement of the tropical rain belt, also known as the Inter-Tropical Convergence Zone (ITCZ), which oscillates between the northern and southern tropics over the course of a year and affects Sierra Leone when in its northern position. The ITCZ produces the West African Monsoon, resulting in exceptionally high coastal rainfall during the wet season.

2.4 Natural hazards

The geology, topography, and physical location of Freetown make it prone to seasonally recurring natural hazards, chiefly flooding and landslides (Arup et al. 2018). Flooding in Sierra Leone is most common in the rainy season between May and November. While flooding occurs across Sierra Leone, flood events in Freetown can be particularly damaging as the steep terrain with narrow incised gulleys can cause rapid flash flooding. These high energy, rapid flows can cause substantial destruction and pose a significant threat to life.

2.4.1 Landslide hazard

Landslide hazards on the Freetown Peninsula are frequent and landslide hazard is widely recognised by government and to a lesser extent by the resident population (Freetown City Council, 2014). Landslide types include deep-seated rotational slides, translational slides which typically initiate as debris slides and develop into debris flows, rock falls and single boulder rolls (Cruden and Varnes 1996; Thomas 1998). Some apparent rock outcrops are merely the projecting tip of large residual blocks embedded in the weathered mantle and these can be distinguished from displaced boulders by the orientation of the gabbro layering. Whilst these largely remain in situ some creep is inevitable on steeper slopes (Thomas, 1994).

Geomorphological evidence of old translational slides is widespread on the slopes around Freetown (Thomas, 1994). Detachment of the slide mass along the bedrock-soil interface, often leaves a relatively fresh bedrock scar, which is recognisable on high-resolution aerial photographs and digital elevation models by absent or sparse forest cover and a dark grey

reflective surface. In the 1970s and 1980s M. Thomas mapped several hundred slide scars (Figure 1) in the central highlands from 1:12,500 scale aerial photo interpretation with some field observations to ground truth remote assessments (Thomas, 1998).

On the Freetown Peninsula, colluvium covered slopes tend to fail at angles of $>26^\circ$ (Thomas, 1983; 1998). The thickness of soil and rock weathering profiles is locally affected by bedrock texture, geochemistry and mechanical discontinuities (joints, faults, and shears) and the degree/depth of laterisation and saprolite development. The landslide material tends to consist of debris: a mix of laterite, fine and coarse soils and weathered rock corestones. Chinsman (1977) investigated the geotechnical implications of unfavourable kinematic relationships between bedding (igneous layering), joints/fractures and major faults in north east Freetown. Slope parallel sheet joints are a commonly observed feature at landslide sites in other tropically weathered igneous terrains, such as in Hong Kong, and impart a structural control on slope instability (Parry, 2016).

Table 1 lists significant landslide events which have affected Freetown. One notable example is the 11th August 1945 Charlotte Landslide, which occurred in Charlotte Village near Bathurst, in the Orugu Valley. This landslide was triggered following significant rainfall amounting to more than 1,000 mm over a period of five days, culminating in approximately 400 mm of rainfall in the 24 hours preceding failure. The landslide is noted to have resulted in at least 13 fatalities and partially blocked the Orugu Valley, causing flooding.

3. The Regent-Lumley Disaster

On the morning of Monday 14th August 2017, a major landslide occurred in the Regent ward, Western Area Rural, Freetown. The combined effects of the landslide and flooding resulted in one of the largest natural disasters to affect Sierra Leone in the last century. No natural disaster anywhere in the world claimed more lives in 2017. The event sparked an

international response, which included the activation of the International Disaster Charter and a World Bank-led Post-Disaster Damage and Loss Assessment (DaLA) (World Bank, 2017).

The rock-debris slide in Regent and ensuing debris flow is referred to as the Regent Landslide, whilst the rock-debris slide, debris flow, flooding and ensuing effects were often referred to in the press as the Regent-Lumley Disaster. The river which ephemerally flows down the channel between Regent and Lumley is called the Babadorie River and hence the valley is referred to as the Babadorie Valley.

3.1 Sequence of events

The following presents a summary of the sequence of events which led to and included the Regent Landslide. The interpretation of events is compiled from eyewitness accounts, photographs taken immediately following the disaster, aerial photography, satellite imagery, and engineering geological and geomorphological fieldwork carried out between August 2017 and April 2018 by Arup and the British Geological Survey (BGS) for the World Bank and United National Office for Project Services (UNOPS). Figure 2 presents an overview of the 6 km long hazard footprint.

3.1.1 Precursors to failure

Precipitation totals in Sierra Leone were above average during the 2017 rainy season. The US National Weather Service's Climate Prediction Center states that 1040 mm of rain fell in Sierra Leone between 1st July 2017 and 14th August 2017 – three times more than expected for the same period during a typical rainy season. Overnight on Sunday 13th August – Monday 14th August 2017, severe rainfall caused significant flooding in Regent and in the uppermost parts of the Babadorie Valley. The US National Oceanic and Atmospheric Administration (NOAA) Africa Rainfall Climatology Version 2.0 (ARC2) model reported total rainfall anomalies of up to 100 mm more than normal for the period 10th-16th August

2017. This equates to almost 200% of the normal rainfall totals for the period. On 14th August 2017 the NOAA ARC2 satellite recorded 25-50 mm rainfall across the area encompassing Freetown (Arup et al. 2018). Accurate rainfall time series data are not available for the Freetown Peninsula area, making the identification of location-specific values not possible. Flooding in Regent and along the Babadorie Valley at this time was such that some people were already being forced to abandon their properties for their own safety. Many properties in Regent are constructed across or near to natural drainage lines and many have concreted yards and driveways. There is little to no provision for surface water management and hence such surface runoff here is erosive and can be rapid.

3.1.2 Initiation

The Regent Landslide initiated on a north-north easterly facing slope, at approximately 06:50 on Monday 14th August 2017 (Figure 3). During post-failure inspection water seepages were observed draining from open joints on the upper parts of the landslide scar. The compound effect of softening of clay-infill within discontinuities, loss of pore suctions due to saturation under an extreme rainfall event, and increased pore-water pressures on key joint sets within the gabbro rock mass are considered to be key factors which led the slope to fail. The landslide is understood to have occurred in two phases, as indicated by eyewitness accounts.

3.1.3 First stage translational rock-debris slides

Two clear failure mechanisms can be identified from the upper part of the landslide scar (Figure 4):

(A) In the upper scar area, the fracture orientation facilitated wedge-type sliding failure mechanisms (recognised in the immediate aftermath of the landslide by Usamah, 2017), along weathered joints within the gabbro, which released large angular blocks of variously-weathered gabbro (Figure 5);

(B) On the lower part of the upper scar the joint pattern is different, with highly persistent and broadly undulating slope-parallel sheet jointing lined with softened clay infill within partially-weathered gabbro being the principal discontinuity set, favouring a more planar translational sliding mechanism.

The exact sequence of the reported two-stage failure remains unclear as it was not caught on camera and visibility was low due to the morning mist. It is difficult to infer which of the above processes occurred first, or indeed if there was some preliminary failure, evidence of which was subsequently eradicated by the catastrophic main failure of the slope. Broadly, the failure mechanism is most accurately characterised as a deep-seated translational rock slide which displaced a mantle of variously weathered gabbro, weathered saprolite and residual soil and trees with it. Unlike many of the historical failures observed on the Freetown Peninsula, the main failure surface was, in places, below the bedrock-soil (regolith) interface which was a contributing factor to the large volume of debris released by the landslide.

The discovery of in situ remains of a house foundation in the mid-slope area, below a prominent bench feature located at approximately 350 mAMS (Figure 6) points to a slope failure contained entirely within the upper slope area, and rules out a basal or toe failure. Quite why the failure broke out at mid-slope and formed a bench feature rather than continuing to some deeper level remains unclear. Broad ~10 m wavelength undulations with an amplitude of ~1 m along the controlling surface-parallel gabbro sheet joints may have brought the failure plane closer to the ground surface here, causing it to daylight in the slope. The debris then ran out and stripped off the slope vegetation and topsoils from the lower slope but did not fail through it (Figure 7).

3.1.4 Second stage transition to channelised debris flow

From approximately halfway down to the foot of the slope, material was no longer falling and sliding from the hillside by wedge and translational mechanisms, but processes shifted to sliding, rolling and flowing over the ground surface. Once this vast volume of material reached the lower parts of the slope, it mixed with the gathering floodwaters at the foot of the slope. The flooding here would have been locally static, accumulating in the natural topographic depressions in this part of Regent. Some of the floodwaters would have continued to flow rapidly from east to west down the Babadorie Valley and out to sea.

At this point along its path the landslide began to display predominantly flow-like behaviour with debris and large boulders entrained in a dense slurry. Internal deformation (abrasion) within the slurry further disaggregated weak weathered rock particles and water content was sustained by incoming surface water. This sort of debris flow commonly develops when landslide debris mixes with surface runoff (Iverson, 1997). The transition from sliding to flow-like behaviour can occur rapidly (Santi et al., 2011).

As the debris flow became channelised it gained mass and greater mobility due to scour erosion of river bank deposits and entrainment of debris picked up from the river bed. The velocity of such debris flows can be as high as 15 m/s (Hungr et al., 2001). At this point, the path of the debris flow was controlled by the alignment and confinement of the east-west trending Babadorie Valley.

Due to the presence of natural pinch-points in the Babadorie Valley, it is probable that the channel may have, at times during the event, become partially blocked or 'choked' by boulders, trees or other entrained debris. The occurrence of temporary dams would have permitted the build-up of material until such a time that the blockage burst suddenly, releasing a further surge of fast-flowing debris along the channel. These natural pinch-points

would also have facilitated acceleration of the flow in places. These factors may account for the extent and scale of building damage and devastation as far as 3 km downstream along the channel in Kamayama.

3.1.5 Third stage: debris-laden flooding

The destructive force of the debris flow would have gradually reduced from east to west as its load was deposited, the topographic gradient reduced, and the floodplain widened. By the time the debris flow reached Lumley, it would have resembled a large, relatively fast flowing flood (compared to what might be a typical seasonal flood in the channel). The floodwaters then flowed out into the Atlantic Ocean, depositing their remaining load as a sediment plume, which can be clearly seen in post-event satellite imagery (Figure 2).

4. Causes and mechanisms

While there were a significant number of properties built into the pre-failure slope profile, and these were generally facilitated by the cutting of a construction platform into the hillslope, it is believed that these works were not a major contributing factor to triggering the landslide. This is because the landslide has liberated much debris of intact, partially-weathered gabbro, indicating a deeper failure surface than could be linked to shallow building cuts on the slope. Construction was limited to the lower half of the slope, which is not the source for the majority of the landslide debris as some foundations remain in situ.

4.1 Discontinuities within the rock mass

The bedrock geology in the landslide source area is olivine-rich layered gabbro, with layers dipping between 20 and 45° to the southwest. The rock mass also contains basalt dykes, some oriented parallel to the slope. The bedrock has been altered in the upper 10 m, producing fresh gabbro core stones typically surrounded by a rind of extremely weak to very strong

rock. This rind disaggregates to loose soil with little mechanical agitation. Material between corestones contains concentric layers of strong red iron cements and low strength (stiff) clay.

The first stage landslide mechanism involved a combination of translational (planar) and wedge sliding along discrete pre-existing bedrock discontinuities, principally weathered sheet joints. The gabbro layering is not a significant structural control on the landslide mechanism on this north facing slope as the rock is tight along layers which are differentiated by slight mineralogical differences (olivine content). The main rupture surface for the Regent Landslide was 5-10 m below ground level, making it a deep-seated movement. This main failure surface follows a persistent undulating joint set with variable dips of between 20 and 45° to the north-northeast, parallel to the slope face (Figure 6). This controlling basal discontinuity may have effectively daylighted at the mid-slope, forming the wide bench feature evident in the landslide scar. The joint characteristics largely control rock mass strength in high intact-strength rocks such as gabbro and provide an indication of the weathering processes. The characteristics of the important joint sets were inspected in the main backscarp. The rock materials along the joint surfaces are heavily altered by weathering and display both red and white discolouration. The presence of kaolinite may indicate that the gabbro along these joints was initially altered by hydrothermal flow when the Freetown Layered Complex was emplaced. Subsequent supergene weathering exploited and further weakened these joint planes. The rock joint material is low strength, such that 1-20 mm thick slabs can be readily dislodged from exposed surfaces by hand, and easily broken by heavy hand pressure and disaggregated to dust between thumb and forefinger. Joints located 5-10 m below the pre-slide ground surface are filled with clay (Figure 8) and several types of secondary mineralisation occur as soft white kaolin and hard red iron oxide. The geological origin and history of all the fracture sets and their infill materials is unclear and the role of

previous phases of slope movement, or possible tectonic and/or hydrothermal activity could be important for engineering geology across the Freetown Peninsula.

4.2 Engineering properties and behaviour

Soil classification and mineralogical testing was carried out on bulk samples collected from the debris of the Regent Landslide at the BGS laboratories in Nottingham. Initial particle size distribution analyses on the landslide debris (matrix, excluding cobbles and boulders) returned 31% gravel, 36% sand, 19% silt and 14% clay. PSD analyses were done to British Standards (BS1377:1990) and with X-ray sedigraph for the fine fraction. Given the 33% fines content the landslide debris should resemble a fine-grained well-graded engineering soil, but inclusion of extremely strong gabbro boulders and cobbles, affects its field-scale properties. The accumulated soil has reasonably poor drainage properties and is prone to development of excess pore water pressures when saturated and sheared (undrained loading), explaining the 'quicksand-like behaviour' described by local geologists on the ground in the hours after the landslide.

Mineralogical testing of the clay fraction of the landslide debris by XRD identified 14% halloysite group clays with natural moisture contents of 29-31%. Halloysite clays have a hollow needle-like morphology that is microstructurally metastable and linked with 'collapsible soil' behaviour, whereby saturated soils can yield very suddenly when rapidly loaded (Moon, 2016). This may account for some aspect of the apparent rapid loss of shear strength that occurred along surface-parallel joints during the first stage translational and wedge failures and the second stage transition to flowing behaviour of the slide mass.

These values should be treated with due caution as the data is based on only a very small number of samples. Furthermore, hydrated halloysite clay morphologies are highly sensitive to environmental and storage conditions which can occur between the field (Sierra Leone)

and laboratory (UK). Other thick clay seams were identified in the bedrock 2 km to the west of the Regent Landslide in the Babadorie Valley. Atterberg Limit tests found these to be high to very high plasticity clays with NMC of 48-55%. XRD returned 28% halloysitic clays. Further XRD, SEM and geotechnical characterisation work is being carried out by BGS to further ascertain the material properties and behaviour.

The identification of clay filled fractures in the gabbro host rock is highly significant to slope stability and ground engineering projects on the Freetown Peninsula, due to the marked reduction in shear strength and rock mass strength these features introduce. Local sources suggest the nearby Sugar Loaf Mountain gets its name from a colloquial understanding of this problematic geotechnical behaviour, whereby hard granular soils rapidly disintegrate to a 'syrup-like slurry' on wetting.

4.3 Deforestation

Comparison of 2005 and 2017 Google Earth imagery highlights the marked reduction in the density of slope vegetation in Regent. Burnt tree stumps and long grass were observed at the top of the ridge behind the rear scarp, indicating that the ridge slope has undergone recent deforestation. Significant deforestation is also apparent on the southerly side of the slope behind the Regent Landslide (Usamah, 2017). Deforestation increased the susceptibility of the slope to failure in two ways: firstly, by reducing the canopy protection and water-uptake associated with dense tropical forest cover, meaning increased seepage of rainwater into the ground; and secondly, by removing the mechanical stabilising effect offered by tree roots, which can be particularly beneficial for slope stability in weathered tropical soils. The stabilising effect of tree roots is evidenced by the retention of a large block of ground on the eastern flank of the landslide scar, which coincides with the elevation at which dense forest

cover is present on the adjacent hillslope. This area is referred to as 'The Return' (marked on Figure 3 and Figure 4).

Despite the obvious negative effects of deforestation on slope stability at the Regent Landslide, it should be noted that several other smaller landslides also occurred at around the same time in forested areas. One of these was located on the back-slope of the Regent Landslide and is shown schematically on Figure 7. Historically, landslides have occurred across the Freetown Peninsula in areas unaffected by deforestation (Table 1; Figure 1). This serves to illustrate that landslides are a natural part of terrain evolution on the Freetown Peninsula and that although more recent deforestation unquestionably has a negative effect on slope stability, it is not the only factor which increases the landslide susceptibility. The answer to the question of whether the Regent Landslide would have occurred were it not for deforestation on the steep hillslopes near Regent is not a straightforward one. Quantitative investigation of this potential effect by experiment or test, and process modelling, is necessary to check whether this assessment is correct or not.

5. Impacts and losses

The Regent-Lumley Disaster claimed the lives of approximately 1,100 people and directly affected more than 5,000 people. Those who survived the disaster were, in many cases, left without family, homes, possessions, savings, transport, jobs, schools and general livelihoods.

The impacts of the disaster varied along the length of the Babadorie Valley. In Regent, despite larger and apparently more structurally robust buildings, the number of fatalities and proportion of buildings destroyed was highest. This can be attributed to the devastating high-energy nature of the landslide which affected this area. To the west, although further from the source of the landslide, damage to properties in the channel near Kamayama was still extensive (Figure 9), which demonstrates the debris-laden nature of the flooding here. In

Lumley, 6 km from the Regent Landslide, the effects of the disaster were still significant due to increased vulnerability of the population in these areas, many of whom live in informal buildings.

In total, the disaster was assessed to have caused approximately \$31M USD damage and loss (World Bank, 2017), the majority of which was in the housing sector (approximately \$14M USD) followed by both social protection and healthcare sectors (each approximately \$5M USD). It has been further estimated that a total of approximately \$82M USD is required to support short, medium and long-term recovery efforts following the Regent-Lumley Disaster.

6. Rehabilitation

Rehabilitation works at the site of the Regent Landslide have been ongoing since April 2018 and have largely comprised the regrading and management of the slopes and watercourses at the foot of the Regent Landslide in Regent (Figure 10). Moving forward, landslide risk in this area will be managed by reducing exposure by preventing rebuilding and resettlement in the Babadorie Valley, much of which, including the affected areas in Regent, is already designated as a National Forest Reserve. Managing risk by more traditional hard-engineering approaches which typically seek to reduce hazard (by rock-bolting or netting etc.) was not appropriate given the urgent need to implement risk reduction measures at the site prior to the 2018 rainy season and other logistical and financial considerations. The site has also been much re-planted which will act to both deter resettlement and promote the local stability of the reprofiled channels. Much of this rehabilitation work and replanting was done by the local population, many of whom were affected by the disaster.

7. Conclusions

The Regent-Lumley Disaster comprised a three-stage hazard event: first stage translational failures through partially weathered gabbro in mountainous uplands; second stage transition

to channelised debris-flows on the lower slopes above partially flooded valleys; and third stage debris-laden channelised flooding. The large volume of material involved may be attributed to a deeper-seated failure through partially-weathered gabbro rather than at the soil-bedrock interface as has historically been observed in Freetown. This mechanism liberated extremely large mega-boulders that contributed to the destructive force of the first and second stage processes. The transition to debris-flowing may have been further encouraged by the presence of highly collapsible halloysitic clays, however this remains the subject of further investigation. Downstream from the Regent Landslide, the energy of the flow may have been maintained and surged by the formation of temporary debris-dams at natural pinch-points in the river valley.

This event shares similarities to the 1945 Charlotte Landslide which resulted in 13 fatalities. Perhaps the most striking difference between the two events is not the nature of the hazard, but the increase in population exposure within the landslide footprint due to urbanization and population growth. Looking forward, climate change may well bring more intense seasonal rainfall patterns, and population exposure is set to rise in Freetown, increasing landslide risk further. Future work must focus on the implementation of practical, effective and implementable risk reduction strategies across the Freetown Peninsula including improved understanding of how and where fractures affect slope stability on natural and man-made slopes.

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Appendices:

None

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Table 1: Recorded landslide events in Freetown. Based on compilation of media reports; Thomas (1998), his unpublished work and updated by BGS in 2017 (Arup et al. 2018).

Date	Location	Impact
Pre – 1945 (ages unknown)	Western Area, includes Salpon and Funima	≥415 landslide scars, impact unknown.
11 th August 1945	Charlotte Community, near Bathurst	At least 13 fatalities.
1963	Guma Dam, Guma valley	No fatalities, construction delays.
2004-2014	Freetown	8 events, no fatalities
2008	Freetown	1 fatality
May 2009	Freetown	2 fatalities
13 th August 2009	Kissy Brook	7, 15 injuries
September 2010	Mountain Cut	14 fatalities,
3 rd August 2011	Moyiba	1 fatalities, 4 seriously injured.
8 th August 2013	Wallace Jonson Street	15 fatalities
4 th May 2014	Grey Bush neighbourhood	5 fatalities
August 2014	Bridge collapse	8 fatalities
13 October 2014	Oloshoro community, Murray Town	4 fatalities
14 th August 2017, ~06:50 [Regent Landslide]	Regent – Lumley. Babadorie Valley.	1,100 fatalities, 5,000 affected.

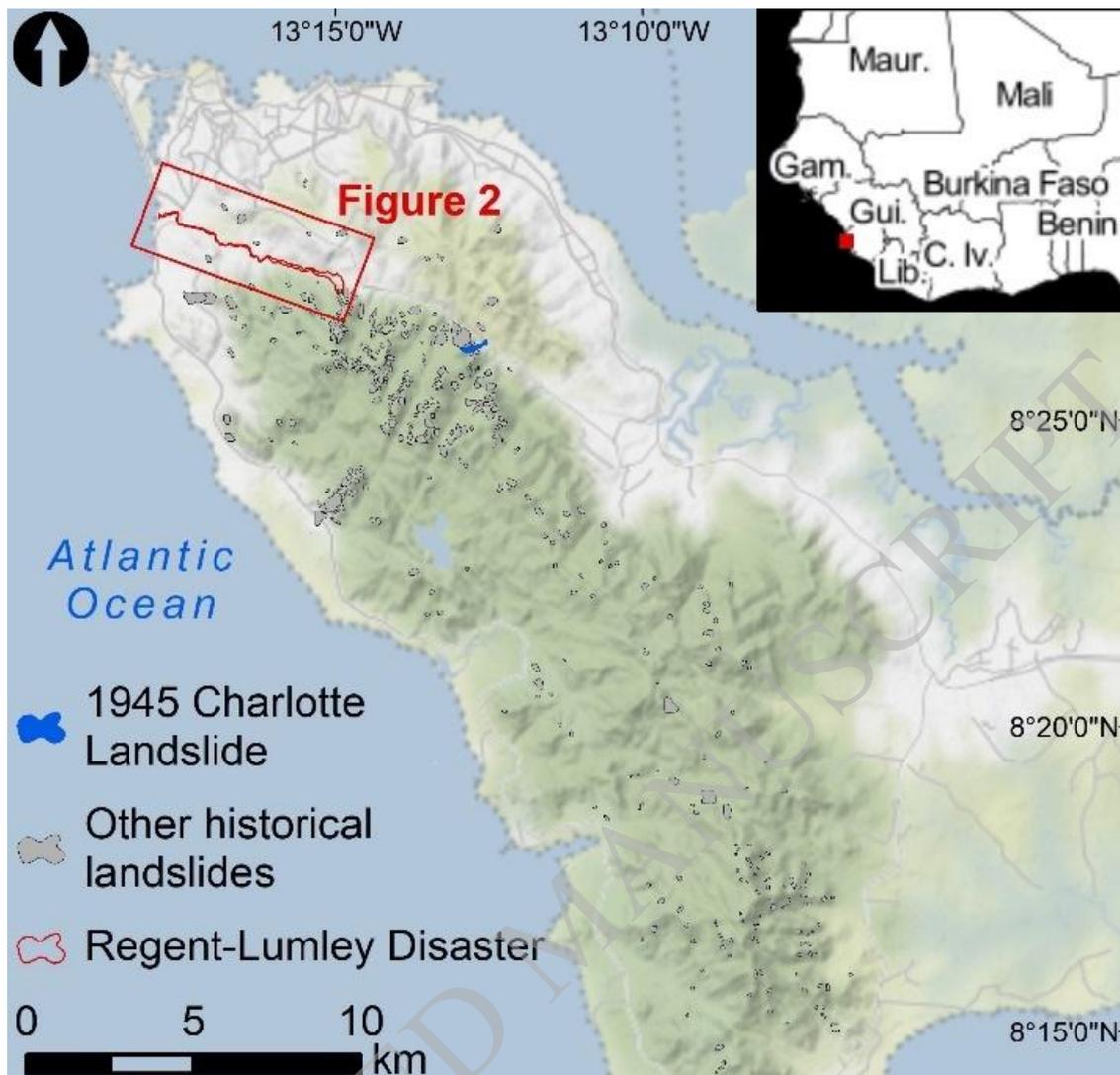


Figure 1: The Freetown Peninsula, showing historical landslide scars (Thomas, 1998, his unpublished work and updated by BGS in 2017 – Arup et al., 2018) and the 2017 Regent-Lumley Disaster. Basemap by Stamen Design, under CC BY 3.0. Data by OpenStreetMap, under CC BY SA. Inset map shows the location of Freetown (as a red dot) in West Africa.

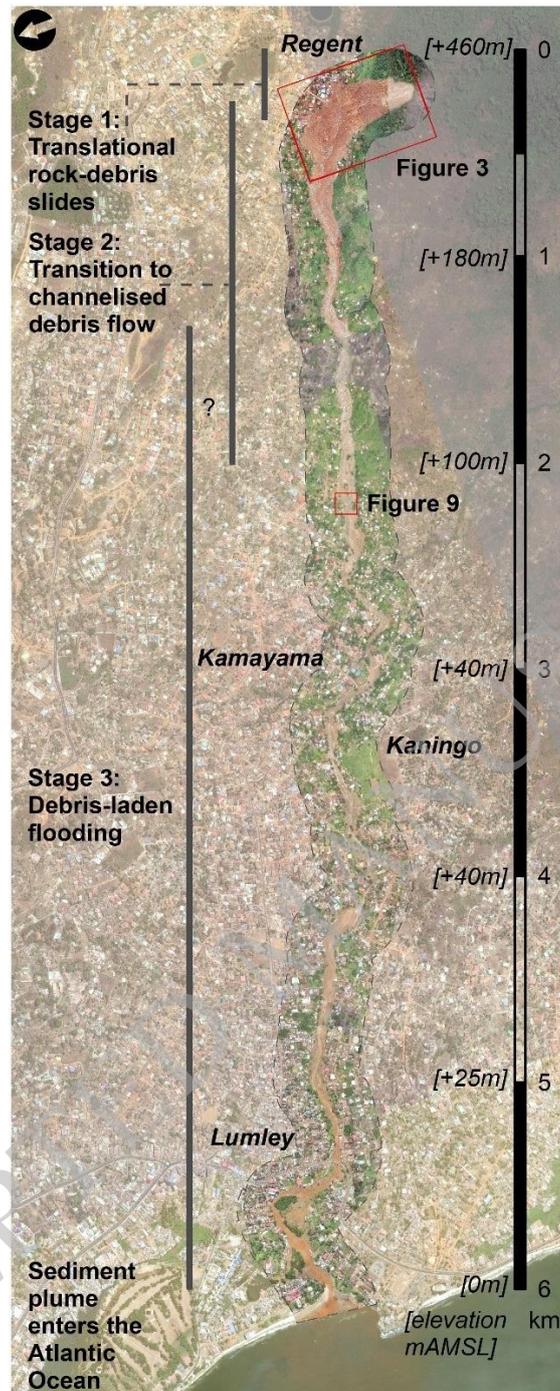


Figure 2: The Regent-Lumley Disaster between along the Babadorie Valley. Imagery shown with a hatched outline of the Regent-Lumley Disaster (centre) by EDA for the World Bank (30th August 2017) and by TYB for UNOPS (24th May 2018). Background imagery by DigitalGlobe (main image 3rd March 2017 imagery, sediment plume shown from 15th August 2017 imagery), under CC Attribution-NonCommercial 4.0 International (<https://creativecommons.org/licenses/by-nc/4.0/legalcode>).

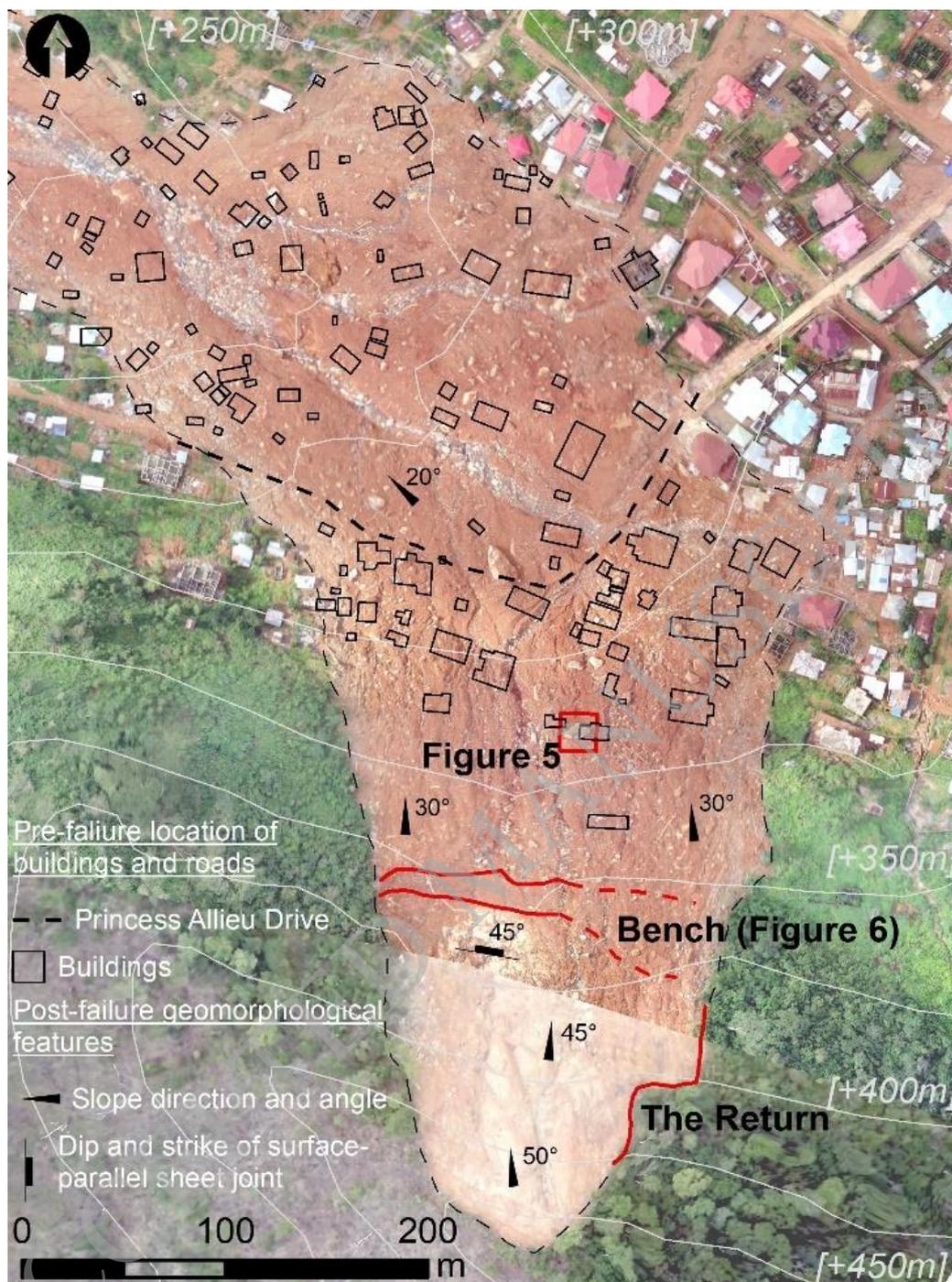


Figure 3: The Regent Landslide (shown hatched black). Imagery by EDA for the World Bank (30th August 2017) and by TYB for UNOPS (24th May 2018).



Figure 4: The Regent Landslide formed a large ~250 m wide ~200 m tall scar on the landscape on the north-facing side of a mountainous valley in Regent, Western Area Rural, Freetown (view looking south, image by Arup, 24th August 2017).



Figure 5: The first stage rock slide processes released angular blocks of gabbro depositing boulders up to 15 m long. (image by Arup, 10th December 2017).



Figure 6: The morphology of the slope features an upper bedrock scar exposing weathered steeply dipping persistent undulating sheet-joints and a flat bench on the mid-slope (centre image), where the deep-seated basal slide surface probably emerged. The lower slope is covered by colluvium with large boulders. All slope vegetation was stripped away and most buildings destroyed (view looking west, image by Arup, 10th December 2017).

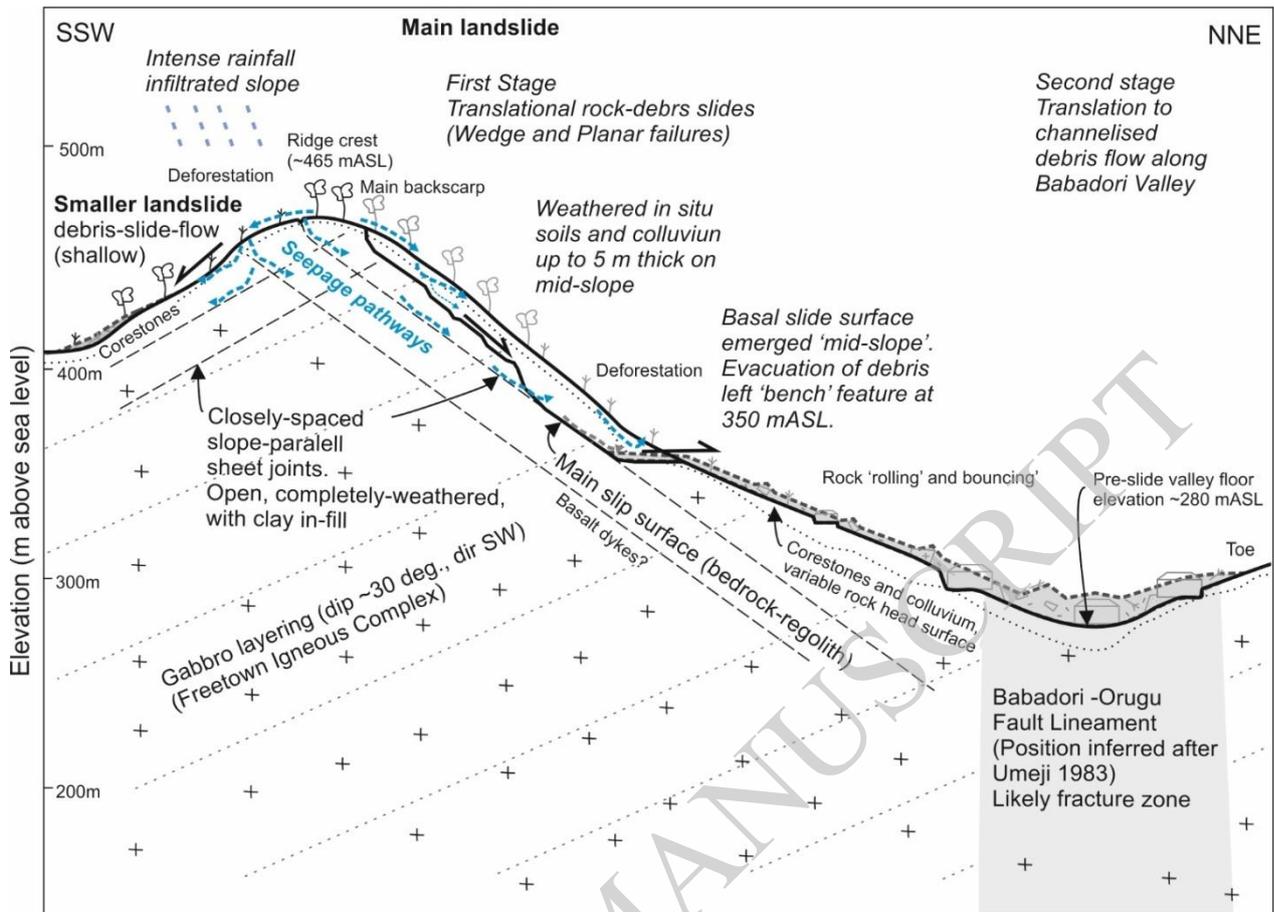


Figure 7: Schematic cross section showing main tectonic, geological and geomorphological features.



Figure 8: Surface parallel joints located 5-10 m below the pre-slide ground surface (now exposed by the Regent Landslide) are filled with clay (image by Arup, 10th December 2017).



Figure 9: Damage to buildings resulting from the second stage debris-flow and third stage debris-laden flooding was significant. This image shows a property destroyed by debris carried by the flood in Kamayama, ~3 km downstream from the site of the Regent Landslide (image by Arup, 25th August 2017).



Figure 10: Oblique aerial photograph of the Regent Landslide in 2018 after partial completion of rehabilitation works, improvement of drainage and replanting in the toe area of the Regent Landslide (image by TYB for UNOPS, 8th October 2018).