

The landslides of the 8th November 2020 in the Gordon Town – Irish Town area of Jamaica: geology, triggers and consequences

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ABSTRACT. Landslides are a major geological hazard induced by either earthquakes or high intensity rainfall causing damage to life and infrastructure. The Hope River Watershed in Jamaica is vulnerable to landslides due to its steep terrain and impermeable surface lithology. In 2020, Jamaica was impacted by two tropical storms, Zeta (October 19-25) and Eta (November 1-9), which triggered three landslides along the Gordon Town and Irish Town roads on the 8th November. Geological field mapping and rainfall analyses were undertaken to understand the trigger mechanism for the landslides. Detailed field mapping showed that one landslide (L1) occurred in colluvial deposits, one (L2) in jointed Wag Water conglomerates, and one (L3) in interbedded sandstones and shales of the Wag Water Formation. Two of the landslides (L1 and L3) occurred through failures of slopes above the roadway, while L2 was caused by a failure below the roadway. Rainfall analysis shows that the total rainfall for the seven days of TS Zeta was 1841 mm. The station at Mavis Bank recorded the highest 24 hour rainfall of 415 mm. The total rainfall for the TS Eta was also 1661 mm which although less than the previous event was enough to increase pore water pressure and thus initiated failure. Antecedent rainfall led to infiltration of colluvium and bedrock along bedding planes and joints and the increased pore-water pressure triggered slope failure. Understanding lithology, bedding orientation and joints is important in determining where landslides are more likely to occur, whereas predicting rainfall totals can indicate whether landslides may be triggered..

Keywords: Landslides, antecedent rainfall, Jamaica, geology.

1. INTRODUCTION

Jamaica is situated in the humid tropics and is a mountainous island with areas of uplifted volcanic/sedimentary rocks and limestone plateaux which are distributed in tectonic blocks and belts (**Figure 1**). The various rocks present in Jamaica reflect its geological history from the early Cretaceous to the present, which can be divided into four broad, although overlapping, stages (**Robinson, 1994; Draper, 1998; Mitchell, 2020**).

Stage 1: A Cretaceous to Paleocene volcanic phase where the rocks in different Cretaceous terranes formed in island arc and large igneous complex settings. The rocks consist of various igneous rocks (lava flows, pyroclastics deposits and intrusives), metamorphic rocks (amphibolites, blueschists and greenschists) and sedimentary rocks (clastics and subsidiary limestones).

Stage 2: A Paleocene to early Eocene rifting phase when the different terranes were assembled along strike-slip faults. The rocks consists of coarse-grained clastic rocks and basinal shales deposited in grabens, locally with lava flows and shallow-level intrusions.

Stage 3: A thick series of Paleocene/Eocene to mid Miocene carbonate rocks formed on carbonate platforms. The rocks consist of mixed clastics and impure carbonates in the lower part passing upward into pure carbonates – although this change is strongly diachronous across the island.

Stage 4: Mid Miocene to Recent uplift and mountain building with extensive erosion, and the deposition of clastics and carbonates around the margin of the island.

The mid-Miocene to Recent uplift has locally stripped off the younger rocks to expose the now weathered clastic and igneous rocks of **Stages 1 and 2**, and these are exposed in mountainous areas with steep slopes. These slopes evolve through natural landslide processes as river systems incise into bedrock, with landslides triggered largely by heavy rainfall (**Maharaj, 1990, 1993; Ahmad, 1996, 2003**) or earthquakes (**Ahmad, 1989, 1996, 2003; Maharaj, 1990, 1993**). Human activity has significantly affected the frequency and location of landslides through deforestation, farming practices, road construction, building, etc. (**Ahmad, 1989**).

In late October and early November of 2020, Jamaica was affected by two tropical storms, Zeta

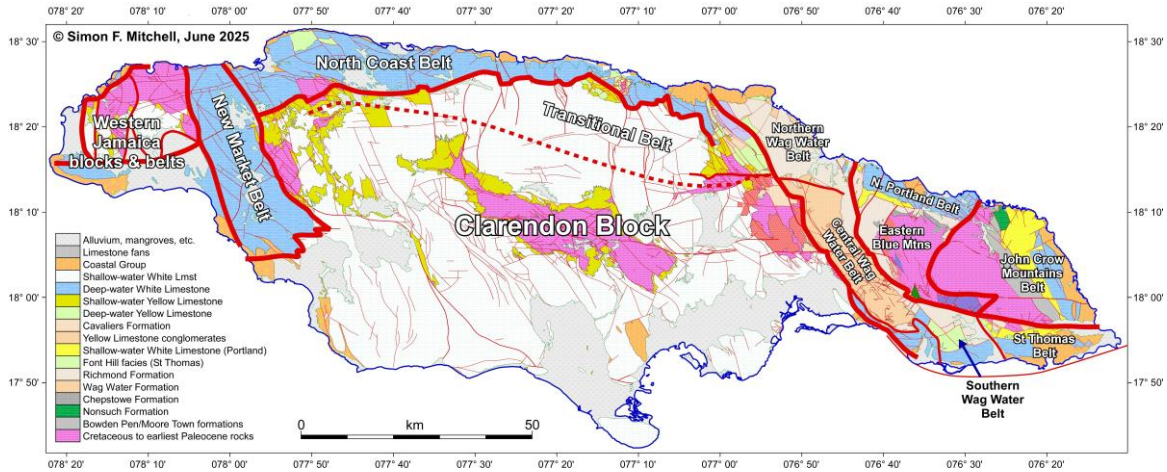


Figure 1. Simplified geology of Jamaica showing main geological units, belts and blocks. The study area lies in the south central part of the Wag Water Belt. Summary map by SFM.

and Eta, which produced very heavy rainfall across the parishes of Kingston and St Andrew. Tropical Storm Zeta affected the island from the 24th–29th of October followed by Tropical Storm Eta from the 1st–8th of November 2020 causing heavy rainfall. This resulted in a series of landslides along the roads connecting Kingston with the communities of Gordon Town and Irish Town within the Hope River Watershed, a watershed prone to landslides and flooding (Maharaj, 1990, 1993; Mandal et al., 2016, 2021) due to its steep terrain, impermeable surface geology and deeply incised river systems.

The traditional Jamaican approach to understanding the distribution of landslides is through GIS analyses, with input data consisting of baseline geology (derived from published geological maps) and slope angle and aspect (determined from topographic maps) (e.g., Maharaj, 1990, 1993; Ahmad and McCalpin, 2000). All of these input files have limitations in terms of accuracy and scale. In particular, many geological maps are of a provisional form and at a scale which is not appropriate for understanding the occurrence of individual landslides.

Following the landslides, we undertook an analysis of the detailed geology of the landslide locations to better understand the underlying physical (rock and colluvial) controls that led to the landslides occurring. In this paper we describe the geology and the triggers for these landslide events and make conclusions and recommendations for future investigations.

2. METHODOLOGY

For this study we used geological data that had

been collected before the landslides occurred. This consisted of detailed geological maps with different lithologies grouped into formations. Geological map data was collected periodically over the period 1996 to 2020 and included mapping onto prepared base maps and collecting data using GPS positioning. Field sheets represented portions of the 1:10,000 and 1:12,500 topographic maps produced by the Jamaican Survey Department. Lithologies were determined along field transects and placed on the map together with other relevant geological data (bedding orientation, joint orientation, faults, etc.). A hand held Garmin GPS unit was used for additional work, particularly in mapping off-road trails to accurately geo-reference them and the existing road network.

More specific studies were undertaken on the areas where landslides occurred during the October–November 2020 rains. This included a series of photographs showing the landslides and their aftermath, lithological data relating to the rocks that had failed, and bedding and joint orientation data from the rocks that had failed.

3. GEOLOGY

Various lithostratigraphic schemes have been used in depicting the geology of the area around Irish Town and Gordon Town, including Matley (1951), Green and Holiday (1974), Green (1977) and Mann and Burke (1990). All of these studies mapped formations and not rock lithologies, and therefore have significant limitations when discussing the occurrences of individual landslides. Here we map lithologies, which are shown on the geological map, and group these into their constituent formations (Boothe et al., 2022). Thus a formation may consist

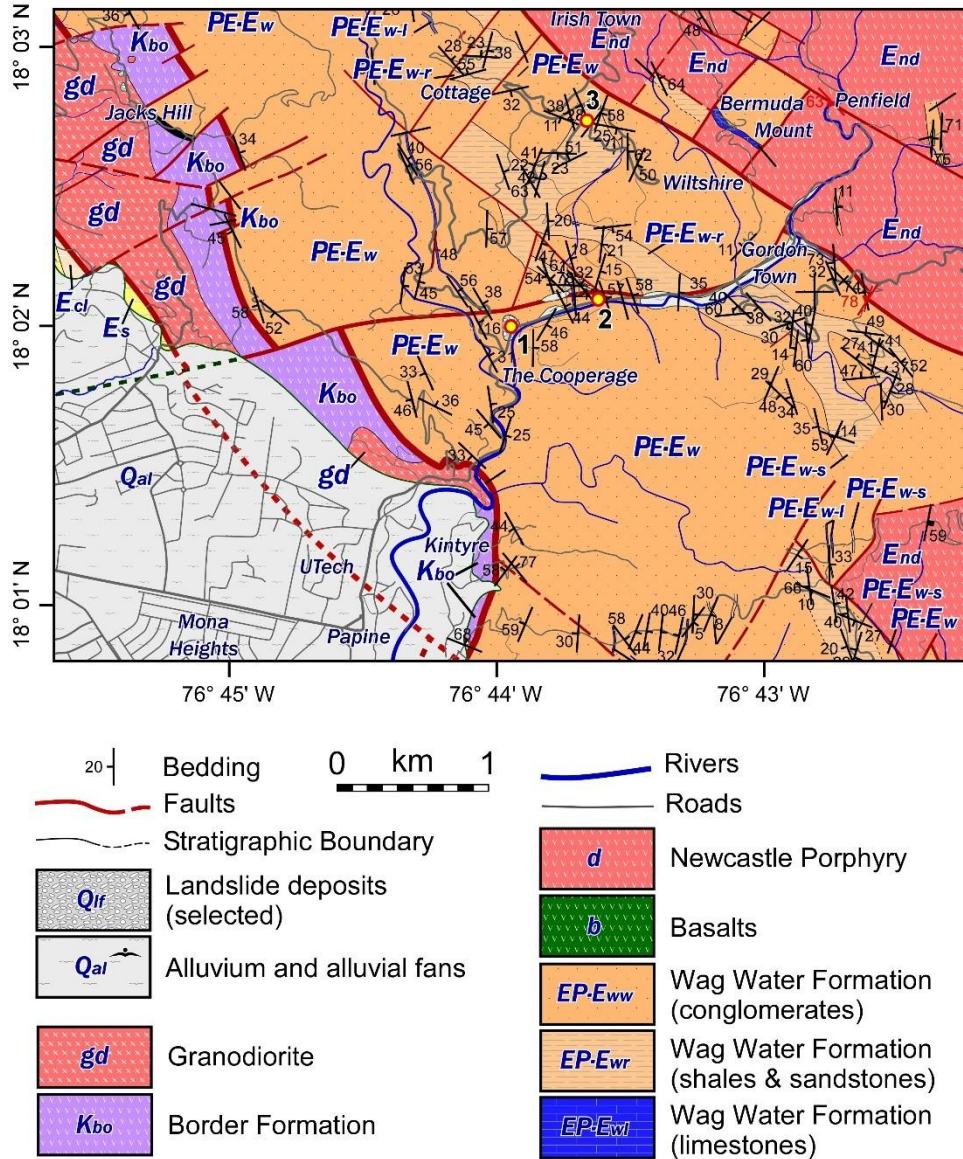


Figure 2. Geology of the area around Gordon Town, Wag Water Belt (based on unpublished map by SFM).

of one or many lithologies, with individual lithologies being shown on the accompanying map (Figure 2).

3.1. Large-scale structure

The area around Gordon Town and Irish Town is situated within the Wag Water Belt (Figure 1), an inverted Paleocene to early Eocene graben which formed during Stage 2 of Jamaica’s evolution and was uplifted and eroded during Stage 4. The Wag Water Belt is separated from the Clarendon Block to the west by the NNW–SSE Wag Water Fault Zone which includes slithers of Cretaceous rocks and granodiorite (Stage 1 rocks), and mid-Cenozoic limestone (Stage 3 rocks). The Wag

Water Fault Zone is best interpreted as an ENE dipping complex fault, either with closely spaced fault planes, or with a basal thrust and a top thrust with a duplex of imbricate thrust blocks between. To the east, the Wag Water Belt is separated from the Blue Mountains Block by the NW-SE Blue Mountain Fault Zone (Figure 1). Some NNW–SSE- to NW–SE-trending reverse faults also occur within the Wag Water Belt, as do some broadly E–W strike-slip faults (Figures 1 and 2).

3.2. Formations and lithologies

The formations and lithologies discussed here include: Cretaceous rocks (‘Border’ Formation), the Wag Water Formation, Newcastle Porphyry,

undivided White Limestone (for simplicity), granodiorite, fan deposits and landslide deposits. Sedimentary and layered units are described first, then large-scale intrusive units and finally superficial units.

‘Border’ Formation. The name ‘Border’ Formation was first used in Versey (1967) and subsequently by Green (1972), for rocks exposed in the Above Rocks Inlier. It is used here for a series of fault slices that occur associated with the Wag Water Fault Zone (Figure 2). The formation consists of a series of volcanoclastic conglomerates and breccias and porphyritic igneous rocks with a fine-grained ground mass (either lava flows or shallow-level sills). They range from relatively fresh exposures (particularly along river and stream courses) to deeply weathered/altered rocks largely composed of clay minerals. The original lithology of the heavily weathered rocks is often difficult or impossible to resolve.

Wag Water Formation. The Wag Water Formation (Matley, 1940; Robinson in Zans et al., 1963; Mann and Burke, 1990; Boothe et al., 2022) contains a range of lithologies in the area shown in Figure 2. The larger part of the formation consists of medium- to thickly-bedded, red/purple to occasionally brown, pebble- to cobble-conglomerates with intervening units of thickly bedded, reddish to brown, coarse-grained sandstone. The distantly spaced bedding planes tend to give rise to thick exposures, often without obvious bedding planes. Irregular joints are present within beds, and are generally widely spaced.

The second most-frequently met lithology in the Wag Water Formation is a series of thin- to medium-bedded, grey, brown or reddish-brown, inter-bedded sandstones and shales (Mann and Burke, 1990). The sandstones range from 10 to 15 cm thick up to about 50–60 cm thick. Between the sandstones are units of shale and siltstone with thicknesses of a few centimetres to several decimetres. Bedding planes are well developed within the sandstone and shale units. Joints in the sandstones are spaced at distances of 10–15 cm up to about 40–60 cm, with joint spacing dependent on bed thickness (thicker beds having more widely spaced joints).

Other lithologies make up only a minor proportion of the Wag Water Formation in this area. They consist of thin beds of grey limestone, with thicknesses from 30–40 cm up to about 1.6 to 2 m (Matley, 1940; Mann and Burke, 1990; Mitchell et al., 2016). They tend to be nodular and have joints spaced at 40 to 200 cm. Pods of gypsum are also locally present (e.g., Green and Holiday, 1974), but do not form recognizable beds.

Newcastle Porphyry. The Wag Water Formation contains a series of lava flows or shallow, sill-like intrusions which are attributed to the Newcastle Porphyry (Matley, 1940). These consist of porphyritic dacites with phenocrysts of plagioclase, quartz and hornblende in a fine-grained ground mass and belong to the distinctive group of Jamaican Type Adakites (Hastie et al., 2010a, b; Boothe et al., 2022). Most of the Newcastle Porphyry is weathered to a lesser or greater degree. When weakly weathered, extensive joints are usually developed with at least three orientations that vary rapidly across individual outcrops. In some places, the Newcastle Porphyry is very deeply weathered and forms a regolith largely comprised of clay minerals replacing the original rock-forming minerals of the porphyry. Alteration to clays may be closely related to mineralized zones or to the proximity of faults.

White Limestone. Rocks belonging to the White Limestone Group are exposed in the Wag Water Fault Zone. These include the Troy, Swanswick, Claremont and Somerset formations (Mitchell, 2004, 2013). In general, the Troy Formation forms massive outcrops with large blocks separated by joints with a spacing of many metres. In contrast, the other formations of the White Limestone (Swanswick, Claremont and Somerset) show extensive brecciation with jointing at a scale of one to a few centimetres. The brecciation is undoubtedly due to the proximity of faults within the Wag Water Fault Zone.

Granodiorite. A series granodiorite stocks (possibly connected at depth) have been intruded into the ‘Border’ Formation (Green and Holiday, 1974). This consists of granodiorite with crystals of plagioclase, orthoclase, quartz, hornblende and biotite. In most places the granodiorite is very deeply weathered and gives rise to a thick regolith comprised of grains/crystals of quartz sitting within a clay ‘matrix’ formed from the disintegration of the non-quartz, rock-forming silicate minerals.

Fan deposits. The Liguanea Formation (Spencer, 1898) consists of conglomerates that were laid down by the Hope River, and other small rivers draining the Wag Water Fault Zone as an alluvial fan system. The formation forms a gently sea-ward dipping fan extending from the foot of the Wag Water Fault Zone southwards towards the sea (Wood, 1976; Wiggins-Grandison et al., 2003). Following river capture, the Hope River has cut an incised valley system through the Liguanea Formation forming the Hope River Gorge (Horsfield, 1973; Wood, 1976).

Landslide deposits. Ancient, recent and modern landslide deposits are found overlying the solid geology across the region (Ahmad and McCalpin, 2000). These can be delineated from aerial photograph interpretation and ground-truthed. Only larger-scale landslide deposits of a non-ephemeral form are shown on the geological map.

4. LANDSLIDES PRODUCED BY THE OCTOBER-NOVEMBER 2020 RAINS

Three road-blocking landslides occurred during the October–November rains of 2020. These are designated Landslides **L1**, **L2** and **L3**, in terms of their proximity to Kingston, respectively. Each landslide has different geological conditions and is therefore worthy of discussion.

Landslide L1 (Figure 3). This landslide occurred on the Kingston to Gordon Town Road a little to the NE of the Junction with the Irish Town Road (18° 02.000' N, 077° 43.948' W). This landslide occurred within colluvial deposits related to previous landslides. The colluvium consists of unstratified, poorly sorted sand, pebbles and boulders. This landslide represented movement within unconsolidated material from previous landslides.

Landslide L2 (Figures 4–5). This occurred on the Kingston to Gordon Town Road about 1 km to the NE of the Junction with the Irish Town Road (18° 02.090' N, 077° 43.610' W). This landslide is a series of rock falls affecting jointed bedrock of the Wag Water Formation (Figure 4). The rock consists of very thickly bedded, pebble conglomerates and breccias. Although bedding is poorly developed (6 orientations were measured), joints and minor faults with slickensides are developed in semi-regular systematic sets. Three joint/minor fault sets can be identified: **J1** has a strike of 120 (NW–SE) and dips at 70° to the SW; **J2** has a strike of 060 (ENE–WNW) and dips and is vertical; and **J3** has a strike of 170 (N–S) and dips at 50° to the SW (Figure 5). Joint sets **J2** and **J3** are aligned such that they could represent a conjugate set related to the principle stress direction (σ_1) related to simple shear associated with the E–W sinistral strike-slip deformation in Jamaica related to its position on the northern part of the Caribbean Plate (DeMets and Wiggins-Grandison, 2007). The three-dimensional interaction of these two joint sets produces rock wedges that are elongated in a downslope direction, and the joint surfaces that are exposed in the landslide failure surface (Figure 4D) indicate that this landslide was a bedrock wedge failure. The failure



Figure 3. Landslide **L1**. This is situated in old landslide deposits. Photograph courtesy of Prof Ralph Robinson.

destroyed half of the road (Figure 4A) preventing vehicular access to Gordon Town and surrounding communities, impacting the districts for more than a year.

Landslide L3 (Figure 6). This occurred on the Irish Town Road at a major bend within a valley to the NW of the community of Wiltshire (18° 02.738' N, 077° 43.662' W). This landslide occurred in a unit of predominantly bedded sandstone, shales and thin limestones that form the core of a small anticline (Figures 2 and 6). Similar sedimentary rocks are exposed for a distance of about 1 km along the Irish Town Road to the SW of the landslide (Figure 2). The bedding in this unit is highly variable and forms an anticline plunging to the SW at the site of landslide L3 (Figure 7) and frequently dips down slope along the road to the SW. This landslide occurred in the bedded sandstone-shale sequence associated with an anticlinal fold dipping down the valley.

5. RAINFALL MEASUREMENTS

The hydrology of the Hope River Watershed shows the presence of basal aquicludes (Cretaceous igneous and sedimentary rocks and clastic rocks of the Wag Water Belt) in the north followed by the alluvium and limestone aquifers to the south. The landslides reported here were associated with tropical storms Zeta and Eta, which produced heavy



Figure 4. Landslide L2 – failure in jointed conglomerates of the Wag Water Formation. **A.** view along the road towards Gordon Town showing the breakaway. **B.** view looking down into break away. **C.** joint surface (with slickensides) exposed along the road. **D.** view of landslide deposit at foot of break away. Photographs taken SFM.

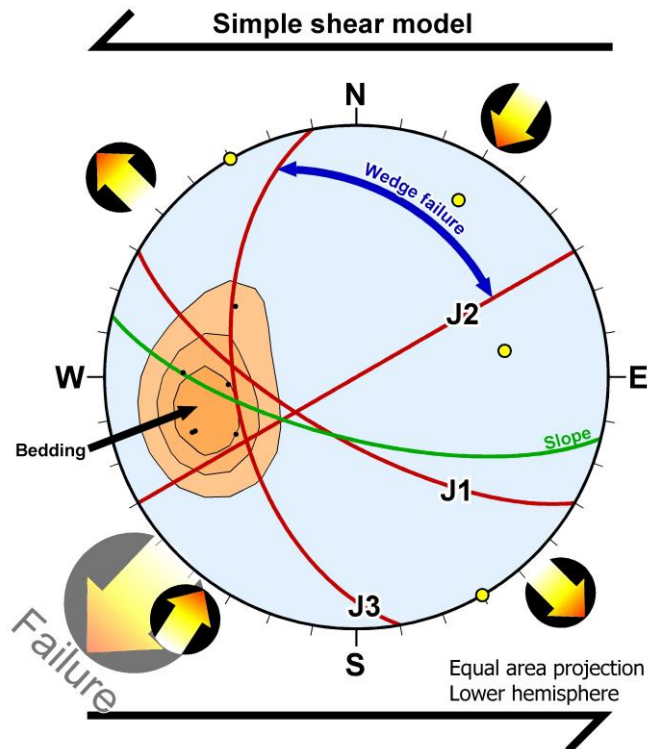


Figure 5. Equal area stereonet for Landslide L2 showing bedding (plotted as poles) and the three systematic joint/minor fault sets (plotted as great circles). The bedding is dipping to the ENE at a relatively steep angle, it is therefore dipping into the slope (green great circle). The three main joint sets (J1, J2 and J3) are shown as great circles. Small arrows show principal stress directions (extension and compression) associated with E–W sinistral simple shear that is characteristic of deformation in Jamaica (DeMets and Wiggins-Grandison, 2007).



Figure 6. Landslide **L3**. This landslide occurred in a series of interbedded sandstones and shales of the Wag Water Formation. This is an area of folding and the sandstones and shales are dipping downslope towards the road (which is situated at the foot of the landslide). Photograph by **SFM**.

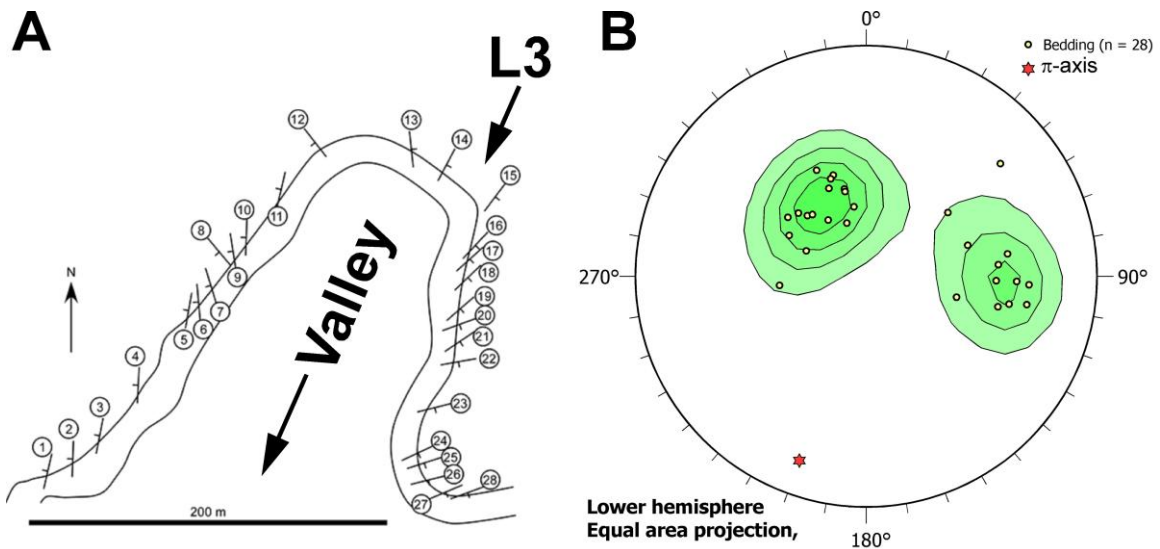


Figure 7. **A**, detailed sketch map along the Irish Town Road in the vicinity of landslide **L3** with bedding orientations. **B**, lower hemisphere, equal area stereonet (poles to bedding) for landslide **L3** showing the anticline (* - π -axis) plunging gentle down the valley. **L3** occurred along the steep valley in the direction of plunge of the anticline.

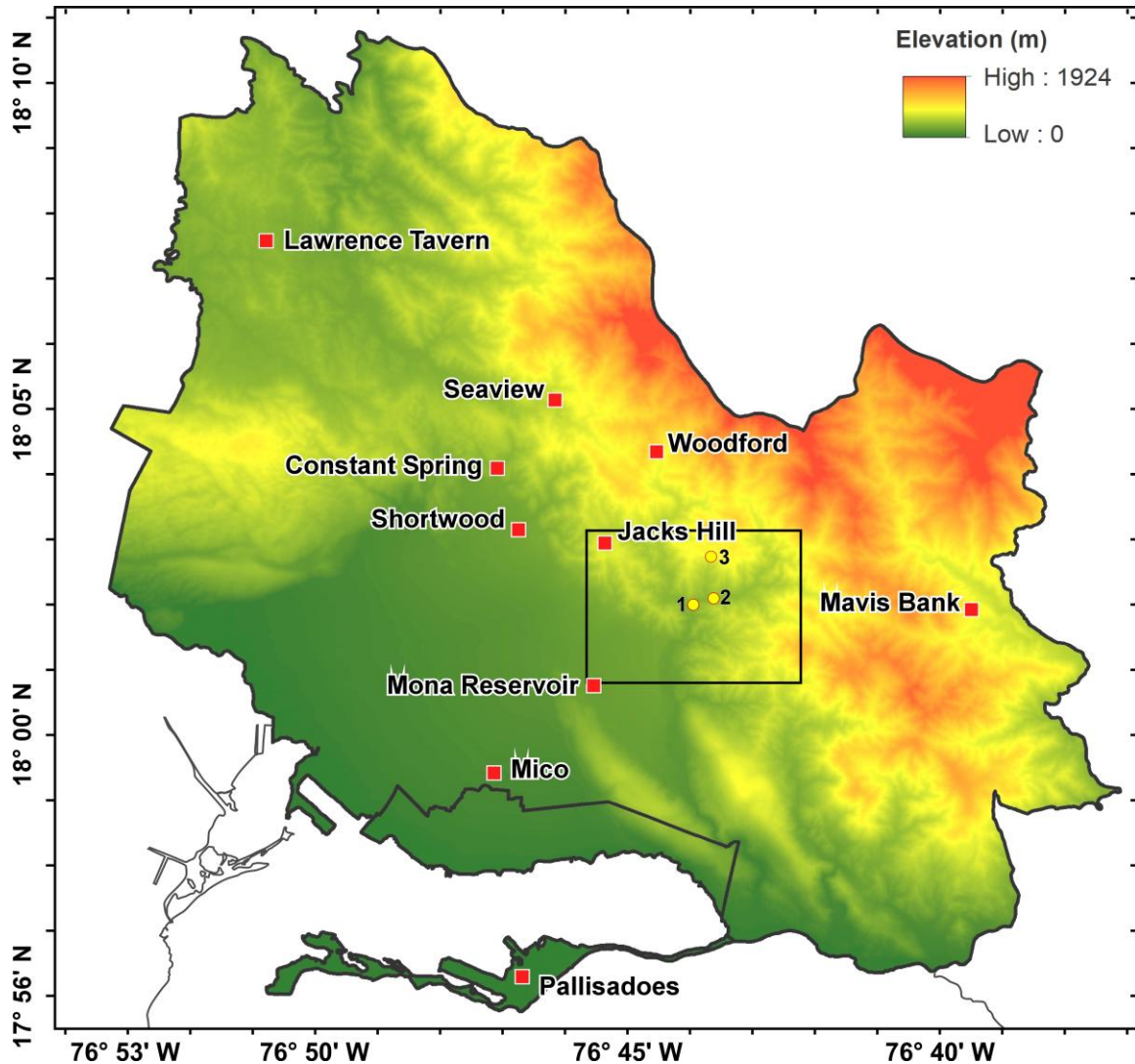


Figure 8. Rainfall gauging stations in the parishes of Kingston and St Andrew. The box shows the location of the geological map.

rainfall and triggered the landslides. The rainfall data for these events were sourced from stations of the Metservice of Jamaica (**Figure 8**) that were operational at the time of the storms. Daily rainfall for Tropical Storm Zeta was available for nine stations, whereas for Tropical Storm Eta, data were only available for seven stations (**Figures 9** and **10**). The rain gauge stations at Constant Spring FP, Lawrence Tavern, Jack’s Hill, Mona Reservoir, Palisadoes and Seaview FP recorded rainfall for both events. The year 2019 was a year of drought in Jamaica due to the El Nino in the Atlantic that affected almost all the parishes of the island. It impacted the stream flow in the Hope River, with flow rates reduced from 25,000 cubic m/day in July 2018 to 12,096 cubic m/day in July 2019 (**National Water Commission, 2019**). Drought conditions

would have led to an overall decrease in soil moisture content, which can lead to slow soil creep and erosion. Rainfall increased in late 2019 and early 2020 followed by an active Atlantic hurricane season in 2020. Jamaica, by virtue of its location in the hurricane belt, is sometimes significantly affected by tropical storms and hurricanes. The two named storms, Zeta and Eta, did not make landfall on the island, however their broad outer bands were enough to generate short-duration, high-intensity rainfall. The presence of bedding planes and joints, allowed for infiltration of rainwater, increasing pore-water pressure, and triggering landslides. The 24 hr rainfall data from the stations showed rainfall started on the 19th October 2020, when tropical storm Zeta passed along the south coast of Jamaica (affecting the parishes of Kingston, St Andrew, St

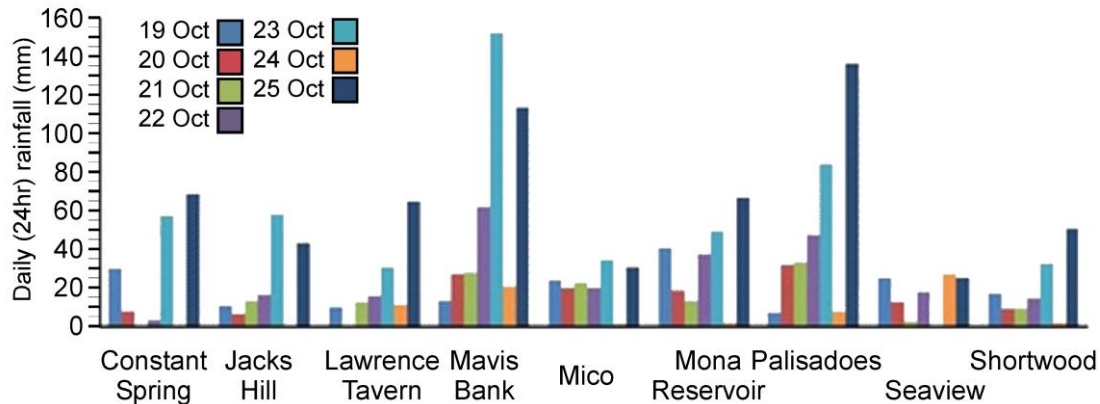


Figure 9. Daily (24 hr) rainfall recorded in the rainfall gauging stations of the Hope River Watershed and the parishes of Kingston and St Andrew for the period 19th–25th October 2020 during the passage of Tropical Storm Zeta.

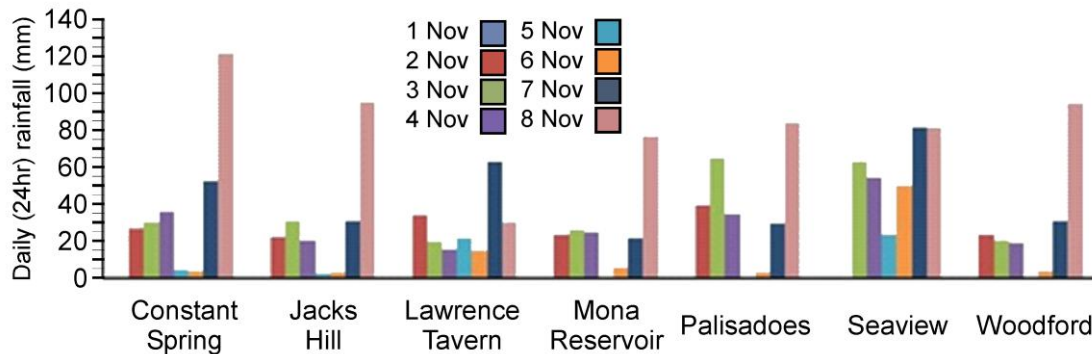


Figure 10. Daily (24 hr) rainfall as recorded in the stations of the Hope River Watershed and the parishes of Kingston and St Andrew for the period 1st–8th November 2020 covering the passage of Tropical Storm Eta.

Catherine and Clarendon). **Figure 9** shows the 24 hr (daily) rainfall associated with tropical storm Zeta for the 19th to 25th October sourced from the nine working stations. The station at Mavis Bank recorded peak daily rainfall of 151 mm and 113 mm on the 23rd and 25th of October, respectively. The station at Palisadoes/Norman Manley International Airport recorded a peak daily rainfall of 135 mm on the 25th of October. Rainfall declined after the 25th of October, with values falling to lows of 0 to 2 mm per day at some stations. The mean total rainfall using data from the nine stations that were active for Tropical Storm Zeta (parishes of Kingston and St Andrew) for the period 19th to the 25th October was 205 mm/station with the station at Mavis Bank recording a total of 415 mm over the duration of the storm.

Tropical Storm Eta followed closely after the passage of Tropical Storm Zeta and affect the island from the 1st to the 8th of November 2020. Intense rainfall was recorded in all of the rainfall stations with maximum daily rainfall of 121.2 mm recorded at the station at Constant Spring. The

mean total rainfall for Tropical Storm Eta for the seven stations (parishes of Kingston and St Andrew) was 237 mm/station. For the stations common to both events (Constant Spring, Jack’s Hill, Lawrence Tavern, Mona Reservoir, Palisadoes and Seaview), the total rainfall was 172 mm/station for Tropical Storm Zeta and 186 mm/station for Tropical Storm Eta.

6. DISCUSSION

Landslides can be triggered by human or natural modification of slopes, intense periods of rainfall and earthquakes. Roadway construction in mountainous terrain clearly affects slope stability through the cutting of terraces, with slopes above the roadway being artificially steepened and therefore more prone to landslide failure. For our landslides, the roads were constructed hundreds of years ago. Lateral and vertical erosion by river systems in gorges can cause a similar naturally produced steepening of slopes. For the three landslides considered here, **L1** and **L3** occurred

through failures of slopes above the roadway, whereas **L2** was caused by a failure below the roadway. The roadway at **L1** was cut in unconsolidated colluvial material, whereas that at **L3** was cut through interbedded sandstones and shales of the Wag Water Formation with a fold plunging towards the roadway down a valley. Both **L1** (colluvial material) and **L3** (interbedded sandstones and shales) have a lithological component that caused the landslides, whereas **L3** also had a structural component. For **L2**, it is possible that river erosion (over hundreds of years) led to slope steepening; yet it is clear that structure (joint orientations) was the main geological control on slope failure.

All three landslides occurred on the same day (8th of November 2020) when daily rainfall associated with the passage of Tropical Storm Eta was greatest (above 80 mm for six stations: **Figure 9**), yet not as great as at some stations with the passage of Tropical Storm Zeta (when daily rainfall amounts exceeded 80 mm for two days each (21st and 23rd of October) at two of the stations (**Figure 8**). The landslides were, therefore, likely triggered by either antecedent rainfall or an episode of intense rainfall after antecedent rainfall (e.g., **Rupp, 2022; Nguyen et al., 2024; Liang et al. 2025**). Luckily, no earthquakes occurred during or shortly after the passage of the two tropical storms (UWI Earthquake Unit), and this was not a trigger for the landslides. If an earthquake had occurred, it is likely that significantly more landslides would have been triggered.

7. CONCLUSIONS AND RECOMMENDATIONS

We conclude that the three landslides that occurred in the Gordon Town and Irish Town area on the 8th of November 2020 had underlying geological controls with some influence from human and possibly natural steepening of slopes, but were triggered by a combination of antecedent rainfall prior to intense rainfall on the day of the landslides. We make the following recommendations:

1. Geological mapping of lithologies including

structural data, rather than just geological formations can provide better information on areas that may be more susceptible to slope failures due to lithologies themselves or unfavourable structural features. Whereas lithologies and bedding structural information can be easily collected in this way, the collection of structural information for joints and minor faults would be very time consuming.

2. Landslide susceptibility maps should take into account detailed geological data (lithology, colluvial material, structural data), rather than just named formations, and these should be combined with other criteria (e.g., aspect and slope) to produce more realistic maps. Such maps should cover areas with human occupation, rather than also including large areas of wilderness.

3. The demonstration that antecedent rainfall may be an underlying trigger for slope failure could be used to provide early warning when recorded rainfall approaches that likely to trigger slope failure.

4. Prediction of potential intense rainfall amounts associated with tropical cyclones and weather fronts could lead to an early warning that slope failure may occur, particularly following large amounts of antecedent rainfall.

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Dedication. This paper is dedicated to the late **Mr Rafi Ahmad** in an acknowledgement of his contribution to the study of landslides in Jamaica.

Author Credits. SFM collected and interpreted the geological data, drew the associated figures, and prepared the initial draft of the paper. AM interpreted the rainfall data, prepared the graphs and wrote the initial draft of that section. Both authors undertook field studies following the landslides and edited the earlier drafts.

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