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Landslide Hazard Mitigation and Loss-reduction for the Kingston Jamaica Metropolitan Area

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1.0 Introduction

Analysis of landslides and their impact on the inhabitants of the Kingston Metropolitan Area (KMA) (Figures 1 and 2), and approaches to landslide management is the subject of this article. The city of Kingston was founded in 1692 on the coastal plain of Liguanea following the devastation of Port Royal by a submarine landslide triggered by the MMI X earthquake on June 6, 1692(Tomblin and Robson, 1977). Earthquake-induced landslides following the Ms 6.5 earthquake of January 14, 1907 and Md 5.4 earthquake of January 13, 1993 caused an extensive damage in the capital city of Jamaica. Rainfall associated with hurricanes Charlie (1951), Flora (1963), Gilda (1973) and Gilbert (1988) resulted in widespread landslides, which destroyed and /or damaged infrastructure.

The terrain in Greater Kingston area, comprising coastal plains, reclaimed land, river fans, steep slopes and fault escarpments, is subject to multiple seismic, atmospheric, slope instability and, hydrologic hazards. Most of the city is built on a presently inactive gravel fan that slopes towards the Kingston harbour (Figure 1). The average annual rainfall varies from 1000 mm on the Liguanea Plain to more than 1500 mm on the mountain slopes. Debris flows, turbidity flows, and floods are common to all the tributaries and steep small channels.

The present population of the Greater Kingston area is 691, 600, which is approximately 28% of the total population of 2,527,700 on the island, with a population density of approximately 1528 persons / km2. Urban expansion is encroaching on potentially hazard-prone landforms.

The excursion covers sections of Kingston and St.Andrew where typical sites of many diverse type of hazards mentioned above will be examined (Fig. 1). The development and urbanization that has taken place in the area will be evident during the course of the excursion.

The aims of this field guide are to: a) facilitate an understanding of active geological processes and related hazards in KMA on a regional scale, b) examine landslides in relation to geology, structure, and geomorphology and their impact, c) introduce landslide loss-reduction and mitigation approaches, and d) highlight the importance of earth science information in landuse planning and environmental management. To meet these ends, an overview of geohazards on the island is presented first, followed by a geological-environmental profile of the Greater Kingston area. Information on the recognition of landslides and landslide loss-reduction measures has also been included. A brief description of the geology in relation to the hazards at various sites to be visited is included in the last section.

2.0 Geohazards in Jamaica: an overview

The vulnerability of Jamaica to geohazards is primarily due to inherent physical conditions arising from geologic, tectonic, and geomorphic factors. The island lies within a 200-km wide, seismically active zone of Neogene left-lateral strike-slip deformation that defines the central section of the boundary between the Caribbean and North American plates (Mann et al., 1985). It is located in the track of north Atlantic hurricanes passing through the Caribbean. The present-day topography on the island has largely resulted from crustal movements during Quaternary (Horsfield, 1974). The highly fractured and deeply weathered and altered bedrock and neotectonics control the landforms and geomorphic processes to a remarkable extent. Slope instability is notable throughout the island. These factors are well known and the resulting vulnerability can be forecast, however, case studies during 1986 to 1995 show that the costs of rehabilitation and reconstruction have increased in the wake of natural disasters (Ahmad, 1995; Carby and Ahmad, 1995).

3.0 Geologic-environmental profile of Kingston and St.Andrew

The capital city of Jamaica is located on the Holocene gravel fan of Liguanea at the base of a faulted mountain front (Figs.1 and 2). A ring of low hills of Tertiary limestones (Long Mountain, Dallas Mountain, and Stony Hill) borders the fan. Overlooking these hills are the Port Royal Mountains of St.Andrew comprising Cretaceous to Paleogene rocks of the Wagwater Belt. Lead-zinc-copper mineralization occurs at several sites within the Belt. Notable among the industrial rocks and minerals are vast reserves of gypsum and limestones. According to Mann & Burke (1990), the Wagwater Belt of eastern Jamaica formed as a transverse intra-arc rift and it appears that the uplift and doming of the sediments in the trough is a consequence of compression at a right-stepping bend on the thoroughgoing, left-lateral Enriquillo-Plantain Garden-Swan fault system which forms the southern part of the plate boundary zone.

Port Royal Mountains-Wagwater Belt

Physiographically, the highly dissected Port Royal Mountains constitute a series of northwest-southeast aligned ridges and fault-controlled valleys. The southernmost, fault bounded Liguanea Ridge, attains a maximum elevation of some 600 m at Mt.Ivor in the Jacks Hill area. The elevation rises on successive ridges to northeast, reaching a maximum height of 1,539 m at Catherines Peak. Further to the northeast, the fault-controlled valley of the Yallahs River marks the eastern boundary of the Wagwater Belt.

The bedrock is deeply weathered and overlain by residual soils. This is an area of neotectonic landforms characterized by colluvium covered steep slopes and frequents slope movements. The rock strata in the Port Royal Mountains comprises of an approximately 7 km thick sequence of highly jointed and faulted, and generally northeast dipping conglomerates, sandstones, shales (Wagwater & Richmond Formations) and andesitic volcanics (Newcastle Volcanic Formation) (Kingston Geologic Sheet No.25, 1974). Cretaceous granodiorites and andesitic rocks are exposed at the base of the sequence.

The western margin of the Wagwater Belt is defined by a major, north -west oriented fault zone, the Wagwater Fault, which may be traced for a distance of some 40 km. The Wagwater fault has been active since the Paleocene and field evidence indicates that movements have continued into the Quaternary (Horsfield, 1974). A similar picture appears to hold true for the Yallahs-Blue Mountain Fault (Plantain Garden Fault zone).

Shepherd (1987) has suggested that there is significant seismic activity occurring within Jamaica associated with a complex series of east-west transcurrent faults and the Wagwater Trough".

Commercial extraction of lead and zinc was carried out at the Hope Mine, Papine district, St.Andrew in 1850's. Gypsum is mined at Bito.

Tertiary Limestones

The limestones exposed in the area are middle Eocene to late Miocene in age. The lithology of the limestones is highly variable and includes well-bedded micrites, recrystallised and dolomitised massive limestones, chalky limestones, bioclastic micrites, sandy marls, and brecciated limestones. Major faults in the limestone terrain are oriented northwest southeast paralleling the Wagwater Fault trend. However, north and northeast trends are also known. The limestones are of a very good quality (pure) and support a cement factory in the area.

Quaternary sediments

The Liguanea Plain is an old gravel fan (Holocene) which was formed by sedimentation from Hope River before the river was diverted into its present channel (Wood, 1976). The fan sediments are referred to as the Liguanea Formation. It incorporates a sequence of very poorly sorted gravels with sands and clays, which is at least 100 m thick. The top 8m of the exposed fan sediments appear to be old debris flow deposits characterized by very large rock blocks and boulders of andesites and conglomerates (Ahmad and Robinson, 1994). Such boulders are found stranded over much of the fan. The sources of these debris flows must have been pre-historic landslides that originated in the catchment of the Hope River and flowed west along the paleodrainage channels. The present-day fan surface is uneven and slopes south towards the Kingston Harbour at 5-150. The fan sediments are highly dissected by the Hope River in the Papine- Kintyre- August Town area. The Hope River fan at Harbour View is underlain by the Harbour View Formation which is lithologically similar to the Liguanea Formation.

The sediments that post-date the Liguanea and Harbour View Formations are:

1. fanglomerates and colluvium deposits along much of the mountain front in the Kingston area which are prone to landslides, and
2. river terraces, colluvium fans and flood plain deposits associated with the Hope, Cane, Chalky, Bull Bay rivers, their tributaries and other drainage lines on the Liguanea Fan.

The most impressive offshore feature southeast of Kingston is the Yallahs Basin described by Burke (1967) as follows. It has an area of approximately 100 km2 , an average depth of 1,350 m, and it has been affected by slides and turbidity currents since it was filled. Two submarine fans, the Hope-Liguanea fan and Yallahs fan occur to the northeast and northwest of the Yallahs Basin. Cable breaks have been reported from the area of the submarine fans during the earthquakes of 1907 and 1993 and also during the passage of the hurricane Flora in 1963.

The youngest feature on the shelf is the Palisadoes tombolo that has been built by the longshore drift of the coarse sediments supplied by the rivers in eastern Jamaica. This area has often experienced liquefaction-related ground failures during each significant earthquake that has affected Jamaica. The Norman Manley International Airport is located on the Palisadoes which is classified as a tombolo rather than a spit because it connects a number of gravel inundated coral cays to the mainland in the Harbour View area (Hendry, 1977-78). Goreau and Burke (1966), and Burke (1967) have described the evolution of the offshore areas of Kingston and St.Andrew. The formation of the island shelf is due to the erosion of the Jamaican landmass during post-Neogene uplifts (Burke, 1967).

4.0 Geohazards in the Kingston Metropolitan Area

A recurring theme in all of the significant earthquakes that have affected Greater Kingston since the 1692 Earthquake is that geological conditions strongly influence the damage (Tomblin and Robson, 1977; Ahmad 1993, 1994, 1996, 1997). The vulnerability of Kingston to seismic shaking was amply demonstrated by the M 5.4 (duration magnitude) earthquake of 13th January 1993(Ahmad, 1996, 1997). Although described as a moderate shock with epicentre located near the Silver Hill Peak in Portland (Wiggins- Grandison, 1996), the effects of this earthquake were felt in area of approximately 500 km2. The results of a mere 10 seconds of ground shaking in eastern Jamaica, with MM intensities ranging between VII-VIII, resulted in two deaths and the economic losses were estimated in excess of J$ 15M. This earthquake triggered some 40 landslides that blocked roads and damaged infrastructure including water pipelines.

Shepherd and Aspinall (1980) calculated the return periods of significant earthquakes in Greater Kingston. According to these authors the return periods of the earthquakes of MMI VII, VIII, IX, and X are respectively 38, 87, 137, and 237 years. Based on a study of earthquake risk in Jamaica Shepherd (1971) has suggested that "From the seismologists point of view the parishes of Kingston including Port Royal, and Lower St.Andrew were probably the worst possible locations to choose for the capital city of Jamaica".

Floods and mass movements generally occur simultaneously as the two most frequent hazards affecting Greater Kingston. Hurricanes are fairly common, but most of the recurrent flood and landslide damage is due to rainfall from tropical storms and tropical depressions that are annual events. The steep weathering-limited slopes favour shallow landslides (Maharaj, 1993; Ahmad, 1995). The landslide inventory map prepared for Caribbean Disaster Mitigation Project Landslide Susceptibility Mapping programme records some 2,321 landslide landforms in the parishes of Kingston and St.Andrew.

The natural vulnerability of Greater Kingston to rainfall -induced debris flows and mud flows has been accentuated by deforestation and vegetation alteration over much of its environment. About 200-300 mm of rainfall in 24hrs would initiate shallow slides on slopes in excess of 250, which constitute about 85 percent of the hilly areas of Kingston. This amount of rain is expected to fall once in 2-5 years (Lirios, 1969) over the hilly suburbs of Kingston. In a majority of cases the old landslides are reactivated during subsequent rainfall events. A cyclic pattern of destabilization of the slopes is quite common. Accelerated soil erosion in the watersheds is intimately linked to these shallow landslides.

Riverine flooding is confined to the Hope, Cane, Chalky, and Bull Bay rivers and their tributaries which create a flood hazard for the less affluent communities of Gordon Town, Papine, August Town, Harbour View, and Bull Bay etc. At Bull Bay, flooding, for example in 1988 and 1995, was related to the debris flows which mobilized tailings at gypsum quarries that entered and choked the channel of Bull Bay River.

On the Liguanea Fan, the increasing impervious cover and the channeling of the gullies concomitant with urbanization have increased the overland flow, and hence, flash floods. Of the seven major gully systems on the fan, only one, Sandy Gully, has been designed to accommodate large floods upto a discharge of nearly 500 m3/sec; the rest of the gullies have discharge capabilities between 20-70 m3/sec(Reid and others,1970).

The Liguanea Formation is an aquifer which has been and continues to be an important source of potable and industrial water for the residents of the parishes of Kingston and St.Andrew. An aspect of urbanization, which has significantly affected this aquifer, is the unregulated disposal of sewage on the Liguanea Plain. Of the thirteen wells assessed by water Resources Authority in 1994 - 95, eleven exceeded the WHO and the Interim Jamaica standard for nitrates, 45 mg / l.

5.0 Identification of landslides and their correction

Following appendices have been provided. These will help in field work and independent observations in future. *[Note: These appendices were provided in photocopy form. Most are not available in this online version of the field guide.]*

- Nomenclature of landslides.
- Landslide types.
- Certainty of landslide identification.
- Influence of rock and soil type, recognition of landslides, surface features, and effect on structure.
- Key to landforms and their susceptibility to landslides.
- Definitions of terms related to soil erosion.
- Summary of landslide investigations.
- Guidelines for geology engineering report.
- How to minimize landslide hazards.
- Debris flows.
- Protection from debris flows.
- Facing landslides (fact sheet produced by US Federal Emergency Management Agency on landslides and mudflows)

6.0 Explanation of field stops

The areas to be visited and field stops are indicated on Figure 1 and are summarized in the road log given below.

Road Log	**Time**
Depart from De la Beche Building, UWI	8.30 a.m.
STOP 1 Norbrook	8.45-9.15
STOP 2 Jacks Hill/ Sunset Avenue	9.30-10.00
STOP 3 Jacks Hill Landslide	10.10-10.30
STOP 4 VTDI Corner, Papine	10.30-11.30
STOP 5 Hope River Water Intake, Grove	11.30-12.00
STOP 6 Lunch stop	12.10-12.45
STOP 7 Gordon Town Landslide	13.00-13.45

STOP 8 Craig Hill Landslide	14.00-14.45
STOP 9 Yallahs Landslide	15.15-15.45
STOP 10 Sangsters, World's End	
Return to UWI	17.30

STOP 1: Norbrook

Explanation of debris flows, their impact and correction. Debris flows have occurred in granodiorites which are highly fractured.

STOP 2: Jacks Hill/ Sunset Avenue

Explanation of landslide landforms, recognition of old landslides, structural and bedrock controls on landslides, human settlements and landslides.

STOP 3: Jacks Hill Landslide

Outline of Disaster: Date: 14 November 1988 Damage: One house destroyed, 2 damaged, 40 m section of the Jacks Hill Road completely destroyed as the toe was located in this area, water pipeline displaced and broken. Trigger: Not known; possibilities- Hurricane Gilbert rainfall 12 September/ M 5.2 earthquake 11 November 1988 / broken water pipeline. Bedrock: Old landslide deposits, granodiorite debris. History: Topographic features indicate ancient landslide landforms; ground modified for residential development; drainage modified; signs of creep.
Debris flows and mud flows triggered by the rainfall associated with Tropical storm Gilda, 16-18 October 1973 caused extensive damage in upper St.Andrew. According to the newspaper reports 6 houses were completely destroyed. In Tavistock area roads were blocked and property was damaged. These landslides occurred in the colluvium and old landslide deposits along the southern slopes of Mt. Ivor.

STOP 4: Old landslides above VTDI, Papine.

The oblique aerial photograph in Figure 3 displays the old landslide landforms and landslide deposits along the southern slopes of Liguanea Ridge. In this area examining the topographic features such as scarp, hummocky topography, and landslide deposits may identify old landslides along the Wagwater Fault zone. During the last few years a number of houses have been built on these unstable slopes underlain by unconsolidated to poorly consolidated landslide debris derived from volcaniclastic sediments exposed on the Liguanea Ridge. A number of new slides may be observed along the road cut. The contact between the landslide deposits and the Liguanea Formation may be observed in the road cut. A landslide triggered by the 1907 Earthquake destroyed a section of the underground water pipeline along the main road. Most of the slopes in this area are prone to landslides.

STOP 5: Hope River Water Intake, Water Works, Grove, Papine to Gordon Town Road.

The rainfall of June 5-6, 1997 triggered debris flows and mudflows in the first and second order channels on the northern slopes above the Water Works area. The debris choked a section of the water intake and also blocked the Gordon Town Road on June 5-6. Most of the slopes in this area are underlain by surficial deposits and are prone to landslides. Figure 4.

STOP 6: Lunch

If the road is wide enough for the buses then we may visit the Old Water Works, Enfield, Gordon Town

This area shows a spectacular development of rock falls and avalanches which, it appears, blocked the Hope River channel at several places. Landslide deposits representing different cycles of landslide activity may be seen in the valley. A number of rapids occur all along the course of the river. These are formed by the accumulation of rock blocks and boulders which may have formed landslide dams. Some of the landslide scarps appear to be active. The slope failures are controlled by three sets of pervasive joints, steep slopes, and weathered andesitic flows and associated rocks of the Newcastle Volcanic Formation. Seismic vibrations may have triggered some of these slope failures.

STOP 7: Gordon Town Landslide

A classical area to see structural controls on landslides. Engineering solutions will be discussed.

STOP 8: Craig Hill Landslide

This is an area of chronic landslide problems. Landslides here have the potential of completely undermining some 500m of the road. This road is an important link between Kingston and northeastern St.Andrew. The social and economic activities of the rural communities are totally dependent on the road.

A large landslide on the western end of the spur was induced by the earthquake of 13th January 1993. Following the rainfall in January 1996 and subsequent events in 1997 and 1998 the central and eastern sections of the slope also failed. A section below the road level failed; a culvert was destroyed, and the landslide debris blocked the road. The bedrock at this locality is deeply weathered and highly fractured andesites exposed in a fault zone. Joints daylight into the road cut giving rise to wedge failures.

STOP 9: Yallahs River Landslide

Bedrock here is sandstone-shale sequence of Richmond Formation. Following the rainfall associated with 1963 hurricane Flora, approximately 11,469 m3 of slope material was dislodged from the slope probably due to undercutting.

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