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A PRELIMINARY INVESTIGATION OF THE CHIMBORAZO HILL LANDSLIDE OF AUGUST 30, 2004

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The Chimborazo Hill landslide occurred on the evening of Monday, August 30, 2004, in the wake of Tropical Depression Gaston. Although the area of the slide at the Chimborazo Park playground at 31st and Grace streets garnered much attention and remediation efforts, it was but a small section of a much larger landslide that covered approximately 11 acres on the west-facing slope of Chimborazo Hill.

On the afternoon and evening of Monday, August 30, 2004, the City of Richmond received 7 to 10 inches of rain in less than 11 hours as Tropical Depression Gaston tracked across southeastern Virginia (Figure 1) (Bacque, 2004). The intense rainfall quickly flooded area creeks and streams and triggered several landslides in the downtown Richmond area. Eight people lost their lives from the flooding (Nolan and Bowes, 2004). Damage from the storm in the City of Richmond is estimated to be over fifteen million dollars (Ress, 2004).

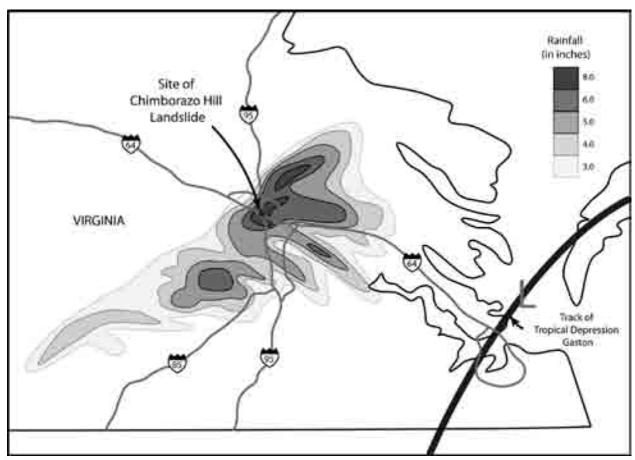

Figure 1. Intense rainfall distribution from Tropical Depression Gaston, August 30, 2004. Source of information from the National Weather Service website at www.nws.noaa.gov.

TIMELINE OF DIVISION OF MINERAL RESOURCES INVOLVEMENT

Division of Mineral Resources geologists responded quickly to document damage resulting from the landslides and flooding and to provide geologic assessment and assistance to city officials. On September 1, Rick Berquist, David Hubbard, and Bo Willis (Chief Deputy Director, Department of Mines, Minerals and Energy) observed and photographed the large landslide at 31st and Grace streets and other landslides and flood damage in the Richmond area. Rick Berquist returned on September 7 to further investigate the landslide at 31st and Grace streets, as well as examine other landslides in downtown Richmond with city officials (see Appendix D). On September 17, Mark Carter accompanied Rick Berquist to landslides at Jefferson Park (20th and East Marshall streets), Monte Maria Academy (21st and East Grace streets), and Chimborazo Park (31st and Grace streets) to collect geologic data in freshly exposed landslide scarps. Rick Berquist and Mark Carter also met with city officials that afternoon to offer use of the DMR drill rig to gather subsurface information at the 31st and Grace streets (playground) site. Discussions and planning continued on September 20, and two holes were drilled on September 21 at the 31st and Grace streets site. Also on the twenty-first, Rick Berquist, Mark Carter, and Stephen Walz (Division of Administration), traversed a larger portion of the Chimborazo Hill landslide and photographed damage at the base of the slope south of 31st and Grace streets. Mark Carter and David Hubbard returned separately on September 27 to further delineate the scope and magnitude of the landslide at Chimborazo Hill. Mark Carter was accompanied part of the day by Federal Emergency Management Agency representatives.

THE CHIMBORAZO HILL LANDSLIDE

The Chimborazo Hill landslide covers approximately 11 acres on the west-facing slope of Chimborazo Hill (Figure 2). It extends from the southeastern corner of the Chimborazo Park playground at 31st and Grace streets southward to the Norfolk Southern Railroad tracks south of Chimborazo Hill and from the crest of Chimborazo Hill westward to the abandoned railroad grade in the stream valley of lower Blood Run.

The main scarp of the slide stands from 7 to 30 feet in height and extends nearly continuously for about 900 feet south from the Chimborazo Park playground along the west-facing upper slope of Chimborazo Hill, just below the crest of the hill. At the playground, the scarp exposes fill material (Figure 3), but from the southeastern corner of the playground portion of the slide southward to its terminus on the upper side-slope of Chimborazo Hill, the scarp exposes fresh outcrops of the Yorktown/Bacons Castle and Eastover Formations[1] (Figure 4).

Transverse tension cracks and minor scarps, some with vertical displacements up to approximately 1 foot in height, can be traced south of the terminus of the main scarp, across the southwestern nose of Chimborazo Hill, and southward to the Norfolk Southern Railroad tracks (Figure 2). Here, they terminate at a small washout behind and beneath an 8-foot-high retaining wall above the tracks. West of the main scarp, transverse and radial tension cracks (Figure 5) crisscross the body of the slide, and transverse and radial minor scarps on up-thrown and down-thrown blocks (Figure 6) show vertical displacements of up to 8 feet in height. Transverse tension cracks and minor scarps, which roughly parallel the trend of the main scarp higher on the hill, extend down-slope to the Norfolk Southern Railroad tracks and the abandoned railroad grade in the stream valley of Blood Run. Post-Gaston grading and slope stabilization (slope lined with rip-rap) along the Norfolk Southern Railroad tracks at Williamsburg Road in the vicinity of the Fulton Gas Works suggest that landslide material spilled out onto the tracks at this point.

Tension cracks and minor scarps bound intact blocks of earth consisting mostly of sandy silty clay (Wentworth classification system of Folk, 1974) of the Eastover Formation that show little evidence of deformation or viscous flow. Several shallow sag ponds were encountered during traverses in the heavily vegetated woods, approximately 500 feet southwest of the intersection of 32nd and Grace streets. At the southern end of the landslide (south of the large debris flow), none of the coherent blocks from the base of the main scarp to the Norfolk Southern Railroad tracks and abandoned railroad grade at the base of the slope show apparent slope reversals. In fact, most blocks, even those at the base of the slope, are tilted down-slope toward the railroad grade, or slope northward or southward, roughly parallel to the trend

[1] In this area, Daniels and Onuschak (1974) defined the stratigraphy above Tertiary and Cretaceous sediments as sand and gravel overlying clayey silt. More recent published and unpublished work suggests that the unconsolidated sediments might be correlative to the Bacons Castle, Yorktown (nearshore) and Eastover Formations (e.g., Mixon and others, 1989). Reexamination of the geology of the Richmond area has begun, and is scheduled for completion in 2006-2007. Appendices B and C contain additional information on the stratigraphy of the Richmond area.

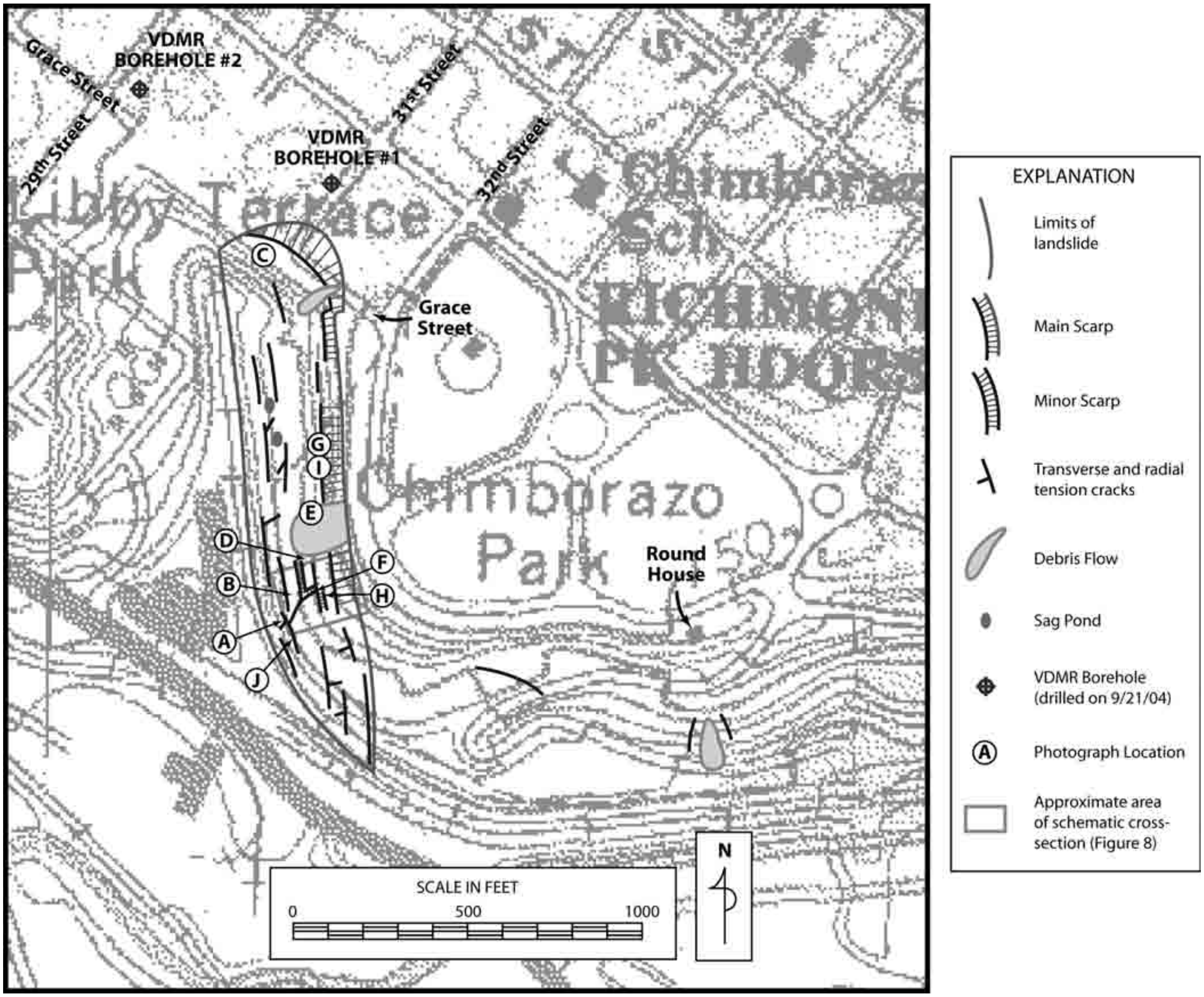

Figure 2: Preliminary reconnaissance map of the Chimborazo Park landslide. Basemap from digital rastergraphic image of the 1994 USGS Richmond 7.5-minute topographic map. Key to photograph locations in figures: Locations A, B, D, J - Figure 5; location C - Figure 3; location E - Figure 7; locations F, H - Figure 6; locations G,I - Figure 4. The abandoned railroad line west of Chimborazo Park occupies the stream valley of lower Blood Run. Upper Blood Run has been partially filled; it originated to the northeast, approximately between 31st and 32nd streets.

of the main scarp. A distinct landslide toe is not readily apparent at the base of the slope. Tree-throw directions, particularly at the base of the slide south of Chimborazo Hill, also indicate a mostly westward translation and tilting of the landslide mass. Below the Chimborazo Park playground, many trees are tilted northeastward, toward the scarp in the fill material (Figure 3), suggesting rotation as a contributing movement mechanism in this part of the slide. At the base of the slope, the abandoned railroad grade in the stream valley of lower Blood Run appears to have been severely washed out during the storm, but there is no evidence that landslide material actually flowed out into the abandoned grade; trees above the grade lean westward toward the warehouses across the valley bottom.

Two smaller-scale debris flows (at 31st and Grace streets, and on the western slope of Chimborazo Hill), composed mostly of unconsolidated fill material and sands and gravels of the Yorktown/Bacons Castle Formations, started within and modified the main scarp, most likely after failure of the much larger slide (Figures 2 and 7). Debris from the flows appears to fill

Figure 3. Panoramic photograph, panning from the north (left side) to east (right side) of the Chimborazo Park playground portion of the landslide, taken on September 21, 2004. Photograph is from location "C" in Figure 2. Notice the successive layers of fill in the main scarp on the left side of the photograph. "Natural ground" crops out along the scarp in the trees behind the fence on the far right side of the photograph.

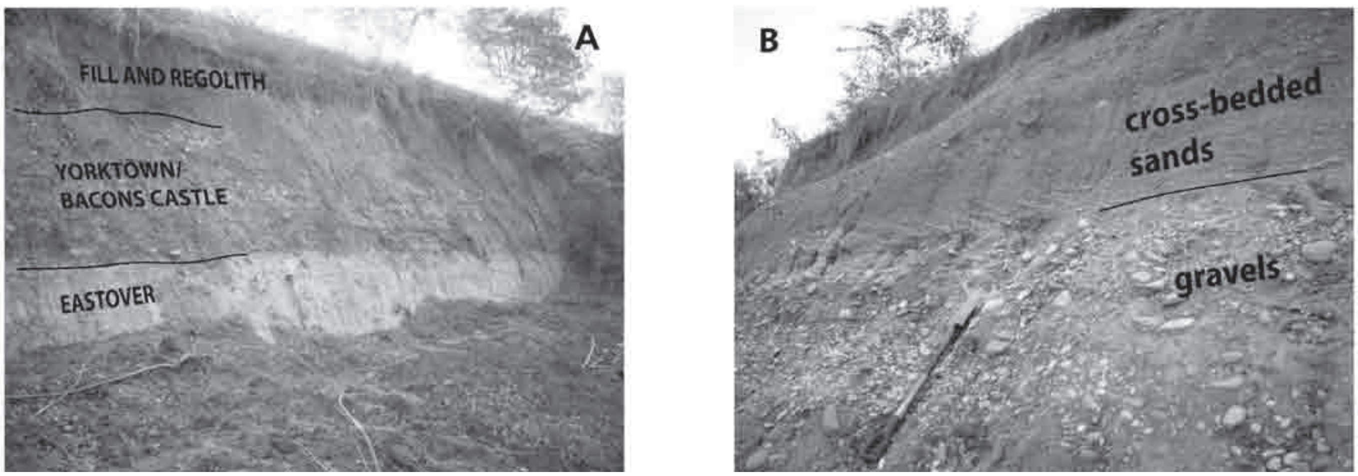

Figure 4. Photographs of the main scarp on the west slope of Chimborazo Hill. A: Photograph, looking southeast, of the fresh exposures of Yorktown/Bacons Castle Formations (sand and gravel layers) above Eastover marine clays in the main scarp. Photograph is from location "G" in Figure 2. Shovel is approximately 3.5 feet long. B: Photograph, looking northeast, of the fresh exposures of Yorktown/Bacons Castle Formations (cross-bedded sand and gravel layers) in the main scarp. Eastover Formation crops out just below shovel handle. Photograph is from location "I" in Figure 2.

and cover tension cracks between coherent blocks at the base of the main scarp. Many tension cracks also apparently served as channels to route excess water draining from the debris flow and overland flow from the sidewalks, roads, and parking areas at the top of the slope, as many appear to have been scoured by flowing water after formation. A third debris flow composed of fill material gave way on the south-facing slope of Chimborazo Hill below the Round House (Figure 2) but does not appear to be connected with the larger landslide on the west-facing slope.

The Chimborazo Hill landslide is classified as a compound earth-debris slide, having components of both rotational and translational sliding (Cruden and Varnes, 1996) (Figure 8). Translational sliding appears dominant in the southern part of the Chimborazo Hill landslide, whereas rotational sliding appears to be the dominant failure movement in the vicinity of the Chimborazo Park portion of the slide.

UNRESOLVED QUESTIONS

Although reconnaissance of the Chimborazo Hill landslide over the past several weeks has grossly delineated the size and magnitude of failure, unresolved questions remain:

1) The geometry and physical properties of the underlying rupture surface. Without a better understanding of the surface and subsurface geometry

Figure 5. Photographs of tension cracks and minor scarps on the west slope of Chimborazo Hill. A: Panoramic photograph, panning from the south (left side) to west (right side) showing minor scarps. The main scarp is just out of view on the far left side of the photograph. Notice the large block (that stands nearly 8 feet higher than the adjoining one), the graben in the middle of the photograph, and the higher elevated block on the right side. Weathering on the face of the minor scarp on the right side of the photograph suggests that the tension crack it utilized (a preexisting fracture or joint in the Eastover?) was open and exposed to weather for some time prior to the August 30 movement (this could also be an indicator of pre-Gaston slope instability). Photograph is from location "D" in Figure 2. B: Photograph, looking north, of a tension crack at location "J" in Figure 2. This tension crack appears to have channelized water after formation as it is partially filled with alluvium. C: Photograph, looking north, of a downthrown block between two north-south trending tension cracks at location "B" in Figure 2. Shovel is approximately 3.5 feet long. The block on the far right of the photograph is on the downslope (western) "toe" of the landslide but is actually higher in elevation that the two eastern blocks closer to the main scarp. None of the blocks here show a reversed slope back toward the main scarp. D: Photograph, looking southwest, of transverse and radial tension cracks in the body of the landslide at location "A" in Figure 2. This photograph serves as a model for the structure of the larger landslide.

of the landslide, information about the underlying rupture surface – what failed and why it failed – remain unknown. More thorough and detailed mapping of tension cracks, scarps, and slope measurements based upon precise elevation data and drilling for subsurface data should shed additional light on the failure mechanics.

2) The timing and progression of slope failure. The smaller-scale debris flows along the main scarp appear to have been the last to develop as their debris apparently overlie pre-formed blocks within the slide. Moreover, many blocks just west of the main scarp appear to be graben structures (lower in elevation than those farther down the slope – Figure 5A), suggesting that the blocks nearer the railroad grade at the base of the slope failed first, allowing the blocks along the main scarp to settle down behind them. Surprisingly, one of the larger blocks along the main scarp in the vicinity of the debris flow on Chimborazo Hill tilts northward into the flow debris, raising questions as to the exact role the debris flow played during failure. Other questions linger as to whether the slope below the main scarp catastrophically failed along its entire length simultaneously, failed in sections, or progressed parallel to the main scarp, either northward into the fill material at the playground or southward from the fill at the playground to the railroad tracks. Detailed mapping of the landslide surface and subsurface data such as depth of rupture surface, groundwater levels and pore pressures, and the shear strength of material at the

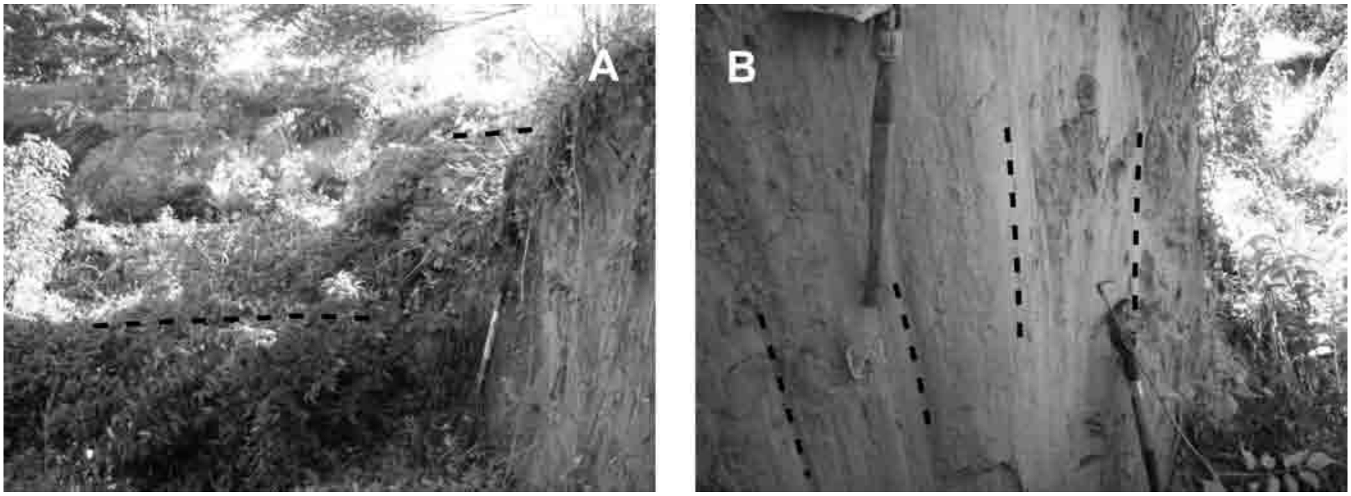

Figure 6. Photographs of minor scarps on the west slope of Chimborazo Hill. A: Photograph, looking east, along a minor radial scarp at location “F” in Figure 2. Notice that the displacement along the retaining wall (top of the wall is highlighted with a dashed line) is mostly vertical, with little translational movement toward the camera. A portion of the main scarp near its terminus is visible in the background. This is the same block that is visible on the left side of the panoramic photograph “A” in Figure 5. Shovel is approximately 3.5 feet long. B: Photograph, looking west, of the face of a minor transverse scarp at location “H” in Figure 2. The face, exposing marine sandy clay of the Eastover Formation, is very fresh and the relatively soft material has preserved slickenlines (highlighted with dashed lines) on the scarp face. Had this face been exposed to weathering prior to the storm on August 30th, the slickenlines would not have been preserved. This photograph was taken on the transverse scarp face behind the retaining wall in Figure 6A.

Figure 7. Photograph, looking southeast, of the debris flow at Chimborazo Hill at location “E” in Figure 2. A portion of the main scarp is visible in the upper part of the photograph below the crest of the hill.

failure surface, is vital to understanding the future stability of the site.

3) Interaction and role of the fill material at the playground and preexisting discontinuities within the Coastal Plain formations. At the playground, the main scarp developed almost entirely within fill material. Fill exposed in the scarp east of the swimming pool consists of three layers: a 3-foot-thick layer of light colored sand and gravel, overlying a 5-foot-thick layer of sand and gravel containing brown to black cobbles and trash (broken bottle glass, bricks, and rotted wood) and the lowest layer, more than 5 feet thick, composed of disturbed marine clay, sand, greensand, and cobbles. The disturbed marine clay is from the Eastover Formation and may have been mined during construction or enlargement of the railroad tunnel under Church Hill and used as basal fill in the old stream valley of Blood Run adjacent to the tunnel entrance.

At the southeastern corner of the playground portion of the scarp, however, “natural ground” is exposed in the fresh scarp face. Dark gray to bluish gray muddy sand, sandy silt, and clay of the upper Miocene Eastover Formation underlies yellowish brown cobbles, pebbles, sand, and sandy to clayey silt of the lower Pliocene Yorktown Formation and pebble and cobble gravel and cross-bedded sand of the upper Pliocene Bacons Castle Formation (see Mixon and others, 1989). These units are exposed in the scarp from this point to its terminus on the upper side-slope of Chimborazo Hill. Of particular note is that undisturbed clay of the Eastover Formation was observed in minor scarps and tension cracks in the toe area of the landslide just

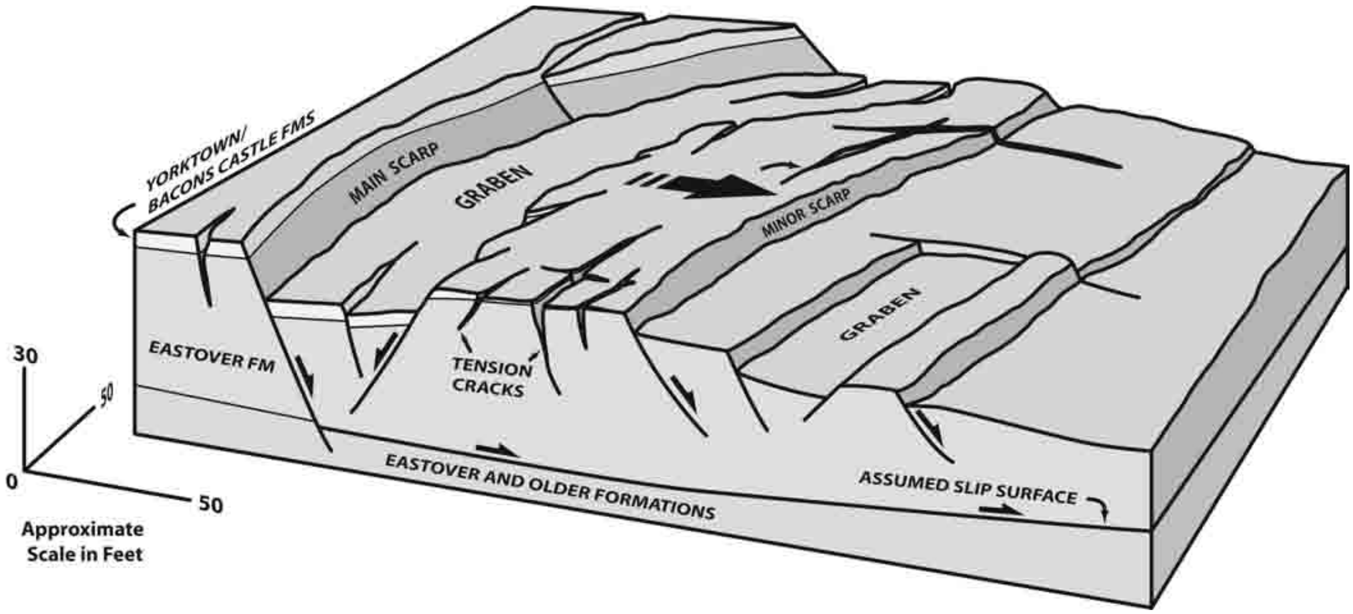

Figure 8. Tentative schematic cross-sectional model of the internal geometry of the Chimborazo Hill landslide (modified from Varnes, 1978). Elements and nomenclature of landslide features are labeled, including the main scarp, minor scarps, underlying rupture surface, and transverse (parallel to main scarp) and radial (perpendicular to main scarp) tension cracks. Smaller arrows show vertical and horizontal displacements of internal blocks, whereas the overall translational displacement in the down slope direction is shown by the large arrow in the middle of the diagram. Rotational movement, in which the landslide toe "kicks out" to allow the mass above to slump down behind it (with slope reversals back toward the main scarp on the slumped blocks), is not portrayed in the diagram.

southwest of the playground, suggesting that the basal landslide rupture surface occurred in or beneath the clays of the Eastover Formation rather than at the fill – "natural ground" interface.

During the September 17 visit to the Richmond area landslides, the authors observed and recorded numerous fractures, or joint sets in the clays of the Eastover Formation and overlying Coastal Plain units (Figure 9). Joint spacing ranged from 1 to 3 feet. A preliminary analysis of the data suggests two regional trends – N50°-70°W and N5°-15°E (Figure 10). The main scarp of the Chimborazo Hill landslide, south of the playground, appears to have developed along the N5°-15°E set. Many of the tension cracks and minor scarps within the body of the slide also appear to roughly parallel these trends. At present, data are too sparse to draw firm conclusions, so the role that pre-existing discontinuities (fractures) in the undisturbed Coastal Plain sediments played in the development of the landslide is suspected but still unclear.

CONCLUDING THOUGHTS

Much attention has been focused on the failure of the fill material at 31st and Grace streets, and rightly so – city property was destroyed and private property condemned as a result of the landslide. The Chimborazo Park playground has been subject to both earthen foundation and structural foundation failures for some years. Historical accounts, exposures in the scarps, and DMR boreholes (Figure 2) show that the park area has been extensively filled. Figure 11 is a schematic cross-section along Grace Street (from 29th to 31st streets) showing the original land surface, fill material in the valley of Blood Run, and interpreted geologic conditions at the playground.

DMR borings encountered saturated sand and gravel above the marine clays of the Eastover Formation in both holes (water was likely filling borehole number 1 from the sands and gravels when the water level was measured to be in the Eastover Formation). Ground water has probably been wetting the fill material for many years, and contributed to the instability of foundations, buried storm and sewer pipes, and the landslide failure of August 30. In addition, the Chimborazo Hill landslide, as well as many others throughout the city, formed below down-slope-oriented roadways, sidewalks, and paved gutters. These features focused the intense rainfall and overland sheet flow from the storm into the area that eventually failed.

Figure 9. Photograph of regional fracturing (jointing) in marine clays of the Eastover Formation in a fresh exposure below the Monte Maria Academy at 21st and East Grace streets in downtown Richmond. The joint (highlighted by a dashed line) trends N52°W into the hill slope and dips 84° to the northeast. Spacing within the joint set is 2 to 3 feet. Horizontal fractures, stained brown from the reduction of pyrite in the clay, parallel primary sedimentary bedding.

It should be noted that the area of the slide in the fill material at the Chimborazo Park playground, which is garnering current remediation efforts, comprises only about 20 percent of the total land surface on the west flank of Chimborazo Hill that failed. While failure within the fill material at 31st and Grace streets may have been the trigger for slope collapse farther south, an alternative hypothesis is that the fill may have actually served to absorb and arrest the landslide as failure propagated along preexisting discontinuities in the Coastal Plain units from the south. Detailed mapping of the landslide could provide many additional answers.

ACKNOWLEDGEMENTS

Reviews by Matthew Heller and Michael Upchurch (Virginia Department of Mines, Minerals and Energy – Division of Mineral Resources) and Richard Wooten (North Carolina Geological Survey) are much appreciated.

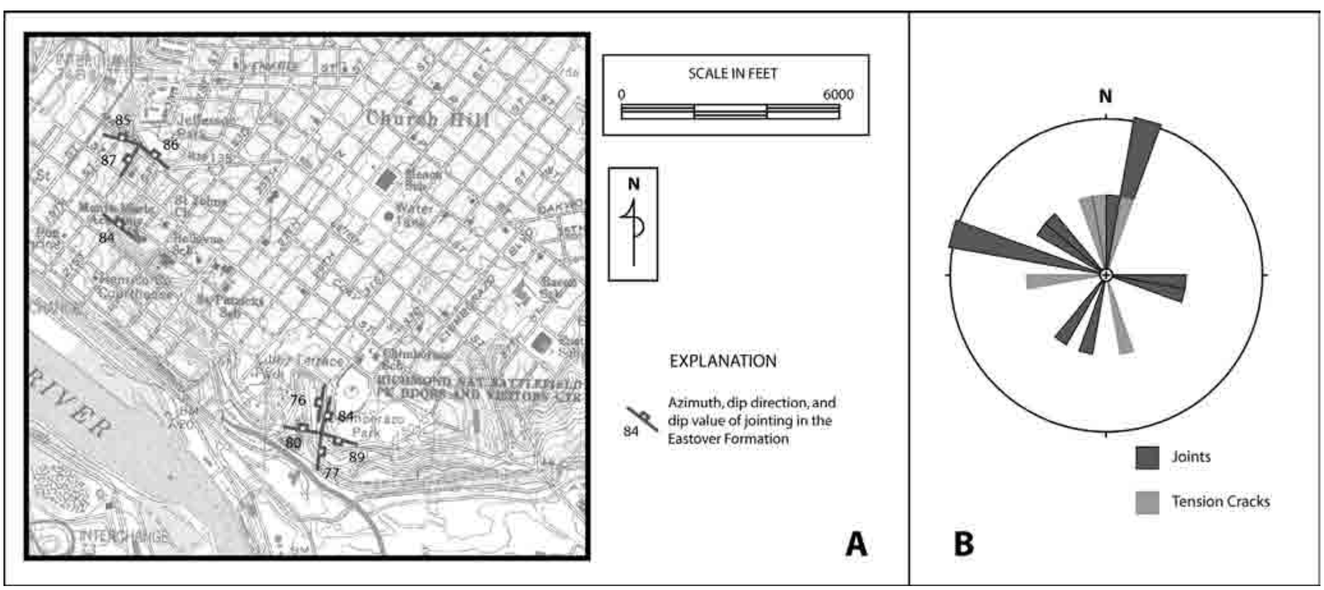

Figure 10. Reconnaissance map of regional joint trends and stereographic projection of joint and tension crack data. A: Reconnaissance map of regional joint trends. Joints were observed and measured at Jefferson Park, Monte Maria Academy, and the Chimborazo Hill landslide. Basemap from digital rastergraphic image of the 1994 USGS Richmond 7.5-minute topographic map. B: Unidirectional rose diagram of joint and tension crack orientations. Tension crack orientations were measured in the body of the Chimborazo Hill landslide.

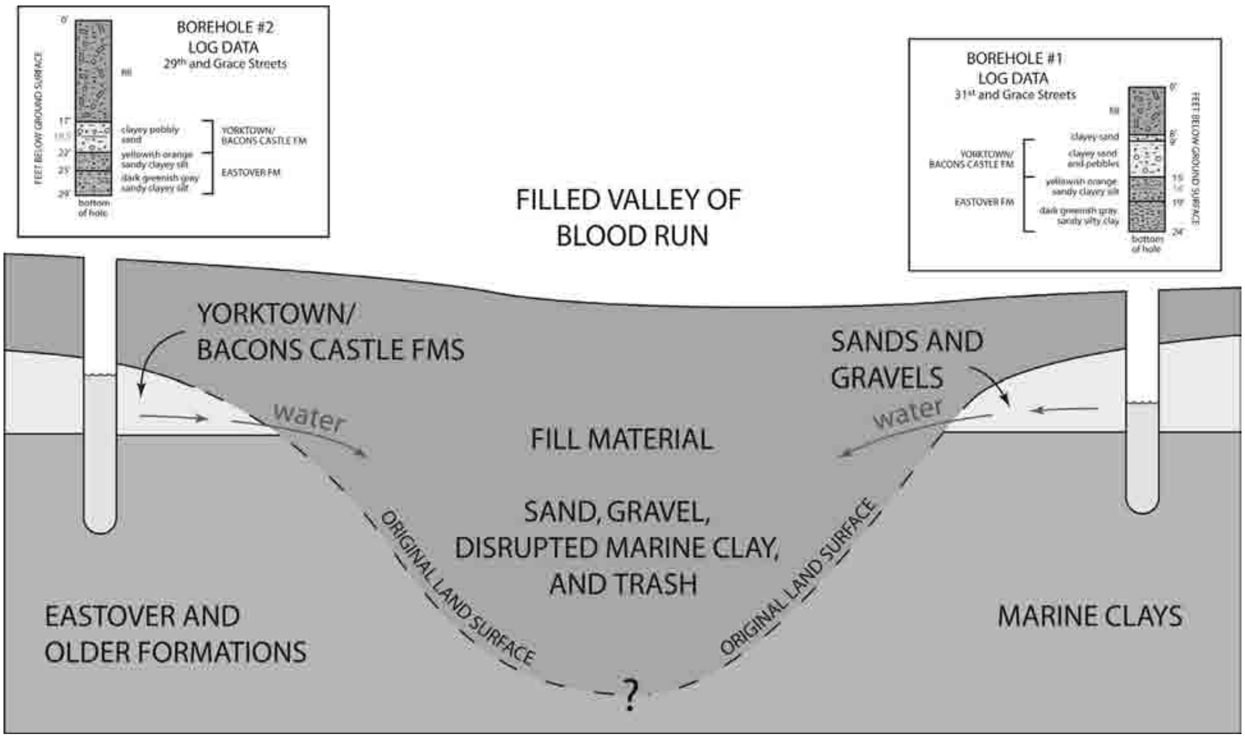

Figure 11. Schematic cross-section along Grace Street (from 29th to 31st streets) showing the original land surface, fill material in the valley of Blood Run, and interpreted geologic conditions at the playground. Ground water has probably been draining into the fill material for many years, which contributed to the instability of foundations, buried storm and sewer pipes, and the landslide failure of August 30, 2004.

APPENDICES

Appendix A: Notes and Comments from Conversations With Area Landowners.

On September 27, 2004, Mark Carter spoke with several area residents about the landslide and their recollections of the slope below Chimborazo Hill before and after the August 30, 2004 rainfall event.

Residents could not give a precise time of failure at 31st and Grace streets, but stated that the slide occurred in the evening after dark. This time coincides with the waning hours of the rainfall event.

Residents stated that cracks had appeared in the pavement near the intersection of 31st and Grace streets the year before, after Hurricane Isabel, and they recalled observing a few very small scarps on the slope below Chimborazo Hill. These observations corroborate Rick Berquist's observations on September 1 and 7 when he noted a number of trees on the slope below the playground having bent (pistol butted) trunks, indicate that the original slope (toward the abandoned railroad) had been moving (creeping) downhill for many years.

The "blocky" topography below the crest of Chimborazo Hill was not present before August 30, according to area residents. The present topography observed below the crest, therefore, must be related to the August 30 event.

Residents stated that the grading and slope stabilization along the Norfolk Southern Railroad tracks at Williamsburg Road occurred after the August 30 event, suggesting that a volume of landslide toe material spilled out onto the tracks and has since been hauled away.

Please note that resident's comments and observations have not yet been confirmed with city or railroad officials; their comments (and interpretations based upon them) are unverified pending further investigation.

Appendix B: Description of the Eastover, Yorktown, and Bacons Castle Formations.

The following are descriptions of the Eastover, Yorktown, and Bacons Castle Formations from various sources, including Coch (1965), Ward and Blackwelder (1980), Mixon and others (1989), and Rader and Evans (1993).

Eastover Formation (upper Miocene) – Dark-gray to bluish-gray, muddy sand, very fine to fine, micaceous, interbedded with sandy silt and clay. Lower part of unit is dominantly medium to very thin-bedded and laminated silt and clay interbedded with very fine sand, lenticular and wavy bedding common; upper part is mainly very fine- to fine-grained sand containing abundant clay laminae. Typical mollusks include *Chestpectin middlesexensis, Marvacrassatella surryensis, Glossus fraterna*. Thickness is 0 to 270 feet.

Yorktown Formation (lower upper Pliocene to lower Pliocene) – Coarse-grained sand and gravel facies of the Yorktown Formation in updip area of the Coastal Plain consists of interbedded yellowish-orange to reddish-brown gravelly sand, sandy gravel, and fine to coarse sand, cross-bedded in part, includes lesser amounts of clay and silt in thin to medium beds. Commonly caps drainage divides (altitude of surface, 250-170 feet) in western part of Coastal Plain. Lower part of unit, showing flaser and lenticular bedding and containing rare to abundant *Ophiomorpha nodosa*, represents deposition in marginal-marine environments and is, in part, a nearshore equivalent of the more downdip, marine facies of the Yorktown Formation. Thickness is 0 to 50 feet.

Bacons Castle Formation (upper Pliocene) – Gray, yellowish-orange, and reddish-brown sand, gravel, silt, and clay; massive to thick-bedded pebble and cobble gravel grading upward into cross-bedded, pebbly sand and sandy and clayey silt; thin-bedded and laminated clayey silt and silty fine-grained sand, characterized by flaser, wavy, and lenticular bedding and rare to common clay-lined burrows including *Ophiomorpha nodosa*; constitutes surficial deposits of high plain extending from Richmond eastward to the Surry scarp. Thickness is 0 to 70 feet.

Appendix C: Description of DMR borehole logs from September 21, 2004.

The following are descriptions of DMR borehole logs, drilled on September 21, 2004. Logging and descriptions conducted by Rick Berquist, Mark Carter, and Stephen Walz. Borehole number 1 is located on the northwest side of 31st Street, between Grace Street and an alley along the northeast side of the Chimborazo Park playground. It is in the grass between 31st street and the sidewalk, adjacent to the Chimborazo Park playground fence. Borehole number 2 is located in grassy area of Chimborazo Park playground, about 25 feet northeast of large oak tree, adjacent to corner of 29th and Grace streets. Surface elevations and coordinates of these boreholes will be provided at a later date. Visual estimation of the Wentworth grain size classification is after Folk, 1974.

BOREHOLE NUMBER 1 (VDMR BORING 04264.1)

Feet Below Surface	Description
0-8	Fill; red bricks at 2-3 feet; pebbles, organic material, clayey sand (dark red), moist to almost wet
8-9	Clayey fine- to medium-grained sand, some granules; subangular; brownish red; muscovite, plinthites, moist
9-15	Clayey sand and pebbles; well rounded; yellowish gray; wet; Yorktown Formation, possibly Bacons Castle Formation
15-19	Very fine-grained sandy clayey silt; color-laminated yellowish orange and yellowish gray; possibly wavy bedded; moist; Eastover Formation
19-24	Very fine-grained sandy silty clay; dark greenish gray; possible shell ghosts moist; Eastover Formation
Notes:	Standing water at 18 feet;

BOREHOLE NUMBER 2 (VDMR BORING 04264.2)

Feet Below Surface	Description
0-17	Fill; (Standard Penetration Test at 4-6 feet: 22,12,10,7 STP N-values; asphalt and gravel); moist
17-22	Clayey pebbly sand; yellowish gray; wet; Yorktown or Bacons Castle Formation
22-29	Very fine-grained sandy clayey silt; color laminated but changing to dark greenish gray at 25 feet; Eastover Formation
Notes:	Standing water at 19.5 feet

Appendix D: Rick Berquist's Report of September 9, 2004.

The following is a copy of the report submitted to the City of Richmond by Rick Berquist on September 9, 2004.

Richmond Landslides
Notes by Rick Berquist on September 9, 2004.

I work for Virginia Department of Mines, Minerals and Energy as State Geologist and Director, Division of Mineral Resources. I visited the large landslide at 31st and Grace on afternoon of 1 September 2004 and met with Dave Hubbard of our staff. Dave was photographing and taking notes of many of the other landslides and flooding effects. He was mobilized by the Red Cross on September 4 and is now in Florida.

I returned to Richmond on September 7 and began to investigate the landslide at 31st and Grace. I ran into Bill Farrar, Richmond Public Works Spokesman and explained how DMR could assist with geologic assessment if they requested it. I later met Johnnie Butler (with Public Works) who asked me to examine the landslide at Jefferson Park, Marshall and 20th street. He drove me to several other sites to ask what I could advise from a geologic perspective.

The typical geology underlying higher elevations of downtown Richmond and Church Hill is composed of a few layers of slightly clayey sand and gravel (sand, pebbles and cobbles) that overlie marine clay. The clay may overlie clayey sand and gravel to the east and granite to the west. Virginia Division of Mineral Resources Report of Investigations 38 by Daniels and Onuschak (1974) contains additional information.

Observations at 31st and Grace: The topographic map shows 2 depressions (sinkholes) on north side of park/playground. Concrete walls are broken and are settling into low areas, toward a drain in the alley. Exposed scarp above landslide block east of the pool shows 3 layers of fill. The uppermost layer is 0 to 3 feet thick, and is composed of light colored sand and gravel, sandy and clayey marine sediments. This overlies about a 5 foot-thick layer of brown to black cobbles, trash, bottles, bricks, rotted wood or other organics. This overlies 5 or more feet of disturbed marine clay, sand, greensand, and cobbles. The marine clays are from the Eastover Formation and contain disseminated pyrite; when this material is exposed to the air and rain, runoff has been found to become acidic, to a pH of 2 or 3. This runoff is known to dissolve concrete, rust metal poles (guardrails), and prevent vegetation growth (I-295, US-360 interchange is an example). On the downhill (toward the abandoned railroad) sides of slump blocks and slopes that have not slid contain a number of trees up to about 16 inches in diameter that show bent trunks. This hillslope is covered with vegetation, construction debris (curbstones, concrete, etc.) other solid waste, and trash.

Interpretations at 31st and Grace: Bent tree trunks indicate that the original slope (toward the abandoned railroad) has been moving (creeping) downhill for many years. The fill appears to have been placed in an old stream valley (Blood Run?). The lower fill layer of marine sediments could have come from the construction of the railroad tunnel under Church Hill. The downhill movement of the slope (the fill) has probably caused storm and possibly sewer drains to break apart over time; this coupled with the depressions on the other side of the playground likely allowed the fill to become saturated over a long time. Intense rainfall on pavement resulted in high rates of runoff, downhill on 31st street, from Broad, likely running over the end of the street and washing out fill on the downhill slope. Removal of material at the bottom of the slope in conjunction with saturated conditions enabled the failure and landslide.

Recommendations at 31st and Grace:

Determine the extent and saturation conditions of the remaining fill material and configuration of the original land surface by borings. The original land surface may be overlain by colluvium and alluvium composed of sand and gravel, in turn overlying marine clay. The engineering properties of all this material can be determined by borings.

Observations and Interpretations at Jefferson Park: I observed sand and gravel (original material from the top of the hill) and fill (bottles, bricks, to cover the hillside. The marine clay is also exposed in the face of the exposed hillside. Hummocky mounds of grass-covered sand, gravel and fill remain on the slope, and indicate that the slope is still unstable. Additional rain and/or removal of material at the bottom of the slope will likely lead to more landslides across Marshall street.

Observations and Interpretations at Oregon Hill: Hummocky mounds toward the bottom of the hill show recent downhill movement of material. Material behind the failed stonework adjacent to roadway is also fill material. Rainfall running downhill (down the road) from the construction area likely cascaded over the stone wall, washing out the supporting sediment/fill at the base of the wall; possible drain failure similar to 31st and Grace?

Observations and Interpretations at Chimborazo Park: Cobblestone road washed out, perhaps from runoff coming down this roadway. I did not examine the exposed hillsides in this park.

Overall interpretation of Landslides in Richmond: Before Richmond was inhabited, hillslopes were vegetated and were at a lower angle than compared to today. In almost every exposure I found fill on the hillslopes and involved in the material washed downhill. In an older city such as Richmond, I can imagine that developable land surface could be increased by fill applied to the tops of hills. City street development also required cutting into hillslopes and removing material from the bottom of hills. The result of this old development made hillslopes steeper than original slopes, and contributed to the instability of hillslope material. Pavement increases the intensity of runoff (greater volume of water flowing over a shorter period of time compared to vegetated slopes) and focuses the flow to a narrow downslope area. Oversteepened slopes, filled areas and areas at the downhill end of paved areas (and combinations of these factors) appear to have contributed to most of the landslides that I observed.

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