Underlying failure mechanism and spatial extent of the Omoto Slip, Greymouth, New Zealand

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Keywords: Slope Stability, Mass wasting, Rotational failure, MID

ABSTRACT

The underlying failure mechanism at the Omoto Slip is translational soil creep of the 5-30 m thick colluvium cover over the Kaiata Mudstone bedrock erosional surface that extends across the entire Omoto slope area. This is driven by major evacuative failures at the toe of the slope. These rotational failures occur during 1 in 20+ year flooding events due to the elevated lower water table increasing hydraulic pressures, creating buoyancy and decreasing the frictional strength of the colluvium. Flooding instigates translational creep along the bedrock erosional surface due to the removal of toe material moving the slope away from equilibrium geometry causing secondary rotational failures and creep to occur. These are assisted by the highly active and variable perched aquifer system within the colluvium that responds to intense rainfall runoff only. The detachment mechanism for the rafted limestone blocks from Peter Ridge are planar and wedge sliding or direct toppling. Large scale failures and high rates of movement are concentrated at McKendries Corner. The large spatial area and random locations of these failures create issues when trying to increase stability across the site. However, the most effective mitigation measure is surface drainage. The site's current system needs maintenance and repairs to ensure efficiency. Riprap scour protection along the edge of the Grey River is also suggested.

1 INTRODUCTION

The Omotomoto (Omoto) Slip, 2 km east of Greymouth has been detrimental to State Highway 7 (SH7) and the KiwiRail Midland Line (MID) that traverse it at the base since 1894. The situation is inherently complex with an approximate lateral limit of 2.5 km (Figure 1). The slip comprises of colluvium, limestone scree and large discrete (> 40,000 m^3) rafted limestone blocks. Movements are governed by the hydrological system, driven by the highly variable rainfall patterns of the Westland region that affect river levels and surface runoff. The following authors; McLean & Read, 1975; Galloway, 1977; Mansergh, 1977 a & b; Paterson, 1984; Mclean, 1987; Leung, 1988; Paterson, 1989 a & b; Golder Associates (NZ) Ltd, 2002; Justice, 2012; ENGEO, 2015, have summarized the site during geotechnical investigations and stability works. However, these are primarily focused on the small portion of the area that failed at that specific time. The mechanism and trigger for these individual failures is well understood. However, there are contradicting statements on the major underlying basal failure mechanism that covers the greater site, whether it is a deep seated rotational failure or translational creep. The presence and effect of the rafted limestone blocks is also poorly understood. Furthermore, previous field maps convey conflicting spatial extents with no evidence for the portrayed head scarp.
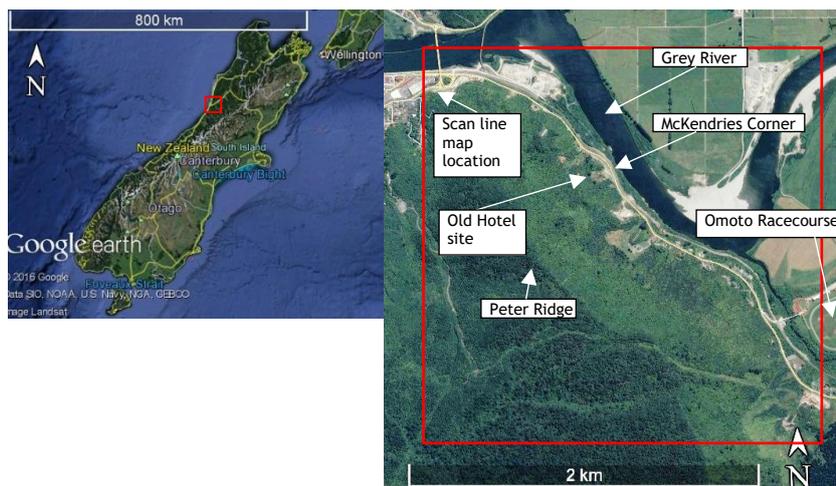
Figure 1: Red square representing the study area, approximately 5.25 km^2. Images retrieved from Google Earth.

2   RESEARCH METHODOLOGY

2.1   Literature Research and Desktop study

A systematic literature review and desktop study was undertaken to understand the geological evolution and history of the Omoto Slip. Reviewing previous geotechnical reports and literature in a chronological order provided an insight into how the understanding of the slip has evolved over time, highlighting contradictions between authors which create uncertainties in the current understanding.

2.2   Engineering Geology/Geomorphic Mapping

Initial mapping was undertaken by stereographic imagery analysis, accompanied with high resolution aerial photography and LiDAR data supplied by the West Coast Regional Council (WCRC). Critically reviewing current maps derived by Suggate, 1953; Mclean & Read, 1975; Mansergh, 1977a; Mclean, 1987; Leung, 1988; Paterson, 1989a; Golder Associates (NZ) Ltd, 2002; Justice, 2012; ENGEO, 2015, enabled cross checking and validation. The first-edition map compiled is thus a rendition of past mapping, assisted with remote mapping techniques that were not available in previous efforts. This stage identified where in-depth field mapping should then be focused. A geological compass, map board with mylar and a handheld GPS was used. The final map is presented as Figure 2. This map was digitally complied using Inkscape drawing software to ensure high resolution and usability.

2.3   Rafted Limestone Blocks

The detachment mechanism for the large Cobden Limestone blocks across the site was assessed in the stereographic computer program "DIPS" by Rocscience. A scan line map was drafted, accompanied by recording all structure in a 1 m^2 area on the mapped rock face. The structure observed and recorded was then assessed for kinematic feasibility for all failure styles. This analysis is portrayed on Figure 4.

2.4   Engineering Geology Block Models

Block models are a fundamental tool for portraying critical geological and geotechnical characteristics and parameters in one, salient 3D diagram. The 3D nature allows for a spatial and temporal insight into the controls and links between the geomorphic, geotechnical and subsurface geological structure allowing for the interpretation and understanding of an engineering geology

phenomenon, such as a landslide (Figure 3). Conversely, aerial photography and 2D maps do not have the ability to tie these links together, creating a disconnection between surface expression, processes and subsurface structure, leading to confusion of the situation (Parry et al. 2014).

3   RESULTS

3.1   Literature review and desktop study

3.1.1   History of the Omoto Slip

The Omoto site is inherently complex with variable rates and scales of slope instability within the area. Five large evacuative failures have occurred since 1894 causing damage and delays to both SH7 and the MID; 1913, 1954, twice in 1972 and once in 1984 (Justice, 2012). Smaller scale failures and soil creep have occurred in-between, causing continued deflection to both life lines. The major failures are attributed to high flood stage levels of the Grey River and intense rainfall runoff in the local catchment, although, Golder Associates (NZ) Ltd (2002), suggest failures in 1954 and once in 1972 were related to earthworks. The failures across the site have led to many geotechnical studies and investigations, with major work re-aligning SH7 and the MID though McKendries Corner. However, failures and creep continue to disrupt this segment, with a permanent speed limit of 10 km/hr between 209.45 km to 209.7 km rail markers on the MID and 80 km/hr on SH7.

3.1.2   Geology

The tectonic regime from the convergent Alpine Fault system has folded and faulted Mesozoic Torlesse composite terrane units into a series of anticline and synclines. The north-south trending Brunner Anticline has a west dipping limb in the Cobden Limestone Member of the Nile Group (nc) which is underlain conformably by the Port Elizabeth Member of the Kaiata Mudstone Formation (rkp) (Nathan, 1978) (Figure 2). Bedding is typically dipping at 25-30° W, creating a scarp slope on the eastern slope (Mansergh, 1977b). The Omoto site is blanketed by 5 – 30 m of colluvium composed of limestone screes, rafted limestone blocks and weathered mudstone over lying the 15° erosional surface of the Kaiata Mudstone bedrock (McLean, 1987). Reports suggest the underlying failure mechanism of the Omoto Slip could be either a deep seated rotational failure (Suggate, 1953; Mansergh, 1977a) or a shallow translational failure (Paterson, 1984 &1989a; Justice, 2012).

3.1.3   Hydrology and hydrogeology

Failures throughout the Omoto area are governed by the complex hydrogeological system present. Two water tables have been identified by (Mclean 1987; Paterson 1989 a; Justice, 2012). 1) The lower is directly related to the Grey River. Christensen, Throssell, & Ferg (2012) conducted a hydrological assessment of the Grey River in 2012. Flood stage heights of 4, 5 and 7 m above sea level have return periods of 2.33, 5 and 100 years respectively. There is no tidal effect on this water table. 2) The upper, a perched aquifer system within the colluvium, confined by the Kaiata Mudstone bedrock. The highly heterogenous hydraulic conductivities over the site created by multiple scree deposits, boulders and rafted limestone blocks allow fast water ingress into the low permeably mudstone derived colluvium (Justice, 2012).

3.2   Spatial extent

Remote and field mapping identified there is no head scarp at the base of the Peter Ridge, indicating the slip is in fact comprised of multiple rotational failures within the colluvium that is also translating along the erosional surface, which is not bound to a lateral limit (Figure 2 & 3). Previous literature and field mapping confirm scale and rates of movement are concentrated in the centre portion of the segment at McKendries Corner.

3.3   Failure mechanism

3.3.1   Omoto Slip

Two types of failure have been observed from reviewing literature and field observations. The underlying failure style across the entire site is translational soil creep (mass wasting) along the Kaiata Mudstone erosional surface. This includes the rafted limestone blocks and colluvium material. Secondary failures are defined as rotational, limited to the colluvium material (Figure 3). There is no feasible evidence for a large deep seated rotational failure to be extending into the Kaiata bedrock due to the scarp slope bedding geometry.

3.3.2   Limestone blocks

Kinematic analysis in the program DIPS identified there are three styles of joint controlled failures that can occur in the Cobden Limestone (Figure 4). Planar sliding, direct toppling and wedge failure can all feasibly occur, acting as the failure mechanism for the detachment of the >40,000 m^3 limestone blocks that are scattered across the McKendries Corner zone of the site. These blocks have tumbled or slid into the current location.

4   DISCUSSION

4.1   Spatial extent

The spatial extent of the Omoto Slip cannot be clearly defined due to the absence of a head scarp. Failures are observed to occur over the entire slope from the limestone/mudstone contact near the Grey River bridge to the Omoto Racecourse, where the two life lines move away from the slope. Therefore, the entire slope is unstable with rates of movement and the scale of failures increasing at McKendries Corner. This is thought to be governed by the limestone blocks and associated discontinuities that are promoting surface water to pool and percolate into the colluvium. Areas either side of McKendries Corner which do not have these limestone blocks and hummocky surface expression do not portray the same scale and rates of movement. A defined scarp has not been drawn onto Figure 3 in this study. Instead, a red box indicates the area where the greatest creep rates, scale and reoccurrence of failures is occurring.

4.2   Failure mechanism

4.2.1   Omoto Slip

The presence of the Grey River at the immediate base of the slope is the primary trigger for slope movements by undercutting and eroding toe material. Additionally, during a major flooding event (> 1 in 20 yr) the lower water table contributes to failures due to increased pore water pressures, creating uplift and buoyancy in the toe. Reduction in shear resistance also occurs and as the water recedes the rapid draw down causes large evacuative failures to occur. Thus, the slope falls away from equilibrium geometry, which causes translational creep and secondary rotational failures in the upper areas of colluvium as it moves back towards equilibrium state. These secondary failures are assisted by the upper water table which responds to intense rainfall events and subsequent water ingress. Limestone scree and rafted blocks allow for high permeability, while colluvium derived directly from the Kaiata Mudstone bedrock does not. Creep is identified to occur continuously, however the rates are exacerbated when a large evacuative failure occurs at the toe. A protection and or support structure along the western bank of the Grey River may assist in mitigating these failures, reducing creep rates. Surface run off is removed from the lower areas of the slope via concrete channels and culverts. This system was observed to be overgrown, full of rubbish and debris and in places damaged causing the system to fail.
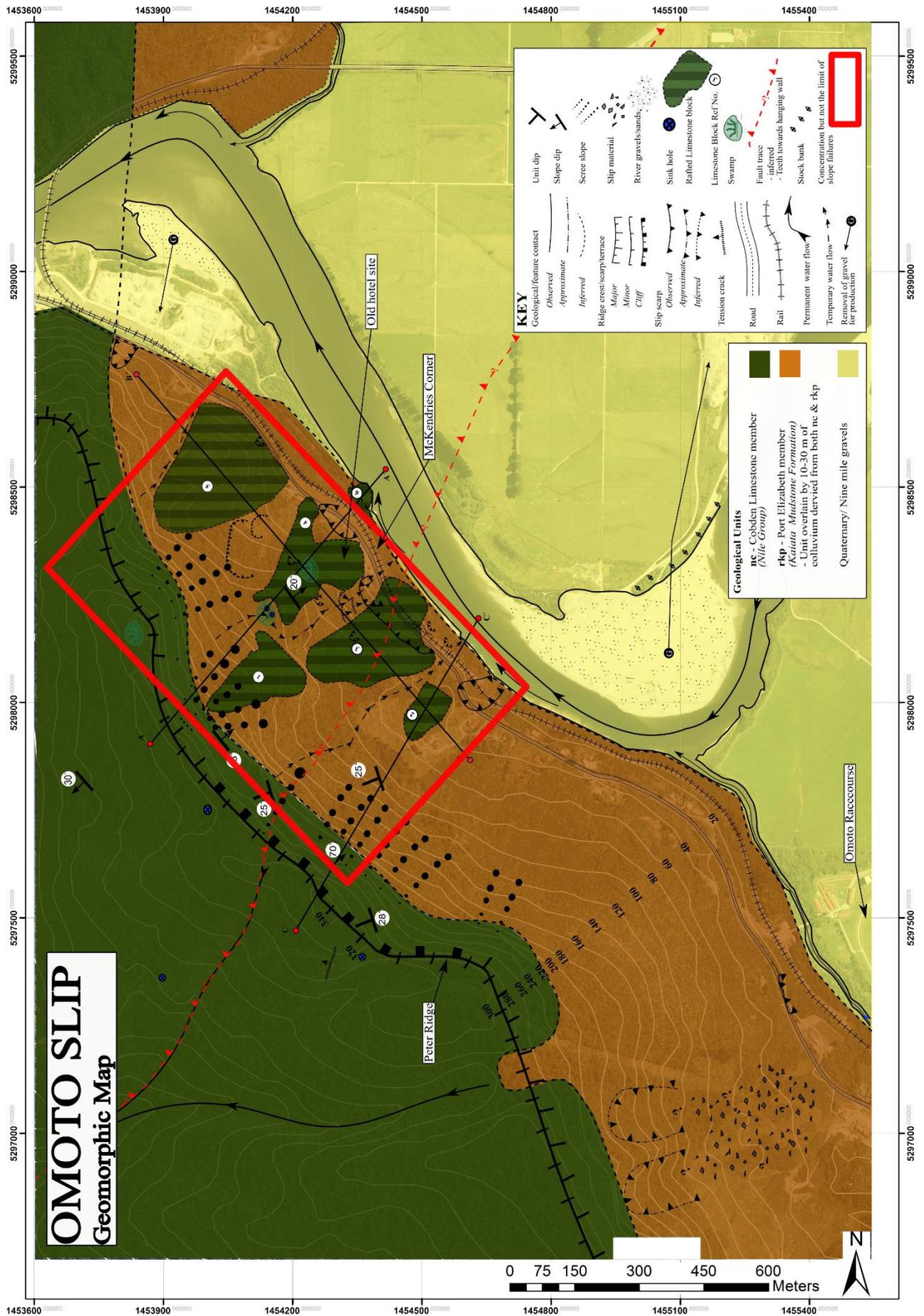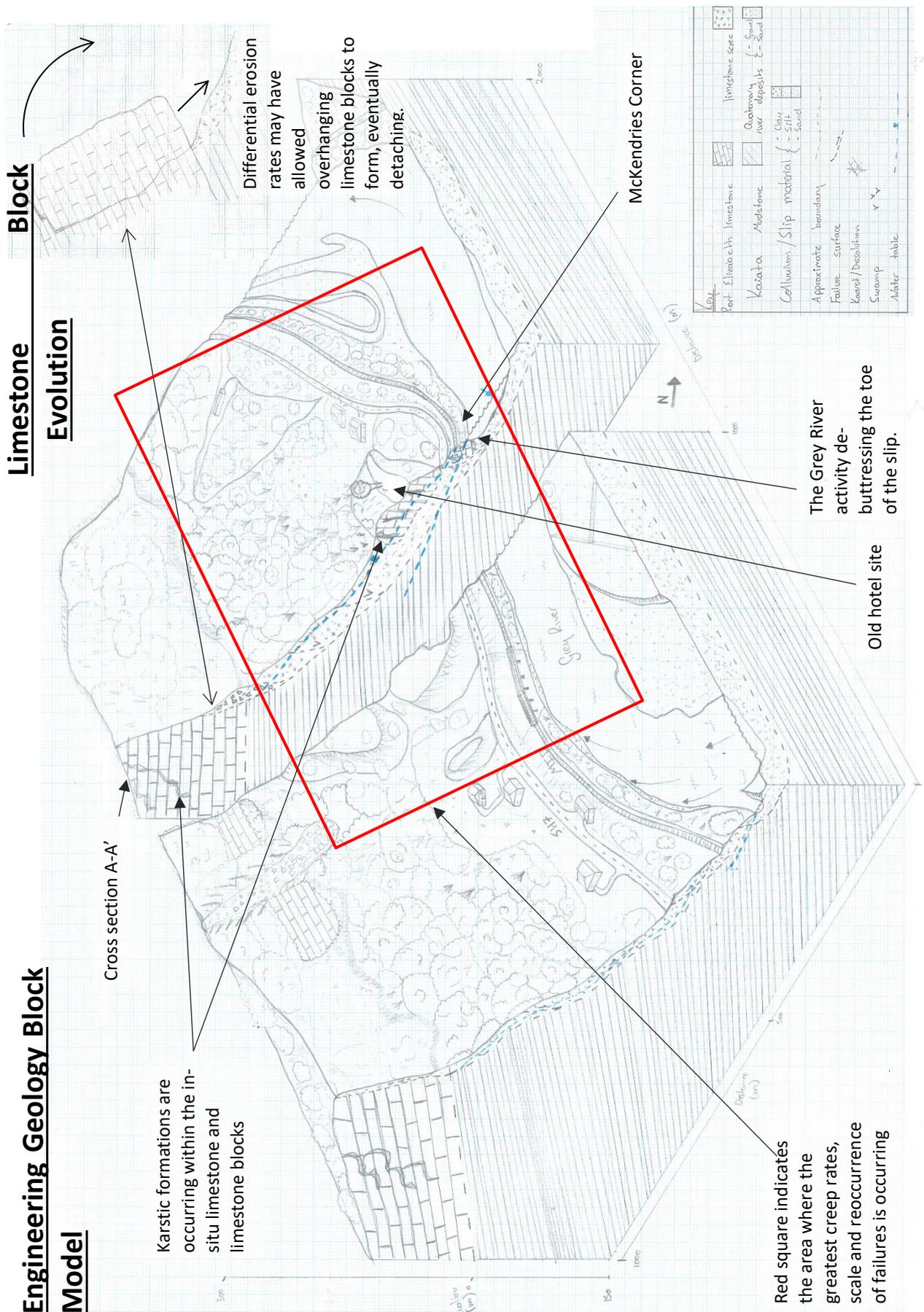
Figure 2: Geomorphic map of the Omoto area

Figure 3: Schematic engineering geology block model portraying the Omoto slip in 3D

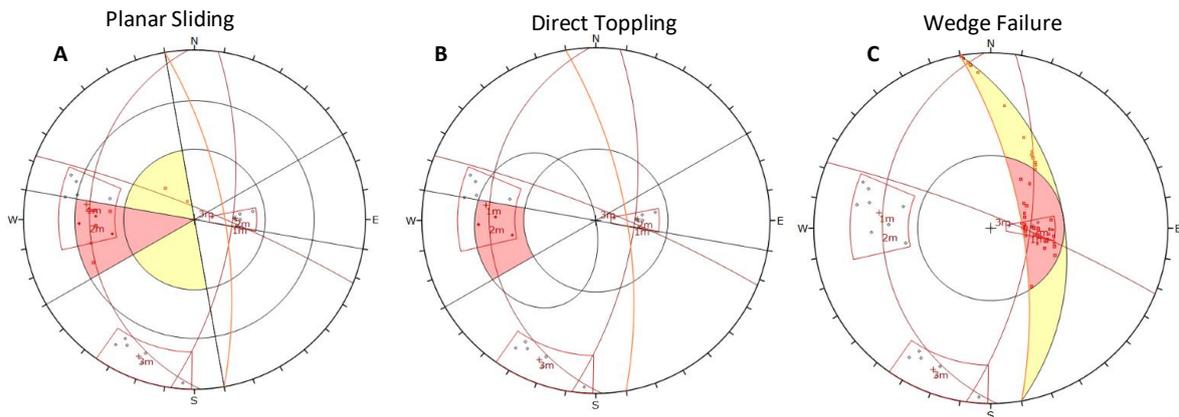**KINEMATIC ANALYSIS OF THE COBDEN LIMESTONE**

Figure 4: Kinematic feasibility analysis for the detachment of the rafted limestone blocks

4.2.2 Limestone Blocks

There are multiple stages in the formation 40,000 m^3 to 1,750,000 m^3 limestone blocks. The differential erosion rates between the Cobden Limestone and Kaiata Mudstone could allow for a large overhang to form. With only some of the beds showing close to moderate spaced discontinuities it is possible that beds showing no jointing structure on available outcrops, in fact have joints at very wide intervals (15-25 m) which have formed perpendicular to the principal stress created by the regional tectonic regime (Gonzalez de Vallejo & Ferrer, 2011). With the assistance of karst processes and internal weathering it becomes feasible for these large limestone blocks to detach via planar/wedge failure or direct toppling off the Peter Ridge face (Figure 3 & 4). Furthermore, Mansergh (1977 a) suggests rafted limestone blocks 2 and 5 portray disorientated bedding while the others portray similar orientations to in situ, indicating some have tumbled down slope, while others have simply slid to the current location.

5   CONCLUSION

The multi-component situation at the Omoto Slip is driven by primary large scale evacuative failures at the base of the slope which in turn, causes the rest of the slope to move back to an equilibrium state via creep and secondary rotational movements (mass wasting). The hydrological and hydrogeological systems present are the driving factor for the instability, thus they need to be managed successfully. Field investigations revealed there is no defined head scarp, nor any indication of it terminating at the fringes, indicating the site is bound within the colluvium mass which is translating along the erosional surface of the Kaiata Mudstone. Major failures are concentrated at McKendries Corner due to the presence of the large discrete limestone blocks with smaller scale failures occurring at either side. These large rafted blocks are detaching from the Peter Ridge via planar and wedge sliding or direct toppling. Some have toppled down slope, while others have slid along and within the colluvium surface, confirmed by the current bedding orientations. The multi-component hydrological and hydrogeological system present is the governing factor for the two failure mechanisms present. Understanding and mitigating the effect this system has on the geotechnical characteristics of the soils and rocks present is imperative to increasing stability across the site. Mitigation efforts should be focused on repairing and maintaining the existing drainage system that is not effective in its current state. Further efforts could be implementing riprap scour protection and or buttress for protecting the toe of the slip.

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