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Notes

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Abstract: Geomorphological landslide models developed to characterize natural hill slope landslides can assist significantly in the evaluation of natural hill slopes for hazard and risk assessment and for the selection of appropriate mitigation measures. Intense rainstorms in 2000 and 2001 resulted in about 45 natural hill slope landslides on a small area in the vicinity of Cloudy Hill, Tai Po, Hong Kong. A detailed study was carried out to examine systematically the characteristics and mechanisms of the landslides for the purposes of identifying the geomorphological and geological factors influencing susceptibility to landslide occurrence and with the aim of improved hazard assessment for similar hill slopes elsewhere in Hong Kong. Site-specific landslide models were developed from an assessment of the geomorphological setting and landslide characteristics, using a combination of morphological and morphochronological mapping based on aerial photograph interpretation together with field reconnaissance and inspection. Detailed field mapping was carried out for selected landslides following initial review, to confirm the relevant geomorphological factors and document relevant landslide characteristics. An outline of the study at Cloudy Hill is given and the development of the landslide models is presented, together with an overview of how the models were used to assist in the evaluation of natural terrain landslide hazards.

As a result of intense rainstorms in April 2000 and June 2001 more than 45 landslides occurred in natural terrain in the vicinity of Cloudy Hill, Tai Po in the NE New Territories, Hong Kong (Figs 1 and 2). As part of a continuing landslide investigation programme of the Government of the Hong Kong Special Administrative Region, a detailed study was undertaken for the Geotechnical Engineering Office (GEO) (Halcrow China Limited 2003). The study included systematic investigation of the characteristics and mechanisms of the failures so as to assess the geomorphological and geological factors influencing susceptibility. Landslide settings and triggering factors were studied for comparison with failures elsewhere in Hong Kong. The study involved detailed aerial photograph interpretation (API) of the 2000 and 2001 landslides as well as historical landslides as shown in Figure 3. The distinction in Figure 3 between pre- and post-1963 landslides is a pragmatic one in that the 1963 set of air photographs was of particularly high quality and resolution, and allows a high level of confidence in the interpretation of landslides as distinct from gradual, erosional features (Styles & Hansen 1989). Engineering geological mapping was carried out for the majority of landslides.

The study area

The Cloudy Hill study area is located in the NE New Territories of Hong Kong about 1 km north of Tai Po (Fig. 1). The study area is about 4 km^2 with the elevation ranging from about 40 m above Hong Kong Principal Datum (PD) to 440 mPD (PD is about 1.23 m below mean sea level). Much of the higher side slopes (above 200 mPD) is grass covered. The lower slopes are generally covered by a mixture of low shrub and woodland, becoming dense woodland along drainage lines (Fig. 2).

Geology

The solid geology of Cloudy Hill comprises volcanic rocks of the Tsuen Wan Volcanic Group of Middle Jurassic to early Cretaceous age; the dominant rock type is an undivided coarse ash crystal tuff of the Tai Mo Shan Formation of Middle Jurassic age (*c*. 165 Ma; GCO 1986, 1991; Lai *et al*. 1996; Sewell *et al*. 2000). The Tai Mo Shan Formation underlies all except the southern part of the southeastern portion of the study area, which is within the Shing Mun Formation, also of Middle Jurassic age, a complex and lithologically variable volcanic rock formation. Two faults are inferred within the study area: a NW–SE-trending fault that runs along the major drainage line within the southern part of the study area, and a NE–SW-trending fault that runs along the western end of the northwestern part of the study area (Fig. 4).

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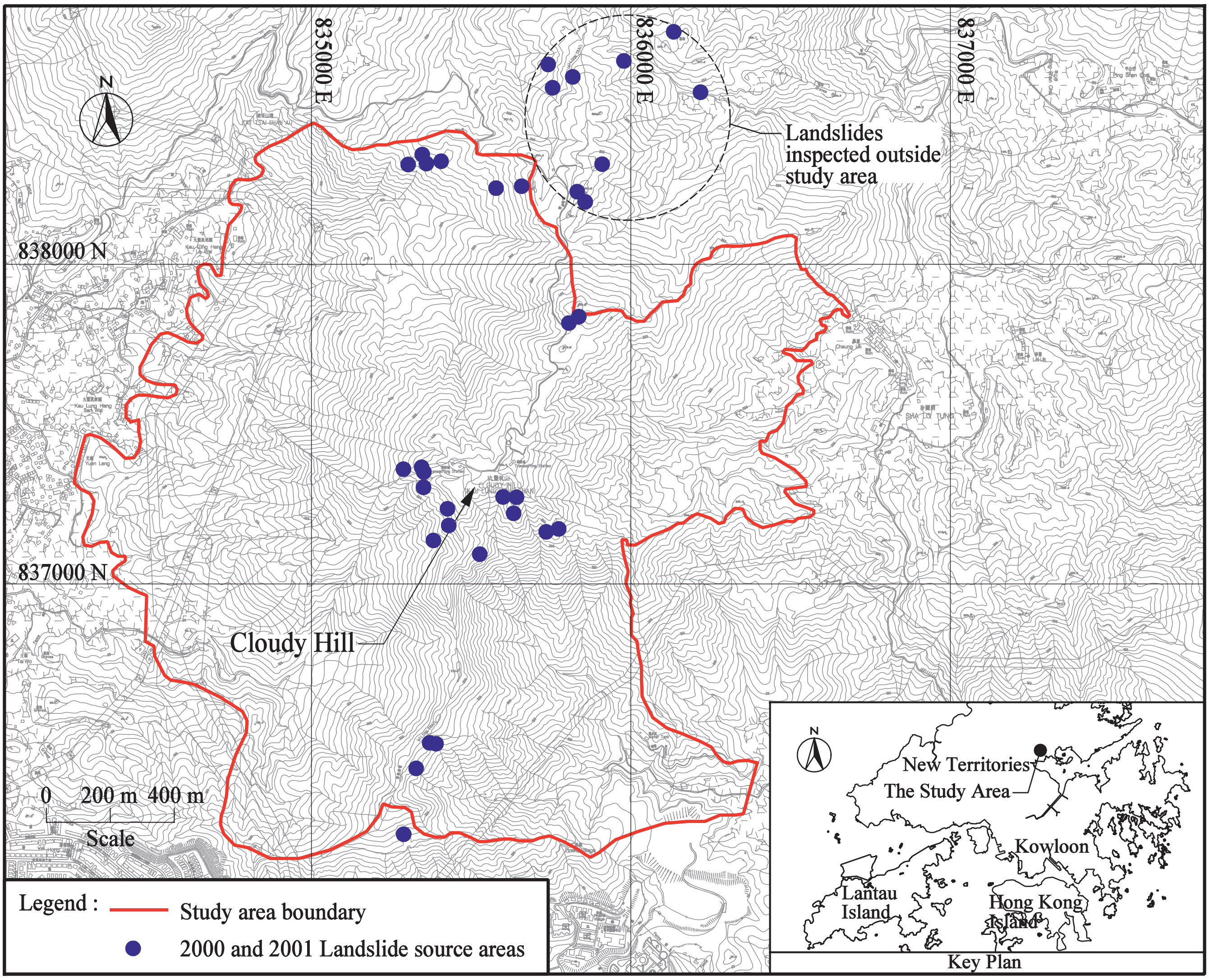


Fig. 1. Location of 2000 and 2001 landslides at Cloudy Hill.

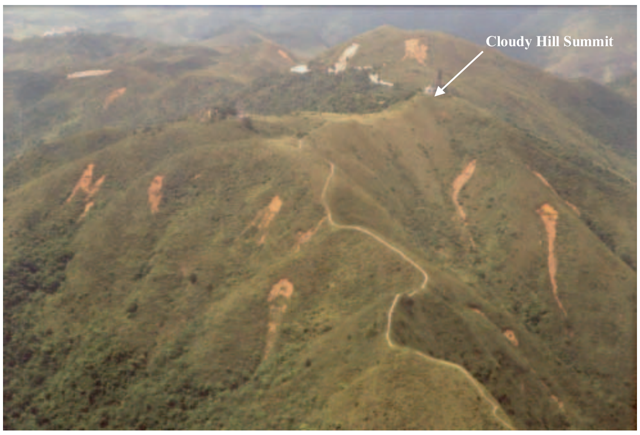


Fig. 2. Oblique aerial view of the 2000 and 2001 landslides on Cloudy Hill (looking north).

Geomorphology

The terrain forming the study area is generally characterized by moderately steep to steep slopes (typically 20–40°) with gently concave side slopes rising to either sharp ridgelines or rounded convex spur lines generally with a prominent convex break in slope below. Based on site observations, the rounded spur lines are generally draped with a continuous, thin (generally <1 m) veneer of fine colluvium (a matrix-supported, loose to medium dense, light reddish brown silty sand (or firm sandy silt) with some gravel and some to many angular cobbles of moderately decomposed tuff, which is probably derived from slope wash processes) underlain by several metres of saprolite (a soil derived from *in situ* chemical decomposition of the parent rock that retains evidence of the original rock texture, fabric and structure). It is to be noted that the weathering terms used here comply with the recommendations of GCO (1988) and generally with BS 5930: 1999 (BSI 1999). The sharper ridgelines are characterized by a shallow layer of saprolite with occasional minor areas of exposed rock and with generally little or no colluvium cover. Below the ridgelines, a thin layer (generally between 0.2 and 2 m thick) of typically

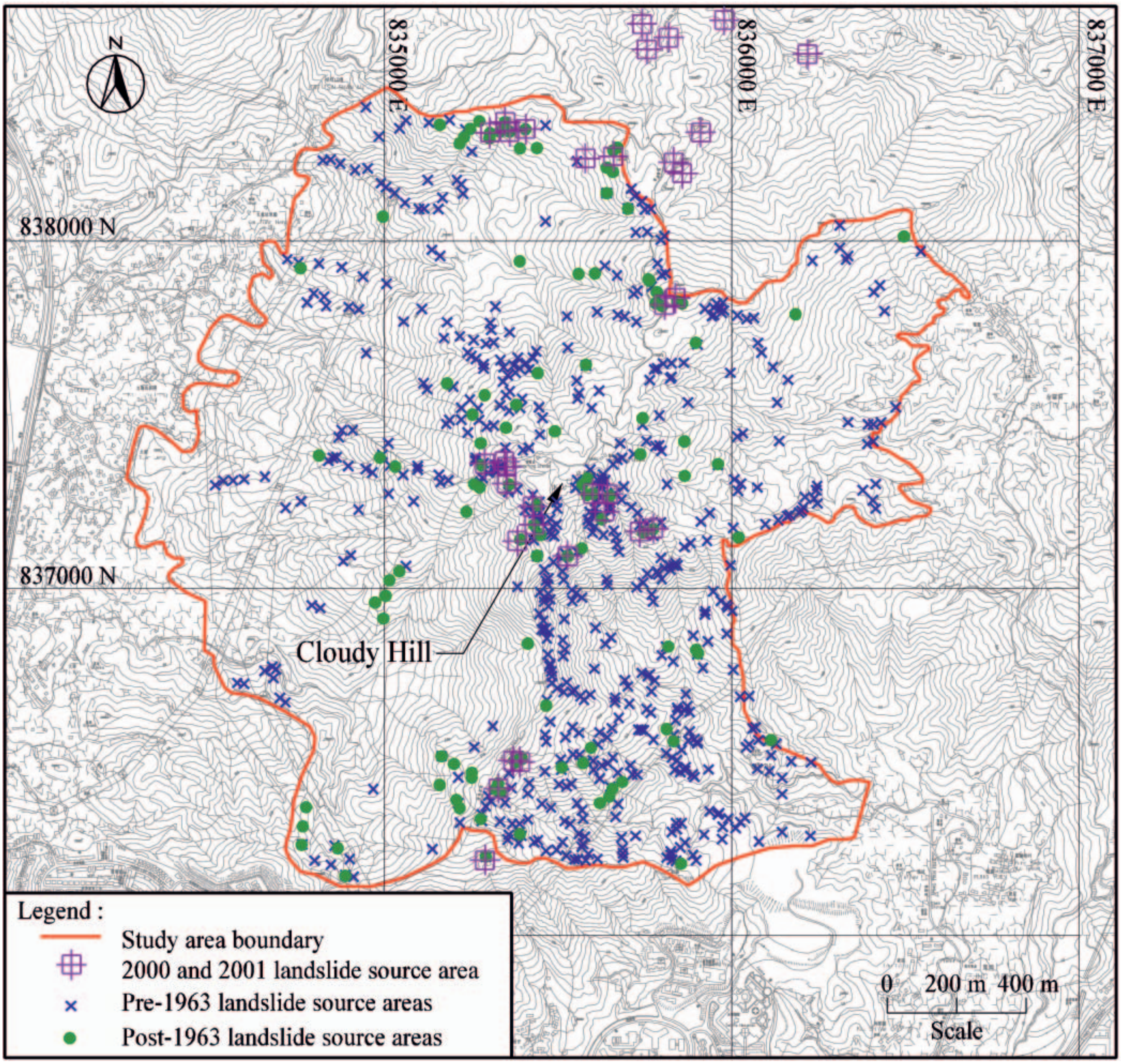


Fig. 3. Locations of landslides at Cloudy Hill identified from API and from field mapping.

cobbly colluvium, comprising light brown to reddish brown and grey cobbles and boulders with much clayey or silty sand mantles the hillside. It is noteworthy that the size of the catchments above most of the 2000 and 2001 landslides at Cloudy Hill tends to be small (<200 m^2), and for landslides immediately below the ridgelines there are practically no catchments.

A geomorphological model for landscape evolution in Hong Kong was proposed by Hansen (1984) and this is reproduced as Figure 5. Hansen proposed a simple two-form model comprising younger and older landform assemblages. The upper 'older' assemblage has relatively deep weathering profiles and a mantle of old colluvial sediments; the lower, 'younger' assemblage, cutting back into the old terrain, was initiated by and owes its characteristics to stream rejuvenation as a consequence of the drop in sea levels in the Pleistocene. Subsequent sea-level rise has resulted in the lower sections of the streams being submerged and largely becoming depositional. The assemblages are distinct in terms of surface processes, and the greatest potential for erosion is at the boundary between the two.

Using Hansen's model and other recommendations (Anon. 1982; Lee 2001; GEO 2004) morpho-chronological mapping (assigning relative ages to identified landforms) allowed two distinct upper and lower landform assemblages, each consisting of convex–concave elements, to be distinguished within the study area. The upper landform generally consists of rounded ridgelines and is characterized by slightly convex, almost planar

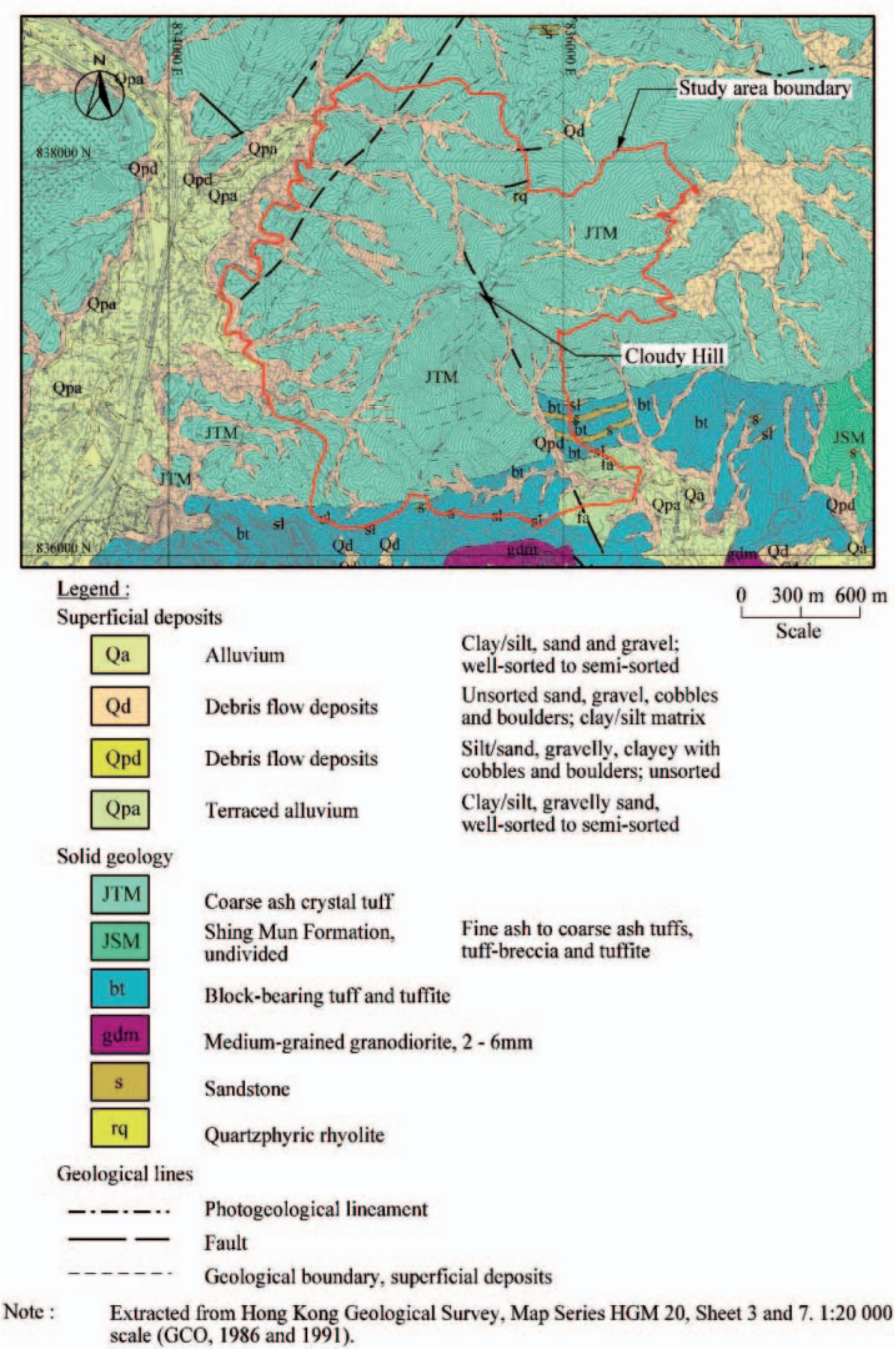
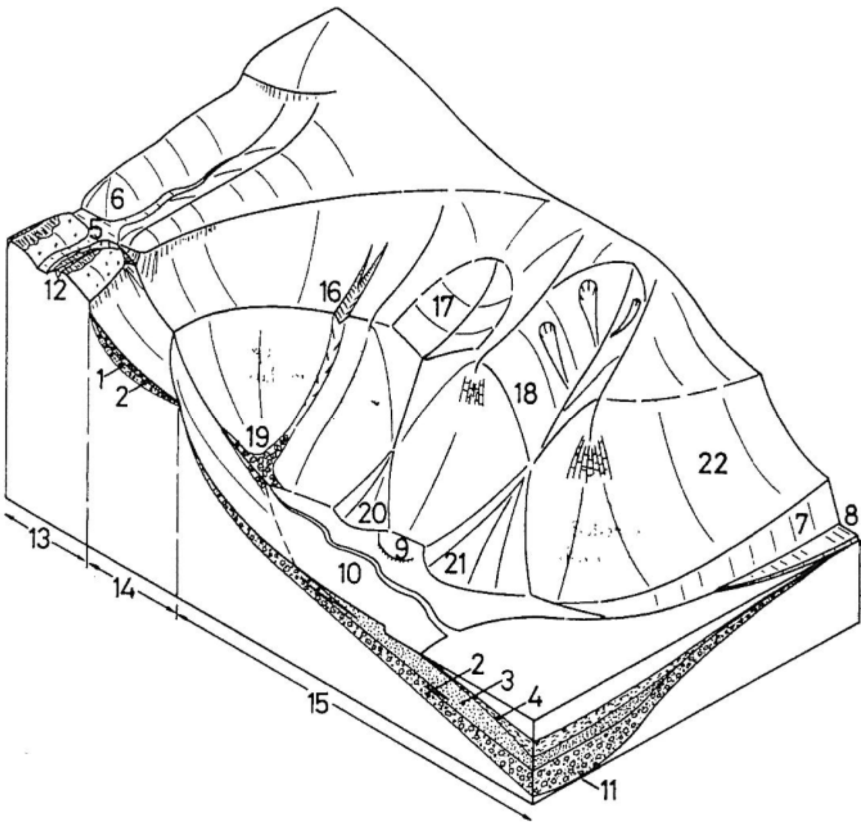


Fig. 4. Geological plan of the Cloudy Hill study area.

surfaces with few drainage lines and a generally smooth surface texture. Typically the upper landform is deeply weathered and often covered with a mantle of 'old' weathered colluvium, probably deposited as a result of long-continued 'creep' and slope wash processes. Locally areas of exposed rock and boulder fields derived from the exhumation of corestones are found. The upper landform is particularly well developed in the SW of the study area and can be seen clearly on the 1987 aerial photograph (Fig. 6). A generally distinct convex break in slope marks the boundary between the upper and lower landforms. The boundary with the lower landform is a zone of hillside retreat, which can be active or relict, with relict zones indicated by an apparent lack of recent activity, and marks the locus of regression of the upper landform as it has propagated upslope. Landslides are concentrated along the boundary between the upper and lower landforms (Fig. 6). In places, the process of hillside retreat has reached the ridgeline, resulting in knife-edge ridges.

Thirty four of the more than 45 recent landslides were inspected in detail. Locations were determined (± 5 m)



Materials
1. Old colluvium
2. Young colluvium
3. Alluvium
4. Marine deposits

11. Submarine buried valley
12. Ridgecrest gully erosion
13. Relict landforms on uplands
14. Older landform assemblage

18. Deep, bowl-shaped valley between spurs, subject to instability on sides
19. Boulders in stream channel

Landforms
5. Upland valley
6. Deeply weathered hills
7. Coastal cliffs
8. Wave cut platform
9. Alluvial terrace
10. Floodplain

15. Younger landform assemblage
16. Stream incising into superficial deposits
17. Initial incision has widened to a small valley

20. Small colluvial fan
21. Large colluvial fan
22. Coastal slope (thin soils)

Fig. 5. Evolutionary model of Hong Kong's terrain (Hansen 1984; Styles & Hansen 1989).

using a Garmin handheld global positioning system (GPS). Preliminary measurements and general observations were made and recorded using standard field sheets as presented in Figure 7. A summary of the key data is presented in Table 1, with the location of the inspected landslides shown in Figure 8. Following an initial review, eight landslides were selected for more detailed study. Selection for detailed study included criteria such as failure volume (over 100 m^3), evidence of reactivation, possible structural control, presence of tension cracks and other evidence of pre-detachment deformation such as deformation of quartz veins during weathering or sediment infilling to joints.

The majority of the 2000 and 2001 landslides at Cloudy Hill were relatively shallow (about 1 m deep) and typically situated at the heads of drainage lines or on the flanks of drainage lines and below ridgelines. Estimated failure volumes ranged from 12 to 630 m^3 with an average of about 100 m^3. Debris from a small proportion of the landslides entered drainage lines and had relatively long runout distances (up to 200 m) excluding outwash, whereas for the vast majority the runout distances were far shorter, as discussed in more detail below.

The slip surface at most of the landslides inspected was along the interface between colluvium and saprolite; it was also observed that in several landslides the slip surface also cut through the underlying saprolite, which typically comprised completely decomposed tuff (dense to very dense, light pinkish to reddish brown silty or clayey sand with occasional fine gravel of quartz).

The main scarps at most of the landslides were either planar or slightly concave in shape. Generally, where the

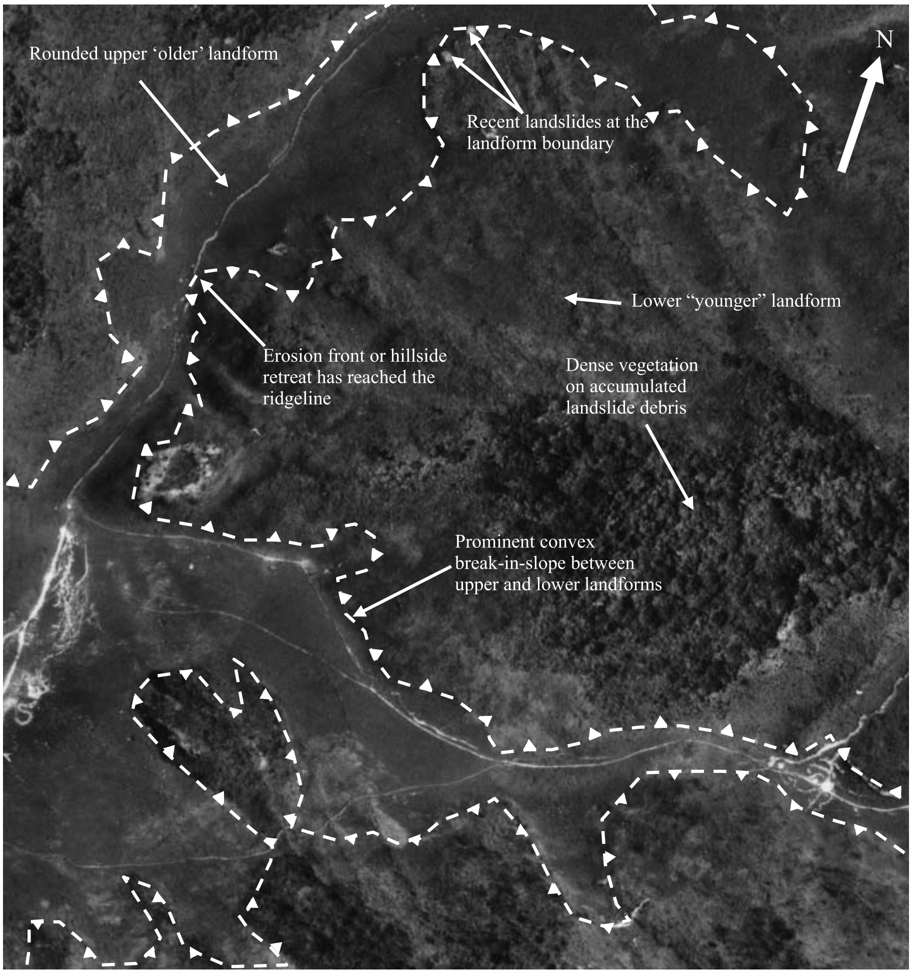


Fig. 6. Aerial photograph taken in 1987 showing a convex break in slope separating upper and lower landforms.

surface of rupture was along the colluvium–saprolite interface, the surface of rupture was concave or slightly irregular. At landslides where the surface of rupture was within the saprolite, the main scarp was typically planar to slightly concave in shape. Erosion pipes were observed in the main scarps (primarily within colluvium) at several of the landslides. Possible structural control was also observed at some landslides where the surface of rupture ran subparallel to fractures within the saprolite. Tension cracks were observed at a number of the landslides, with the tension cracks typically located to one side of the landslide crown and usually discontinuous and less than 1 m long.

Observations at the recent landslides on Cloudy Hill indicate that the majority are of the shallow debris avalanche type (Cruden & Varnes 1996; Ng *et al.* 2002), where the displaced material has broken up and become remoulded but no additional surface water has been incorporated into the debris. There is much evidence from the intact displaced masses found at most landslide sources that several of the landslides were initially debris slides that subsequently developed into debris avalanches. Debris from several of the landslides ran into drainage lines and became channelized.

Landslide models

Based on the field observations, landslide characteristics and morphological setting, the recent landslides at Cloudy Hill were grouped into two broad types: Types I and II.

Type I landslides

The field setting and mechanism of typical Type I landslides is shown in Figures 9 and 10, respectively. Type I landslides generally occur a short distance above the head of a drainage line or below a ridgeline, and commonly at a prominent convex break in slope. In the field, the landslides usually have a planar main scarp with a planar to slightly concave surface of rupture. The failure generally occurs through the uppermost portion of the deeply weathered saprolite and may include an overlying thin layer of older weathered colluvium.

Type I landslides are generally located at, and essentially define, a zone of high susceptibility to instability, representing an erosional front of hillside retreat, that progressively destroys the upper, older landforms. The erosional front essentially defines the boundary between

Landslide Investigation Consultancy Agreement No. CE 2/2000 **Landslide No.**
Landslide Reconnaissance Field Proforma - Cloudy Hill **01W**

Mapped by DMD Date 22/08/01 Weather V Hot
Grid Ref. 835818 E 838586 N (X) GPS ( ) Estimated
Date of failure Jun-01 Evidence Helicopter trip in July

SOURCE

Length	30	Width	15	Depth	1	**Volume**	**225**
B.Colluvium	0.8	F. Colluvium	0.2	RS		Grade V	
Grade IV	0.1	Grade I - III	0.1	Others			

LOCATION
( ) Open hillside (X) Head drainage channel ( ) Flank drainage channel
( ) Below exposed rock (X) Below ridgeline Slope angle 40 Slope Aspect 325

DEBRIS
( ) Non-channelised (X) Channelised ( ) Not known ( ) Entrained material
Estimated travel distance 100 Estimated travel angle 35

LANDSLIDE TYPE
(X) Soil ( ) Rock ( ) Soil/Rock
(X) Shallow translational slide ( ) Deep translational slide (X) SOR at Colluvium/Rock interface
( ) Planar ( ) Topple ( ) Wedge ( ) Structural control ( ) Partial structural control

GENERAL OBSERVATIONS
(X) Man-made disturbance ( ) Tension cracks ( ) Post failure widening
( ) Evidence of previous movement (X) Deterioration of rock mass ( ) Seepage
( ) Within scar of relict failure (X) Infilled joints (X) Erosion pipes

Notes:
Wilson trail footpath crosses landslide near toe
Very large boulders within the bouldery colluvium (>3 m across)

FURTHER STUDY (X) Yes ( ) Possible ( ) No particular interest

Photo. No.CH01WXCC Date 22/08/01 (Looking SE)

Photo. No.P8220077 Date 22/08/01 (Looking E)

Photo. No.P8220076 Date 22/08/01 (Looking E)

Photo. No.P8220078 Date 22/08/01 (Looking E)

Fig. 7. Example reconnaissance fieldsheet.

landform assemblages. Commonly, several Type I landslides coalesce along the line of instability to form a single large curved depression as illustrated in Figure 10. Evidence from field inspection and API indicate that groups of Type I landslides often tend to occur simultaneously as clusters (i.e. triggered by the same rainstorm event).

Type II landslides

Type II landslides are illustrated in Figures 11 and 12. They occur in concave depressions that are typically situated directly at the head of a drainage line (Fig. 12). Type II landslides occur following long-term accumulation of colluvial debris in a depression and may be

Table 1. *Summary characteristics of inspected landslides*

Landslide number	Slope gradient (degrees)	Slope aspect (degrees)	Length *L* (m)	Width *W* (m)	Depth *D* (m)	Volume *V* (m)	Runout (m)	Travel angle (degrees)	Landslide type	Underlying regolith type
93C	36	273	24	8	1.5	144	320	28	I	Sv
99A	31	200	12	10	0.5	30	95	33	II	Sv+/Cd
00A	37	135	15	12.5	0.8	75	105	42	II	Sv+
00B	40	200	55	25	0.8	550	152	38	I	Sv+
00C	35	144	18.2	12.5	1	114	250	42	II	Cd
00C2	32	255	10	18	0.8	90	86	33	II	Sv
00D2	29	200	14	10	0.5	35	104	31	II	Sv
00E2	28	197	14	10	0.5	35	90	30	II	Sv
00F1	38	220	8	6	0.5	12	40	31	I	Sv+
01A	31	170	20	8	2	160	60	29	II	Sv+
01B	35	195	27	16	1.5	360	120	34	I	Sv
01C	36	210	12	7	0.5	21	50	30	I	Sv
01D	42	222	15	8	0.8	48	60	30	II	Sv+
01G	32	235	17	12	0.5	51	40	29	I	Sv
01H1	35	208	22	8	1	88	60	30	II	Cd
01H2	35	210	8	6	0.5	12	50	40	II	Cd
01I	35	265	10	5	0.8	20	30	32	II	Sv+
01J	34	134	20	16	0.8	128	60	22	II	Cd/Sv+
01K	34	138	8	7	0.8	22	40	28	I	Sv+
01L	35	165	8	5	1	20	20	30	I	Sv+
01M	25	170	30	5	2	150	60	25	I	Sv(dw)
01Na	35	227	12	5	0.8	24	30	25	II	Cd
01N	24	210	20	42	1.5	630	100	20	Misc.	Sv+
01Q	35	265	10	8	0.5	20	30	18	II	Cd
01S	38	120	15	10	0.8	60	80	28	II	Cd
01Sa	40	100	15	11	1	82.5	50	24	II	Cd
01Sb	36	085	15	8	1	60	50	32	II	Cd
01W	40	325	30	15	1	225	100	35	II	Cd
01X	34	325	20	12	1	120	80	23	II	Cd/Sv+
01Y	30	206	8	14	1	56	10	28	II	Sv+
01CC	35	320	8	5	0.8	16	–	–	I	Sv
01DD	35	225	15	7.4	0.3	16.65	60	28	II	Sv+/Cd
01DDa	40	050	12	8	0.5	24	–	–	I	Sv
01EE	35	000	22	12	1	90	125	12	II	Sv+/Cd

Sv, volcanic saprolite (saprolite thickness less than 10 m); Sv+, volcanic saprolite with occasional corestones and typically an overlying thin (<2 m) veneer of fine colluvium or slope wash; Sv(dw), volcanic saprolite deeply weathered (saprolite thickness greater than 10 m); Cd, depression colluvium (a topographically confined typically bouldery colluvium).

triggered by a rainstorm once the debris attains a critical thickness. This process was identified following field observation that these failures were associated with significantly thicker colluvial deposits than those on the surrounding hillsides. The debris filling the hollow may derive in part from local failure of the exposed back scarp, from debris derived from other landslides upslope and from general slope wash processes. Type II landslides are probably triggered by perched water pressures within the colluvium above the colluvium–saprolite boundary as discussed below. The slip surface is along the colluvium–saprolite boundary and is typically concave but may sometimes be irregular.

In general, erosion pipes, which act to concentrate subsurface groundwater flow towards the landslide site, are more commonly observed in the colluvium in the main scarps of Type II landslides than in Type I landslides. The surface of rupture sometimes exhibits signs of previous exposure through the presence of a patina of relic algal growth. In some Type II landslides there is also evidence of possible deterioration of the *in situ* saprolite exposed subsequent to failure of the colluvium from the concave depression, such as quartz veins deformed through weathering of the saprolite and sediment, typically clay, infilled joints.

Other landslides

Other landslides are those that do not satisfy the general definitions of either the Type I or II landslides, but lack sufficient common characteristics to allow a third type to be defined. They tend to be open hillside failures that have no apparent relationship to the topographical setting or the geological setting, and include those that occur within drainage lines, usually only a very short distance from the axis of the drainage line. These

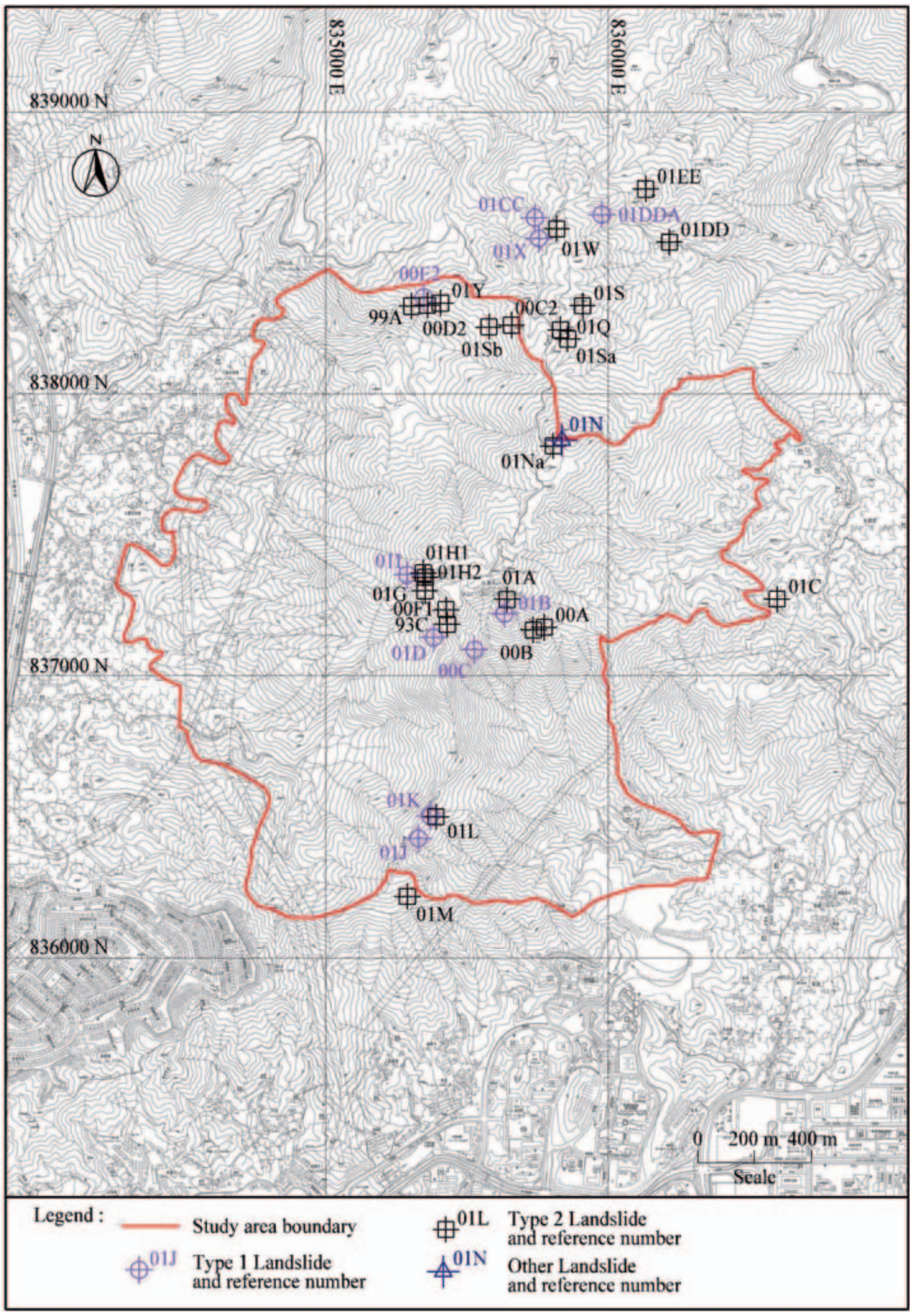


Fig. 8. Locations of inspected landslides.

landslides, which are usually small in size, are interpreted as being essentially related to minor erosional events, such as undercutting.

Mechanisms and causes of failure

The close correlation between rainstorms and the first observations of the 2000 and 2001 landslides at Cloudy Hill confirms that the landslides are triggered by rainfall. Based on field observations and API, contributory factors include geomorphological setting and ripening of the terrain.

Type I landslides

Type I landslides typically occur at prominent breaks in slope that delineate the limit of a zone of instability. The process involves retrogressive failure of over-steepened hillsides. The progressive deterioration of saprolite at the location of the Type I landslides, together with local adverse geological and/or groundwater conditions, can lead to landslides occurring repeatedly at the same or similar location over several tens of years as identified from API. The bedrock geology at Cloudy Hill is fairly uniform, coarse ash crystal tuff and therefore geological variation plays little part in the occurrence of landslides.

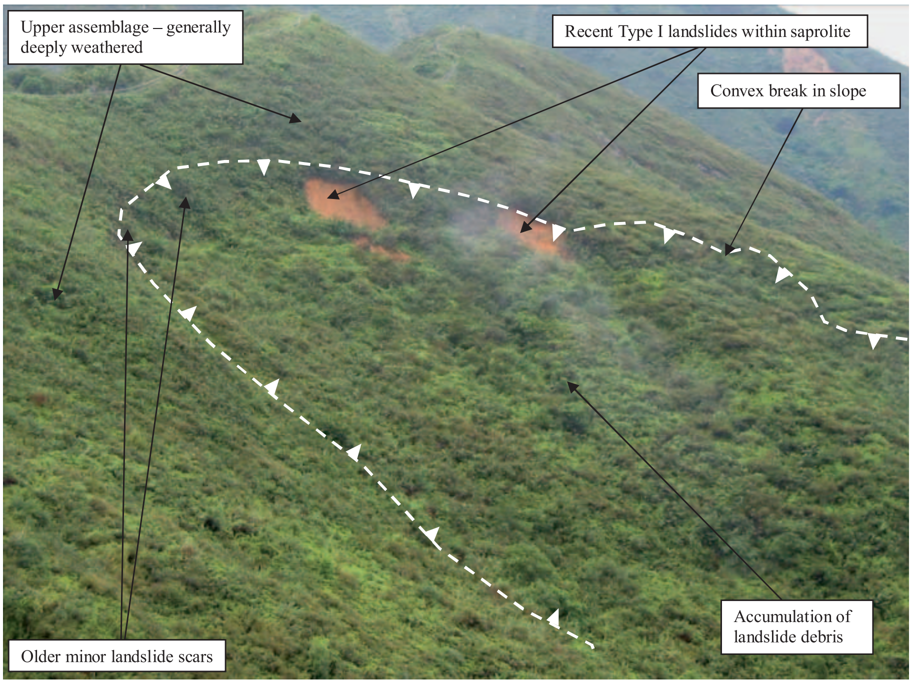


Fig. 9. Setting of Type I landslide.

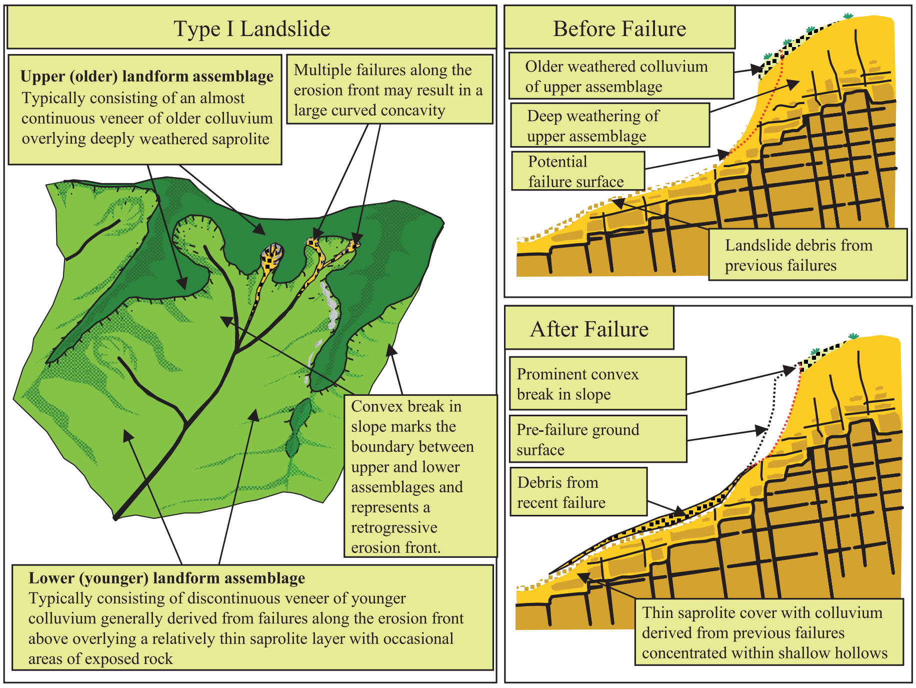


Fig. 10. Setting and mechanism of a Type I landslide.

The structural control recognized for some landslides that extend into the underlying saprolite may not be related to ancient geological processes but instead to stress relief fractures forming as part of the terrain development. The predominant influence on the development of Type I landslides in the Cloudy Hill study area appears to be the geomorphological setting.

Type II landslides

The failure mechanism of Type II landslides relates to morphological setting. The landslides occur within colluvium that has accumulated in topographic depressions to which both surface and subsurface water flows converge. Erosion pipes directing groundwater flow towards

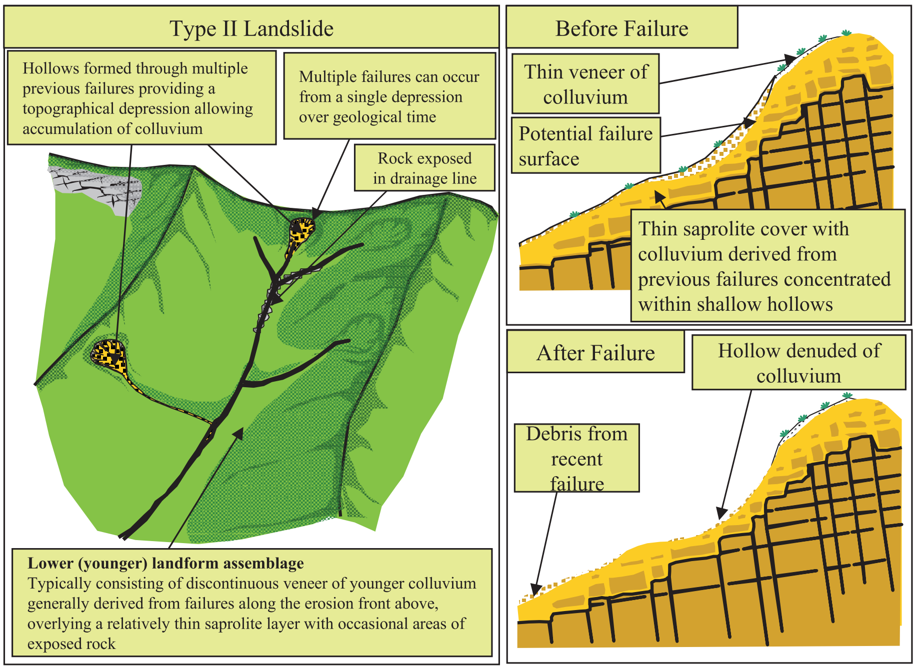


Fig. 11. Setting and mechanism of a Type II landslide.

the depression are commonly seen in the back scarps of these failures. The relatively high permeability of the colluvium compared with the underlying saprolite leads to the development of transient perched water tables above the colluvium–saprolite interface during intense rainfall. This in turn leads to reduced effective stress and shear strength in these predominantly frictional materials with consequent sliding failure along the colluvium–saprolite interface.

Type II landslides are interpreted as being related to a ripening of the topographic depression, with gradual accumulation of colluvium until it reaches a critical thickness that makes it prone to failure. Because ripening is generally a slow and progressive process that takes place over a long time, Type II landslides are unlikely to occur from the same location for a considerable period of time. As Type II landslides are typically located immediately at the heads of drainage lines, they have high potential to develop into channelized debris flows.

Landslide volume

The landslides at Cloudy Hill had estimated source volumes ranging from 12 to 630 m^3. The average estimated landslide volume was about 100 m^3 but less than a third of the landslides inspected had an estimated volume greater than 100 m^3.

The volume of a Type II landslide is influenced by the physical dimensions of the hollow within which the source is located, and in general the Type II landslides observed at Cloudy Hill had estimated volumes of less than 250 m^3. There are fewer physical constraints for

Fig. 12. Setting of a Type II landslide.

Type I landslides, which, although typically observed to be minor failures of less than 50 m^3, can be significantly larger in volume.

Two landslides had volumes greater than 500 m^3. One was a Type I landslide and had an estimated volume of 550 m^3. It involved the displacement of a thin veneer of colluvium together with a small section of the underlying saprolite. The landslide debris fell into a drainage line and travelled a total distance of about 150 m with minor (<5 m^3) entrainment. The largest landslide inspected had a volume of 630 m^3 and was an open hillside landslide (neither Type I nor Type II). The landslide had a length of 42 m and was probably predisposed by ancient geological structure with a thick (>50 mm) quartz vein running subparallel to the surface of rupture. Much of the 400 m^3 debris comprised bouldery colluvium that remained within the source area as intact debris rafts. The mobilized debris, with a volume of about 250 m^3, travelled into a poorly defined drainage line below the source for a distance of about 85 m with little evidence of entrainment.

Landslide mobility

The travel angles of the landslides measured from the landslide crown to the distal end of the debris lobe (Cruden & Varnes 1996) were used as an empirical method of assessing the debris mobility (Wong & Ho 1996). The travel angles of Type I landslides varied within a range of 25–37°, whereas the travel angles of the Type II landslides were significantly more variable at 12–40°.

The travel distances of the debris from the landslides were also measured and ranged from 10 to 250 m. The average travel distance was about 80 m and the corresponding average travel angle was about 30°. The longest travel distance measured was for a Type II landslide from which the debris entered a steep drainage line immediately below the source and travelled a distance of about 250 m with a travel angle of 40°. This may have indicated a rather limited mobility of the landslide debris, as the travel distance was probably influenced primarily by the steep gradient of the drainage line, at 38–58° (on average 45°), below the landslide source.

The terrain in the vicinity of the source locations of the landslides varied in inclination between 24° and 42°, although the majority (over 75%) of the landslides occurred on terrain inclined at angles greater than 34°. Because debris from most of the inspected landslides ran into drainage lines, either immediately below the source or at a short distance (20–30 m) below the source, the travel angle might have been primarily influenced by the steep gradient of the stream channel immediately below the landslide source and may therefore not fully reflect the possible landslide mobility, particularly in relation to channelized debris flows, where other factors such as surface water flow and temporary debris damming of the stream course could be important influencing factors.

Given the inherent limitations in using the travel angle approach to the assessment of debris mobility from landslides on steep natural terrain, more recent studies have adopted an analytical approach to dynamic modelling of debris flows (Kwan *et al.* 2007). The mobility of one of the Cloudy Hill landslides was back-analysed by Kwan & Sun (2006). The landslide involved detachment and movement of about 90 m^3 of landslide debris, which travelled along a topographic depression. The results of dynamic modelling closely matched the observed runout distance and debris deposition profile of the landslide using a Vollemy model with an apparent friction angle of 8° and turbulence coefficient of 500 m s^{-2}. The modelling also indicated that the maximum velocity of the landslide debris was about 6 m s^{-2}. As indicated in this example, site-specific rheological parameters can be obtained from back-analyses of selected cases in regional landslide studies. The results can be benchmarked with long runout landslides at other sites and can be used to improve the reliability in landslide hazards and consequence assessments.

Hazard model

The classification of landslide type based on the geomorphological models developed for this study allows inferences to be made on the nature of the hazard generated. Figure 13 shows a preliminary hazard model based on the geomorphological models developed. Areas of high hazard include the following.

(1) The boundary between the upper and lower landforms, which represents the zone where Type I landslides occur. Based on site observations at Cloudy Hill, typically the landslides involve multiple minor failures of an over-steepened main scarp and generally have relatively high travel angles. The multiple failures often result in the formation of a large bowl-like feature that might appear on first examination to be a single, very large landslide scar (as observed in the Type I landsides labelled in Fig. 13). There is an obvious danger of misinterpretation, thereby resulting in a significant overestimate of the design hazard.

(2) Well-defined hollows, located at the heads of minor drainage lines and just below ridgelines, are the typical source zones of Type II landslides. As the landslide sources are located directly above drainage lines, there is a high propensity for such landslides to develop into channelized debris flows. Furthermore, it has been observed at Cloudy Hill that several such landslides can occur within the same catchment or even on the same flank of a catchment during a single rainstorm event, although not as the clusters observed

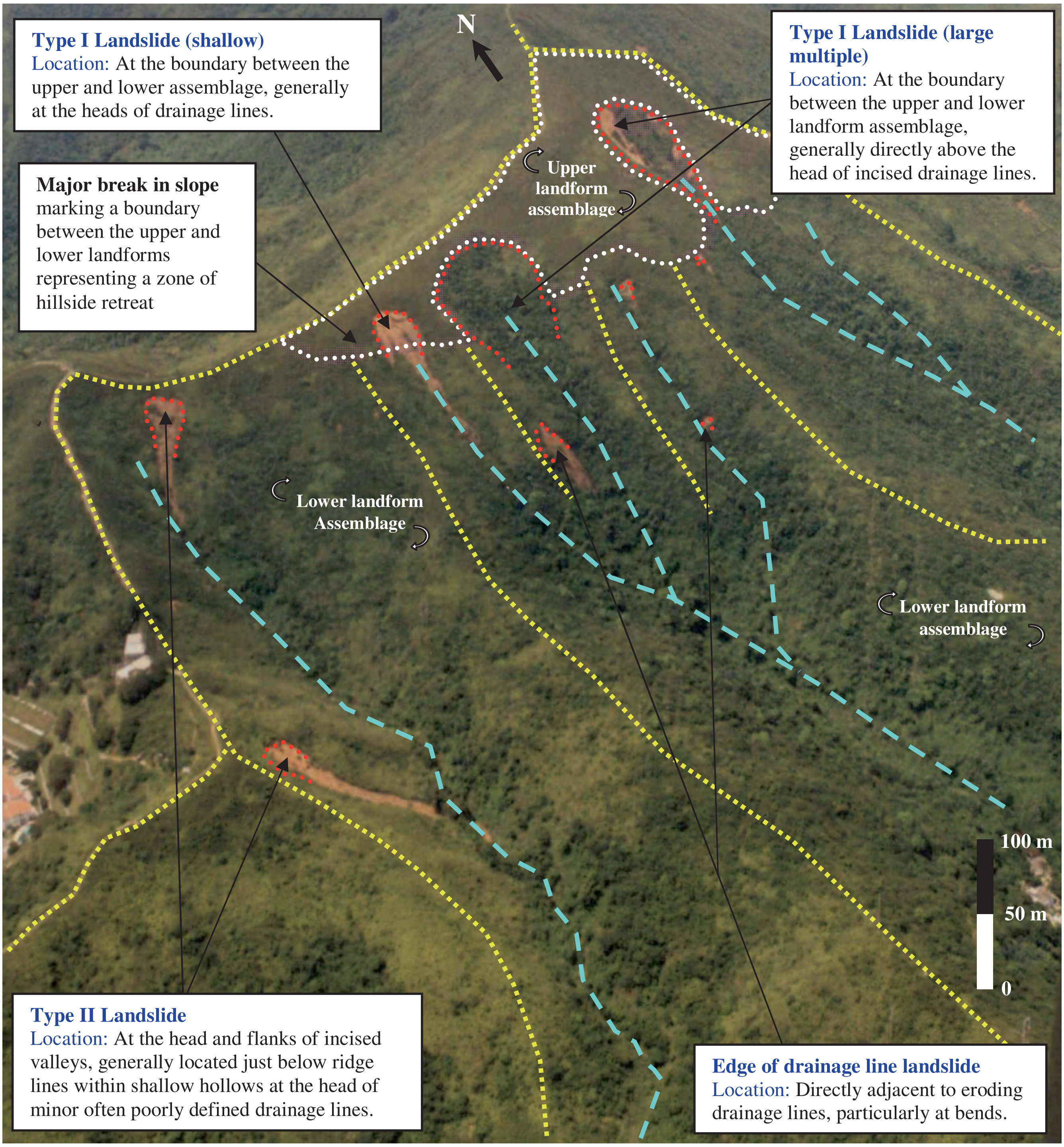


Fig. 13. Landslide hazard model.

for Type I landslides. The resulting coalescence of debris may result in relatively large debris flows and possibly the formation and breaching of debris dams, resulting in significantly long travel distances.

Conclusions

Through a detailed systematic study of landslides at Cloudy Hill, geomorphological landslide models have been developed for the study area. These models allowed the landslides to be categorized, commonality between the landslides to be recognized and an overall geomorphological model of the site to be developed. The proposed geomorphological models provide better understanding for a natural hill slope landslide hazard assessment. Such models can add value to a risk assessment approach in which landslides are classified on factors such as failure volume, mechanism of failure and mobility of the resulting debris.

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