TSING SHAN DEBRIS FLOW AND DEBRIS FLOOD

GEO REPORT No. 281

J.P. King

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT

THE GOVERNMENT OF THE HONG KONG SPECIAL ADMINISTRATIVE REGION

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (http://www.cedd.gov.hk) on the Internet. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

The Geotechnical Engineering Office also produces documents specifically for publication in print. These include guidance documents and results of comprehensive reviews. They can also be downloaded from the above website.

The publications and the printed GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the second last page of this report.

H.N. Wong
Head, Geotechnical Engineering Office
June 2013

EXPLANATORY NOTE

This GEO Report consists of two Landslide Study Reports on the "Tsing Shan Debris Flow and Debris Flood" (LSR 2/2001) and "The 2000 Tsing Shan Debris Flow" (LSR 3/2001).

They are presented as three separate sections of this Report. Their titles are follows :

It should, however, be noted that all appendices of Sections 1 and 2, with the exception of Appendix G of Section 1 and Appendix C of Section 2, have not been included in this GEO Report, but they are available for reference in the Geotechnical Information Unit of the GEO in Volumes 2 and 3 of Report SPR 6/96 and Report SPR 7/96.

SECTION 1:
THE 1990 TSING SHAN DEBRIS FLOW

J.P. King

This report is largely based on GEO Special Project Report No. SPR 6/96 produced in October 1996

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FOREWORD

This report presents the results of a detailed study of the September 1990 Tsing Shan Debris Flow (TSDF). The study was warranted because the TSDF is the largest recorded natural-terrain landslide to have occurred in Hong Kong in recent years. At a time when the risk from landslides of various types is coming under closer scrutiny, it is important to attempt to understand the nature and causes of large mobile failures on natural terrain, even if, as in this case, the event did not have serious consequences. The work reported here should provide a useful reference for further detailed studies of large mobile landslides.

The aim of the study was to identify the factors that caused the debris flow and to provide the basis for assessing the probability of occurrence and possible locations of similar events in the future. The study included a literature review, detailed field mapping, ground investigation and laboratory testing. The report is divided into three volumes. Volume 1 contains the main report, photographs and drawings. Volume 2 contains Appendices A to L which include a bibliography, calculations, detailed field observations and the basis for selecting the proposed causative factors. Volume 3 contains Appendix J which is a report on the ground and laboratory investigations carried out for the study.

In 1992, a debris flood event occurred in an adjacent catchment. A comparison of this event with the TSDF has been useful in establishing some causes of the debris flow and is therefore included in this report. The full results of the debris flood study are contained in report no. SPR 7/96.

This report was prepared by Mr Jonathan King. It is based on detailed field work carried out by Mr King in 1992 and 1993. The lengthy period of report production is a result of Mr King undertaking the study on a part-time basis (i.e. in addition to other duties), and the time allowed for various interested parties to make comments on earlier drafts. Field survey and comparison of digital elevation models was provided by the Survey Division of the GEO. The Lands Department especially prepared the 1:500 scale base maps from post-event aerial photography. Mr Vitus M.C. Chan assisted with field mapping of the debris flow scar. Discussions and field visits were carried out with many professional staff from the GEO. Photographs have been compiled from many sources but those taken immediately after the event by Mr D. Hadley of the Project Manager Tuen Mun's Office were particularly useful. Assistance with editing the report was provided by Dr S.D.G. Campbell, Mr N.W. Woods, Mr H.H. Choy and various staff from the Special Projects, Mainland West and Advisory divisions provided useful comments on the draft report.

Technical work for the project was mostly managed by Mr K.T. Tang and comprised supervision of field tests by Mr W.C. Lee and Mr C.F. Chow, laboratory testing by Mr Y.L. Cheng and Mr Y.C. Chow, and presentation of laboratory test data and report production by Mr K.S. Tsui and Mr P.C. Cheng. Drafting of the drawings for the report was done by Mr Y.L. Lee and Ms P.L. Ho. The assistance of all the above are acknowledged.

(R. P. Martin)
Chief Geotechnical Engineer/Planning

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ABSTRACT

This report describes the study of a debris flow that occurred on the steep natural slopes to the west of Tuen Mun in September 1990. The debris flow involved approximately 19,000 m^3 of soil and rock and the debris trail extended some 1,035 m to Area 19 Tuen Mun. Fortunately as this area was not developed, no one was injured and damage to property was negligible. A factual report was made by Mainland West Division very shortly after the event and provides a valuable record of initial observations (Chan et al, 1991).

A detailed study of the causes and nature of the debris flow was warrented in order to provide information to assess the probability of occurrence of similar events at other locations in Hong Kong. The work included desk study, aerial photograph interpretation, field mapping, a ground investigation and the study of a debris flood in an adjacent drainage line.

The debris flow occurred during an unexceptional rainstorm of increasing intensity in which 136 mm fell in 5 hours. It was generated by a parent landslide on the steep upper slopes of Tsing Shan. This occurred on a spur line sloping at 28° where a thick deposit of loose granite colluvium was actively accumulating over completely decomposed granite from which seepage was occurring. The debris flowed over an exposed sheeting joint into a steep drainage line where it eroded and entrained bouldery colluvium and increased in volume by 200%. Significant deposition started at the mouth of the drainage line but debris continued a further 500 m over an excavated area, cut slope and platform, eroding insitu material and depositing a total of 19,000 m^3 of bouldery debris. Flooding late in the event was responsible for about 3,000 m^3 of gully erosion and redistribution of the earlier flow deposits.

There was severe damage to reinforced concrete drainage structures at the mouth of the drainage line. Immediately downslope bouldery debris lobes more than 2 m thick were rapidly emplaced. These were severe hazards to life and property; however further downslope on the cut slope and at the slope toe the debris up to 1 m thick flowed non-erosively around small obstacles and the hazard was less.

The study indicates that the characteristics of the parent landslide most relevant to the generation of the large debris flow were its volume of more than 2,000 m^3, its location at 300 mPD immediately upslope from a steep rock outcrop, the loose condition of the displaced material and the presence of sufficient fines in it to reduce permeability allowing slurry flow, and the presence of seepage from bedrock below the deposit. The important characteristics of the drainage line were its steep slope of 16° to 27°, its V shape that channelised the debris and the presence of bouldery colluvium.

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1. INTRODUCTION

1.1 Background

In the early morning of 11th September 1990 a debris flow occurred from high on the eastern flank of Tsing Shan, a mountain near Tuen Mun in the Western New Territories (Figure 1). The event, which became known as the Tsing Shan Debris Flow (TSDF), deposited about 20,000 m^3 of debris over the cut slope and platform of Area 19, Tuen Mun.

The GEO response to the debris flow was outlined in a Mancom discussion paper of 26 September 1990 which suggested a study to determine:-

(a) the causes of initiation and the nature of the debris flow in motion, and

(b) the probability of occurrence and probable locations of similar events in the future.

Mainland West Division of the GEO then produced a factual report on the landslide (Chan et al, 1991). This included a photographic record of the event, a surface materials map, a detailed estimate of quantities involved, a record of some field measurements of the debris, a collection of relevant data such as rainfall records and the account of a witness who heard the event. However, items (a) and (b) were beyond the scope of the report.

1.2 Study Programme

In 1992 Planning Division of the GEO commenced an investigation into the causes and nature of the TSDF. This report presents the results of the investigation and provides a basis for prediction of locations, and probability of occurrence, of similar events in the future. Terminology used in the report is defined in Appendix G. The study programme for the investigation comprised the following key tasks.

(a) A desk study of previous investigations at the site and information on natural terrain landslides both in Hong Kong and elsewhere,

(b) Interpretation of rainfall and climate records,

(c) Aerial Photograph Interpretation (API) of both pre- and post-debris flow photographs of the site,

(d) Field mapping to record the geological, hydrogeological and geomorphological characteristics of the scar, and

(e) A ground investigation comprising trial pits and trenches with insitu and laboratory tests.

In June 1992, during the course of the study, a debris flood of much lesser magnitude occurred in a drainage line adjacent to the TSDF. This was investigated as part of the study,

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and a report on this event, called The Tsing Shan Debris Flood of June 1992, has been released concurrently with this main study report. The two events are compared in Appendix L of the main report.

The main report comprises three volumes. The text, photographs and drawings are in Volume 1. Volume 2 contains all appendices except for Appendix J, which is Volume 3 and which contains part of the ground investigation report (see Section 2.4). All base data, calculations and working drawings associated with the report are stored as Planning Division Files GCP 2/D9/3-1 to 3-17 and listed in Appendix I. Appendix figure and table numbers are prefixed by the appropriate letter.

1.3 Study Area Location

Tsing Shan is located about 2 km west of Tuen Mun at the southern end of the north-east to south-west trending range that forms the western side of the Tuen Mun Valley. The summit rises to 583 mPD and is the highest peak of the range.

The scar from the debris flow runs down the eastern flanks of Tsing Shan along the ridgeline of a spur and then enters a drainage line which it follows to Area 19. The study area is the whole catchment of the drainage line from the ridgeline at the summit of Tsing Shan to the Area 19 platform. This drainage line will be referred to as the drainage line in the report. A chainage along the debris flow scar, starting from Ch 0 at the top was established by Chan et al (1991) and is used on all plans and sections of the present study. The scar can be broadly divided at the mouth of the drainage line (Ch 500) into the upper depletion area comprising the spur and drainage line and the lower deposition area of Area 19. However, the whole event involved an estimated 19,000 m^3 of material eroded and 20,000 m^3 deposited (Table 3). Of this some 12,000 m^3 was eroded from the depletion area, 11,000 m^3 discharged from the drainage line onto Area 19 and a further 7,000 m^3 of material was eroded, entrained and re-deposited in the deposition area (see Section 6.5 and Appendix B).

Access to the upper part of the study area is along a footpath that contours the mountainside at about 200 mPD and is cut by the debris flow trail at Ch 300. A track to San Shek Wan San Tsuen provides access to Ch 550 and the lower part of the study area can be accessed from Area 19.

1.4 Study Area Development History

The depletion area is located on natural terrain. Prior to 1980 the only development here was small water intake pools with associated footpaths in the lower part of the drainage line. In 1980 two power transmission line towers were constructed on the lower part of the spur. In 1989 a concrete footpath was constructed that traversed the drainage line at about 200 mPD. An access track for its construction was excavated up the side of the spur to the north of the drainage line but had been partially backfilled at the time of the debris flow (Drawing GEO/P/PTE/1).

The drainage line discharges onto the footslopes at a point where a large borrow area was excavated to form Area 19 Tuen Mun. The history of this excavation is reported in

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Styles et al (1984) and numerous geotechnical reports which are summarised in Scott Wilson Kirkpatrick & Partners (1986 & 1987). These reports have been used together with API observations recorded on Drawing GEO/P/PTE/1, to summarise the development history of the deposition area.

Excavation of the borrow area commenced in 1977. At the same time four house platforms and an access track were constructed across the drainage line just above the borrow area. Houses were constructed on the platforms in 1978 (Plate 18) but were demolished in 1980.

The main borrow excavation was completed in 1980 but, due to creeping slope movements and erosion of the cut slope, further stabilisation works were carried out. A diversion weir and concrete channel were constructed in 1984 to carry the stream in the drainage line around the top of the cut slope to the south west and into a large concrete channel at the slope toe. In 1984 the cut slope was re-formed at an angle of 17° with extensive surface drainage both on the slope and above it. The Area 19 platform was used as a rock fill stockpile from this time.

After the works in 1984 the area above the main cut slope was left as a gently sloping, irregular, boulder-strewn platform (Plate 16). The upper limits of the borrow excavation was a steep, excavated scarp located immediately downslope from the abandoned house platforms and access track (Plate 17). The creeping slope movements continued after 1984 and resulted in the development of small scarps and areas of heave on and above the cut slope.

2. METHODOLOGY OF THE STUDY

2.1 Desk Study

The desk study for this investigation comprised a review of:-

(a) previous technical reports on the TSDF including:

a descriptive account (Langford & Hadley, 1990);
the factual report by the GEO Technical Note No. TN 4/91 (Chan et al, 1991); and
a discussion of the landslide at the scar source (Workman, 1990).

(b) technical literature on the study area including:

geological maps (Geotechnical Control Office, 1988);
terrain classification maps (Geotechnical Control Office, 1987);
engineering reports (Scott Wilson Kirkpatrick & Partners, 1986 & 1987); and
more general literature (Langford et al, 1987).

(c) aerial and ground photographs of the study area before and after the debris flow including:

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vertical black and white stereo air photographs;
hand held oblique colour aerial photographs; and
a large collection of terrestrial photographs.

All photographs used are listed in Appendix H.

(d) a selection of technical literature on the geology and geomorphology of Hong Kong, listed and briefly reviewed in Bibliography A, Appendix K.

(e) a selection of technical literature on debris flows in general, listed and briefly reviewed in Bibliography B, Appendix K.

2.2 Rainfall

The closest raingauge to the site of the TSDF is GEO automatic raingauge number N07. This is located at about 20 mPD on the foot slopes of Tsing Shan, less than 1.5 km from the catchment where the debris flow occurred (Figure 1).

Gauge N07 is located in the Tuen Mun Valley while the debris flow occurred on the upper slopes of Tsing Shan. Thus the gauge may not accurately reflect the rainfall at the site. To check this, more extensive climatic data from the area for the period 10th - 11th September 1990 was collected for assessment by a climatologist at the Royal Observatory. This data comprised: rainfall data from all other raingauges in the vicinity (R21, Tuen Mun Chief Resident Engineers's Office, N12, 174 & R26), local synoptic charts, 3 hourly wind charts, satellite weather photographs and weather radar records. The data is archived in File GCP 2/D9/3-1.

The data was assessed by Mr C.Y. Lam, a Senior Scientific Officer at the Royal Observatory. He estimated that the cloud height was about 10,000 feet with a wind direction from 225° to 240°. He concluded that the record at N07 was likely to be a good representation of the temporal distribution of rainfall in the catchment but that the totals recorded might be higher than those occurring at the catchment due to delayed orographic effect. Thus the rainfall at the catchment might have been between the totals at raingauges N07 and R21, located about 3 km west of the TSDF and which recorded less rainfall. He considered that the readings at gauge N07 may reasonably be considered the maximum that was likely to have fallen at the site. However, due to the often very localised nature of intense rainfall in Hong Kong the possibility of more rain having fallen at the site cannot be discounted.

The cumulative and 15 minute data from raingauge N07 for the 2 weeks preceding the date of failure (11.9.90) are given in Figure 4 and for the preceding 24 hours in Figure 5. Table 1 gives the maximum rolling rainfall at N07 and estimated return periods for different durations preceding 07:00 on 11th September 1990, estimated by Gumbel's method as outlined in Peterson & Kwong (1981).

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2.3 Engineering Geology Mapping

Engineering geological mapping was carried out using aerial photograph interpretation (API) and field mapping. The base map used was compiled from three blank, 1:500 scale contour sheets that were included in Technical Note No. TN 4/91 as Figures GCMd 90/86, 90/87 and 90/88. These sheets were prepared by Lands Department using photogrammetry from post-event aerial photographs dated 14th September 1990. The debris flow trail was divided at about Ch 500 into an upper depletion area and a lower deposition area and the three 1:500 scale map sheets were combined to form two sheets that each covered one of these areas.

The description of the site prior to the debris flow was made using API of the photographs listed in Appendix H. The geomorphology of the depletion area was better observed in the earlier 1963 and 1980 photographs while the most recent developments were recorded from 1990 photographs. The results are given in Appendix E and on Drawing GEO/P/PTE/1.

In December 1991 Survey Division set out a series of control points along the centre of the debris flow scar (Drawings GCS 2072/VII A, XII A & XIII A). These were used to locate features on the ground during field mapping that was carried out by the author and Mr Vitus Chan during January, February and March 1992. The fieldwork commenced more than 1 year after the debris flow. The debris was dry and often difficult to distinguish from fresh exposures of eroded regolith. Its distribution and composition may have been locally modified by subsequent rainfall. The deposition area was also partially obscured by vegetation re-growth. However, many terrestrial photographs were taken soon after the debris flow and these were used as a control to ensure that as far as possible the mapped debris distribution reflects that immediately after the event. Many of the photographs are included as plates in this report.

The depletion area was mapped onto oblique aerial photographs in the field. This mapping was combined with API in the office and then transferred onto the 1:500 scale base map. Mapping shows the distribution of bedrock and regolith materials. The regolith materials are the weathered profile which comprises residual soil, saprolite and partially weathered rocks and slope deposits of both colluvial and alluvial origin. The slope deposits will be referred to in this report by the commonly used term colluvium (Appendix G, Section 5.3.1) and were mapped to a minimum thickness of about 0.5 m. Also mapped were pre-existing geomorphological features, the morphology of the debris flow, the location of debris deposits, the superelevation of the trail at bends, field checking the assumed pre- and post-event cross sections used for estimate of quantities and other evidence of the debris flow development.

Mapping of the deposition area was mainly by API using the immediately post-event (14th and 18th September 1990) vertical and oblique aerial photographs with point field observations at selected locations. Mapping concentrated on variations in the surface composition of the debris and morphological features of the deposit.

The draft engineering geological map was used as the basis for location of the subsequent Ground Investigations (GI). It was updated using the GI data and is presented on Sheets 1 and 2 of Drawing GEO/P/PTE/1. Sheet 1, which covers the depletion area, emphasises the geology of the slope whereas Sheet 2 covers the deposition area and highlights

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the type and thickness of the debris. Both sheets include API of the ground prior to the debris flow, morphological data and field observations on the debris flow. Some of the field observations are copied from Chan et al (1991).

2.4 Ground Investigation

A ground investigation was carried out from November 1992 to February 1993. The programme concentrated on the properties of the regolith on the upper slopes where the debris flow originated and properties of the debris taken from various locations along the scar. Both the colluvium and the debris have a very large range in grain size from boulders of over 5 m diameter to clay particles. It was only possible to sample and test the finer fractions of these materials as detailed below. The water replacement insitu density test was used as it samples a comparatively large volume of ground but still cannot be representative for the whole deposit. The test results must be used in this context.

The Contractor for the ground investigation was Geotechnics & Concrete Engineering (Hong Kong) Ltd. (GCE) and the results of their work are presented in a two volume report (GCE, 1993) dated 22 March 1993. However, some of the logging and insitu testing for the investigation was carried out in-house by the author and is presented in Appendix J which is Volume 3 of the main report. GCE (1993) and Appendix J give a complete report of the ground investigation. The location of all investigation stations and samples are shown on Figure 2 of Appendix J and on Drawing GEO/P/PTE/1. Summaries of all test results are included at Appendix A in Tables A1 and A2.

The investigation comprised the following works.

(a) 26 hand-dug trial pits located in debris with the pit numbers prefixed by the letters 'TP'. Of these:

TP1 to TP5 were trenches up to 20 m long and 1.5 m deep;

TP19 and TP24 were cleaned scarps from creeping slope failures; and

the others were pits about 1.5 m x 1.5 m and of variable depth.

(b) 2 machine-excavated trial trenches located across the scar in areas of thickest deposition:

Trench 1 was 105 m long and up to 2 m deep, located at about Ch 570; and

Trench 2 was 130 m long and up to 2 m deep, located at about Ch 675.

(c) 20 hand-dug investigation pits with the pit numbers prefixed by the letter 'D'. Of these:

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D1 to D15 were located in the regolith materials of the depletion area;

D8 was located in decomposed granite and all others were in colluvium;

D16 to D18 were located in colluvium in an adjacent drainage line where a debris flood occurred in 1992 (GEO Report SPR 7/96); and

D19 and D20 were located in thick debris in the deposition area.

In all the D series pits, water replacement insitu density tests (Standards Association of Australia 1977 AS 1289. Test E.3.5-1982) and soakaway permeability tests (Somerville, 1986) were carried out by the GEO. The results of these tests are given in Appendix J. They are also used to estimate boulder content (Appendix J Section 7.4) and saturated moisture content of the deposit.

(d) 9 sand replacement insitu density tests were carried out by GCE in the fine-grained matrix of regolith materials at the D series pits and of debris deposits at selected locations.

(e) 40 disturbed bulk samples of about 10 kg of debris selected for material of < 200 mm diameter were taken from various locations as the opportunity arose throughout the field mapping and ground investigation. Sample numbers are prefixed by the letter ‘M’.

(f) Samples were taken from all the D series pits in January 1993. These comprised moisture content and density samples of different particle sizes for the insitu density tests and 10 kg disturbed bulk samples. The different samples were labelled with the pit number which was given a suffix to indicate the sample type and depth (see Appendix J).

(g) In June 1993 it was necessary to re-sample many of the ‘M’ bulk samples due to a laboratory error that resulted in the need to repeat some of the particle size distribution (PSD) tests. These repeat samples were labelled with the suffix A.

2.5 Laboratory Testing

A laboratory testing programme was carried out to characterise the geotechnical properties of the sampled materials.

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All the bulk samples were sent to MateriaLab Ltd. for index tests. Samples were selected to be representative of each D series pit. These were tested for moisture content, rock dry density and soil specific gravity for the calculation of bulk and matrix insitu density from the water replacement tests. All laboratory test results are reported in the 4 volume report (MateriaLab, 1993).

The PSD tests first reported were found to have been carried out on an un-representative sub-sample. Most of the original locations were then re-sampled (Section 2.4(g)) and re-tested for PSD. The results were reported in the "repeat testing" volume of MateriaLab (1993). Where these repeat samples were re-taken at the same location as the original sample the revised PSD is reported in Appendix A under the original sample number. In a few instances the repeat samples were taken from new locations, these are reported separately using the 'A' suffix.

Bulk samples from the D series pits, and some of the M series samples, were tested in the Public Works Laboratory to determine the moisture content at which they became mobile and were able to flow more than 2 m down a flume sloping at 15°. This has been called the Mobility Moisture Content (MMC) in this report and is explained in Appendix J.

Relevant results from all the tests have been compiled in Appendix A as Table A1 for the regolith materials (23 colluvium and 2 decomposed granite samples) and Table A2 for 45 debris samples.

3. GEOLOGY AND GEOMORPHOLOGY OF THE STUDY AREA

3.1 Geology

The geology of the study area has been mapped at 1:20,000 scale (GCO, 1988) and is described in Langford et al (1989). The 1:20,000 scale geological boundaries in the study area are shown at 1:5,000 scale on Figure 2.

The summit and upper slopes of Tsing Shan are formed of fine grained granite. Downslope from the granite on the lower slopes and footslopes of the eastern side of Tsing Shan, sedimentary and volcanic rocks of the Upper Jurassic, Repulse Bay Volcanic Group occur. On the lower slopes these are the sedimentary rocks of the Tsing Shan Formation which comprise sandstone, siltstone and mudstone with conglomerate and tuff. At lower elevations the footslopes are underlain by the volcanic rocks of the Tuen Mun Formation, which comprise andesite with tuff and tuffite.

The contact between the granite and the sedimentary rock is faulted and the granite along it is mylonised in a zone about 10 m wide. The contact strikes approximately north-south and dips steeply into the slope. The contact rises across the eastern side of Tsing Shan from 60 mPD in the south, to 360 mPD at the top of the ridge, 700 m north of the Tsing Shan summit. This boundary divides the rocky granite upper slopes from the more gently rounded lower slopes of sedimentary rock.

Pleistocene and Holocene superficial deposits, classified by the Geological Survey as debris flow deposits, are shown in the larger valleys and mantling the footslopes. In this report these slope deposits are referred to as colluvium to avoid any confusion with the

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material deposited by the 1990 debris flow which will be called debris. The Geological Survey only mapped deposits more than 2 m thick at a scale of 1:20,000, more detailed mapping of the colluvium was carried out for this project as reported in Section 5.3.

The debris flow scar is generally incised into the surface deposits of colluvium. It starts on the granite upper slopes, encounters the contact with sedimentary rock at Ch 300 and passes onto the volcanic rock at Ch 500. The characteristics of the bedrock and weathered profile underlying the debris flow scar are described in Section 5.2.

3.2 Geomorphology

The Tsing Shan summit and ridge tops are generally rounded with occasional isolated outcrop and gullied areas. From this the granite bedrock is interpreted to be locally mantled by a weathered profile several metres thick. Below the ridge line, the upper slopes have an overall inclination of about 45° and consist of irregular granite cliffs and bluffs dissected by a network of rocky gullies (Figure 2). In this area the weathered profile is generally absent. Soils consist of bouldery colluvium confined to thin linear deposits lining the gullies. Sporadic, thicker accumulations of loose, angular boulders occur as talus below cliffs and rock outcrops.

Downslope from these rocky areas the sideslopes have average slope angles that decrease from 37° at the top to 20° at the foot. They comprise valleys choked with bouldery colluvium, separated by rounded spurs that are generally mantled by a thicker weathered profile. In their upper areas these slopes are underlain by granite but the lower parts are underlain by sedimentary rock. A well-developed weathered profile, up to 5 m thick typically overlies the sedimentary rock on the ridges. This thins towards the valley bottom where colluvium is commonly present, overlying fresh bedrock which may be exposed in the stream channel.

The footslopes of Tsing Shan have an overall slope of about 10° south-east towards the pre-development coastline. However, this area has undergone considerable modification since 1977 with the excavation of a platform as explained in Section 1.4. API shows that before development the area comprised a series of small insitu ridges with low hummocky ground between them that can be interpreted as the arcuate scars of several large creeping slope failures (Figure 2). At the mouth of the drainage line was a boulder strewn fan with a stream channel incised into the southern side. The stream channel extended down slope over a 15 m high scarp interpreted to be the main scarp to one of the failures. Downslope from this is a second smaller fan shaped bouldery deposit with a trail of boulders scattered for 100 m downslope on hummocky ground that is interpreted to be landslide displaced material.

The debris flow scar starts on a spur near the top of the side slopes and continues down a valley to the footslopes.

The study area is included in the 1:20,000 scale terrain classification map for the West New Territories and the maps derived from it in the Geotechnical Area Studies Programme (GASP) report (GCO, 1987). The terrain classification data and geotechnical land use classes (GLUM) have been superimposed on a 1:5,000 scale map of the TSDF in Figure 2a. The TSDF scar originates in an area mapped as rock outcrop with recent general instability,

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passes down to convex insitu ground with minor sheet erosion and then drainage plain with recent general instability before encountering disturbed (developed) terrain. The scar is generally in areas mapped as GLUM classes III and IV with high to extreme geotechnical limitations to development.

3.3 Hydrology and Hydrogeology

First order (Strahler, 1952), dry, bouldery, ephemeral stream beds are found in most of the rocky gullies of the upper slopes. These feed into larger, second order ephemeral streams in the valleys. The streams only flow strongly during and just after heavy rain but low flows occur during much of the rainy season. During this time they are fed by seepage and springs with small, seasonably variable discharges that occur from major joints in bedrock. These are often associated with a change of lithology such as where basalt dykes are intruded into the granite and at the granite-sedimentary rock boundary.

In the drier season the flow ebbs, most water in the drainage lines moves as seepage through the colluvium and only comes to the surface where bedrock outcrops in the stream bed. Logs of pits TP1, TP2, TP3, and Trenches 1 and 2 all show areas of highly permeable, open textured, clast supported colluvium associated with the stream bed along the bottom of the drainage line (Plate 97). Pits D16, D17 and D18 are located in the adjacent debris flood drainage line and show similar loose colluvium. Discrete soil pipes were often observed at these locations and where bedflow appears to be distributed throughout the whole deposit (see Section 5.3.5). In the more fine grained matrix of residual soil and saprolite on the spur, groups of pipes comprising many smaller (1-10 mm) with occasional larger (up to 50 mm) distinct soil pipes occur locally.

The ground in the vicinity of the debris flow trail has been divided into catchments that would have contributed overland flow to the drainage line followed by the debris flow. These are labelled E to H and shown in Figure 2. The catchment to the head of the scar is less than 300 m^2, and the catchment to the scar before it enters the drainage line is 10,000 m^2. At this point the drainage line catchment is 63,000 m^2 which increases to a total catchment of 114,000 m^2 at the mouth of the drainage line.

Streamflow in the drainage line responds quickly to rainfall. On 8th of May 1992 the author observed that streamflow more than doubled and then receded to its previous flow during a 30 minute cloudburst in which 15 mm to 20 mm of rain fell (Appendix D).

3.4 Vegetation

On the summit and upper slopes grass is generally the only vegetation. On the sideslopes scrubby bushes and small trees occur locally in depressions and become larger and more extensive in the main valleys. Examination of the 1949 and 1963 aerial photographs shows at that time there was a similar but slightly less dense distribution of vegetation to the present day.

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4. DESCRIPTION OF THE DEBRIS FLOW

4.1 Introduction

From its origin at 404 mPD the debris flow cut a 1,035 m long scar through the soil and vegetation on the side of Tsing Shan (Plate 1, Figure 3). The first part of the scar is aligned along a spur on the upper side slopes. It comprises a gully eroded into loose bouldery colluvium with areas of abraded rock outcrop locally stripped of superficial deposits. After 100 m the gully becomes a larger eroded depression in an area of thicker colluvium underlain by decomposed granite from which seepage occurs. This is located at the crest of a steep rock outcrop over which the scar descends into a drainage line. Throughout these upper parts of the scar, thin deposits of debris comprising boulders, cobbles, gravel and vegetation fragments in a remoulded silty sand matrix occur locally on the ground surface beside the scar. There are tracks of bouncing and rolling boulders beyond the scar.

The scar follows the drainage line to a bend where it widens and spreads high up the valley side but then narrows again at the constriction formed by the valley mouth. Throughout the valley bouldery colluvium has been intermittently eroded to bedrock and small local debris deposits occur along the edges of the scar. There is a larger accumulation of debris mixed with insitu material in the lower valley. At the valley mouth a concrete water intake has been badly damaged and beyond here the scar intersects the footslopes where the slope angle reduces, channelisation ends, and debris deposits fan out to 100 m wide across some abandoned house platforms. The northeastern edge of the scar is a thick ridge of bouldery debris that extends down over an excavated scarp onto an old borrow area. Debris with more matrix forms a thinner deposit along the southwestern edge and the centre of the scar comprises thin homogeneous debris and alluvial deposits.

In the old borrow area there is a thick lobe of inhomogeneous debris with bouldery medial and lateral ridges. Downslope from here is a 17° cut slope mantled with homogeneous debris up to 0.6 m thick that flowed around small obstructions and left occasional boulders stranded on the slope. Debris accumulated at the slope toe to form two fan-like mounds up to 2 m thick from which thinner deposits extend a further 200 m to 12 mPD at the middle of the Area 19 platform. Three channels are eroded into the thick debris lobe in the borrow area and these extend over the cut slope as a system of braided channels associated with severe gully erosion. Alluvial deposits are present in the channels and locally form the debris surface beyond the slope toe.

4.2 Scar Morphology

The detailed morphology of the scar is shown by Plates 1 to 15 and is mapped with Aerial Photograph Interpretation (API) and field observations on the 1:500 scale Drawing GEO/P/PTE/1. The depletion area (Ch 0 to Ch 500) is shown on Sheet 1 and the deposition area (Ch 500 to Ch 1035) on Sheet 2. These are combined to form Drawing GEO/P/PTE/6 which is a single 1:1,000 scale sheet showing the main features of the debris flow. Many geomorphological features of the debris flow are illustrated in the Plates of this report, which include field photographs taken soon after the event. The scar has been sub-divided into the 15 geomorphological units listed below.

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			Plate No.
Upper Spur	Ch 0 - Ch 40		2
Bedrock Outcrop	Ch 40 - Ch 75		3
Eroded Gully	Ch 75 - Ch 120		4
Parent Landslide	Ch 120 - Ch 170	Depletion	5
Sheeting Joint	Ch 170 - Ch 200	Area	6
Valley-side Fan	Ch 200 - Ch 240		6
Upper Valley	Ch 240 - Ch 365		7
Lower Valley	Ch 365 - Ch 500		8
Mouth of Drainage line	Ch 490		9
House Platforms	Ch 500 - Ch 575		10
Borrow Scarp	Ch 575 - Ch 605		10, 11
Borrow Area	Ch 605 - Ch 725	Deposition	11, 12
Cut Slope	Ch 725 - Ch 830	Area	13, 15
Slope Toe	Ch 830 - Ch 875		1, 12
Area 19 Platform	Ch 875 - Ch 1035		13

Detailed descriptions of each unit from field mapping, API and literature search together with possible interpretations of the features observed are given in Appendix E. Summary notes on each unit and API observations of the ground prior to the debris flow are included on Drawing GEO/P/PTE/1.

4.3 Timing of the Debris Flow

The debris flow was first reported to the GEO by Project Manager Tuen Mun on the morning of 11th September 1990. Mr Y.T. Chow, a local resident who lives about 100 m north of the scar (see Figure 2), heard the event and is the only witness that could be identified. He was interviewed by the GEO about 3 weeks after the event (Chan et al, 1991) and was re-interviewed on the 13 March 1992 as part of the present study. Both interview records are in Appendix C. They differ slightly in details but on the basis of the repetition of the basic timing in both interviews, and the reasonable nature of Mr Chow's supporting observations, the following account is accepted for the study.

Mr Chow was woken at about 02:30 hrs by the noise of heavy rain, light vibrations and noises. These continued at a similar level until there was a particularly loud noise at about 03:00. Some time from 5 to 30 minutes after 03:00 hrs his telephone and electricity lines were cut and the noises stopped soon after. Mr Chow visited the drainage line at Ch 500 before 07:00 on 11th September. He found muddy water flowing down the drainage line at a level similar to that shown in photographs taken near Ch 500 later in the morning (Plate 19 and Appendix D).

Mr Chow's electricity and telephone lines crossed the debris flow centreline between Ch 550 and Ch 575 as shown on Drawing No. GEO/P/PTE/1. The location of the telephone poles was supplied by Hong Kong Telephone and the location of the electricity pole was taken from the 1:1,000 map. Both were confirmed by API.

Other information that might help to establish the time of failure was information from the management of the Light Rail Transit system (LRT) that runs along the seaward side of

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the Area 19 platform about 250 m from the slope toe. Floodwater inches above the track was reported between 05:30 and 07:00 hrs on 11th September.

The record from a seismograph located at Tsim Bei Tsui, 12 km from the site, was inspected by the Royal Observatory but no event that could be correlated with the debris flow had been recorded.

4.4 Rainfall

Rainfall at the site on the 11th September is best represented by the record of rain gauge N07 (Section 2.2). This recorded a rainstorm that started at 02:30 hrs, the time Mr Chow first heard noises, and reached its greatest intensity at 06:00 hrs when the LRT tracks were flooded. It would seem reasonable to link this storm with occurrence of the debris flow. Rainfall preceding the storm was about 50 mm of rain in the previous 24 hours, 16 mm in the two days before that and no rain for the previous 9 days (Figure 4).

At the start of the storm recorded at N07 hourly rainfall was 9.5 mm by 03:00 hrs but then increased hourly to 23 mm, 34 mm and 50 mm before tailing off to 18 mm between 06:00 hrs and 07:00 hrs after which it stopped (Figure 5). The total rainfall of the storm was 136 mm in 5 hours.

The return period of the maximum rolling rainfall for periods of 5 minutes to 4 days before 07:00 hrs on the 11th September 1990 were calculated by the method outlined in Peterson & Kwong (1981) and are shown on Table 1. All rainfall had a return period of less than 2 years except for the 2 hour and 5 hour totals at about 06:30 hrs which had return periods of 2.5 and 2.4 years. This shows the most extreme rainfall was near the end of the storm. The calculated return period should not be considered an absolute value as it is based on the Royal Observatory in Kowloon which has a mean annual rainfall of about 2,200 mm as opposed to the mean annual rainfall of about 1,700 mm at the site (Evans, 1996). However, storms of similar or greater intensity have been recorded fourteen times at rain gauge N07 between 1982 and 1994 (Table D1) and heavier rainfall was recorded on 4 occasions - once in 1988, twice in 1993 and once in 1994. This seems to indicate that the storm was not exceptional for the site.

If Mr Chow's record is accepted, it would appear that the debris flow occurred in the first hour of a four hour rainstorm of increasing intensity. In this case the debris flow deposits would have been subjected to several hours of heavy rain and consequent floodwater from the drainage line. The peak runoff flow at Ch 500, calculated using the rational method (Drainage Services Department, 1994), was over 1 m^3/s during the most intense 15 minutes of the storm (20 mm total) but was no more than 0.6 m^3/s during the most intense 2 hours (80 mm total) (Appendix D). The heavy rain during and after the debris flow was probably important with respect to the form of the final debris deposit and its runout distance as discussed in Section 7.

4.5 Estimate of Velocity

The velocity of a channelised flow can be estimated from the superelevation angle

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(angle from horizontal) of the flow surface where it flows around a bend in a channel. Superelevation angles of the TSDF were measured for four adjacent sections at Ch 350 and Ch 475 where the trail follows bends in the valley. The superelevation angle at each location was measured from the outermost traces of remoulded debris or erosional scarp and it is assumed that these are from the same pulse of debris which would be the largest past that location.

Velocity was estimated using equations given in p.308 of Johnson & Rodine (1984) and calculations are given in Appendix F. At Ch 350 the average velocity calculated was 60 kph (16.5 m/s) and at Ch 475 was 45 kph (12.5 m/s). These velocities do not appear unreasonable compared to those reported in Ikeya (1989) of 3 to 10 m/s for bouldery debris flows and 2 to 20 m/s for muddy debris flows. Johnson & Rodine (1984) report velocities of 3.5 to 11 m/s and Aulitzky (1990) reports velocities of up to 28 m/s.

5. SOURCE MATERIALS

5.1 Introduction

The debris flow involved the erosion and transportation of soil and rock from the flanks of Tsing Shan and the deposition of these displaced materials along the scar and at the slope toe. The origin of the displaced materials was colluvium and, to a lesser extent, the weathered profile and bedrock. The geotechnical properties of these were determined from the field investigation and laboratory testing programme detailed in Section 2. This concentrated on defining the insitu properties of the regolith on the upper slopes where the debris flow originated. Materials from other locations are described mainly in terms of field observations.

The distribution of the materials is shown on Drawing GEO/P/PTE/6. The laboratory and field test results are all given in Appendix A. For the descriptions given below the materials have been divided into colluvium and bedrock and the weathered profile.

5.2 Bedrock and the Weathered Profile

The three types of bedrock that underlie the debris flow scar are granite, sedimentary rock and volcanic rock (Geotechnical Control Office, 1988; Langford et al, 1989).

5.2.1 Granite

Granite underlies the debris flow scar from Ch 0 to about Ch 300 where it is in contact with the sedimentary rock (Drawing GEO/P/PTE/6). When fresh the granite is very strong, pinkish brown, megacrystic and fine grained but decomposes to form sands and silts. Decomposed granite was investigated with pit D8 located at the parent landslide, Ch 150. Test results show a disturbed sample to vary from a light yellow, slightly gravelly, sandy, clayey silt near the top of the pit to a clayey, very silty, gravelly sand at the bottom. Index and insitu test results for decomposed granite from pit D8 are given on Table A1.

The granite rock mass has three prominent joint sets dipping approximately 55°/065°, 50°/190° and 65°/325°. The last of these has a similar orientation to the faulted

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granite/sedimentary rock contact and is often accompanied by quartz veins and basalt dykes. Where these occur the joint set is often more closely spaced and the rock mass may be more deeply weathered comprising extremely to moderately decomposed and locally kaolinised granite with corestones (e.g. Plates 22 & 32). These locations form areas of low relief often masked by slope deposits and several of these were eroded by the debris flow. Where the joints are widely to medium spaced fresh to slightly decomposed rock generally outcrops forming positive relief on the natural slope.

Slightly decomposed (SD) to fresh (Fr) granite occurs as irregular outcrops on the natural slope around the scar. Within the scar, SD to Fr granite is exposed; at an outcrop from Ch 40 to Ch 75 (Plates 24 & 27), at the sheeting joint cliff where the scar descends into the valley and locally in the invert of the upper valley between Ch 175 and Ch 290. Bedrock was exposed at these locations before the debris flow but the area of outcrop has extended due to erosion of superficial deposits by the debris flow. In particular, large new exposures are present in the upper valley below the sheeting joint. Slightly to highly decomposed granite is newly exposed at the V-shaped gulley from Ch 10 to Ch 30 (Plate 21) and as outcrops along the south western side of the choked gully from Ch 75 to Ch 120.

Extremely decomposed (ED) to highly decomposed (HD) granite occurs at the head of the scar in a 2 m wide linear zone striking 060° (Plate 20) and as a wider zone just above the rock outcrop at Ch 30 to Ch 40 (Plate 22). The most extensive ED to HD zone in the debris flow scar is the parent landslide area from Ch 120 to Ch 170 (Plates 32 & 33). Here the rock mass has been intruded by quartz veins and basalt dykes and has weathered to homogenous highly to extremely decomposed granite. The only other ED to HD granite exposed in the scar is at Ch 265, just above the contact with the sedimentary rock. This is exposed in the scar from a secondary slump failure on the south western side of the debris flow (Plate 45).

5.2.2 Sedimentary Rock

Sedimentary rock of the Tsing Shan Formation underlies the debris flow scar from a faulted contact with granite at Ch 300 to their concealed contact with the volcanic rock of the Tuen Mun Formation near Ch 600. Fresh rock is exposed in the bottom of the drainage line channel for most of this part of the scar. It comprises moderately strong, grey, indistinctly bedded, very closely jointed, fine grained sandstone and siltstone. Before the debris flow, this was exposed at the waterfall (Ch 350, Plates 46 & 47) and above the intake (Ch 500, Plates 49 & 53), but erosion of overlying superficial deposits by the debris flow has considerably extended these exposures.

On the valley side-slopes, the sedimentary rock is overlain by an orangeish brown weathered profile several metres thick. This has been exposed by debris flow erosion along the south western side of the scar and can be clearly seen at Ch 500 (Plate 54). The profile was encountered in TP1 to TP4, where the fresh rock grades up into weathered rock comprising slightly to highly decomposed angular clasts that have separated at joint planes and are surrounded by an orange brown clayey silt. Higher in the profile the proportion of clasts decreases and they become less regularly orientated until at the top of the profile orangeish brown, silty residual soil is present below topsoil.

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5.2.3 Volcanic Rock

Volcanic rock of the Tuen Mun Formation underlies the debris flow scar from about Ch 600 to the end of the scar. Its contact with the sedimentary rock is masked by thick superficial deposits that extend downslope partially covering the bedrock. The volcanic rock has weathered deeply and forms the low topography of the footslopes. In the study area the volcanic rock is andesite which is only exposed at excavated ground. The freshest andesite exposed is moderately strong, greenish grey, slightly to moderately decomposed andesite in a small area at the south western toe of the cut slope. All other exposures of andesite are highly to completely decomposed forming soft to firm, light green, stained orange brown along relict joint surfaces, slightly dispersive silt (Plates 73 & 74). This material underlaid large creeping failures in the pre-development topography and creeping failures formed on the 17° cut slope soon after excavation. The material is highly susceptible to erosion by flowing water which causes the formation of deep gullies and soil pipes have also been reported. Exposures in the study area are confined to gullies that were eroded at the toe of the borrow scarp, at the scarps formed by the creeping failures and on the cut slope.

5.3 Colluvium (Slope Deposits)

5.3.1 Introduction

Colluvium at Tsing Shan comprises a range of heterogenous material with variations in clast shape, grading and decomposition and in the proportion of matrix and its characteristics. These differences reflect the mode of origin and depositional history of the deposits which grade from angular rock talus with little matrix through a well graded bouldery colluvium to gap graded deposits with silty matrix and material that has been partially reworked by water. The colluvium has been separated into 5 types named spur colluvium, upper valley colluvium, lower valley colluvium, channel colluvium and fan colluvium to reflect the topographical position in which they typically occur. While each type has distinctive characteristics described in Sections 5.3.2 to 5.3.6, the contacts between different types are often gradational and the mapped boundaries on Drawing GEO/P/PTE/6 should be read in that light.

The spur, upper and lower valley and channel colluvium all fit the description of Holocene (< 10,000 years ago) debris flow deposits in Langford et al (1989) and are generally equivalent to the Class G3 of Lai & Taylor (1984) which is also suggested to be of Holocene age. Mottling of the matrix and more decomposed clasts occurs locally at the base of these colluvium types and this is a characteristic of Lai & Taylor's older G2 colluvium. However this only forms a small proportion of the colluvium and may be related to variations in groundwater level. The main part of these deposits are probably of holocene age. The fan colluvium is mapped by the Geological Survey as Pleistocene (< 2,000,000 years ago) debris flow deposits. It has the characteristics of Lai & Taylor's G1/G2 and is in general considerably older than the other types of colluvium.

The colluvium is an inhomogeneous mixture of clasts and matrix. Previously in Hong Kong matrix and clasts have been divided at the 60 mm diameter grain size, the gravel/cobbles boundary (Binnie and Partners (Hong Kong), 1981; Irfan & Tang, 1992). While this may be suitable for a gap graded material there appears to be no particular reason to use it for a relatively well graded material such as most of the Tsing Shan Colluvium and in

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this report 20 mm diameter is used to allow sand replacement insitu density and mobility moisture content tests to be carried out on the matrix of both colluvium and debris.

Test pits D1 to D7 and D9 to D15 are located in colluvium, and were used for insitu density and soakaway permeability tests (Section 2.4). Matrix samples were also taken for laboratory index and mobility moisture content tests (Section 2.5). The detailed results of all colluvium test results are reported in Appendix A. A summary of test results for the different types of colluvium is given in Table 2 and discussed in Section 5.3.7. The table also includes a summary of all colluvium test results combined for comparison with the combined results of all debris and all decomposed granite tests.

5.3.2 Spur Colluvium

The spur colluvium is typically very loose to medium dense, yellowish brown, angular, slightly decomposed to fresh, granite boulders and cobbles with some gravel, sand and low plasticity finer material. It occurs along the spur line and is intermittently exposed in the scar from Ch 0 to Ch 175. It grades down the side of the spur into the upper valley colluvium as part of the valley side fan.

Spur colluvium is thickest and best exposed along the northeastern side of the scar from Ch 75 to Ch 170 (Plates 29, 30 & 31). At this location the deposit is clast supported with generally fresh to slightly decomposed, mainly boulder-sized, angular clasts. At the surface there is little matrix, abundant voids exist between the clasts and individual clasts may be so loose that they move when walked on. The deposit is denser and more weathered at depth with the matrix becoming loose to medium dense, low plasticity clayey, very silty sand and gravel filling the voids and clasts becoming more decomposed. Where underlain by decomposed granite the extremely decomposed matrix and boulders are hard to distinguish from the decomposed granite and core stones.

Four indistinct layers about 1 m thick and of limited lateral extent can be seen in the side scarp at Ch 125. The upper layer has more large boulders, below this is a layer of cobbles and smaller boulders. This grades down into a layer with very large boulders below which are is a bouldery layer of more decomposed material. Spur colluvium is interpreted to be actively accumulating, mainly rock debris from slope failures on the slopes above.

Pits D1 to D7 and D10 are in spur colluvium adjacent to or within the debris flow scar. Samples of matrix are low plasticity, very silty, sandy gravel or very silty, gravelly sand (Table 2, Figure A1). Estimated boulder content for the whole deposit is about 60% to 80% (Appendix J, Section 7.4). Insitu matrix dry density varies with depth in the profile (Figure A5) and typical values for the top 1 m (D1 to D5 & D10) are from 1.3 - 1.6 Mg/m^3 and from deeper in the deposit (D6 & D7) are 1.7 and 1.85 Mg/m^3.

5.3.3 Upper Valley Colluvium

The upper valley colluvium is typically loose to medium dense, orangeish brown, rounded, slightly decomposed to fresh, granite boulders and cobbles with some gravel and some sand and low plasticity finer material. It is located along the bottom and lower sides of

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the upper valley (Plates 37, 40 & 41) and forms most of the valley side fan below the sheeting joint (Plate 36).

The upper valley colluvium is exposed in the scar from below the sheeting joint at Ch 200 to the waterfall at Ch 365. Pits D9 and D11 to D14, and sand replacement insitu density test D10A are located in the upper valley colluvium. The deposits are clast-supported with a matrix of low plasticity, brown, clayey, silty, very sandy gravel or gravelly sand (Figure A1). Estimated boulder content for the whole deposit is about 70% to 85% (Appendix J) and matrix content increases slightly away from the stream channel. In the bottom of the drainage line there may be iron staining and mottling of the matrix, especially at the contact with generally fresh bedrock (Plate 42). Three or four discontinuous indistinct layers 1 m to 2 m thick with gradational boundaries can be seen along the northeastern side of the scar from Ch 225 to Ch 325. There is a more bouldery surface layer underlain by a layer of smaller boulders and cobbles below which is a thick chaotic layer with many larger boulders (Plates 37 & 41). The upper valley colluvium is considered to be older than the spur colluvium from which it has developed through reworking by slope failures, eluviation and alluvial processes.

5.3.4 Lower Valley Colluvium

The lower valley colluvium is typically firm to stiff, orangeish brown, gravely, sandy clayey silt of low plasticity with some rounded to sub angular, slightly to moderately decomposed, granite boulders. It occurs along the south western side of the lower valley from the waterfall to the mouth of the drainage line and grades down the valley side into channel deposits near the stream line.

The lower valley colluvium is encountered in TP1, TP2, TP3 and possibly TP4 (Drawing GEO/P/PTE/5). It is matrix-supported except where local concentrations of boulders occur at its gradational boundary with the channel colluvium. The matrix is orangeish brown, firm, clayey sandy silt and the presence of this material defines lower valley colluvium. Two types of clasts are present, rounded, fresh to slightly decomposed granite boulders and occasional gravel-sized, angular, sedimentary rock fragments.

The lower valley colluvium is interpreted to be upper valley colluvium, mixed with slopewash from the weathered profile over the sedimentary rocks on the valley sides above. Unlike the spur, upper valley and channel colluvium it is not active and may be considerably older than them.

In TP3 and possibly TP4, the lower valley colluvium is overlain by an orange brown silty clay that is similar to, and appears to be continuous with, the upslope weathered profile over sedimentary rock. This suggests that bouldery colluvium must have been present in the lower valley long enough for the residual soil to creep/wash from the slope above and become mixed with it to form the lower valley colluvium. This indicates a considerable age for the deposit.

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5.3.5 Channel Colluvium

The channel colluvium is typically loose to medium dense, light brown, sub-rounded, slightly decomposed to fresh, granite boulders and cobbles with some loose to medium dense gravel, sand and low plasticity silt. It occurs along the stream channel in the lower valley and along the pre-development stream channel in the colluvial fan at the mouth of the drainage line.

It is encountered in D15, TP1, TP2, TP3 and Trench 1, and exposed on the borrow scarp. The channel colluvium is generally clast supported and beds about 0.1 m thick are locally present. At D15 the matrix is a low plasticity, slightly gravelly sandy clayey silt (Figure A1) and the deposit has an estimated boulder content of 83%. Near the stream bed the deposit may have an open, loose structure where matrix has washed away leaving interconnected voids that form a network of small pipes up to a maximum of about 100 mm^2 in cross section (Plate 97).

The channel colluvium is interpreted to result from the reworking and eluviation of the upper and lower valley colluvium by ground and surface water.

5.3.6 Fan Colluvium

The fan colluvium is typically medium dense to dense, orangeish brown-stained, rounded, slightly to highly decomposed, granite boulders and cobbles with much gravel, sand and silt. The deposit is generally clast-supported and has occasional gravel sized angular clasts of sedimentary rock. It occurs as a colluvial fan at the mouth of the drainage line and is encountered by Trench 1 and exposed on the borrow scarp. The fan deposits have a maximum thickness of about 10 m at about Ch 600 (Scott Wilson Kirkpatrick & Partners, 1986 & 1987) from where they thin upslope to feather out at about Ch 475. Downslope they have been largely removed by borrow activities but remnants at least 1 m thick were encountered at Ch 675 in Trench 2. At the eastern end of the trench the colluvium was observed actively sliding over the underlying decomposed andesite.

These deposits are broadly equivalent to the Qpd of Langford et al (1987) and GCO (1988) in which they are described as Pleistocene (from 2,000,000 to 10,000 years ago) debris flow deposits. However some of the upper material on the fan is almost certainly of Holocene (< 10,000 years ago) age. The fan represents an accumulation of material that has been channelled down the drainage line by mass wasting during the last 2 million years. However the pre-development morphology of the fan (Section 3.2) with an incising drainage line and development of a smaller bouldery fan downslope, indicates that deposition is still occurring. The occurrence of the TSDF is similar evidence.

5.3.7 Colluvium Test Results

The spur, upper valley and channel colluvium were tested and sampled by the D series of pits and test results are given in Appendix A. The results are summarised on Table 2 where they have been grouped by colluvium type and subdivided by their relative position in the soil profile as this shows a correlation with the insitu matrix dry density test results.

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Apart from the density test results all other test results for the spur and upper valley colluvium show little variation and have been combined to give generalised index properties in the second part of the table. These can be compared with those of decomposed granite and debris which are also shown on Table 2. Summary envelopes for grading of different size fractions and for plasticity are presented with those for completely decomposed granite and debris on Figures 6 to 9.

All colluvium matrix samples have low plasticity fines that plot above the A line (Figure A3). Mobility moisture content for the spur and upper valley deposits are also within a similar range (25% to 40%) but sample D15 from the channel colluvium was considerably higher at 47% (Figure 10). This may be related to its relatively high fines content (Figure 11).

The particle size distribution (PSD) of the matrix (< 20 mm diameter) of the spur and upper valley colluvium are similar being silty, very gravelly coarse sand (Figure A1). The one sample from the channel deposit (Sample D15-2a) was much finer grained, being very sandy silt with some gravel.

The proportion of the 20 mm to 60 mm, and 60 mm to about 200 mm (4 kg) fractions of the colluvium were measured on site during the water replacement insitu density tests. These were combined with the laboratory test data for the matrix to give grading curves for the < 200 mm diameter fraction of the colluvium in Figure 7. A further adjustment of the grading curve can be made if the boulder content is estimated (Appendix J). Figure 8 shows an envelope of grading curves that include the estimated boulder content which is from 65% to 85%.

Insitu matrix dry density test results for the spur, upper valley and channel deposits can be divided into two ranges based on their relative depth in the profile of the deposit (Figure A5). Test pits D1 to D5 and D10 were excavated to just below the topsoil in the top 0.5 m to 1.0 m of the profile however pits D6 and D7 were in the lower part of the profile where it was exposed by erosion from the debris flow. The results from these tests in the upper profile are grouped around 1.3 Mg/m^3 to 1.6 Mg/m^3 with the exception of D1 and D11 which gave even lower values of 1.1 Mg/m^3. Pits D6, D7 and test D10A were carried out at exposures within the debris flow scar, where erosion had exposed the lower part of the deposit. These results varied from 1.6 Mg/m^3 to 1.84 Mg/m^3. The saturated moisture content, which is directly related to the insitu dry density is in the range of 22% to 36% for the upper deposits (excepting D1 & D11) and 15% to 22% for the lower deposits.

Relative insitu permeability measured by a crude soakaway test is extremely variable, ranging over several orders of magnitude from 10^{-5} to 10^{-2} m/s (Figure A10). Permeability was too great to measure at pit D9 where water flowed out through a soil pipe.

6. DEBRIS FLOW DEPOSITS

6.1 Introduction

The material displaced by the Tsing Shan Debris Flow *en mass* is mainly poorly sorted clasts up to boulder size with a matrix of remoulded debris comprising clayey, very silty, very gravelly coarse sand. The debris deposits locally segregated into matrix supported

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remoulded debris, clast supported blocky debris and sorted alluvial debris. There are also debris trails at the edges of the scar and subsequent debris deposits from small post-debris flow failures of over-steepened scarps at the edge of the scar. The distribution of these materials is shown on Drawings GEO/P/PTE/1 and GEO/P/PTE/6. The debris surface was mapped on the basis of clast to matrix (< 20 mm diameter) ratio and divided into; clast supported boulders, mixed boulders and matrix, and matrix rich debris with occasional boulders.

During the ground investigation the texture of the insitu debris matrix was found to generally fall into one of two distinct types, homogenous and inhomogeneous. These are used to divide the remoulded debris into Class 1 or Class 2. Clast supported boulders with small amounts of either matrix type are designated Class 3 and a minor clast supported deposit only observed at Trench 2 is Class 4. The distribution and thickness in the deposition area of these remoulded debris classes, and the alluvial debris, is shown on Drawing GEO/P/PTE/4. Although layering within the debris was looked for throughout the fieldwork the only divisions that could be recognised were the often gradational ones between the four classes of remoulded debris and the more distinct contact of these with the sorted alluvial debris.

Remoulded debris is described in Section 6.2 and other debris in Section 6.3. The quantities and distribution of the debris is described in Section 6.4 and debris is contrasted with the insitu regolith material from which it is derived in Section 6.5.

6.2 Remoulded Debris

6.2.1 General

Laboratory and field tests on the remoulded debris are reported in Section 6.2.4 and were used to compile the following generalised description.

Remoulded debris is a poorly sorted mixture of up to 70% angular to sub-rounded, moderately decomposed to fresh, granite boulders (up to 5 m diameter) and cobbles with sand, gravel and less than 5% silt and clay. Clasts of gravel size and above are supported in the matrix and there are occasional inclusions of intact orange silty soil and gravel derived from the sedimentary rock weathered profile. There are many remains of vegetation and occasional fragments of foreign objects such as broken concrete, pipes and general garbage. Matrix is a low plasticity, loose to medium dense, light greyish-brown, clayey, very silty, very gravelly coarse to medium sand.

Immediately after emplacement the debris at the footpath and in the deposition area was very soft and appeared saturated (personal communication, D. Hadley, Plates 44, 69 & 77). More than 1 year after emplacement the matrix is firm when moist becoming dense and lightly cemented by the fines content when dry. Bubble shaped voids were observed in some deposits of the dry remoulded debris and when the debris was mobile during the event these were presumably full of air and/or water. At tested locations the insitu matrix dry density varies from 1.5 - 1.7 Mg/m^3.

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6.2.2 Classification

The proportion of matrix and clasts in the remoulded debris varies considerably. The following three divisions were used for mapping the surface of the deposits by API and limited field observations:

- clast supported boulders with little matrix,
- clast or matrix supported mixed boulders and matrix, and
- matrix rich deposits with occasional clasts.

Their distribution is shown on Drawings GEO/P/PTE/1 and GEO/P/PTE/6 which also include an estimate of debris thickness based on ground investigation data.

On the basis of detailed field description of remoulded debris texture, the matrix was divided into the following two basic types:

- A very homogeneous, well mixed material with abundant spherical voids that generally occurs in deposits of less than 1 m thick, and
- an inhomogeneous material with more inclusions that occurs in thicker deposits.

Samples of both debris matrix types were taken from locations throughout the scar for laboratory tests as described in Section 6.2.5 below. However, the index tests could not distinguish between the two types and showed little variation between samples from different locations. The matrix in all cases was a light greyish brown, low plasticity, clayey, very silty, very gravelly coarse to medium sand.

The two matrix types, in combination with the matrix/clasts ratio, have been used to establish the four debris classes described below. The distribution of these classes within the deposits varies both in plan and vertically and often they can only be positively identified in trenches, test pits and exposures. The contacts between these classes is sharp at some locations but at others it is gradational and the classes may represent end members of a deposit with varying clast content and matrix type. The interpreted debris classes are marked on the trench logs and TP1 to TP4 (Drawings GEO/P/PTE/3 & GEO/P/PTE/5). They are not marked on the other test pit logs but the debris type at each TP location is shown on Drawing GEO/P/PTE/4 along with the inferred lateral extent of the classes.

Class 1 Debris (Plates 80, 81 & 82)

This comprises mainly granitic gravel and cobbles in a homogeneous silty sand matrix with some granite boulders and occasional small inclusions of orangeish brown residual soil and highly decomposed to fresh sedimentary rock. When dry, the matrix is lightly cemented by the fines content and often has bubble shaped voids. There are abundant vegetation remains within the matrix. These are usually too small to identify but occasional wood branches and twigs may be embedded in the surface of the deposit which is usually relatively

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smooth (Plate 83). Individual boulders may be present, usually with a thin layer of debris below them and a capping of debris on top (Plates 72 & 73). In the distal parts of the deposit (below about Ch 700), small randomly-orientated fissures with a dark brown surface deposit occur. These may have developed since deposition and be organic in origin.

This class of debris is seldom more than 0.6 m thick. It occurs most extensively as a layer of uniform thickness on the cut slope (Plates 70 & 72) but is also found along Channels 1 and 3, in the central part of the scar above the borrow scarp and, with a higher vegetation content, forms most of the debris deposits in the depletion area (Plate 34).

<u>Class 2 Debris</u> (Plates 84, 86, 88 & 90)

This comprises matrix-supported (occasionally clast-supported) granite boulders and cobbles in a medium to coarse silty sand, with gravel of both granite and sedimentary rock. Generally, the matrix is very heterogeneous with large (up to 50 mm diameter) inclusions of, usually orange clayey soil, but also grey and brown topsoil (Plate 85). This locally gives a spotted appearance to the matrix, which also may be mottled dark brown, possibly from decomposed organic material. Large vegetation fragments are often present in the matrix, as are occasional fragments of man-made artifacts. Voids may be present around boulders (Plate 96).

This class of debris varies in thickness from about 1 m to more than 2 m and often has a more uneven surface than Class 1 debris. In the deposition area it occurs as a large lobe on the borrow area at Ch 600 to Ch 675 and a more bouldery lobe at Ch 675 to Ch 700 on the north eastern side of the scar. Lateral ridges along the margin of the Class 1 debris on the cut slope comprise debris that is transitional between Class 1 and Class 2 with an uneven surface and larger vegetation fragments but a relatively homogenous Class 1 type of matrix (Plates 70 & 71). In the depletion area this debris occurs as small deposits caught up among rock outcrops on the southwestern margin of the scar along the eroded gully where it is transitional to Class 3 debris.

<u>Class 3 Debris</u> (Plates 57 & 68)

This comprises clast-supported granite boulders with many voids and occasional crushed or abraded branches. Small deposits of flow aligned homogenous and inhomogeneous matrix are present in the lower part of the deposit (Plates 92 & 93) and capping some of the boulders. Class 3 debris is generally more than 2 m thick and occurs as lateral and medial ridges between Ch 500 and about Ch 675. Occasional boulders are freshly broken and many have scratch marks.

<u>Class 4 Debris</u> (Plate 95)

This comprises sand, gravel and cobbles with a coating of fines. This material looks like no fines concrete and is lightly cemented by the fines content when dry. It has a very limited distribution and was observed as a layer up to 0.4 m thick below sorted "alluvial" debris at stream channels 1 and 2 in Trench 2.

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6.2.3 Debris Contacts

The contact between the debris and the insitu substrate was exposed in many of the test pits and trenches. It has been classified into three basic types as described below and summarised on Table 5. The location and Type of all observed contacts are shown on Drawing GEO/P/PTE/4.

Type 1 Contact (Plates 67, 80, 81, 86 & 87)

At this contact debris has been emplaced upon the substrate without disturbing it. Usually there is a topsoil profile, and/or a vegetation mat (from 5 mm to 200 mm thick) below the debris. Topsoil may not be present where the insitu material is fill, or excavation had occurred prior to the debris flow.

The undisturbed vegetation or topsoil indicates that any debris passing over or deposited at this location must have been moving by a process of flow of either the whole debris body or a more fluid layer at its base. The flow of debris must have been in a range of speed and viscosity in which erosion and entrainment of the substrate did not occur. The potential for erosion increases with both speed and viscosity. The faster and more viscous a flow is the more erosive it will be. If the flow was occurring in a layer at the base of a mass of debris the layer must have been thick enough to flow around irregularities in the ground which would have been embedded boulders at least 1 m high. The presence of this Type of contact indicates that sliding/shearing has not occurred in the substrate or at the debris/substrate boundary at this location during debris movement and emplacement. This contact is referred to as a low energy depositional contact.

Type 1 contact was observed below Class 2 debris at the edges of the scar in Trench 1 and extensively in the middle of the main debris lobe at Trench 2. The contact occurs below Class 1 debris over much of the cut slope and at the trails around the depletion part of the scar. It probably occurred on the platform at the slope toe but the debris was cleared from this location before the GI was carried out.

Type 2 Contact (Plates 88, 89 & 90)

This is an irregular contact where there is some mixing between the debris and the substrate. This may include boulders pushed into the substrate and large pieces of the substrate surface (generally vegetation and topsoil) incorporated into the lower part of the debris deposit.

This indicates that limited local shearing of the substrate was occurring during deposition of the debris and thus the debris was either undergoing very slow, very viscous flow or was sliding and not flowing at this time. This contact is referred to as a high energy depositional contact.

Type 2 contact was only observed below debris Class 2 and is generally adjacent to the Type 1 contact. It occurs below most of the Class 2 debris in the lower valley at TP2 and TP3 and also occurs quite extensively in Trench 2. Local occurrences were observed near the edge of the deposit at Trench 1, under the main debris lobe at TP14 and on the cut slope at TP17, TP27 and TP33.

Type 3 Contact (Plates 91, 94 & 95)

At this contact the original surface layer of the substrate has been removed before deposition of the debris. The contact is usually planar and smooth but although carefully searched for, no distinct shear plane could be identified at any location during fieldwork.

This contact indicates scouring, corrasion and entrainment of insitu material by debris or water passing over it. As there is no shear plane it indicates that fluid debris was the last material to pass over the location however, the velocity and viscosity was in a range where erosion occurred rather than transport or deposition. This contact is referred to as a high energy erosional contact.

Type 3 contact is often overlain by a relatively thin deposit of the homogeneous Class 1 debris. It occurs at Trench 1 in the central part of the scar between the mouth of the drainage line and the borrow scarp. It occurs below Class 1 debris or alluvial deposits adjacent to the channels in Trench 2 and on the cut slope. It also occurs below all debris deposits within the scar in the depletion area.

6.2.4 Soil Test Results

6.2.4.1 Samples

Samples of remoulded debris were taken for laboratory index tests. The ‘M’ series of samples, in which clasts greater than about 200 mm diameter were manually excluded during sampling, were taken throughout the scar. Samples of the < 20 mm fraction were taken at test pits D19 and D20 as part of the insitu density test programme. The grading results for the ‘D’ and ‘M’ series samples should not be compared due to these differences in sampling. Some of the samples were tested for mobility moisture content. Insitu density tests of the debris deposit were carried out by both the water replacement (D19 & D20) and sand replacement (S1 to S5) methods. Soakaway tests were also carried out at D19 and D20. All debris test results are given in Table A2.

6.2.4.2 Particle Size Distribution (PSD)

The PSD of samples D19 and D20 (< 20 mm diameter) is given in Figure A2-4 which includes the test results for the debris samples (all with a PSD of < 20 mm diameter) reported in Chan et al (1991). These show a clayey (3 - 6%) very silty (14 - 21%), very gravelly sand (Samples D19 & D20, Figure A2-4). Figure 6 shows a PSD envelope of the ‘D’ series samples in comparison with those for colluvium and decomposed granite.

The PSD of individual ‘M’ series samples (< 200 mm diameter) is given on Figures A2-1 to A2-3 which show a silty, very sandy gravel with some cobbles. Most samples are 50 - 70% gravel and cobbles, 9 - 16% silt and 2 - 7% clay. An envelope of all samples in comparison with the colluvium, is given in Figure 7. This envelope also includes the PSD curves from the < 20 mm diameter D19 and D20 samples adjusted to a notional < 200 mm diameter using field grading data from the insitu density tests.

In the entire debris deposit matrix is mixed with clasts of up to boulder size in

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proportions that vary from a recorded minimum of 20% coarse gravel (Sample M22, Ch 720), to the boulders with only traces of matrix that occur between Ch 500 and Ch 700 (Plates 57 & 60). Due to the large size of some clasts and local variations in PSD's throughout the deposit, this overall PSD cannot be tested for. However, the boulder content at D20 was estimated as 57% by weight. As this is one of the less bouldery locations within the deposit, it may be a lower bound estimate of the overall boulder content of the debris. At D20 matrix was estimated as 28% and silt and clay as about 6%. Thus, an overall grading for the debris may be about 70% boulders 25% matrix and less than 5% silt and clay.

6.2.4.3 Plasticity and Mobility Moisture Content

The plasticity of all the tested debris samples, including those from TN 4/91, are shown on a plasticity chart, Figure A4. All samples are of low plasticity, have a small range and generally plot above the 'A' line. Linear shrinkage is less than 6% for all samples. Mobility moisture content (MMC), which can be equated to a bulk liquid limit for the matrix, varies from 22 - 32% (Table A3, Figure A8).

6.2.4.4 Density, Permeability and Saturated Moisture Content

These insitu properties of the debris are listed in Table A3. The range of insitu matrix dry density recorded in the debris deposit varies from about 1.5 to 1.7 Mg/m^3 (Figure A6). Insitu relative permeability (Ki) from the two soakaway tests was 9 and 23 m/s x 10^{-6}. The saturated moisture content (SMC) of the insitu deposit has been calculated at D19 and D20, where there are laboratory determinations of the density of the soil materials. Where these were not available, the SMC was estimated from the insitu matrix dry density (Figure A7). The SMC of the debris deposit varies from 18 - 29% and the range is shown in comparison with the MMC in Figure A8.

The mobility moisture content of the debris is generally higher than the saturated moisture content by up to 12%. At the large-scale water replacement insitu density test sites D19 (SMC 24%, MMC 28%) and D20 (SMC 29%, MMC 28% and 30%) the difference is no more than 4%. This appears reasonable as the MMC should be equalled or exceeded for saturated flow to occur and some loss of water and consolidation might be expected as flowing debris stops and forms a deposit.

6.3 Other Debris

This comprises boulders, debris trails, debris from small subsequent landslides in the debris flow scar and sorted debris that forms alluvial deposits.

6.3.1 Boulders

Loose, generally angular, granite clasts, without any associated traces of remoulded debris matrix, occur around the edges of the upper part of the scar from Ch 50 to Ch 265. The clasts are mostly boulders but vary from cobble size up to a maximum dimension of

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about 5 m diameter. Their surface may include some stained faces with a weathered patina from sub-aerial weathering or may be entirely freshly exposed (Plate 31). Rock outcrops and insitu boulders at the ground surface adjacent to the scar show marks caused by impacts from clasts rolling and bouncing down the slope (Plates 25 & 38).

The largest deposit of boulders is at the area of loose bouldery colluvium on the northeastern side of the parent landslide from Ch 100 to Ch 175. Here there is bouldery debris with traces of matrix (Class 3 debris) adjacent to the scar and this grades out through matrix free boulders to a few scattered boulders about 20 m away (Plates 5 & 34). Just downslope from here on the southwestern side of the scar in the upper valley just below the sheeting joint from Ch 200 to Ch 225 there is a second large deposit of loose boulders banked up behind a very large debris boulder (Plate 38).

Smaller deposits of loose boulders are caught up amongst rock outcrops on the sides of the scar from about Ch 50 to Ch 265 (Plates 3, 4, 5 & 6). On the northeastern side of the scar the boulders die out below Ch 175. On the southwestern side of the scar a few isolated loose boulders occur adjacent to Class 2/3 debris at the edge of the trail and caught up in the vegetation. Toppled blocks from a rock outcrop are present in the scar at Ch 105. Downslope from the large boulder between Ch 225 and Ch 265 there are a few large boulders in the scar (Plate 39).

6.3.2 Trails

Debris trails of aligned vegetation, bounce and slide marks, isolated clasts, thin traces of remoulded debris matrix and scattered sand and gravel were present on the undisturbed natural slope surface at the edge of the scar throughout much of the depletion area. These are partly ephemeral features that may be destroyed or modified in time by factors such as weather and vegetation growth. The fieldwork for this report was carried out more than 1 year after the event occurred and many of the observations below are from photographs taken soon after the event. The locations of the trails are shown on Drawing GEO/P/PTE/1.

Trails from boulders, rolling and bouncing down the slope, include aligned vegetation (Plate 5) and impact marks on soil and rock. Boulder impact marks in the form of dents in topsoil and small patches of crushed rock could be easily identified during field work. They are common around the debris flow scar from Ch 0 to about Ch 250.

Trails comprising occasional boulders, aligned vegetation, impact marks and little matrix are found spilling over the rock outcrops along the south western side of the choked gully (Plates 3 & 4) and downslope of the large boulder below the sheeting joint at Ch 225.

A narrow trail of aligned vegetation, patches of bare earth and occasional rock fragments leaves the southwestern side of the main scar at about Ch 60 (Plate 3) and terminates in a pile of small clasts level with Ch 125 (Plate 4). A similar indistinct trail of aligned vegetation is present between the narrow trail and the main scar. These trails are clear in Plates 3, 4 and 5 but the only evidence found 1 year after the event was occasional small rock fragments and no matrix. Because of the loose bouldery debris from which they originate at the main scar and the lack of any matrix evident in photographs or found during fieldwork, the trails are thought to be caused by the passage of very bouldery debris with only

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an insignificant proportion of matrix.

Trails comprising a thin sheet of matrix with stranded clasts on aligned vegetation are common along the edges of the scar in the depletion area. The thickness of the matrix varied from about 50 - 200 mm and may be related to the matrix viscosity and the slope angle. This type of matrix rich trail can be identified on photographs (Plates 23, 34, 35, 46 & 47) and was identified during the 1992 fieldwork.

The passage of water is indicated by aligned vegetation with cohesionless deposits of sand and gravel caught up in it, but no debris slurry. This was only observed along the outer edge of the trail on the southwestern side of the lower valley (Plate 48) where the trail dies out in the grass and only scattered sand and gravel could be found on the ground during fieldwork. The erosion of topsoil on the south western edge of the scar below the destroyed intake at Ch 550 (Plate 54), may also be the result of flowing water.

6.3.3 Subsequent Debris

Debris from small failures of the marginal scarp to the debris flow scar is present at Ch 0, Ch 35 and Ch 100. The debris is from small local collapses of the weathered rock and colluvium that was over-steepened by the debris flow erosion. As these deposits have remained within the scar the failures must have occurred after the debris flow. This is in contrast to the larger secondary failure scars in the side of the debris flow scar at Ch 120 and Ch 265 from which no deposits are present in the scar.

6.3.4 Sorted/Alluvial Debris

Deposits of roughly bedded sandy gravel with cobbles and occasional boulders occur within the stream channels in the deposition area (Plate 95), at the toe of the cut slope and locally within the low points of the scar in the depletion area.

Within the depletion area deposits are generally small, less than 0.1 m thick and found in local depressions and flatter parts of the stream course (Plate 47). At the stream channel in the mouth of the drainage line thin (0.05 m) alluvial deposits overly Class 1 debris (Plate 54). At the toe of the borrow scarp there is a thick deposit of alluvial debris (TP12) from which thinner ribbon shaped deposits extend downslope along three channels (Plates 64, 66 & 67, Appendix B) to join thin deposits on large washed areas of the cut slope (Plates 74, 75 & 76).

The most extensive area of alluvial deposits is beyond the toe of the main slope. Here two overlapping fans with braided water channels on their surface overly lobes of remoulded debris and boulders (Plates 12, 13 & 15, Drawing GEO/P/PTE/4). These were dissected by a wider channel that descends into the borrow area (Plate 78) where alluvial sand and gravel forms the debris surface and remoulded debris occurs below (TP36, Plate 79).

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6.4 Quantities and Distribution of Debris

6.4.1 Estimate of Quantities

The quantities of material eroded and deposited by the debris flow were estimated by comparing pre-event ground profiles from the 1:1,000 scale survey sheet and 1:500 scale site plans with profiles from the post-event 1:500 scale photogrammetric map. All profiles were field checked and modified as necessary. Details are given in Appendix B with calculation of erosion on Table B-1 and deposition on Table B-2. Table B-3 shows the volumes of both erosion and deposition and the cumulative and active volumes (the total volume of debris transported past any given point). Volume data is summarised in Table 3 and active volume is shown on the long section, Drawing GEO/P/PTE/2.

Additionally, in the deposition area pre- and post-event digital elevation models (DEMs) were produced from the same sources and compared using a computer to estimate erosion and deposition in this area. The results of this are shown on Drawing GEO/P/PTE/4 but were not used to calculate the debris volume due to limitations detailed in Appendix B.

The material eroded by stream erosion in the deposition area was estimated using post event plans and field evidence to find the volume of the steep sided gullies cut into the pre-event ground surface. The volume of a pre-dissection debris lobe in the borrow area was estimated by extending the post-event surface on the borrow area to form a single convex profile.

6.4.2 Distribution of Debris

The distribution and relationships of the debris is described briefly below and should be read in conjunction with Table 3 and Drawings GEO/P/PTE/1 and GEO/P/PTE/4. More details are given in Appendix B. The total volume of erosion was about 18,800 m^3 and deposition was 20,300 m^3 which is a swell factor (Cruden & Varnes, 1996) of 8%.

In the depletion area total erosion is estimated to have been more than 12,000 m^3 and deposition was less than 1,000 m^3. In the deposition area about 19,000 m^3 of debris flow deposits were emplaced of which over 11,000 m^3 was from the slopes above (Table 3). About 7,000 to 8,000 m^3 was mobilised and redeposited within the deposition area but this includes some 3,000 m^3 of alluvial deposits derived from gully erosion of both insitu material and remoulded debris by stream flow late in the event.

In the depletion area more than half of the deposition is remoulded debris and the rest is other debris. Typically, the remoulded debris occurs as thin deposits of Class 1 debris around, and draped over, insitu boulders and bedrock outcrops in the scar. Occasional transported debris boulders and cobbles are embedded in larger patches of matrix below the footpath and in the lower valley. Loose transported boulders are scattered on the undisturbed ground surface around the upper part of the scar and may occasionally rest within it. A trail of flow-aligned grass and undergrowth, with small, scattered deposits of sand and gravel or remoulded debris caught up in it, is locally present along the edges of the scar. Sorted debris of alluvial deposits occur locally within the scar and at three locations there are deposits of debris from failures of the marginal scarp.

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In the deposition area most of the deposition was remoulded debris but about 15% was alluvial deposits. On the house platforms (Ch 500 to Ch 600) bouldery Class 3 debris up to 3 m thick is present along the north eastern edge of the scar and on the southwest edge there is about 1 m of matrix rich Class 2 debris. Matrix rich Class 1 debris and alluvial deposits from 0 m to 0.4 m thick occur in the central part of the scar. Below the borrow scarp (Ch 600) the primary deposition lobe extends to the top of the cut slope (Ch 675) and comprises Class 1, 2 and 3 debris up to 3 m thick and dissected by alluvial channels. On the cut slope there are matrix-rich deposits of Class 1 debris averaging 0.6 m thick and occasional large isolated boulders. At the slope toe, on the platform and along a trapezoidal drainage channel lobes of Class 1 debris up to 1.5 m thick were removed soon after the event. These thin to 0.6 m by Ch 1035 and are overlain by the alluvial deposits that form fans at the slope toe. Alluvial deposits also occur along the channels eroded into the primary debris lobe and cut slope.

6.5 Comparison of Remoulded Debris and Regolith Materials

The laboratory and field test results for debris and the regolith materials (colluvium and decomposed granite) are summarised and contrasted on Table 2. PSD of the < 20 mm diameter, < 200 mm diameter samples and estimated full grading curves are compared on Figures 6, 7 and 8. Plasticity is compared on Figure 9.

Figures 6 and 7 show that the PSD of the finer fractions of the debris is very similar to that of the spur and upper valley colluvium. The < 20 mm debris fraction is a little finer and this may be due to mixing with other finer source materials (lower valley colluvium and CDG) or may show a small amount of grain crushing during the event. Figure 8 shows the estimated full grading of the debris at D19 and D20. This is much finer than that estimated for the colluvium but the pits were located in a relatively boulder-free part of the debris deposit and do not represent the total boulder content.

Both the colluvium and the debris have low plasticity but the debris has a greater range (Figure 9). The higher values for the debris may be explained by mixing with the intermediate plasticity, completely decomposed granite and with topsoil. The lower values may indicate the removal of the fines in some samples by water.

The average mobility moisture content of the debris was 28% with a range of 25 - 32% (Figure A-8). These figures are less than for the colluvium which was 33% and 21 - 62% (Figure A-9). The greater range colluvium than the debris suggests that the debris flow caused a thorough mixing of the source materials. MMC appears to have a general relationship with both silt and clay content and plasticity index, but the debris generally has a lower MMC than colluvium for the same values (Figures 11 & 12).

The insitu matrix density of the debris ranges from 1.5 to 1.7 Mg/m^3 and is much less variable than that of the insitu regolith materials. It is similar to the decomposed granite and the lower part of the colluvium profile but is slightly higher than the upper part of the colluvium profile. This could be the result of elimination of the voids and soil pipes that are present in the upper part of the colluvium profile.

Overall the debris flow process appears to have resulted in a thorough mixing of the

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source materials to produce a more homogeneous material that is slightly finer, more plastic and denser than the colluvium that forms the main source.

7. INTERPRETATION

7.1 Introduction

The Tsing Shan Debris Flow was a complex geomorphological event that occurred over several hours. The following outline of the probable sequence of events has been interpreted from the description of the landslide in Sections 4 to 6 and the evidence discussed in Sections 7.2 and 7.3. This interpretation divides the debris flow into four phases:

- a small "trigger" landslide at the head of the scar, initiated by rainfall;
- a larger "parent" landslide that was initiated by the "trigger" landslide and which instigated the debris flow;
- large pulses of channelised debris flow in the drainage line that eroded and entrained colluvium, followed by erosion of the scar during an ongoing rainstorm; and
- accumulation and re-mobilisation of debris in the deposition area beyond the mouth of the drainage line.

The main characteristics of each phase are summarised in Table 4.

The possible mechanisms of movement are discussed in Section 7.2, evidence for the event occurring as a number of phases of debris movement is presented in Section 7.3 and the proposed sequence and classification of the failure is in Section 7.4. Based on this interpretation some aspects of the risk posed by the event are discussed in Section 7.5 and the key characteristics of the event, in relation to factors considered to be responsible for the relatively large size of the debris flow, are given in Section 7.6.

7.2 Mechanisms of Movement

7.2.1 Initial Displacement

The mechanism for the initial displacement of materials that formed the debris would have been different at different parts of the scar and at different times during the event.

The first displacements were of loose colluvium on a 50° slope at the head of the scar. These were presumably triggered by the rainstorm causing a rise in the watertable, or perched watertable, resulting in saturation of the deposit and decrease in effective stress leading to sliding. If very high pore pressures were generated due to the presence of soil pipes a possible mechanism would be insitu liquefaction of the colluvium. The joint bounded gully at Ch 5 to Ch 35 slopes at 40° and could have been the site of a rock wedge failure that would have started as a slide (Workman, 1990) but could also be the site of a failure of the colluvial

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infill to a gully that was formed by an old wedge failure. Examination of the remnants of material within the scar could not establish which of these possibilities occurred. However, the presence of remoulded debris on the slope around the scar from Ch 10 (Plate 23) indicates that whatever the mechanism of initial displacement, the intact material rapidly disintegrated into flowing debris.

The parent landslide occurred on a 28° slope with 4 m of actively accumulating loose colluvium overlying decomposed granite from which seepage was occurring. It was presumably triggered in some way by the upslope failure. This could have been by loading from the upslope failure debris and/or the increased surface and ground water flow due to enhanced runoff from the scar above and release of groundwater into it. The initial displacement could have been sliding rapidly followed by collapse of the loose colluvium structure leading to liquefaction. As with the trigger landslide, whatever the initial mechanism, remoulded debris is present just downslope from the source (Plates 31, 34 & 35) and thus the debris appears to have commenced to flow soon after displacement.

The scar upslope from the parent landslide (Ch 75 to Ch 120) is a scarp bounded gully eroded into a 35° colluvium slope. The presence of large insitu boulders half blocking the downslope end of the gully shows that the colluvium could not have failed as a single intact displaced mass and that failure of this part of the scar must have been incremental. The parent landslide would have removed downslope support from this deposit. Following this, backsapping of the main scarp as a combination of small landslides and gully erosion could have formed this part of the scar. The colluvium was loose (Pit D3) and matrix that had apparently flowed was observed adjacent to a void in the deposits at this location (Plate 28, Chan et al, 1991). This suggests that debris from this location rapidly fluidised and flowed around the insitu boulders.

Over large parts of the scar within the drainage line the regolith materials have been eroded away to expose bedrock. The relatively smooth feathered edges to these eroded areas indicate that the colluvium did not fail as a mass but was progressively worn away by an erosive flow of debris and/or water that loosened the substrate by impacts and picked it up and entrained it by hydraulic action. A similar mechanism of impact and hydraulic action is probably what was responsible for the mobilisation of the loose surface boulders and cobbles that were incorporated into the debris.

7.2.2 Debris Transport

The Tsing Shan Debris Flow was not observed and therefore the mechanism of debris movement can only be inferred from the resulting scar. Possible mechanisms of debris movement are falling, rolling and bouncing, sliding, flowing and washing. Evidence from the gross morphology of the scar, the relationships of the materials within it and the sedimentological characteristics of the debris indicate that rolling and bouncing, flowing and washing of debris all occurred as discussed below.

7.2.2.1 Rolling and Bouncing

Evidence for rolling and bouncing of intact rock debris with no or minimal, matrix

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comprises trails of aligned vegetation, impact marks on rock outcrops and the ground surface and the presence of isolated cobbles and boulders as debris. Such evidence is mainly preserved on the slope around the edges of the scar in the depletion area. It occurs on the north eastern side of the scar from Ch 50 to Ch 200 and the south western side from Ch 150 to Ch 250. At early stages of the TSDF rolling and bouncing may have occurred within the area now occupied by the central part of the scar but any evidence for this has been removed by subsequent erosion. Below about Ch 250 traces of remoulded debris are found below or capping any isolated clasts. This suggests transport in conjunction with a fluid matrix which would have modified any rolling and bouncing that occurred.

7.2.2.2 Sliding

Evidence for sliding as a significant mechanism of transport, such as the presence of shear planes at the base of or within the debris deposits or significant deposits of intact displaced material, was not found during the investigation. Any material initially displaced by sliding must have rapidly disintegrated into remoulded debris or loose clasts although some sliding of clasts and soil over vegetation and topsoil may have occurred at the trails around the upper part of scar. A shear plane was encountered between colluvium and decomposed andesite in Trench 2 but this was not related to the debris flow.

7.2.2.3 Flowing

Evidence that some debris flowed is present in the form of remoulded debris matrix. This material is soil that has lost its original structure but retains a significant silt content, was not sorted by particle size as it came to rest and which suspends material of gravel size or larger (Section 6.2.1). All matrix in Class 1, 2 and 3 debris comprises remoulded debris which is found as significant deposits or thin traces throughout the scar. The presence of remoulded debris could not be established from Ch 0 to Ch 40 during fieldwork, but downslope from here deposits were found on the rock outcrop at Ch 40. The first deposit of remoulded matrix from the top of the scar that was large enough to take a 10 kg sample was at Ch 85 (sample M28).

The following characteristics of the remoulded debris deposits indicate deposition from a flowing material. Sheets of remoulded debris have a relatively smooth surface (Plates 56, 72 & 83) and in the concrete diversion channel this is level with the top of the channel (Plate 98). Remoulded debris deposits are built up on the upslope side of obstructions and form a trail on the downslope side (Plate 43). Thin deposits of remoulded debris occur on and below boulders (Plates 72 & 73) and around the bases of bouldery Class 3 debris (Plate 68). Locally there is flow alignment of vegetation and clasts within the remoulded debris (Plates 92 & 93). The debris deposits commonly have a lobate steep sided outline both in the gross morphology of the scar (Plates 13 to 15 & 70) and of small areas within it (Plates 76 & 99). The relatively uniform thickness of the debris in the primary lobes and on the cut slope (Drawings GEO/P/PTE/2 & GEO/P/PTE/3). The extensive presence of undisturbed vegetation below remoulded debris in the deposition area (Type 1 contact, Section 6.2.3, Plate 65).

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The potential of the matrix of the colluvium at the site to flow if remoulded when saturated is shown by the comparison in Figure 10 of the insitu saturated moisture content (SMC) and the moisture content which allows flow in a 15° flume (MMC). At six sites the SMC was greater than or equal to the MMC and at most other sites was within 10%. This indicates that, if disturbed when saturated, the matrix of this colluvium has potential to flow. The matrix (< 20 mm diameter) forms about 20% by weight (30% by volume) of the colluvium and it is considered probable that this is enough to significantly influence the behaviour of the mass of colluvium on failure.

The main debris deposit lobe is some 75 m long, 75 m wide and, apart from eroded channels, a fairly uniform 2 - 3 m thick. For the debris to have taken this configuration after passing through the narrow (20 m) mouth of the drainage line flow must have occurred. Rolling, bouncing and sliding would have resulted in a thicker accumulation of debris at the toe of the borrow scarp and washing would have resulted in a sorted deposit.

Taken together the above observations suggest that flow was a significant mechanism of debris movement in the Tsing Shan Debris Flow. Peirson & Costa (1987) classify sediment-water flow and, using their terminology, the remoulded debris would have undergone slurry or granular flow depending upon whether the debris was pore fluid or grain-supported during movement, which in turn is dependant upon the sediment concentration and whether the debris is saturated. Slurry and granular flow are subdivided into inertial and viscous flow on the basis of velocity (inertial flow is > 7 kph for slurry and > 0.36 kph for granular flow). Class 1 debris has no voids and forms relatively thin deposits, which indicates it was less viscous and was probably saturated during flow (Section 6.2.1). Class 2 debris was reported as very soft and saturated immediately after the event (Plates 69, 77 & 83) but it forms much thicker deposits and has occasional voids (Trench 1 Ch 85, Trench 2 Ch 45) and may locally have not been saturated during movement. The debris velocity estimated in the depletion area was from 45 kph to 60 kph. Thus it is probable that on the steep slopes inertial slurry flow and possibly inertial granular flow were occurring. As velocity slowed in the deposition area viscous slurry and granular flow may have occurred.

7.2.2.4 Washing

Evidence for movement of debris by stream flow, and probably hyperconcentrated stream flow (Peirson & Costa, 1987), is provided by the deposits of sorted debris that form alluvial deposits of locally bedded sand and gravel. The lack of silt and clay sized material, the occurrence local bedding and sorting by grain size indicate deposition from running water. These deposits generally occur along sharply incised V-shaped channels, which also indicate erosion by running water.

7.3 Sequence of Events

7.3.1 Multiple Phases of Movement

At several locations on the spur and in the upper valley there is evidence of three different modes of debris transport. These are rolling and bouncing boulders, passage of a large, short pulse of debris and a longer lasting and more intense erosion confined to the central part of the scar. Examples of this and other evidence for multiple phases of

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movement are considered below.

The debris trails around the upper part of the scar extend down over the Ch 40 rock outcrop as traces of remoulded debris on flatter rock ledges with little erosion of insitu soil. The narrow trail down an adjacent gully from debris that tipped off the southwest side of the outcrop is of a similar type and was probably contemporaneous. However the rock outcrop is intensely scoured along a 2 - 3 m deep and up to 2 m wide steep sided cleft and there are marks from bouncing, rolling and sliding boulders on the slope adjacent to the outcrop. This is interpreted as evidence for a wide, generally non erosive pulse of debris that incorporated or displaced the many loose boulders on and around the rock outcrop, and a more intense, and longer lasting, flow of debris confined to the cleft.

In the upper valley below the sheeting joint there are boulders and traces of remoulded debris on the southwestern side of the scar but little erosion of insitu deposits (Plates 38 & 39). On the northeastern side there has been extensive deep erosion of the colluvium and scouring of the bedrock surface (Plates 36 & 37). Remoulded debris is mainly found along the edge of the scar. This indicates that while a single large pulse of remoulded debris and boulders passed down over the whole width of the scar there was also a longer lasting and more erosive flow on the northeastern side.

The only witness to the event reported intermittent pulses of vibration/sound that included at least one exceptionally large noise and continued for at least 30 minutes. If the cross sectional area of the largest debris pulse at the locations where the velocity was estimated is compared to the total active volume of the debris flow it can be seen that the whole debris flow could have passed these locations in 5 to 15 seconds (Appendix F). Therefore the limits of the scar must represent the track of a large, short lived pulse(s) of material while the ongoing sounds and vibrations must have been caused by a longer lasting movement of considerably smaller volumes of material.

In the lower valley, the inflection in the south western margin of the scar just below the waterfall suggests two separate pulses with different characteristics such as direction, volume, consistency and speed. Interpretation of Plates 8 and 48 suggests that the trail from an earlier, more fluid surge that rode high up the valley side and dissipated in the grassy vegetation was cut by a later surge that was responsible for most of the deposition in the lower valley. One of these surges could have been from the breaching of a blockage at the footpath platform (Ch 300) on which debris may have accumulated causing an abrupt widening of the scar at this point, before the path failed which resulted in a surge of debris.

Other possible locations of temporary blockages are around the large boulders in the upper valley and at the mouth of the drainage line. At the mouth of the drainage line, the south western edge of the scar rides high up the hillside, even though it is located on the inside of a bend (Plate 54). This could be the result of a surge of debris and/or water around, or over, a blockage centred on the diversion bund that was present before the debris flow.

The concrete diversion channel at Ch 500 was blocked at several locations. The proximal blockage comprises boulders with remoulded debris matrix and stands higher than the sides of the channel (Plates 56 & 58). Downslope from this, remoulded debris is banked up behind a further blockage of boulders in the channel (Plates 59 & 60). Neither of these blockages could have been subject to significant water flow as remoulded debris matrix is

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preserved around the boulders. However, just downslope from them, a large boulder (2 m diameter) jammed in the channel has an alluvial deposit of sandy gravel at its base (Plate 61). Some 20 m downslope from here a distal blockage is formed of boulders up to about 0.5 m diameter with alluvial deposits and flow aligned vegetation (Plates 62 & 63).

The large boulder was probably emplaced by debris slurry as indicated by its size and the traces of remoulded debris capping it (Plate 61). However, both it, and the distal blockage, are associated with alluvial deposits and therefore these blockages were affected by water flowing in the channel before the un-washed, proximal blockage of remoulded debris closed the channel. Thus, early in the event a pulse of debris, including the large boulder, reached the channel inlet and was diverted into it. Following this there was a period when water flow was diverted down the channel before the final proximal blockage by remoulded debris. At this time the diversion bund may still have been functioning or an early deposit from the debris flow may have acted to divert the debris.

Throughout the scar alluvial debris deposits locally overlay the other types of debris. At many locations Class 1 remoulded debris occurs adjacent to or either side of a central area washed clean of debris (Plates 47 & 50). At the mouth of the drainage line Class 1 remoulded debris has been locally completely eroded or the surface has been washed and the fines removed to form a thin sorted alluvial surficial deposit overlying remoulded debris (Plate 54). These observations indicate reworking and deposition from streamflow late in the event.

7.3.2 Sequence of Development

The first slope failure of the debris flow must have occurred at the main scarp of the debris flow scar (Ch 0) as the pre-event bedrock outcrop at Ch 40 would have been a barrier to the upslope extension of any slope failure that might have occurred lower down the slope.

In the area above the rock outcrop from about Ch 10 there is a trail of debris on the ground surface beside a V-shaped gully that forms the scar (Plate 2). This suggests that debris from above Ch 10 passed down the slope before the gully was formed and thus the event must have started at or very near Ch 0.

At the downslope end of the bedrock outcrop intense scouring along a cleft that forms the lowpoint of the scar gradually decreases and gives way to newly exposed but un-scoured rock. This indicates the colluvium that first protected the rock from scouring was removed incrementally (Plates 26 & 27).

On the 35° slope below the rock outcrop the scar is a steep sided gully with traces of remoulded debris and rolling bouncing boulders on the ground surface beside it (Plate 4). Before the debris flow there was a subdued hollow at this location. Debris flowing down the hollow before the gully was formed may have spilled over the ground surface but once the gully was formed this would have channelled any debris. Thus debris beside the gully was probably deposited before the gully was formed.

Downslope from here the slope reduces to 28° above a sheeting joint at Ch 170, the scar widens from about 15 m to more than 30 m and deepens to form a steep sided depression with a total volume of more than 2,000 m^3. There are extensive deposits of boulders,

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cobbles and matrix on the ground surface beside the scar (Plates 5, 31, 32 & 34) which suggests that much of the initial debris from above was deposited here before the depression formed. This area was underlain by weak, saturated deposits. After the small landslide above occurred it would have been subject to loading by debris and increased infiltration from surface water flow out of the new scar. Downslope from here there is evidence of several large pulses of debris (Section 7.3.1) and this is the only part of the scar with sufficient volume to be the source of the debris. This area is thus interpreted to be the location of a landslide that resulted in the large debris flow in the drainage line (parent landslide) and that was triggered by the smaller landslide on the spur above (trigger landslide). The gully that forms the scar upslope from here was probably formed by backsapping of the parent landslide main scarp (Section 7.2.1) and would have been the source of material for the longer lasting erosive flow on the northeastern side of the valley below.

7.3.3 Order of Deposition

The morphology, composition and relationships between the deposits in the deposition area provide evidence that the debris was deposited by a series of pulses of varying composition, velocity and transport mechanism.

The association of the debris classes and contact types is described in Sections 6.2.2 and 6.2.3 and summarised on Table 5. Class 1 debris is homogenous and generally occurs in thin (0.6 m) deposits. Class 2 debris is inhomogeneous and generally occurs in thick (1 m to 3 m) deposits. Class 1 always overlies or occurs adjacent to and never underlies Class 2 debris. Type 1 contact indicates flow was the transport mechanism operating at the time of deposition and underlies both Class 1 and Class 2 debris. Type 2 contact indicates shearing and disruption of the substrate during deposition and generally underlies Class 2 debris. Contact 3 indicates that erosive flow was occurring prior to deposition and only underlies Class 1 or alluvial debris. The above observations allow the following conclusions to be drawn. As Class 1 and Class 2 debris both overlie Type 1 contact both must have been emplaced by flow. As Class 1 debris deposits are much thinner than Class 2 debris deposits Class 1 debris must have been less viscous. As Class 1 debris may overly Class 2 debris, but never the reverse, some Class 1 debris must be younger than Class 2 debris. Type 2 contact indicates energy transfer from the moving debris to the substrate which would require very viscous flowing debris, debris that was ceasing to flow and starting to slide, or debris moving by rolling and bouncing that penetrated the substrate and slid a little as it stopped.

At the mouth of the drainage line the scar is displaced from the centre-line to the southwest (SW) (Plates 1 & 10) and there are wash marks up the hillside on the SW margin even though this is on the inside of a bend (Plate 54). The deposits in the concrete diversion channel show a sequence of first bouldery debris with matrix, then water flow and finally blockage by a more matrix rich debris (Section 7.3.1). These observations would be explained by the presence of a bouldery lobe of debris blocking the centre-line at the mouth of the drainage channel early in the event and displacing subsequent watery and matrix rich debris to the SW. This would also explain why there is considerably less erosion of the substrate in this part of the scar as it would have been protected by the bouldery debris. The re-mobilisation of this bouldery debris lobe later in the event could be the event that caused the disruption of Mr Chan's services. The thick (2 m) bouldery ridge on the northeastern (NE) edge of the scar could be the remnant of this lobe. The 1 m thick, matrix rich

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remoulded debris with occasional boulders on the SW edge of the scar could have been later matrix rich debris displaced by the bouldery lobe.

The thick Class 2 debris deposits on the flat borrow area are generally more bouldery on the NE side. On the NE margin and in the central part of the scar are thick, large bouldery ridges of Class 3 debris and the SW edge is a smaller less bouldery ridge. There is an indistinct line of large boulders along the downslope margin of the thick debris. A bouldery margin is often reported for debris flow lobes but the medial ridge is unusual. The medial ridge could have been formed as the lateral ridge of an initial bouldery debris lobe that built up on the northeastern side before a second more matrix rich lobe was emplaced to the SW. Most of the high energy depositional Type 2 contact encountered in Trench 2 is located on the NE side of the main lobe and could be due to the rapid emplacement of the bouldery lobe. The presence of more Type 1 low energy depositional contact on the SW side would be explained by slower deposition of more matrix rich debris displaced to the SW side.

There is a bowl shaped depression in the main debris lobe bordered by the medial and NE bouldery ridges. Downslope from here a lateral lobe of bouldery matrix rich Class 1/2 debris on a Type 1 contact extends from the NE side of the scar. This could result from streamflow mixing with the debris of the primary lobe at the toe of the borrow scarp, reducing its viscosity so that it re-mobilised and drained out of the main lobe to form the lateral lobe and leave the bowl shaped depression.

Thin sheets of Class 1 debris with occasional large boulders stranded on the slope and a predominantly low energy, depositional Type 1 contact form the whole scar on the cut slope. The debris flowed around small obstructions to form two interconnected areas divided by ribbons of insitu vegetation. In the borrow area Class 1 debris is only found along the channels but the debris sheets extend over the whole slope. The Class 1 debris on the slope must have either flowed along these channels from the depletion area or have been derived from the broader lobe of Class 2 debris by an increase in moisture content. The boulders scattered on the slope suggest that the sheets of Class 1 debris on the slope are derived from surges of debris that were not confined to the channels and which could have originated from a partial re-mobilisation of a primary debris lobe on the borrow area. However the superficial lobes of debris at the slope toe originate from the channels, which indicates that at the later stages of the event some Class 1 debris was confined in the channels on the slope.

The washed central part of the scar at the mouth of the drainage line, the three channels that flowed sequentially through the deposition area (Section 3 of Appendix B) and the alluvial fans at the slope toe indicate that the last parts of the event comprised streamflow, that caused the alluvial redistribution of the debris, and gully erosion into the debris lobes and insitu materials of the cut slope.

7.4 Model of the Debris Flow

7.4.1 Preferred Interpretation

This summary represents the preferred interpretation of the field evidence discussed in Sections 7.2 and 7.3 and is outlined on Drawing GEO/P/PTE/7.

The event started with the failure of a few tens of m^3 of loose colluvium and

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decomposed granite along a spurline sloping at 50°. This developed into the trigger landslide, where several hundred m^3 of bouldery decomposed granite and colluvium was displaced from a V-shaped bedrock gulley to form a fluid remoulded debris with boulders that spilled over a rock outcrop onto an accumulation of loose, bouldery spur colluvium below. Some of the debris continued over a steep sheeting joint into a colluvium-lined valley dislodging boulders from a valley-side fan.

Immediately above the sheeting joint was a 28° slope of spur colluvium that was highly decomposed at the base and underlain by kaolinised completely decomposed granite (CDG) which was probably saturated from seepage. Loading from the trigger landslide debris, and increased run off from the landslide scar above, caused a failure of this slope at, or near, the CDG/colluvium boundary. The debris from this failure comprised some 2,000 m^3 of boulders in a remoulded debris slurry which flowed over the sheeting joint into the valley. Debris from this parent landslide surged down the valley with an estimated velocity of up to 16 m/s and was the start of the large channelised debris flow. It entrained loose boulders, valley bottom colluvium, vegetation and stream water and left a trail high on the lower valley side. Debris would have accumulated on the footpath platform and the failure of this would have formed another large pulse of debris and a second trail on the lower valley side. Early in the event boulders built up at the mouth of the drainage line displacing subsequent debris to the south west. The bouldery debris extended down over the borrow scarp to form a thick primary lobe on the northeast side of the scar while the subsequent debris formed a second thick lobe of more matrix rich debris to the southwest.

Rainfall continued and the scars from the trigger and parent landslides enlarged shedding debris that continued to flow and wash down the valley. A major debris source would have been the 1,000 m^3 gully that was eroded into the spur colluvium by the ongoing retrogression of the main scarp to the parent landslide. Debris and water would have locally accumulated at small blockages in the valley and then re-mobilised as rapid, erosive surges. Small deposits of debris were left along the sides of the scar and fast moving bouldery debris mixed into insitu deposits in the bottom of the lower valley however significant deposition only started on the house platforms at the mouth of the valley (Ch 500).

As the rainstorm intensified, floodwater and debris from the drainage line would have loaded the bouldery blockage in the mouth of the drainage line until the central part of it failed and displaced over the borrow scarp breaking the power and telephone lines and leaving thick debris ridges along the sides of the scar. Floodwater loaded with finer debris continued to pour over the borrow scarp locally increasing the moisture content of the debris lobes on the borrow area which partially re-mobilised and extended a lobe of viscous debris to the north east. Surges of less viscous remoulded debris slurry with boulders passed down the cut slope flowing around small obstructions and leaving stranded boulders and deposits of debris less than 1 m thick. Remoulded debris accumulated at the slope toe to form lobes up to 2 m thick that blocked a 2 m deep trapezoidal drainage channel. A thinner lobe of remoulded debris extended from this and flowed through a low point out onto the Area 19 platform.

Floodwater from the drainage line continued to flow over the debris flow deposits locally washing away remoulded debris and sequentially eroding three channels into the thick primary debris lobes on the borrow area. A system of braided channels developed on the cut slope and deep gullies eroded into the underlying completely decomposed andesite. At the slope toe the floodwater flowed over the remoulded debris lobes cutting shallow braided

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channels, washing fines out of the surface layer and depositing alluvial fans over the debris lobes. The water followed the debris out onto the platform and deposited fine grained alluvial debris.

As the rainstorm ceased and the floodwater abated the final form of the debris flow scar was a combination of deposits from the main debris pulses in the drainage line and their subsequent re-mobilisation, erosion and re-deposition by floodwater. At the mouth of the drainage line remains of the early blockage formed piles of boulders on the abandoned house platforms adjacent to thin alluvial and remoulded debris deposits. On the borrow area the thick primary remoulded debris lobe was dissected by three alluvial channels and the remains of the bouldery northeastern lobe formed boulder ridges along the centre and the northeastern side. On the cut slope were thinner deposits of re-mobilised debris and at the slope toe, lobes of remoulded debris were overlain by alluvial fans and braided channels.

Debris flows comprising a series of pulses that become smaller and more fine-grained as the event continues, and with the re-mobilisation of debris deposits from earlier pulses by subsequent wetting up, have been described by many authors e.g. Ikeya (1989), Johnson & Rodine (1984), Pierson (1980).

7.4.2 Gross Characteristics

The division of the TSDF into the individual components described above is necessary to understand the event and to establish the factors involved in the generation of such events. However, the gross characteristics of the event are listed below.

Length	1,035 m		
Elevation Loss	405 mPD to 10 mPD = 395 m		
Reach Angle	21° (head to end of deposition)		
Approximate Deposition Volumes	Spur and Upper Valley	-	300 m^3
	Lower Valley	-	500 m^3
	House Platform	-	1,800 m^3
	Borrow Floor	-	6,000 m^3
	Cut Slopes	-	5,000 m^3
	Slope Toe	-	6,700 m^3
	Total	-	20,300 m^3
Approximate Erosion Volumes	Trigger Landslide	-	350 m^3
	Parent Landslide	-	2,500 m^3
	Spur Erosion	-	1,000 m^3
	Valley Erosion	-	8,000 m^3
	Deposition Area	-	6,500 m^3
	Total	-	18,350 m^3
Swell Factor	8%		

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Mechanism	Debris/Rock slide that rapidly disintegrated into a channelised debris flow, the deposit from which was redistributed by alluvial erosion and transport of fines.
Overall Slope Angle (Length)	Spur (erosion) 39° (175 m) Drainage Line (erosion) 22° (315 m) Primary Deposition Area 15° (180 m) Whole Deposition Area 10° (545 m)
Source Material	Recent, loose granite derived colluvium and kaolinised CDG that formed a fluid debris of vegetation, boulders, cobbles, in a silty sandy gravel matrix with local variation of proportions.
Hydrogeology	Drainage line has catchment of 114,000 m^2. Seepage from dykes, quartz veins and joints related to granite/volcanics contact.
Topography	Trigger and Parent landslides on a spur. Debris channelised in a valley. Deposition on excavated cut slopes and platforms.
Vegetation	Grass and small shrubs on the spur and deposition area with small trees and shrubs in the valley.

7.4.3 Classification

The landslide described above would be classified as a debris flow by Varnes (1978) based on the following: the material involved was considerably less than 50% sand, silt and clay and thus debris; this debris was saturated and its very rapid movement partly resembled that of a viscous fluid thus is classified as flow; channelisation of debris in a drainage line and deposition at its mouth is also the typical morphology given. The initial displacement of material in the trigger, parent and secondary landslides can be described as translational rock or debris slides.

Classifications of sediment water flows are also presented by the following authors. When these are applied to the Tsing Shan Debris Flow they give the following classifications.

- Vandine (1985) — *Channelised debris flow* (Debris Torrent), based on the PSD and water content of the material and the mechanics and location of the movement.

- Ikeya (1989) — *Debris flow*, based on PSD and morphology.

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• Aulitzky (1990)	*Debris flow torrent*, based on mechanism of movement and morphology of deposition.
• Sassa (1984)	*Slope type debris flow*, based on location of initiation, debris flow is not considered in Sassa 1985's geotechnical classification of landslides which only considers mechanism of initiation.
• Pierson & Costa (1987)	Mainly *Inertial and viscous slurry flow*, but locally *granular flow* may have occurred. Late in the event *normal stream flow* (and presumably transitional *hyper concentrated streamflow*). These are based on sediment concentration and mean velocity.
• Cai Ze-Yi (1992)	*Local Debris Flow*, based on the type of initiating rainfall.
• Ying & Bifan (1992)	*Viscous Debris Flow*, based on grain size distribution and water content.
• Hutchinson (1988)	*Channelised Debris Flow*, based on material, mechanism and morphology.

Thus the Tsing Shan Debris Flow can be more fully classified as a rock or debris slide that rapidly became a channelised bouldery debris flow during which the transport mechanisms of rolling and bouncing, flow (slurry flow, granular flow), washing by hyperconcentrated and normal stream flow and possibly limited sliding operated. Channelised debris flows can be divided into those caused by landslides into drainage lines during heavy rain and those that result from the failure of the stream bed deposit due to flooding. The Tsing Shan Debris Flow can be grouped with the former.

A complex event such as the TSDF involves a number of different materials and movement mechanisms. The whole event is classified as a debris flow (Appendix G) on the basis of the materials involved, the presence of slurry flow as the dominant mechanism of movement and the channelised elongate scar. This wide definition of a debris flow as an event avoids confusion with the mechanism of slurry flow (Pierson & Costa, 1987) which is often referred to as debris flow in technical literature.

7.5 <u>Risk</u>

7.5.1 <u>Risk Potential</u>

Using the terms defined in Fell (1994), the magnitude of the TSDF can be considered as the area affected by the event, i.e. the whole scar. However, the degree of vulnerability

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varies at different locations within the scar. For instance in the upper part of the depletion area there was intense scouring along the centreline of the scar while outside this area flowing debris in some cases passed over rock outcrops and vegetation without any erosion. The ground surface beside the scar was affected by occasional bouncing and sliding boulders.

In the lower valley, on the house platforms and in the borrow area, large confined pulses of flowing debris with many large boulders caused intense erosion and damaged concrete structures (Plates 53, 54 & 55). Any housing in these locations would have been extremely vulnerable to impact from moving debris (Plates 18 & 19). These areas of primary deposition are relatively limited and easy to define. They have a high probability of being affected should a debris flow occur in the drainage line.

However on the cut slope downslope from the primary deposition lobes, re-mobilised debris with occasional small boulders flowed around insitu boulders and high points. This secondary deposition was generally not erosive and deposited less than 1 m of debris slurry. Thicker lobes of debris did build up at the slope toe but rapidly thinned where they extended onto the platform. Any substantial housing in these areas would have been unlikely to suffer serious damage from debris impact although entry of debris into the ground floor through doors and windows would be a hazard. The movement of this debris was easily diverted by small variations in topography. The area that could possibly be affected by such secondary deposition is relatively large and complex to define, however any specific location within such a large area would have a relatively low probability of being affected.

7.5.2 Return Period in the Drainage Line

An indication of the probable return period for events similar to the TSDF in the drainage line is given by the nature of the deposits in the lower valley. These are described in the logs of trenches TP1 to TP4 on Drawing GEO/P/PTE/5. They show no deposits that could be interpreted as debris from a single event of a similar nature to the TSDF. While bouldery granite colluvium is present, and some of this may have been emplaced by similar events to the TSDF, it has been modified by insitu processes of eluviation and soil creep from the side slopes with more than 1 m of soil derived from the side slope overlying granite colluvium at TP3. While no technical references could be found that gave typical rates of soil deposition in such an environment, it is the authors opinion that for this thickness of such a deposit to build up would take 100's, if not 1,000's of years. This indicates a minimum return period for an event of a similar magnitude although smaller event confined to the central parts of the drainage line may have occurred.

Additional evidence is provided by the colluvium fan at the mouth of the drainage line. Many clasts within the fan colluvium are moderately to highly decomposed and the matrix has abundant iron staining. This must have occurred as a result of insitu weathering which indicates a probable Pleistocene age (> 10,000 years ago) for much of the deposition that formed the fan (GCO, 1988). However the younger Holocene age (< 10,000 years ago) of much of the colluvium in the drainage line indicates its accumulation, and thus the possible occurrence of debris flows during this time.

On the pre-development 1963 and 1949 aerial photographs the stream is incised some 5 m into the fan. Many boulders are present at the ground surface but no distinct lobes or

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fans of debris can be seen. This suggests that the active process on the fan at these times was reworking of the deposit rather than deposition.

In 1949 there is also a small extension of the fan across the creeping landslide back scarp that forms its downslope boundary. This may be the deposit from the most recent large debris movement in the drainage line. It is considerably smaller than the deposit from the TSDF (possibly 2 - 3,000 m^3) and its shape is not fresh or distinct.

The TSDF was associated with a rainstorm with total precipitation of about 136 mm (Section 4.3) and a return period of no more than 2 to 3 years. Between 1982 and 1994 fourteen storms of equal or greater intensity have been recorded at raingauge N07, some 1.5 km from the site (Appendix D). However, despite these much larger storms there has been no recurrence of long run out flows on Tsing Shan. The rainfall associated with the event was unexceptional and appears to have little correlation with the possible return periods discussed above. This suggests that rainfall or its return period may be of little use to predict the return period of similar events.

7.5.3 Return Period in Hong Kong

An indication of the overall probability of recurrence of an event similar to the Tsing Shan Debris Flow (TSDF) anywhere in Hong Kong can be gained from examination of evidence for similar events in the past.

The geological record shows extensive materials mapped as debris flow deposits on the 1:20,000 series geological maps. Some of these form distinct fans and may be mapped as Pleistocene to Holocene age which indicates activity in the last 10,000 years. Debris fans are present at the mouth of a number of the drainage lines on the east side of Tsing Shan. Some of these have been deeply dissected which indicates that at present they are loosing more material than is being deposited. One of the least dissected debris fans is at the mouth of the TSDF drainage line. Trenches dug in the lower part of the TSDF drainage line show no evidence for previous debris flows of a similar magnitude in the last few thousand years.

Historical documents concerning Hong Kong since European settlement record a number of heavy rainstorms with associated flooding and flood deposits. None of these are detailed enough to compare their volume with the TSDF. An event of this type might go unrecorded unless located adjacent to a developed area. Only very limited references with case studies of natural slope failures in Hong Kong have been found during a search of technical literature.

A more comprehensive record of landslide activity in Hong Kong for the last 30 years is provided by the aerial photograph record. Observations of various aerial photographs during the last 2 years, personal communications from others and a limited number of visits to the sites of natural slope landslides by the author suggest that it is common for displaced material from landslides on natural terrain to become fluid on failure and to form a debris flow over slopes below. However it is only when the debris is channelised in a drainage line that a longer run-out away from the steep natural slope may occur. There is little information on the volume of these events but they appear to generally be much smaller than the Tsing Shan event.

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A number of larger landslides with channelised debris run-out of 200 m to 1,000 m have been noted mainly from aerial photographs. These are: Mount Parker (1961, 400 m), Victoria Peak (1963, 250 m), Tsing Shan (1963, 230 m), Sham Tseng (1982, 2 x 250 m), below Route Twisk (1982, 1,000 m), Tung Chung (1992, 300 m & 1993, 400 m), Tsing Shan (1992, 400 m), Cloudy Hill (1993, 2 x 200 m), Nam Shan (1993, 4 x 200 m) and South Lantau (1993 at least 2 x 400 m). The volumes of these landslides, grain size distribution of the debris, extent of bulking and pattern of debris deposition has not been quantified but they all appear smaller than the TSDF.

In summary, the geological record indicates that debris flows with a similar or greater volume to the TSDF have probably occurred in Hong Kong in the last 10,000 years. The present investigation suggests they have not occurred in the valley of the Tsing Shan debris flow for at least the last few thousand years. A number of landslides with a long channelised run-out of debris have occurred in the last 30 years but none appear to have had as great a volume as the TSDF.

The return period for an event of the magnitude of the TSDF occurring somewhere in Hong Kong should therefore be somewhere between 1 in 10,000 years and 1 in 30 years. An estimate of between 1 in 1,000 years and 1 in 100 years might be a reasonable starting premise. These figures could be to some extent checked and refined by a database of natural slope landslides in Hong Kong which might show a relationship between landslide size and return period and any possible correlation with intensity, magnitude and duration of rainstorms.

7.6 Key Characteristics

7.6.1 Introduction

The key characteristics of the TSDF and the geological environment in which it occurred are summarised in Table 4. The debris flow was exceptionally large for Hong Kong where debris flows on natural slopes are generally at least an order of magnitude smaller in terms of debris volume. It follows that some of the environmental factors will have been important in the generation of the large channelised debris flow. Rainfall is an environmental factor often linked to landsliding, however the storm associated with the TSDF was not exceptional and no significant correlation could be made with the initiation of the debris flow. However the TSDF did occur at the start of a storm of increasing intensity and it is likely that flooding down the drainage line after initial emplacement of the debris resulted in the redistribution of the debris and its extension further from the slope toe by both slurry flow and stream flow.

An indication of which other factors may be important can be gained from a comparison of the TSDF with smaller debris flows. Little data is available on smaller natural slope debris flows in Hong Kong although a much smaller debris flood that occurred in a drainage line adjacent to the TSDF is described in King (1996). The debris flood is compared with the TSDF on Table 4 and details of this are discussed in Appendix L. This comparison, combined with observations by the author of other natural terrain landslide in Hong Kong, has been used to suggest some important factors for the generation of a large channelised debris flow in Hong Kong. These have been divided into factors related to the occurrence of a parent landslide with potential to form a large debris flow (Sections 7.6.2) and

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the characteristics of the drainage line that, in combination with a parent landslide, make it susceptible to large debris flows (Section 7.6.3). While a large landslide with mobile debris is a hazard even if not channelised, and a debris flow could occur in a drainage line due to entrainment of bottom and bank sediments by a flood event, it is the combination of the two that has the greatest risk potential through emplacement of debris far from the natural slopes on which it originates.

7.6.2 Parent Landslide Factors

The large channelised TSDF has been interpreted to have started with the failure of a parent landslide at Ch 125. This was initiated by a much smaller trigger landslide of a few 100 m^3 from Ch 0. Such a landslide is typical of many that occur on natural terrain in Hong Kong, but they do not usually develop into large channelised debris flows. The characteristics of the trigger landslide itself are thus not considered important factors in the initiation of the debris flow other than its location above the site of the parent landslide. The parent landslide site is characterised by an actively accumulating, loose, saturated, 4 m thick colluvium deposit overlying CDG from which seepage was occurring. The following characteristics of the parent landslide are considered important in the generation of the large debris flow and are discussed in more detail in Section 3.1 of Appendix L.

(1) A "large" volume - the TSDF parent landslide was over 2,000 m^3. The volume of the final debris flow will be to some extent controlled by the volume of the parent slide.

(2) Sufficient fines (silt and clay) should be present in the debris matrix to reduce permeability enough to form a slurry that can flow. An approximation of the fines content necessary for flow to occur may be about 15% for the matrix (< 20 mm diameter), 10% for the < 200 mm diameter fraction and 5% for the full grading.

(3) A low matrix insitu density that may be contractive on failure. The TSDF parent was in a deposit with a matrix insitu dry density of 1.4 to 1.8 Mg/M^3.

(4) Presence of seepage from bedrock which increases the moisture content of the deposit thus decreasing the quantity of rain necessary for saturation of the deposit.

(5) Location in a drainage line or hollow that will concentrate surface and subsurface drainage. The TSDF parent was in a first order gully with a catchment of 10,000 m^2.

(6) A high elevation and located immediately above a steep rock outcrop that leads down to a drainage line or gully. The TSDF parent was at 300 mPD and located above a 47°, 35 m high rock slope.

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7.6.3 Drainage Line Factors

Debris from a parent landslide must pass into a steep drainage line of a suitable dimension, shape and slope angle to form a channelised debris flow. The drainage line should also contain sufficient erodible deposits that can be entrained for the debris flow to increase its volume and potential to run out far from the parent landslide. Such a drainage line can be referred to as a 'susceptible' drainage line. The part of the TSDF scar that is considered to be the drainage line is from the valleyside fan at Ch 225 to the mouth of the drainage line at Ch 500. The following characteristics of the drainage line in which the TSDF occurred are considered important factors in the generation of the large channelised debris flow.

(1) Catchment size is not considered an important influence on the generation of a large debris flow (Appendix L) however it will influence the potential for re-mobilising primary debris flow deposits and extending this hazard (Section 7.5.1). The catchment at Ch 225 is 63,000 m^2 and at Ch 500 is 114,000 m^2.

(2) The cross section shape of the drainage line and area of a debris pulse combine to give the degree of channelisation of a debris flow pulse (Appendices G & L) which is a factor in runout distance. Channelisation ratio at Ch 225 was 4.5, this increases to 7.7 at Ch 375 in the lower valley where minor deposition occurred and was it 4.7 at Ch 500 downslope from which it rapidly increased and the main deposition started.

(3) The slope angle along the drainage line provides energy for the movement of channelised debris and erosion of insitu material. Combined with channelisation this is a primary control of where deposition will start. The slope angle of the TSDF drainage line varied from 70° at the waterfall to 16° below the path with an overall slope of 22° (Table 3, Drawing GEO/P/PTE/2). Erosion was 25 to 27 m^3 per m throughout the drainage line but deposition varied with slope angle. When channelised there was no deposition on 27° and only minor deposition on 16° and 20° slopes even with reduced channelisation. The main deposition occurred on 8° where channelisation ended.

(4) Insitu deposits eroded and entrained by a debris flow in a drainage line result in its growth. Most of the entrained material in the TSDF was young bouldery colluvium which lined about 70% of the drainage line. Some 4,000 m^3 of material from the spur eroded and entrained some 8,000 m^3 of material in the drainage line, an increase of 200%.

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8. CONCLUSIONS

(a) The debris flow scar on Tsing Shan was caused by a large channelised debris flow that occurred during a heavy rainstorm of increasing intensity in the early hours of the morning on the 11 September 1990.

(b) The rainstorm was not exceptional with an apparent return period of 2 to 3 years for most durations.

(c) The debris flow scar can be divided into three parts:

(i) the source area on a spur where landslides generated debris that flowed into a drainage line,

(ii) the channelised erosional part where debris descended the drainage line eroding and entraining materials and increasing in volume, and

(iii) the deposition area beyond the mouth of the drainage line where most of the debris was deposited and some localised erosion also occurred.

(d) The total volume of erosion in the debris flow was almost 19,000 m^3. Some 11,000 m^3 passed the mouth of the drainage line and down slope from here a further 7,000 m^3 of surface material was incorporated into the debris of which about 3,000 m^3 was eroded by alluvial action.

(e) The mechanism of debris movement was mainly slurry flow and several pulses travelling at up to 60 kph occurred. Rolling and bouncing boulders also occurred in the upper part of the scar and there was alluvial erosion and redistribution of the debris in the later stages of the event.

(f) The parent landslide to the debris flow was initiated by deposition of debris and run off from an up slope, smaller, trigger landslide onto a metastable slope. The characteristics of the parent landslide most relevant to the generation of the large debris flow were: its volume (more than 2,000 m^3); its location at 300 mPD immediately upslope from a steep rock outcrop above a drainage line; the presence of sufficient fines (more than 17%) and loose condition (1.4 to 1.8 Mg/M^3) in the matrix of the deposit that failed; and the presence of seepage from bedrock below the deposit.

(g) The important characteristics of the drainage line were: its steep slope of 16° to 27°; its V shape that channelised the debris (channelisation ratio of 5 to 10); and the presence of

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bouldery colluvium within it that was eroded and entrained increasing debris volume by 200%.

(h) Significant deposition started at the mouth of the drainage line (Ch 500) where channelisation ended and the slope reduced to 8°. Thick primary deposition lobes of Class 2 debris were deposited up to Ch 700. These were re-mobilised by run off from the later part of the storm forming Class 1 debris that extended over the Area 19 cut slope to Ch 1035.

(i) A debris flow of this magnitude has probably not occurred in the drainage line for at least hundreds of years. However, conditions in the drainage line have not significantly changed and further debris flows of a similar magnitude could occur.

(j) The prediction of probability of occurrence of similar events in Hong Kong in the future should be based on the systematic collection of data on all natural slope landslides and debris flows that have occurred in Hong Kong since the start of the aerial photograph record. The possible locations for such events can be predicted by identification of locations with similar characteristics to the Tsing Shan Debris Flow. That is, where a parent landslide could occur into a susceptible drainage line.

9. REFERENCES

Aulitzky, H. (1990). About methods of judgement of slope stability and torrents in Austria. Canceli, A. (ed), 6th International Conference and Field Workshop on Landslides. ICFWL, Milan, pp 9-15.

Binnie and Partners (Hong Kong) (1981). Mid-Levels Study, Case Histories Subject Report Po Shan and University Areas. Geotechnical Control Office, Hong Kong.

Cai Ze-Yi (1992). A preliminary study of the relationship between heavy rainfall and serious debris flows, pp 201-205 In: Walling, D.E., Davies, T.R. & Hasholt, B. (ed), Erosion, Debris Flows and Environment in Mountain Regions. International Association of Hydrological Sciences, Wallingford.

Chan, Y.C., Lam, C.H. & Shum, W.L. (1991). The September 90 Tsing Shan Landslide: A Factual Report. Technical Note 4/91, Geotechnical Control Office, Hong Kong, 91 p.

Corominas, J. (1986). The Angle of reach as a mobility index for small and large landslides. Canadian Geotechnical Journal, vol. 33, pp 260-271.

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Cruden, D.M. & Varnes, D.J. (1996). Landslide Types and Processes. Landslides Investigation and Mitigation, Transportation Research Board Special Report 247 (Turner, A.K. & Schuster, R.L. (eds.)), National Research Council, National Academy Press, Washington D.C., pp 36-75.

Drainage Services Department (1994). Stormwater Drainage Manual. Hong Kong Government, Hong Kong, 145 p.

Evans, N. (1996). Rainfall Distribution and Orographic Effects in Hong Kong. Discussion Note 3/96, Geotechnical Engineering Office, Hong Kong, 30 p.

Fell, R. (1994). Landslide Risk Assessment and Acceptable Risk. Canadian Geotechnical Journal, vol. 31, pp 261-272.

Geotechnical Control Office (1987). Geotechnical Area Studies Programme - West New Territories. Geotechnical Control Office, Hong Kong, 155 p.

Geotechnical Control Office (1988). Tsing Shan (Castle Peak), Hong Kong Geological Survey Sheet 5, Solid and Superficial Geology. HMG 20 1:20,000. Geotechnical Control Office, Hong Kong.

Geotechnics & Concrete Engineering (Hong Kong) Ltd. (1993). Site Investigation Report. Tsing Shan Debris Flow Study. Contract No. GC/91/11. Works Order No. PW7/2/36.77.GCE, Hong Kong, 2 volumes, GIU Nos. 17336 & 17337.

Hungr, O., Morgan, G.C. & Kellerhals, R. (1984). Quantitative analysis of debris torrent hazards for design of remedial measures. Canadian Geotechnical Journal, vol. 21, no. 4, pp 663-677.

Hutchinson, J.N. (1988). General Report Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology: pp 3-34 In: Bonnard, C. (ed), Proceedings of the Fifth International Symposium on Landslides. A.A. Balkema, Rotterdam.

Ikeya, H. (1989). Debris flow and its countermeasures in Japan. Bulletin of Engineering Geology, vol. 40, no. 1 Debris flows, Report of the IAEG Commission No. 2, pp 15-33.

Irfan, T.Y. & Tang, K.Y. (1992). An Engineering Geological Characterization of Colluvium in Hong Kong. Technical Note 4/92, Geotechnical Engineering Office, Hong Kong, 128 p.

Johnson, A.M. & Rodine, J.R. (1984). Debris Flow. pp 257-361 In: Brunsden, D. & Prior, D.B. (ed), Slope Instability. John Wiley and Sons Ltd.

King, J.P. (1996). The Tsing Shan Debris Flood of June 1992. Special Project Report 7/96, Geotechnical Engineering Office, Hong Kong, 81 p.

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Lai, K.W. & Taylor, B.W. (1984). The classification of colluvium in Hong Kong. Geology of Superficial Deposits in Hong Kong, Geological Society of Hong Kong Bulletin No. 1.

Langford, R.L., Athurton, R.S. & Lai, K.W. (1987). Geological survey and ground investigation in Tuen Mun, western New Territories, Hong Kong, pp 199-207 In: The Role of Geology in Urban Development, Geological Society of Hong Kong Bulletin No. 3, October 1987.

Langford, R.L. & Hadley, D. (1990). New Debris flow on the flanks of Tsing Shan, Hong Kong. Geological Society of Hong Kong Newsletter, vol. 8, no. 3, pp 2-12.

Langford, R.L., Lai, K.W., Athurton, R.S. & Shaw, R. (1989). Geology of the Western New Territories. Geotechnical Control Office, Hong Kong.

MateriaLab (1993). Report on Soil Tests for the Geotechnical Engineering Office, Tsing Shan Field Investigation. Contract No. GC/91/06. Works Orders Nos. PW 6/3/29.71 and PW 6/3/29.77. MateriaLab, Hong Kong, 4 volumes, GIU Nos. 18610, 18611, 18612 & 18613.

Peterson, P. & Kwong, H. (1981). A Design Rain Storm Profile for Hong Kong. Royal Observatory, Hong Kong Technical Note No. 58, Hong Kong Government, Hong Kong, 30 p.

Pierson, T.C. (1980). Erosion and deposition by debris flows at Mt Thomas, North Canterbury, New Zealand. Earth Surface Processes, vol. 5, pp 227-247.

Pierson, T.C. & Costa, J.E. (1987). A rheological classification of subaerial sediment-water flows, pp 1-12 In: Costa, J.E. & Wieczorek, G.F. (ed), Debris Flows/Avalanches: Process, Recognition, and Mitigation. The Geological Society of America, Boulder, Colorado, USA.

Sassa, K. (1984). The Mechanism to initiate Debris Flows as Undrained Shear of Loose Sediments. Proceedings of the International Congress Interpravent 1984, Villach, Villach.

Sassa, K. (1985). The geotechnical classification of landslides. Proceedings of the Eleventh International Conference and Field Workshop on Landslides. ICFWL, Tokyo.

Scott Wilson Kirkpatrick & Partners (1986). Tuen Mun New Town Area 19 Slope Monitoring, April 1983 - March 1986, Summary Report.

Scott Wilson Kirkpatrick & Partners (1987). Tuen Mun New Town Area 19, Report on Study of Remedial Measures to Main Slope.

Somerville, S.H. (1986). Control of Groundwater for Temporary Works. CIRIA, London.

Standards Association of Australia (1977). Methods of Testing Soils for Engineering Purposes AS 1289. Standards Association of Australia, Sydney.

Strahler, A.N. (1952). Hypsometric (area altitude) analysis of erosional topography. Geological Society of America Bulletin, vol. 63, no.11, pp 1117-1142.

Styles, K.A., Nash, J.M. & Hansen, A. (1984). Historical Review of Slope Failure in Tuen Mun Area 19 Using Aerial and Other Photographs. Planning Report 1/84, Geotechnical Control Office, Hong Kong, 82 p.

Vandine, D.F. (1985). Debris flows and debris torrents in the Southern Canadian Cordillera. Canadian Geotechnical Journal, vol. 22, no.1, pp 44-68.

Varnes, D.J. (1978). Slope movements types and processes, pp 11-33 In: Schuster, R.L. & Krizek, R.J. (ed), Landslides; Analysis and Control. Transportation Research Board, Washington, DC.

Workman, D.R. (1990). The recent Castle Peak landslide - was rock sliding involved? Geological Society of Hong Kong Newsletter, vol. 8, no. 4, pp 40-45.

Ying, W. & Bifan, Z. (1992). Conversion mechanism of gravelly soil to viscous debris flow, pp 315-323 In: Walling, D.E., Davies, T.R. & Hasholt, B. (ed), Erosion, Debrisflows and Environment in Mountain Regions. International Association of Hydrological Sciences, Wallingford.

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Table 1 - Maximum Rolling Rainfall at Raingauge No. N07 and Estimated Return Periods for Different Durations Preceding 07:00 on 11/09/90

Duration	Max. Rolling Rainfall (mm)		End of Period		Estimated Return Period (Yr)
	1990 Debris Flow	1992 Debris Flood	Time	Date	
5 min	8	(6)	05:40	11/09/90	< 2
15 min	20	(16.5)	05:40	11/09/90	< 2
1 hour	53.5	(49)	06:10	11/09/90	< 2
2 hours	91.5	(70)	06:20	11/09/90	2.5
5 hours	136	(103)	06:25	11/09/90	2.4
12 hours	153	(152)	06:20	11/09/90	< 2
24 hours	189	(158)	06:55	11/09/90	< 2
2 days	195	(158)	07:00	11/09/90	< 2
4 days	207.5	(220)	07:00	11/09/90	< 2

Note: Maximum rolling rainfall is also given (in brackets) for the 1992 debris flood for comparison with that of the debris flow.

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Table 2 - Summary of Colluvium, Decomposed Granite and Debris Test Results

Type	Test/Sample Nos.	Matrix (< 20 mm d)	Estimated Boulder Content (%)	Plasticity Index (%)	Linear Shrinkage (%)	Mobility Moisture Content (%)	Saturated Moisture Content (%)	Insitu Matrix Dry Density (Mg/M^3)	Relative Permeability (K_j) (m/s x 10^{-6})
Spur Colluvium upper profile	D1; D2; D3; D4; D5; D10:	Clayey, very silty sandy GRAVEL/Gravelly coarse SAND	62; 83; 65; 65; 68; 81:	11,12; 11; 11,12; 13,12; 10,11; NP:	4,5; 5; 6,7; 7,6; 5,5; 4:	32,32; 32; 30,36; 35,36; 32,32; 21:	51; 21; 36; 27; 32; 28:	1.09; 1.61; 1.3; 1.45; 1.38; 1.46:	497797; 132,72; 241,276; 13031,1951 ; 401,263; 126,86:
Spur Colluvium lower profile	D6; D7:	Clayey very silty very gravelly coarse SAND	76; 82:	NP; 13:	4; 4:	28;40:	20; 15:	1.7; 1.84:	87,52; 62
Upper Valley Colluvium upper profile	D9, D11, D12, D13, D14	Clayey silty GRAVEL & coarse SAND	83; 78; 69; 87; 78:	13,12; 14; 12,12; NP; NP,12:	8,7; 5; 5,6; 5; 4,4:	34,37; 33; 31,31; 27,25:	32; 51; 28; 26; 34:	1.38; 1.1; 1.48; 1.51; 1.35:	piping; 252,236; 933,1875; NT; 5325,4287:
lower profile	D10A						21	1.68	
Channel Deposits	D15	Slightly Gravelly sandy clayey SILT	83	12,11	4,5	47	36	1.32	49
Combined Spur and Upper Valley Colluvium		Clayey, silty very gravely coarse SAND	62 - 87	12 -14 and NP	4 - 8	30 - 36 (25 - 40)	26 - 36 (15 - 51)	1.3 - 1.51 (1.1 - 1.84)	piping to 86
Decomposed Granite	D8	Light yellow gravelly, sandy, clayey SILT	35	16 - 20	7 - 9	49 - 52	20 - 25	1.57 - 1.69	7 - 12
Debris	M1 to M35, D19, D20	Clayey, silty, very gravelly coarse to medium SAND	> 57	8 - 15 and NP	3 - 6	28 - 30 (22 - 32)	20 - 29	1.5 - 1.7	9 - 23

Note: NP = Non-Plastic; NT = Not tested.

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Table 3 - Summary of Erosion and Deposition along the Scar from Appendix B

Chainage Interval	Description of Feature	Channelisation Ratio	Slope Angle	Erosion		Deposition		Active Volume
				Volume (m^3)	m^3/m	Volume (m^3)	m^3/m	
Ch 0 - 38	Trigger Slide		40°	355	9	11	0.3	344
Ch 38 - 70	Rock Outcrop		40°	132	4	7	0.2	469
Ch 70 - 109	Choked Gully		35°	856	22	20	0.5	1,305
Ch 109 - 170	Parent Slide		28°	2,518	41	45	0.7	3,813
Ch 170 - 200	Sheeting Joint		47°	283	9	10	0.3	4,055
Ch 200 - 225	Valleyside Fan		40°	720	29	62	2.5	4,713
Ch 225 - 300	Upper Valley and Path	4.5	27°	2,019	27	132	1.8	6,591
Ch 300 - 350	Upper Valley below Path		16°	1,936	25	95	1.9	8,432
Ch 350 - 362	Waterfall		70°	60	5	0	0	8,492
Ch 362 - 475	Lower Valley	7.7	20°	2,959	26	503	4.5	10,948
Ch 475 - 500	Shotcrete & Outcrop	4.7	30°	300	12	7	0.28	11,250
Depletion Area	Sub Total			12,138		888		11,250
Ch 500 - 575	House Platforms	> 10	8°	1,969	26	1,863	25	11,327
Ch 575 - 600	Borrow Scarp		37°	1,437	57	625	25	12,139
Ch 600 - 675	Borrow Area, Primary Lobe		2°	1,424	19	5,275	70	9,068
Ch 675 - 700	Borrow Slope		12°	262	10	1,000	40	8,330
Ch 700 - 835	Main Cut Slope		17°	1,662	12	3,908	29	6,084
Ch 835 - 875	Slope Toe		0°	-	-	4,649	116	1,435
Ch 875 - 1035	Rock Stock Pile		3°	-	-	2,173	14	-1,498
Depletion Area	Sub Total			6,754		19,493		
	TOTAL			18,892		20,381		-1,499

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Table 4 - Summary of Characteristics of the 1990 Debris Flow and the 1992 Debris Flood

Characteristic	1990 Debris Flow				1992 Debris Flood		
	Trigger Landslide	Parent Landslide	Channelised Debris Flow Ch 170 - Ch 500	Deposition Ch 500 - Ch 1035	Parent Landslide	Channelised Debris Flood Ch 10 - Ch 110	Debris Flood Ch 110 - Ch 350
Initiation	Rainstorm (9.5 mm/hr).	Loading by debris and run off from trigger landslide above. Rainfall, 50 mm in 24 hrs, 9.5 mm hour.	Debris from the trigger and main slides plus later erosion on the spur instigated the debris flow during a rainstorm of increasing intensity.	End of channelisation slope angle reduces from 20° to 8°.	Loading by excavated rock from above and run-off from heavy rainstorm possibly combined with groundwater seepage pressures, 49 mm/hr.	Debris from the parent landslide.	End of channelisation slope reduces from 46° to 37°.
Rainstorm	50 mm in preceding 24 hours, 151 mm storm total				0 mm is proceeding 24 hrs, 155 mm storm total		
Rain Fall Intensity	8 mm in 5 min, 53 mm in 1 hour, 91.5 mm in 2 hours (most extreme)				6 mm in 5 minutes, 49 mm in 1 hour		
Movement Type	Colluvium, soil and/or rock slide/liquefaction that rapidly became a debris flow with fluid matrix and rolling bouncing boulders.	Colluvium/decomposed granite slide that rapidly disintegrated and became a debris flow.	Channelised Debris Flow with inertial and viscous slurry flow and possible inertial granular flow. Some rolling, bouncing boulders and alluvial erosion. Velocity estimates of 16.5 m/s and 12.5 m/s.	Thick primary lobe rapidly deposited by channelised debris flow. Increased moisture content by streamflow causing re-mobilisation of the primary lobe and viscous slurry flow on the cut slope. Erosion of debris by streamflow and alluvial transport of material to slope toe.	Colluvium slide initiated by and combined with hydraulic action from a surge of boulders and water.	Channelised Debris Flood, probably normal channelised streamflow with an estimated velocity of 7 to 9 m/s.	Normal stream flow with local deposition, blockage and erosion. Deposition on a flat 5 m wide footpath platform with water continuing down the 30° stream below. Fines redistributed along the footpath.
Erosion Volume	355 m^3	2,500 m^3	9,000 m^3	5,500 m^3	20 m^3	50 m^3	143 m^3
Deposition Volume	-	-	900 m^3	17,700 m^3	-	20 m^3	217 m^3
Slope Angle (Length)	50° → 40° (38 m)	28° (61 m)	26° (330 m) Drainage Line 22°	10° (535 m)	30° (local) 45° (General)	46°	37° - 32°
Angle of Reach (h/l)		21° (Tan 0.38)			39° (tan 0.81)		
Downslope Condition	40° rock outcrop then 35° colluvium.	47°, 30 m high, sheeting joint of bedrock rock, followed by a 40° 15 m high valleyside colluvium fan.	Excavated slopes and house platforms (8°, 36°, 2°, 17°).	Area 19 platform (2°).	45° overall, 37° minimum, 10 m high 70° rock cliff immediately below, 46° gully.	Wide colluvium lined valley (37° - 32°).	30° slope below.
Source Materials and Debris	Up to 2 m loose angular granite spur colluvium, estimated boulder content 62% to 83%, matrix of low plasticity, clayey very silty very gravelly sand.	Up to 6 m of loose angular spur colluvium, estimated boulder content 62% to 83%, matrix of low plasticity clayey very silty very gravelly sand with 17 - 28% fines.	Up to 3 m of valley colluvium, estimated boulder content 69% to 87%, matrix of low plasticity clayey silty gravel and sand with 15 - 20% fines.	Debris vegetation, boulders, cobbles, in a silty sandy gravel matrix with local variation of proportions of clast to matrix, estimated boulder content > 57%, matrix of low plasticity clayey silty very gravely sand, 17 - 26% fines.	Up to 2 m of loose/moderate dense colluvium. Angular boulders and cobbles with a little gravel sand and silt matrix of low plasticity very gravelly sand with 13% fines.	Up to 1 m of loose colluvium locally in gully bottom.	Up to 2 m of loose colluvium. Angular boulders and cobbles with a little gravel sand and silt (estimated boulder content 58% to 68%, matrix of low plasticity very silty very gravelly sand with 11 - 28% fines.
Insitu matrix dry density	1.3 - 1.6 Mg/M^3	1.6 - 1.8 Mg/M^3	1.35 - 1.5 Mg/M^3	1.5 - 1.7 Mg/M^3	-	-	0.6 - 1.35 Mg/M^3 (voids)
Mobility Moisture Content (Mc)	21 - 36%	28 - 40%	25 - 37%	28 - 30%	-	-	28% - 44%
Saturated Mc	21 - 36%	15 - 20%	26 - 34%	20 - 28%	-	-	35% - 127%
Bed Rock Geology	Decomposed granite, locally completely decomposed with quartz veins. Fresher (MD) granite has medium spaced joints that make kinematically feasible wedges.	Completely decomposed kaolinised granite, intruded by basalt dykes and quartz veins.	Slightly decomposed to fresh granite and volcanic sediments.	-	Slightly decomposed to fresh granite.	SD to fresh granite.	SD to fresh granite.
Topography	At 405 mPD in a subdued local hollow along the ridgeline of spur on the upper slopes of Tsing Shan.	At 300 mPD in a hollow along the spur that discharges into a valley over a sheeting joint with a valleyside fan at its toe.	Perennial stream valley on the side slopes of Tsing Shan.	Excavated cut slopes and platforms.	At about 500 mPD, 80 m below the summit of Tsing Shan in a hollow on the rocky upper slopes that discharges into rocky gully.	Step rocky gully on upper slopes of Tsing Shan.	Perennial stream valley on the upper side slopes of Tsing Shan.
Hydrogeology (Channelisation Ratio)	Catchment of less than 100 m^2. Possible small surface channel and pipes with some seepage in CDG at Ch 5 and Ch 35.	Catchment of about 10,000 m^2 extensive seepage at dykes and veins.	Catchment from about 63,000 m^2 where debris flow enters valley to 114,000 m^2 at the mouth of the drainage line (4.5 to 7.7).	No surface channel but run-off from the later stages of the storm flowed onto debris deposits. Gully erosion of insitu slope materials (much > 10).	Catchment of about 2,880 m^2 small pipes.	Strong seepage from bedrock of Ch 100. (5 - 8)	Total catchment at end of deposits about 22,250 m^2. (much > 10)
Vegetation	Low shrubs and grass.	Low shrubs and grass.	Low trees and shrubs.	Grass and shrubs.	Low shrubs and grass.	Shrubs.	Low trees and shrubs.

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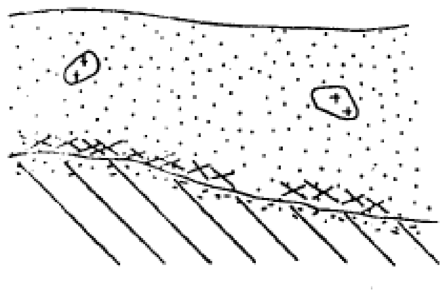
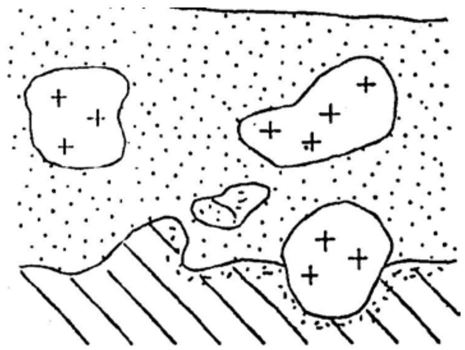
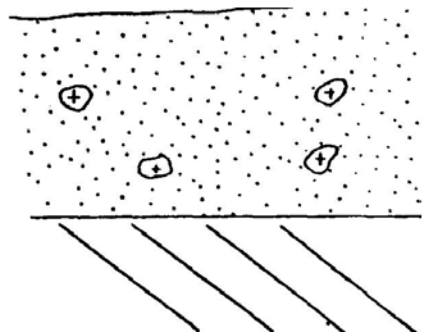
Table 5 - Characteristics of Debris/Substrate Contact

Contact Type	1	2	3
Typical Configuration Legend:  Debris Boulder Debris Vegetation Topsoil Substrate			
Diagnostic Features	Original ground surface not eroded. Vegetation mat or topsoil under the debris. Plates 65, 80, 81, 86 and 87.	Irregular contact. Substrate incorporated into debris and debris boulders pushed into substrate.	Planar contact. Substrate material eroded and entrained prior to deposition.
Debris Type	Class 1 and Class 2 debris.	Mainly Class 2 and occasionally Class 1 debris.	Class 1 and Sorted (Alluvial) Debris.
Distribution	Below Class 1 debris at the trails around the scar in the depletion area. Locally at the edge of the scar, on the cut slope and the platform in the deposition area. Below Class 2 debris in the primary debris lobe.	Below Class 2 debris in the lower valley and main debris lobe. Locally below Class 1 debris on the cut slope.	Below Class 1 debris within the scar throughout the depletion area, in the centre of the scar downslope from the mouth of the drainage line, on the cut slope and locally adjacent to alluvial debris. Below alluvial debris in the stream channel of the depletion area and the eroded channels in the deposition area.
Interpretation	Low Energy Depositional.	High Energy Depositional.	High Energy Erosional.

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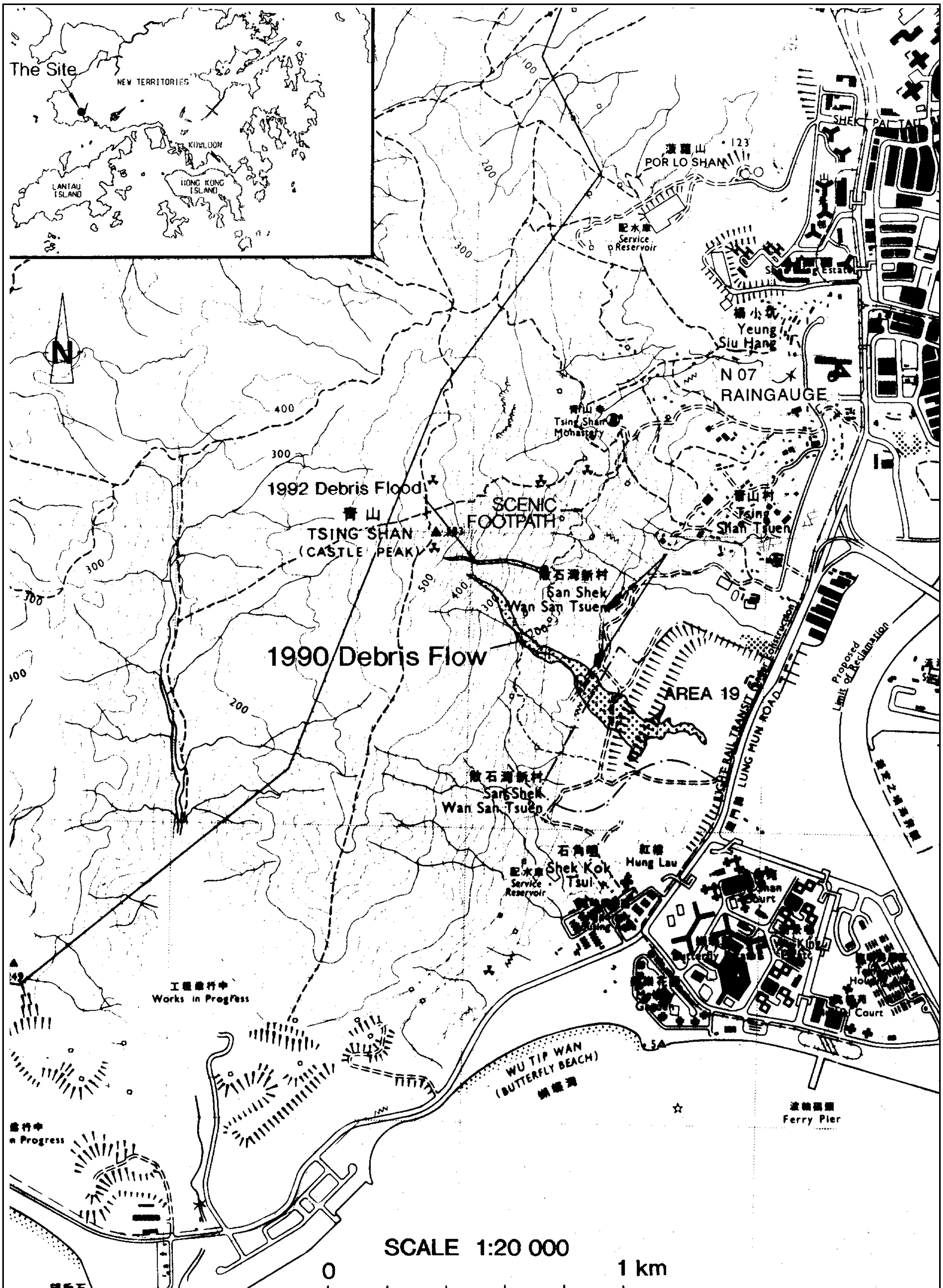

Figure 1 - Site Location Map

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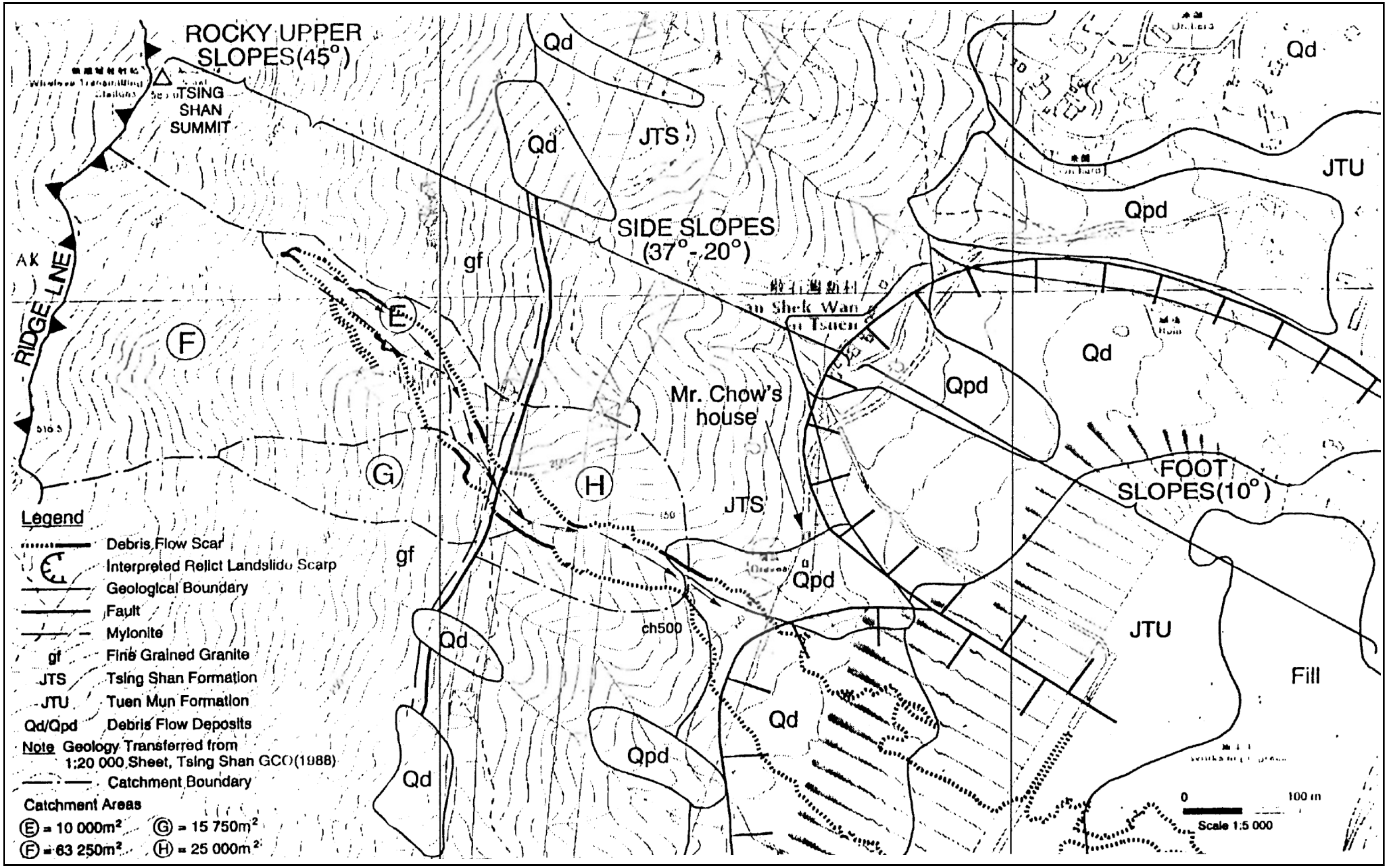
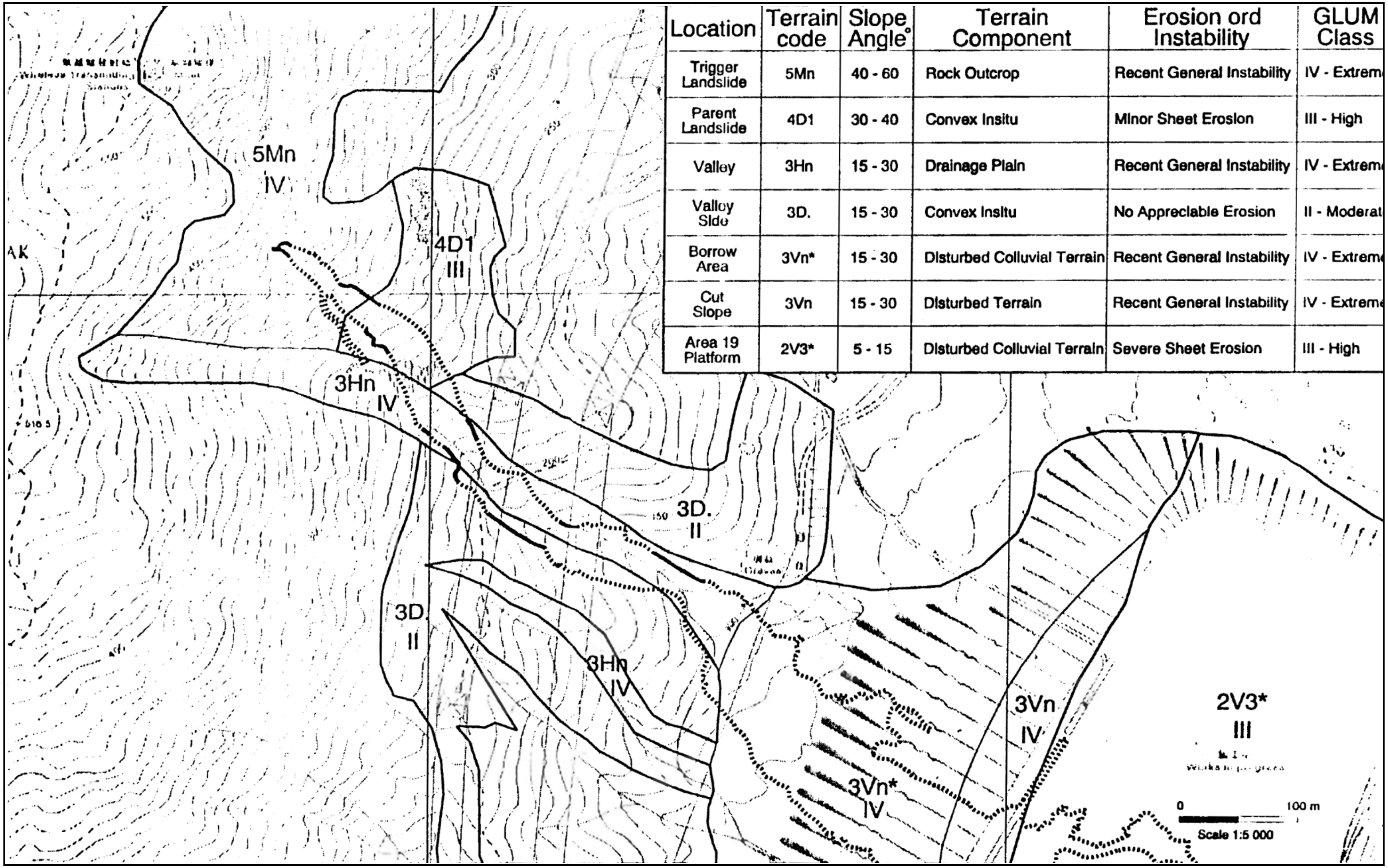


Figure 2 - Geology, Geomorphology and Catchment Map



Location	Terrain code	Slope Angle°	Terrain Component	Erosion ord Instability	GLUM Class
Trigger Landslide	5Mn	40 - 60	Rock Outcrop	Recent General Instability	IV - Extrem
Parent Landslide	4D1	30 - 40	Convex Insitu	Minor Sheet Erosion	III - High
Valley	3Hn	15 - 30	Drainage Plain	Recent General Instability	IV - Extrem
Valley Side	3D.	15 - 30	Convex Insitu	No Appreciable Erosion	II - Moderat
Borrow Area	3Vn*	15 - 30	Disturbed Colluvial Terrain	Recent General Instability	IV - Extrem
Cut Slope	3Vn	15 - 30	Disturbed Terrain	Recent General Instability	IV - Extrem
Area 19 Platform	2V3*	5 - 15	Disturbed Colluvial Terrain	Severe Sheet Erosion	III - High

Figure 2a - GASP Terrain Classification

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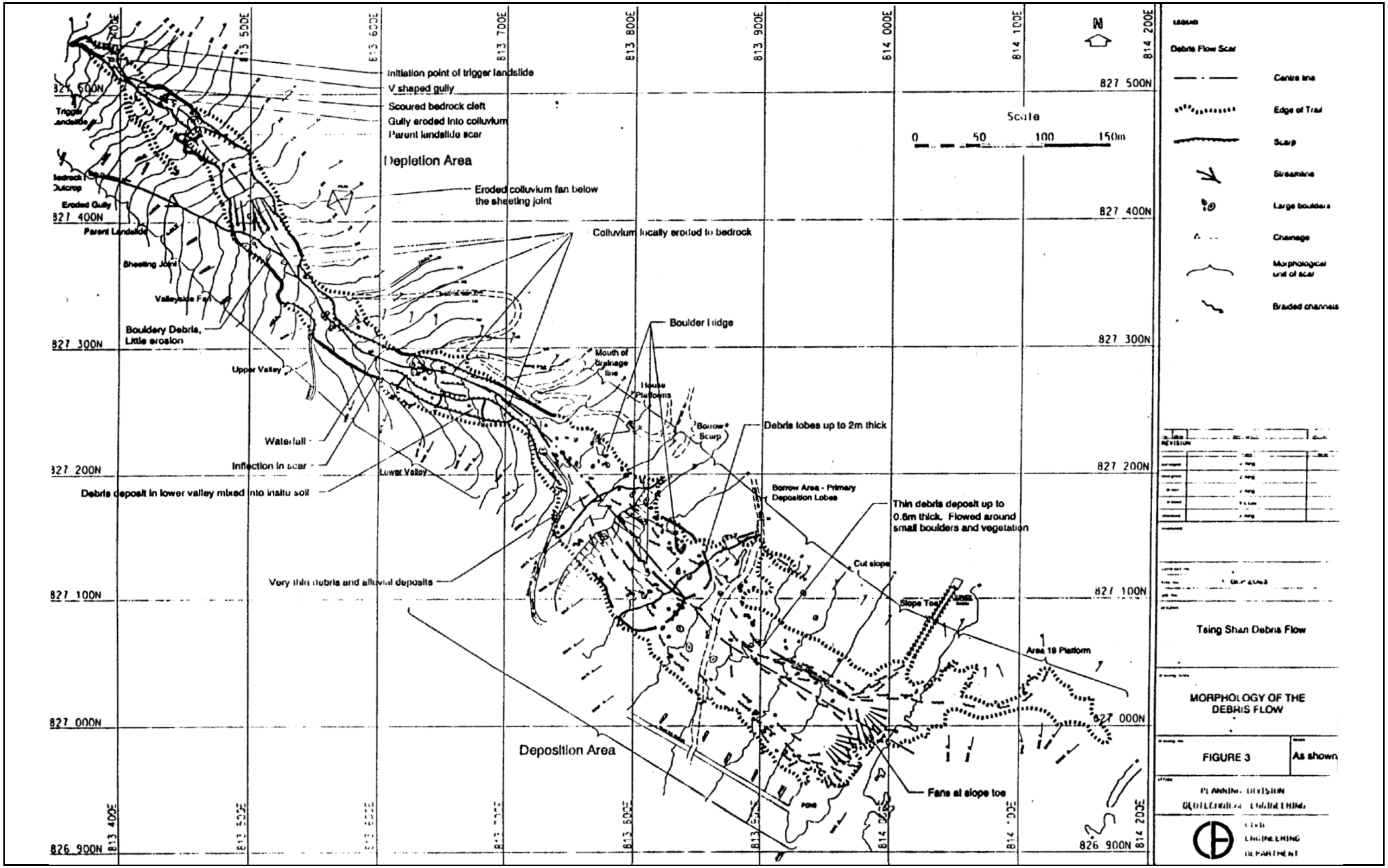

Figure 3 - Morphology of the Debris Flow

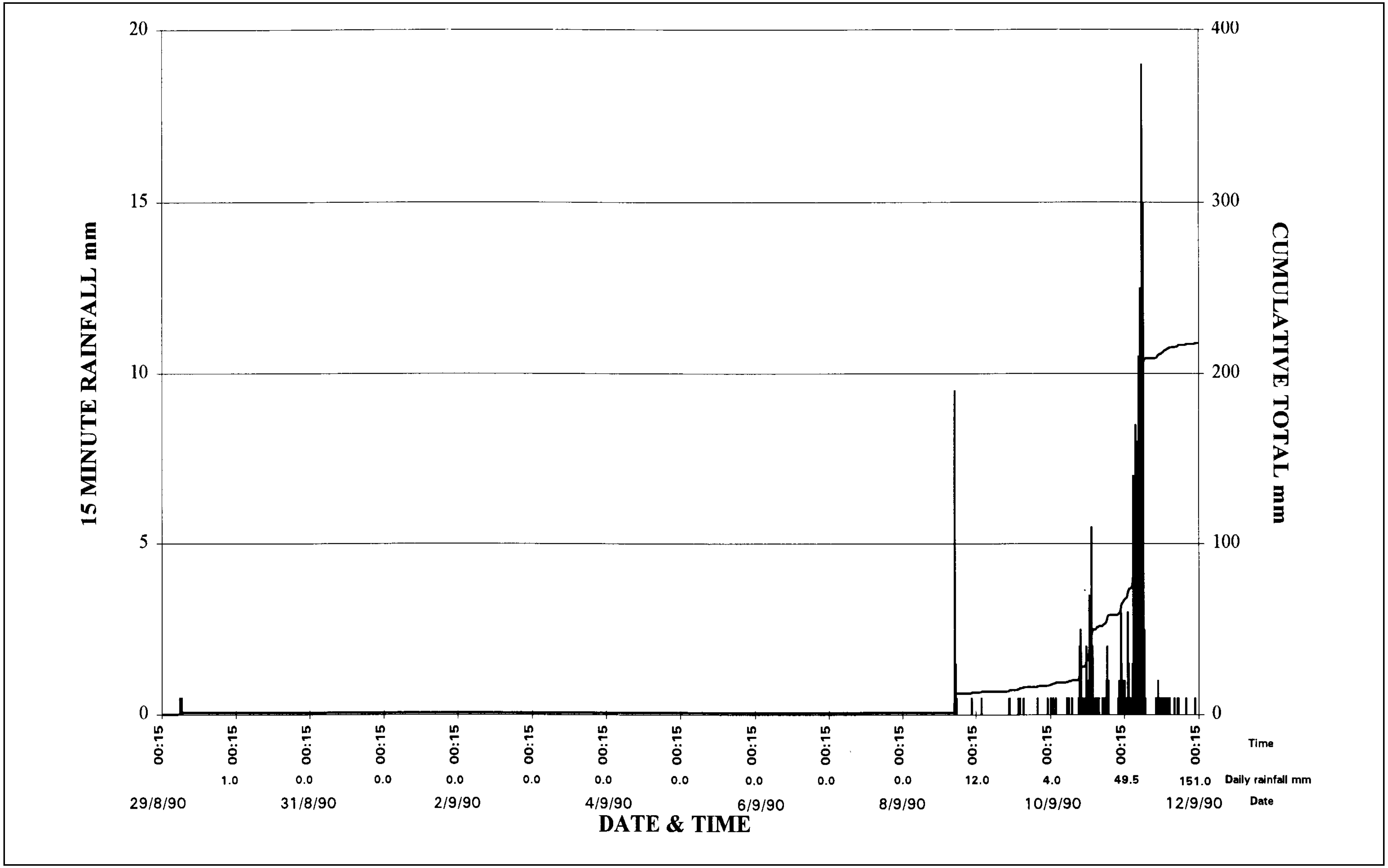

Figure 4 - Rainfall Data from Raingauge No. N07 from 29/08/90 to 12/09/90

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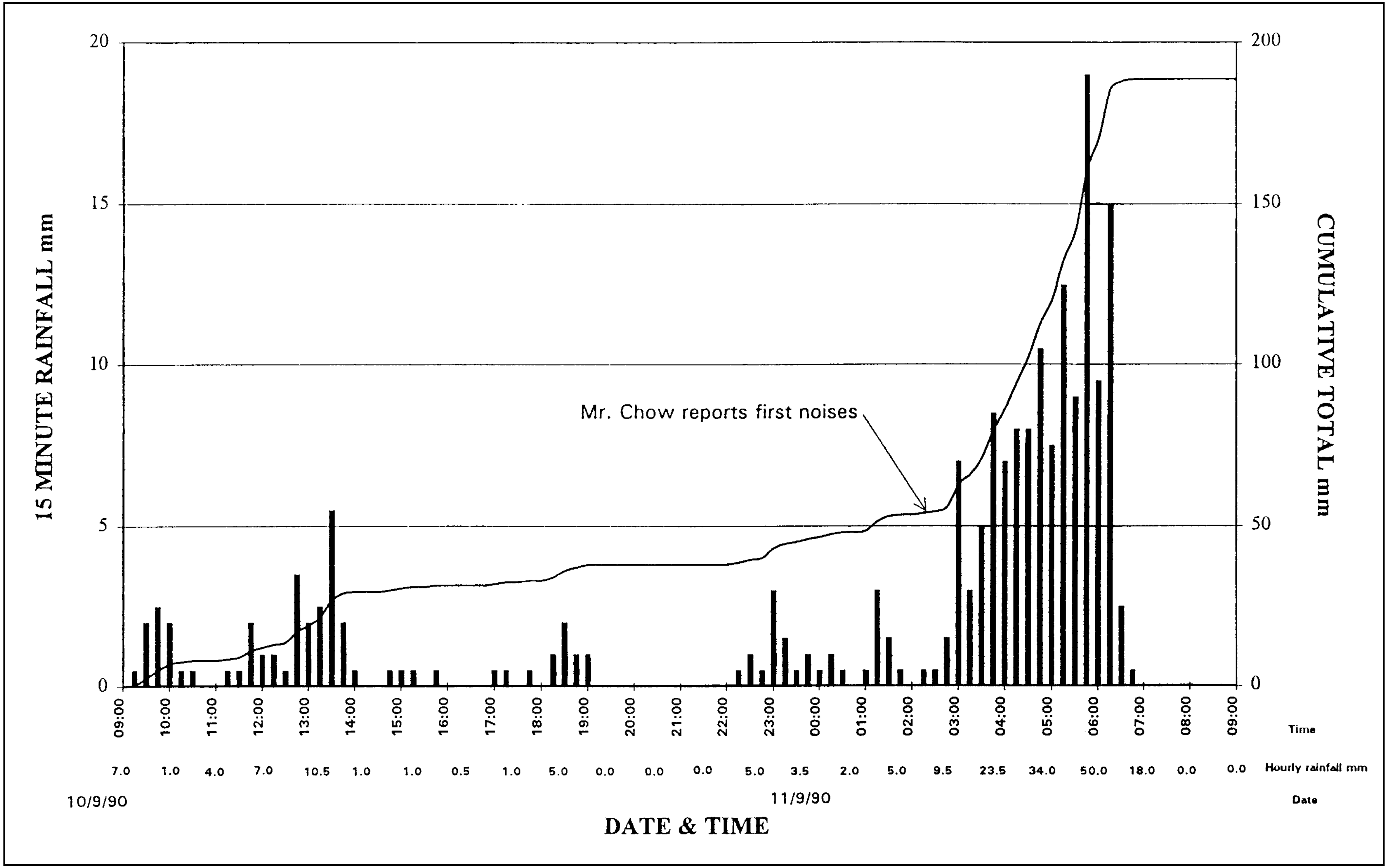

Figure 5 - Rainfall Data from Raingauge No. N07 from 10/09/90 to 11/09/90

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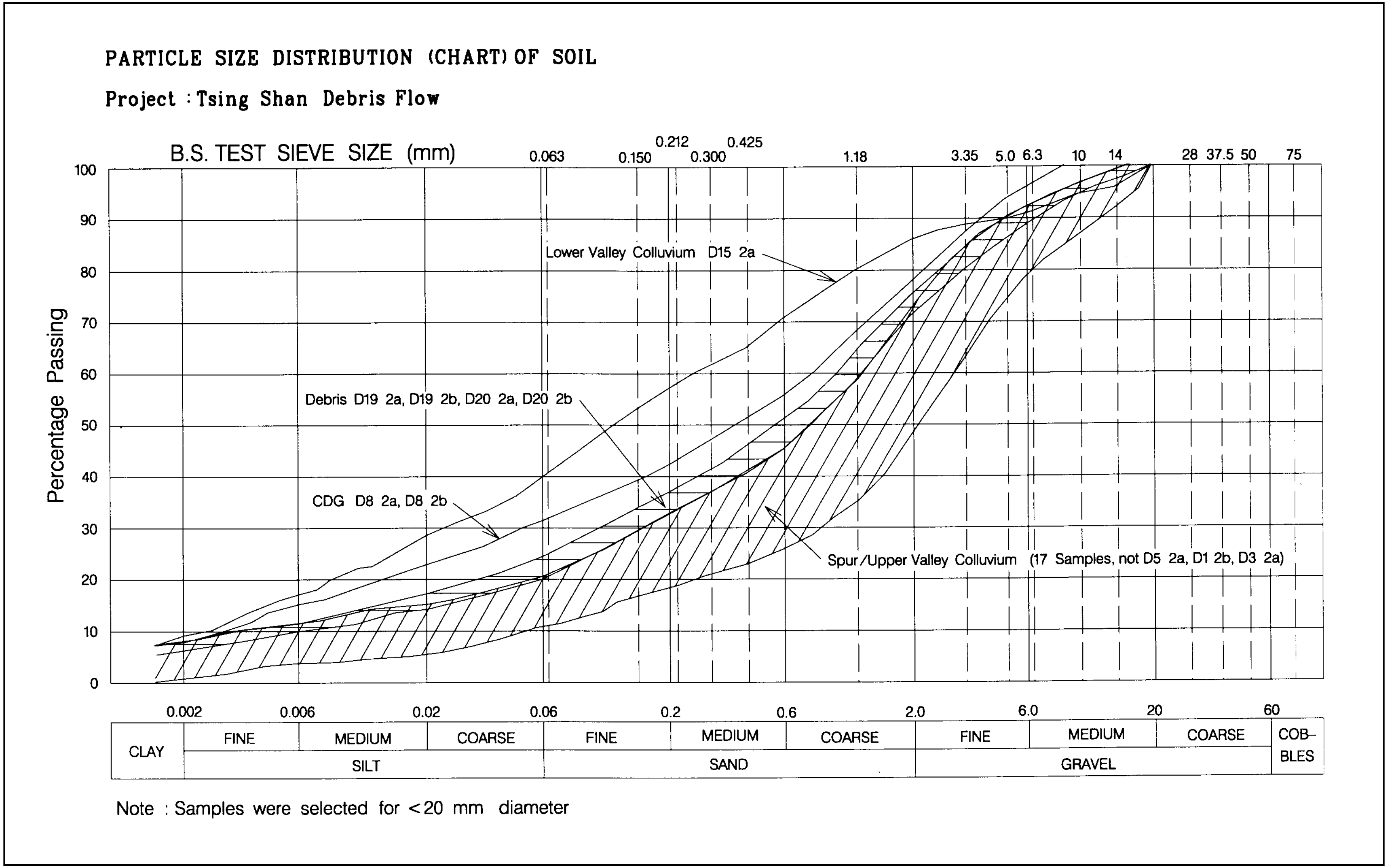

Figure 6 - Particle Size Distribution Envelopes for < 20 mm Diameter Samples of Colluvium, CDG and Debris

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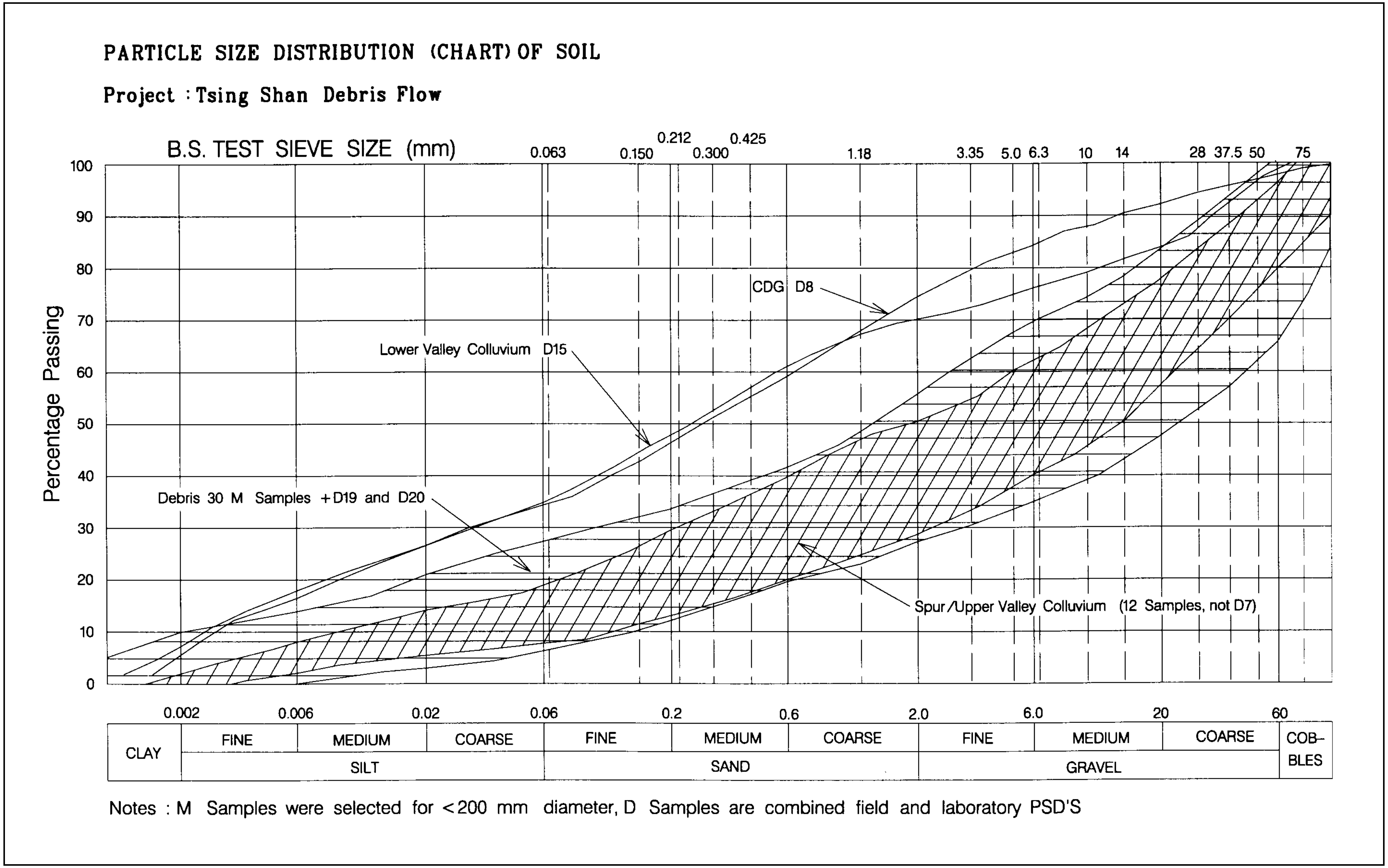

Figure 7 - Particle Size Distribution Envelope for < 200 mm Diameter Colluvium, CDG and Debris

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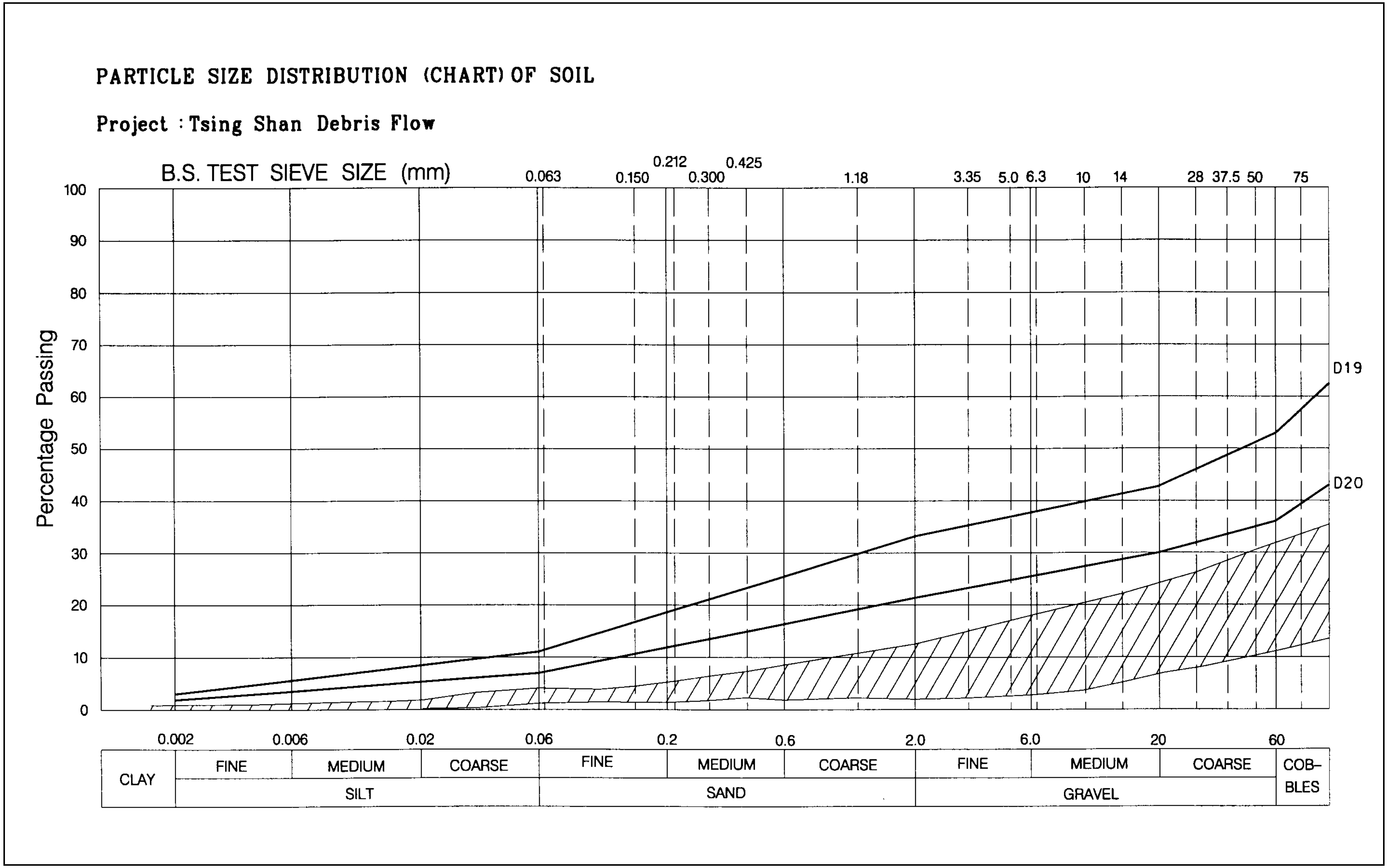

Figure 8 - Estimated Particle Size Distribution Envelope for Colluvium (D1 - D15) and Debris (D19, D20)

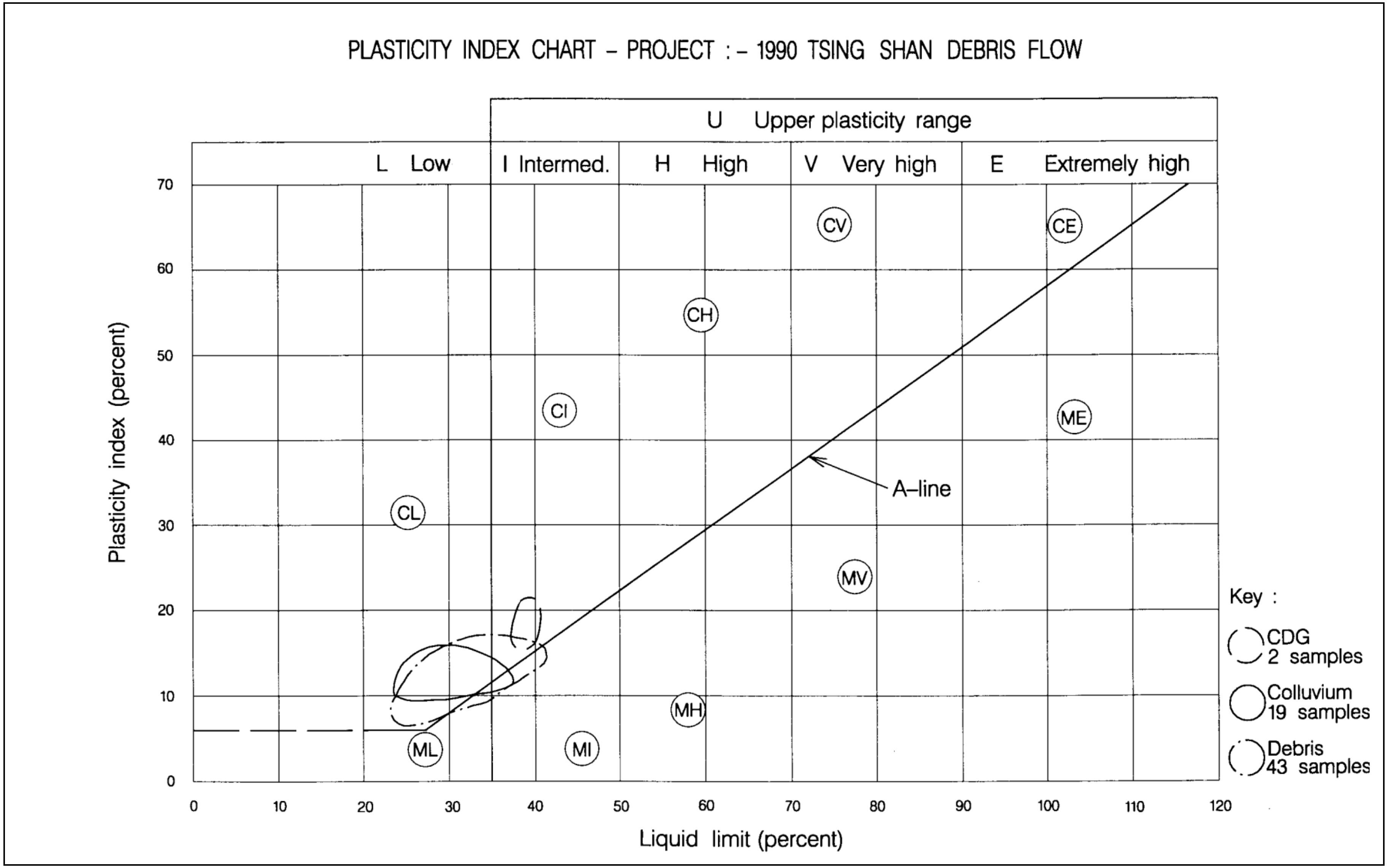

Figure 9 - Plasticity Envelopes for Fine Material in Matrix of Debris, Colluvium and CDG

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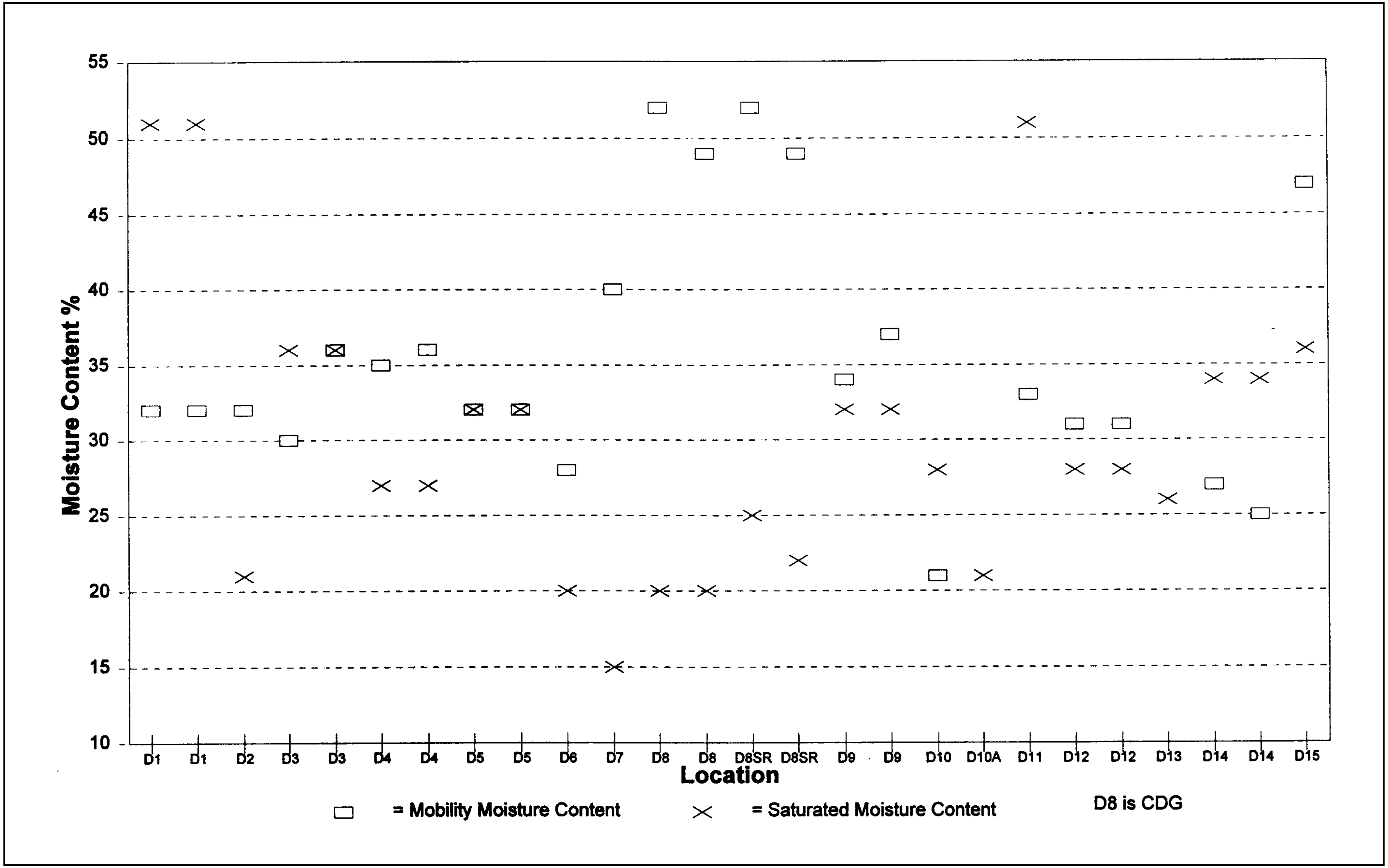

Figure 10 - Range of Saturated and Mobility Moisture Content of Colluvium and CDG

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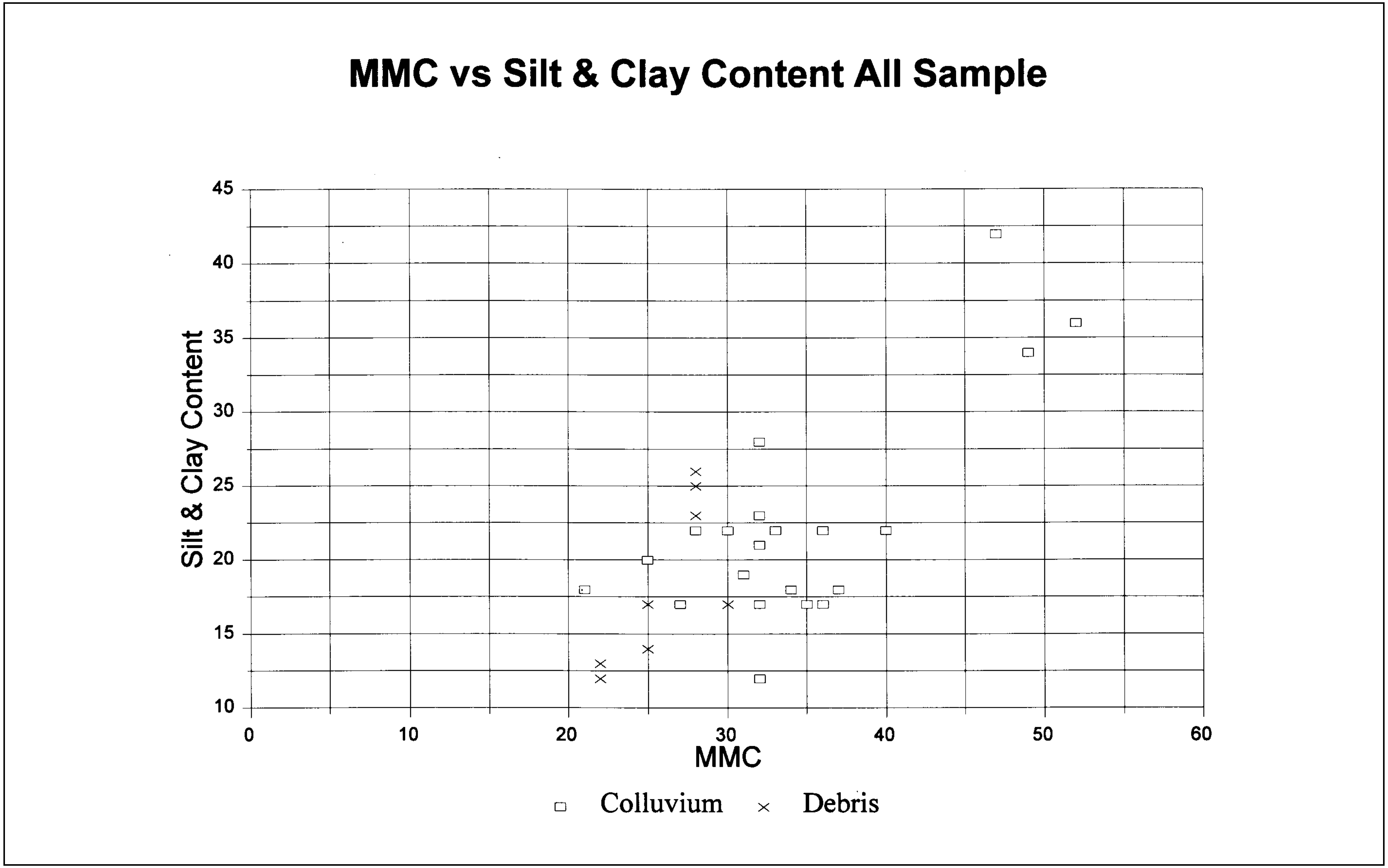

Figure 11 - Silt and Clay Content against Mobility Moisture Content of Colluvium and Debris Matrix

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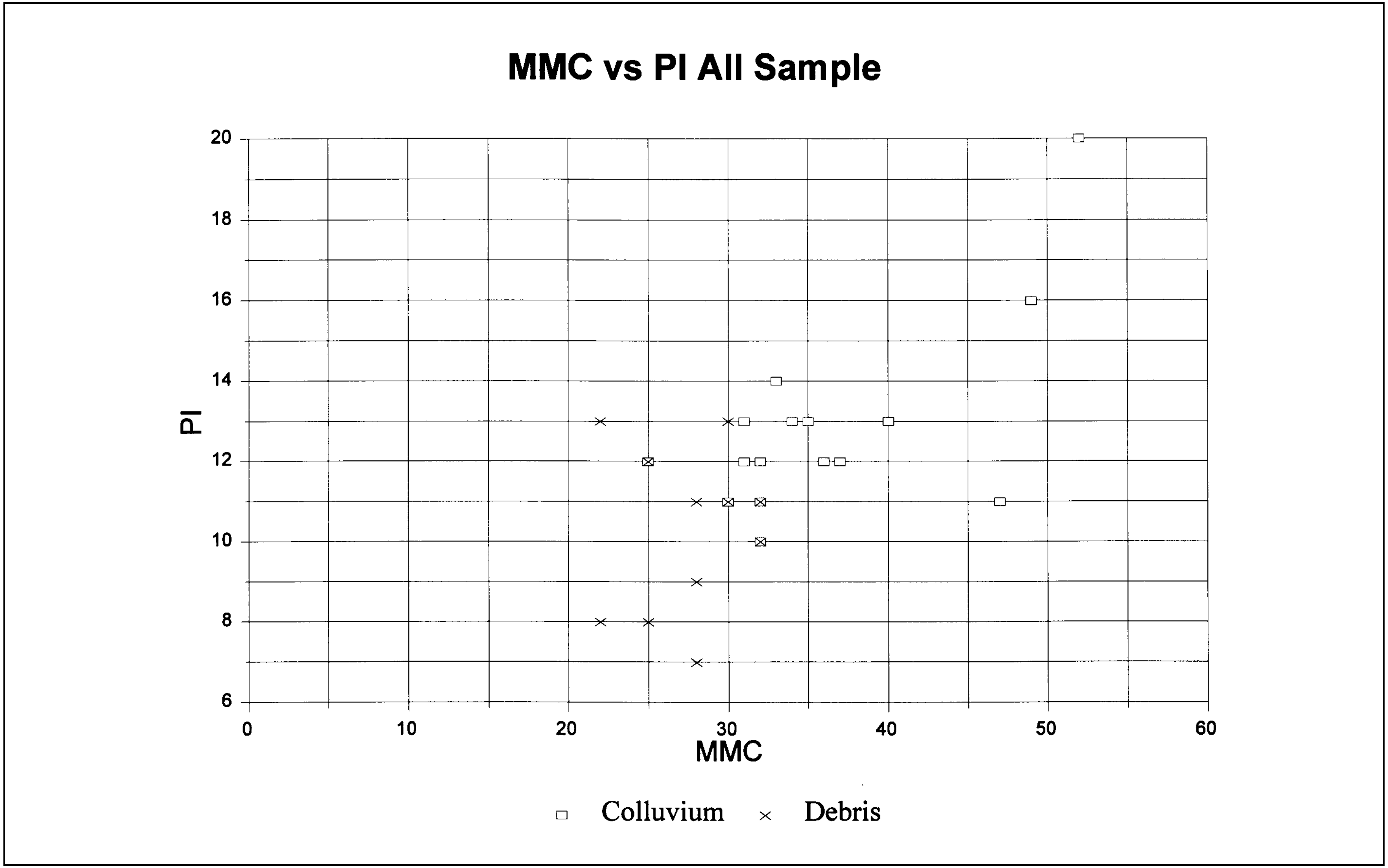

Figure 12 - Plasticity Index against Mobility Moisture Content of Colluvium and Debris Matrix

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Plate 1 - Overall View of Tsing Shan Debris Flow 14.9.90

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Plate 6 - Parent Landslide, Sheeting Joint and Valleyside Fan

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Plate 10 - Intake, House Platforms and Borrow Scarp

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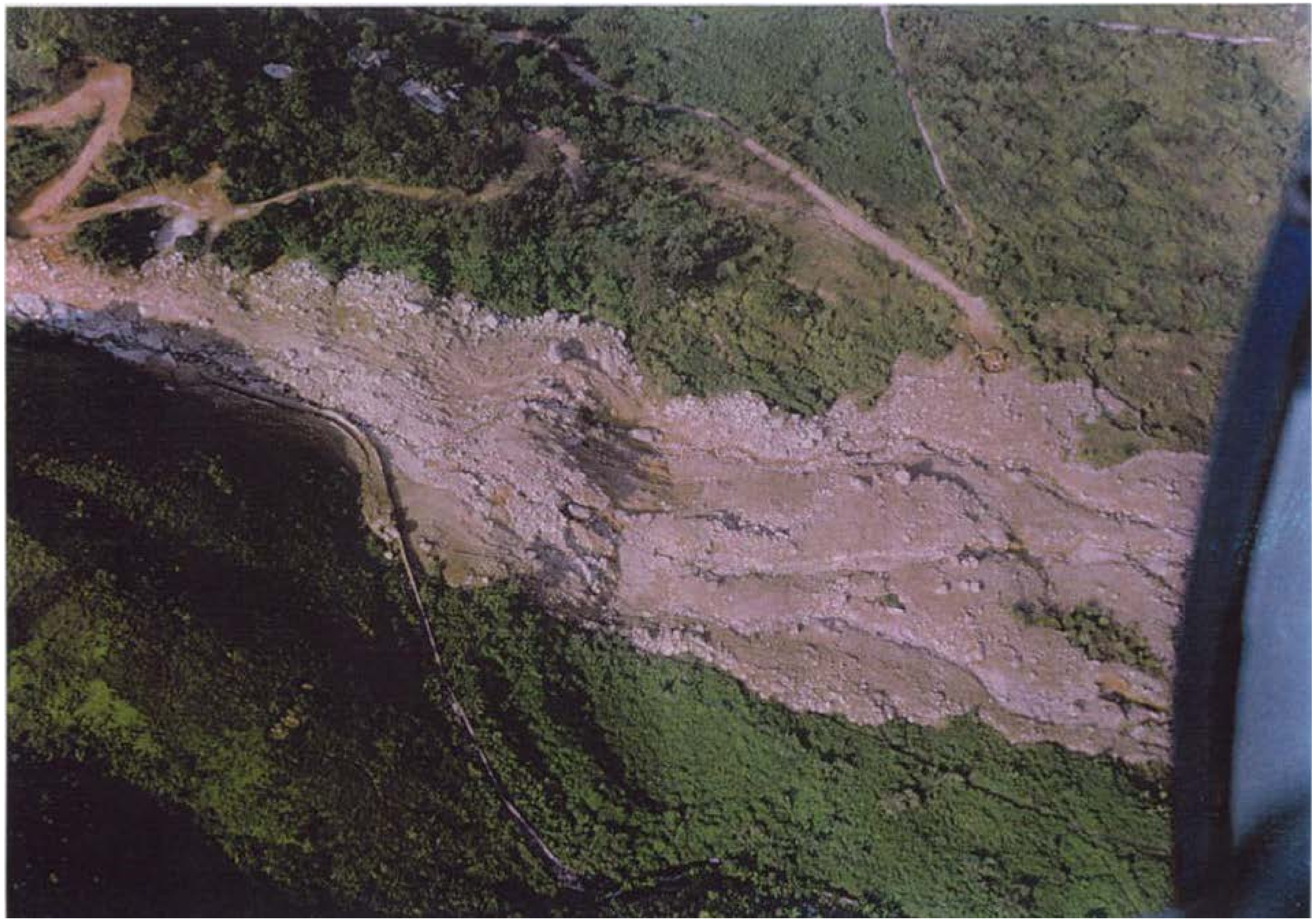

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Plate 11 - Intake to Access Track, Primary Debris Lobes

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Plate 12 - Intake to Slope Toe, Deposition Area

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Plate 13 - Access Track to Platform

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Plate 14 - Oblique View of Deposition Area

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Plate 19 - House Platform after Debris Flow 11.9.90

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Plate 22 - Decomposed Granite at Toe of V-shaped Gully (Ch 38). Similar Material Could Have Filled the Gully Prior to Failure

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Plate 23 - Trail of Clasts and Remoulded Debris at Ch 40

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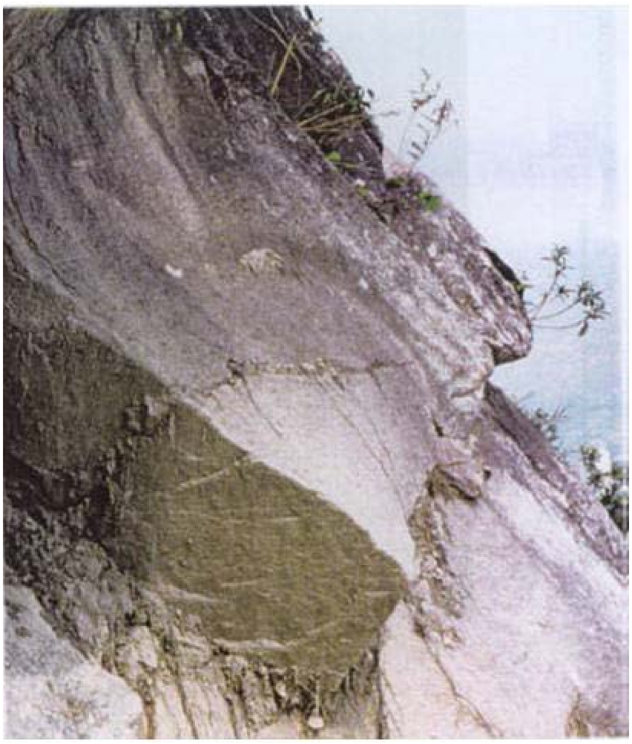
Plate 24 - Cleft in Rock Outcrop Ch 65

Plate 25 - Contact between Weathered and Freshly Exposed Rock (Ch 70). Note Impact Marks from Bouncing Boulders



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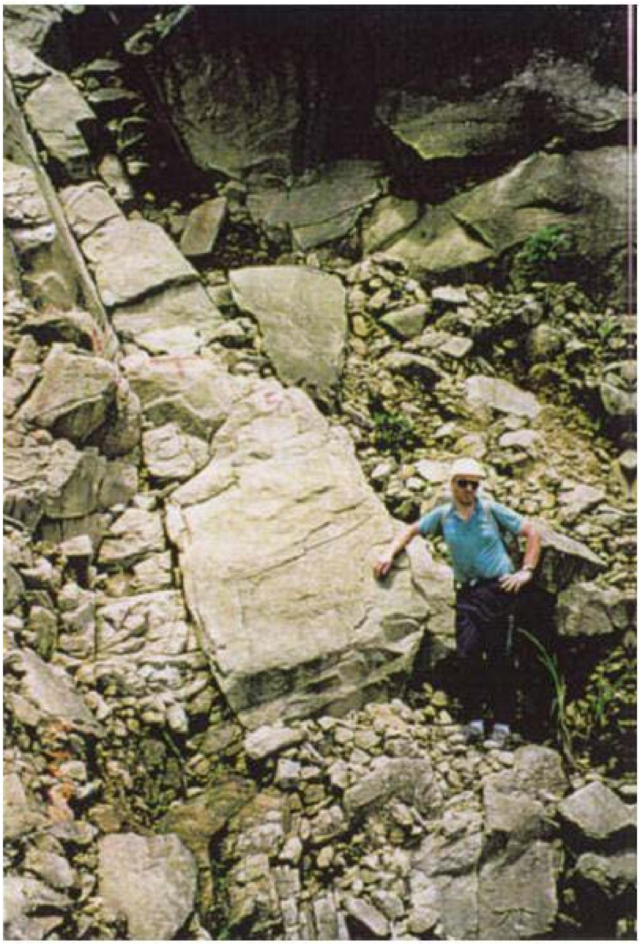

TP 206-8

Plate 26 - Toe of the Cleft in the Rock Outcrop (Ch 70) Plate 27 Is Located about Halfway up the Outcrop

TP 206-12

Plate 27 - End of Scouring. Lines are Scored into the Rock on the Top RHS but Have Died Out by the Lower LHS

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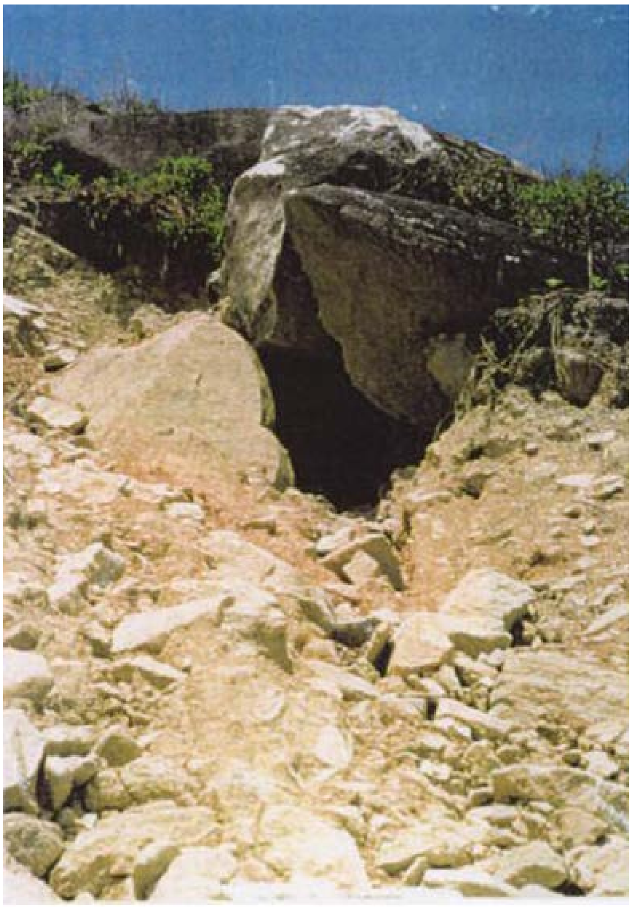

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Plate 28 - Void between Boulders at Ch 85. Matrix Was Interpreted to Have Flowed from Here in Chan et al (1991)

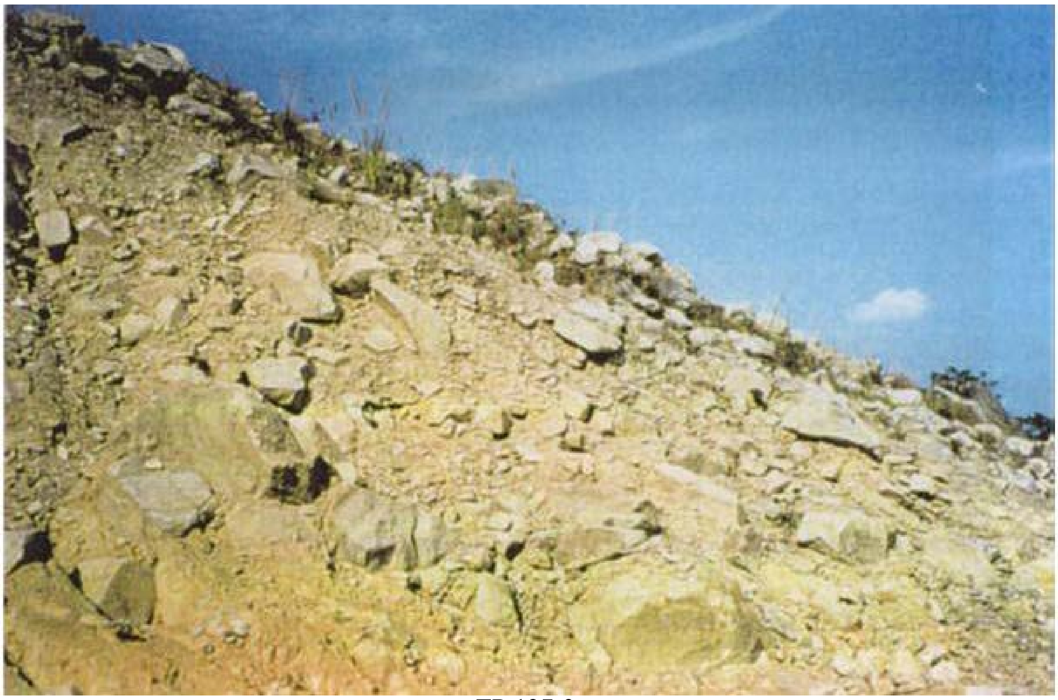

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Plate 29 - Spur Colluvium at Ch 125

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Plate 33 - Completely Decomposed, Kaolinised Granite in the Floor of the Parent Landslide at Ch 135

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Plate 37 - Upper Valley Colluvium Ch 225 - 275

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Plate 38 - Large Boulder at Ch 175 with Accumulation of Boulders Upslope. Note Impact Marks from Bouncing Boulders on the Rock Outcrop

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Plate 39 - Matrix Poor Bouldery Trail Downslope from the Large Boulder

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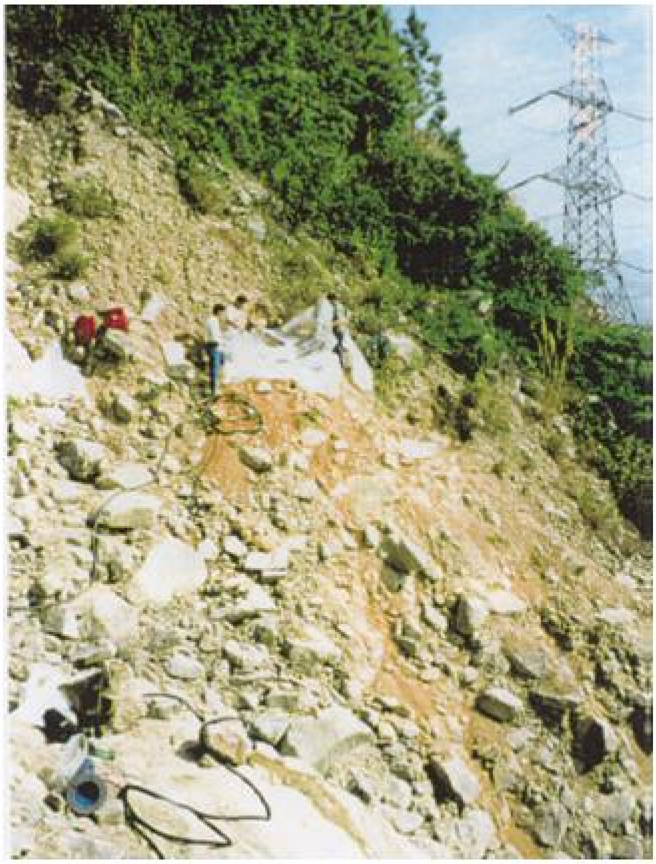

TP 170-7

Plate 40 - Spur/Upper Valley Colluvium Exposed by the Debris Flow. Note Water Replacement Insitu Density Test D11 in Progress

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Plate 41 - Upper Valley Colluvium Ch 275 - 325

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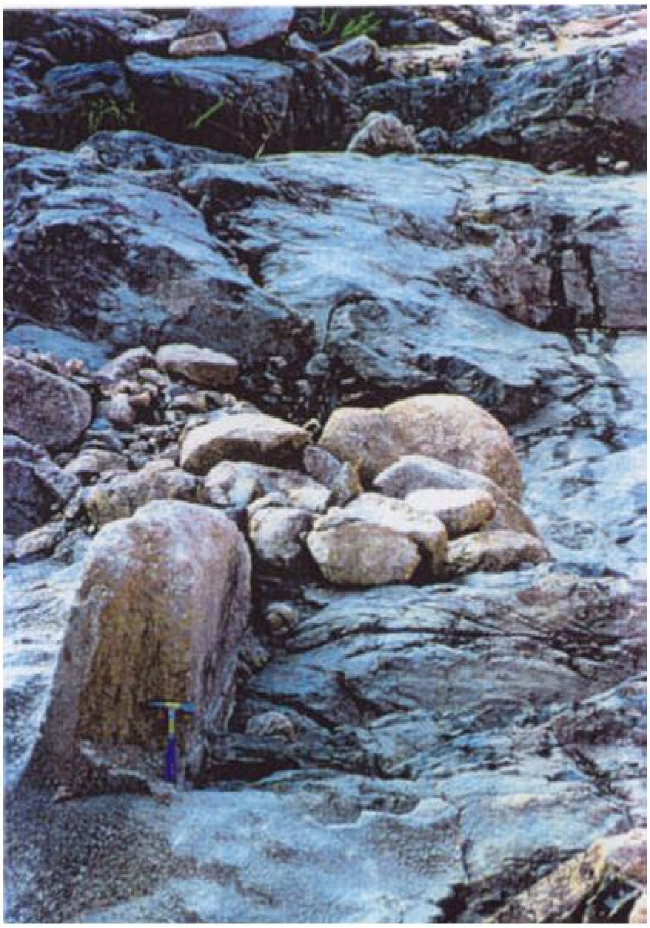

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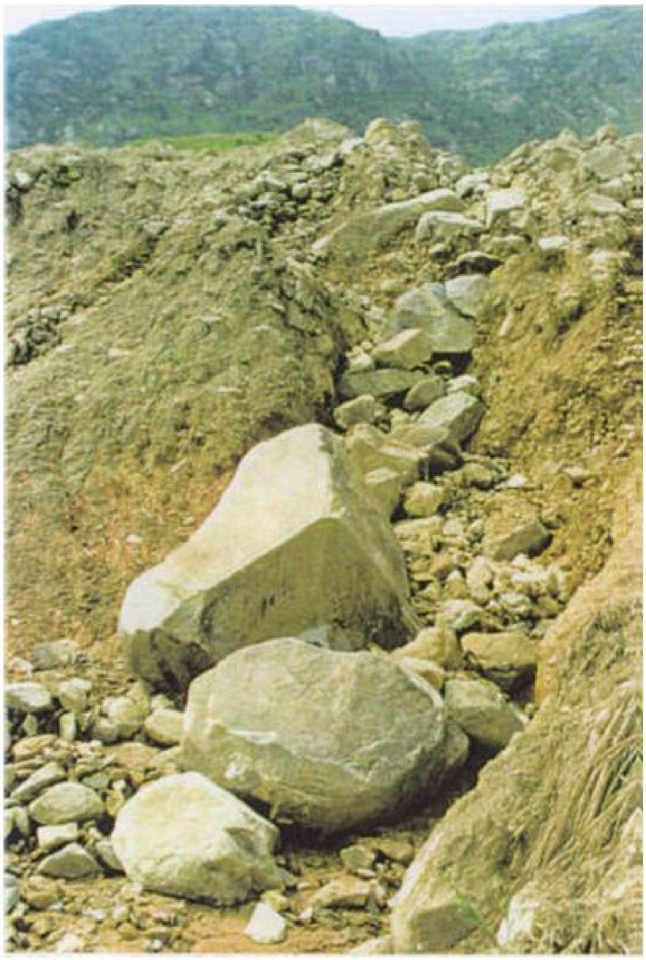

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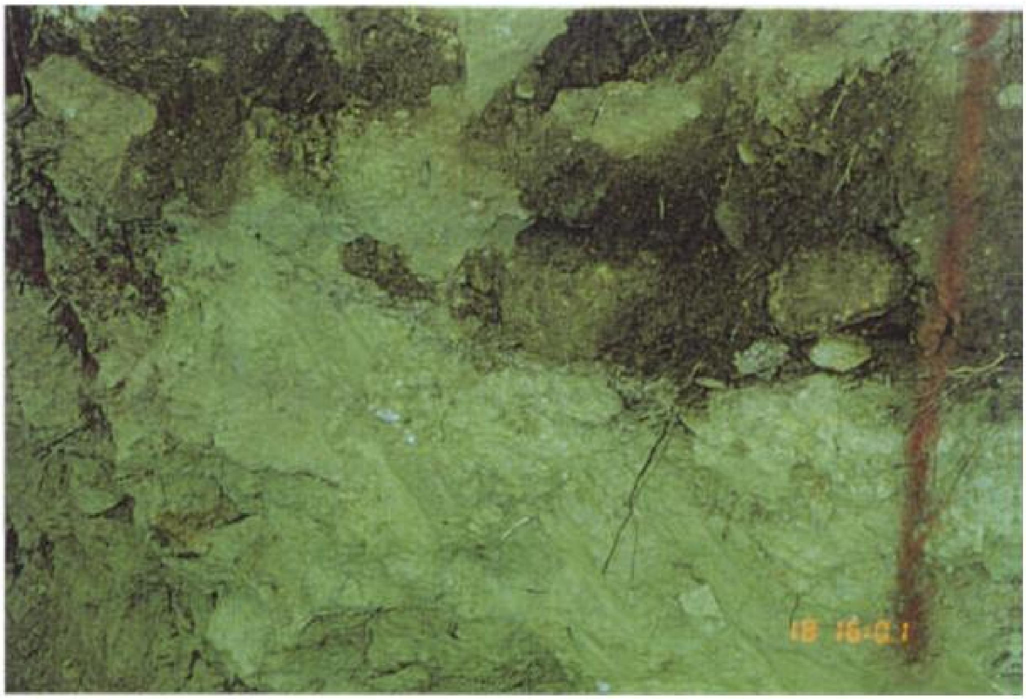

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APPENDIX G

LIST AND DEFINITIONS OF TERMS USED IN THE PROJECT

A Proposed Terminology for Study of Natural Terrain in Hong Kong

The proposed terminology is divided into two sections: Section One defines general and descriptive terms while Section Two outlines a scheme for the classification of natural terrain landslides (NTL) which is based mainly on processes. The two sections are linked by assumptions that relate field observations to probable processes. Some assumptions are suggested in Section Two, based on field observations of NTLs. These may be modified as more detailed field studies become available. There is no reason why users of the terminology should not define and use their own assumptions in any specific project.

The terminology is largely based on Varnes (1978) and Hutchinson (1988). Terms for description of features within a landslide scar are based on IAEG (1990) modified as necessary to accommodate high mobility long run out failures, and for description of sediment-water flows on Pierson and Costa (1987). Where a term is based on one of these sources the reference is given. If the wording has been taken verbatim the reference is underlined.

The proposed terminology is not meant to encompass all terms used when describing landslides, and is biased towards defining those terms which may not be being used in a consistent way at present. The proposed terminology is also biased towards terms used when describing elongate, relatively shallow natural terrain landslides which are dominated by flow and alluvial processes. Such features are common in Hong Kong and have not yet been extensively reported or described.

For some of the terms a strict definition is followed by comments that start with "Note" to illustrate the suggested application. When defined terms are used in the definitions of other terms they are underlined.

SECTION ONE

GENERAL TERMS

Natural terrain. Terrain that has not been modified substantially by human activity such as site formation works, agricultural terraces, cemetery platforms or squatter habitation. Note that in most of the Territory natural terrain has been influenced by deforestation and fire and locally may have been influenced by prehistoric agriculture.

Landslide. A general, all-encompassing term used to describe an event comprising the downslope movement of a discrete mass of soil and/or rock. Note that the term makes no inference as to process, i.e.: true sliding may not be involved. It is proposed that extremely slow slope movements such as soil creep and gravitational sagging are not included under the general term landslide.

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Natural terrain landslide. A landslide in which the scar is located entirely within natural terrain. Note that a landslide involving both natural terrain and terrain that has been modified substantially by human activity is not considered to be a natural terrain landslide, e.g. failure immediately above and extending into an excavation or immediately below fill.

Quasi-natural terrain landslide. A large failure in predominantly natural terrain triggered by, or possibly triggered by, a relatively small human activity. Landslides for which there is an element of doubt with respect to the importance of human activity are placed in this category.

Natural Slope. A sloping section of natural terrain with boundaries defined for geomorphological or administrative purposes.

LANDSLIDE FEATURES

Scar. The land surface affected by a landslide. This includes the source, the displaced material and any trail.

Relict scar. A scar on which vegetation has re-established but which still has a well-defined main scarp.

Displaced Material. Material displaced from its original position on the slope by movement in a landslide (IAEG, 1990). Note that an accumulation of displaced material forms a deposit.

Crown. The practically undisplaced material still in place and adjacent to the highest parts of the main scarp (IAEG, 1990).

Trail. Part of a scar downslope from the main scarp dominated by transport and deposition of debris, although erosion may also occur.

Head. The upper parts of a landslide along the contact between the displaced material and the main scarp (IAEG, 1990). Note that an elongate landslide may not have a definable head.

Surface of Rupture. A surface on undisturbed ground that was originally below ground level and along which displaced material has moved away (IAEG, 1990).

Main scarp. The exposed steep part of the surface of rupture (IAEG, 1990).

Floor. Any exposed shallow part of the surface of rupture.

Source. The space above the surface of rupture and below the original ground level.

Entrained Material. Displaced Material from any location other than the source.

Toe. The lower margin of the displaced material of a landslide, it is the most distant part of the scar from the main scarp (IAEG, 1990). Note that for a landslide with a trail this will be the distal part of the trail.

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Reach angle. The arc tangent of the height (H) over length (L) ratio, where H = elevation difference between the crown and the toe; L = the horizontal distance from the crown to the toe. Note that this is similar to the apparent angle of friction (Sassa, 1987), equivalent coefficient of friction (Hsu, 1975) and average coefficient of friction (Scheidegger, 1973). However these terms have in some cases been used when H and L are defined on the basis of the centre of gravity of the displaced material and the term reach angle is proposed in conformity with its use by Corominas (1996). The same angle is termed Travel Angle by Cruden & Varnes (1996).

Channelisation Ratio. Width to depth ratio of the cross section area in a drainage line occupied by a pulse of debris. Channelisation may be defined as when the value of the ratio is less than a particular value. Hungr, Morgan et al (1984) suggest 5, the Tsing Shan Debris Flow started to deposit at about 7.

Substrate. Insitu material over which debris is transported.

Parent Landslide. Initial landslide that increases in volume through erosion and entrainment of the substrate to become a sediment water flow.

TYPES OF DISPLACED MATERIAL

Colluvium. A general term applied to any heterogeneous, generally structureless mass of soil and/or rock material and sometimes organic matter, deposited on and at the base of natural slopes by predominantly mass-wasting processes (AGI, 1972). Note that usually this is debris from a past landslide.

Intact displaced mass. The full mass of displaced material (soil, colluvium or rock) from a landslide when it largely retains its original morphology.

Intact displaced material. Displaced material (soil, colluvium or rock) that retains its original structure. Note that Intact displaced material may occur as clasts or slabs within debris.

Debris. Displaced material from a specific landslide which has disintegrated and lost its original morphology. Debris may include clasts of intact displaced material. Note that debris is very young colluvium and it is proposed that the term is used to distinguish the debris of a specific landslide from pre-existing insitu colluvium which may have the same composition. This differs from Varnes' (1978) definition of the term debris, which he uses to describe any deposit of predominantly coarse engineering soil. In Hong Kong this has usually been described as colluvium, or talus. Specific types of debris include:

Blocky Debris. Debris comprising loose blocks of intact displaced material, generally rock but possibly soil.

Remoulded Debris. Debris that has largely lost its original structure and comprises a remoulded matrix that supports particles of gravel size or larger. Note that remoulded debris may occur as steep sided deposits such as lobate fronts, lateral levees, accumulations on the uphill side of, or capping, obstructions in the trail.

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Sorted Debris. Debris in which grain size sorting and/or layering is present and that has little or no fines.

Boulder. Rock fragment greater than 200 mm diameter that is not part of a rock mass.

TYPES OF LANDSLIDE SCAR

The following typical types of landslide scar have been observed on natural terrain in Hong Kong. The divisions reflect differences in the mobility of the displaced material.

Confined (Slump). A scar with an intact displaced mass which partially overlies the surface of rupture. Note that a confined scar has no trail.

Translational. Scar in which the surface of rupture is relatively planar or gently undulating in downslope section (Varnes, 1978).

Rotational. Scar in which the surface of rupture is curved and concave upwards and imparts a degree of backward rotation or tilt to the displaced material. Note this is termed a slump by Varnes (1978) and a slip by Hutchinson (1988).

Compound. Scar in which the surface of rupture comprises a distinct main scarp and floor and may include a rising downslope part. The source material cannot displace until it is transformed into a kinematically feasible geometry by internal displacements or shears (Hutchinson, 1988).

Elongate. A scar in which some or all of the displaced material has mobilised from the surface of rupture forming debris. Note that an elongate scar has a trail and the source is often a spoon shaped or planar depression.

Elongate channelised. An elongate scar in which the debris has been channelised in a drainage line or depression and the trail has a low channelisation ratio in the order of less than 10.

An elongate scar may be further described by the distribution of displaced material within it.

Uniform Deposit. Debris deposit comprising a sheet of debris of uniform thickness within the trail.

Lateral Deposit. Debris deposit comprising ridges aligned along the trail at or near its lateral margins.

Intermediate Deposit. Debris accumulation at some point along the trail between the source and the toe.

Terminal Deposit. Debris deposit at the toe. Note that this is commonly lobate or fan shaped.

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SECTION TWO
PROVISIONAL LANDSLIDE CLASSIFICATION

MOVEMENT TERMS

Sliding. Shear displacement along one or several surfaces, or within a relatively narrow zone, which are visible or may be reasonably inferred (Varnes, 1978).

Liquefaction. Generation of high positive excess pore water pressures during shearing and hence a substantial reduction of the effective stress and the shearing resistance. Note that in Hong Kong liquefaction is known to have occurred in the rain induced failure of loose fill slopes.

Flow. Broadly defined as continuous irreversible deformation of a geologic material that occurs in response to an applied stress that is usually gravity (Pierson & Costa, 1987). Types of flow include:

Slurry flow. The movement of a saturated sediment/water mixture having sufficient yield strength to exhibit plastic flow behaviour in the field and yet to become partially liquified as they are remoulded. When movement ceases, fine and coarse particles settle together with no inter-particle movement (Pierson & Costa, 1987).

Streamflow. The flow of water with a sufficiently small sediment concentration that its flow behaviour is unaffected by the presence of sediment in transport (Pierson & Costa, 1987).

Hyperconcentrated streamflow. The flow of a mixture of water and sediment that possesses a small but measurable yield strength but that still appears to flow like a liquid. Particles settling out of a hyperconcentrated streamflow suspension settle independently, giving deposits sorted by grain size (Pierson & Costa, 1987).

Inertial Granular Flow. Flow in which the full weight of the flowing granular mass is borne by grain to grain contact or collisions in which grain inertial effects dominate but frictional effects are still significant (Pierson & Costa, 1987).

TYPES OF LANDSLIDE EVENT

SIMPLE

A landslide with the same mechanism for detachment and movement of the displaced material.

Slide. A landslide in which the movement is by sliding. Note that this may be further qualified by a prefix describing the morphology of the scar and specifying the material involved, e.g. Slides may result in translational, rotational, compound or confined scars from failures of colluvium, saprolite or rock.

Liquefaction Slide. Slide in which liquefaction occurs within a zone at the sliding surface and the debris is not saturated. (Hutchinson, 1988; Cassagrande, 1971). Note that liquefaction that results in a debris flow would be considered complex.

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Topple. Movement of a detached rock mass by overturning about a pivot point below the centre of gravity of the unit (Varnes, 1978). Note that topples are often multiple.

Sheet Erosion. The removal of soil or decomposed rock by the surface flow of water or a mixture of water and sediment.

Gully Erosion. The creation of an incised drainage line by channelised surface flow.

Outwash. The redistribution of debris by streamflow and hyper-concentrated streamflow.

COMPLEX

A landslide in which debris is moved by one or several transport mechanisms that differ from the detachment mechanism. Note that the landslide is classified on the basis of the type of scar and the assessed dominant transport mechanism, i.e. falling, rolling, bouncing, sliding, flowing or streamflow. In any complex landslide some or all of these processes may have occurred to different degrees at different parts of the scar. Recording the displaced material can be used to further refine the classification of the landslide.

Rockfall. The displacement of a piece of rock from a rock face chiefly by free fall through the air but may include sliding leaping and rolling. Note that this is a simple landslide if the initial displacement does not involve another mechanism such as sliding or toppling.

Boulderfall. The displacement of a boulder where the movement may include free fall through the air, sliding leaping and rolling. Note that in Hong Kong boulder falls commonly result from the undercutting by erosion or landsliding of exhumed corestones or colluvial boulders on steep natural hillsides.

Debris Avalanche. A landslide in which generally unsaturated debris moves rapidly by the dominant mechanisms of rolling and/or bouncing and/or inertial granular flow (Pierson & Costa, 1987; Varnes, 1978).

Debris slide. A landslide in which debris moves by the dominant mechanism of sliding. Note these often occur on steep hillsides where they typically form an elongate scar and that intact displaced material is normally present.

Debris flow. A landslide in which debris moves by the dominant mechanism of slurry flow. Note that these often occur on steep hillsides where they typically form an elongate scar. The presence of remoulded debris is a good indication that flow has occurred. Debris flows may be separated into either unconfined hillslope debris flows which form an elongate scar on a relatively planar hillslope or channelised debris flows which form a channelised elongate scar.

Mud flow. A landslide with the same characteristics as a debris flow in which the displaced material is predominantly fine grained.

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Debris flood. The transport of a significant load of sediment by the dominant mechanisms of streamflow or hyperconcentrated streamflow. The load can range in grain size from clay to boulders. A debris flood may originate from outwash or gully erosion.

Debris Torrent. The channelised transport of a significant load of sediment, that may include landslide debris, by the mechanisms of flow, hyperconcentrated streamflow and streamflow but none is clearly dominant.

REFERENCES

AGI (1972). Glossary of Geology. Gary, M., McAfee, R. and Wolf, C.L. (eds), American Geological Institute, Washington, D.C.

Cassagrande, A. (1971). On liquefaction phenomena: report of a lecture. Geotechnique, 21, pp 197-202.

Corominas, J. (1986). The Angle of reach as a mobility index for small and large landslides. Canadian Geotechnical Journal, vol. 33, pp 260-271.

Cruden, D.M. & Varnes, D.J. (1996). Landslide Types and Processes. Landslides Investigation and Mitigation, Transportation Research Board Special Report 247 (Turner, A.K. & Schuster, R.L. (eds.)), National Research Council, National Academy Press, Washington D.C., pp 36-75.

Hsu, K. (1975). Catastrophic debris streams (surtzstrons) generated by rockfalls. Bulletin of Geological Society of America, vol. 86, pp 129-140.

Hutchinson, J.E. (1988). General Report: Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. Proceedings of the Fifth International Symposium on Landslides, Ed. Bonnard, C., Lausanne, Switzerland, vol. 1, pp 3-35.

IAEG (1990). Suggested nomenclature for landslides. Bulletin of the International Association of Engineering Geology, no. 41, pp 13-16.

Pierson, T.C. & Costa, J.E. (1987). A rheological classification of sub-aerial sediment-water flows. In Costa, J.E. & Wieczorek, G.F. (eds) Debris Flows/Avalanches : Process, Recognition and Mitigation, Geological Society of America, Boulder, Colorado, pp 1-12.

Scheidegger, A. (1973). On the prediction of the reach and velocity of catastrophic landslides, Rock Mechanics 5, pp 231-236.

Varnes D.J. (1978). Slope movement types and processes. Published as Chapter 2 in Landslide Analysis and Control (ed. R.L. Schuster and R.J. Krizek). Transportation Research Board, Special Report 176, National Academy of Sciences, Washington, D.C., pp 11-33.

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LIST OF DRAWINGS

SECTION 2: THE 1992 TSING SHAN DEBRIS FLOOD

J.P. King

This report is largely based on GEO Special Project Report No. SPR 7/96 produced in October 1996

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Frontispiece. The 1992 Debris Flood trail on Tsing Shan.

Note the start of the 1990 Debris Flow trail on the LHS of the photograph.

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FOREWORD

In June 1992, a small landslide high on the steep upper slopes of Tsing Shan resulted in a debris flood some 350 m long. The event occurred in a drainage line close to the 1990 Tsing Shan Debris Flow (TSDF) but differed from the TSDF in that it was almost two orders of magnitude smaller and did not extend beyond the steep natural slopes.

This report presents the results of a detailed study of the debris flood. It was prepared as part of the TSDF Study in order to contrast the debris flood with the debris flow. The full results of the TSDF study are given in report no. SPR 6/96.

The report was prepared by Mr. Jonathan King. Field tests were supervised by Mr W. C. Lee and Mr. C. F. Chow, laboratory testing by Mr Y. L. Cheng and Mr Y. C. Chow, presentation of laboratory test data by Mr K. S. Tsui and Mr P. C. Cheng. The drafting was done by Mr Y. L. Lee.

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Chief Geotechnical Engineer/Planning

ABSTRACT

The Tsing Shan debris flood was a linear erosive flow of water and sediment that cut a 350 m long, 4 - 10 m wide scar through the vegetation on the upper slopes of Tsing Shan on 13th/14th June 1992 (Table 4). It originated from the toe of a rubbish filled hollow at 485 mPD, about 100 m below the summit of Tsing Shan. It extended down to a concrete footpath on the lower side slopes at 200 mPD. The event had an estimated volume of less than 250 m^3 and comprised boulders, cobbles and sand with only minor traces of silt and clay and no evidence of a slurry matrix. It has been classified as a debris flood which is described by Aulitzky 1990 as "the very rapid turbulent flow of muddy water transporting coarse sediment including boulders".

The event occurred in a drainage line close to the 1990 Tsing Shan Debris Flow (TSDF) but differed from the TSDF in that it was almost two orders of magnitude smaller and did not extend beyond the steep natural slopes. Consequently a brief investigation of the event was carried out as part of the Tsing Shan Debris Flow Study. The investigation comprised a desk study, several days field survey, aerial photograph interpretation, a ground investigation comprising three water replacement insitu density tests and associated sampling for laboratory index and mobility moisture content tests.

A small slope failure at the head of the trail is considered the parent landslide for the event. This is thought to have been initiated by loading from a surge of water, rubbish and rock from the hollow above which in turn was caused by run-off from heavy rainfall (49 mm/hr, Figure D6). Debris from this parent failure passed over a small steep cliff and was channelised in rocky gullies on the upper slopes. The channelised debris flood passed down the rocky gullies and at Ch 120, 370 mPD, joined a perennial streamline in a wide, well vegetated, colluvium choked valley where channelisation ended. Colluvium was locally eroded in approximately an equal volume to the debris that was deposited as bouldery levees. There was only limited erosion of the colluvium and most of the scar was caused by the debris stripping off vegetation and incorporating loose surface boulders. Lower in the valley the scar alternates between colluvium and granite bedrock and the event was mostly depositional. It ended on a 5 m wide footpath platform where a small fan of boulders and gravel was deposited and the flood water flowed on down the stream. Sand and finer gravel was washed up to 80 m along the path.

The debris flood probably occurred as a series of mixed debris and water surges of rolling and bouncing boulders in normal or possibly hyperconcentrated streamflow.

The risk to life from this event was not high as the debris only affected the lightly-used country park footpath and did not extend downslope towards the houses of San Shak Wan San Tsuen which are located beside the drainage line at the toe of the slope. Debris deposits remaining within the trail are loose and include potentially unstable boulders that could easily be dislodged and roll down the trail. The trail will revegetate but the loose debris deposits will still be present below the vegetation as occurs locally adjacent to the trail.

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CONTENTS

1. INTRODUCTION

A debris flood occurred on the upper slopes of Tsing Shan in the North West New Territories on the 13th/14th of June 1992 (see frontispiece). It originated about 90 m below the summit from the toe of a gully choked with construction rubbish at 495 mPD and extended to 200 mPD at a concrete footpath on the lower side-slopes. This event cut a trail 350 m long and from 4 m to 10 m wide through the vegetation on the mountainside but the estimated volume of material involved was less than 250 m^3.

The main debris materials were boulders and cobbles with some sand and gravel and a little silt and clay. These formed deposits of sorted, alluvial debris and there was no evidence of remoulded debris. As such the event has been classified as a Debris Flood which is defined as "the very rapid turbulent flow of muddy water transporting coarse sediment including boulders" by Aulitzky (1990). Definitions of the terminology used in this report are given in Appendix C.

The debris flood is of particular interest as it is located in the drainage line adjacent to the much larger (about 19,000 m^3) 1990 Tsing Shan Debris Flow (Chan et al, 1991; King, 1996). This report has been prepared from field mapping, aerial photograph interpretation (API) and limited field and laboratory tests. It records the characteristics of the debris flood.

2. METHODOLOGY OF THE STUDY

2.1 Desk Study

The desk study for this investigation comprised reference to 1:20,000 scale geological maps, Geotechnical Control Office (1988); 1:20,000 scale terrain classification maps, Geotechnical Control Office (1987); historical aerial photographs and rainfall records. The base map used for the geological mapping was the 1:1,000 scale topographic map sheet.

2.2 Field Mapping and Survey

The first recorded observation of the debris flood was from Lung Mun Road by the author on 14th June 1992. On the 16th June observations were made from the footpath at the toe of the event and on 19th June the trail was traversed from the footpath to the summit of Tsing Shan. A further traverse was made down the trail from the summit to check the API on the ground and collect samples on 2nd September 1992. A chainage was established on the base map from Ch 0 at the start of the trail to Ch 360 at the footpath (Drawing GEO/P/PTE/8). The chainage was extended back up to Ch -90 at Tsing Shan summit. The site was also visited several times during the ground investigation for the main study in January 1993.

2.3 Aerial Photograph Interpretation (API)

On the 19th June, 35 mm and 54 mm, hand-held, oblique colour aerial photography, including stereo pairs, was taken of the area from the Tsing Shan summit to the footpath. API of these was combined with ground observations to prepare a 1:1,000 scale map of the

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event (Drawing GEO/P/PTE/1). This map shows the distribution of colluvium and bedrock along the trail and areas of erosion and deposition from the debris flood. Vertical large format aerial photographs from Lands Department were used to help interpret the geology of the area and construction history at the summit.

2.4 Estimate of Quantities

The quantity of material involved in the debris flood was estimated using field observations and sketch cross-sections combined with API. Where parts of the trail had similar linear characteristics, the estimated cross-sectional areas of erosion and deposition were multiplied by the length of the trail to give a volume. At other locations the plan area and thickness of erosion or deposition were estimated and used to calculate the volume. These calculations are detailed in Appendix B, Tables B-1 to B-3, and the results are shown graphically on Drawing 2.

2.5 Ground Investigation

In January 1993 three water replacement insitu density tests at trial pits D16, D17 and D18 were carried out at the site during the ground investigation for the 1990 Tsing Shan Debris Flow study. These investigations included sampling for laboratory tests, assessment of relative permeability and estimate of boulder content of the deposit. They are reported in full in the debris flow study report. The locations of all investigations are shown on Drawing 1 and the pit logs and all test results from the debris flood site have been copied to Appendix A.

2.6 Samples and Laboratory Tests

On 2nd September 1992 disturbed samples of in situ soil (DFM1, DFM2 & DFM3) and debris (DFM4) were taken from the trail and sent to the Public Works Laboratory in Kowloon Bay for index tests. The results are reported with Test Certificate 012525 in Appendix A.

In January 1993 samples of colluvium were taken from pits D16, D17 and D18.

On 17th February 1993 another colluvium sample was taken at Ch 0 (M36) and samples of debris were also taken at Ch 40 (M37) and Ch 150 (M38). All the samples were sent to MateriaLab for index tests.

In June 1993 samples M36 and M38 were re-sampled (as samples M25A & M24A) with an additional debris sample from Ch 315 (M23A) and tested for Particle Size Distribution (PSD).

Samples from the D series pits were also tested in the Public Works Laboratory to identify the moisture content at which they become mobile and able to flow. This is called the Mobility Moisture Content (MMC) fully explained in Appendix J of the debris flood report and the results are reported in Appendix A. The results of the index tests carried out by MateriaLab are given in MateriaLab (1993). All relevant test results have been copied to

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Appendix A; sample locations are on Drawing GEO/P/PTE/8 and photographs of sample locations for samples M36 (M25A), DFM1, DFM4 and M38 are reproduced as Plates 15, 18, 32 and 23.

3. DESCRIPTION OF THE STUDY AREA

3.1 Site Location

The debris flood occurred on the eastern flanks of Tsing Shan, a mountain rising to 583 mPD in the North West New Territories about 2 km west of Tuen Mun (Figure 1). Tsing Shan is the highest peak of the north-east to south-west trending range that rises steeply as the western side of the Tuen Mun valley. At the foot of Tsing Shan, Area 19 Tuen Mun was excavated as a borrow area in the late 1970's and now comprises a large platform with a cut back slope of about 17°.

The scar from the debris flood starts about 100 m below the summit of Tsing Shan. From here it descends a drainage line to terminate at a concrete footpath that contours the lower side-slopes at 200 mPD some 400 m from Area 19. However, material tipped from building works on the summit was involved in the event and the study area is thus the whole drainage line followed by the trail, from Tsing Shan summit to Area 19.

Access to the top of the debris flood is from a footpath to the summit of Tsing Shan, to the toe is along the 200 mPD footpath.

3.2 Geology

The regional geology of the study area has been mapped at 1:20,000 scale by the Hong Kong Geological Survey (GCO, 1988), and is described in Langford et al (1989). To show the bedrock geology of the study area the regional geological boundaries have been transferred from the 1:20,000 scale map to a 1:5,000 scale plan (Figure 2).

The upper parts of Tsing Shan are formed of granite and the eastern side is mapped as fine-grained granite. Downslope from the granite the lower slopes are shown as sandstone, siltstone and mudstone with conglomerate and tuff from the Upper Jurassic Tsing Shan Formation of the Repulse Bay Volcanic Group.

The boundary between the granite and the volcanic rock is faulted and rises across the eastern side of Tsing Shan from 60 mPD in the south to 360 mPD at the top of the ridge 700 m north of the Tsing Shan Summit. This boundary divides the upper, rocky granite slopes from the more gently rounded, lower volcanic slopes. The end of the debris flood trail intersects this boundary about 10 m above the concrete footpath.

Deposits of Pleistocene and Holocene Debris Flow Deposits more than 3 m thick are mapped in the larger valleys and mantling the lower parts of the footslopes. Their distribution shown on Figure 2 is generalised due to the original mapped scale of 1:20,000. These deposits will be referred to by the more general term of Colluvium in this Report to avoid confusion with references to debris from the event. They are described in detail in Section 4.3.2.

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3.3 Geomorphology

The summit and ridge tops of Tsing Shan are generally rounded and the granite bedrock is interpreted to be locally mantled by residual soil several metres thick. The steeper rocky granite upper sideslopes below the ridgeline have an overall angle of about 45° and are formed of irregular cliffs and bluffs dissected by a network of rocky gullies. In this area residual soil is generally absent and soils are bouldery colluvium confined to thin linear deposits lining the gullies and occasional thicker accumulations below cliffs.

Downslope from these rocky areas the lower sideslopes have average slope angles that decrease from 37° at the top to 20° at the foot. They comprise valleys choked with thick deposits of bouldery colluvium, separated by rounded spurs mantled with residual soils. In their upper areas the colluvium is underlain by granite and may have local surface deposits of loose angular boulders that have fallen from the cliffs above. The lower parts of these slopes are underlain by volcanic rock which typically has a well-developed residual soil profile up to 5 m thick on the ridges. This frequently thins towards the valley bottom where colluvium is often present and fresh bedrock may outcrop in the stream channel.

First-order (Strahler, 1952), dry, bouldery, ephemeral stream beds are found in most of the upper gullies and feed larger second-order ephemeral streams in the valleys. Springs with small, seasonably variable, discharges occur from major joints in bedrock; however most groundwater on the slopes moves as seepage through the colluvium and comes to the surface in bedrock areas.

On the summit and upper slopes vegetation is generally confined to grass. Scrubby bushes and small trees are present locally in depressions on the sideslopes and are larger and more extensive in the larger valleys.

3.4 Development History of the Study Area

The elongate depression just upslope from the source of the debris flood trail is choked with building rubbish which presumably originated from the transmitting station on the summit of Tsing Shan (Plates 1, 2, 11 & 12). The rubbish appears to have accumulated over a number of years however building work was in progress at the station when the event occurred and field observations six days after the event indicated that rubbish had been recently tipped from the summit.

3.5 Rainfall

The rainfall in the vicinity of the event can be estimated from GEO automatic rain gauge number N07. This is located at about 20 mPD on the footslopes of Tsing Shan, less than 1.5 km from the catchment where the debris flood occurred (Figure 1). The cumulative and 15 minute data from this raingauge for the 2 weeks preceding the assumed date of failure (13th June 1992) is given in Figure 3 and for the preceding 24 hours in Figure 4.

Table 1 gives the maximum rolling rainfall at raingauge No. N07 and estimated return periods for different durations preceding 24:00 on 13th June 1992. Return periods were

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estimated by Gumbel's method as outlined in Peterson & Kwong (1981). This shows that for a selection of durations from 5 minutes to 4 days, the estimated return period for the recorded rainfall is less than 2 years. The calculated return period should not be considered an absolute value as it is based on the Royal Observatory in Kowloon which has a mean annual rainfall of about 2,200 mm as opposed to the mean annual rainfall of about 1,700 mm at the site (Evans, 1996). However, storms of similar or greater intensity have been recorded fourteen times at rain gauge N07 between 1982 and 1994 (King, 1996) and heavier rainfall was recorded on 4 occasions - once in 1988, twice in 1993 and once in 1994. This seems to indicate that the storm was not exceptional for the site.

The ground in the vicinity of the trail has been divided into catchments that contribute overland flow to the debris flood drainage line. These are labelled A to D and shown on Figure 2. Catchment A (3,880 m^3) is located above the main scarp at Ch 0. Catchment B (17,120 m^3) is the rest of the catchment to the trail at Ch 230 where the trail joins catchment D (14,750 m^3). The final section of the trail from Ch 230 to the footpath has a catchment (C) of 2,250 m^3.

4. THE DEBRIS FLOOD

4.1 Timing

The debris flood was not seen in progress but its time of occurrence has been estimated from the following observations and the rainfall distribution. At 09:30 hrs on 13th June 1992 the Chief Resident Engineer for Tuen Mun, Mr Sim, would have seen Tsing Shan from the window of his office at Tsing Hoi Circuit, but did not notice the debris flood scar. However he immediately noticed the scar when he returned to his office on 16th June. The first recorded observation of the event was from Lung Mun Road at about 16:00 hrs on 14th June by the author.

The event is assumed to have occurred between the above observations during which time GEO raingauge N07 recorded two relatively light rainstorms (Figure 4). The first storm started at about 11:30 hrs on 13th June 1992 and resulted in about 90 mm of rain in 3 hours with a maximum 15 minute intensity of 16 mm. The second storm was smaller. It started about 18:00 hrs on 13th June and resulted in 28 mm of rain in 1 hour with a maximum 15 minute intensity of 10 mm. It is probable that one of these rainstorms initiated the debris flood.

4.2 Description of the Debris Flood Scar

4.2.1 General Morphology

The erosive scar from the debris flood is a prominent linear feature on the mountainside where all vegetation has been cut off at ground level (Plates 24, 25 & 26). It has been divided into four parts based on the geomorphology of the hillside: rocky gully, upper valley, lower valley and footpath. In addition, a trail of tipped rubbish leads from Tsing Shan summit to the scarp that forms the top of the scar. This is described as a separate part of the event: the upper slopes. The location of the parts are shown in plan on Drawing GEO/P/PTE/8 and as longitudinal and cross-sections on Drawing GEO/P/PTE/9.

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The part of the event located on the upper slopes extends down from the summit over slopes strewn with construction waste to the outlet of a rubbish-choked depression 100 m below at Ch 0. The scar starts at 495 mPD with the main scarp of a small colluvium slide and the trail from this descends through a rocky gully on the upper side-slopes of the mountain to a colluvium-filled valley at Ch 120, 370 mPD. In the upper part of the valley, the trail follows the western edge along the boundary between granite outcrops to the west and thick deposits of bouldery colluvium in the valley to the east. In the lower valley, the trail alternately crosses granite bedrock and colluvium for a further 230 m and stops at a concrete footpath (Ch 350, 200 mPD). The terminal deposit of material on the footpath and its redistribution along the path forms the final part of the trail.

4.2.2 Upper Slopes (Ch -90 to Ch 10)

The upper slopes have an overall angle of about 45° but comprise both steeper cliffs and more gentle slopes that occur near the summit and in depressions. Building rubbish tipped from works at the transmitting station on Tsing Shan summit clads the slopes. The rubbish includes fence wire and posts, steel rods, steel and plastic drums, old machinery and many angular blocks of recently-excavated, fresh, light grey granite (Plates 11 & 12). These materials are caught up in piles on the slopes below the summit. The slopes show signs of abrasion from material sliding down to accumulate in an elongate depression some 100 m below the summit (Plate 2). The depression also contains a number of large angular, natural boulders and previously tipped rubbish but significant quantities of recently-tipped material were present during the first site visit. Vegetation within the depression was damaged and the marks from individual rock blocks bouncing down from the summit could be seen on rock outcrops and in the vegetation.

At its outlet, the depression constricts to form a gully sloping at about 30° with a thin deposit of loose to medium dense colluvium comprising silty sand and gravel with many cobbles and boulders. Broken and aligned vegetation, with no associated topsoil erosion, leads along the gully to a small slope failure in the colluvium. The failure source is 2 m wide, 5 m long and has a main scarp 1 m high which exposes the full thickness of the colluvium. Many small soil pipes up to several millimetres in diameter can be seen in the scarp (Plate 15). Slightly decomposed to fresh bedrock is exposed on its floor (Plate 14). Its down-slope end is at the lip of a small, 10 m high, 70° cliff below which the trail continues in a rocky gully. This failure is the start of the debris flood trail.

4.2.3 Rocky Gully (Ch 10 to Ch 120)

The overall slope of the rocky gully is about 45° but bedrock outcrops form steeper cliffs while the intervening lengths of the gully have a minimum slope of about 37° (Plates 4 & 19). In this section of the trail, erosion greatly exceeded deposition which only occurred as small accumulations in the lee of larger boulders or below bedrock steps.

Along the trail, loose surface clasts have been removed, there is local erosion of the top few centimetres of topsoil and vegetation has been cut off or aligned by the flow. Occasional thin, sandy, gravelly deposits and/or scattered cobbles and boulders may be present in the trail or lying on the vegetation at its margin (cross-section Ch 20). Where

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colluvium is present a small clean channel with a maximum cross-sectional area of about l m^2 has been eroded into it near the centre of the trail or at the low point of the gully. Where the line of this channel crosses areas of bedrock, weathered material and loose blocks have been eroded and the rock appears abraded or polished.

On the outside of a bend below a steep rock slope at Ch 40 vegetation at the edge of the trail is aligned and gravel and cobbles are caught in it up to 1.5 m above the main channel (cross-section Ch 50). This shows the super-elevation of about 10° of a surge of material as it passed around the bend (Plate 17).

At the toe of a small cliff (Ch l00) where the steeper upper gully joins the gentler slopes of a second order valley, a small colluvial fan was partly eroded by the event. However, a similar volume of debris was also deposited at the same location. Consequently there has not been a significant change in material volume or morphology at this location.

4.2.4 Upper Valley (Ch 120 to Ch 230)

This part of the trail is along the upper section of a colluvium-filled valley with an average slope of about 37°. The trail intersects an indistinct, dry stream bed at Ch l30 and follows this past rocky granite bluffs along the western edge of the colluvium deposit.

Within the trail, all vegetation, including occasional trees up to about 150 mm diameter, has been cut off at ground level, most of the thin topsoil has been removed and the colluvium deposit is exposed (Plates 21 & 22). A small intermittent channel with cross-sectional area of less than l m^2 has been eroded into the colluvium along the trail (e.g. cross-section Ch 150). At Ch l30 there are loose angular boulders that rock when stepped on at the ground surface in the vegetation adjacent to the trail (Plate 27). However no loose boulders are present in the trail which implies that the debris flood probably entrained loose surface boulders at this location.

At Ch 170 a bedrock bluff projects into the valley and the trail is deflected slightly around it. Deposits of loose boulders with an estimated total volume of 50 m^3 extend back up-slope from the bluff, forming boulder levees along either side of the trail (cross-section Ch 165, Plate 21). Several oil drums and fresh angular blocks from the building works at the summit are in this deposit (Plate 24). A channel is cut into the underlying colluvium between the levees. Its up-slope extension includes two eroded scarps more than 1 m high and total erosion is estimated to be about 30 m^3. There appears to have been a temporary blockage of the flood at this point.

The trail downslope from the bluff curves to the west and has boulder levees along the outer edge. Within the trail, there are at least 6 small scarps eroded into the colluvium that have a total estimated eroded volume of about 50 m^3. At about Ch 210 there is a pile of debris in the trail that was deposited on a surface already cleared of vegetation. This includes one large boulder propped by another smaller one (Plate 25). At the debris pile, the flood line on the southern side of the trail dips down but then rises again about 10 m down slope.

At Ch 230 the indistinct stream bed followed by the debris becomes larger as it

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combines with another small, dry stream bed from catchment D to the north.

4.2.5 Lower Valley (Ch 230 to Ch 360)

The lower valley slopes at an average of about 32° but the trail alternates between steeper bedrock areas and flatter colluvium. Debris appears to have been transported over the areas of bedrock but deposited on the flatter, rougher colluvium.

The trail is located over colluvium from Ch 260 to Ch 300. About 60 m^3 of debris (mainly large boulders) was deposited here as a boulder levee on the outside of the bend and as a pile of debris around three very large boulders at Ch 295. The boulders may have caused a temporary blockage resulting in the deposition. There is a small erosion scarp in the original ground surface at the location where a channel appears to have cut through the blockage.

The trail then passes over two steep rock areas separated by an area of colluvium with large boulders. At this point the remaining material in the flood was mainly small boulders (up to 0.5 m diameter) and finer materials. This material appears to have passed around the boulders with little erosion or deposition. However, bedrock is polished at one location and there is a distinct line separating it from the ground above, which appears to have only experienced water flow (cross-section Ch 340, Plate 31). A tree was broken off 3 m above stream level in this location but the bark on the trunk was not marked above 1 m.

At the toe of the final rock slope (Ch 355) there is a small accumulation of debris and broken vegetation that might have been the site of a temporary blockage. Below this a fan of debris with an estimated volume of 40 m^3 was deposited on the 5 m wide area of flat ground adjacent to a concrete footpath (Plate 32).

4.2.6 Footpath

The debris fan next to the path is composed of sand with a little silt, gravel, cobbles and occasional boulders up to a maximum diameter of about 250 mm. The footpath slopes to the south at less than 5° and stream flow appears to have divided at this point, partly following the drainage line down the hillside and partly following the footpath. There were minimal debris deposits in the drainage line which appeared to have only experienced high water flows, but alluvial debris deposits and evidence of water flow were present along the footpath. The flow spilled off the side of the path on the outside of two bends depositing up to 1 m^3 of debris down-slope. Debris deposits along the path start about 60 m from the fan with a pile of boulders, cobbles and gravel (Plate 33) beyond which deposits of sand, and finally silt, extend a further 20 m.

4.3 Materials Involved in the Debris Flood

All materials moved by the debris flood are referred to as debris. This includes eroded colluvium, vegetation and relatively small quantities of construction waste from the transmission station on Tsing Shan summit. The location of the debris deposits are shown

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on Drawing GEO/P/PTE/8.

4.3.1 Construction Waste

The construction waste in the debris comprised a few old oil drums and a quantity of very distinctive angular blocks of freshly excavated grey granite with drill marks (Plate 24). Similar materials to this are present in large quantities in the depression at the head of the trail and on the slopes above that lead up to the summit. Scattered fresh granite blocks are also present in the undergrowth around the upper part of trail in the gully. These were presumably emplaced by rolling and bouncing from the summit.

4.3.2 Colluvium

Colluvium from both the small linear deposits in the rocky gullies on the upper part of Tsing Shan and from the larger deposit in the lower valley was eroded by the event and formed debris. Field observations and the laboratory test results from both these locations indicate the colluvium is similar comprising mainly angular boulders and cobbles with a little gravel, sand and silt (Plates 15, 18 & 26). However, these areas differ slightly in that the diameter of the largest boulders usually present is 1 m in the rocky gullies but 3 m in the lower valley. Very large boulders over 3 m are occasionally present in both locations. Top soil is very poorly developed over most of the deposit, especially in the rocky gullies and upper valley. Here the colluvium is bound together by roots (Plate 15) and appears to be actively accumulating from rock fall and other mass wasting processes such as the debris flood.

Samples of the finer fraction of the colluvium along the trail were tested for particle size distribution and plasticity limits and the results are presented in Table A-1 and Figures A-1 and A-3. These show this fraction can be classified as a very sandy gravel with some silt (Geotechnical Control Office, 1988). The finer fraction of the colluvium was visually estimated to be about 15% of the whole deposit by volume. At the location of the insitu density pits (D16, D17 & D18) boulder content was estimated as between 58% and 68% on the basis of the quantity of material that could be excavated to form the pit, as described in Appendix J of the Debris Flow report (King, 1996). Locally the deposit is loose with voids between clasts (Pit D16 log) and soil pipes were identified in the colluvium exposed in the scarp at Ch 0 (Plate 15).

The colluvium deposit as a whole can be described as angular cobbles and boulders with a little finer material (very sandy gravel with some low plasticity silt). Photographs illustrate the colluvium at some sample locations along the trail (Plates 18 & 26). Logs of Pits D16, D17 and D18 are in Appendix A. The colluvium on the upper slopes has less cobbles and boulders and in the scarp at the head of the event (Plates 14 & 15) is described as silty sand and gravel with many cobbles and boulders.

Water replacement insitu density tests and soak-away relative permeability tests were carried out in the colluvium at Pits D16, D17 and D18. Test results are given in Table A-1. These show the dry density for the whole tested deposit to be 1.37, 1.92 and 1.87 Mg/m^3 and for the matrix (< 20 mm) 0.6, 1.35 and 1.18 Mg/m^3 respectively. Relative permeability was about 4×10^{-4} m/s for D17 and 2×10^{-2} m/s for D18 but at D16 could not be calculated as the

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pit emptied very rapidly due to flow in soil pipes.

The comparatively low insitu density and very high permeability recorded at Pit D16 reflects its very loose condition with voids between clasts and a low fines content (23% < 20 mm). This may be due to its location in a perennial stream bed directly below a rock outcrop that becomes a waterfall at times of high rainfall. As such it is in an area of rapid flow and high infiltration where the stream water re-enters the colluvium deposit after flowing over the bedrock surface. The values recorded for D17 and D18 are probably more typical for the colluvium deposit in the valley.

4.3.3 Debris

Debris comprises cobbles and boulders with sand and gravel. This includes building waste of angular excavated blocks and several steel and plastic drums. The major debris deposits from the event can be divided into boulder piles and levees in the valley from Ch 120 to Ch 300 and a fan of finer material at the distal part of the event on the concrete path (Ch 360). Debris from the event was also deposited in small quantities all the way along the eroded trail as individual cobbles, boulders and building rubbish left behind on the eroded surface or caught in the vegetation alongside the trail. Light grey granite blocks from the summit are occasionally present all the way along the trail to Ch 300. This indicates both that some material from the initial failure remained within the active debris for most of the event and that deposition occurred throughout the event.

The larger bouldery deposits form levees on both sides of the trail at Ch 140 to Ch 170 and on the outside bend of the trail at Ch 200 to Ch 290 (Plate 28). These comprise boulders up to 3 m diameter with some finer material and vegetation fragments including roots and abraded trunks and branches. No significant quantities of finer material that might have formed a supporting matrix during movement of the boulders could be found around or capping them. A few small patches of finer debris materials (Plate 22) were located and sampled for laboratory tests. The results are given on Table A-2 and show these materials are non-plastic sandy gravel with a little silt and clay. A sample was also taken from the fan of debris on the footpath (DFM4) and classified as a very sandy gravel with a little low plasticity silt. Thus all the debris deposits from the event were sorted, alluvial debris.

When the debris samples are compared with the colluvium samples, they generally have a little less silt and fine sand and are less plastic. This is probably because the finer fraction in the eroded colluvium would have been washed out by the floodwater and carried downstream or along the footpath.

4.4 Volume of the Debris Flood

To facilitate discussion the volumes of material given below are gross volumes referred to as if all the debris was transported in one single pulse. However, the event was probably a series of sequential debris surges of varying composition interspersed with, and followed by, episodes of stream flow (Section 5.4). This should be kept in mind while reading the following section.

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The volume of material involved in the event was estimated as explained in Section 2.4 and is tabulated in Appendix B. Table B-1 shows the calculation of erosion and Table B-2 of deposition. Table B-3 is a summary which combines the two and gives the difference between the cumulative erosion and cumulative deposition which is called the active volume. This represents the total quantity of debris that was transported past any given point. In the event, erosion must have balanced deposition but they were calculated independently and have a difference of 14 m^3. The active volumes given on Table B-3 are consequently only approximate as they are derived by the combination of Tables B-1 and B-2. The total volume of debris estimated to be involved in the event is 232 m^3. However, the maximum volume mobilised at any point along the trail (active volume) is about 100 m^3 (see Drawing 2) and this was probably made up from more than one debris surge.

As the flood descended the rocky gully into the valley, erosion exceeded deposition and the active volume steadily increased from about 20 m^3 at the first cliff (Ch 10) to 87 m^3 at Ch 170. From Ch 170 to Ch 190 deposition exceeded erosion and the volume decreased to 48 m^3. Below this the volume increased again to about 91 m^3 by Ch 240. Deposition of about 60 m^3 occurred from Ch 260 to Ch 300. This reduced the volume of debris to about 40 m^3, which was all deposited on or near the concrete footpath at Ch 360. The total volume of debris eroded in the event was estimated as about 223 m^3 and deposition was 237 m^3.

5. DISCUSSION

5.1 Initiation

The debris flood is assumed to have occurred during the larger of the two rainstorms on the 13th June (see Section 4.1). The scar starts at the main scarp of a small landslide in colluvium at the start of a drainage line that forms the outlet to a rubbish-filled depression near the summit of Tsing Shan. However, up slope from here to the summit there is an indistinct trail of construction debris, aligned vegetation and bounce marks. The small landslide may either be interpreted as the trigger that initiated the debris flood, or as the first significant erosion of a flood event that developed into the debris flood. In either case about 10 m^3 of debris from this landslide, combined with an estimated 10 m^3 of construction debris appears to have initiated the debris flood. Factors that may have influenced how this relatively small volume of debris developed into the debris flood are discussed below in Section 5.4, Mechanism.

During the preceding week, 175 mm of rain had fallen. The groundwater level in the colluvium of the depression and its outlet was probably high. The colluvium exposed in the landslide scarp is porous, with many small soil pipes (Plate 15), and seepage would have been occurring through it. The seepage would have increased as the rainstorm progressed and the colluvium would have probably become saturated to the surface. The colluvium thins downslope from the depression towards the cliff where bedrock outcrops. This decreasing cross-sectional area would have resulted in an increase of seepage pressure and reduced the stability of the slope (Johnson & Sitar, 1987).

Rubbish appears to have been tipped from the building works on the summit for some weeks prior to the event. This would have built up marginally stable piles of material on the rocky slope above the depression, in the lower part of the depression and at its outlet. Any material that accumulated on the colluvium in the location of the failure would have acted as a

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surcharge and reduced the stability of the slope.

Trails of broken and aligned vegetation lead from the rubbish-filled depression to the failure. Little erosion is associated with these trails and they appear to have been caused by a flow of water with little solid material. The catchment above the failure is 2,880 m^2. Using the Rational Method (Drainage Services Department, 1994) with a runoff coefficient of 0.6, and the maximum recorded rainfall intensity of 16 mm in 15 minutes, a maximum discharge of 30 litres per second can be calculated. This is not enough on its own to result in the overland flow necessary to cause the trails, but if it was stored and then released quickly, a much larger flow of water could have been discharged. For instance, 5 minutes of storage would be more than 9 m^3 of water.

Such storage could have occurred by runoff accumulating behind piles of rubbish which formed small temporary dams on the hill side above the depression and by impeded drainage within the boulders and rubbish in the depression. If a number of these small rubbish dams failed sequentially during high intensity rainfall, a surge of water containing some rubbish and rock would have been discharged from the depression. This would have induced scour and hydrostatic drag forces at the ground surface and reduced the stability of the slope in the location where the failure occurred.

Seepage pressure within the saturated colluvium, loading from rubbish and rock tipped during the previous weeks, and scour from a sudden release of temporarily-stored surface water with debris could have combined to initiate the landslide in the colluvium. This landslide had an estimated volume of < 10 m^3. The saturated debris from the landslide would have combined with the overland surge of water and rubbish (say a further 10 m^3) to become the start of the debris flood.

5.2 Erosion

The debris flood eroded and entrained colluvium along its whole trail. However, the bulk of erosion occurred within the upper parts of the rocky gully and upper valley. The erosion has been classified into three types: the general erosion of vegetation and surface material along the trail; the incision of a small channel into colluvium along most of the trail; and local enlargements of this channel with a distinct scarp.

The least intense erosion by the debris flood formed the full width of the trail (Plate 26). This involved cutting off all vegetation at ground level, shallow localised scour of topsoil, where present, and incorporation of any loose blocks at the surface. About 35% of the total estimated erosion is in this form. At some locations along the edge of the trail, this process grades up into a strip of aligned vegetation where water appears to have flowed over the ground surface without causing noticeable erosion (Plate 31).

A small channel with a maximum cross-sectional area of about 1 m^2 was eroded wherever the trail crossed colluvium from Ch 0 to about Ch 240. The channel is locally irregular due to the large boulders in the colluvium but is usually located near the centre of the trail or at the low point of the drainage line cross-section. The channel can be seen on most of the cross-sections in Drawing GEO/P/PTE/9 and forms about 30% of the total estimated volume of erosion. It may have initiated during the surge/s of the debris flood

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(streamflow and possibly hyperconcentrated streamflow with a high bedload) that eroded the full width of the trail but probably mainly developed by gully erosion from more localised smaller flows between and after the larger surges of the debris flood.

The channel locally enlarges to form distinct erosion scarps (e.g. Plate 26). These could be caused by small discrete failures of the colluvium or could be nick points (sharp angles in the longitudinal profile) where the scour which caused the incision of the channel was concentrated as it eroded back upstream. These scarps all occur in the upper valley part of the trail between Ch 150 and Ch 230, with the exception of one in the lower valley at Ch 280. Two scarps are located adjacent to the boulder pile between Ch 150 and Ch 170, which is interpreted to be a breached temporary blockage of the debris flood. Six others are located along the trail directly below this blockage where a second blockage is interpreted to have occurred at Ch 220. The scarp at Ch 280 is located where another blockage is interpreted to have built up and breached. These scarps thus seem to be associated with blockages of the debris flood, where there would have been a surcharge from the accumulation of debris followed by increased scour from a surge of material when the blockage breached. About 35% of the total estimated erosion is in this form.

5.3 Deposition

A detailed description of the debris deposits from the event are given in Section 4.3.3. Most deposition was concentrated as loose boulder piles and levees in the upper and lower valley (67% by volume) and as a fan of material on the footpath at the end of the trail (22%). More general deposition also occurred along the whole length of the trail (11%). All these deposits are sorted alluvial debris.

The general deposition comprised pockets of debris downslope from boulders or bedrock steps, individual blocks caught in the vegetation at the edge of the trail (Plate 16), thin localised deposits of washed sand and gravel, and traces of sand on aligned vegetation on the edges of the trail (Plate 33).

Loose boulder deposits occur on either side of the trail from Ch 150 to Ch 180 and join to become a single pile of boulders at Ch 180 (Plate 21). These appear to have been deposited where the flow was constricted by a bluff on the valley side and a blockage formed. When this breached, the central part of the pile was washed out, leaving behind the linear boulder deposits on either side of the trail and a pile of boulders with a channel eroded through it at Ch 180.

Downslope from Ch 180 the trail curves gently to the south, the overall slope decreases to 32°, and a boulder levee has been deposited along the outer edge from Ch 200 to Ch 280 (Plate 30). The levee was probably formed as the surge of material from the breached blockage swung to the outside of the bend and lost momentum, causing a second blockage at Ch 220 (Plate 25). The boulders on the outer edge of the trail are caught in the dense vegetation beside the trail and may have formed a nucleus against which the inner boulders were deposited, thereby causing the blockage. Just downslope from the Ch 220 blockage, the flood line on the southern side of the trail dips down but then rises again about 10 m down slope. This could indicate the point where one surge of debris stopped and deposited causing the blockage. Material accumulated here until this breached and the next

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surge then continued down the slope. The remains of the blockage appears to have been deposited on a surface that was already cleared of vegetation by an earlier debris flood surge and includes a large boulder propped by a smaller one (Plate 25).

The levee grades into a pile of bouldery debris that accumulated across the full width of the trail around three very large boulders (over 5 m diameter) at Ch 290. This appears to have been the site of a temporary blockage caused by the boulders, and its subsequent washout. The large boulders were probably close to this location before the debris flood but may have been moved a few metres downslope by the event.

The fan of material deposited on the 5 m wide flat platform at the footpath is mainly sand, gravel, cobbles and small boulders less than 1 m in diameter (Plate 32). Finer, up to cobble-sized material, was washed down along the footpath that slopes to the south at about 5°. A small quantity of this material was washed off the side of the path on the outside of bends but most was deposited along the path (Plate 33). It was sorted by grain size, with the distal portion some 100 m from the fan being silt and fine sand. This shows the material was carried by a high water flow that was probably a contemporaneous process to the deposition of the fan but may partly have been redistribution of the fan deposits after the main event.

5.4 Mechanism

The debris flood appears to have been generated from no more than 20 m^3 of debris that flowed over the small cliff at Ch 10. This initiating flow went on to entrain material in the rocky gully and first part of the upper valley and increased in volume to about 90 m^3 by Ch 170. Despite variations caused by blockages and re-mobilisation, the active volume was still 90 m^3 at Ch 240. Below here the volume decreased down to Ch 360 where the debris flood terminated at the footpath. Total volume of debris involved in the event was about 320 m^3 and the angle of reach is about 39°.

Conditions in the rocky gully and part of the upper valley (Ch 0 to Ch 170) were conducive to erosion and entrainment of material. In the remainder of the upper valley (Ch 170 to Ch 240) erosion balanced deposition and from Ch 240 to Ch 360 deposition was the main process. Factors that may have influenced this balance of erosion and deposition include slope angle, volume of water available, composition and volume of debris, channel dimensions, and the availability and characteristics of the substrate material available for erosion. Some of these factors are compared for the different parts of the event in Table 1.

The cross-sectional area of the debris flood greatly exceeds that which would be expected from the maximum stream flow that could have been generated by the recorded rainfall. Using the Rational Method and the recorded rainfall at gauge N07, the discharge from the combined A and B catchments at Ch 220 can be estimated as a maximum of 0.6 m^3/s. Using Manning's equation, the velocity of water flow in the debris flood channel can be estimated as 7 to 9 m/s. If this velocity occurred within the recorded minimum debris flood cross-sectional area (3 m^2) it would be associated with a minimum flow of 21 m^3/s. For this flow to have occurred with a catchment discharge of 0.6 m^3/s implies damming of the stream flow by debris and its release as one, or a series of pulses surging down the channel.

The debris, which included low-density steel drums and plastic rubbish, moved much

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further from the initial failure than is likely to have occurred by sliding or rolling alone. It therefore must have been transported in a fluid medium.

No traces could be found of remoulded debris in the locations where it might be expected to be deposited from slurry flow such as along the edges of the trail or capping boulders.

Aligned vegetation and pockets of washed alluvial sand and gravel are found along the edges of the trail. Boulders were filtered out of the flood when caught in dense vegetation while the fluid transporting medium flowed away with no trace. At the footpath all the remaining active debris was deposited as a cone on the 5 m-wide horizontal platform but the transporting fluid continued on down the drainage line. These examples of the complete separation of the debris from its transporting fluid would not have occurred had the debris been transported in a slurry remoulded debris. The fluid medium must have been water and therefore the event would be classified as normal or hyperconcentrated streamflow in the rheological classification of Pierson & Costa (1987).

Given that the debris was transported by water, a relatively high velocity and volume would have been necessary to move the larger boulders involved. This supports the hypothesis that the debris and fluid moved in one or a series of surges rather than as a continuous flow. The debris flood probably occurred as a series of mixed debris and water surges of rolling and bouncing boulders in normal or possibly hyperconcentrated streamflow. These were interspersed by periods while streamflow was accumulating behind blockages. At Ch 350 trees with undamaged bark were broken off at up to 3 m above the stream bed which suggests that some boulders were rolling and bouncing at this point.

The surges would have been the main episodes of debris transport and trail erosion. Each blockage, and possibly some of the slower-moving surges, may have been overridden by stream flow which would account for the marginal strips of aligned vegetation with little erosion around the erosive central part of the trail. Active debris transport probably occurred over a relatively short time, say 5 to 10 minutes. It would have been followed by a longer period of high stream flow down the eroded trail. This would have enhanced, or possibly formed, the narrow eroded channel near the centre of the trail. It would also have redistributed any smaller loose debris downstream to the fan on the footpath.

5.5 Risk

The risk to life from this event was not high as the debris only affected the lightly-used country park footpath and did not extend downslope towards habitation. However, had the event continued to entrain material and increase in volume as it did in the upper areas, or had it even continued past the footpath at its maximum volume of 100 m^3, it might have posed a significant risk to the houses at San Shek Wan San Tsuen. These are located beside the drainage line at the toe of the slope (Plate 27). At this location deposits of colluvial boulders suggest that similar events and/or debris flows have reached here in the past.

Debris deposits remaining within the trail are loose. They include potentially unstable boulders such as those supported by other loose boulders (Plate 25). These could be easily dislodged to roll down the trail. The continuing instability of this slope is

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illustrated by observations of the trail made during fieldwork in the area in September 1994, two years after the event. A number of boulders were observed rolling and bouncing down the upper part of the trail but did not reach the footpath. The trail will revegetate but the loose debris deposits will still be present below the vegetation. There are loose boulders below vegetation adjacent to the trail at Ch 120 (Plate 20) and similar conditions probably also occur at other locations within the colluvium deposit.

All the above deposits are available to become incorporated into any future slope failure on this slope. As such there is a high probability of repetition of similar, or possibly larger, events on this slope.

6. CONCLUSIONS

(a) A debris flood occurred in a steep drainage line on the south eastern upper slopes of Tsing Shan on 13th June 1992. It was probably associated with a relatively light rainstorm of about 103 mm in 5 hours with a maximum hourly intensity of 49 mm.

(b) The debris flood scar starts at a small (< 10 m^3) landslide of colluvium in a drainage line sloping 30° at the outlet of a small depression at 495 mPD, about 80 m below the summit. Factors that may have caused this landslide include high groundwater levels, seepage pressures, loading from construction waste and scour from the sudden release of an accumulation of surface water and construction debris.

(c) The debris flood scar extends about 350 m plan and 286 m elevation down a 45° rocky gully and along the edge of a colluvium-choked valley sloping from 37° to 32° to terminate on a flat 5 m wide footpath. The angle of reach is 39°.

(d) The overall volume of the debris flood was about 230 m^3 but this was probably divided into a number of smaller surges and the maximum mobile volume at any point along the trail was about 100 m^3.

(e) The deposits of displaced material are all washed alluvial debris comprising boulders up to 3 m but generally 1 m to 2 m diameter with cobbles, some gravel and a trace of sand, vegetation fragments and some construction waste of fresh granite blocks and old oil drums.

(f) The mechanism of debris transport is interpreted as stream flow, and possibly local and limited hyperconcentrated streamflow, which occurred as a series of surges caused by the breach of temporary blockages. The event is thus

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classified as a debris flood.

(g) There are loose potentially unstable debris deposits and colluvial boulders within and around the scar. These could become incorporated into any future slope failure and there is a high probability of repetition of similar or larger events in this steep drainage line. A larger event that extended to the toe of the slope would pose a hazard to houses adjacent to the drainage line in San Shek Wan San Tsuen.

7. REFERENCES

Aulitzky, H. (1990). About methods of judgement of slope stability and torrents in Austria. pp 9-15 In: Canceli, A. (ed), 6th Proceedings of the International Conference and Field Workshop on Landslides. ICFWL, Milan.

Chan, Y.C., Lam, C.H. & Shum, W.L. (1991). The September 90 Tsing Shan Landslide: A Factual Report. Technical Note 4/91, Geotechnical Control Office, Hong Kong, 91 p.

Drainage Services Department (1994). Stormwater Drainage Manual. Hong Kong Government, Hong Kong, 145 p.

Evans, N. (1996). Rainfall Distribution and Orographic Effects in Hong Kong. Discussion Note 3/96, Geotechnical Engineering Office, Hong Kong, 30 p.

Geotechnical Control Office (1987). Geotechnical Area Studies Programme, Report III - West New Territories. Geotechnical Control Office, Hong Kong, 155 p.

Geotechnical Control Office (1988). Guide to Rock and Soil Descriptions, Geoguide 3. Geotechnical Control Office, Hong Kong, 191 p.

Geotechnical Control Office (1988). Tsing Shan (Castle Peak), Solid and Superficial Geology. 1:20,000 scale Sheet 6, HMG 20. Geotechnical Control Office, Hong Kong.

Johnson, K.A. & Sitar, N. (1987). Debris Flow Initiation: An Investigation of Mechanisms. Department of Civil Engineering, University of California, Berkeley, San Francisco, 179 p.

King, J.P. (1996). The Tsing Shan Debris Flow. Special Project Report SPR 6/96. Geotechnical Engineering Office, Hong Kong, 3 volumes, 427 p plus 7 drgs, 129 p &166 p.

Langford, R.L., Lai, K.W., Arthurton, R.S. & Shaw, R. (1989). Geology of the Western New Territories, 1:20,000 Sheets 2, 5 & 6. Geotechnical Control Office, Hong Kong, 139 p.

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MateriaLab (1993). Report on Soil Tests for the Geotechnical Engineering Office, Tsing Shan Field Investigation. Contract No. GC/91/06. Works Orders Nos PW 6/3/29.71 and PW 6/3/29.77. MateriaLab, Hong Kong.

Peterson, P. & Kwong, H. (1981). A Design Rain Storm Profile for Hong Kong. Technical Note No. 58. Royal Observatory, Hong Kong Government, Hong Kong.

Pierson, T.C. & Costa, J.E. (1987). A rheological classification of subaerial sediment-water flows. pp 1-12 In: Costa, J.E. & Wieczorek, G.F. (ed), Debris Flows/Avalanches: Process, Recognition, and Mitigation. The Geological Society of America, Boulder, Colorado, USA.

Strahler, A.N. (1952). Hypsometric (area altitude) analysis of erosional topography. Geological Society of America Bulletin, vol. 63, no. 11, pp 1117-1142.

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Duration	Max. Rolling Rainfall (mm)	End of Period		Estimated Return Period (Yr)
		Time	Date	
5 min	6	13:20	13-June-92	< 2
15 min	16.5	13:30	13-June-92	< 2
1 hour	49	13:55	13-June-92	< 2
2 hours	70	13:50	13-June-92	< 2
5 hours	103	15:40	13-June-92	< 2
12 hours	152	23:05	13-June-92	< 2
24 hours	158	23:25	13-June-92	< 2
2 days	158	00:00	14-June-92	< 2
4 days	220	23:00	13-June-92	< 2

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Table 2 - Summary of Characteristics of the Debris Flood That May Relate to Run-out and Volume

Section	Slope Angle	Volume (m^3)	Channel X-section Area (m^2)	Substrate Material as % of Colluvium	Relative Volume of Water	Process
Rocky Gullies Ch 0 to Ch 120	46°	20 initial failure over cliff at Ch 5 from 20 to 92	3	Colluvium with low shrubs. Rock bare. 52%	Initial catchment 3,880 m^2 Volume increasing in bedrock gully from rainfall and temporary damming	Erosion and entrainment
Upper Valley Ch 120 to Ch 230	37°	66 over cliff at Ch 110 from 92 to 101	3.5 - 5.0	Colluvium with low trees and large loose surface boulders 100%	Catchment 21,000 m^2 at Ch 200 Volume decreasing from infiltration into large colluvium deposit	Balanced erosion and entrainment with deposition
Lower Valley Ch 230 to Ch 360	32°	101 over cliff at Ch 230 from 101 to 0 (37 m^3 on path)	indistinct	Colluvium with low trees and occasional large loose surface boulders 69%	Catchment 38,000 m^2 at Ch 360 Smaller decrease from infiltration into smaller area of colluvium	Deposition on slope and footpath platform

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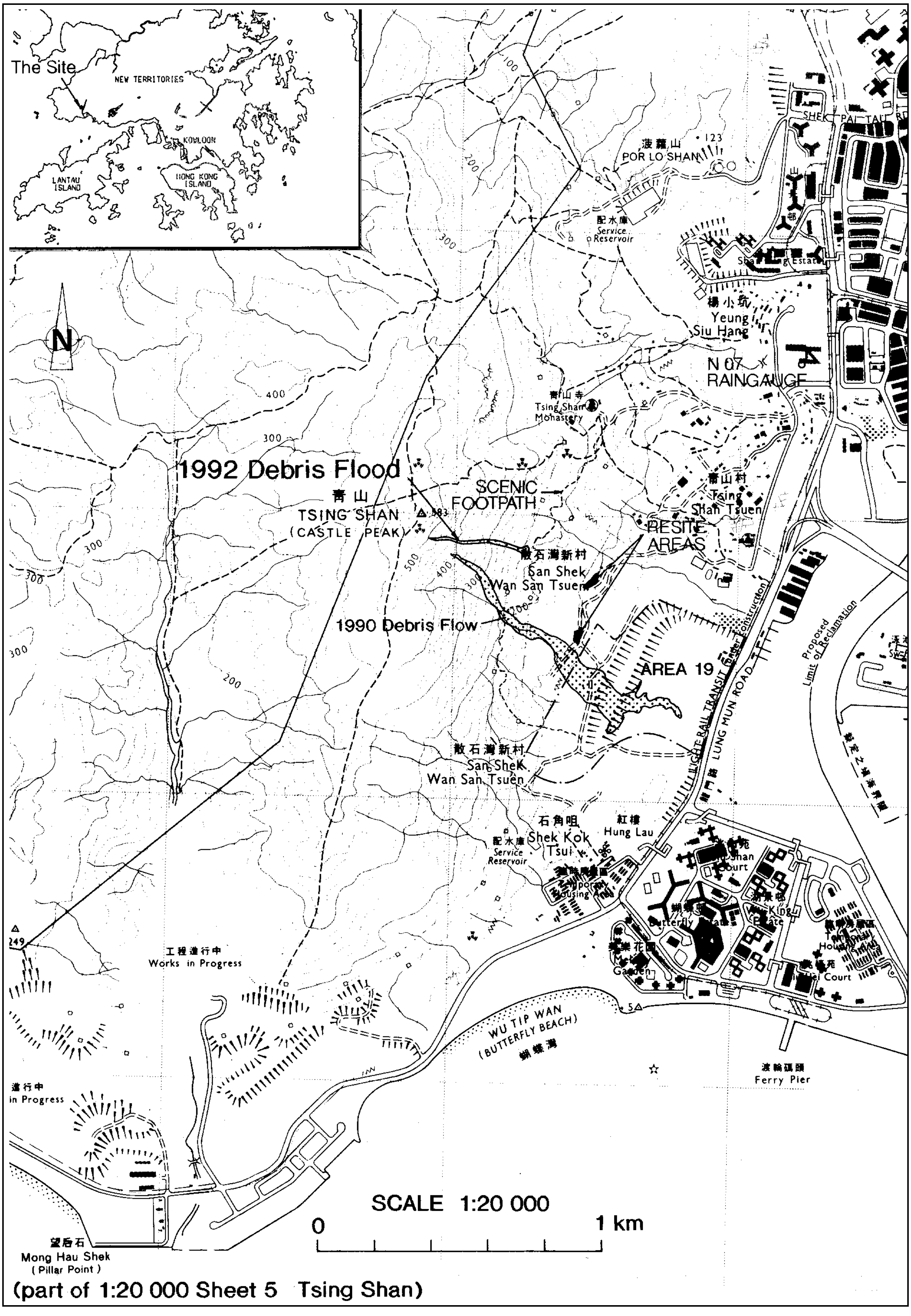

Figure 1 - Site Location Map

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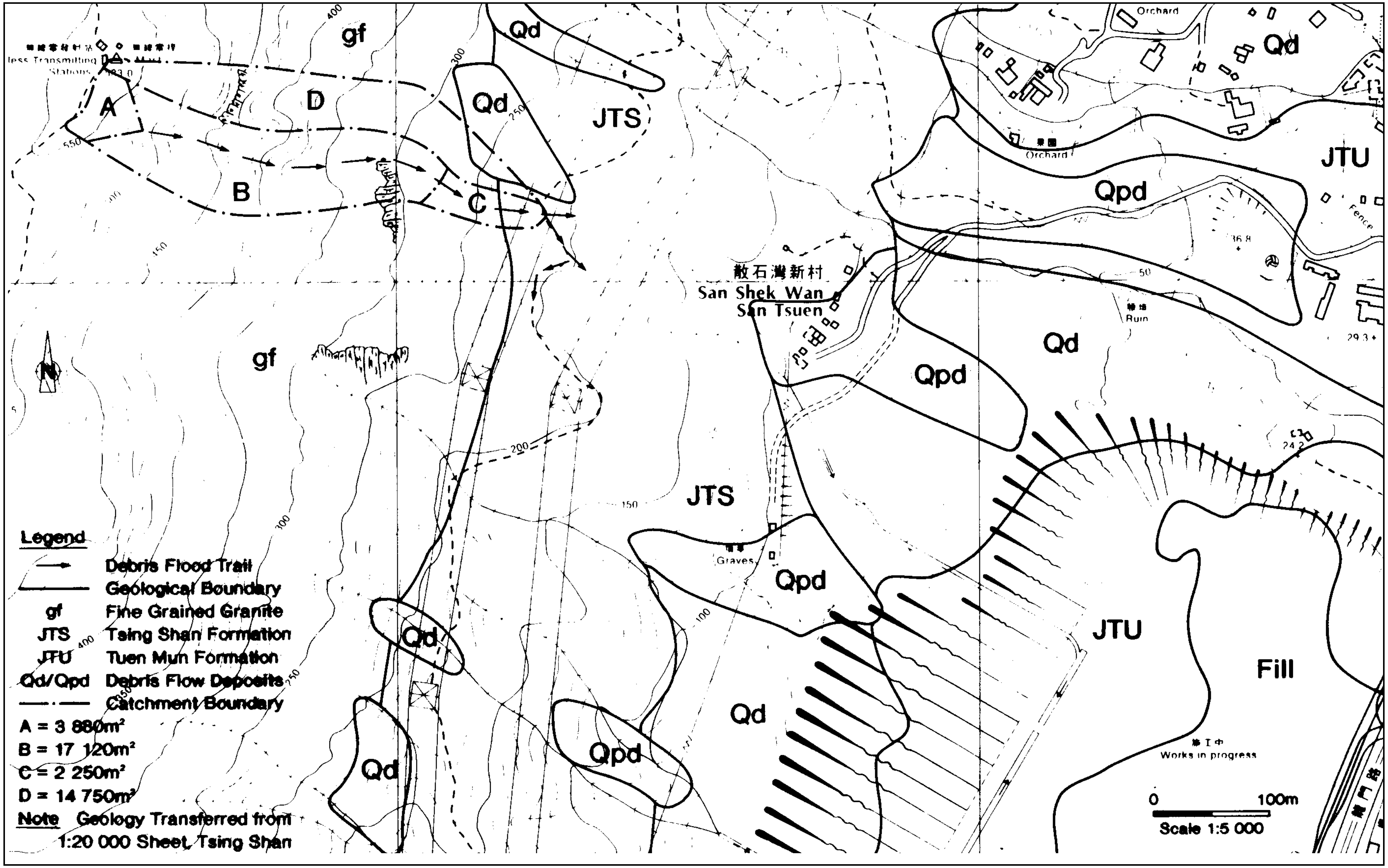

Figure 2 - Geology and Catchment Map

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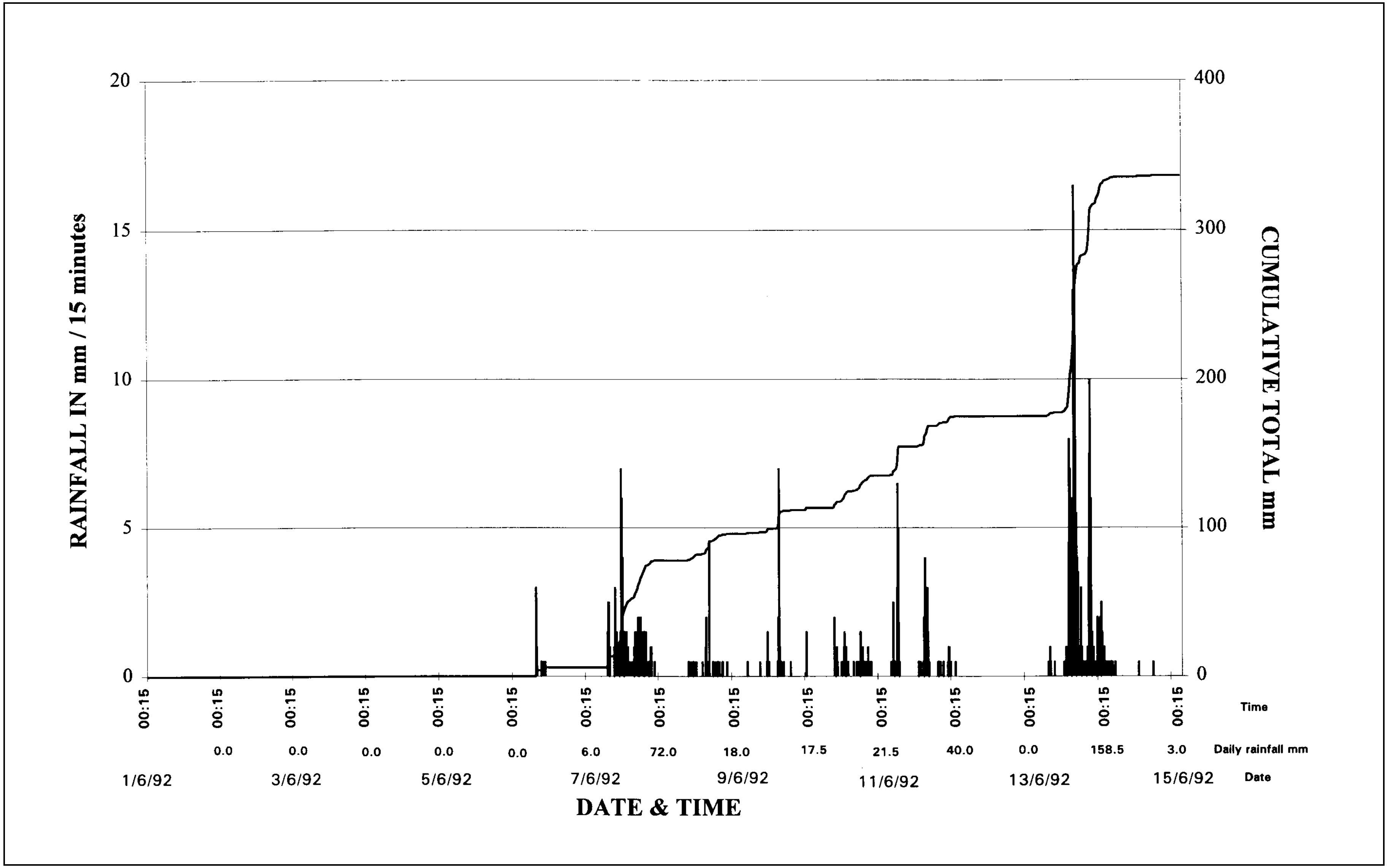

Figure 3 - Rainfall Data at Raingauge No. N07 from 01/06/92 to 14/06/92

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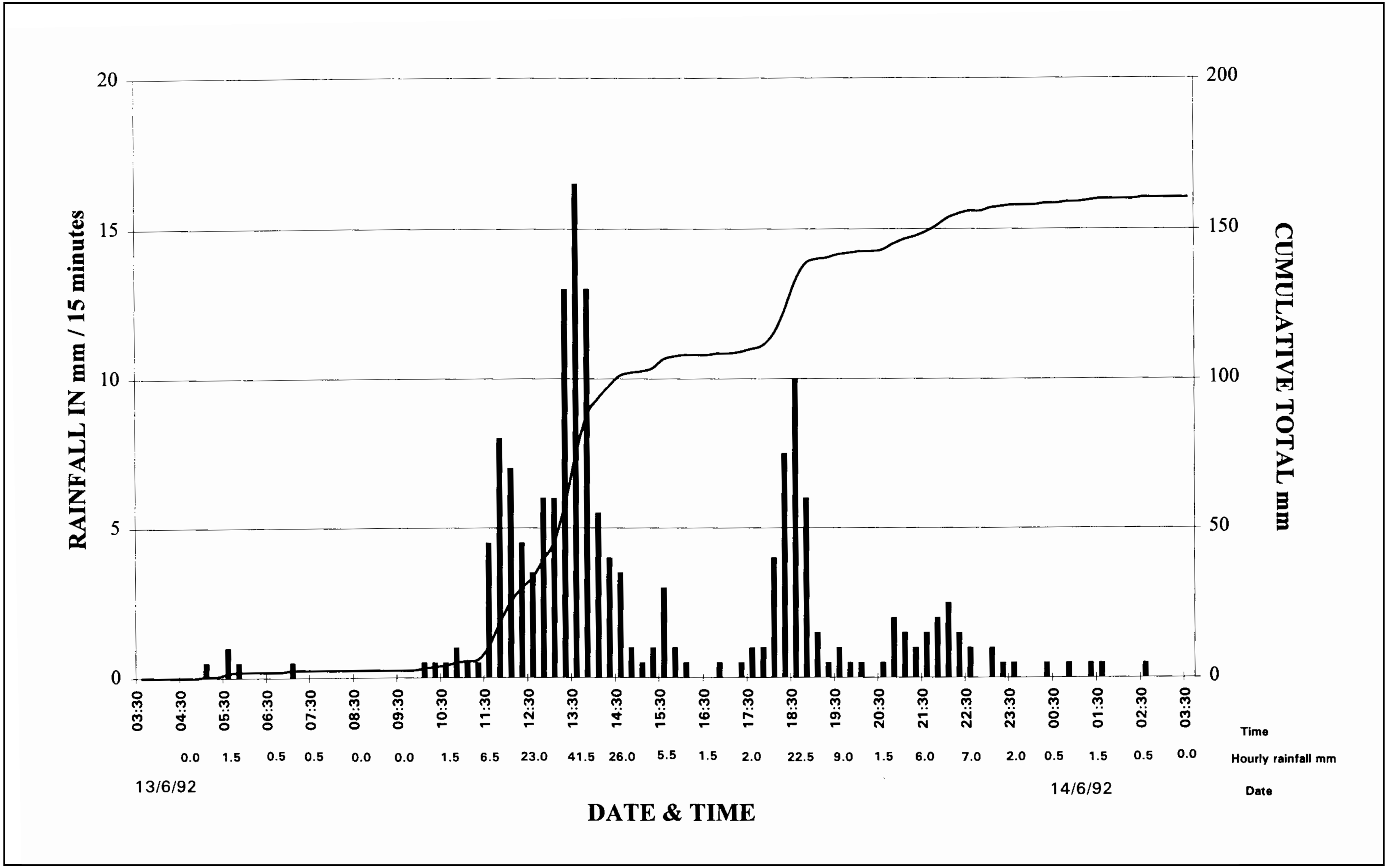

Figure 4 - Rainfall Data at Raingauge No. N07 from 13/06/92 to 14/06/92

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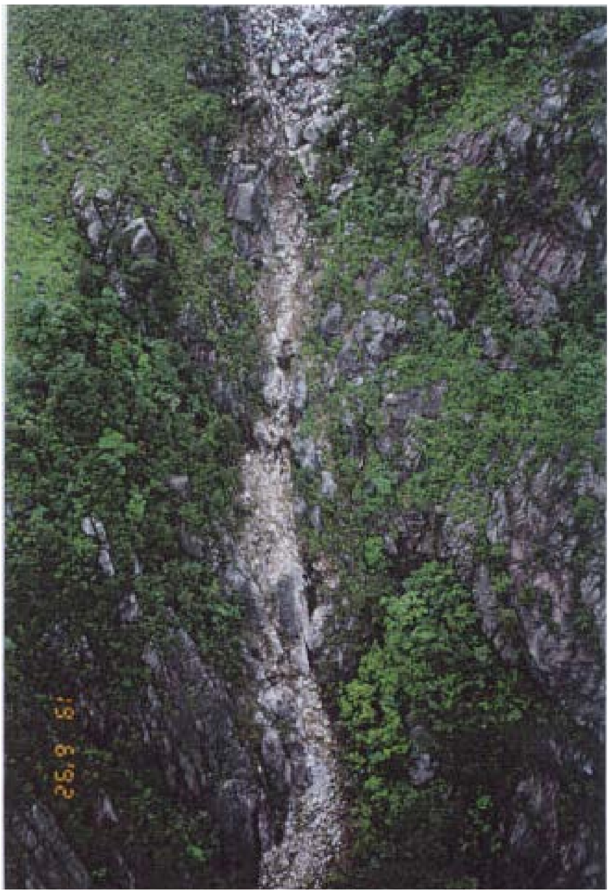

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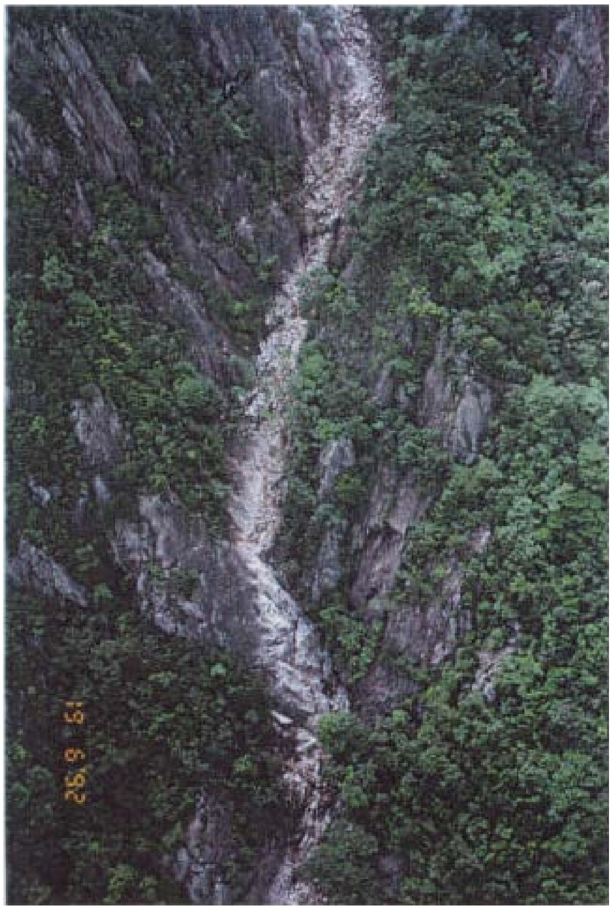

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Plate 7 - Upper Valley Blockage Ch 130 to Ch 220

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Plate 8 - Lower Valley Ch 180 to Ch 280

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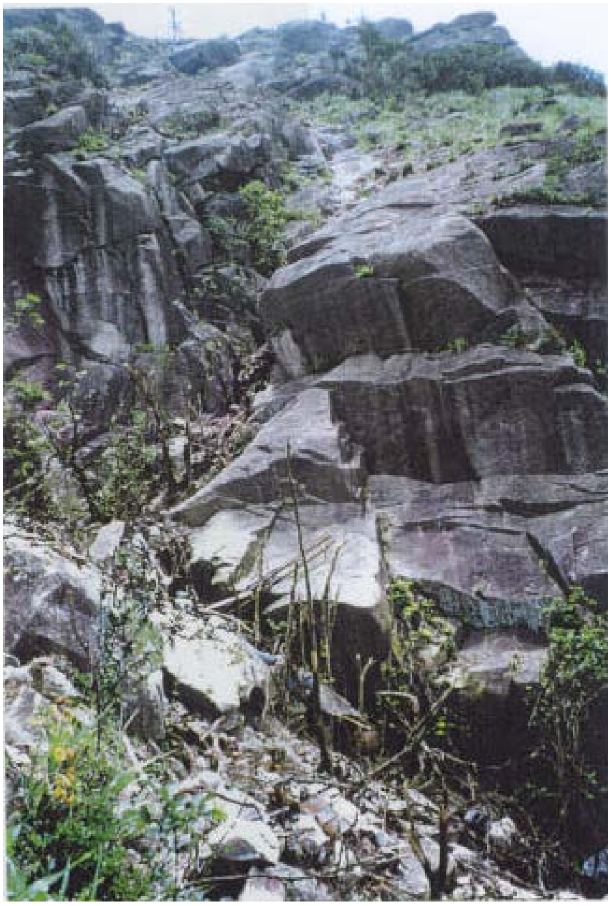

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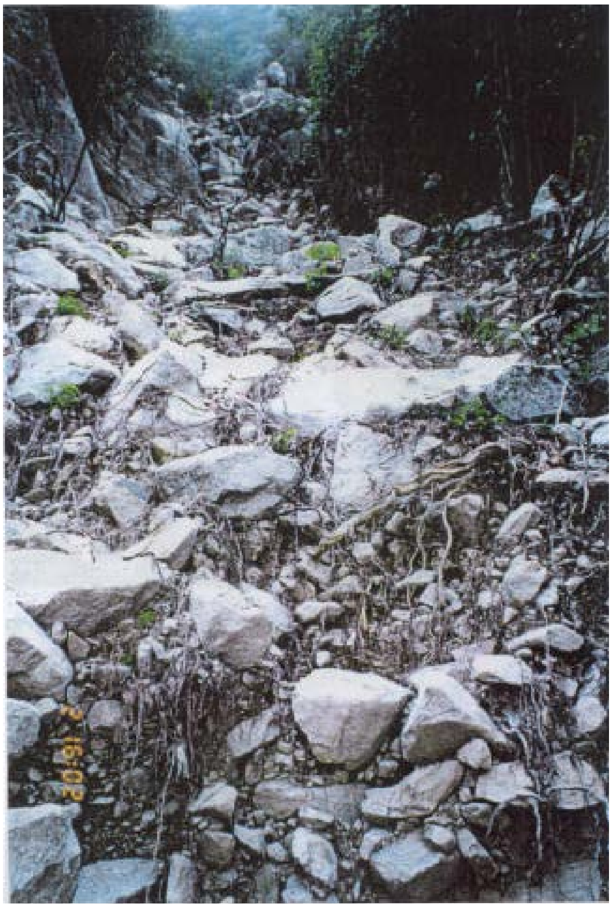
Plate 27 - Loose Colluvium Exposed in Scarp, Ch 205

General Erosion can be Seen in the Trail above

TP 145-25



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SECTION 3: THE 2000 TSING SHAN DEBRIS FLOW

J.P. King

This report is largely based on GEO Landslide Study Report No. LSR 3/2001 produced in May 2001

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PS 1118/10 &12

The 2000 Tsing Shan Debris Flow

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FOREWORD

The 2000 Tsing Shan Debris Flow occurred in the early morning on 14 April 2000. It was reported to the GEO about mid-morning and Planning Division staff made a site visit on that day. This report presents the findings of a detailed landslide study carried out on the debris flow. The main fieldwork for the study was carried out in the following week by a team comprising J.P. King, K.C. Ng, J.C.F. Wong and L.N.Y. Wong from the GEO and C. Massey and S. Williamson of the Fugro Maunsell Scott Wilson Joint Venture Landslide Investigation Consultancy. This fieldwork carried out soon after the landslide allowed mapping evidence for determining the processes that occurred and for interpretation of the event.

The report was prepared by J.P. King. The report was reviewed by K.C. Ng and H.N. Wong. The drafting was carried out by Charles So supervised by K.K. Lau, and Anthea Wong supervised by K.W. Wong.

H. N. Wong
Chief Geotechnical Engineer/Planning

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ABSTRACT

On 14 April 2000 a rainstorm initiated more than 50 landslides on the eastern side of the Tsing Shan Range. During the rainstorm a landslide originated at about 360 mPD on the rocky upper slopes of Tsing Shan. The landslide debris moved down to a spur at 180 mPD where it bifurcated to flow down two drainage lines and deposited bouldery debris at the mouth of both drainage lines. Floodwater and some debris entered the Foothills Bypass construction site, blocking drainage and eroding unprotected soils. Sand, silt and gravel were washed off the site and deposited on the Light Rail Transit tracks, the Tuen Mun Golf Centre driving range and Lung Mun Road.

The estimated volume of natural slope landslide debris involved in the event is about 1,600 m^3. Some 800 m^3 of debris was deposited along the scar, of which 500 m^3 was on a spur in the vicinity of a China Light and Power pylon. About 800 m^3 of the debris was transported off the steep natural terrain, 300 m^3 from the northern drainage line and 500 m^3 from the southern. In addition 3,000 m^3 of material was estimated to have been eroded and washed from the Foothills Bypass site by floodwater that were primarily due to overflow from drainage channels blocked by the landslide debris.

The event is interpreted to have started in a rocky gully and extended down over a planar colluvial slope as a debris avalanche. At the slope toe the debris formed a channelized debris flow in the southern drainage line while a bouldery lobe accumulated on the spur before flowing down the northern drainage line. In both drainage lines most debris moved as a single surge that reached a velocity of up to 18 m/s in the steepest parts.

The trigger for the initial landslide was probably elevated pore water pressure in the bouldery colluvium and weathered profile of the source area. This was promoted by its location at the outlet to a small catchment that is constricted by rock outcrops and narrows to about 20 m.

The geomorphological combination of steep slope gradient (about 40°) and materials characteristics in the source area and the downslope rocky gullies is similar for both the April 2000 and the September 1990 debris flows on Tsing Shan. The environmental factors that pre-disposed the Tsing Shan range to generation of the debris flow are the accumulation of loose bouldery deposits on steep slopes above well-incised colluvium-lined drainage lines that serve to channelize the debris and contribute additional material.

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CONTENTS

1. INTRODUCTION

A landslide occurred on Tsing Shan during a rainstorm at about 05:00 hrs on 14 April 2000 (Figures 1 & 2; Plates 1 to 5). It originated at about 360 mPD on the rocky upper slopes and extended down to a spur at 180 mPD where it divided to form channelized debris flows in the two drainage lines on either side of the spur (Figure 2). Bouldery debris was deposited at the mouth of both drainage lines at about 70 mPD. Floodwater and some debris entered the Foothills Bypass construction site, blocking drainage and eroding unprotected soils (Plates 6 to 8). Sand, silt and gravel were washed off the site and deposited on the Light Rail Transit tracks, the Tuen Mun Golf Centre driving range (Plate 9) and Lung Mun Road. The estimated volume of natural slope landslide debris involved in the event is about 1,600 m^3. About 800 m^3 of the debris was transported off the steep natural terrain, about 300 m^3 from the northern drainage line and 500 m^3 from the southern. A further 3,000 m^3 of material was estimated to have been eroded and washed from the Foothills Bypass site by floodwater that were primarily due to overflow from drainage channels blocked by the landslide debris.

2. THE SITE

The debris flow occurred on the southeastern slopes of Tsing Shan above Area 19, Tuen Mun. Area 19 was excavated as a borrow pit in the late 1970s and was not developed due to deep-seated landslide problems. This area is now part of the construction site for the Foothills Bypass and further east the area is occupied by the Tuen Mun Golf Centre. The debris flow is about 200 m southwest of the 1990 Tsing Shan Debris Flow (King, 1996a).

The geology and geomorphology of Tsing Shan have been described in detail in King (1996a). In general, it comprises steep rocky upper slopes of granite above the gentle spurs and colluvium choked valleys of the lower slopes, which are formed of andesitic volcanic rocks of the Tuen Mun Formation. The andesite at the footslopes is completely decomposed at most exposures.

3. TIME OF FAILURE AND RAINFALL

The debris flow was reported to have occurred between 04:00 and 06:00 hrs by a resident of San Shek Wan San Tsuen Phase II, whose house is about 10 m from the stream channel that contains the southern branch of the debris flow. The debris flow appears to be related to the rainstorm that had started as a gentle rain in the late evening on 13 April 2000.

The nearest raingauges to the debris flow are GEO raingauge N07 and the Foothills Bypass site office raingauge (Figure 1). These were installed in 1982 and 2000 respectively. Records from both raingauges show similar temporal distribution of rainfall (Figure 3). The rolling maximum for the storm peaked at 7:00 hrs. By 05:00 hrs on 14 April 2000 when the debris flow reportedly occurred, the cumulative rainfall was about 160 mm and by 09:00 hrs on 14 April 2000 when the rainstorm was over, a total of 350 mm had been recorded. For all durations from 5 minutes to 48 hours, the estimated return period for the rainfall preceding 05:00 hrs is less than 2 years (Table 1). According to the records from raingauge N07, the area has been subject to rainstorms with considerably greater maximum rolling rainfalls in

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previous years (Figure 4). However, the 3 to 4 hour rolling maxima at the peak of the storm was more severe than all preceding storms recorded by rainguage N07 except for one in 1993 (Figure 4). This indicates the relative severity of the rainfall from 04:00 to 07:00 hrs.

4. THE LANDSLIDE

4.1 General

An initial appraisal of the incident was carried out on 14 April 2000. The materials in the landslide scar, areas of erosion and deposition, and volumes of eroded and accumulated materials were mapped on 17-19 April and 4 May 2000 and from oblique aerial photographs taken on 20 April 2000 (Drawing 1).

Detailed aerial photograph interpretation had previously been carried out for the area as part of the Tsing Shan Debris Flow study (King, 1996a) and the Foothills Bypass geotechnical appraisal report (Scott Wilson, 1998). More recent (1996 to 1999) aerial photographs have been examined in this landslide study. There is no evidence of previous erosion or landsliding in the area occupied by the scar.

A chainage (Ch) was established along the scar from the crown (Ch 0) and separate chainages (prefixed N and S) were used for the northern and southern branches of the debris flow. The scar and its asociated sub-catchments are shown on Figure 2 and longitudinal sections along the centrelines of the scar are given in Figure 5. The volumes of erosion and deposition along the scar were estimated during field mapping (Table 2).

4.2 Upper Part

The crown of the scar is located at 360 mPD, in a vegetated area of angular colluvial boulders that slopes at about 40° between steeper rock outcrops (Plate 1). The colluvial deposit is clast supported, with about equal proportions boulders and cobbles and up to 15% silty sand with gravel. From Ch 0 to Ch 20, the scar forms the source area of a 150 m^3 debris avalanche (Plates 10 & 11). This area is near the ridgeline where the drainage pattern between the outcrops is indistinct. However, it appears to be located at the narrow outlet of a 6,400 m^2 sub-catchment (Figure 2) where flow of surface water, and groundwater in the superficial deposits, converges. On 4 May 2000, groundwater was discharging from the lower part of the source area at an estimated flow rate of about 0.1 1/s. The source area merges downslope into an indistinct rocky gully where there is evidence of considerable erosion of colluvium and weathered granite but little deposition (Plates 12 to 16). At Ch 125 the remains of a large python (about 150 mm in diameter) were found. The snake appears to have been cut in half by the debris flow.

At Ch 135 (250 mPD), the gully ends at a planar to convex 30° slope of bouldery colluvial deposits that forms the upper part of a spur line descending to the China Light and Power (CLP) pylon at 180 mPD (Plate 2). The debris trail fanned out at this point with bouldery levees deposited along both sides of the scar (Plates 16 & 17) and erosion of colluvium and weathered granite in the area between them. Just upslope from the CLP pylon is a large rock outcrop. This outcrop deflected some of the debris down into the southern drainage line, but formed an obstruction above the northern drainage line and more than

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200 m^3 of landslide debris was deposited at the toe of the outcrop around the pylon (Plates 18 to 21). The pylon suffered minor damage in the form of several slightly buckled struts (Plates 18 & 21). Dent marks on the legs and landslide debris caught in the joints suggest that the active debris was up to 3 m above ground level at this location. When the location was first visited at about 13:00 hrs on 14 April 2000, the debris was very soft and up to 1 m thick. Small channels cut by flowing water extend through the debris into the underlying colluvium (Plate 18). There was some erosion around the pad foundations of the pylon legs (Plate 20) but this did not appear to present any threat to the stability of the pylon.

4.3 Northern Branch

The northern drainage line is relatively straight and its upper parts slope at 50° (Figure 5) with bedrock exposed at Ch N315 and along the stream channel below it (Plate 4). Colluvial deposits are restricted to a thin ribbon in the lower parts from Ch N430 to Ch N480. The debris flow was mainly transportational in this part of the scar. Minor erosion of the weathered profile averaged 0.62 m^3 per linear metre. Super-elevations recorded at Ch N420 and Ch N460 both indicate a velocity of about 14 m/s (50 kph). Along the centreline of the trail at Ch N440 there is a 1 m deep eroded gully in the pre-existing colluvium and residual soil. This was probably eroded by floodwater after the main debris flow. From Ch N480 the natural drainage channel had been trained into a concrete cascade channel (1.5 m wide by 2 m high). Debris followed the cascade and overflowed both sides but was still channelized by the valley sides as far as the crest of the old Area 19 cut slope (Ch N525) where the cascade joins with another one and becomes larger (5 m wide by 2 m deep). Here about 100 m^3 of boulders (up to 2 m in diameter) with some finer materials were deposited on a 12° slope beside the cascade (Plate 20). Debris followed the wider cascade onto the Foothills Bypass construction site spilling onto the slope on both sides and overrode a small concrete bridge at Ch N600 (Plates 23 & 24). Some 10 m beyond the bridge, the concrete channel had been diverted 90° into a temporary trapezoidal channel (Plate 6) where the main deposition occurred (Plate 23). The diversion channel was blocked, the bridge deck was damaged (Plate 24), and about 200 m^3 of bouldery debris was deposited (Plate 25). Boulders at this location range from 2 m^3 to 15 m^3 in size. The travel angle from the crown of the scar to this point is about 27°.

Due to the blocked channel, floodwater and a small amount of debris overflowed onto a newly formed cut slope and eroded sand from a 1 m thick drainage blanket and recently backfilled deep trench drains (Plate 26). The floodwater flowed through the site, eroding deep gullies in exposed completely decomposed andesite and recently placed fill. Part of the flood joined water from the southern drainage line, part washed onto the golf driving range depositing sand, silt and gravel, and part flowed northeast, off the site (Plates 8, 9, 34 & 35).

4.4 Southern Branch

The southern drainage line has a more regular long profile than the northern drainage line (Figure 5) and the lower parts are choked with bouldery colluvial deposits into which the stream channel has incised. The debris flow trail continues smoothly down the valley and a super-elevation at Ch S380 indicates a velocity of about 18 m/s (65 kph). The average erosion of weathered profile and colluvial deposits along the valley was 0.85 m^3 per linear

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meter. Minor deposition occurred at Ch S400 to Ch S425 where the channel has a slope of about 17° (Plate 25). This was mainly associated with the partial blockage of the incised stream channel by several large boulders in the colluvium. The main deposition was beyond Ch S530 where the valley becomes wider and flat-bottomed with a slope angle of about 10°. At this location, the nature of the extensive pre-existing bouldery colluvial deposits are very similar to the current landslide debris (Plate 32).

Near the start of this wider part of the valley (Ch S550), a 30 m long by 3 m high ridge of bouldery landslide debris was formed (Plate 28). The ridge includes a boulder about 3 m in diameter. Beyond the ridge, debris with boulders and cobbles was deposited in patches on the wide flat valley floor. San Shek Wan San Tsuen Phase II is adjacent to the stream valley but most of the village is located about 8 m above the valley floor on higher ground to the south, and was not affected by the debris flow. However, two houses located on lower ground to the north are less than 20 m from the bouldery debris ridge. Floodwater, and possibly late stage debris, was deflected by this ridge against the stream bank, which was eroded to within 10 m of one house (Plate 29). At Ch S650 the debris overrode a culvert on the San Shek Wan San Tsuen access track, blocked the 0.9 m diameter concrete pipe (Plate 31) and flattened a 110 mm diameter steel electricity supply pole (Plate 30). The debris flow continued down the stream course onto the Foothills Bypass construction site where some 250 m^3 of debris was deposited (Plate 33). The travel angle from the crown of the scar to this point is about 24°.

Some landslide debris and floodwater overflowed the stream course and followed the village access track to merge with floodwater from the northern valley and then rejoined the main southern flood. The flood carried finer material from the debris flow, and material eroded from the construction site down the site access road. Sand and gravel were deposited on the access road (Plate 34) whereas mainly silt was deposited beyond this on the LRT track and Lung Mun Road (Plate 35).

4.5 Mode of Failure

Debris flows are complex events with both spatial and temporal variations of the processes involved. They are seldom observed in motion and interpretation of the likely sequence and mode of failure is often based on interpretation of field observations made long after the event. Data collection for the 2000 debris flow was carried out shortly after the failure and observations that could be made are useful for interpretation of the debris flow.

4.5.1 Process

Field observations that provide indications of the processes and mechanisms involved are given below starting from the source (Ch 0).

At the source area the surface of rupture was uneven with height variations of at least 1 m. About 75% by area exposed colluvium with angular boulders, mainly less than 0.5 m long but with occasional boulders up to 2 m long. The other 25% was in-situ weathered profile varying from completely to moderately decomposed granite, mainly exposed as a sub-planar joint face that dips out of the hillside (60/080). No slickensides were observed on

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this plane. Immediately downslope from the source (Ch 25) there were traces of remoulded debris and occasional gravel, cobbles and small boulders deposited on the hillside where low vegetation had been flattened and aligned downslope. The ground at these locations was not significantly eroded. These observations suggest that the start of the event was mobilisation of a significant proportion of the source volume as a single mass in which the fines rapidly developed into remoulded debris and started to flow. While minor sliding components may have initially operated along the joint plane, a large proportion of the displaced material probably flowed from the source with smaller clasts carried in a fine matrix, while larger boulders rolled. As the debris flowed downslope it eroded material along the centreline of the trail, effectively extending the source area downslope to form the concave eroded part of the trail. The presence of debris on the undisturbed ground at the edge of the scar immediately downslope from the source (Plate 12) suggests that at the time of initial failure, the ground downslope from the source was undisturbed as debris flowed over it and erosion occurred along the centreline. Had the scar developed by failures progressively extending up into the source area, it is more likely that the remoulded debris would have remained within the eroded part of the scar.

From the source to about Ch 135 there were several deposits of remoulded debris forming small lobes on the ground beside the eroded part of the trail (Plate 13) and accumulations of small boulders and cobbles banked up against boulders and tree trunks (Plate 14). A number of displaced boulders could be seen in the undergrowth around the trail and bounce marks were present on rock outcrops. These observations suggest that the landslide debris moved as a flow with a fine remoulded matrix carrying along larger clasts in suspension or by rolling and sliding. Individual large boulders from the debris, or in-situ boulders dislodged from the ground surface, probably rolled and bounced down the steep hillside outside the main mass of debris.

On the colluvium-covered slope from Ch 135 to Ch 300, there are levees of boulders and vegetation up to 2.5 m high on either side of the trail. The trail widens downslope from less than 25 m to about 70 m (Plates 2, 16 & 17). The levees probably result from sorting of the larger clasts to the front and sides of a debris surge, and frictional edge effects along the sides of the trail. Based on the width of the trail a debris surge probably had about 50 to 100 m^2 cross-sectional area. Given that the maximum volume of material that could have passed along the trail at this point was less than 1,000 m^3, a single surge of debris would have been a maximum of 20 m long. It is unlikely that surges smaller than this could have remained coherent on this rough slope. This, and the lack of other levees in the trail, suggests that on this slope the main failure was probably a single surge of debris.

On the northern side of the scar, near the CLP pylon, there are larger deposits of boulders protruding from a finer matrix (Plates 17 & 19) and evidence of debris up to 3 m high at the pylon legs. About 6 hours after the event the matrix was very soft and wet but later when dry it became stiff. The bouldery deposits are up to 2.5 m thick and their tops are at a similar level although separated by irregular gullies. The base of the gullies has been eroded into the underlying existing colluvium by flowing water. At this location debris may have accumulated in a thick lobe from the flow down the southern drainage line. As the lobe built up it either overflowed into the northern drainage line leaving the irregular gullies or was subsequently eroded by water, or more fluid debris, that carried it down the northern drainage line.

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On the southern side of the scar the debris trail continues smoothly down into the southern drainage line with minimal deposition, except a small lobe of debris up to 1 m thick that rode up onto the spur at the head of the drainage line.

The trails down the two drainage lines vary in width with the degree of channelization. Along the edges there were commonly traces of remoulded debris associated with in-situ aligned vegetation and deposits, sometimes bouldery, banked up against obstructions. Near the centreline of the trail, there were occasional smooth patches where the upper layers of vegetation and soil had been removed and traces of remoulded debris had been deposited. The debris trail showed super-elevation at bends. The main debris deposits were bouldery lobes where the slope flattened and channelization ended. These observations suggest that the main debris surge in the drainage lines behaved *en masse* as a high-density erosive fluid that comprised boulders in a fluid remoulded matrix.

The largest boulders transported in the landslide were angular, up to 3 m long and 15 m^3 in size. It is most unlikely that these were transported by floodwater as the volume of water required to give sufficient cross-sectional area and velocity is much greater than would be expected to have occurred given the rainfall and catchment characteristics. However, a debris flow pulse would have had sufficient cross-sectional area and the remoulded debris matrix is more viscous than water and could have supported them. The loose open structure of the levees on the colluvial slope and the bouldery deposits at the mouth of the drainage lines indicate that the finer matrix must have been easily drained, or washed away, after deposition of the boulders. A debris surge thick enough to support such boulders would have to be in the order of 1 to 2 m deep.

Along the centerline, the lowest point of the trail was washed clean of debris with gully erosion into the substrate and occasional small accumulations of washed sand and gravel. The significant water erosion appears to have occurred after the main debris flow event as it cuts through all debris deposits. Up to 10% of the estimated erosion (Table 2) was probably caused by water. Heavy flooding with brown muddy water can be observed on photographs of the scar taken at about 09:00 hrs on 14 April 2000 (Plate 23), some 3 hours after the witness reported the end of the debris flow event in the southern drainage line (see paragraph 4.5.2 below). By 11:30 hrs, the flow had decreased and the water was clear. The debris flow cleared out the vegetation and surface irregularities along the drainage lines, which would have resulted in considerably faster flood flows and hence greater water erosion than if no debris flow had occurred.

4.5.2 Timing and Velocity

The villager who lived next to the southern drainage line reported the event started with boulders in a flood at about 04:00 hrs on 14 April 2000 and lasted until 06:00 hrs. This gives the duration of the event in the southern drainage line. The time that channelized debris flow occurred in the northern drainage line is not certain and it might not be until the later part of this period.

The rainfall records show the most intense rainfall occurred from 5:00 to 7:00 hrs. This was probably after the first initiation in the source area but may have contributed to development of the channelized debris flow in the northern drainage line. It would have

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enhanced the gully erosion and final distribution of debris after the main surge(s).

The python killed near Ch 120 indicates the debris flowed with a velocity greater than it could avoid. At the CLP pylon (Ch 240), the damaged bracing struts on the northwest leg (50 mm angle bar, 10 mm thick) indicate that debris arrived at this point with enough impact velocity to bend them; however, the main struts (100 mm angle bar, 10 mm thick) were not noticeably distorted.

Debris flow velocity was estimated as 14 to 18 m/s at locations where super-elevation of the trail could be measured. These locations were below the steepest sections, which were probably the points of highest velocities. Given the active volume through these sections was about 300 to 400 m^3 , and the cross section area was about 10 m^2, the bulk of the debris could have passed through in a few seconds.

Other evidence of high velocities is the remnants of vegetation still present below rock ledges in the waterfall area of the northern drainage line. This indicates that the debris was moving fast enough at this point to have the momentum to arch out from the ledge without affecting the vegetation below.

4.5.3 Summary

The event is interpreted to have started in the rocky gully as a debris avalanche that continued down over the open colluvial slope (Ch 0 to Ch 300). At the slope toe some debris flowed down the southern drainage line while a bouldery lobe accumulated on the spur at the CLP pylon before flowing down the northern drainage line. Channelized debris flows occurred in both drainage lines and in each case most of the debris probably moved as a single surge with a velocity of up to 18 m/s in the steepest parts. The estimated total volume of the natural terrain landslide is about 1,600 m^3 (Table 2A). Some 800 m^3 of debris was deposited along the scar, 500 m^3 of which was in the vicinity of the CLP pylon. About 300 m^3 of bouldery debris was deposited at the mouth of the northern drainage line and some 500 m^3 in the lower part of the southern drainage line and at its mouth. The travel angles for the northern and southern branches are 27° and 24° respectively.

4.6 Consequences of the Landslide

4.6.1 Foothills Bypass Site

The debris flow resulted in deposition of about 700 m^3 of bouldery debris on the Tuen Mun Foothills Bypass site which blocked a drainage diversion channel (Plates 22 to 25 & 33). The floodwater overflowed and eroded the sand from deep trench drains on a newly formed cut slope and a 1.5 m thick drainage blanket (Plate 26). It also cut gullies several meters deep into the exposed completely decomposed andesite at several locations. The total material eroded and washed from the site is estimated at about 3,000 m^3. Vehicles parked along the site access road were embedded in debris (Plate 34).

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4.6.2 China Light and Power Pylon

The China Light and Power (CLP) pylon located on a spur at about Ch 240 received almost a direct hit from the debris (Plates 18 to 21) and the debris impact bent several bracing struts. Debris piled up to 1 m thick against the uphill legs and there is evidence of active debris up to 3 m above ground level. The debris flow also caused some erosion around the pad footings. CLP have since constructed some deflection barriers to protect the pylon.

4.6.3 Other Facilities

A section of Lung Mun Road was closed and shops at Glorious Gardens on the other side of the road were reported to have been affected by the floodwater carrying fine debris. The Golf Centre was closed due to deposition of up to 0.5 m thick sand and silt on the driving range. The Light Rail Transit service was suspended for several hours on the morning of 14 April 2000 due to flooding elsewhere but the silty debris deposited on the tracks required clearing before resumption of service (Plate 35).

4.6.4 San Shek Wan San Tsuen Phase II

San Shek Wan San Tsuen Phase II was not directly affected by the debris flow although stream bank erosion came within 10 m of a house (see Section 4.4 above). On 14 April 2000, following the debris flow event, the GEO advised the residents of this house to seek shelter elsewhere in periods of heavy rain. Further downstream the debris flow blocked and overrode the culvert at the access road to the village and floodwater eroded along the sides of the concrete roadway. Adjacent to the culvert a 110 mm diameter steel pipe power pole was pushed down by the debris (Plate 30).

5. PREVIOUS ASSESSMENTS

5.1 Non-Development Clearance

After the 1990 Tsing Shan Debris Flow, a review of the previous Non-Development Clearance (NDC) recommendations in the area was carried out by GEO in 1993. This included San Shek Wan San Tsuen Phase II. Most houses are located on the spur to the south at least 8 m above the stream channel. The closest ones to the stream line were judged to be beyond the range of landslide debris from an event similar to the 1990 debris flow, and were not cleared.

A few structures were located about 2 m above the stream channel along the northern bank of the stream course around Ch S600. These structures were judged to be of high risk and an NDC was recommended to Housing Department (HD). HD reported that these structures had been demolished. One of the demolished structures was located on the northern bank that was eroded during the 2000 debris flow. The structure occupied by the resident who reported the 2000 debris flow was judged to be near the limit of landslide debris, i.e. of moderate risk. Following the April 2000 debris flow, the GEO has inspected this and adjacent stream courses and recommended additional NDC (but not in this stream course).

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5.2 Foothills Bypass Natural Terrain Hazard Assessment

A study of the natural terrain hazards to the Foothills Bypass, now under construction, was carried out by Scott Wilson (1996). The study identified representative sites that could give rise to debris flows and the potential impact of such events to the proposed Foothills Bypass. As the Bypass along this section of the alignment will be located on an embankment, the study also assessed the effects of a debris flow of the magnitude of the 1990 Tsing Shan Debris Flow on the embankment. It was concluded that as the retaining capacity of the area upslope of the embankment exceeds the volume of the design event, there is no significant risk to the Bypass.

In view of the qualitative nature of the assessment, Scott Wilson (1996) proposed some debris flow hazard mitigation measures. These took the form of check dams in some drainage lines, and erosion protection and subsoil drainage in the source area of the 1990 debris flow. Boulders in the 1990 debris flow drainage line that are in excess of 1 m in diameter, and considered to pose a significant hazard, are to be removed or stabilised. The primary purpose of the check dams was to provide protection to the Area 19 slope works and surface drainage provision by retaining future debris flow materials (from relatively small events), alluvial materials or discrete boulder falls. For a medium size debris flow, the check dams would also dissipate energy and encourage deposition. In the event of a large debris flow, it is possible that the check dams would be destroyed and have to be reconstructed. Cost-benefit analyses of the check dams were carried out in late 2000 and resulted in them being replaced by prescriptive works at some cascade intakes intended to protect them from small debris flows. At each intake the works comprise concrete lined basins to promote deposition and provide storage for 300 to 400 m^3 of debris.

6. OTHER LANDSLIDES IN THE VICINITY

6.1 Historical

The 2000 debris flow (Figure 1) occurred in a valley adjacent to the 19,000 m^3 1990 Tsing Shan Debris Flow (King, 1996a) and the 250 m^3 1992 Tsing Shan Debris Flood (King, 1996b). The Natural Terrain Landslide Inventory (NTLI) also recorded a number of other features in the vicinity and these were reviewed using low-level aerial photographs. A 1963 debris avalanche about 100 m long was confirmed on the northern side of the spur where the 1990 debris flow initiated. Another small landslide of the same year was identified nearby. Other NTLI landslides are small relict interpretative features that could not be confirmed due to the poor 1945 aerial photography but could be recognized as possible degraded source areas on the 1963 aerial photographs. None of them were located near the source area of the 2000 debris flow. Several small landslides have occurred on the Tsing Shan mid-slopes since the NTLI was compiled in 1994 but none are near the 2000 debris flow source area.

The Large Landslide Study (Scott Wilson, 1999) identified a feature with a large source area near the CLP pylon and a trail down the southern drainage line of the 2000 debris flow. The trail is a well-defined ridge of colluvium that could be the levee from an earlier debris flow in this valley or the remnant of a linear valley in-fill debris lobe. The source is a broad area of rocky cliffs on the upper slopes of Tsing Shan and it is not possible to identify a single well-defined depletion area. The colluvial deposits along the drainage line lead into a more fan-like deposit at the mouth of the drainage line, which is an indicator of past landslide

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activity. The colluvium is mainly formed of granite clasts, indicating its origin from the upper slopes. Extensive bouldery colluvial deposits are also present in the vicinity of the CLP pylon, which is presumably an accumulation point for debris from landslides and rock falls on the steep cliffs above.

The lack of colluvial deposits along the northern drainage line of the 2000 debris flow suggests there has been little historical large scale landslide activity in this sub-catchment.

6.2 Current

The 14 April 2000 rainstorm initiated more than 50 landslides on the eastern side of the Tsing Shan Range. Some locations plotted from oblique aerial photographs taken on 20 April 2000, are shown in Figure 1.

At about 200 m to the southeast of the 2000 debris flow source area, a large debris avalanche/flow originated from rocky cliffs on the upper slopes. There was also some erosion and small landslides along the scars of the 1990 debris flow and the 1992 debris flood. At least three smaller natural terrain landslides occurred on the eastern side and one on the western side of the ridge (Figure 1). About six small failures occurred at the cut slopes along the Tsing Shan scenic footpath and several more on the natural slopes around the Tsing Shan Monastery.

Along the range to the northeast, about 20 landslides occurred on the slopes above the Leung King Estate and more than 20 landslides further northeast above Area 54, Tuen Mun. A brief aerial reconnaissance of parts of the western side of the Tsing Shan Range on 20 April also revealed several tens of landslides.

7. CAUSES OF THE DEBRIS FLOW

The causes of the debris flow can be divided into those relevant to the initial failure in the source area, and those that contributed to the increase in volume from entrainment along the flow paths. The trigger in the source area was probably development of elevated pore water pressure in the bouldery colluvium and weathered profile during the rainstorm on 14 April 2000. The environmental factors that pre-disposed the site to generation of the debris flow are the accumulation of loose bouldery deposits on steep slopes above well-incised drainage lines containing bouldery colluvium that serve to channelize the debris and contribute additional material to the debris flow.

7.1 The Source Area

The slope angle in the source area of the initial failure is about 40°. The displaced materials are mainly clast supported angular bouldery colluvium estimated to be about equal proportions of boulders and cobbles, and up to 15% silty sand with gravel. About 75% of the surface of rupture is irregular and within colluvium while 25% is along a joint plane (60/080) in weathered granite.

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The source is located at the point where a 6,400 m^2 catchment on the upper slopes is constricted by rock outcrops and narrows to about 20 m wide. Such a location would serve as a focal point for surface and subsurface water flows. This would have promoted the rapid saturation of the bouldery colluvium during the rainstorm on 14 April 2000.

The loose clast-supported colluvium has a relatively high permeability compared to the underlying weathered profile and bedrock or overlying topsoil. This could form a partially confined aquifer for through-flow from the upper part of the catchment and locally cause elevated pore water pressure. It might also have resulted in development of artesian conditions.

There are sufficient fines in the colluvium that when mixed with water it may form a slurry capable of supporting clasts and flowing downhill. This appears to have occurred rapidly in the source area as there were deposits of remoulded fines on *in-situ* grass at Ch 25.

7.2 The Flow Path

The upper rocky slopes of Tsing Shan are formed of jointed granite, commonly with sheeting joints. Wide to closely spaced joint sets intersect to form rocky gullies such as the one followed by the debris avalanche from Ch 0 to Ch 120. The intersecting joints favour small wedge and planar failures into the gully, resulting in the accumulation of angular blocks in some parts of the planar sided gullies. These marginally stable deposits are particularly susceptible to entrainment by landslide debris.

From Ch 70 to Ch 120 a closely spaced joint set (66/048) is a locus for relatively deep weathering; moderately to highly decomposed granite is exposed in the scar. Similar material was probably eroded and incorporated into the debris, which would have helped the generation of a remoulded slurry around cobbles and boulders in the debris.

The 36° planar to convex mid-slopes from Ch 135 to about Ch 220 are mantled with loose angular boulders and locally underlain by moderately to highly decomposed granite. Although the debris spread out and deposited levees along both sides of the scar, erosion occurred at the central part of the trail and the debris volume continued to grow.

Beyond Ch 220 the debris bifurcated and entered the two drainage lines where it was channelized with ratios of 2 to 8 and would have mixed with additional surface water. These factors would have enhanced the debris mobility. The southern drainage line has extensive deposits of colluvium that served both as a source of easily eroded material and an irregular surface that promoted deposition. The lower volume of erosion in the steeper northern drainage line was due to the lack of any significant accumulation of loose colluvium or a thick weathered profile.

8. DISCUSSION AND CONCLUSIONS

The occurrence of the April 2000 debris flow in drainage lines adjacent to the September 1990 and June 1992 events suggests that the Tsing Shan area is susceptible to generation of channelized debris flows from debris avalanches on the upper slopes. Both

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1990 and 2000 debris flows involved significant entrainment along the flow paths. The combination of steep slope gradient (about 40°) and presence of loose angular bouldery colluvium that is susceptible to mobilisation and entrainment, in both the source area and the rock gully immediately downslope, is similar for both debris flows. This appears to be a sensitive geomorphological combination where a relatively small trigger may be sufficient to initiate failure and result in development of relatively large-scale debris avalanches. Once a sufficient volume of rapidly moving debris is mobilised from the upper slopes, this is capable of eroding and entraining large volumes of loose materials from colluvial deposits in narrow V-shaped drainage lines with lower slope angles.

Loose angular bouldery colluvium was present in the source area and immediately downslope at both the April 2000 and the September 1990 debris flows. API and field mapping can identify loose boulders on the ground surface and in this environment, they may provide geomorphological indications of debris flow hazard locations.

The 2000 debris flow was moderately mobile with travel angles of 27° and 24° for the northern and southern branches respectively. However, the main debris deposits from both branches extended more than 50 m beyond 15° ground slopes defined on a 1:5,000-scale map. The "Alert Criteria" for natural terrain hazard study with respect to channelized debris flow should be examined in the light of this event.

Weak weathered profile and loose colluvium that could be easily entrained were present along most of the trail. In these areas the availability of material would not have influenced the rates of erosion and deposition but factors such as slope angle and degree of channelization might have been the main controls. Erosion rates of 1 to 10 m^3 per linear metre were estimated on slopes of 26° to 40° and rates of 0.1 to 1.0 m^3 per linear metre occurred on slopes of 9° to 29° (Table 2). The overall erosion rate along the northern drainage line (0.62 m^3 per m) was slightly lower than that along the southern drainage line (0.83 m^3 per m). This was due to the outcrop of fresh rock along an 80 m length of 35° to 50° slopes in the northern drainage line where erosion was less than 0.1 m^3 per m. Limited deposition occurred on the upper steeper convex slopes of 26° to 30° where the debris flow was not channelized, but most deposition was in partially-channelized and unchannelized conditions on 7° to 15° footslopes.

The bifurcation of the debris flow resulted in two relatively small debris flows. The north drainage line appears to have a low likelihood of debris flows due to its small catchment and the general lack of colluvium from previous events. Conversely, debris flows appear more likely in the south drainage line, which has a large catchment and extensive colluvium deposits. These include a colluvium ridge from Ch S420 to S610, that is visible on the 1963 low-level aerial photographs and which may be the levee from a much larger previous debris flow. The bottom of the drainage line from Ch S530 to S660 can also be identified as an area of past debris deposition although it is not of the typical fan shape due to physical constraint by the valley sides. Had all the debris from the upper slopes been channelized into the southern drainage line, much higher erosion rates may have ensued and a considerably larger debris flow could have occurred.

Both the 2000 and the 1990 debris flows occurred in the early part of a rainstorm with a return period of less than 3 years. This suggests that the scale of the debris flows is not directly related to the severity of the rainfall that triggered the events. Also the data shows

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that the actual rainfall trigger may not be related to the macro characteristics of the whole of the rainstorm, such as hourly or total rainfall. Where the actual time of failure is not known, interpretation of rainfall and landslide relationship is difficult and may give misleading results. Source materials for both debris flows were loose angular boulders with 10% to 15% fines that have high permeability and possibly extensive piping. On steep slopes this material would be relatively free draining. To saturate this material and generate significant pore water pressure would require a high rate of water input into the system. This could be provided by a short period of high intensity rainfall, possibly in combination with concentration of groundwater flow at the constricted outlet to a catchment. Such a situation may develop during any part of a rainstorm, which could be very localised and hence difficult to predict.

The irregular nature of much of the plane of rupture and the lack of slickensides on the planar part suggest that sliding was not a large component of the initial movements in the source. The presence of remoulded debris in the scar immediately downslope from the source suggests that the finer part of the displaced material rapidly became mobile and moved by slurry flow. The loose nature and high permeability of the source materials combined with the hydrogeological conditions at the source that would have promoted the development of elevated and even artesian pore water pressures in the source materials before failure. These observations suggest that the initial movements of the displaced material may have involved very rapid transformation of the source materials into a slurry by a process similar to liquefaction. While a slurry could have supported some clasts, the movement of some boulders and large cobbles by rolling and bouncing is indicated by impact marks on exposed rock along the trail.

9. REFERENCES

King, J.P. (1996a). The Tsing Shan Debris Flow. Special Project Report SPR 6/96. Geotechnical Engineering Office, Hong Kong, 3 volumes, 427 p plus 7 drgs, 129 p &166 p.

King, J.P. (1996b). The Tsing Shan Debris Flood of June 1992. Special Project Report SPR 7/96. Geotechnical Engineering Office, Hong Kong, 83 p plus 2 drgs.

Scott Wilson (1996). Agreement No. CE44/95, Foothills Bypass, Tuen Mun Road/Wong Chu Road Interchange and Other Road Junction Improvement Works, Final Geotechnical Appraisal Report, Appendix B, Debris Flow Potential along the Foothills Bypass. Report for the Territory Development Department, Hong Kong Government, 22 p plus 1 drg.

Scott Wilson (1999). Specialist API Services for the Natural Terrain Landslide Study – Task B Factual Report. Report prepared for the Geotechnical Engineering Office, Hong Kong.

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Table 1 - Maximum Rolling Rainfall at GEO Raingauge No. N07 for Selected Durations Preceding the Landslide of 14 April 2000 and the Estimated Return Periods (Failure Assumed 05:00 hrs)

Duration	Maximum Rolling Rainfall (mm)	End of Period	Estimated Return Period (Years)
5 Minutes	8.0	04:10 on 14 April 2000	< 2
15 Minutes	19.0	04:20 on 14 April 2000	< 2
1 Hour	47.0	05:00 on 14 April 2000	< 2
2 Hours	59.0	05:00 on 14 April 2000	< 2
4 Hours	99.0	05:00 on 14 April 2000	< 2
12 Hours	128.5	05:00 on 14 April 2000	< 2
24 Hours	145.0	05:00 on 14 April 2000	< 2
48 Hours	145.5	05:00 on 14 April 2000	< 2
4 Days			
7 Days			
15 Days			
31 Days			

Notes:
(1) Return periods were derived from Table 3 of Lam & Leung (1994).
(2) Maximum rolling rainfall was calculated from 5-minute data for durations up to 48 hours, and from hourly rainfall data for longer rainfall durations.
(3) The use of 5-minute data for durations between 2 hours and 48 hours results in better data resolution, but may slightly over-estimate the return periods using Lam & Leung's 1994 data, which are based on hourly rainfall for these durations.

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Table 2A - Summary of Erosion and Deposition along the Natural Terrain Debris Flow Scar

Chainage Interval	Description of Feature	Channelization Ratio	Slope Angle	Erosion		Deposition		Active Volume
				Volume (m^3)	m^3/m	Volume (m^3)	m^3/m	
Ch 0 - 20	Source	3	37°	150	7.5	0	0	150
Ch 20 - 135	Rocky Upper Slopes/Gullies	3 - 7	40°	530	4.6	20	0.2	660
Ch 135 - 220	Colluvial Mid Slope	12 - 30	36°	330	3.9	180	2.1	810
Ch 0 - 220	Depletion/Debris Avalanche		38°	1010	4.6	200	0.9	810 (300N, 510S)
North Branch								300
Ch N220 - N310	Spur	15	26°	160	1.8	240	2.7	220
Ch N310 - N525	Northern Drainage Line	8 - 2	21°	130	0.6	25	0.1	325
Ch N525 - N620	Old Cut Slope (Colluvium Area), Diversion Channel	10 - 13	14°	5	0.05	310	3.3	20
Ch N620 - N660	New Cut Slope	25 - 50	17°	0	0	20	0.5	0
Ch N220 - N660	North Channellized Debris Flow		20°	295	0.7	595	1.4	0
South Branch								510
Ch S220 - S260	Spur	15 - 6	29°	25	0.6	240	6.0	290
Ch S260 - S530	Southern Drainage Line	3 - 5	19°	230	0.9	80	0.3	440
Ch S530 - S660	Colluvial Deposits (Fan)	9 - 15	9°	60	0.5	290	2.2	210
Ch S660 - S750	Foothills Bypass Site	12 - 50	11°	0	0	250	2.8	-40
Ch S220 - S750	South Channellized Debris Flow		16°	315	0.6	860	1.6	-40
Natural Terrain Debris Flow, Total Volume				1,620		1,660		

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Table 2B - Summary of Floodwater Erosion and Deposition in Area 19

Chainage Interval	Description of Feature	Slope Angle	Erosion		Deposition		Active Volume
			Volume (m^3)	m^3/m	Volume (m^3)	m^3/m	
North Branch							
Ch N620 - N670	New Cut Slope, Deep Trench Drains, Drainage Blanket	18°	800	16	(20)	0	800
Ch N670 - N800	Foothills Bypass Site (no measurements)	3°	700	5	0	0	1,500
Ch N800 - N820	Golf Centre Boundary	6°	0	0	400	20	1,100
Ch N820 - N990	Golf Centre	3°	0	0	1,080	6	20
Ch N620 - N990	North Branch Total	5°	1,500	4	1,480	4	
South Branch							
Ch S660 - S750	Foothills Bypass Site (mapped)	11°	60	0.7	(250)	0	60
Ch S750 - S950	Foothills Bypass Site (no measurements)	5°	700	3	0	0	760
Ch S950 - S970	Gully Erosion	5°	600	30	0	0	1,360
Ch S970 - S1150	Upper Site Access Road	3°	0	0	250	1.4	1,110
Ch S1150 - S1225	Lower Site Access Road	1°	0	0	910	12	200
Ch S1225 - S1240	LRT Track	1°	0	0	190	13	10
Ch S1240 +	Lung Mun Road	0°	0	0	150	3	-140
Ch S660 - S1240 +	South Branch Total	5°	1,360	2.2	1,500	2.6	
Site Erosion and Deposition, Total Volume			2,860		2,980		

Notes: (1) Volumes are approximate and have been estimated from a small number of observations and measurements.
(2) (20) Volume of debris deposited from natural slope debris flow, not included in site totals.

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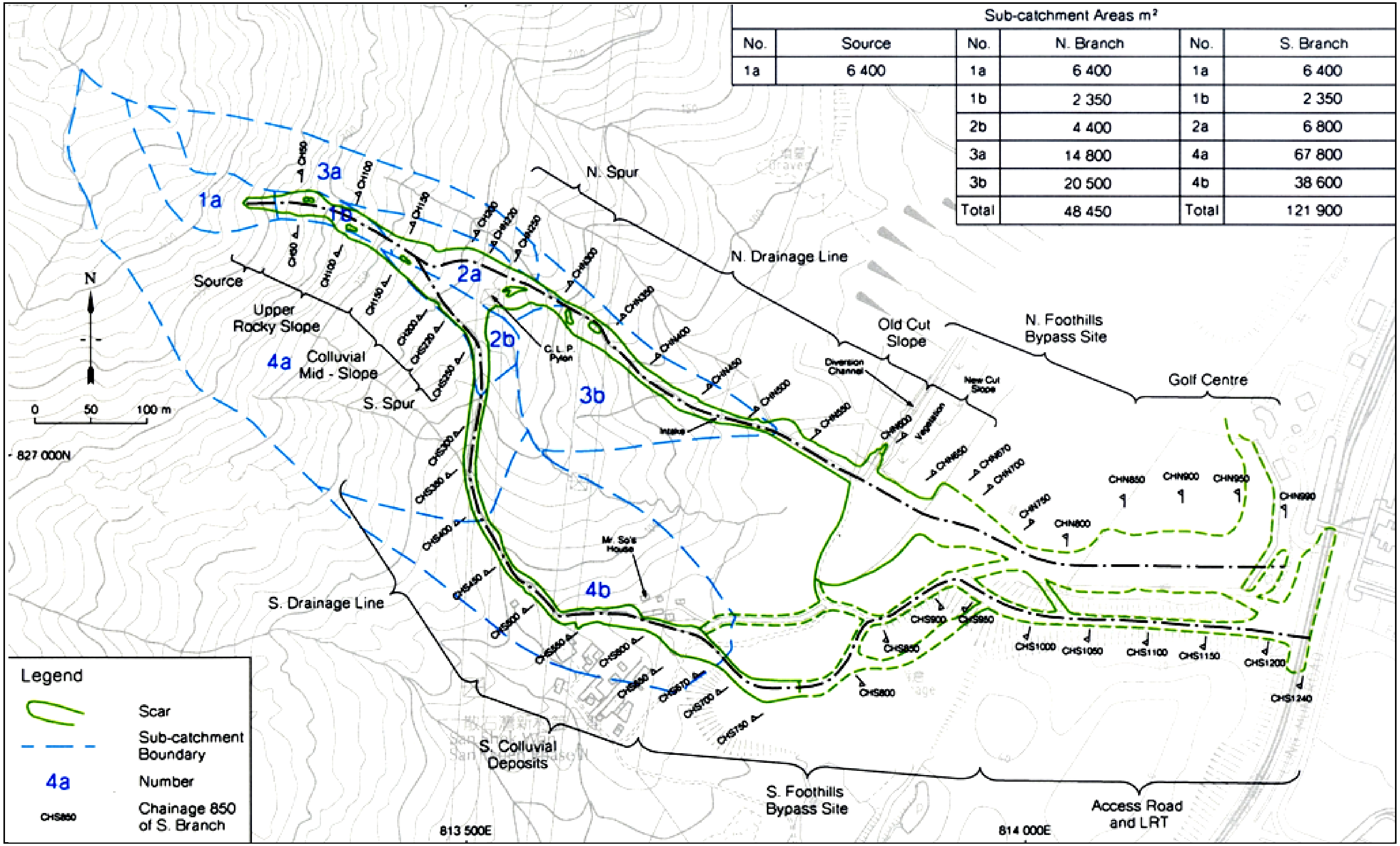

Sub-catchment Areas m²					
No.	Source	No.	N. Branch	No.	S. Branch
1a	6 400	1a	6 400	1a	6 400
		1b	2 350	1b	2 350
		2b	4 400	2a	6 800
		3a	14 800	4a	67 800
		3b	20 500	4b	38 600
		Total	48 450	Total	121 900

Figure 2 - 2000 Debris Flow Scar and Sub-catchment

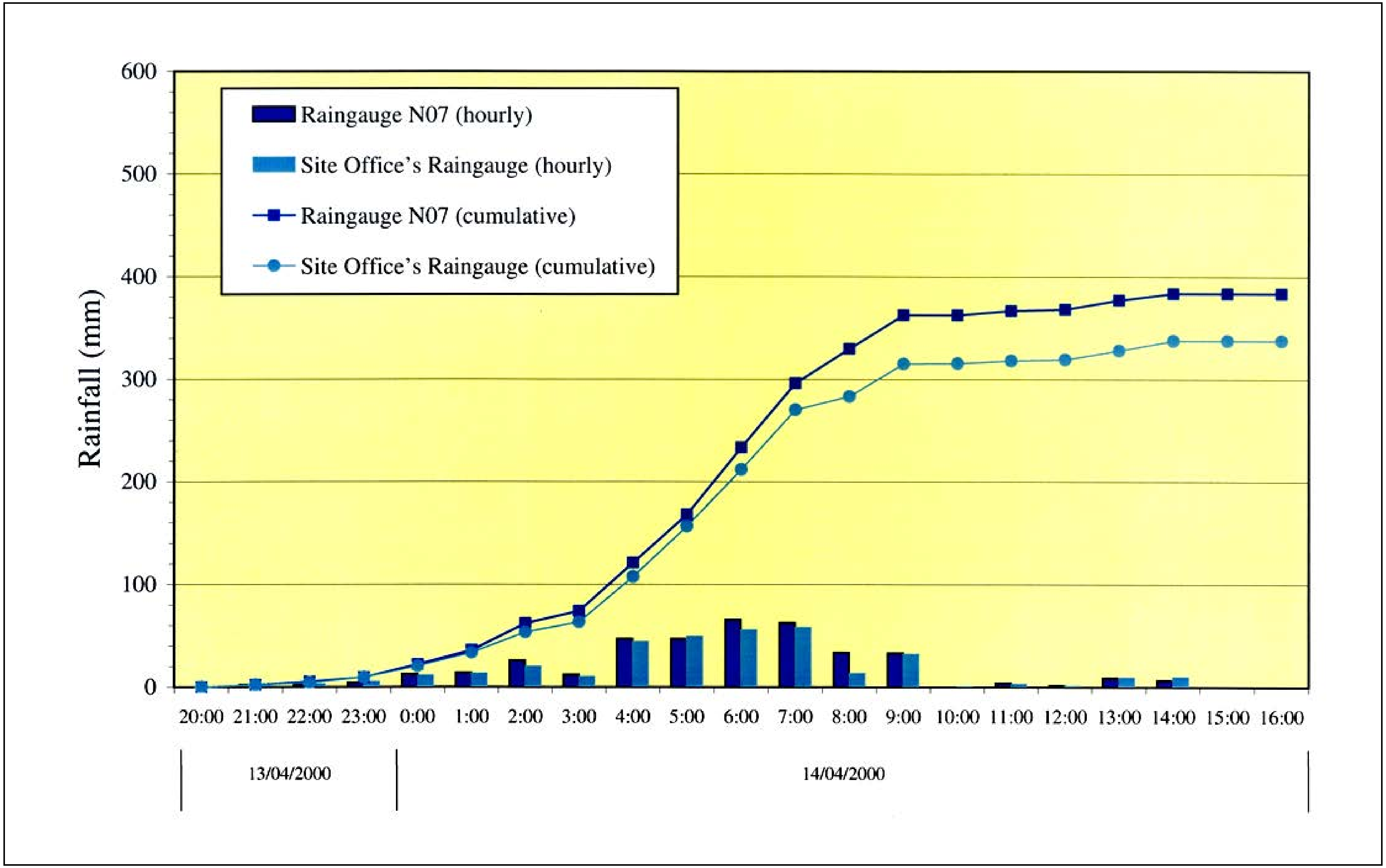

Figure 3 - Hourly Rainfall Recorded by Raingauge No. N07 and Site Office's Raingauge

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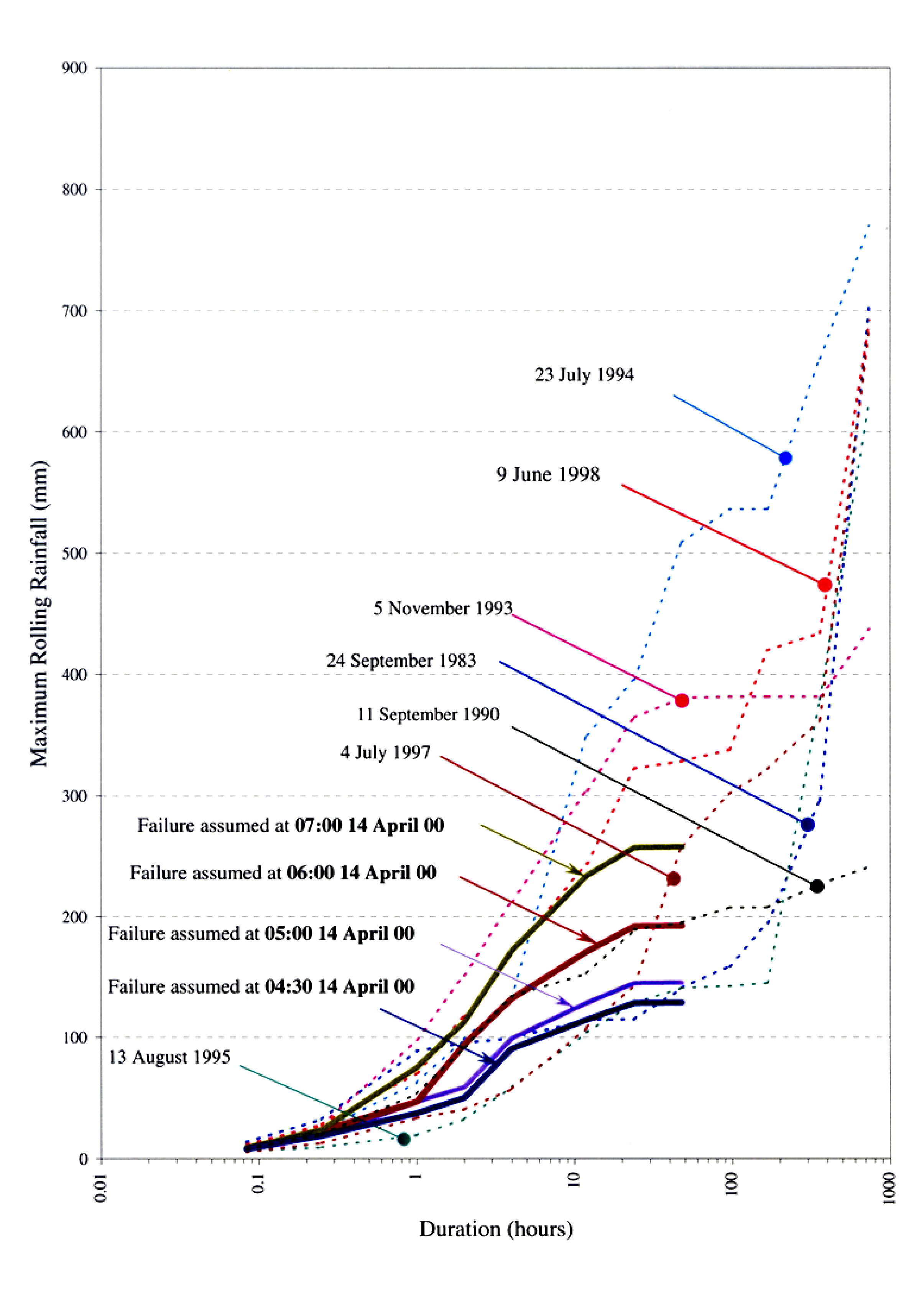

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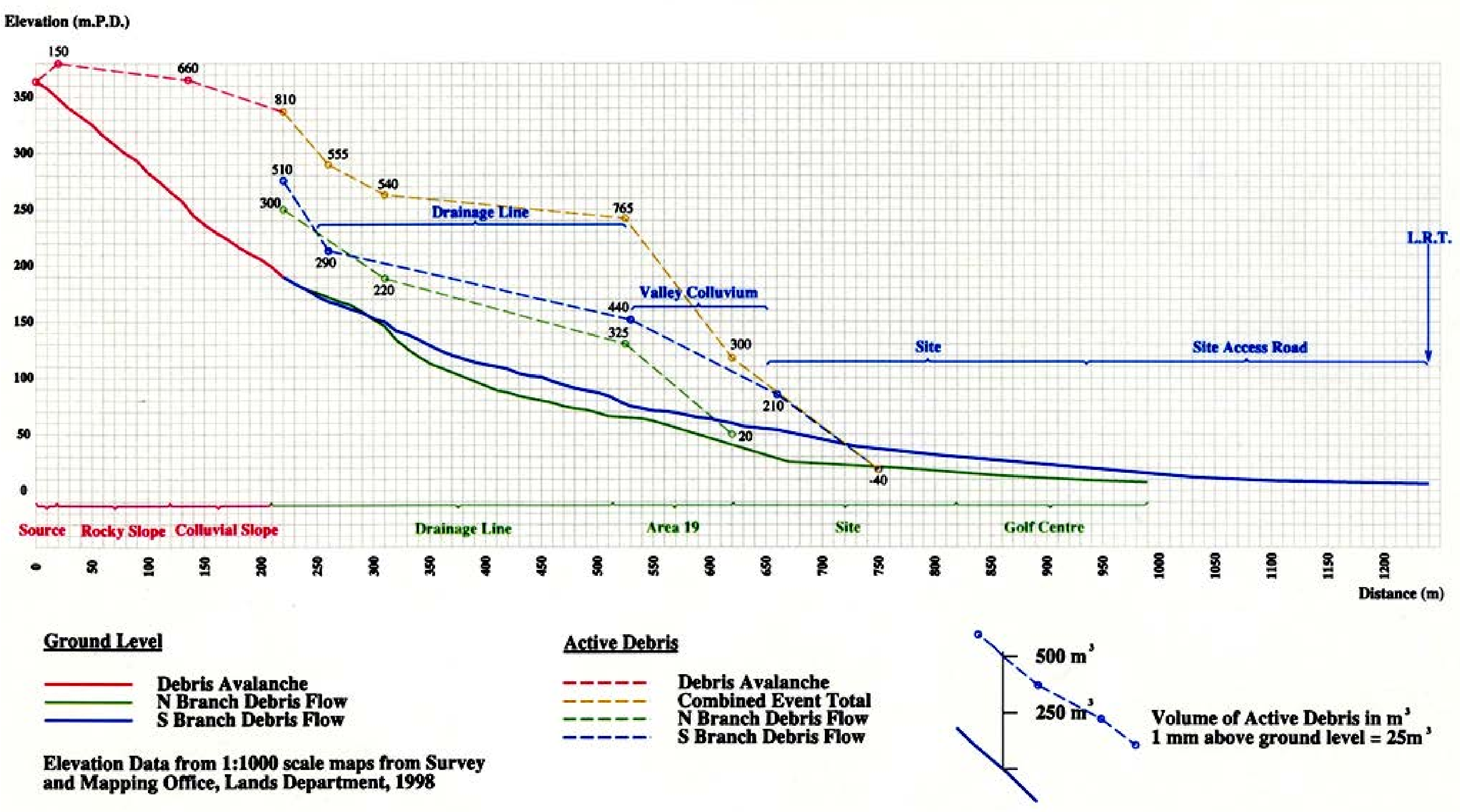

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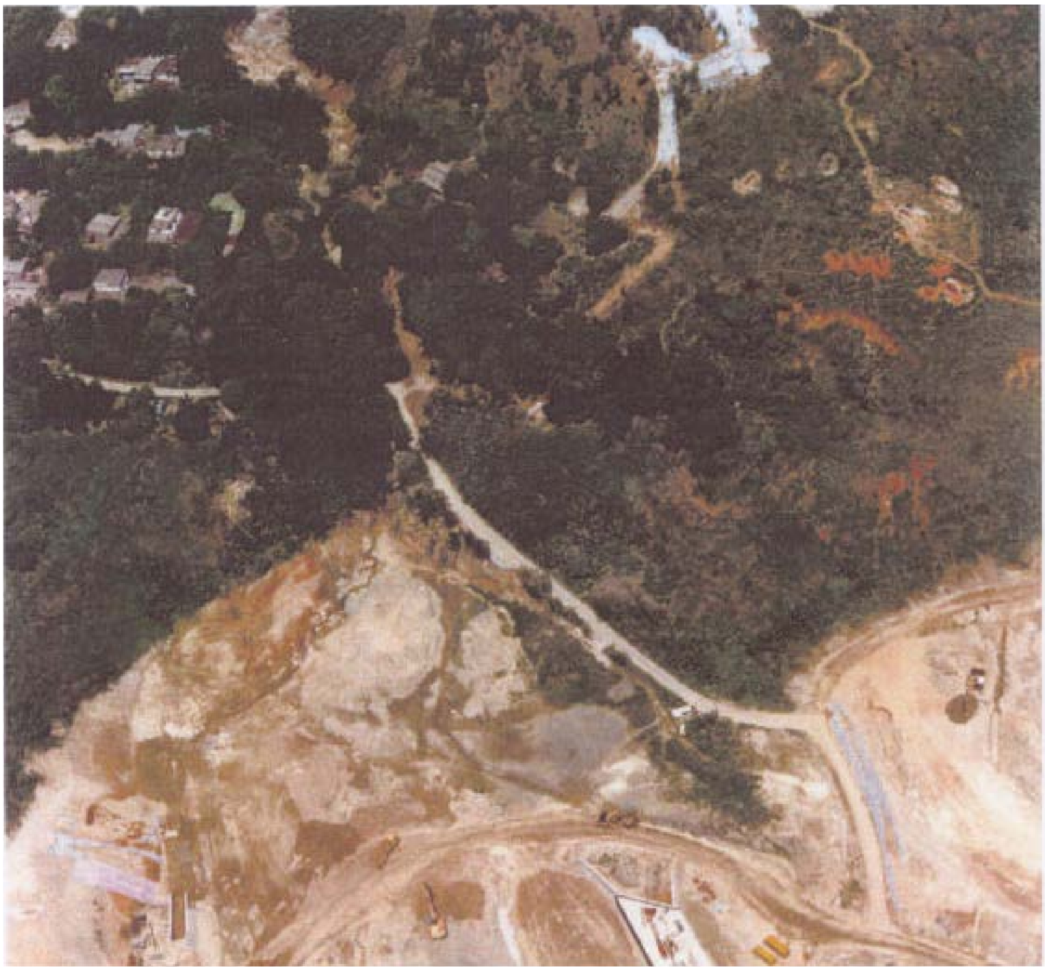

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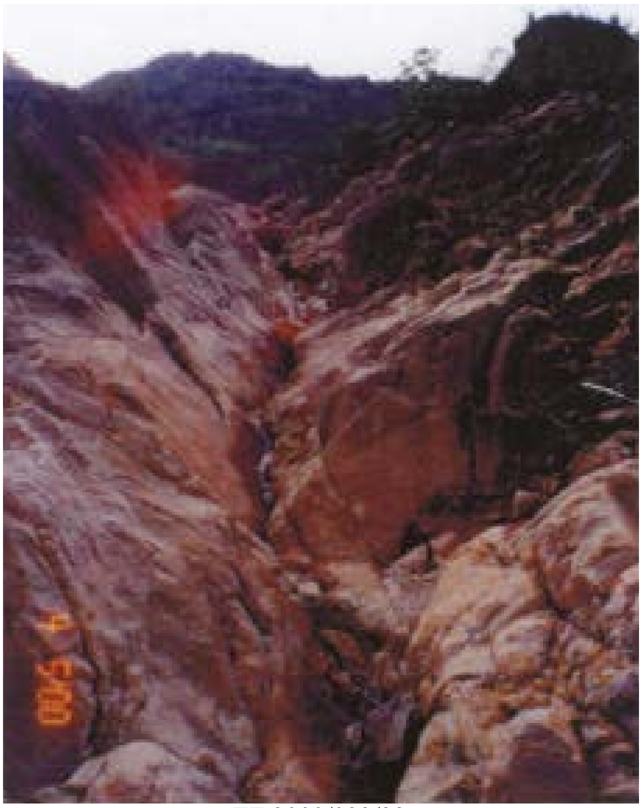

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GEO PUBLICATIONS AND ORDERING INFORMATION
土力工程處刊物及訂購資料

A selected list of major GEO publications is given in the next page. An up-to-date full list of GEO publications can be found at the CEDD Website http://www.cedd.gov.hk on the Internet under "Publications". Abstracts for the documents can also be found at the same website. Technical Guidance Notes are published on the CEDD Website from time to time to provide updates to GEO publications prior to their next revision.

部份土力工程處的主要刊物目錄刊載於下頁。而詳盡及最新的土力工程處刊物目錄，則登載於土木工程拓展署的互聯網網頁http://www.cedd.gov.hk 的"刊物"版面之內。刊物的摘要及更新刊物內容的工程技術指引，亦可在這個網址找到。

Copies of GEO publications (except geological maps and other publications which are free of charge) can be purchased either by:

Writing to
Publications Sales Unit,
Information Services Department,
Room 626, 6th Floor,
North Point Government Offices,
333 Java Road, North Point, Hong Kong.

or

- Calling the Publications Sales Section of Information Services Department (ISD) at (852) 2537 1910
- Visiting the online Government Bookstore at http:// www.bookstore.gov.hk
- Downloading the order form from the ISD website at http://www.isd.gov.hk and submitting the order online or by fax to (852) 2523 7195
- Placing order with ISD by e-mail at puborder@isd.gov.hk

讀者可採用以下方法購買土力工程處刊物(地質圖及免費刊物除外):

書面訂購
香港北角渣華道333號
北角政府合署6樓626室
政府新聞處
刊物銷售組

或

- 致電政府新聞處刊物銷售小組訂購 (電話：(852) 2537 1910)
- 進入網上「政府書店」選購，網址為 http://www.bookstore.gov.hk
- 透過政府新聞處的網站 (http://www.isd.gov.hk) 於網上遞交訂購表格，或將表格傳真至刊物銷售小組 (傳真：(852) 2523 7195)
- 以電郵方式訂購 (電郵地址：puborder@isd.gov.hk)

1:100 000, 1:20 000 and 1:5 000 geological maps can be purchased from:

Map Publications Centre/HK,
Survey & Mapping Office, Lands Department,
23th Floor, North Point Government Offices,
333 Java Road, North Point, Hong Kong.
Tel: (852) 2231 3187
Fax: (852) 2116 0774

讀者可於下列地點購買1:100 000、1:20 000及1:5 000地質圖：

香港北角渣華道333號
北角政府合署23樓
地政總署測繪處
電話: (852) 2231 3187
傳真: (852) 2116 0774

Requests for copies of Geological Survey Sheet Reports and other publications which are free of charge should be directed to:

For Geological Survey Sheet Reports which are free of charge:
Chief Geotechnical Engineer/Planning,
(Attn: Hong Kong Geological Survey Section)
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5380
Fax: (852) 2714 0247
E-mail: jsewell@cedd.gov.hk

For other publications which are free of charge:
Chief Geotechnical Engineer/Standards and Testing,
Geotechnical Engineering Office,
Civil Engineering and Development Department,
Civil Engineering and Development Building,
101 Princess Margaret Road,
Homantin, Kowloon, Hong Kong.
Tel: (852) 2762 5346
Fax: (852) 2714 0275
E-mail: florenceko@cedd.gov.hk

如欲索取地質調查報告及其他免費刊物，請致函：

免費地質調查報告:
香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
規劃部總土力工程師
(請交:香港地質調查組)
電話: (852) 2762 5380
傳真: (852) 2714 0247
電子郵件: jsewell@cedd.gov.hk

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香港九龍何文田公主道101號
土木工程拓展署大樓
土木工程拓展署
土力工程處
標準及測試部總土力工程師
電話: (852) 2762 5346
傳真: (852) 2714 0275
電子郵件: florenceko@cedd.gov.hk

MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 302 p. (English Version), (Reprinted, 2011).

斜坡岩土工程手冊(1998)，308頁(1984年英文版的中文譯本)。

Highway Slope Manual (2000), 114 p.

GEOGUIDES

Geoguide 1	Guide to Retaining Wall Design, 2nd Edition (1993), 258 p. (Reprinted, 2007).
Geoguide 2	Guide to Site Investigation (1987), 359 p. (Reprinted, 2000).
Geoguide 3	Guide to Rock and Soil Descriptions (1988), 186 p. (Reprinted, 2000).
Geoguide 4	Guide to Cavern Engineering (1992), 148 p. (Reprinted, 1998).
Geoguide 5	Guide to Slope Maintenance, 3rd Edition (2003), 132 p. (English Version).
岩土指南第五冊	斜坡維修指南，第三版(2003)，120頁(中文版)。
Geoguide 6	Guide to Reinforced Fill Structure and Slope Design (2002), 236 p.
Geoguide 7	Guide to Soil Nail Design and Construction (2008), 97 p.

GEOSPECS

Geospec 1	Model Specification for Prestressed Ground Anchors, 2nd Edition (1989), 164 p. (Reprinted, 1997).
Geospec 3	Model Specification for Soil Testing (2001), 340 p.

GEO PUBLICATIONS

GCO Publication No. 1/90	Review of Design Methods for Excavations (1990), 187 p. (Reprinted, 2002).
GEO Publication No. 1/93	Review of Granular and Geotextile Filters (1993), 141 p.
GEO Publication No. 1/2006	Foundation Design and Construction (2006), 376 p.
GEO Publication No. 1/2007	Engineering Geological Practice in Hong Kong (2007), 278 p.
GEO Publication No. 1/2009	Prescriptive Measures for Man-Made Slopes and Retaining Walls (2009), 76 p.
GEO Publication No. 1/2011	Technical Guidelines on Landscape Treatment for Slopes (2011), 217 p.

GEOLOGICAL PUBLICATIONS

The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents