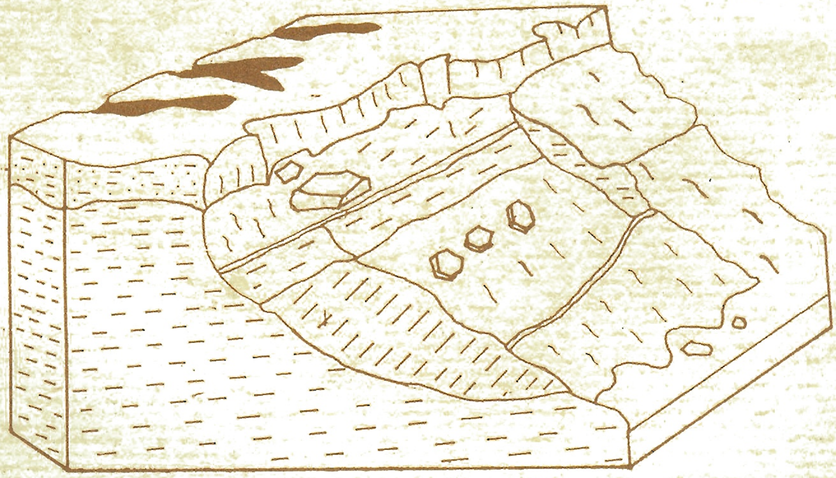
SEMINAR ON LANDSLIDES - CAUSES & PREVENTION

Proceedings of a Workshop held on

12th July 1986, at the NARESA Auditorium



Natural Resources, Energy & Science Authority of Sri Lanka

March 1988

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Organized by the Physical and Engineering Sciences Working Committee

of the Natural Resources, Energy and Science Authority of Sri Lanka

Proceedings Edited by D.E. de S. Jayewardene

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C O N T E N T S

INTRODUCTION

Landslides and earthslips are a common occurence in Sri Lanka. Heavy rains generally bring about numerous landslides and earthslips, and occasionally, such as the landslide that occured recently at Agalawatte, they cause considerable loss in life and property. The Working Committee decided to hold a public seminar on the subject. Experts on various aspects of the subject were to be invited to address the seminar, and members of the public were to be invited as participants in order to bring about a better understanding of the issues involved and the precautionary measures that might be taken.

The seminar, titled: Landslides - causes and prevention, was held in the NARESA auditorium on 12 July 1986. Several experts spoke on different aspects of the subject. The proceedings are now being published in the hope that they would reach officials and others who are invloved and interested in any aspects of land use, the vast majority of whom could not attend the seminar.

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SUMMARY OF PROCEEDINGS

BY

D.E. DE S.JAYAWARDENE

The Seminar was inaugurated by Mr. L.C.A. de S. Wijesinghe, Addl. Director-General of Natural Resources, Energy and Science Authority of Sri Lanka. In this inaugural address he stressed the importance of Seminars pertaining to landslides specially in the light of recurrent occurrences of such natural disasters over the past few years. He also stated that the proceedings of this Seminar will be summarised in the form of a report and after submission to the General Council of NARESA the report could be presented to the government.

The first address was by Prof. P.W. Vithanage, Professor of Geology, University of Peradeniya, on "Geological Aspects of Landslides and Preventive Measures". The areas studied were mainly in the Hill Country and the relationship of landslides to regional tectonic features such as lineaments were described. The illustrations displayed showed the various geological structures that could trigger-off landslides during periods of excessive precipitation. However, the presence of active lineaments in rocks of Precambrian age is subject to controversy as such movements are common only in rocks of a much younger age. Prof. Vithanage also spoke of a long term research programme to study the various causes that lead to landslides and, in this connection, he mentioned of a pilot study to be launched in collaboration with the National Building Research Organization (NBRO). This study will include the preparation of hazard maps showing high risk areas and also long-term monitoring of micro-seismic activity. The area where this pilot study is to be undertaken is Uda-Pussallawa.

The probability of reservoir induced earthquakes and tremors were also spotlighted and such studies are of importance as the impounding of large water bodies by construction of large scale dams has been undertaken for the first time in Sri Lanka under the Accelerated Mahaweli Programme. There are no early warnings prior to the triggering of major landslides. However, the behaviour of animals prior to such movements and, specially during periods of excessive precipitation, could be important in evacuation of people from danger zones.

Dr. A.N.S. Kulasinghe, Chairman of the Central Engineering Consultancy Bureau, in his address explained in detail the problems of landslides in connection with the construction of the Kotmale dam as the valley where the water has been now impounded is a landslide prone area. Most of the problems were due to soil and rock debris from earlier landslides located at the proposed dam site and the reservoir periphery. The detailed geotechnical studies conducted during the feasibility stage of the project were helpful in shifting the damsite downstream from the site selected earlier. It was also stated that when the decision of constructing the Kotmale dam and reservoir was taken the problem of landslides in the area was known to the engineers who were involved with the detailed design plans. Further, a team of world renowned geotechnical engineers also carried out detailed field studies and such studies were helpful in the construction of the dam at its present location. The dam has been designed to take a maximum wave of 4 meters over the crest and with these precautions no one should have fears about the stability of this structure.

Dr. Ashok Kumara, Geologist, who presented this joint paper with Dr. A.N.S. Kulasinghe, explained the detailed geological mapping and geotechnical studies carried out at Kotmale. The outcome of such studies was the preparation of a landslide hazard map showing the high risk areas and also areas where soil creep, rock falls and slumping had taken place. This map was of utmost importance in locating the dam and also deciding on the full-supply level of the reservoir.

In conclusion Dr. A.N.S. Kulasinghe stated that a few landslides on the reservoir periphery have got activated since impounding the Kotmale reservoir but these areas have now stabilised. Such movements were expected at the initial stages when the reservoir filled up.

I, in my address, highlighted the increased incidence of landslides specially in the hill country during the last decade. The main causes of such landslides could be attributed to bad land use and not to geological reasons such as rock type and geological structure. The cultivation of steep hill slopes in villages lead to soil degradation and during periods of excessive precipitation such conditions could trigger-off landslides. In order to avoid such catastrophes the villagers should be educated in proper land use practices and cultivation of steep hill slopes should be avoided. A map displayed at the seminar clearly showed that the incidence of landslides has increased during the past decade in the Kandy, Nuwara-Eliya, Badulla and Ratnapura districts. The most striking feature is the occurrence of landslides in the Kalutara district during the recent past. It has been observed that most of the areas that are subject to landslides are located in abandoned tea estates, chena cultivations, areas where timber has been extracted, and areas subject to illicit gem mining specially along steep hill slopes.

The last speaker at this seminar was Professor Madumma Bandara, Chairman of the Presidential Lands Commission. His address was primarily on land policy vis-a-vis land use and landslides. Due to the land policies periodically adopted by the colonial regime in the hill country, the people living in purana villages had difficulty in obtaining adequate land for agriculture. The main obstacle was that most of the land was leased out or sold by the colonial regime to the foreign planting community for tea cultivation. The land policies adopted by the government since independence too have led to land degradation as the Kandyan villagers were not provided with adequate land for village expansion.

Prof. Madduma Bandara quoted from various reports and sessional papers presented to the Government during the past where adequate warnings were given about soil erosion that leads to land degradation and landslides. The Soil Conservation Act was not strictly enforced although it had been passed by the then Legislative Council. The natural water courses were not properly maintained and the stream reservations were cultivated or used for illicit gem mining. Extraction of timber from forest reservations specially along steep slopes result in the triggering of landslides during periods of excessive precipitation. The main cause of landslides is bad land use which can be attributed to the various land policies adopted by the governments prior to and since independence.

Prof. Madduma Bandara also stressed the need to effectively maintain irrigation channels so that seepage of water along hill slopes could be avoided. Such maintenance work was carried out during the past and is quite evident by the complex network of ancient irrigation channels specially in the Hewaheta area. In conclusion Prof. Madduma Bandara stated that the total land area now under tea is excessive and his contention is that this area could be reduced to 1/3 while still earning the same revenue. If such a land policy is adopted there will be enough land available for alienation to the people in the hill country and cultivation along steep slopes that result in landslides could be avoided.

LAND POLICY AND LANDSLIDES IN THE HILL COUNTRY

by
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The causes of recent landslides in the hill country became a subject of lively discussion among the natural scientists in Sri Lanka during the last few months. The geologists, climatologists, engineers, foresters and soil scientists among many others have made their contributions to this debate which brought the subject to national significance due to the devastating experiences of rural communities living in the earthslip prone areas. The Social Services personnel, local administrators and estate managers were drawn in to look after the more practical and human aspects of the landslide problem. The thesis of my paper today is that the land policies adopted by the colonial government and later by successive national governments since Independence had been pre-dominantly responsible for the present problems of landslides which form only one manifestation of the general phenomenon of land degradation. I shall argue that there is a need for reconsidering the present land policy and for rationalising the land use pattern based on the concept of watershed management. I shall also argue that there is a need to develop a new pattern of human settlements for which a beginning could be made through the relocation of the large number of families rendered homeless by the landslides.

Before the advent of plantation agriculture, the hill country remained for the most part under a canopy of tropical montane forests. Human habitation was largely confined to the valley bottoms where the staple food, rice had been grown with water tapped from natural streams of the forest-clad hills. Except for occasional forays into the hill slopes for chena cultivation, almost all agricultural activities were confined to the valleys or deniyas which suffixed the name of the village itself as in the case of Gurudeniya, Peradeniya, Teldeniya, etc. It is possible that landslides triggered off by extreme rainfall events would have taken place during pre-colonial times, often confined, however, to steep slopes devoid of human habitation. Therefore, the damage to life and property by such a catastrophe should have been minimal at that time.

The ecological status of the hill country at the time when British planters entered these virgin terrains is vividly described by Sir Emersson Tennent: "The first ardent adventurers pioneered their way through pathless woods, and lived for months in log huts, whilst felling the forest and making preliminary nurseries preparatory to planting, but within a few years the tracks by which they came were converted into highways and their cabins replaced by bugalows, which though rough were picturesque. The new life in the jungle was full of excitement and romance, the wild elephants and the leopards retreated before the axe of the forester; the elk supplied their table with venison, the jungle fowl and game were within call and abundant". It has been reported that some 4,000 elephants were killed in the process of opening land for plantation agriculture. Le Mersieur, in his 'Manual of the Nuwara Eliya District' compiled in 1873 describes the intricate network of irrigation channels, particularly in the area around Hanguranketa and Walapone, which depicts the land use pattern prevailing in the valley bottom lands. Land use in most parts of the hill country was well adjusted to the terrain and its natural resource endowments as exemplified by the sequence of uses down hill slopes along the catena. The local terminology used to describe each segment of the slope beginning from the ridgetop down to the banks of a natural stream as <u>ovilikande</u>, <u>ovilla</u>, <u>deniya</u> and <u>ovita</u> indicate this adjustment clearly. The homestead gardens located above <u>deniya</u> took the form of a forest of planted trees which some writers now describe as 'Kandyan forest gardens'.

Even after the conquest of Kandy a larger proportion of the hill country remained a 'terra-incognita' for the colonial rulers, which provided havens for rebels who resorted to guerrilla warfare. Therefore, the colonial land policy was geared to open up the remote areas of the hill country by some means or another. Although the attempts made in this direction could be traced since 1818, it was the Crown Lands Ordinance of 1840 which paved the way for the denudation of the hill country on a massive scale. This Ordinance created the presumption that all 'waste, unoccupied or uncultivated land' belonged to the Crown and, therefore, at its disposal. The Crown land thus declared was sold at five shillings an acre and any person occupying such land was subject to summary eviction.* Thus, from 1835 - 1838, the average sale of land was 6, 412 acres. In 1841 the sales reached the high figure of 78,685 acres. The Hon. Member for Kelaniya in the State Council in 1943 described the impact of this land policy in no uncertain terms: "The Government of the day, armed with the Land Ordinance of 1840, adopted the role of the highway robber and took away, chiefly from the Kandyan peasants, the land they loved so much. The rebellions of 1842 and 1848, spoke, only too eloquently, of the sufferings of the Kandyan peasant. Today, when we see the mountain ranges covered with plantations, we feel that they stand as an immovable monument, not only to the enterprise of the British planter, but also to the dumb sufferings of the people whose homesteads they once were. I think this House, and the Board of Ministers, must some day take every measure possible to restore these lands to the people. We must not rest till this purpose is achieved"**. He went on further to say, that even in 1943, '50 miles away from where we sit as representatives of the people, in the Rate Mahattayas division of the three korales of the Kegalle District, there are 2,000 people who walk the streets without land". It is pertinent to mention that, according to the records maintained by the Social Services Department, the highest number of landslides of serious nature are reported from the Kegalle District since 1947.

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* E.W. Perera, 1927.

** Extracts from the speech made on the Appropriation Bill of 10th August 1943 by Hon. J.R. Jayewardene.

The devastating impact of colonial land policy on the stability of hill slopes as well as on the general ecological balance of the hill country began to emerge within a few decades. Thus, Sir. J.D. Hooker in 1873 and K.W. Trimen in the 1880s warned of the possible adverse consequences of clearing forests in the hill country. These warnings led the Colonial Government to establish a convention that no cultivation should be permitted over an elevation of 5000 feet. This was consequently incorporated in the Standing Orders to Surveyors and Administrators and had been fairly generally observed up to the end of the Colonial Era.

The beginning of a new era in the land policy of the country was seen in 1927 with the appointment of the Land Commission of 1927. The recommendations of this Commission of 1935 transformed the land settlement process of the country during the last 50 years. It has opened avenues for small farmers to obtain State land for village expansion and agriculture. The ideology behind this land policy as derived to some extent trom the thinking of Sir Hugh Clifford* the Governor of the time. It was based on the vision of 'multiplication of small holdings and the bringing into existence of a prosperous, self-supporting and self-respecting multitude of peasant proprietors'. The implementation of the Land Development Ordinance established a process of giving back the land acquired by the Colonial Government since 1840s to the small farmers particularly for village expansion in the hill country. Today, nearly one quarter of the people in Sri Lanka live on State lands alienated under the L.D.O. The beneficial impact of this policy on relieving congestion in the villages is well known and needs hardly any reiteration. At the same time it should be mentioned that lands which were not utilised for plantation agriculture were of a marginal type with steep slopes and infertile soils. The opening of human settlements on such lands did not always prove satisfactory. Thus, an examination of the list of serious earthslips that have taken place in the hill country since 1947, indicate their occurrence sometimes in 'colonies'.

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* Sir Hugh Clifford (1972) Some Reflection on the Ceylon Land Question. Address to the 2nd Annual Agricultural Conference, March 11, 1927.

The Soil Conservation Act of 1951 could be considered as an important step taken to mitigate land degradation particularly in the hill country areas. Under this Act the Minister-in-charge of the subject was vested with the powers to declare certain areas as 'erodible areas' within which land degradation was controlled under regulations made from time to time. The regulations authorised the Soil Conservation Officer, where he is satisfied that 'any land cultivated in tea is likely to suffer by stream bank erosion or by earthslip caused by soil erosion', to direct the owners or the occupiers of such land to change the land use or to afforest it. The Soil Conservation Act which was enforced effectively during the 1950s was gradually relaxed in certain instances particularly in the early 1960s to encourage tobacco cultivation. With the nationalisation of estates, the soil conservation measures that were taken earlier began to be relaxed. The maintenance of stream reservations as stipulated by the Crown Lands Ordinance have also been neglected by the district level implementing authorities. Thus, a survey conducted by the Water Resources Board in the Kumbalawela Korale of Badulla District, indicated that less than 17% of the total area that should have actually been retained as stream reservations is left as reservations in the area concerned in 1968. Repeated communications from the Soil Conservation Officer to the authorities received scant attention over the years. For example, the Soil Conservation Officer has advised the authorities as far back as 1958 to close a part of Ketayapatana village where one of the worse landslide disasters had taken place.

While the legislative provisions available for controlling soil conservation and earthslip damage remain neglected, the population in the villages have increased, and an acute land hunger became a rampant phenomenon. The rural people began to enchroach upon the available Crown lands and to use them for chena cultivation, tobacco and for vegetables. It should be mentioned that a considerable proportion of leaf tobacco received by leading Tobacco Companies originate from such lands. The village expansion process pushes the villagers in need of land to the vulnerable frontier with the adjoining tea plantations leaving the villagers almost marooned.

In the light of the above historical background a change in the land policy appears to be an imperative need in the formulation of strategies aimed at mitigating the landslide hazard. Without an overall policy change it could be argued that only piecemeal solutions could be formulated. A desirable future land policy in the hill country may be outlined as follows: An effective programme of mountain hazard mapping may take the form of a mapping exercise that has been carried out in Nepal recently. This should be followed by a land use planning programme based on natural watersheds of the areas concerned.

These two programmes would form the basis of restructuring land use and settlement planning, for the future.

It has been established that the present production level of tea could be maintained through the application of improved technologies such as replanting with clonal tea, even if considerable proportions of marginal and unproductive tea land could be taken out of major plantations*. If a land policy based on this thinking could be vigorously pursued, it would make available a large extent of land for resettlement of people from congested villages where acute land hunger exists. While agreeing that available land is necessarily limited, I would argue that a change of land policy can create enough land for the people. It has been estimated that only one-third of existing tea land is adequate to maintain a reasonable level of production while maintaining the competetive position of the country in the markets of the world**. The State ownership of the bulk of plantation lands and the fluctuating price of tea may facilitate this process now, more than ever before.

In the Nuwara Eliya District, it has been estimated that only 9% of land remains under a forest cover as compared with 23% for the entire Island. Therefore, on the basis of sound principles of watershed management, watershed

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* Report of Tea Commission, Sessional Paper No. XVIII, Colombo, 1968.

** This could provide an indication of the extent of land that could be released from plantations.

forests will have to be established on a planned basis while strictly adhering to the ban on any forest clearing above an elevation of 5000 feet. The present policy of reforestation of available State land without reference to their relative location on watersheds may not prove to be obtaining timber and fuel wood. It could be argued that the forest policy should necessarily be based on the watershed management policy.

In the more urgent need for resettlement of present earthslip victims, many of whom were languishing in improvised accommodation since January, there appears to be several options: (i) to resettle them in the areas around their villages where suitable land is available; (ii) to relocate them in downstream Mahaweli Development areas; (iii) to absorb them into present plantations as employees depending on their vocational and educational backgrounds; (iv) to resettle them on uneconomical or marginal land released from the SLSPC and the JEDB for agricultural settlement; or (v) to resettle them on acquired private lands in the neighbouring areas. Regarding the first option it may be noted that availability of State land is extremely limited in the neighbourhood of affected villages. In view of the large number of families exceeding 10,000, who had to leave the hill country areas in the recent past, a further exodus of people from these areas who are not eligible to become Mahaweli settlers on their own merit may not prove to be desirable option. However, in view of the considerable number of vacancies that may have occurred in the labour force by the repatriation of estate workers of Indian origin in the recent past, absorption into the plantation sector would prove to be a viable option. In my view, settlement of earthslip victims on land acquired from uneconomical plantations may be the best out of all available options. In this contect, it should be mentioned that, a unit alienation should be an economic one, and the land alienated under such a programme should be under scientific land use practices. The experience of NADSA shows that an economical unit should be at least a half a hectare if it is located away from townships. The last option of acquiring private lands should be confined to land that remains in a neglected state. Neglection of developable land particularly in the environs of the congested Wet Zone and hill country villages is a luxury that the country cannot afford any longer.

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LANDSLIDES - GEOLOGICAL ASPECTS AND PREVENTIVE MEASURES
(with special reference to Sri Lanka)

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ABSTRACT

The term "landslide" refers to a rapid downward or outward movement of a rock mass, residual soil, colluvial and taluvial materials or sediments along a slope. A similar movement, but at a slower imperceptible rate is called "creep". In Sri Lanka, evidence of creep can be seen on most slopes.

Landslides are of diverse types and they have been classified on different criteria, for example : (i) mass movements and soil erosion, (ii) geotechnical, (iii) morphometric, and (iv) general slides.

The obvious factors which cause the triggering of landslides are (i) excessive intensity of daily rainfall (for example 10 inches/250 mm in 24 hours and a total cumulative precipitation of over 500 mm to 1000 mm, e.g. in January, 1986, in the central highlands of Sri Lanka); and (ii) the degree of the slope and intensity of weathering. The other contributing factors, which are mainly geological and tectonic, are (a) the fracture density; (b) lithology and degree of weatherability; (c) local and regional lineament tectonics; (e) local micro-tremors; and (f) possible geodetic influence of impounding and drawdown of the newly constructed reservoirs - Moussakalle, Kotmale, Victoria and Randenigala.

With the exception of man-made slope failures it is difficult to prevent completely the occurence of landslides. Landslides are one of the

factors of landform evolution. However, it is possible to take measures to mitigate the vulnerability of life and property to landslide hazard and risks.

Introduction

Definition

The term landslides refers to a rapid downward or outward movement of a rock mass, residual soil, colluvial materials or sediments adjoining a slope. As shown by Terzaghi (1950), a similar movement, but at a slower imperceptible rate is called "creep". Slides on the slopes of man-made cuts are referred to as slope failures.

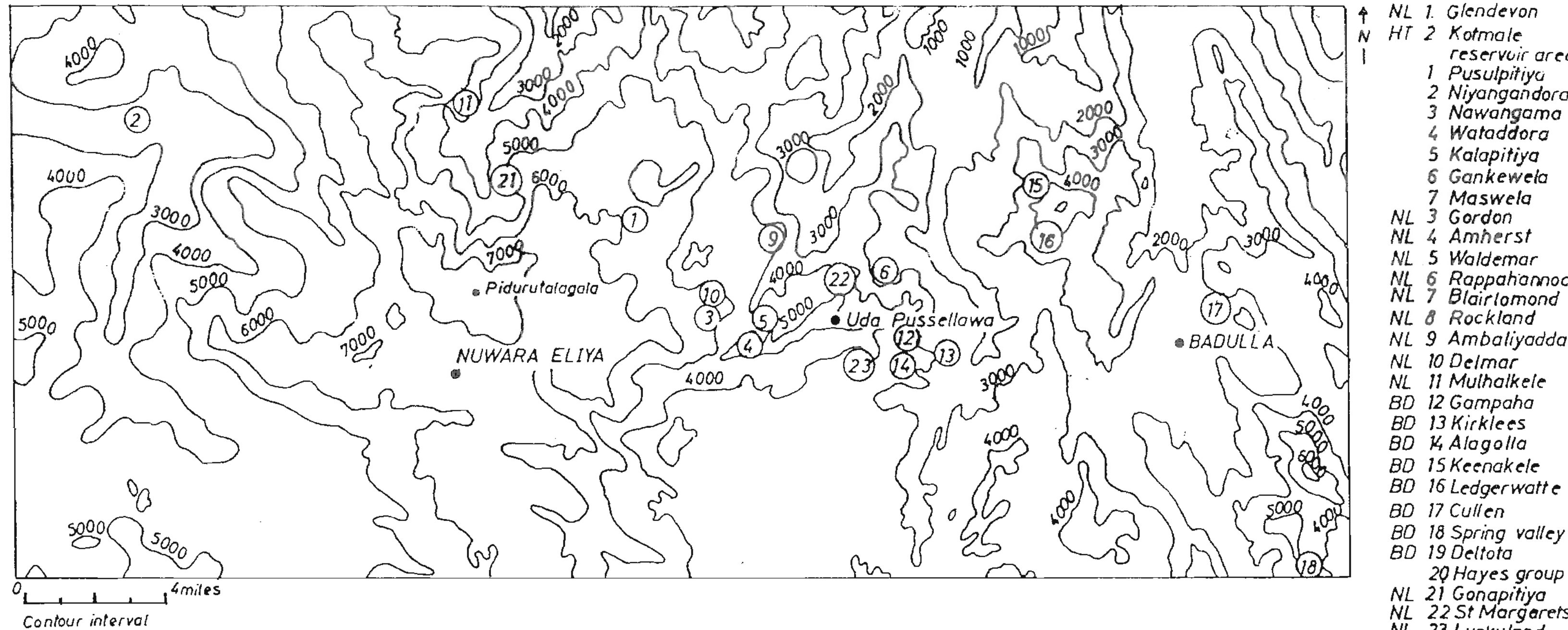
Landslides and Creep

The difference between landslides and continuous creep is not only in the velocity of the movement but also in the pattern of the deformations. According to Terzaghi (1950) "As long as the shearing stresses in the material beneath a slope are smaller than the 'fundamental' shearing resistance of the material, the slope is at rest. If they exceed this value the slope creeps, and if they become equal to the stress required to produce a shear failure, a landslide occurs". In Sri Lanka, evidence of creep can be seen on most slopes. Although, in terms of volume-distance of material removed, continuous creep is a minor surface process, in landslide studies creep should be taken into account since it is a precursor of rapid mass-movements (Young, 1972).

Landslides and Processes

Landslides, which involve materials of diverse kind ranging from hard rock to soft clay or any combination of materials resulting from a wide variety of geological, hydrological and tectonic processes are of diverse types (Fig.2)

The slope movements have been classified on the basis of different criteria, e.g (i) Mass Movements and Soil Erosion (Campbell, 1951); (ii) Geotechnical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11
3000
4000
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21
6000
1
7000
Pidurutalagala
NUWARA ELIYA
10
3
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5
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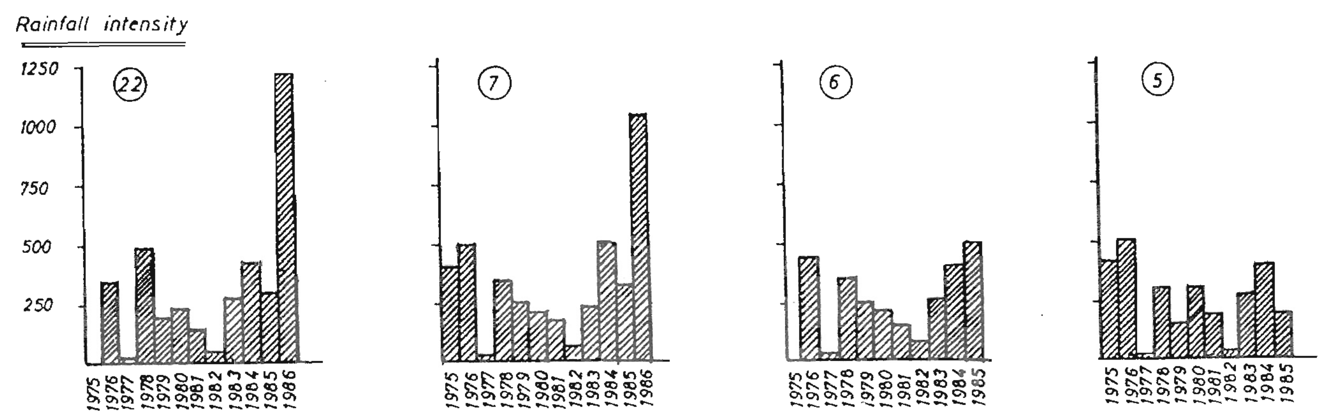
22
6
Uda Pussellawa
12
13
14
23
15
16
17
BADULLA
18
1000
2000
3000
5000
6000
0
4 miles
Contour interval
N
NL 1. Glendevon
HT 2 Kotmale reservoir area
1 Pusulpitiya
2 Niyangandora
3 Nawangama
4 Wataddora
5 Kalapitiya
6 Gankewela
7 Maswela
NL 3 Gordon
NL 4 Amherst
NL 5 Waldemar
NL 6 Rappahannock
NL 7 Blairlomond
NL 8 Rockland
NL 9 Ambaliyadda
NL 10 Delmar
NL 11 Mulhalkele
BD 12 Gampaha
BD 13 Kirklees
BD 14 Alagolla
BD 15 Keenakele
BD 16 Ledgerwatte
BD 17 Cullen
BD 18 Spring valley
BD 19 Deltota
20 Hayes group
NL 21 Gonapitiya
NL 22 St Margarets
NL 23 Luckyland

Fig. 1


Rainfall intensity
1250
1000
750
500
250
22
7
6
5
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986

Classification (Hutchinson, 1978);(iii) Morphometric Classification (Crozier, 1973). A more general classification for initial assessment is the general classification of Varnes (1978) (Table I; Table 2a & 2b).

The main processes which may lead to landslides, creep and slope failures are:

1. river erosion
2. man-made excavation
3. change in the ground water regime
4. progressive structural changes in the material adjoining slopes (Terzaghi, 1950)

Causes of landslides may be (a) External and (b) Internal. External causes include a steepening of the slope by erosion or man-made excavation, deposition of material along the upper edge of slopes and earthquake shocks. These external causes produce an increase of shearing stresses at unaltered shearing resistance of the slope material.

Internal causes give rise to a decrease of shearing resistance of the slope material. The most common causes are an increase of the pore-water pressure, and a progressive decrease of cohesion of the material adjoining the slope. Landslides as a result of rapid drawdown, subsurface erosion and spontaneous liquefaction are due to causes which are intermediate between external and internal.

Landslides in 1986

With excessive daily rainfall (over 10 inches/255 mm in 24 hours and 900-1000 mm in 3 to 4 days) for several successive days, a series of landslides occurred in the highlands of Sri Lanka in 1986. Field studies of most of the major slides have been carried out recently by the author in the following estates : Moray, Forres, Dalhousie, Luxapana, Glentilt, Watawala, Galboda, Watagoda, Mount Jean and Midford in the Hatton district; Kirklees, Gampaha, Alagolla, Spring Valley, Cullen, Ledgerwatte and Keenakalle of the

DIFFERENT TYPES OF LANDSLIDES (Varnes 1978)

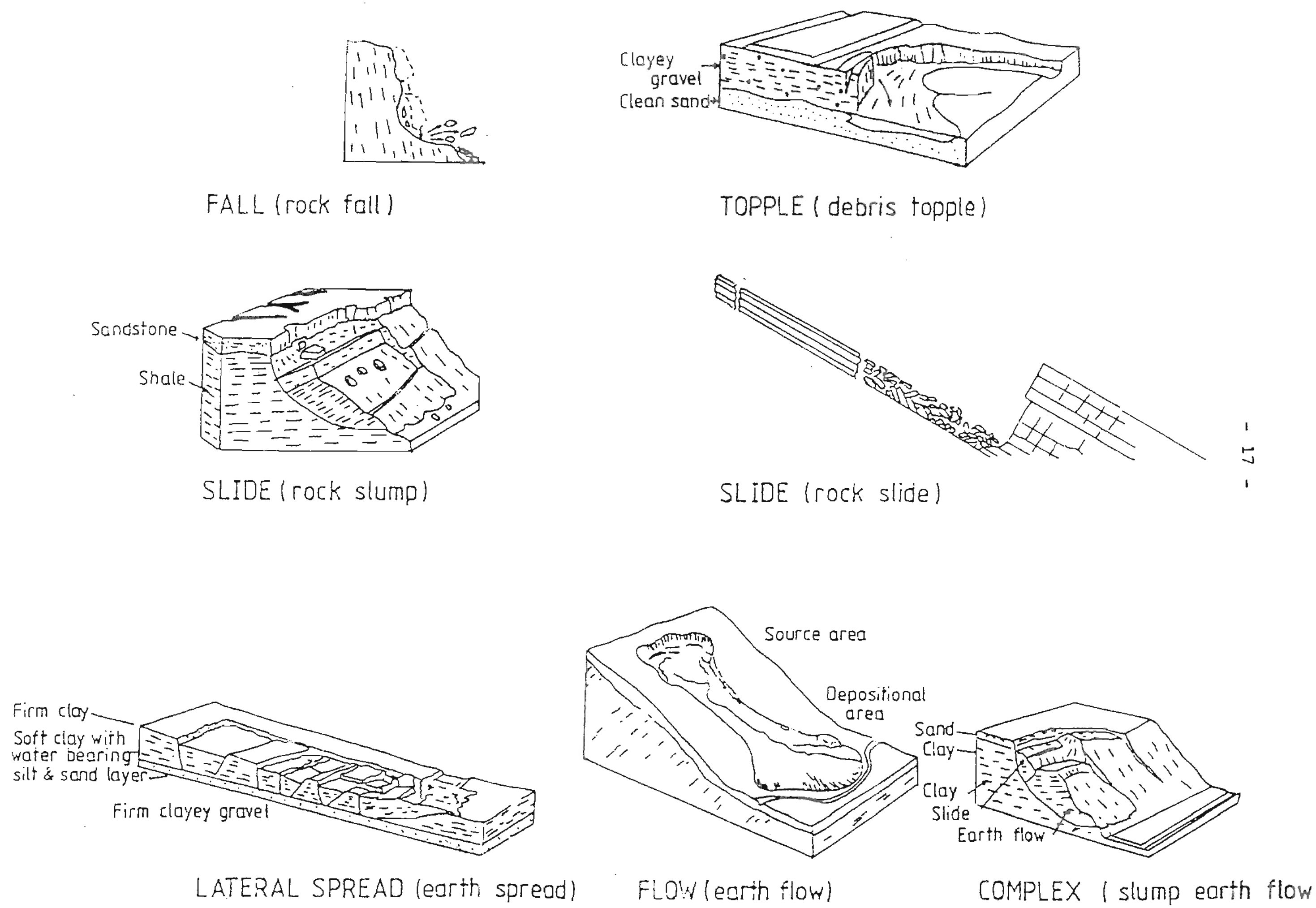


Fig. 2

Badulla district; Gonapitiya, Glendevon, Gordon, Amherst, Delmar, Blairlomond, Gampaha, Rapphannock, Alnwick, Mulhalkolla, Tulles, Waldemar and Rockland in Nuwara Eliya District (Fig. 1 & Table 3).

Geological Aspects of Landslides

Valuable information has been obtained by the study of these sites and the buildings damaged by landslides. The results of the preliminary geological surveys indicate that in addition to the obvious causes of the slides: (i) excessive intensity of the daily rainfall (over 10 inches/250 mm in 24 hours) and the high total cumulative precipitation (ranging from 500 mm to 1000 mm) within 4 to 5 days (ii) the degree of the slope, and (iii) intensity of weathering, there were other contributing factors, which are mainly geological and tectonic, viz. (a) the fracture density, (b) lithology and degree of weathering, and (c) local and regional lineament tectonics and local micro-tremors.

Another factor is the possible geodetic influence of the effects of hydrological changes (water-table and pore-pressure) induced by the newly constructed reservoirs - Moussakalle, Kotmale, Victoria and Randenigala. The slumping and creep of 400 acres of tea in Moray and Forres along the banks of the Mousakalle reservoir in the Maskeliya area (Fig. 8) and the slow creep of the 7 villages (5 square miles) - Niyangandora, Wataddara, Pusulpitiya, Nawangama, Kalapitiya, Gankewela and Maswela towards the reservoir (Vitanage 1986) are good evidence in support of neotectonic movements as a result of impounding and drawdown of these reservoirs (Fig. 7 & 8).

Lithology and Differental Weathering

In Sri Lanka, with the exception of quartzites and marble (crystalline limestone), the rock types themselves have no direct influence on slope movements. Quartzites with numerous fractures and their potential tendency for the occurence of subsurface springs may trigger mass-movements. While the presence of solution cavities (swallow holes) and subsurface channels lead to subsidence and creep e.g. in field No. 6 in Glen Devon estate in Nuwara Eliya District (Fig. 4).

Table I Abbreviated Classification of Slope Movements (Varnes 1978)

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				Predominantly coarse	Predominantly fine
FALLS			Rock fall	Debris fall	Earth fall
TOPPLES			Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
	TRANSLAT-IONAL	FEW UNITS	Rock block slide	Debris block slide	Earth block slide
		MANY UNITS	Rock slide	Debris slide	Earth slide
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
COMPLEX			Combination of two or more principal types of movement		

However, it is the degree of weathering (physical, chemical and biological), especially along the discontinuities, that convert the original rocks of very high shear strength into soil and overburden (regolith) of relatively low shear strength. In addition to the original mineralogy, the nature of the climatic and biological environment is responsible for the degree and the rate of this change. These weathering changes give rise to a systematic decrease in the critical angle for slope stability (Durgin 1977). As indicated by Crozier (1986), the form and type of landslide produced reflect the characteristics of the constituent materials (Fig. 5).

Density and Orientation of Joints and other Structural Discontinuities

The destablishing mechanisms of slopes occur closely associated with the density, inclination and orientation of structural surfaces much as joints, fractures, bedding planes, foliations and faults. Good examples could be seen in the tea estates around Uddapussellawa (Fig.I). In Amherst estate, shallow rock and debris slides with average slope angle 30^0 (eastwards) occur along rocky slopes with outward dipping foliation and joint surfaces at an average angle of 26^0 E (Fig 6A). These slopes in Amherst with outward dipping rock outcrops are less stable than similar slopes on inward dipping structures of the westward facing scarp of Delmar estate (Fig. 6B). Terzaghi (1962) has shown that "in slopes with outward dipping strata, the limiting hillslope angle is equal to the angle of dip in situations where the angle of dip is greater than the angle of friction on the sturctural surface". Where joints and discontinuities show no pronounced orientation, the limiting hillslope angle is controlled by the tightness and frictional properties of the joint-blocks and this angle is equal to the angle of internal friction.

Tectonic Uplift and Neotectonics

In recent years, in Sri Lanka, convincing evidence for the occurrence of at least a few currently active lineaments (Vitanage 1972 and 1986a) and for recent movements as a result of geodetic movements or plate tectonics is gradually accumulating (Vitanage 1983). There is a good correlation of

Table 2a   Morphometric Indices (Crozier 1973)
(see Figure 3 for measurements)

Index	Calculation
Depth	$\frac{D}{L} \times 100\%$
Dilation	$\frac{Wx}{Wc}$
Tenuity	$\frac{Lm}{Lc}$
Flowage	$\left\lvert \frac{Wx}{Wc} - 1 \right\rvert \frac{Lm}{Lc} \times 100\%$
Viscous Flow	$\frac{Lf}{Dc}$
Displacement	$\frac{Lr}{Lc}$
Fluidity (water content)	Ranked residuals from regression of flowage on slope

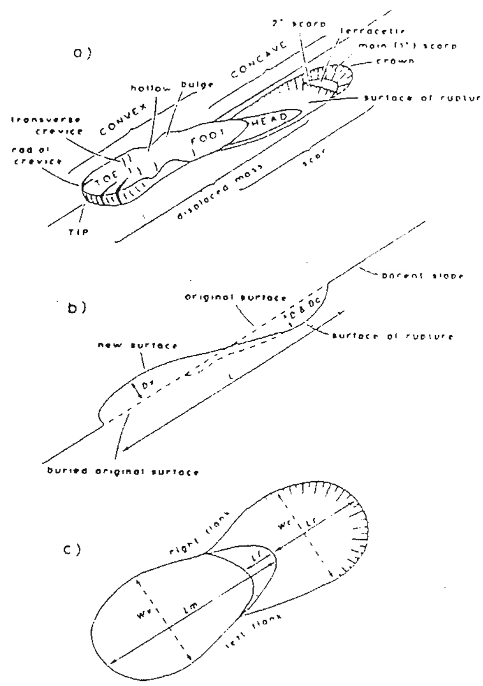


Figure 3   Terminology used in the morphometric classification (Crozier 1973)

Classification

Table 2b.   Geotechnical Classification of Landslides
After A W Skempton and J N Hutchinson
(Hutchinson 1978)

Soil fabric conditions (affecting cohesion and internal friction)	Pore fluid pressure conditions on slope surfaces (affecting porewater pressure)
1. First-time slides in previously unsheared ground: soil fabric tends to be random (or oriented as a result of depositional history) and shear strength parameters are at peak or between peak and residual values.	A. Short-term (undrained) - no equalisation or excess porewater pressure set by changes in total stress.
	B. Intermediate - partial equalisation of excess porewater pressures.
2. Slides on pre-existing shears associated with: (a) previous landslides (b) colluvium (c) periglacial solifluction (d) other freeze-thaw processes (e) tectonics (f) lateral expansion	C. Long-term (drained) - complete equalisation of excesss porewater pressures to steady seepage values.
In these cases the soil fabric surface is highly oriented in the slip direction and shear strength parameters are at or about residual values.	Note that combinations of A, B and C can occur at different times in the same landslide; for example, a particularly dangerous type of slide is that in which long-term, steady seepage conditions (C) exist up to failure but during failure, undrained conditions (A) apply; that is, a drained/undrained failure.

landslide and creep occurrence with the mega-lineaments, for example, (i) the slow creep of houses and landslides in Niyangandora, above Kotmale reservoir, and (ii) the extensive landslides in Loolkkandura and Medakumbura areas along the 150 km long Rangala-Kotmale-Hatton lineament. (Fig. 7).

Seismicity and Microtremors

Sri Lanka is considered to be an area of low seismicity. However, there have been 55 small earthquakes from 1823 to 1979, which have been felt in several localities both in the highlands and lowlands (Fernando and Kulasinghe, 1983). The author was informed during the inspection of the landslide areas in Spring Valley Estate that a local fracture developed in field number 8 after a micro-tremor. Later, the fracture developed into a gully.

Another example could be seen in the Kirkles Estate, Udapussellawa (Fig. 9&10A). The extensive landslide damaged areas (Fig. 10a) show that most of the buildings especially the chimneys, have been subjected to a certain amount of vibration before they collapsed and before the extensive local fracturing took place. This field evidence is noteworthy and it points out the importance of tectonics and microseismicity in the triggering of slope movements. Up to now, this aspect of neotectonics and micro-tremors as one of the contributing factors has been neglected in the study of landslides in Sri Lanka.

Preventive Measures

No landslides occur without a warning, with the exception of slides triggered by earthquakes or by spontaneous liquefaction (Terzaghi 1950). Hence short and long monitoring of slope movements is a pre-requisite for mitigating the landslide activity and hazard. Terzaghi (1950) has shown that the foremost requirement for slide prevention is the availability of reliable information on the geologic structure obtained by (a) a detailed geological survey of the affected area, (b) geophysical investigations, (c) drilling, and (d) a clear understanding of the processes which may lead to another slope failure. These data will help to take the necessary measures required "to make the

Map 1

LANDSLIDE AREAS IN GLENDEVON ESTATE

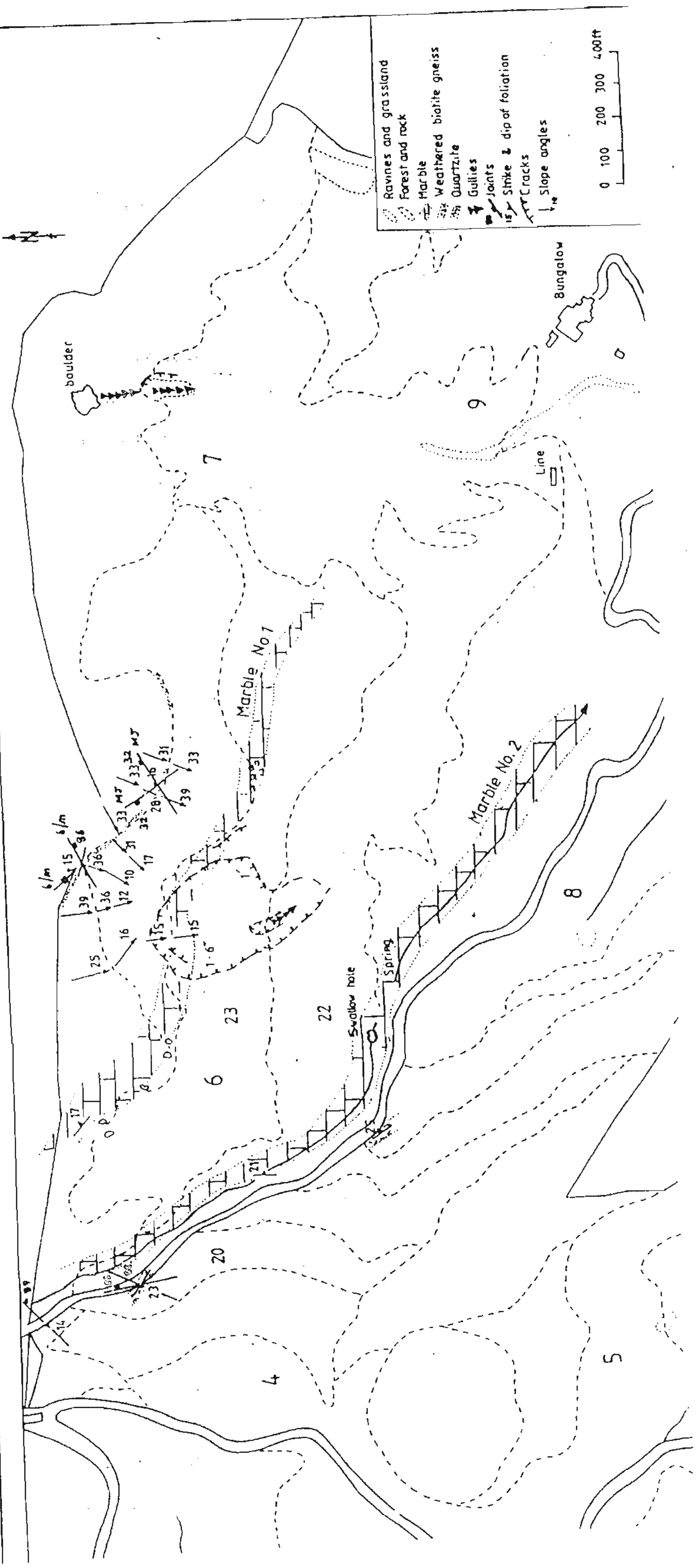


Fig. 4

slide-producing processes as ineffective as possible". In addition to these data, measurement of slope angles, mapping of overburden, and assessment of its geotechnical properties are also necessary.

Terzaghi (1950) has listed some of the preventive measures. The preventive measures fall into two categories (i) short term and (ii) long term. Short term measures include (i) the reduction of the piezometric surface behind the slope during heavy rain storms; associated with a displacement of air by covering the exposed area beyond the crest of the slope with a layer or lining having a low permeability, (ii) avoiding the formation of deep shrinkage cracks, by covering the slope with sods or a thick layer of sand, (iii) eleminating the danger of spontaneous liquefaction, by compaction.

Long term measures include: (i) avoiding the risk of slope failure and flow lines at the foot of the slope after rapid drawdown, and covering the slope with an inverted filter of weight sufficient to counteract the seepage pressure exerted by the percolating water; (ii) gauging the pore-water pressure; (iii) having standard observation wells; (iv) locating perched water-tables (v) periodic geodetic surveying of reference points - bench marks; and (vi) in areas prone to be frequent landslides, installation of warning signals.

Occurrence of landslides is part of the natural morphological evolution of landforms. Nearly 60 per cent of the landforms in the central highlands and uplands of Sri Lanka is the result of shallow and deep slope movements - landslides, creep or slump (Vitanage, 1970). Therefore, it is not possible to prevent completely the incidence of every type of landslide. As aptly commented by Crozier (1986), we have to live with landslides. However, it is possible to control and mitigate the landslide related damage and hazards.

According to Crozier (1986), the direct options of mitigating the landslide hazard include (i) permanent avoidance of unstable areas - usually archieved by government land acquisition, (2) temporary avoidance of unstable areas, (3) restricted land-use activities, (4) imposition of building design

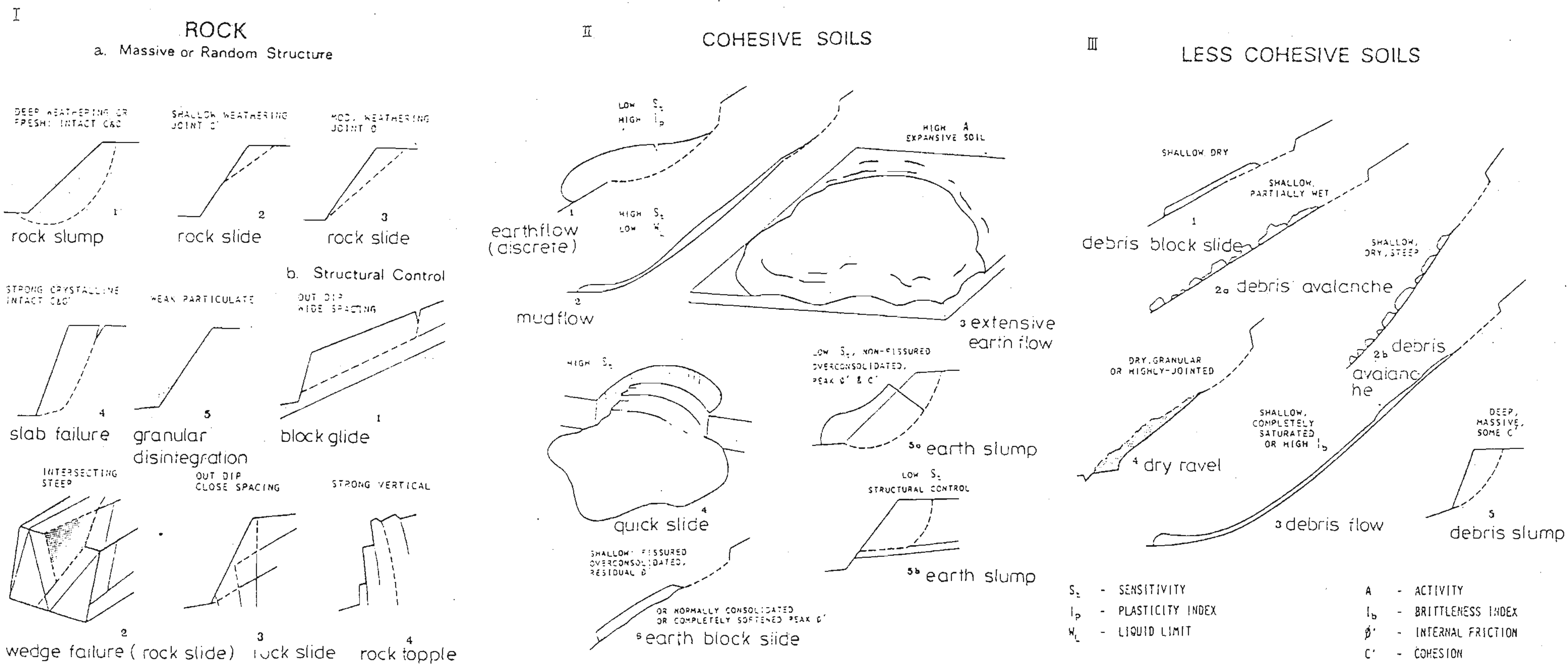


Figure. 5 The influence of material and structure on landslide form

(after Crozier)

standards e.g. vibration tolerance, (5) prevention of potential landslides by engineering works or other treatment, (6) control of landslide activity, e.g. installation of rock-fall chutes, debris run-out areas, or tree planting to reduce movement rates, and (7) relief, compensation, repair and replacement - by insurance or government grants.

Case Histories of Some landslides

As stated earlier, in early 1986, the author inspected several landslide affected areas in the highlands of Sri Lanka (Fig. I) The probable causes of these slope failures and the preventive measures recommended are given in Table 3.

Need for Monitoring of Slope Movements and Landslide Hazard Mapping

As shown in the previous section (Fig. 8, 9&10); (Table 3) on case histories, the causal factors influence landslide activity in a more or less predictable manner For this reason, it is possible to identify zones and construct maps showing different potential areas of landslide hazard and risk.

According to Crozier, the procedure of preparing a hazard map involves 5 tasks :

1. Identification of internal and external destabilising factors;
2. Determination of terrain sensitivity;
3. Integration of 1 and 2 to produce a measure of the probability of landslide occurrence;
4. An assessment of potential landslide hazard
5. Statement on landslide hazard risk

Landslide hazard mapping is a costly and long-term undertaking. But a hazard map will provide a regional assessment of landslide hazard and risk suitable for national planners, decision makers in the government.

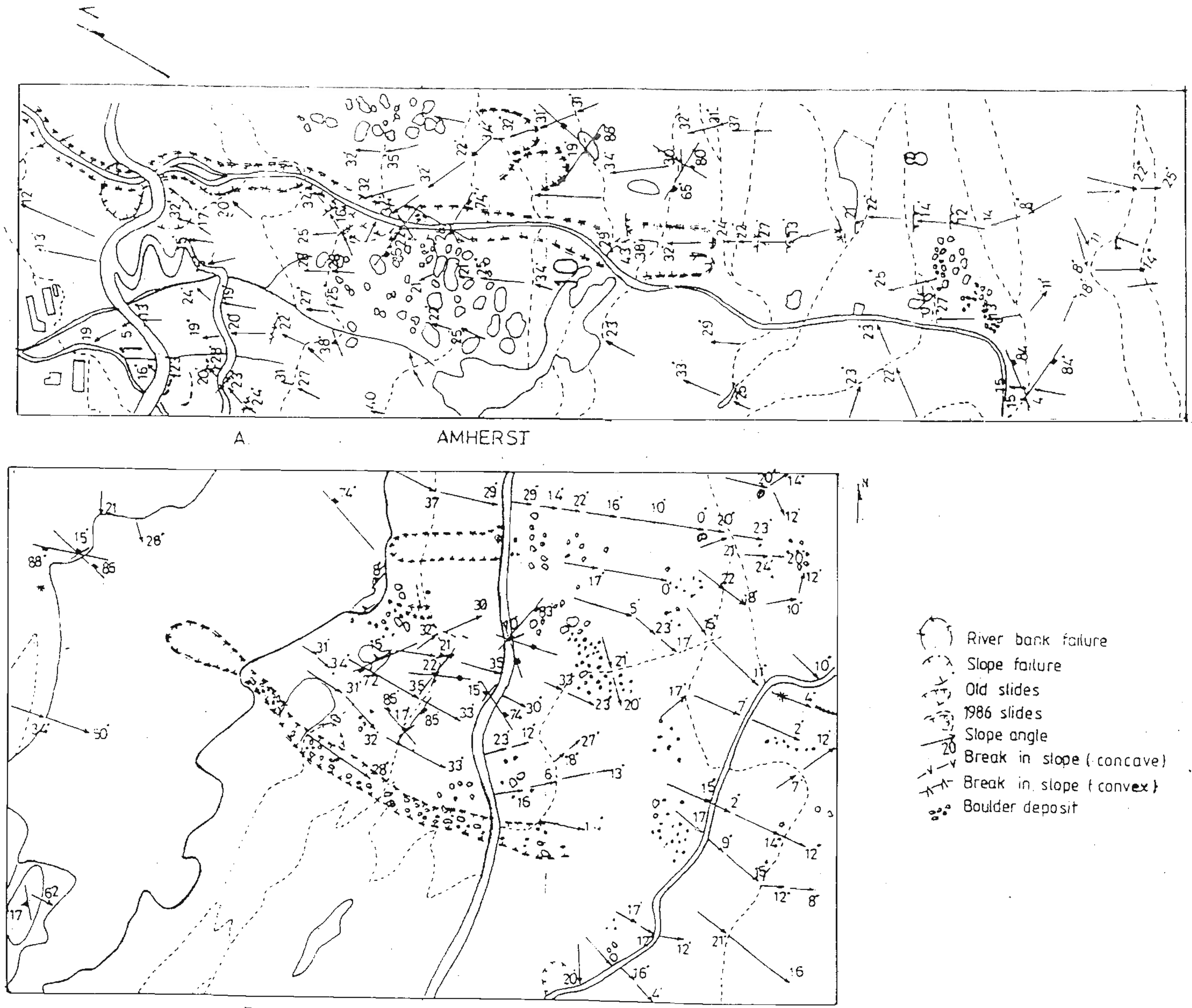
TABLE 3: LANDSLIDES

NUMBER AND NAME	LOCATION	DATE OF OCCURRENCE	TYPE OF SLIDE AND SIZE	RAINFALL	SLOPE MATERIAL	TECTONICS	DAMAGES	RECOMMENDATIONS
NL 1 Glen Devon	Ragala, NLD	Jan. 6 - 7, 1986	Solution subsidence & creep (3 hectares)		Colluvium and marble		Along cracks and areas of subsidence tilting of trees	Filling of cracks with impermeable soils and improved surface drainage
NL2 Kotmale reservoir area	Kotmale NLD	1985 - 1986	Creep subsidence 8 sq.km.		Talluvium and colluvium and marble			
1. Pusulpitiya 2. Niyangandora						Lineament	Nearly 500 houses damaged cracks subsidence	Evacuation of villagers. Rehabilitation of clopes - Terracing and surface drainage, reforestation
3. Nawangama 4. Wataddara 5. Kalpitiya 6. Gangkewela 7. Maswela						Lineaments & master joints	2 hectares of tea affected	Clearing and opening up of drains improvement of surface drains
NL3 Gordon	Udapusellawa FLD	Jan. 6 - 9, 1986	Rock & debris flow slope failures stream bank slides slumps & creep		Talluvium, colluvium, charnovkite, gneisses biotite gnesses and quartzites	E-W joints	Roads damaged	Improvement of surface drainage lining of step drains
NL5 Waldemar	"	"	Debris flow slope failure slumps		Colluvium, quartzite and charnokites	Lineament	Road & tea bushes damaged	Improvement of drainage and terracing
NL6 Kappanannock	"	"	Rotational slide, debris avalanche 1 km.		Colluvium, charnockite and garnet sillimanite gneiss	E-W joints Lineaments	Road and houses damaged	Improvement of drainage evacuation oin landslide proved areas. Reforestation after rehabilitation terracing and drains
NL7 BianLomond	"	"	Rockfall slides		charnockites & Biotite scrap slopes			Filling up of cracks and improved drainage control landuse -- new paddy land
NL8 Rocklands	"	"	Slides, slumps, & rock falls slope failures, river banks slides, subsidence		Charnockites & Biotite gneisses colluvium boulder trains		Rocks blocked houses damaged deep cracks	
NL9 Ambaliyadda	"	"	Rock falls and slides shallow debris flow - 1 km.		Charnockite & biotite gneiss colluvium	Master joints & Linemanets	Road and houses damaged	Evacuation and reforestation
NL10 Delmar	"	"	Rock falls, Debris flow 1/2 km.		Charockite & Biotite gneiss colluvium & taluvium	Joints	Road and tea bushes	Cleaning of drains and improved drainage and terracing
NL11 Mulhalkale	Watumulla	Jan. 6 - 9, 1986	Debris & Mud flows 1 km.		Weathered rock & colluvium	Along major lineaments	Roads and buildings damaged	Transporting of the debris deposit clearing of road and repair bridges (causew[illegible] irrigation channel
BD12 Gampaha	Udapussellawa	Jan. 6 - 9, 1986	Debris flow slides & creep		Weathered rock & colluvium	Along major lineaments'	Roads and buildings damaged	Cleaning of roads, Diverting underground seepage
BD13 Kirklees	Udapussellawa	Jan. 6 - 9, 1986	Creem, large slides 1/2 km. and 10 hectare containing		Colluvium weathered rock Old slide materials	Microtremors	crack building roads and tea plants damaged	Worst affected estate. Cracks to be filled up. Cleaning and reparing drains. Surface and Sub-surface monitoring
BD14 Alagolla	Udapussellawa	Jan. 6 - 9, 1986	Sliding & Subsidence Relational slides		Quartzite weathered rock colluvium	Microtremors	Building and roads damaged	Filling up of cracks. Improve drainage. Repair roads and drains.
BD15 Keenakalle	Badulla	Jan. 6 - 9, 1986	Slides, Creep Subsidence		Weathered rock marble	Lineament	Roads and buildings damaged	Repair drains and preven sub-surface drainage
BD16 Ledgerwatte	Badulla	Jan. 6 - 9, 1986	Slides and Cracks near factory		Weathered rock colluvium	Cracks and seepage	Retaining wall subsided new Factory	Remove buildings along the boundary of the Factory premises. Rebuild the retaining wall.
BD 17 Cullen	Badulla	Jan. 6 - 9, 1986	Slides, circular cracks					
BD 18 Spring Valley	Badulla	1979, 1986	Cracks, Creep and Subsidence		Weathered rock & colluvium	Cracks and seepage	3 buildings damaged slides, cracks and subsidence	Fillup cracks. Improve drainage demolish and re-build.
BD 19 Deltota	Galaha	1985, 1986	Cracks and Sliding		Colluvium weathered rock Old Slides	Microtremors and rocks	Buildings damaged, cracks opened up in 3rd Division	
GL 20 Hayes Group	Deniyaya	1985, 1986	Cracks Slides (1 hectors)		Weathered rock and colluvium	(1979)	Tea plants damaged	Filling up cracks and monitoring
NL 21 Conapitiya	Kandapola	Jan. 6 - 9, 1986	Sliding and Subsidence		weathered rock colluvium	Cracks subsidences	½ hectare tea plants damaged	Repair water tank near factory. Remove Nursery.
					weathered rock	Microtremors	45 buildings damaged	Filling up of cracks ramped in. Repair drains and monitor.

There is a proposal by the National Building Research Organization to undertake a pilot project of hazard mapping of the Obada Oya basin in the Udapussellawa area and later to extend the mapping on a district basis to Badulla and Nuwara Eliya districts. This mapping programme will be the first scientific approach to the recurrent problem of landslides in Sri Lanka. Up to now, the landslide problem has been given ad-hoc treatment. Mitigating measures are often implemented after the event. Another important proposal is the Presidential Land Commission recommendation of water management in the catchment areas of the rivers in Sri Lanka.

Acknowledgements

Financial support was provided for field geological survey of landslide affected areas by several tea estates of the JEDB and SLSPC in the Hatton, Nuwara Eliya, Badulla and Galle Districts, and in the case of the Kotmale reservoir area, by the Mahaweli Authority. The final year geology students assisted me in the field work. The illustrations were prepared by Mr. S.M.B. Amunugama and the typing of the manuscript was done by Mr. K. Dunuhappawa.



A. AMHERST

B. DELMAR

Fig. 6

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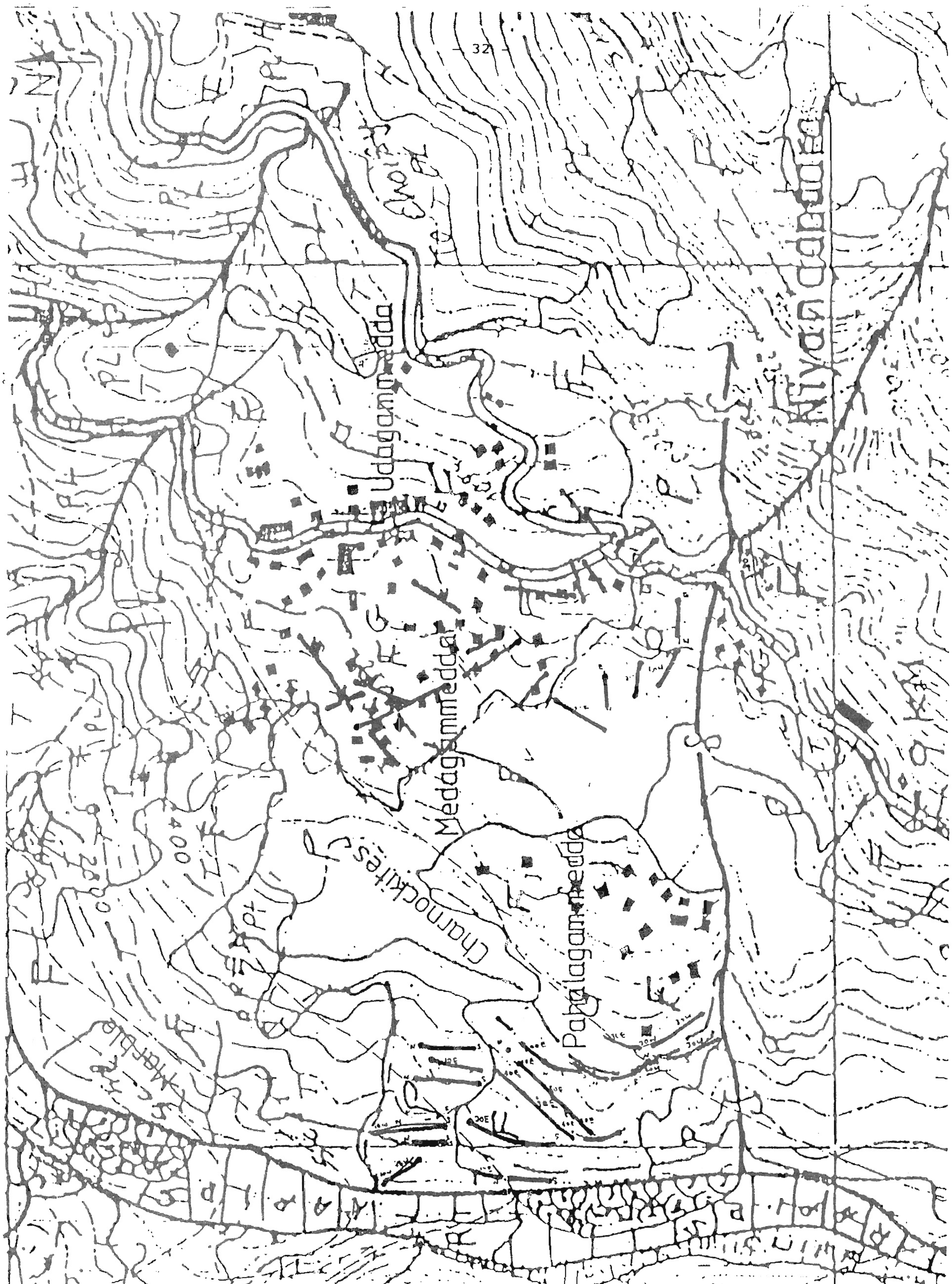

Uddagammedda
Medagammedda
Pahalagammedda
Charnockites
Marble
400
32

Fig. 7

LANDSLIDES IN MORAY ESTATE

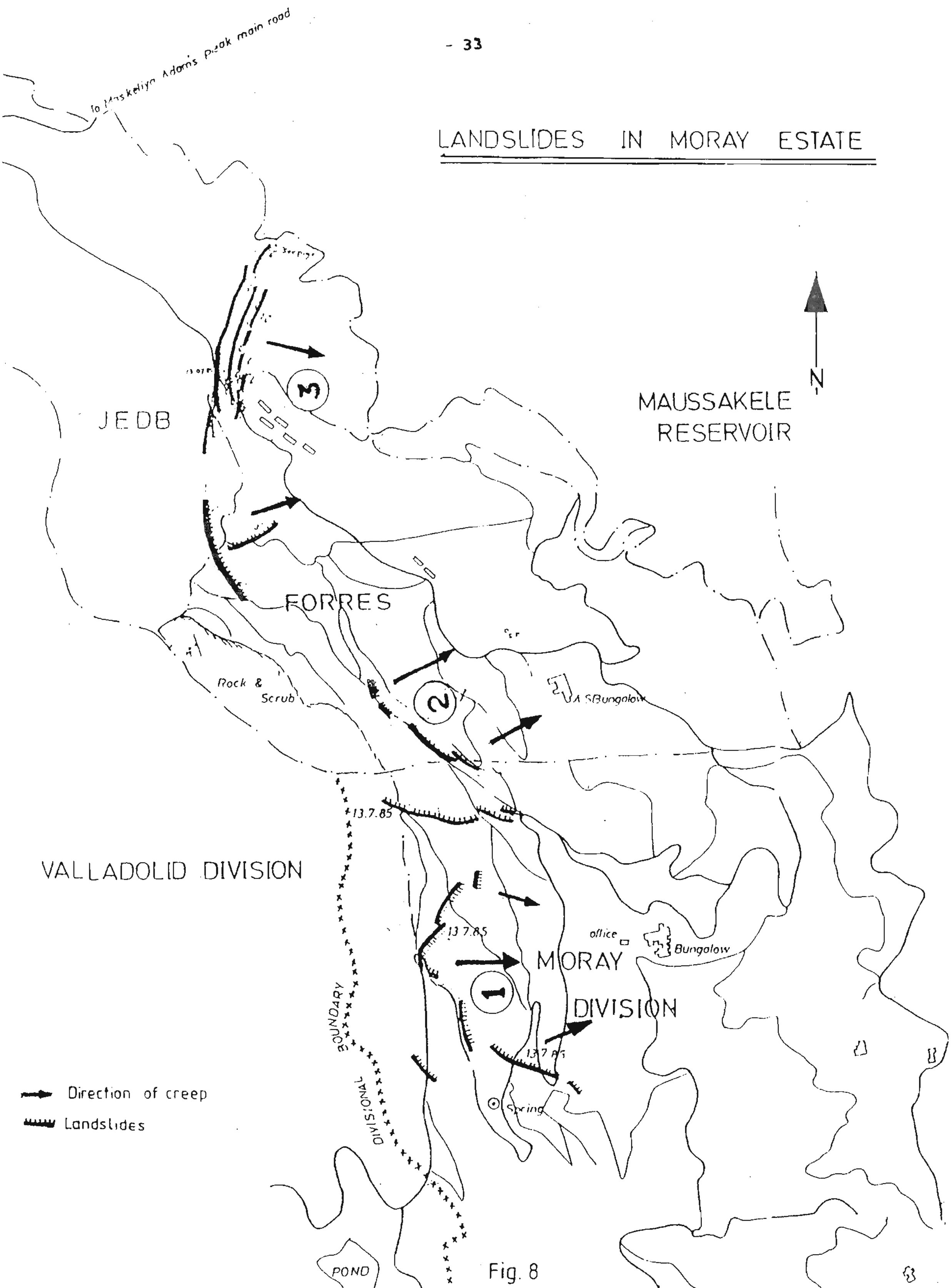


Fig. 8

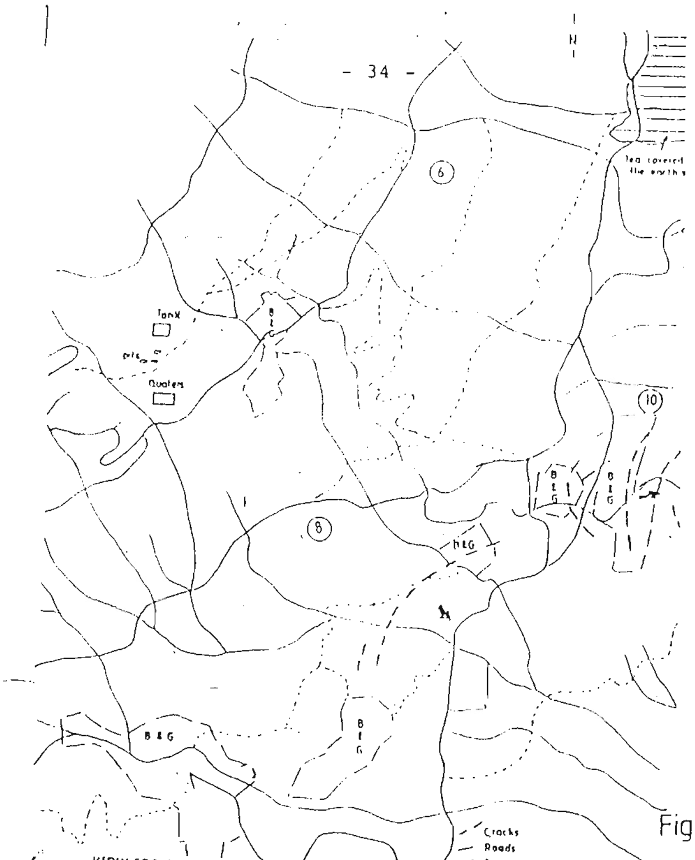


Fig. 9a

KIRKLEES ESTATE Field Nos. 16, 15, 14, 2

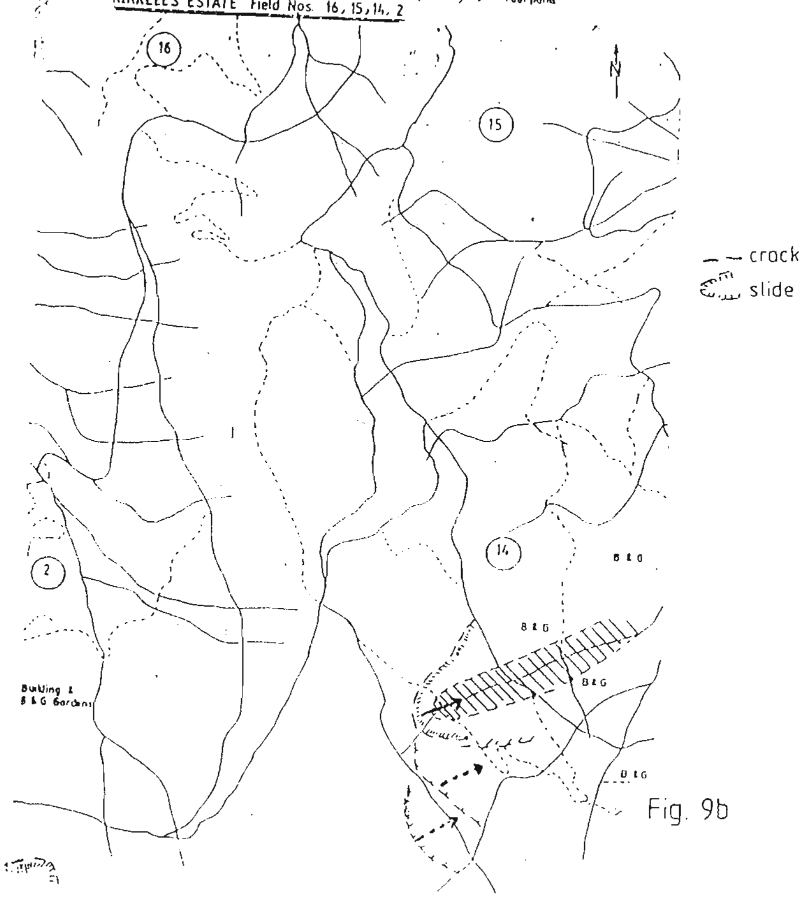


Fig. 9b

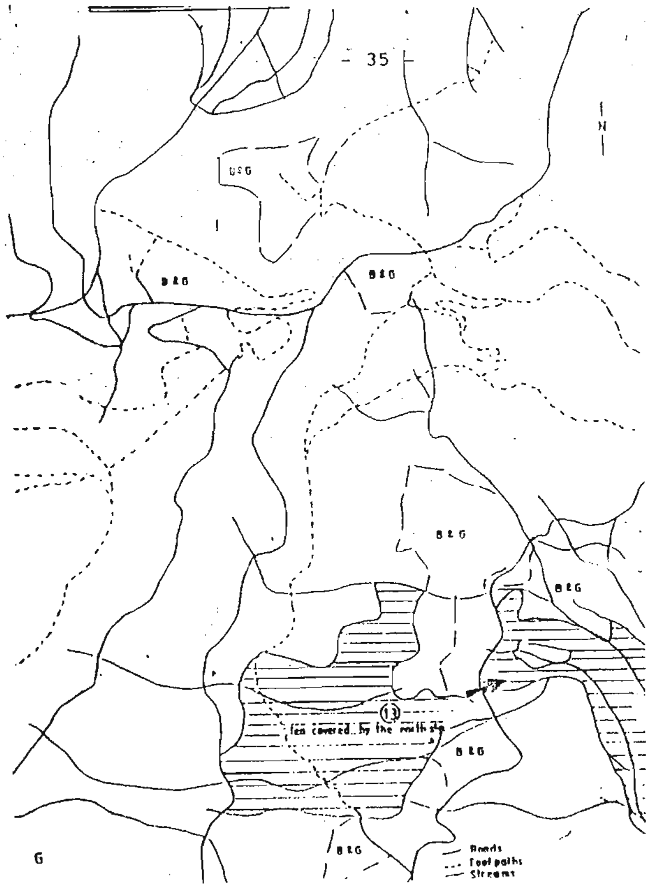
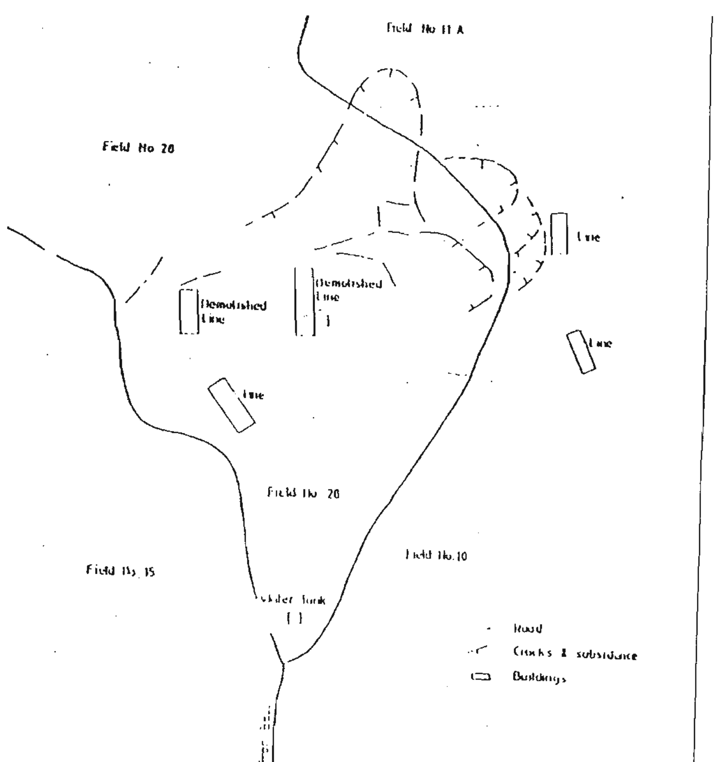


Fig. 10 a.



AREAS SUBJECTED TO LAND SLIDES CULLEN ESTATE

Fig. 10 b

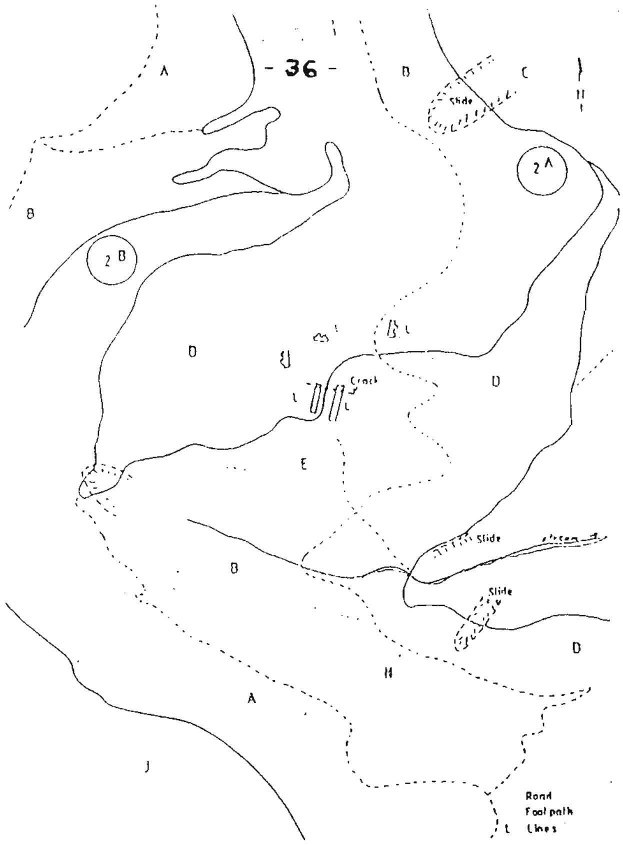


Fig.11 a

GAMPAHA ESTATE - Nuwara Eliya Field No 7 & 8

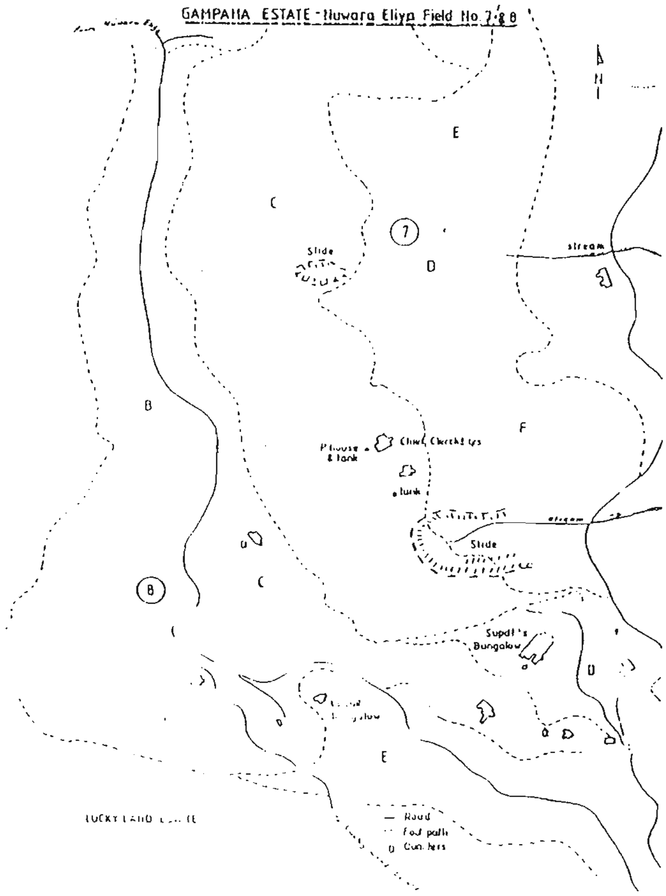


Fig.11 b

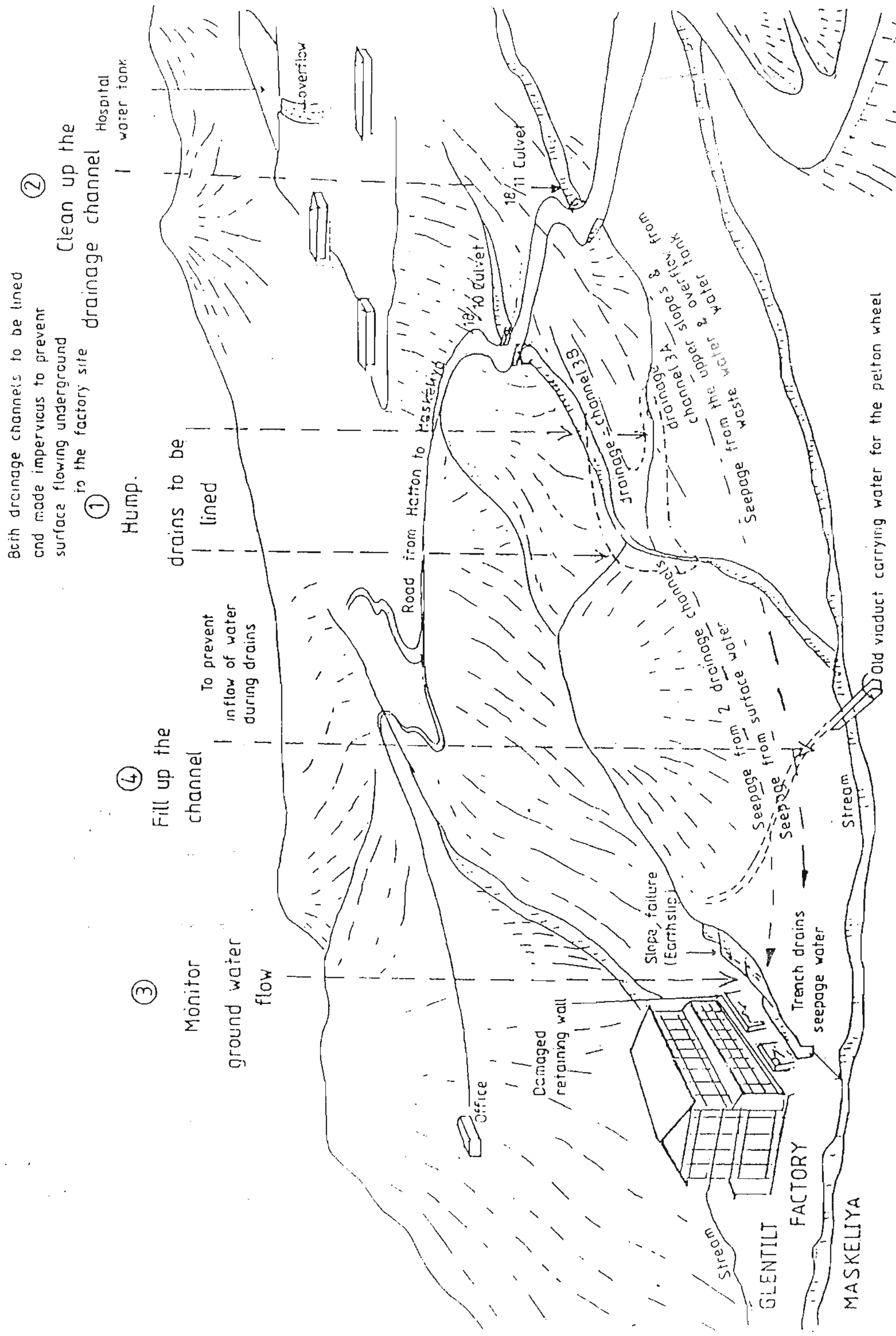


Fig. 12 Landslides in Glentilt Estate, Maskeliya

HA - 68 - 38

STUDIES OF THE SLOPE STABILITY PROBLEMS IN THE KOTMALE HYDROPOWER PROJECT AREA - SRI LANKA

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ABSTRACT

The Kotmale valley of Sri Lanka, the location of a recently completed major hydropower project, has serious stability problems arising from widespread sheared discontinuities and weak seams parallel to foliation, steep topography, valley slopes consisting of thick deposits of colluvium and the karstic processes in a thick marble bed. A number of major lineaments (faults) and associated joint systems also influence slope form, stability and erosional activity throughout the area. As the reservoir filled, reactivation of old landslides of the colluvial masses was observed and rock falls along the high cliffs are anticipated. Further karstic action in the marble could have adverse effects on the stability of the reservoir flanks but is considered a remote possibility.

INTRODUCTION

The construction of a 90 m high concrete faced rockfill dam on the Kotmale river in central Sri Lanka has been completed recently as part of the "Mahaweli Irrigation and Hydropower Scheme". The Kotmale area is infamous for landslides, both ancient and recent, as was recognised at the outset of the project.

As construction began, a geomorphological survey was carried out to assess the potential hazards of landsliding in the project area. All potential landslides were identified, including one on the left abutment which necessitated a change of the dam site to a location approximately 200 m downstream.

Subsequent investigations during the construction period revealed specific characteristics of the stability problems predetermined by the geological and tectonic features of the area; foremost of these being the presence of foliation shears and karstic processes in a marble bed.

GEOLOGY

The project area is underlain by Precambrian metamorphic rocks of the Highland Series of Sri Lanka, which have undergone several episodes of metamorphism and deformation.

Medium grained intermediate charnockitic gneiss with occasional acidic or basic bands is the predominant rock in the area. Other major rock types present are quartzite and marble. Calcic pegmatite occurs as a minor type, contained in the charnockities, but some bands are found to be continuous for considerable lengths. Among the rock groups, the presence of carbonate rock (marble), which is overlain by charnockites and quartzite, was considered very significant as it has a pronounced effect on the morphology of the area.

The Kotmale river valley, narrow and V-shaped, broadens into an almost circular amphitheatre-like form, surrounded by nearby vertical cliffs. This is believed to be the result of accelerated erosion of the marble bed which is typical of that underlain by marble in other highland areas of Sri Lanka.

STRUCTURE

The area had been subjected to fairly open folding, into antiforms and synforms striking northwest. The reservoir valley was eroded on a north-west plunging anticlinorium, where the foliation has a gentle dip (about 15 degrees) approximately downstream in the dam area.

Several important strong lineaments striking approximately NNE-SSW and NW-SE control the alignments of the Kotmale river and its tributaries as reflected by their straight courses and angular bends. Underground excavations revealed that these were either subvertical faults or shear zones (narrow and altered almost to clay, even at great depths).

The most important feature for the evaluation of the engineering and geological conditions of the area, apart from the presence of a thick marble bed, was the occurrence of sheared and slickensided discontinuities parallel to foliation. They were considered to be the origin of most of the slides on the area and posed many problems in the design of the dam and other surface and underground excavations involved in the project.

FOLIATION SHEARS

Shear zones parallel to foliation are particulary prevalent in metamorphic rocks (Deere 1973). Relatively weak, thin micaceous and feldspathic bands, formed by metamorphic differentiation were found in the charnockitic gneisses of the Kotmale area. Foliation shears were the result of differential movement along these weak layers or other inherent weaknesses of the rock mass during folding (Casinader 1980). As the rocks in the project area were folded into a broad, open anticline it was inferred that these shears would be continuous over considerable distances, which was later confirmed in the surface and underground excavations. The micaceous or feldspathic hands, along which shearing had occurred, had undergone varying degrees of weathering; some often altered to clayey seams.

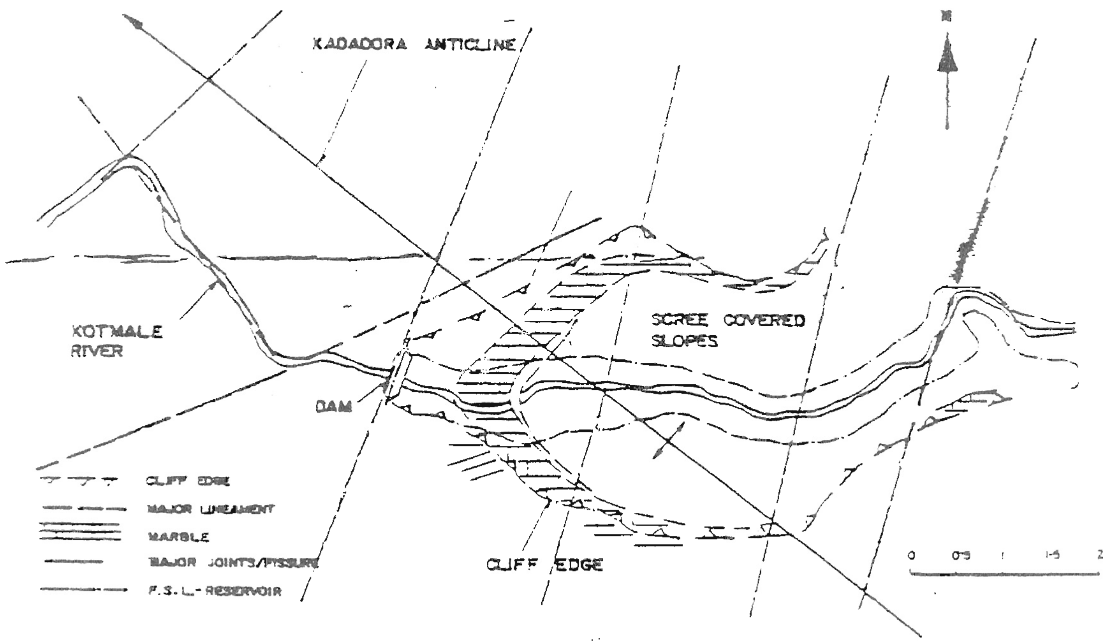

Fig. 1 Major geological and structural features of the Kotmale Reservoir area

SHEAR STRENGTH

A number of laboratory and in-site direct shear tests conducted on the foliation shears of the dam foundation and parameters obtained by back analysis of certain slides on some of these zones indicate that most foliation shears are at their residual shear strength corresponding to such low values as $C^1=0$ and $\Phi = \Phi_r = 12^0-15^0$. The dam designs and slope stablisation works were based on these parameters. This is well illustrated by the common occurrence of slides down dip-over-foliation shears in the hill slopes of Kotmale area. Daylighting foliation shears often caused stability problems in the numerous excavations of the project.

STABILITY PROBLEMS

In a broad scale, the stability problems of the Kotmale Project area were attributed to the differential weathering and solution effects of the carbonate rocks (marble and calcic pegmatite) and the wide spread occurrence of foliation shears.

Karstic processes in Marble

The marble bed running below the dam and around the reservoir area has a pinch and swell nature. Even within the dam area its thickness varies from 60 to 130 m, decreasing to 20 m four kilometres upstream on the right bank.

Drilling data revealed that marble contacts were generally highly weathered or solution-pitted. Ground water movement was often seen at the upper horizon (CCTV inspection) and karst development is advanced.

Slump blocks and settled rock units at 2 km and 4.5 km on the left bank cliffs indicate ongoing solution of marble. One such major potential slide was identified in the initial geomorphological survey, about 4.5 km upstream on the left bank. Here graben like deep open cracks had formed in the rear part of a protruding bluff escarp (Fig. 2). Either side of the bluff was marked by previous landslide activity.

These fractures were subparallel to a major lineament of the area. The nearby horizontal foliation indicates that solution of the underlying marble is one possible way in which the deep open fissures form. This fissure is likely to fail with the slightest disturbance but is too far from the reservoir edge to cause a destructive wave, and is being monitored periodically by geodetic surveying.

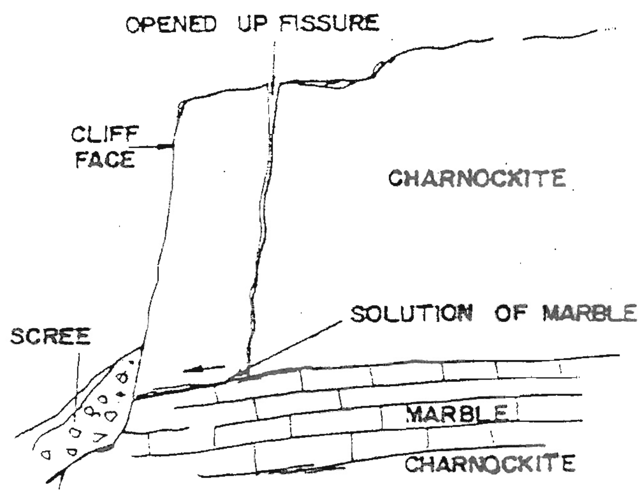

Fig 2. Potential slide formed by marble solution

Although there is very little evidence for on-going cambering of the reservoir cliffs, continued solution of the marble would have an adverse effect on the stability of the valley flanks. Changes in solution activity after impounding of the reservoir could be important. Solution activity could extend further into the valley flanks with the raised water table, as the marble bed is elevated upstream.

Another possibility is solution by transbasin leakage. Continuity of the marble bed on the right bank is established to an adjoining valley about 7 km away, towards north. There exists a hydraulic gradient about 1:100-150 between the two valleys. In the interbasin area the marble bed lies beneath a substantial cover of rock, and the degree of solution there could be considered minimal or non-existent. Therefore transbasin leakage is considered a remote possibility and further solution of marble in this was not anticipated.

COLLUVIAL SLOPE DEVELOPMENT

Morphology of the Kotmale Valley was marked by the steep cliffs bounding the reservoir area. The cliffs have gentle foot slopes formed by colluvium and debris derived from the high cliffs and upslope sources by various mass wasting processes in which marble solution plays a key role. Here colluvial slope development had advanced to such an extent that the whole reservoir bed is a complex mass of colluvium, shown by drilling to be up to 100 m thick in places.

LANDSLIDES IN COLLUVIUM

Slow downhill creep of the entire slope section has created 'hummocky' ground. As most of these scree slopes have been used for paddy cultivation (which requires ponding of water) a high state of saturation of the material exists most of the time, increasing the potential for sliding.

In the development of colluvial slope, equilibrium of accumulating masses could be affected by internal factors such as increased pore pressures or by external factors such as overloading by additional accumulation of colluvium moving downslope or removal of tow support by erosion (Gray & Gardner 1977). These reasons were true for Kotmale colluvial slopes where landsliding had been observed during and after periods of high precipitation.

Some slips on these slopes had developed at the water's edge, being partly submerged after impounding of the reservoir. The reduction of shear strength of the submerged material and the effects of the rising water table possibly caused this. More slides of this nature could be expected on the reservoir banks, especially at a draw-down. However, these are not considered hazardous to the reservoir.

CLIFF STABILITY

Most of the potential major landslides were confined to the steep escarpments. Accelerated weathering and erosion along the major lineaments and fracture zones parallel to them had imposed a breached appearence on the cliffs, forming a series of protruding sections marked by deep gully indentations as shown in Fig. 3.

Fig. 3 A view of the left bank cliff

The left bank cliffs were accentuated by the partial droning of a section (approximately the first km from the dam), in view of potential slides which could generate a significant wave. There seems to be no danger on the right bank as the majority of the cliffs were a safer distance away from the reservoir edge. Potential instabilities on the upper parts of the cliffs including topples, rock falls, rock slides and associated over burden failures could be attributed mainly to unfavourably oriented joint sets.

Apart from the foliation joints, two other major subvertical joint systems, approximately perpendicular to each other, usually occur as conjugate pairs. One system was parallel to the major lineament direction with a strike of 0 - 10^0 and the other sub-parallel to the cliff faces, strike 80^0 - 110^0. Some of these and most of the stress release joints formed by the erosional unloading had dips towards the river forming potential failure planes (Fig. 4). Minor to moderate rock falls and slides on the upper parts of the cliffs were expected to occur this way with high precipitation.

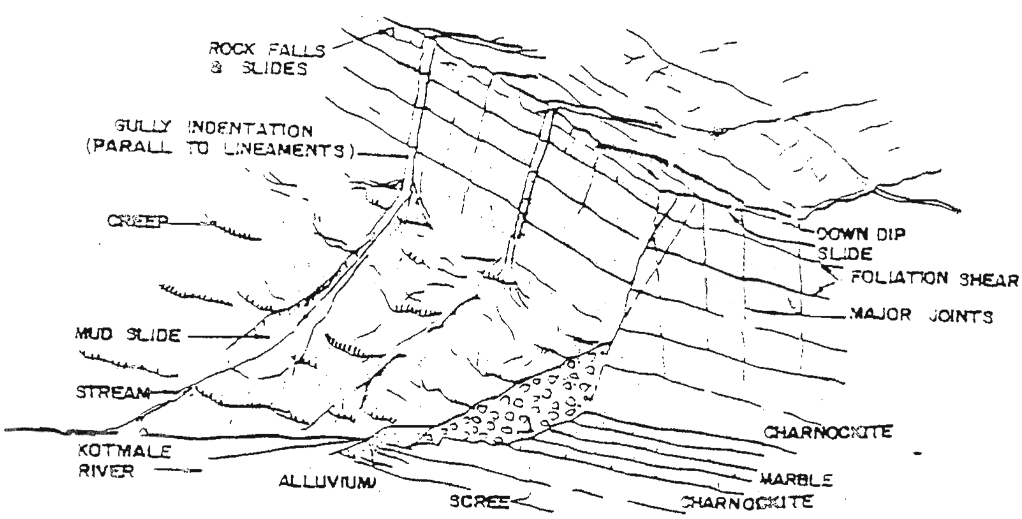

Fig. 4 Typical diagram of Kotmale left bank cliff

MAJOR SLIDES ON FOLIATION SHEARS

The geological conditions of the reservoir cliffs suggested that the most significant way a major instability could occur is by a large mass moving on a deep seated foliation shear or a completely weathered band (with the possible exception of solution effects of the marble). This is possible in two ways, by foliation shears or cliffs, or on the cliff face itself, due to local flexuring (local flexures were commonly observed on the dam foundation).

One good example for this kind of sliding is the left abutment of the original dam site. It was believed to have moved or settled en masse on a deep seated completely weathered calcic pegmatitic band, which had an unfavourable dip component towards the river. Even though there was little evidence for open fissures at the back of the slide, except a sheared subvertical joint (found in an exploratory adit), investigation drillings revealed a very high degree of fracturing of the rock mass indicative of disturbance. Extensive anchor support was provided in the plinth area as this weathered layer was found to be continuous under the dam.

Geological surveys of the protruding cliff sections of the left bank revealed that the foliation dips $7^{\circ} - 10^{\circ}$ into the hillside, the apparent dip towards the deep fractures being about 5°. Even though high pore pressures could develop on the potential failure surfaces due to the downing by the reservoir, it is anticipated that failue by this mode would not occur as the dips are low. These sections are periodically monitored by geodetic surveying and terrestrial photogrammetry.

Accelerated weathering and erosion of the fracture zones which had resulted in the formation of deep gullies on the cliff face had in turn developed large outwash fans at the bases of the gullies. It was observed that these were subjected to periodic slumping, however, without any disastrous effects.

CONCLUSIONS

1. Foliation shears and marble solution were the main causes of landslides in Kotmale area.
2. Further karstic solution in the marble bed would be a major hazard, but is considered a remote possibility.
3. Revival of the old slides and development of new slides were observed on the colluvial slopes after impoundment. This is not considered as a serious problem.
4. Further behaviour of the more impressive cliff sections is difficult to predict. Certain areas of the left bank cliffs are potentially dangerous and could create large waves that could overtop the dam. This fact had been taken into account in the dam design and a wave wall and a large capacity bottom outlet had been constructed especially to control the first impounding.
5. Unstable sections are being monitored periodically by geodetic surveying and terrestrial photogrammetry. So far there had been no signs of movement which is a very encouraging sign.

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THE GEOLOGICAL ASPECTS OF LANDSLIDES

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The term 'landslides' has been used for movement of earth strata and rocks due to slope failure during periods of excessive precipitation. It has been observed that the incidence of landslides has increased during the past few years specially in the hill country and the Kalutara district. During January, 1986, a number of landslides occurred in the Nuwara Eliya and Badulla districts with serious destruction to property, and many human lives were lost. The catastrophe attracted the attention of various government agencies and voluntary organizations, and steps were taken to evacuate people from danger areas and accommodate them temporarily in school buildings and abandoned tea factories.

The Geological Survey Department was called upon to undertake rapid reconnaissance surveys with the main objective of advising the various government agencies on evacuation of people from danger zones. During the course of these investigations, the geologists observed that most of the landslides had originated at higher elevation along steep hill slopes, specially slopes over 40^0 in gradient. Most of these areas were in cultivated land and the main crops on such steep hill slopes were vegetables and chena crops. In a few instances the lands had been cleared for tobacco cultivation.

The main cause of such slope failure triggering landslides is excessive precipitation. The other contributory factors are the geological structure, rock types and bad land use. There are no practical remedial measures to stabilise slopes that are structurally weak and such activity involves heavy expenditure. During the course of investigations, geologists have observed that slope failures could be avoided if proper land use practices were followed by villagers. Most of the recent landslides specially in the Maturata area have been caused by the disturbance of the top soil along steep slopes. Once the vegetative cover along steep slopes is removed, rain-water tends to percolate through the soft soil to the rock/soil interface and, due to the lubrication, gives rise to slope failures. The rock boulders that rest on the top soil along suchslopes get dislodged and move downslope devastating property along its path. Soil creep also causes the slow movement of debris along slopes. Such a movement was seen near the Mulhalkelle government hospital, and the dispensary which was on the path of this soil creep was completely destroyed.

The map displayed clearly indicate that the incidence of landslides has increased over the past 10 years in the Kandy, Nuwara Eliya, Badulla and Ratnapura districts. It was also observed that serious landslides occurred for the first time in the Kalutara district in 1984, and the cause of such movement was due to the uprooting of old rubber trees.

There are no direct scientific methods for predicting landslides. However, the presence of soil cracks at higher elevations, the sudden appearance at the valley bottoms of turbidity of well waters due to the percolation of sediments, and the unusual behaviour of animals could signal the triggering of major landslides.

In order to minimise the dangers caused by landslides, villagers have to be educated in land-use practices, and the cultivaion of crops at higher elevations should be avoided. Villagers should also be given instructions to evacuate from danger areas during periods of excessive precipitation and specially when the signs stated above are noticed.