LANDSLIPS IN THE TAMAR VALLEY:
an updated report on a continuing investigation.

DEPARTMENT OF MINES
TASMANIA

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ABSTRACT

The Tamar Valley is subject in many places to a landslip hazard which is increasing in impact as the area develops. The surface geology and geomorphology of this phenomenon has been studied and mapped, advisory classes of risk have been set up and maps issued. Subsurface investigation is under way and will continue.

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LANDSLIPS IN THE TAMAR VALLEY

P.C. Stevenson

The Tamar Valley, lying between Evandale and George Town, contains the second largest population centre in the State which is developing steadily and is considered likely to grow as a regional industrial centre. It is appropriate therefore that the area should be the subject of special examinations such as the Tamar Outline Development Plan. An important aspect is the geology of the area; geological map sheets at scales of 1:63 360 (Longman, 1964; Marshall, 1965; Gee & Legge, 1971; Gulline *et al.*, 1973) and 1:250 000 (McClenaghan & Baillie, 1975) have been published. It was realised early (Friend, 1848) that parts of the area were liable to landslip but since the beginning of this century the need to take account of this hazard has become more and more pressing.

The Tamar Area comprises the City of Launceston and the municipalities of Longford, Westbury, Evandale, St Leonards, Lilydale, George Town and Beaconsfield. With the exception of Longford all these divisions contain some evidence of the landslip problem. The physiography of the area is one of several factors controlling the phenomenon.

Landslips result from the interaction of three factors, each in itself complex. These can best be described in turn before any synthesis is attempted. The factors are:

(1) Physiography - the shape of the land, steepness and height of slopes, processes and rates of erosion under climatic influences.

(2) Geology - the kinds of rocks present and their distribution; their behaviour under natural conditions of geological change.

(3) Land use - a very broad term involving here the disturbances which man may inflict on the balance established between the first two factors.

1. PHYSIOGRAPHY

The Tamar Valley is a straight strip of land 8 to 10 km wide and nearly 70 km long extending SSE from the north coast of Tasmania. It lies between parallel ranges of hills which rise to 300 m overlooking the valley and to greater heights beyond.

The Tamar River is a drowned estuary (Sutherland, 1971) which receives water from the confluence of the North and South Esk Rivers at Launceston. The South Esk enters the valley by Cataract Gorge and its drainage does not otherwise affect the simple shape of the Tamar Valley. The North Esk likewise enters the Tamar Valley through a gorge in its straight side ranges but here the valley of its tributary, Rose Rivulet, forms an extension to the Tamar lowland as far as its own head just east of Evandale. A general view of the Tamar Valley shows that it is incised into otherwise hilly country. The existence of an estuary stretching so far inland is anomalous, but accounts largely both for the beauty and, as we shall see, the problems of the area.

The Tamar River is now estuarine, but its course within the straight valley is marked by many more or less narrow and abrupt turns as it swings from side to side between its high confining hills. This configuration causes many slopes to be locally steep and makes the otherwise small erosive power of the river more effective in cutting at the foot of these slopes. The swings of the river are in no modern sense meanders, for the land within each bend is often high and again locally steep slopes are present. Over 30% of the land between the East Tamar-Tasman Highway and the West Tamar-Midlands Highway has a slope angle greater than 7° and slopes of 20° and over are not uncommon.

The local and general steepness of slopes in mainly soft rocks, springs from several related causes. Major base level oscillations although of unknown magnitude, duration or date have undoubtedly taken place since the beginning of the Tertiary period. Most recently, in Quaternary time, the fall in sea level caused by the glaciations must have affected the area and has lead to steeper slopes which have been partially drowned by the subsequent rise of the sea.

In addition the coexistence of hard basalt cappings over soft clay causes steep slopes which retreat as the cap disintegrates and remain steep because of the differential resistance to erosion.

The valley of Rose Rivulet is the result of active downcutting by a stream and it is here that the greatest relief in soft rocks is seen. Elsewhere in the Tamar, side streams to the estuary are small and few with the exception of the North and South Esk. Where even small creeks do flow over soft rocks into the Tamar as at Muddy Creek, Atkinsons Creek, Egg Island Creek and that into Spring Bay, steep and unstable slopes are usual.

The present erosional history of the Tamar must be regarded as at quite a youthful stage, which implies rapid erosion and gives rise in places to mass movements.

2. GEOLOGY

The geology of the area attracted scientific attention as early as Strzelecki (1845) and Friend (1848) and was considered quite fully by Johnston (1874 and 1888). Other accounts include Montgomery (1892) and, more recently, Skeats (1922), Carey (1946), Kershaw (1955 and 1958) and Sutherland (1971).

A very recent general commentary on landslips in Australia is given by Ingles (1974).

Many reports refer specifically to the landslip problem but only those by the Department of Mines are readily available. Some of these have been published in Technical Reports (from 1968 onwards) whilst others are held as Unpublished Reports (see Appendix 1). Among those not readily available is one by Carey to the Launceston City Council in 1959, and one by Aitchison and Gill on an investigation by CSIRO in 1961 which has yet to be published.

The explanatory report on the geology of the Launceston Quadrangle was published in 1966 (Longman, 1966) and there are similar reports for the Pipers River Quadrangle (Marshall, 1970), the Beaconsfield Quadrangle (Gee & Legge, 1974) and the Frankford Quadrangle (in preparation).

The account by Sutherland (1971), although concerned primarily with the basalts, gives an account of the deposits of the area, and is best read in conjunction with Longman (1966) who deals with the basement structure. The part of the succession of greatest significance in a landslip study has been treated in least detail and is discussed as "600-900 ft [180-270 m] of clays, sands, gravels and lignites." Gill (1962) gives a short paragraph on these sediments and quotes Johnston, whose account remains the best we have. Johnston (1888) describes a section at Corra Linn, showing basalt with associated tuff and agglomerate, alternating beds of sand and clay "in most wanton unconformity" at Windmill Hill and Sandhill, fossil trees in tuff at Breadalbane, gravel, sand and clay at Stephensons Bend, and lignite and clay at Muddy Creek. He gives a log of the Carr Villa Borehole showing 174 m of clay and lignite with some soft sandstone. All this information although valuable is derived from isolated localities and no full account has yet been attempted. Such an attempt, leading to an analysis of the depositional conditions throughout the basin and through Tertiary time would be a most valuable achievement but it seems to the writer that insufficient resources exist for this to be brought about.

The rock types and geological relationships involved in a particular landslide occurrence are usually obscure, because of the general ground disturbance, and the soft nature of many of the rocks precludes the presence of clean sections. Nevertheless, examinations of many slips show some common factors.

The surface soils are usually clay based, and shrink strongly in dry weather. Where basalt is close up-slope, the soil may be dark brown, stony and up to 5 m in thickness. Fossil or modern rock falls, scree slopes or rock streams exist in some places, for instance at Craigburn and to the north of Bradys Lookout.

The clay mass of the slide is universal. The clay may be very stiff, almost dry and light red brown as at Lawrence Vale, grey, buff, or almost white but is remarkable for its high plasticity. Consistencies reminiscent of toothpaste are commonly seen in clays in the toes of slips, although the main mass of the slide may consist of quite dry and firm blocks. Base failures, that is failure along the surface of a competent rock layer, have been shown to exist and hard layers of sandstone, ironstone and basalt occur beneath some slides.

Slides of sand are rare, only being known at Legana Cliff, and are here mixed with finer material of silt or clay grade.

The Department of Mines has been required to advise on landslips at various times but in 1971 was given general instructions to examine the whole problem in the Tamar Valley.

Investigation methods

This programme began in February 1971, and its first phase consisted of geological and morphological mapping. Although regional geological mapping had been carried out in the area the criteria employed during this work were not directly applicable to the landslip problem. The geology of the rocks known to be involved in the problem were therefore re-examined where possible and at the same time the surface expression of the landslips was recorded. Some 800 slips have been recognised, of which 200 are intermittently active. The soft rocks involved rarely show intelligible sections.

Subsurface investigations are in progress. In the first instance some information on the presence and nature of clay and related slip-prone material can be gained from trial pits dug to 4 m with a back-hoe. This technique has been used in many instances (about 120 pits have been dug) in order to solve immediate problems of land classification; it is cheap, quick and can provide some information on clay strength and the presence of water. It is severely limited in depth however. It cannot be used for detailed investigations because of its depth limitation.

Auger drilling can provide samples from greater depths (up to 20 m) and details of water movement which vitally control slip movement. This has been done at Batman slip, Deviot, McEwans Rd, St Leonards, Wanstead Farm and White Hills.

Diamond core drilling gives better and more continuous samples to greater depths to give greater knowledge of the overall geological structure of the slip-prone beds and has been done at George Town, Beauty Point and Freshwater Point. In all 53 drill holes have been put down. Additional information is available from other investigations at Stephensons Bend, Lawrence Vale, Cosgrove Park, Launceston General Hospital, the Bell Bay Railway route, Batman Bridge and many other minor works.

Geophysical methods have been used to amplify the results of pitting and drilling.

Up to early 1975 the Department had issued about 114 reports on landslips and a dozen others on related subjects. Advice is constantly being given to local authorities, land- and house-owners, State departments, solicitors and estate agents and anyone else who requires it.

Landslipping is an intermittent process, the cycle for some earthflows is annual, and for larger movements may be from two years to many thousands of years. Many landslip features are in a dormant or fossil state when examined and they require some judgement and experience in their recognition. This subjective element can, however, be reduced by an insight into the geological environment of a particular type of slip. There follows a description of landslip forms.

Landslip types and their recognition

The literature of landslides is full of classifications and the variety and complexity of these phenomena provide good reasons for this. Rather than introduce another classification specifically for Tasmanian conditions it appears to be more useful to use two existing systems, so that the Tasmanian types may be seen in their correct place in the general spectrum.

Varnes (1958) uses a system based on rock types, mode of movement, geometry and the abundance of water. It is a classification well suited to engineering purposes and is summarised in Table 1.

The classification of Záruba and Mencl (1969) is mainly based on rock types and geological processes which makes it attractive to geologists. This sytem is shown in Table 2.

Table 1. LANDSLIDE TYPES (Varnes, 1958)

TYPE OF MOVEMENT		TYPE OF MATERIAL				
		BEDROCK		SOILS		
FALLS		*ROCKFALL*		*SOILFALL*		
SLIDES	FEW UNITS	ROTATIONAL *SLUMP (1)*	PLANAR *BLOCK GLIDE (4)*	PLANAR *BLOCK GLIDE (5)*		ROTATIONAL *BLOCK SLUMP (3)*
	MANY UNITS		*ROCKSLIDE*	*DEBRIS SLIDE*	*FAILURE LATERAL SPREADING*	
		ALL UNCONSOLIDATED				
		ROCK FRAGMENTS	SAND OR	SILT	MIXED	MOSTLY PLASTIC
FLOWS	DRY	*ROCK FRAGMENT FLOW*	*SAND RUN*	*LOESS FLOW*		
				RAPID EARTHFLOW	*DEBRIS AVALANCHE*	*SLOW EARTHFLOW (2)*
	WET		*SAND OR SILT FLOW*		*DEBRIS FLOW*	*MUDFLOW*
COMPLEX		COMBINATIONS OF MATERIALS OR TYPE OF MOVEMENT				

Examples from the Tamar Valley

(1) Beauty Point Main Landslip.
(2) Beauty Point toe area (Flinders Esplanade).
(3) Wanstead Farm, St Leonards.
(4) Bradys Lookout or Windermere.
(5) Batman Slide.
(6) Evandale.

Table 2. LANDSLIDE TYPES (Záruba and Mencl, 1969)

IN SOILS AND DEBRIS

- Debris creep
- Sheet slides (6)
- Earthflows (2)
- Debris flows

IN PELITIC ROCKS

- Landslides caused by out washing of sands
- Landslides on cylindrical surfaces (1) (3)
- Landslides on predetermined surfaces
- Slope movements caused by squeezing out of soft rocks
  - Block slides (4)
  - Valley bulging
  - Sliding of embankment

IN SOLID ROCKS

- Rock slides on predetermined surfaces
- Long term deformities
- Rockfalls

SPECIAL KINDS

- Solifluction
- Subaqueous slides

Having then these two classifications it becomes possible to use them for two purposes. Firstly the characteristic landforms resulting from landslide processes may be used as means of recognising modern or old slips in the mapping, and secondly the slips where mapped may be described by reference to one or other of the systems.

Rotational slump - in rock overlying unconsolidated sediments (Varnes) - Beauty Point type. *Rotational failure* (Záruba & Mencl).

The Beauty Point landslip occurred in clay and sand with intercalated basalt in an escarpment about 60 m high. Its age is unknown and probably prehistoric, but secondary effects have continued intermittently since at least 1900.

The basalt is the Upper Olivine Basalt of Sutherland (1971, p. 22) who indicates that it lies 25-30 m above the Lower Olivine Basalt in the succession and is about 5 m thick, but is severely displaced at Beauty Point by landslide movements.

These movements formed a crown about 1200 m long parallel to the coast and about 200 m from it (Jennings, 1964). Such a wide crown in relation to its downslope length is possibly the result of the coalescence of several slips. The mode of movement appears to have been Rotational Slump and the back tilt which has caused the ponding mentioned by Jennings and is still seen would indicate a rotational nature. The position and radius of the slip surface have not been determined and although an adit was excavated in an attempt to drain the area, the information from this was of little value.

The destruction of property in Beauty Point has resulted from a secondary activity in the form of slow earthflows moving down from the heaved foot of the primary slip. (Stevenson, 1972*a*).

Of similar type, but on a smaller scale, is the Tamar Avenue landslip, George Town (Stevenson, 1973*b*) where basalt capping an escarpment has dropped down to a lower level and slightly back tilted, but basalt talus has masked the sediments beneath except on the seashore, and it seems likely that the present stability of this slip is in some measure due to the talus cover.

Rotational Block Slump - in unconsolidated sediments (Varnes). *Rotational failure* (Záruba & Mencl).

A failure of this type has been examined in detail at Wanstead Farm near St Leonards. The slip has occurred in the uppermost slope of a knoll rising about 16 m above and about 60 m upslope from the toe which habitually encroaches on the road as an earthflow. Although the clay is capped by some metres of gravel forming the top of the hill, the gravel has not exhibited any appreciable cohesion and has failed passively. The gravel now stands as a vertical crown about 30 m wide above the head of the slip which is occupied by a pond.

Five auger holes have shown this slip to be of base failure type. The succession is:

			m
7.	Rounded quartz gravel overlying sand, spring at base		6
6.	Grey stiff fissured clay with some organic matter and sandy partings containing water.		6
5.	Brown crumbly clay		5
4.	Sandy brown clay		0.5
3.	Clayey quartz sand with water	at least	2
2.	Stiff grey plastic clay		1.75
1.	Stiff red-brown moist crumbly clay (continues in depth)		

All clays show high plasticity.

The lower aquifer (Bed 3) is 11 m below the rotated heel of the slip and during winter months shows up to 3 m of water pressure. Movement appears to take place between Beds 2 and 3. The water pressure produces a soft area in the toe of the slip about 2 m thick from which the earthflow moves onto the road. Monitoring of water levels is being continued.

A similar failure of larger size is that which has been investigated at St Leonards. This slip threatens the installations of the Rivers and Water Supply Commission and has been investigated by means of 27 holes to a maximum depth of 12 m. These indicate:

Basalt talus and soil.
Upper blue-grey clay.
Red-brown fragmented sandy silty clay.
Lower blue-grey clay

with a dip down hill.

Tests have shown the high plasticities and sensitive nature of these clays and their high shrinkage on drying.

As at Wanstead, high water pressures are encountered at some levels and a base-failure movement is postulated. More than one slip plane is possible and water levels and movements are being monitored.

Both here and at Wanstead the water involved is saline particularly in dry weather and it appears that the dissolved ions could have a deleterious effect on the clay strength.

The results of drilling have been confirmed by seismic and electrical resistivity surveys.

Block glide in rock - overlying unconsolidated sediments (Varnes)
Slope movement caused by squeezing out of soft rocks (Záruba & Mencl)

This type of failure is seen in basalt at Bradys Lookout where basalt blocks of 20 metres cube are sinking and moving outward on clay. No detailed investigation has been made, but this occurrence is not unique, as a similar situation exists at Craigburn, and at Windermere.

Block glide - in soil (Varnes). *Pressure-sand slip* (Záruba & Mencl)

This type of movement is exhibited by the Batman slide.

Here blocks of soil although initially in rotational failure are migrating down a slope of about 9° and are being deformed as the blocks jostle one another, so that pressure ridges and hollows are formed which change from day to day when the slip is moving. The main body of the slip is in no sense an earthflow as each piece remains discrete and quite firm under foot although large cracks are constantly opening and closing.

Some drilling and geophysical work has been conducted here and results may be summarised as follows.

Drilling on the plateau to the south and uphill from the slip showed about 20 m of basalt, well fractured but not deeply weathered, followed by grey clay with sandy clay and thin lignites. Grey firm clay is normal but soft sandy clay and fawn clay are noted at about 30m, 50 m and deeper. The combination of soft and fawn clays indicating water and oxidation suggests that water is moving through the succession at these depths.

A bore hole near the slip crown showed more sand beds, some of clean friable quartz sand up to 25 cm thick and at about 28 m pressure water rising to near ground surface was struck. Other hard but friable sands up to one metre thick were seen about 36 m and again where the hole bottomed at 43 m. Other bore holes gave similar results.

The conclusion has been drawn that the slip was partly caused by high pore pressure in the shallower sands and partly by water draining from the basalt into the slip.

Some aspects of the Lawrence Vale slip as commented on by Stevenson and Jennings (1971) show a soil block-glide type of movement. In this case the block-glide movement is secondary after primary movements of as yet unknown type.

Sheet slide movements (Záruba & Mencl)

These are related to block-glide movements but are undoubtedly primary and form prominent scar features in open grass hillsides on slopes of about 18° between Evandale and White Hills. The geology appears to be of basalt derived soils and basalt float overlying clays. The slip movement appears to involve laminar surface sheets about 2-3 m thick which become detached from the underlying clay and ruck up into folds at the foot, which then develops a slow earthflow.

These features seem to appear on apparently undisturbed hillsides, become active for a period perhaps of some years and then stabilise, so that only slight traces of fossil features that could be of this kind can be recognised. It may be that activity of this kind is a general feature of these hillsides, but at such a long cycle time that only local activity is seen at any one time.

Base failure slides (Terzaghi & Peck).

These do not appear to be well represented because of the absence of hard consolidated layers in the Tertiary succession. A soft sandstone occurs beneath the Lawrence Vale slide (Stevenson & Jennings, 1971) and this might behave as a base for the slip, since no appreciable movement is known below this level, but such a suggestion has not been investigated.

Secondary or Parasitic slides

These small slides form on the foot of an existing primary slide of any type, and in the Tamar are always of the slow earthflow type. The Batman slide shows this feature well, the toe being 2-3 m high. The flow advances by overturning and bursting; and except when it is very active at which times it may move at 2-3 m per day, readily grows a grass and weed cover which produces a local healing of the cracks. No significant amount of water is visible and indeed soft plastic mud is not obvious although it can be found deep in the cracks of the toe.

The occurrence of **this** type of movement has already been mentioned in connection with the Beauty Point landslip. The toe of the St Leonards slip is very similar except that more water is evident at wetter seasons.

Potential failure situations

The above types have been examined in some detail on the surface and in selected cases by boring, pitting and by geophysical methods, and therefore in the present state of knowledge the above applications of the existing classifications have some validity. A greater variety of landslips are being recognised from continued study and slip types characteristic of the following geological environments are becoming evident.

Clay
Clay with intercalated sand
Clay with overlying sand and gravel
Clay with overlying and/or intercalated basalt
Weathered basalt overlying basalt
Sands overlying weathered basalt
Basalt talus overlying clay
Weathered basalt talus
Sand and poorly cemented sandstone.

Each of these environments can under suitable conditions of slope and land use (or abuse) react by landslip movements, and all exist within the Tamar Valley.

3. LAND USE

Landslip is a fundamental hazard which can adversely affect or destroy the value of land for most purposes. Landslip on agricultural or grazing land does not cause significant hardship while at the other end of the scale landslip in residential areas can result in total loss of land and development value. The impact on roads, public buildings or industry may be expensive but the cost does not usually fall on the individual. When dwellings are threatened the problem is seen at its worst.

The causes of landslipping are very complex and variable but certain broad observations can however, be made under the headings of *water, soft rocks* and *slope*.

Water

Rainfall and climatic change. It is accepted that the landscape including the vegetation is in equilibrium with the climate (Gillott, 1968). Run-off and erosion rates and hence slopes, neglecting any question of tectonic tilt, will be balanced against rainfall. The assumption is that there is a dynamic balance between erosion rates and climatic impact, such that barring accidents, broadly similar landscape processes will continue. These processes may include landslips and if these occur they will do so at more or less regular, but perhaps long intervals.

If however, a change occurs in the climate then the landscape will respond by change and for a sharp change the response may be severe.

Rainfall records provide some insight into this cause, but no well defined trend is recognisable either in Tasmania or elsewhere. Local responses to high rainfall seasons are obvious and have been clearly recognised in the detailed landslip studies, but no predictions can be made.

Not only the wettest, but the driest years are of interest. The significance of these is that in dry weather clays shrink and crack and become more deeply receptive of following rains, so that landslip maxima may correspond not to wet periods or shorter periods of more intense rain, but to the greatest swings between dry and wet.

Man's interference with natural conditions. Probably of greater significance is the disturbance of natural water which is associated with man's activity. The following list indicates some of the ways in which natural rainfall is channelled, diverted, redirected and changed from a spatially homogeneous influence to a concentrated and directed influence:

Field ditches
Waterholes, dams
Land drains
Creek diversions
Road gutters and table drains
Culverts
Road sealing
Paving
Building roofs
Stormwater drains.

Each of these items increases the difference between the wet and the dry in a way quite unrelated to natural processes and landscape, so that an area previously wet or dry in response to the natural influence of rainfall may be dry for a hundred years. Another area may happen to be used as a disposal area for stormwater, and may therefore be subject to a rainfall total some thousands of times greater than its natural share.

The energy of the rain, instead of being evenly applied over the landscape and then concentrated by run-off channels which develop shapes in equilibrium with the release of that energy, is allowed willy nilly to act on parts of the landscape in concentration and those parts are often quite unfit to absorb it safely.

All this applies to the rainfall, but, brought by piped supplies, more water is added to the assault as:

Sullage
Septic tank effluent
Garden watering
Water for cattle
Vehicle washing
Pipe leaks.

This water often acts most strongly close to houses and other buildings where it is well situated to bring about their destruction.

Leaks in pipes which may contain water supplies or channelled rainfall are possibly the most potent source of water for ground failure because they are hidden, can act for long periods unsuspected, and are perfectly positioned to produce the greatest effect. In addition landslip can be both cause and increased effect, because a slight movement can crack a pipe, cause it to leak and so increase the movement.

Soft rock, clay, silt and sand

The presence of these materials is generally necessary for the type of mass movement known in the Tamar and as we have seen they are abundant.

Clays are the most important and their physical properties have been studied in some detail.

Grain size, by which is meant the percentage of the material below 2 μm is of major significance in the behaviour of clay. Most clays contain coarser material of silt and sand grade and this considerably modifies the behaviour of the clay. The percentage has been measured directly by mechanical analysis and the Atterberg limits (liquid limit, plasticity index and linear shrinkage) are a useful empirical means of describing clay behaviour at varying moisture contents.

X-ray diffraction has been used to identify the particular clay minerals present and this fundamental approach can add considerably to theory of the clay's behaviour particularly if treatment to modify the clay minerals is possible. More elaborate soil mechanics methods using unconfined compression, triaxial compression, vane, shear box and permeability tests intended to determine the soil strength parameters of cohesion (c) and angle of internal friction (ϕ) under conditions simulating those in actual slips have been used with the ultimate aim of being able to calculate a stability analysis. This is a mathematical model using the measured dimensions and parameters of a slip to show that when combined correctly these data will provide answers that satisfactorily represent and explain the failure. This combination can then be used to study unfailed slopes to test their safety, or to design measures to stabilise existing slips.

The silts and sands have properties usually less complex than the clays but because of their permeability can profoundly modify and control the behaviour of the clays around them. They are studied by methods broadly similar to those outlined above for clays except that X-ray methods can be replaced by microscopic examinations. Their permeability *in situ* can be measured by pump-in or pump-out water testing of bore holes.

The work in soil mechanics is valuable but cannot provide complete answers to slip problems. The landslip is a natural process, even though it may be aided unwittingly by man's activity and as such can only be delayed or modified and not prevented. The value of the scientific work is that it enables slips to be understood, and to some extent avoided or controlled, but prevention or absolute prediction is not possible. Tasmania is not alone in this problem and visits overseas by Department officers have shown that nowhere are significantly better methods available than are being used.

Slopes

The steep slopes in soft sediments in the Tamar Valley are the result of erosion acting on rocks which have been uplifted in the recent geological past.

Uplift increases the relief and therefore the energy available to the agents of erosion and in the earlier stages of the erosion cycle, steep slopes are to be expected. Landslipping is only one of several processes including stream erosion, rain wash and soil creep, by which the landscape is cut down. Landslip or mass movements act significantly at particular localities in response to the conditions at the time and place and are strongly affected in their incidence by changes in these conditions.

Another cause of steep slopes in the Tamar, unrelated to the stage of erosion cycle has been pointed out by Matthews (pers. comm.). The Tertiary rocks contain both soft and resistant elements and where erosion exposes these in close lateral proximity, steep slopes are produced. Where the hard bed produces springs, the landslip effect is magnified.

The Tertiary sediments were deposited in non-marine, and probably lacustrine, conditions and remnants are left at heights up to 360 m above sea level. The present deposits are therefore often over-consolidated and may owe part of their propensity for failure to rebound fractures. The depositional basin, confined by higher ground and well supplied with weathering products would account for the variability and intercalated nature of the sands and clays. There is some evidence that the margins of the basin exercise some control on the lithology and therefore the instability of the Tertiary sediments. Where the margin shows a low angle overlapping relationship as at Prospect or Abels Hill the materials actually along the basement contact tend to be coarser, more cemented or are bauxitised. The lower clay content reduces the risk of mass movement. Similarly there appears to be areas where deposition was more sandy as at Stephensons Bend and Legana and although these areas do exhibit some erosion, landslips are of a less serious type than usual. Where the basin margin is faulted and steep contacts are the rule, clay grade deposits can occur very close to the margin and therefore closeness to the margin is no guarantee of stability.

It is in the widespread slope failure that we see the coming together of the many factors of origin and history.

When artificially steep slopes are created, the natural stability of the original slope may be lost, giving rise to a failure. A natural frequency of failure which may be measured in decades or centuries becomes annual and slumping continues until a lower angle of slope has been created. Because the cohesion of soft rocks, once destroyed is very slowly regained, this angle will be lower than that of the original surface. Where a slope in soft sediments has to be disturbed a short-term economic view which ignores these factors is unlikely to be able to assess the final cost.

An idea of 'slope-management' must be instilled into the minds of planners and engineers in the Tamar Valley if slope failure is to be minimised. Any development on slopes usually means that cuts will be made for roads or buildings and poor judgment or a chance taken may result in successive failures occurring over decades.

4. THE ZONE MAP

The existence of landslips in the valley is a matter of public concern and is at the same time under active investigation. In order to alert the public to the locations and nature of the problem, a zone map has been compiled. This document is advisory but is being used as the basis of landslip area proclamations under the *Local Government Act* (No. 2) of 1973. The special regulations referred to are contained in the *Building Amendment Regulations* (No. 5) of 1974.

The valley has been divided into five zones, the definitions of which are outlined below. The exact definition of these zones is a matter of considerable difficulty as the criteria for decision between one zone and another have not been fully determined and boundaries may be gradational. The zoning is not intended to take over any of the responsibility that a builder or engineer must exercise in development.

It is intended as a general guide and has been produced on a scale of 4 inches to the mile.

Zone 1. Stable ground on hard rocks. No abnormal problems or risks.

This zone is basically on the hard rock areas and might appear to be simply decided. Many of the hard rock areas, however, are very steep as at Trevallyn and weathering in dolerite can be deep and very irregular. Locally, care with foundations is necessary. Basalt areas also can be hazardous because of the steep slopes and deep weathering of the rock.

Zone 2. Stable ground but on soft rocks. Strict adherence to existing building code.

These areas are flat or nearly so and so are not regarded as subject to slip. Foundation failure can occur because of poor design or construction on soils of low bearing strengths. A shrinkage hazard also exists in these areas and construction in the past has often been poorly adapted to cope with this. Deeper and wider footings and suitable control of soil moisture would help but pier and beam foundations may be advisable in some areas.

Zone 3. Potential landslip areas. Building methods in accordance with special regulations.

It is within this zone and the next that decisions become most difficult. The geology of the Tertiary sediments has been described as being variable and therefore the prediction of clays and water bearing sands at any particular place is not possible. Nevertheless if a piece of ground exists having a slope known to be above the safe angle for clay, and surface evidence indicates that clay is present, then it can only be assumed that a risk exists. Building by whatever method imposes stresses on the ground not only by loading it, but by the diversion and concentration of natural water flow, by physical disturbance of the surface, by cutting of trenches, by cut and fill, by cutting of trees and each of these effects may be sufficient to bring about a ground failure.

In this zone landslip is deemed possible, but not probable.

Zone 4. Old landslips and adjacent areas. No building permitted pending further studies.

In this zone old landslips have been positively identified and the reasoning is that given the right set of adverse conditions the area could slip again. Development invariably puts additional stress on the ground and the marginal stability attained by an old slip could easily be disturbed. Designs are possible which would enable buildings to be erected but this would be expensive because of individual design unless economies spin-off from codification.

Zone 5. Active landslip. No building permitted.

Here decision is once again made easy. Active slip is taking place and no cheap and effective method is known whereby housing can be placed on it. Engineering methods do exist, such as deep piling, excavation, toe loading, draining, but these are expensive and impractical for any structure other than a large one. Such measures have been used for example at Bell Bay, but smaller scale measures as at Beauty Point or Lawrence Vale have not met with comparable success.

5. CONCLUSIONS

The landslips of the Tamar Valley present a many sided problem, requiring studies in geology, hydrology, engineering, sociology, law, education and communication. Piecemeal, ad hoc or improvised measures are unlikely to offer a real or economic answer in the long run, particularly as the impact of any failure falls heaviest on the individual, usually a private householder, while only uneconomic measures have yet been devised to cope with it.

Long term studies and planning, including warnings of hazard and vigilance against unsafe practices are beginning to control the problem and although there are many difficult and painful problems still to be solved, the measure of the hazard has been taken and investigation continues.

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APPENDIX 1

Select list of Department of Mines Unpublished Reports on landslips and land stability.

1971/8	Slope stability at Preservation Bay.	S. Elmer
1971/13	Report on the failure of a clay bank near Comalco's dam, Bell Bay.	P.C. Stevenson
1971/20	Slope stability at Freshwater Point.	S. Elmer
1971/21	Slope stability of Danbury Park.	S. Elmer
1972/9	Report on a landslip at St Leonards	P.C. Stevenson
1972/11	The assessment of land stability at Panorama Heights subdivision, Devonport.	P.C. Stevenson
1972/15	Seismic survey, Tamar Avenue, George Town.	D.E. Leaman
1972/18	Possible landslips in the Hillwood district.	C.J. Knights
1972/23	Proposed subdivision at Windermere.	D.E. Leaman
1972/25	Landslip risk in an area to the south of Leith.	P.C. Stevenson
1973/27	Stability conditions near Launceston Church Grammar School, Mowbray.	P.C. Stevenson
1973/29	The landslip situation at Aerodrome Hill, St Helens.	P.C. Stevenson
1973/39	Stability of a house block at Thelma Street, Launceston.	P.C. Stevenson
1973/47	The stability of a proposed subdivision at Clara Street, West Ulverstone.	P.C. Stevenson
1973/51	The stability of an area at Parklands, Burnie.	P.C. Stevenson
1973/60	Stability of a proposed subdivision at Ellice Hill, Spreyton.	P.C. Stevenson
1974/26	Stability of land at Danbury Heights, West Tamar.	W.L. Matthews
1974/51	Stability zones in the Leith-Forth area.	P.C. Stevenson
1974/64	A landslip in basalt soil at East Devonport.	P.C. Stevenson
1975/10	A threat of rockfall on the Wilmot Main Road.	P.C. Stevenson
1975/28	The stability of slopes at the Bay View Motel site, Strahan.	P.C. Stevenson