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1987/60. Geology in relation to forest practices.

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EXAMPLES OF FORESTRY-RELATED INVESTIGATIONS BY DEPARTMENT OF MINES

	Report No.
Slope stability at West's block, Cluan Tier	1982/17
Potential landslide and erosion problems, Great Western Tiers and Mt Barrow	1986/67
The potential effect of forestry operations on slope stability and springs in the Mt Clark - Mt Koonya area	1987/56
Slope stability in an area of the Douglas-Apsley State Forest	1987/58

PART 1: HYDROLOGIC CYCLE AND EROSION

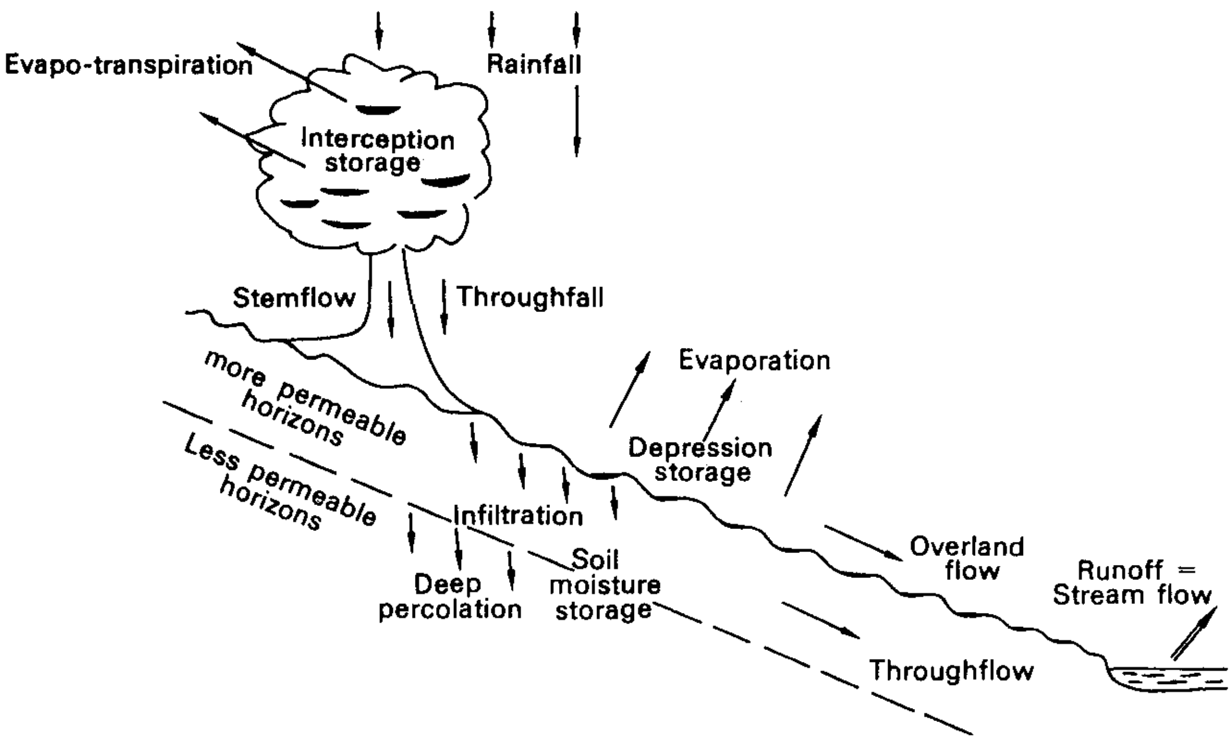
D. J. Sloane

HYDROLOGIC CYCLE (see also Sloane, 1983)

A basic knowledge of the hydrologic cycle and fluvial processes is required in order to understand and avoid potential erosion problems following the clear-felling of forested catchment areas.

The initial input to the hydrologic cycle is falling rainwater, which is divided into several components as it reaches the ground surface. Initially some of the falling rainwater is intercepted by vegetation which prevents direct raindrop impact on the ground surface beneath. Some water is held on the foliage surfaces, from where it may evaporate; some drops to the ground after a delay; and some runs down the stems and branches to reach the ground at the plant or tree base.

The water which reaches the ground surface either directly or indirectly may infiltrate into the ground, may be stored temporarily in small surface hollows as depression storage, again available for evaporation, or may be diverted downslope as overland flow across the ground surface.



Simplified diagram showing components of the near-surface hydrologic balance (from Carson and Kirkby, 1972)

Overland flow or runoff

Horton's model of overland flow simply states that "overland flow will occur when rainfall intensity is greater than the infiltration capacity of the soil".

Considering a uniform hillslope, infiltration capacity can be considered as uniform over a small area, and therefore the rainfall excess is more or less constant over the slope. The overland flow discharge therefore increases linearly downslope with distance from the drainage divide. The greatest amount of overland flow occurs at the base of the slope due to uniform contributions from all areas upslope.

In many cases, soil profile development has resulted in a reduction of soil permeability with depth or, where soils are thin, the bedrock is less permeable than surface soil horizons. As the surface soil horizons are of higher permeability, some of the water percolating down from the surface is frequently diverted laterally as throughflow.

New work indicates that Horton's overland flow model may be considered as an expanded form of the throughflow model. Throughflow can occur when infiltrating water reaches an horizon of lower permeability, above which saturated throughflow may occur. If a storm is of sufficient duration and intensity, the saturated throughflow horizon may expand in thickness until it intersects the surface and water seeps out. This is commonly observed where soils are thin, and on the lower parts of slopes and in areas of flow concentrations produced by slope concavity or contour curvature.

Infiltration Rate

Infiltration rate is defined as the maximum rate at which water can penetrate into the soil.

Many factors are related to the infiltration rate or capacity of the soil. Infiltration decreases rapidly from the beginning of rainfall. Infiltration is related to soil grain size or, more strictly, the pore size or the open spaces within the structure of the soil mass. Infiltration is also related to the soil moisture at the start of rainfall, and also to the density and type of vegetation cover which influences infiltration by affecting soil structure, and by providing protection from rain impact.

Infiltration can be also greatly affected by soil compaction during forestry operations.

The Forest Practices Code requirements for wet weather operations are therefore essential, as this is the time of greatest runoff, especially when preceding ground moisture conditions are high. Disturbance during periods of high runoff can not only result in direct incorporation of sediment in runoff but can also greatly increase soil compaction problems by 'puddling' effects.

RUNOFF MODELS

HORTONS

- rainfall intensity > infiltration ⟶ runoff
- increases linearly downslope
- problems towards foot of slope

THROUGHFLOW

- permeability contrast ⟶ lateral diversion of infiltration
- throughflow horizon expands with rainfall
- problems where soils are thin:

  lower slope/sections

  slope concavity

  contour curvature

INFILTRATION CAPACITY IS DEPENDENT ON:

SOIL PROPERTIES – grainsize & pore size

PRECEDING SOIL MOISTURE

DENSITY and TYPE OF VEGETATION COVER

SOIL COMPACTION

HENCE – FP CODE WET WEATHER RESTRICTIONS

ESPECIALLY ON HIGHLY ERODABLE SOILS

EROSION (see also Sloane, 1983)

There is an important distinction between geological erosion and 'accelerated' erosion. Geological erosion is the normal rate at which the land is eroded without the effects of disturbance. 'Accelerated' erosion refers to an increase in the rate of erosion which often arises when man alters the natural system by various land use practices.

Particle detachment and transportation

Soil erosion by water involves the detachment of particles and their subsequent transportation. The two main agents involved are raindrops and flowing water. Raindrop erosion results from the detachment of particles by raindrop impact, and particle movement by splashing. Overland flow erosion generally involves the transportation of particles previously detached by raindrops, but may also involve particle detachment. Transportation is by turbulent water flowing as sheets, in rills, or gullies.

Investigations have shown that the amount of soil carried in runoff increases rapidly with raindrop energy. The detachment and movement of soil particles as a result of raindrop impact is a fundamentally important and often initial stage of soil erosion.

Raindrop impact may also have an effect by reducing infiltration by dispersing clay particles which form a surface crust on drying.

Horton's model of surface runoff provides a basis for an understanding of the causes and control of runoff erosion. To reiterate, in simple terms, precipitation equals infiltration plus runoff. As runoff occurs a thin layer of water develops on the ground surface as overflow from depressions takes place. Initially the water does not have enough energy to transport and detach soil, but as it proceeds downslope the force increases until there is sufficient energy for erosion to begin. Upslope from this critical or threshold point, no runoff erosion occurs and rain splash is the main erosive force. Below the critical point rilling and gullying may be initiated and the erodability of the ground surface will determine the amount of erosion occurring.

One of the salient features of this relationship is that the most easily moved particles are between 0.5 mm and 0.1 mm diameter, in the medium to fine sand size range. Runoff follows the lines of least resistance and becomes concentrated in rills and gullies, forming eroded channels. The depth and velocity of the water increases with this concentration, as does the ability to detach and transport sediment particles.

The water and sediment mixture is extremely erosive, the mixture scouring the base and sides of a channel. Waterfall erosion occurs at the head of the channels with the formation of plunge pools and undercutting, and slumping occurs due to undercutting and steepening at the sides of channels. Patterns of rill and gully formation may be guided by pre-existing structures such as culverts, snig tracks, and wheel ruts.

In the case of the saturated throughflow model, the important controls are soil characteristics, distance downslope, slope angle, and intensity of rainfall. The attainment of fully saturated conditions occurs most readily on concave slopes or in hollows where soil is thin and impermeable. Erosion due to the surface appearance of seepage from saturated throughflow

EROSION

GEOLOGICAL AND 'ACCELERATED'

PROCESS:

PARTICLE DETACHMENT AND TRANSPORTATION

RAINSPLASH

RUNNING WATER

- sheets
- rills
- gullies

RUNOFF

ENERGY INCEASES DOWNSLOPE

CRITICAL POINT

- energy sufficient for erosion

SAND SIZED PARTICLES EASIEST TO ERODE

Granites, Sandstones, Windblown deposits

SOIL + WATER MIX IS EXTREMELY EROSIVE

involves the upslope extension of existing channel systems, and is independent of the distance from the slope crest. As with the Horton model, the erosion force of the runoff increases downslope and increases with increasing slope angles. On a slope with a convexo-concave profile, the erosive forces reach their maximum on the steepest, and often central, part of the slope profile. Most of the erosion occurs downslope of the central part of the slope, initiating gullies and channel flow. Overland flow and throughflow are likely to be two extremes of a continuous sequence of possible conditions for erosion and gully development, with throughflow being more common in humid areas and overland flow more likely in semi-arid areas.

Erosion control

Consideration of these flow theories gives a basic outline of the causes and effects of erosion and sediment yield caused by precipitation runoff. The aim of erosion control is to reduce soil loss so that soil productivity is economically maintained and deterioration of regional water quality is prevented. The purpose of implementing controls is to restore equilibrium, so that the rate of loss is equal to the rate of regeneration, that is to reduce 'accelerated' erosion to 'geological' erosion.

In summary, the variables that determine runoff erosion and which must be modified, where possible, to reduce erosion are:

- rainfall intensity and infiltration capacity expressed as runoff intensity;
- length of overland flow;
- angle of slope;
- surface roughness.

Soil conservation practices fall into three main groups; crop management practices, supporting erosion prevention practices, and practices designed to restore eroded land. All these relate to the manipulation of one or more of the variables in the precipitation-erosion system.

Crop management practices are generally used in agriculture and do not apply to any great extent in forestry operations. Specific applications include the mulching and seeding of road embankments and quarries, and the sowing of road surfaces and snig tracks after harvesting operations cease.

Supporting erosion-prevention practices in forestry operations include the correct planning and design of road and snig tracks systems as well as road drainage. The purpose of these practices is to disrupt surface water flow by reducing flow velocity, dispersing the water, or by increasing the surface roughness, as well as restrict the loci for rill development, and conserving water.

Restoration of previously eroded areas includes covering waterways with vegetation or encouraging natural vegetation. Gullies may also be converted to stable artificial channels with dimensions more appropriate for the water discharge carried.

SOME PREVIOUS INVESTIGATIONS OF FOREST HYDROLOGY AND EROSION

Numerous references can be found in Sloane (1983).

A continuous cover of mature forest is probably the best protection that a water supply catchment can have to minimise erosion and turbidity. The role of forests in protecting against erosion has been accepted for a long time. Accelerated erosion due to poor forest land management activities may result in reduced productivity of forest soils over sizeable portions of affected watersheds, in damage to roads, bridges and other structures, and may have adverse impacts on stream environments downstream.

The main effect on the hydrological cycle that occurs is that clear-felling produces an increase in runoff. This increased runoff, and therefore its effect on water quality, lasts for a period of between two and four years from the time of clearing and reseeding to the time when the new forest provides adequate protection to the soil.

Generally within Australia, turbidity or suspended sediment load problems resulting from increased runoff and accelerated erosion have occurred in catchments providing town water supplies, and have been a source of conflict between forestry and water supply authorities in many areas. Appendix 1 of the Forest Practices Code details the major town water supply intakes, and therefore extreme care should be exercised in these catchment areas.

It is interesting to note that the Melbourne and Metropolitan Board of Works has opposed the logging of mature forests from water supply catchments, not because of the increased runoff after clear-felling, but because they considered that in the long term the reseeded forest will take about 25% more water than the mature trees they replace.

Previous investigations have shown that soil type is a prime factor with respect to turbidity problems. Granitic rock types in particular are a problem, as are sandy soils derived from Permian and Triassic rocks, and aeolian deposits and dispersive soils.

All studies point to the deleterious effect of forest roads on turbidity and sediment yield. Turbidity in some areas has been shown to increase up to nine times during the first rain storm after road construction. The other major identified source of erosion is snig tracks. Generally, sediment yield is considered to originate from point sources, rather than uniform soil loss. The erosion potential of roads and snig tracks must be stressed, especially where they concentrate water, intersect other snig tracks or roads, and encroach on stream channels.

Particular erosion problems may occur with roads on midslope and lower footslope locations. The runoff model indicates that these areas are prone to rilling and gullying. Often, and particularly in areas of highly erodible soils, soils are thickest in footslope regions. A wedge of easily erodible material derived from slopewash may occur.

All studies stress the importance of planning operations, with attention to erosion control procedures immediately after harvesting. It is considered that the first erosive rain after harvesting results in the greatest damage.

Soil disturbance from forestry operations will not necessarily be reflected in an increase in erosion and deterioration of water quality, provided the potential for erosion from various sources is recognised and attempts made to reduce or nullify the effects. To this end the Forest Practices Code has been produced.

PREVIOUS INVESTIGATIONS

FOREST CLEARING —> INCREASED RUNOFF

INCREASED RUNOFF —> WATER QUALITY DETERIORATION

RUNOFF RETURNS TO NORMAL AFTER 2-4 YEARS

WATER QUALITY PROBLEMS
ARE A MAJOR CONFLICT AREA

FP CODE DETAILS MAJOR TOWN
WATER SUPPLY CATCHMENTS

GRANITIC ROCK TYPE MAIN PROBLEM
SANDY AND DISPERSIVE SOILS TO SOME EXTENT

ROADS AND SNIG TRACKS ARE MAJOR
EROSION LOCI AND SOURCE OF SEDIMENT

FOREST PRACTICES CODE

The Forest Practices Code shows three major erosion classes based on the parent rock/soil type. This is a first approximation, which can be initially assessed from a geological map. It is important to remember that soils on various rock types may be derived from other rock types upslope. Soils may also be thinner towards slope crests and thicken towards the base of a slope.

The planning of road and snig track locations and patterns is highly important. These features are the main source of sediment and erosion within an area, and are thus the major factors which may result in water quality deterioration, and high bedload and suspended sediment yield in adjacent streams and rivers.

The planning of operations can be assisted by attempting to stratify an area on the basis of erodability. Factors such as rock type, slope angle and length must be considered.

Road location must be carefully planned with respect to erodability. The Code suggests that to reduce disturbance, roads should be 'fitted' to the topography. As mentioned previously it is better to avoid midslope-lower slope locations, as these areas are prone to gullying. Roads located at the base of slopes may assist erosion control by collecting runoff. In this respect and at these locations, the road drainage and associated erosion control methods are highly important.

FOREST PRACTICES CODE

RECOGNITION OF POTENTIAL EROSION
EROSION CONTROL PRACTICES

RECOGNITION:

EROSION CLASSES BASED ON
PARENT ROCK TYPE:

CONSULT: – Geology map
– Topography map

Provides "First Approximation" Assessment

STRATIFY ON ERODABILITY BASIS

ROAD PLANNING:
– LANDING LOCATION
– SNIGGING PATTERN

HIGHLY IMPORTANT

FIT ROADS TO TOPOGRAPHY WHERE POSSIBLE

INSPECT SUSPECT LOCATIONS IDENTIFIED

The Forest Practices Code and erosion control

The FPC drainage requirements are simply designed to reduce the quantity and flow of runoff, and hence reduce its erosive force and sediment carrying capacity. The placing of sediment traps in the form of rip-rap, logs, and slash barriers at the mouths of culverts, and the diversion of road drainage 50 m before a stream crossing, are designed for the purpose of dissipating runoff energy. I tend also to favour the construction of 'scoops', particularly in areas of highly erodable soils.

The pattern of log snigging is highly important on areas of highly erodable soils. Uphill snigging is highly desirable, as it produces a diverging network of snigs, rather than a converging pattern as in downhill snigging. This may not be practicable in some areas and on some slopes due to wheel rutting. However, from observations, a combination of methods can be very effective.

The construction of effective drainage grips is a major problem on snig tracks which converge downhill to a landing. In some cases the grips are constructed without due regard to the effect of their discharge, and they occasionally drain directly into an adjacent snig. The problem tends to become compounded where the snig tracks converge towards the landing. The construction of grips in these areas is often ineffective.

Perhaps the most important feature is to dig the grip deeper than the bottom of the snig track. Logging debris is not favoured as the sole means of providing a water and sediment barrier for reasons previously discussed, but debris can be used as an adjunct to grip construction, and is considered to be very effective when used in conjunction with other drainage methods. Due consideration must be given to the direction of discharge of grip drainage, as there is little benefit if runoff is directed into an adjacent track. Scoops could also be constructed where practical, especially near the discharge points of major snig tracks.

In areas with high erosion class soils, snig tracks must be drained as soon as operations cease and in some cases, during operations. Erosion problems have occurred in areas where control methods have been applied too late. Once gullying has started, control becomes more difficult and expensive.

In summary:

(1) Timber harvesting does tend to accelerate erosion and sedimentation which may cause on-site or off-site damage.

(2) Erosion hazards vary greatly with topographic position and soil type.

(3) The construction of logging roads contributes a disproportionate share of the problems.

(4) Runoff and accelerated erosion and sedimentation increase after harvesting ceases but return to normal levels after a period of 2-5 years.

(5) Care taken and controls implemented during harvesting operations can have a considerable influence.

EROSION CONTROL

DESIGNED TO REDUCE RUNOFF

QUANTITY

VELOCITY

EROSIVE FORCE

SEDIMENT CAPACITY

SEDIMENT TRAPS:

RIP RAP (rocks)

SLASH BARRIERS

LOG BARRIERS

SCOOPS

SNIGGING PATTERNS

UPHILL – divergent

DOWNHILL – convergent

RUNOFF BARRIERS:

WATER BARS

HIGH EROSION CLASS SOILS

IMPLEMENT EROSION

IMMEDIATELY AFTER OPERATIONS

EROSION CONTROL

AIM:

- REDUCE SOIL LOSS
- MAINTAIN SOIL PRODUCTIVITY
- MAINTAIN WATER QUALITY
- RESTORE EQUILIBRIUM

  i.e Reduce 'accelerated' to geological erosion.

VARIABLES TO BE MODIFIED:

- RUNOFF INTENSITY
- LENGTH OF OVERLAND FLOW
- ANGLE OF SLOPE
- SURFACE ROUGHNESS

SOIL CONSERVATION PRACTICES:

- CROP MANAGEMENT
- EROSION PREVENTION
- RESTORATION

The Forest Practices Code should be used as an overall guide with respect to erosion control. The requirements are basically commonsense, and this approach is also important where local conditions provide problems not adequately covered by the code. Problems will occur and there may be different erosion control measures required for these specific problems. In many cases it will be up to those familiar with the local situation to decide on extra or special measures to be taken. It is generally important to act quickly, as in the long term it is easier and less expensive to implement initial control methods rather than restoration methods at a later date.

It is extremely important that field problems which are not covered by the Forest Practices Code are documented, together with the appropriate control measures undertaken.

This information should be supplied to the Chief Forest Practices Officer of the Forestry Commission. In supplying this information the Forest Practices Code can be revised with respect to these practical solutions to local problems.

PART 2: WEATHERING

B. D. Weldon

The processes that alter the physical and chemical state of rocks at or near the surface of the earth, without necessarily eroding or transporting the products of alteration, are collectively termed weathering. Implicit in this definition is the concept of *in situ* or non-transported alteration. Notwithstanding this, when a mineral grain reacts with water (or any other solution), the soluble products are carried away in solution.

Basically the weathering process is subdivided for convenience into two groups of processes - a mechanical or physical group (known as disintegration) and a chemical group (known as decomposition).

MECHANICAL WEATHERING

Whenever a brittle mass such as rock is fractured, the resulting fragments have sizes with a statistical distribution that produces an excess of fine fragments.

Thermal expansion and contraction

For rocks at shallow depths, thermal contraction or expansion is a minor process except during cooling of igneous rocks. Rock is a poor conductor of heat, so the diurnal thermal effects are shallow in extent and perhaps limited to only a few centimetres. Fire has a notably destructive effect on rocks, especially those with a granitic texture. Generally, limestone and sandstone are more resistant than granite to fire damage, and coarser grained rocks are less resistant than fine grained rocks. Unequal thermal expansion of the dominant mineral species is the controlling factor and most minerals expand under heat in a highly anisotrophic fashion.

Growth of foreign crystals in cracks and pores

Certain minerals, (e.g. pyrite in shale or slate), oxidise readily on exposure to oxygen-bearing groundwater or moist atmosphere. The newly formed iron oxides are lower in density and larger in volume than the original material. The volume increases can be sufficient to split weak rocks and cause spalling in stronger rocks.

Ice and hydrofracturing by freezing

When water freezes under atmospheric conditions, it increases in volume by 9%. Water freezing in rocks is a complicated process and is most likely to aid in forcing capillary films of water deeper along tight joints and pre-existing micro-fractures. Disaggregation may thus occur well below the depth of actual freezing. In soils, heaving by unconfined freezing is an important process.

Plants and animals as agents of mechanical weathering

Cracks opened by other processes can be maintained by rocks. Roots do not exert much force on the rock by themselves. Decaying vegetable matter and washed-in dirt will, however, keep rock surfaces wet and chemically active for long periods. The lever action of roots when trees sway in strong wind can pry apart rocks and increase disaggregation. When trees topple during storms, large masses of rock may be displaced.

CHEMICAL WEATHERING

The minerals in rocks at the surface of the earth tend to weather by chemical reaction that produce new compounds of greater volume and lower density.

Hydrolysis

Perhaps the most important chemical weathering process is the solution of minerals in water. Pure water is not efficient at dissolving minerals but as soon as some dissolved carbon dioxide is present (forming a weak acid known as carbonic acid), the chemical reactivity is greatly enhanced. Carbon dioxide is obtained by rain drops passing through the atmosphere. Soil is greatly enriched in carbon dioxide (from 10-1000 times more carbon dioxide than the free atmosphere) and biogenic carbon dioxide in soil air is the major source of carbonated groundwater.

Base exchange

The exchange of cations between minerals and groundwater may expand or collapse the mineral structure and free other chemical compounds.

SOIL FORMATION

Soil is weathered mineral and organic matter found in genetically related horizons in response to physical, chemical and biological processes. The sequence of horizons down to and including the parent material is the soil profile. The soil profile consists of two parts; the solum (the altered horizon), and the weathered parent material (not sorted into horizons).

The most important distinction is between horizons which have lost constituents, and those that have gained constituents, mainly by leaching. The former are called eluvial (washed out of) and the latter illuvial (washed into). The letter A is used to designate eluvial horizons, and B is used for illuvial horizons. Since clay, iron, lime and humus are the most common eluvial (and subsequently illuviated) constituents, the A and B horizons may be subdivided on the basis of properties reflecting their movements.

If the slope is steep, then runoff is rapid, erosion removes the soil as fast as it forms, little water enters the soil, and profiles are thin and poorly developed. On more level terrain, runoff is inhibited and more water enters the ground to weather minerals and translocate clay and other mobile components of the profile.

PART 3. LANDSLIDES

D. J. Sloane

Landslides are a particular type of erosion hazard. Tasmania has numerous areas of landslide problems, involving nearly all rock types. Some rock types are more predisposed to failure than others, due mainly to the nature of the overlying unconsolidated weathered mantle and soil.

The steeper slopes are most vulnerable to landslide problems and areas of drainage concentration and seepage are also likely areas of instability.

Landslides commonly occur where residual or colluvial soils and weathered bedrock slide on a solid bedrock surface. On steep slopes, the unconsolidated materials and soil cannot maintain as steep a slope as the underlying rock surface and are consequently in a delicate balance. Any of several factors such as heavy rainfall, the removal of vegetation or excavation at the top of the slope, may result in the sliding of the materials overlying the bedrock.

Causes

Three main factors are involved in the stability of soil or colluvial mantle. These are the slope angle, the material properties (angle of internal friction and cohesion) and water (pore pressure). Landslides on natural undisturbed slopes are usually a result of an increase in internal pore pressure due to heavy rainfall. This has been reported from areas such as the Western Tiers, where the benching of underlying bedrock has resulted in perched water table conditions, i.e. preventing free drainage.

Generally landslides are caused by various triggering mechanisms. A major cause is by removal of lateral support, largely by road excavation. The construction of roads across steeply sloping areas often results in large steep embankments on the upslope side. The road is often excavated to bedrock which can result in the instability of the embankment due to artificial oversteepening and removal of lateral support.

The introduction of water into embankments and adjacent slopes can be caused by road drainage from culverts. Examples have been seen where culvert drainage has either caused landslides or reactivated old landslides.

Reduced evapotranspiration after forest cutting can significantly increase soil moisture and therefore induce slope failure through higher pore pressure conditions. Areas of bare soil may also be more susceptible to dessication cracking caused by shrinkage of soils during drying. This dessication cracking provides a ready mechanism by which water can be introduced more quickly and deeper into the soil or colluvial mantle.

Many studies have shown that there is a loss of shear strength in the soil after the removal of vegetation. This is caused by not only a decrease in evapotranspiration but also a reduction of root binding as roots decay. The studies show about a three to five year time lag between deforestation and the onset of landslide problems. There are also suggestions that in particularly sensitive areas, landslides may occur after bushfires.

LANDSLIDES

STABILITY FACTORS

MATERIAL PROPERTIES
SLOPE ANGLE
WATER (Pore Pressure)

TRIGGER

REMOVAL OF LATERAL SUPPORT

WATER

FOREST REMOVAL

ROCK TYPES PRONE TO INSTABILITY

TERTIARY CLAY & BASALT
PERMIAN & TRIASSIC MUDSTONES
QUATERNARY DOLERITE TALUS

PRONE SLOPES

LONG STEEP SLOPES
DEEP SOILS
CATCHMENT HEADS
STREAMSIDE SLOPES

Remember that landslides do occur under natural vegetation conditions and that as for other forms of erosion it is the high magnitude - low frequency rainfall events which causes the problems.

Geology

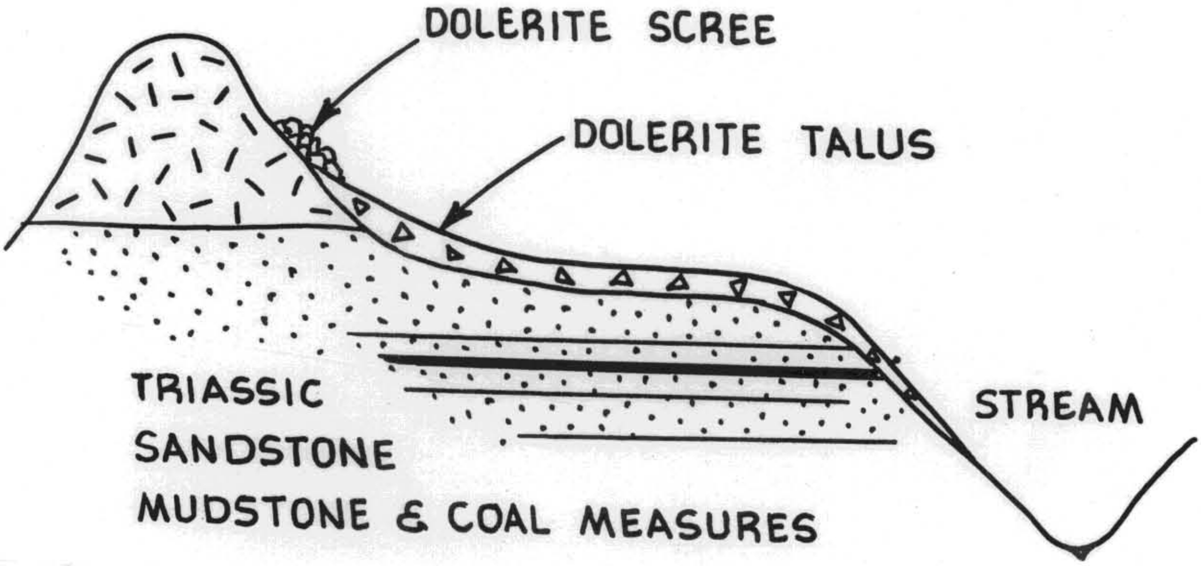
Getting back to our slope stability factors (concerning material properties), the parent bedrock has an influence on the properties of the weathered material and soil - generally the angle of internal friction and cohesion (e.g. sand - 35°). In Tasmania, the most landslide-prone geology is weathered basalt, and sedimentary clay and sandy clay of Tertiary age. Landslides also occur on slopes underlain by clay-rich mantles of weathered Permian and Triassic mudstone. Dolerite talus of Quaternary age is also prone to failure in various circumstances. Most of these rock types weather to clay-rich materials but apart from the inherent properties of these materials, the relationship between the weathered or colluvial mantle and bedrock is also important, as mentioned earlier.

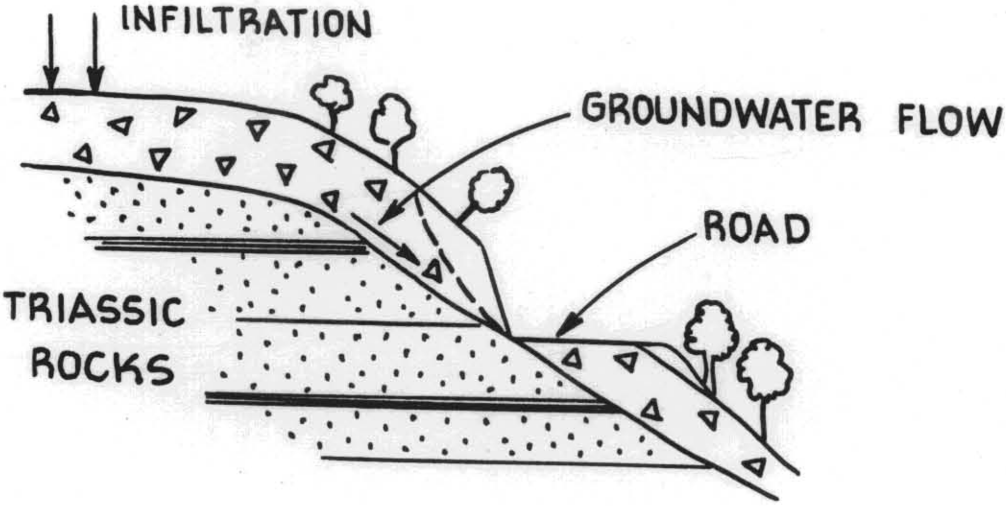
Long steep slopes are more prone to failure than short slopes. Slopes around the heads of catchments are also susceptible due to steepness, seepage and drainage concentration.

Examples

Examples of instability problems incorporating several of the factors described above occur in many parts of the State (e.g. Mt Nicholas, East Coast, Western Tiers, Cluan Tier etc.). The main geological feature consists of dolerite-capped mountains overlying sub-horizontal Triassic rocks, sandstone, mudstone and coal measures. The Triassic rocks often form distinct benches below the main peaks, with steeper slopes adjacent to river valleys. The benches are covered by a veneer of dolerite talus - angular boulders of dolerite in a dolerite-derived silty clay matrix. The dolerite boulders are often as large as houses. A note of caution here; the surface occurrence of boulders often bears no relationship to the boulder content below. These talus deposits have resulted from solifluction processes (essentially water-saturated creep) under much different climatic conditions than exist today. The talus thins on the steeper slopes at the edge of the resistant benches. Where roads have been excavated on the steep slopes, bedrock is often exposed in the table drains. Often the talus benches have few surface streams and water can be seen issuing from the upslope embankments, flowing along the bedrock - talus interface. During heavy rainfall pore pressure within the talus may rise, and combined with the factors of an oversteepened embankment and removal of lateral support, the embankment fails.

Similar problems have been encountered on the Western Tiers. Numerous benches occur here, caused by differential weathering and usually representing more resistant bands of sandstone. The main problems occur with road routes that traverse the steeper slopes to gain access to the benches. The Forest Practices Code therefore indicates that road routes should be 'fitted' to the topography (i.e. ridge roading and bench roading), obviously good in theory but not always possible. The main advice is therefore to minimise crossing the steeper slopes and inspect the routes carefully. Forestry operations can obviously be seriously affected in areas of landslide if access is periodically affected. Once a landslide occurs it is likely to extend headward and laterally as the scarps are oversteepened. In one sensitive area looked at it was decided to leave the forest on the upslope segment to preserve stability.


DOLERITE SCREE
DOLERITE TALUS
TRIASSIC
SANDSTONE
MUDSTONE & COAL MEASURES
STREAM


INFILTRATION
GROUNDWATER FLOW
ROAD
TRIASSIC
ROCKS

Planning

In the planning stages potential problem areas can be possibly identified from contour and geological maps. Our approach with office-based reports is to slope class the contour map - this shows major topographic benches reasonably well - and then produce a geological overlay. This gives a broad first approximation in identifying potential problem areas. The limitations of this method, mainly due to the scale of the baseline maps, must be realised. Field inspection is then necessary to determine the potential problems. The benches may have bedrock close to the surface or even outcropping, or soils may be sandy - not clayey - and therefore little landslide potential is apparent (but may highlight potential erosional problems).

Features of old landslide areas

One of the most important aspects of a stability assessment involves the recognition of creep, active and old landslides.

The evidence of previous instability is an important input in determining landslide risk. The morphological features associated with old landslides are summarised below.

DRAINAGE

Stream channels or gully depressions aligned across the slope rather than in a downslope direction. Swampy depressions, especially when associated with 'backsloping' slope segments, are caused by ponding of runoff by ground disturbance or fed by seepage from landslide headscarps.

LANDSLIDE MORPHOLOGY

Head scarp - Arcuate area of steeper slope on an otherwise uniformly sloping area.

Slide mass - Often a semicircular 'backsloping' area caused by rotation during failure. May be hummocky and ridged across the slope. Ponding or swampy depression may be associated.

Toe region - Often lobate or tongue shape in plan. Hummocky or bulged in profile. Seepages may be present at toe front.

OTHER FEATURES

Slope complexity is often a good indicator of previous instability. This can be identified in the field or from topographic maps with a small contour interval. Areas of complex slope on an otherwise uniform or simple slope profile should be outlined.

Tension cracks are generally associated with active or recently active landslides and can occur in toe or slide mass regions, or above head scarps.

Leaning trees or 'kinked' sections of trees often indicate slope instability during growth.

Several of these features may be associated, providing greater confirmation of previous instability.

OLD LANDSLIDE AREAS

DRAINAGE PATTERNS

STREAMS OR GULLYS ACROSS SLOPES

SWAMPY DEPRESSIONS ON BACKSLOPE AREAS

LANDSLIDE MORPHOLOGY

HEAD SCARPS – ARCUATE STEEPER SLOPE SEGMENTS OR 'AMPITHEATRES'

SLIDE BODY – BACKSLOPING AREAS

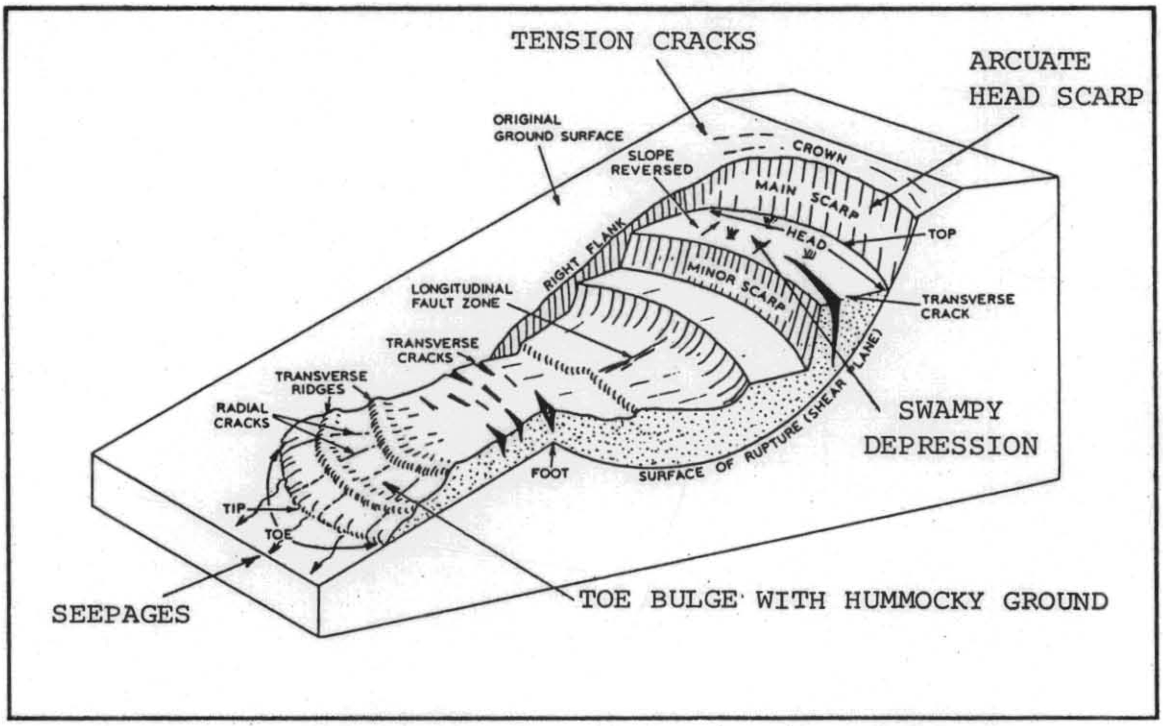
TOE – 'HUMMOCKY' GROUND LOBATE OR TONGUE SHAPED

TENSION CRACKS

LEANING OR 'KINKED' TREES

SLOPE COMPLEXITY

DISRUPTION OF NORMAL SLOPE



Essential features of a rotational landslip.
[Adapted from Cooke and Doornkamp 1974 (after Varnes, 1958)].

Note: All of the above features may not be present, depending on the type of failure. The failure plane may not be circular. The slip may have more of a flow component resulting in a long, narrow failure with few of the slip mass features described above. With increasing age, the slip features become more subdued due to erosion.

Threshold or critical slope angles

Our approach, when examining landslides, is to measure the slope angle on which they occur. This results in a figure, which we use for planning purposes, called the 'threshold or critical slope angle'. Below this angle for a particular rock-type, no landslides are known to occur. For Tertiary clays this angle is 8° (14%), for weathered basalt 14°(25%), for dolerite talus, Permian and Triassic rocks 15° (27%). Slopes steeper than 20°(36%) on these rock types have a high potential for failure, depending on, of course, the depth of soil and weathered mantle. It should be noted that in areas of roading, slopes of 12° (21%) have been known to fail above embankments.

These critical slope angles can be used as a planning guide. They are based on the results of investigations to date.

THRESHOLD SLOPE ANGLES

TERTIARY CLAYS	- 8° (14%)	
BASALT	- 14° (24%)	
DOLERITE TALUS PERMIAN MUDSTONE TRIASSIC MUDSTONE	15°(25%)	12°(21%)

EXTREME CAUTION ABOVE 20°(35%)
ON THESE ROCK TYPES

PART 4: KARST

B. D. Weldon

Karst is a terrain with distinctive characteristics of relief and drainage arising primarily from a higher degree of rock solubility in natural water than is found elsewhere.

Solution

Solution, as used in the context of karst, is essentially the hydrolysis of $CaCO_3$ in the presence of dissolved CO_2. The calcium cation does not form a hydroxide but remains in ionic equilibrium with the bicarbonate. Limestone solubility is controlled primarily by addition or loss of CO_2 gas to a great excess of water. Changes in the temperature or pressure, mixing of unlike waters, and biologic process, can all promote solution or deposition.

In an aerated aqueous solution, the solubility of $CaCO_3$ is about 63 mg/L. Under anaerobic conditions in a soil the quantity of available CO_2 is usually increased so that up to 700 mg/L of $CaCO_3$ can be in solution. Most ground water contains 200 to 400 mg/L of dissolved $CaCO_3$. Limestone solution and therefore karst is clearly accentuated by biologically generated CO_2 in decaying humus.

Biological effect

In addition to providing decaying humus that enriches soil air in CO_2, plants and animals corrode limestone directly by generating acidic solvents.

Mixing effect

When two unlike waters, both saturated with $CaCO_3$ mix at the water table, the resulting water invariably is undersaturated with respect to $CaCO_3$. This mixing effect is probably the reason that most caves develop just below the water table.

Flow rate effect

Somewhat related to the mixing effect are the solubility changes relating to variations in the rate of flow of surface and underground water. If water is moving slowly over or through soluble rocks, it should approach saturation equilibrium. However during rapid runoff periods, river water is notably undersaturated, because the water is not in contact with mineral soil long enough. If undersaturated water, normally with a low dissolved CO_2 partial pressure, enters a karst terrain and mixes with saturated groundwater, the extreme difference in their compositions greatly enhances the mixing effect. This process may be especially important in enlarging caves that normally drain outward to a surface river but become backflooded when the river is in flood.

Landforms

I will not elaborate on the numerous karstic landforms apart from mentioning that there are three basic groups:

1. Surface landforms, usually depressions, but positive relief features known as hums and towers occur along with fluted bedrock;

2. Subsurface landforms, dominantly caverns, either with or without streams;

3. Cave deposits which may be chemical (speleotherms), biological (biogenic), or earth and rock fragments (clastic) in origin.

Of greater importance is the karst hydrology.

Karst hydrology

In classical hydrology, the concept of a water table below which pore spaces are permanently water filled (the phreatic zone) exists.

Permeable rocks which contain water are known as aquifers and impermeable rocks which retard the movement and storage of water are known as aquicludes. However in a karst environment, where cave-bearing limestone occurs, water may be held in joints and solution openings which may not interconnect, giving rise to a three dimensional maze of aquifers and aquicludes. The water within this system may be static or mobile, have access to cave atmosphere or the free atmosphere, may flow uphill in conduits driven by hydraulic heads etc.

Precipitation moves through the hydrologic cycle of evapotranspiration, overland flow, through flow, and by infiltration. In karst areas, overland flow and through flow tend to be restricted by a high infiltration capacity, and are usually only of significance during high intensity storms and on steep slopes. Infiltration is greatly influenced by the nature of the bedrock and also the nature of any soil mantle, either residual or transported material.

Crystalline limestones are usually massive and infiltration is concentrated along structural openings (joints, bedding planes, fractures, etc.) or solution openings. In granular limestones, infiltration occurs through the pore spaces. Loose textured residual soils and granular transported mantles which are permeable also favour infiltration.

In a karst aquifer infiltration occurs by:

1. Percolating into a bedrock mantle or soil cover

2. Percolation into crevices in bare rock

3. Interception of concentrated overland flow via conduits.

Human activity

It is clear that human activity can modify the infiltration process significantly, and thus alter the balance of karst water transfer and storage with deleterious effects on cave systems, groundwater quality, and quantity. This can be achieved by changing the rate of either soil erosion (alters the method of infiltration from mantle to bare rock which in turn alters the amount of dissolved CO_2 in the water) or sedimentation (where the capacity for conduit flow is diminished as conduits become blocked).

Some impacts of human activity are unseen until major events such as short torrential downpours, floods, or even droughts occur. The quarrying of limestone from a positive landform, the infilling of depressions with soil, rocks and organic matter, large scale excavations will affect drainage changes. Any activity which alters the rock structure, temperature, moisture available, organic matter etc. will have an affect on the development of the karst by changing the availability of CO_2 in solution.

The soil mantle is of fundamental importance to the character of the karst that develops. The susceptibility of the mantle to erosion depends on many factors: the texture, fabric, grain size distribution and lithology of its constituents, as well as the local slope, vegetative cover, physical disturbance, precipitation type and intensity. Loose sandy mantles tend to be more susceptible than compact clay-rich mantles, particularly on steep slopes.

Limestone-derived soils are frequently shallow and susceptible to erosion, particularly if poor in clay products. The loss of this thin soil cover will affect dramatically the development of karst. It was noted earlier the enrichment in CO_2 that occurs in the soil air. This determines the amount of limestone that can be dissolved (or precipitated). Because these soils are usually thin, they do not rejuvenate quickly and even small disturbances may have far reaching impacts.

Some residual soils will suffer from compaction under the load of machinery. The nett effect of this is to decrease the capacity of precipitation to infiltrate the soil. Water very rarely lies in sheets but quickly forms into channels, and a new surface drainage system can become established very soon after the soil has been compacted. Less water enters the underground system and may alter the subsurface drainage patterns. Because water is channelled there is then increased potential for erosion and subsequent siltation and problems when the velocity of the water decreases.

Human activity can impose loads (e.g. roading) over ground which has little support and roof collapse of caves may occur. This may affect a hydrological change as will the roading itself. It is thus important to identify potential problems at the planning stage and avoid sensitive areas. If failure or subsidence occurs, it is considered best to induce rapid subsidence, backfill the area, and implement appropriate control measures. The backfill should initially be very blocky material which will allow any water to pass through it, as it will not always be evident whether a cave carries a stream during flood stages. The final cover should attempt to seal off the ground against excessive water ingress.

Karst areas often have poor surface storage (due to leakage), and waste disposal is a problem because of leakage. There is little natural filtration of karst waters and pollution can be a major problem. Sinkholes are often used as convenient places of rubbish disposal but at the cost of rendering the water un-potable.

Disruption to existing drainage patterns can have a dramatic impact on karst features which are usually not readily visible. Speleotherms may start to dehydrate if deprived of their water supply. If the sediment load is increased, then siltation in caves and solution conduits may be accelerated, thereby effecting changes in the underground drainage systems. All these effects can decrease the recreational value of a karst area.

Karst areas are interactive systems. The key to their management is to protect existing water patterns. To this end karst inventories and drainage maps are a fundamental management tool.

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[5 January 1988]

3/64

APPENDIX 1

Examples of forestry-related investigations
by the
Department of Mines

32/64

UNPUBLISHED REPORT 1982/17

Slope stability at West's block, Cluan Tiers

by D.J. SLOANE

TASMANIA DEPARTMENT OF MINES

60-32

1982/17. Slope stability at West's block, Cluan Tier

D.J. Sloane

Abstract

A sequence of Quaternary dolerite talus, Triassic sandstone, and Permian mudstone is exposed on the north-eastern flanks of Cluan Tier, near Westbury. Topographically the region has been divided into distinct units, basically consisting of a talus bench and a sandstone bench separated by a steeply sloping unit, and dissected lower slopes underlain by the Permian rocks. Slopes greater than 15° (27%) underlain by dolerite talus or deeply weathered Triassic rocks are potentially unstable. Guidelines for making decisions about the stability of areas have been presented and suggestions have been made as to further field inspections required to determine the instability potential of marginal areas. Initially, the most suitable areas for plantation operations are located on the topographic benches. Other areas are probably suitable depending on the outcome of field investigations and the implementation of stability guidelines. Forestry operations should be planned with respect to the potential instability of this area.

INTRODUCTION

In response to a request from Associated Pulp and Paper Mills Ltd an inspection of an area known as West's Block on the north-eastern slopes of Cluan Tier [DQ835940] was made. Minor landslipping has occurred adjacent to a logging road located at a higher altitude to the south, beneath Cluan Tier. APPM are concerned that proposed forestry activity in West's Block may have an adverse effect on the stability of the area. The area in question covers approximately 4.25 km^2 and experimental plantations are proposed. The area was inspected in the company of APPM personnel.

TOPOGRAPHY

West's Block is approximately located between the 300 m and 500 m contours on the north-eastern slopes of Cluan Tier and has a regional slope of about 10° (17%). The lower, north-eastern boundary is adjacent to the Swamp Gum Rivulet flood plain, while the higher south-western boundary lies close to the peak of Cluan Tier. The area is drained to the north-east by several small tributaries of Swamp Gum Rivulet. Well-defined streams occur approximately below the 400 m contour.

The morphology of the area is shown in Figure 1 and is based on an inspection of aerial photographs. The morphology can be subdivided into 5 distinct units, described below and arranged in order of descending altitude.

Unit 1

Cluan Tier, the main dolerite-capped peak of the region with its associated steep slopes, often covered with dolerite scree.

Unit 2

A gently sloping dolerite talus covered bench between 500 m and 750 m in width and with an overall slope of about 5° (8%).

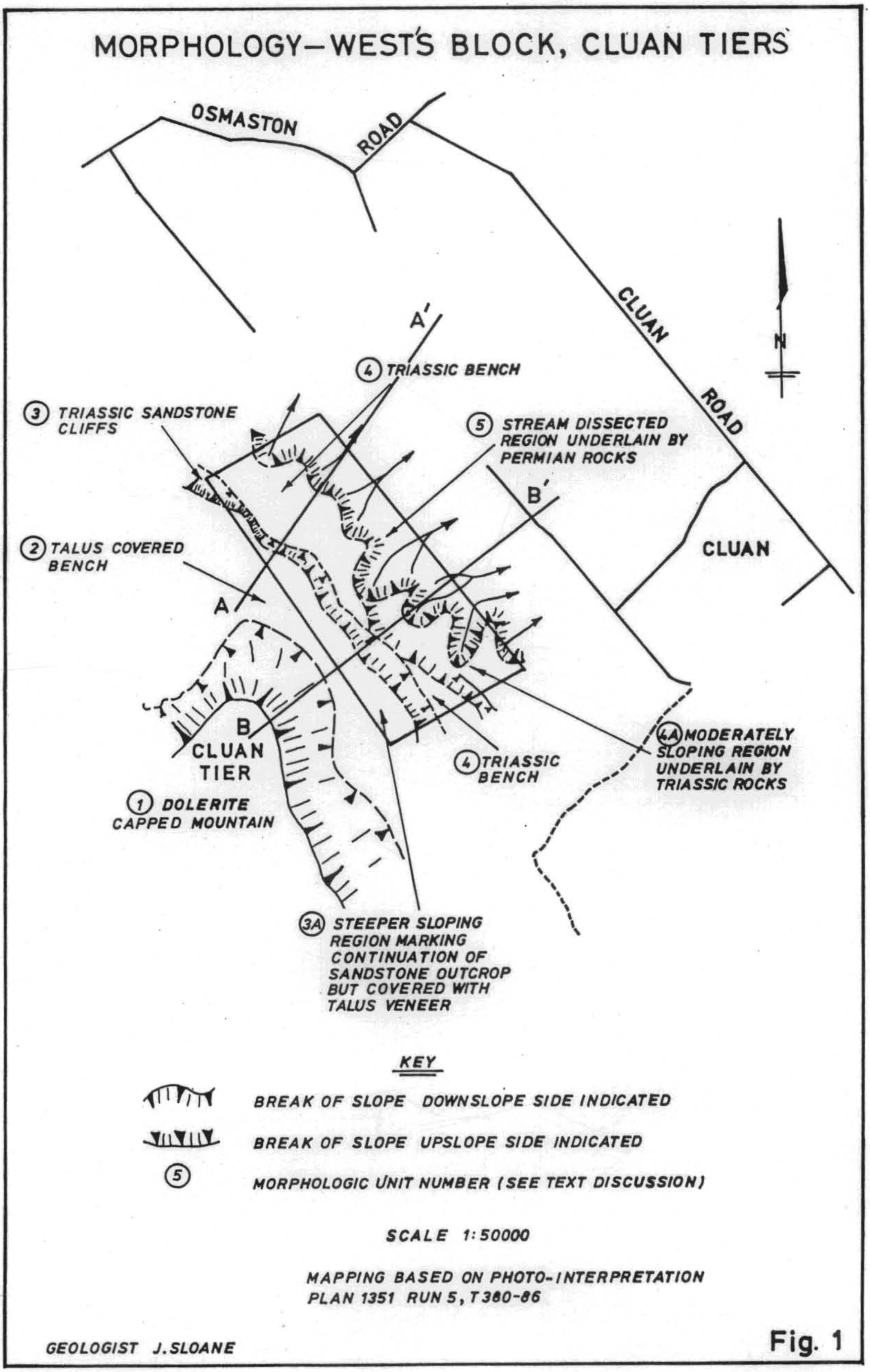

MORPHOLOGY—WEST'S BLOCK, CLUAN TIERS
OSMASTON ROAD
CLUAN ROAD
CLUAN
N
A'
A
B'
B
CLUAN TIER
④ TRIASSIC BENCH
③ TRIASSIC SANDSTONE CLIFFS
⑤ STREAM DISSECTED REGION UNDERLAIN BY PERMIAN ROCKS
② TALUS COVERED BENCH
① DOLERITE CAPPED MOUNTAIN
④ TRIASSIC BENCH
4A MODERATELY SLOPING REGION UNDERLAIN BY TRIASSIC ROCKS
3A STEEPER SLOPING REGION MARKING CONTINUATION OF SANDSTONE OUTCROP BUT COVERED WITH TALUS VENEER
KEY
BREAK OF SLOPE DOWNSLOPE SIDE INDICATED
BREAK OF SLOPE UPSLOPE SIDE INDICATED
⑤ MORPHOLOGIC UNIT NUMBER (SEE TEXT DISCUSSION)
SCALE 1:50000
MAPPING BASED ON PHOTO-INTERPRETATION
PLAN 1351 RUN 5, T 380-86
GEOLOGIST J. SLOANE

Fig. 1

5 cm

Units 3 and 3A

An area of sandstone cliffs and steep slopes up to 20° to 25° (36% to 46%).

Units 4 and 4A

A gently sloping Triassic sandstone bench up to 700 m in width which has been partially dissected and eroded in Unit 4A to produce moderate slopes at the head of several streams.

Unit 5

An area of dissected topography where a series of streams drain towards the north-east. Moderate to steep slopes are associated with the head and side slopes of these streams, with several small spurs which have developed as drainage divides.

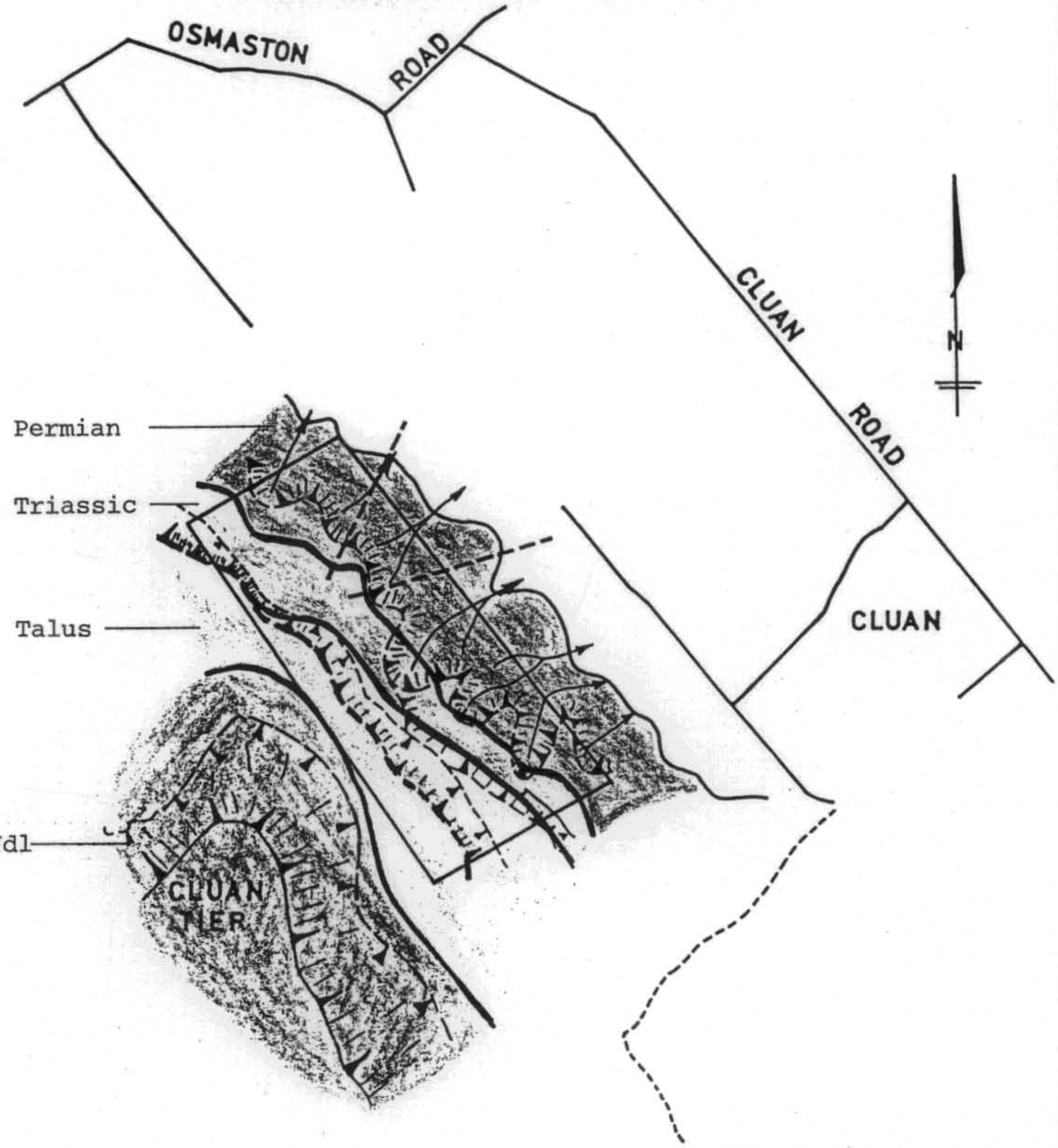
GEOLOGY

The topography of the region closely reflects the underlying geology (figs. 2, 3). Morphologic unit 1 is underlain by *in situ* Jurassic dolerite, a remnant of an intrusive sill which has subsequently been exhumed by erosion and now caps the Cluan Tier peak. Underlying the dolerite is sandstone of Triassic age. The sedimentary rock can be clearly seen exposed in cliffs near the western corner of the area. This resistant band of sandstone undoubtedly underlies steeper slopes to the south-east in Unit 3A. It is considered that the talus covered bench (Unit 2) is a structural feature related to the top of the Triassic sandstone which has horizontal to subhorizontal bedding. Triassic sandstone and siltstone also underlies the topographic bench (Unit 4) and steeper slopes (Unit 4A). The Triassic sediments can be readily identified in the field as they are composed largely of medium sand-sized quartz grains. Where exposed the sandstone is often friable and has weathered to a clayey sand. The main West's Block access road passes below the Triassic sandstone cliffs (Unit 3) and traverses the Triassic bench (Unit 4). Triassic rocks are exposed in several road cuttings in this area.

Conformably underlying the Triassic sandstone is mudstone of the Upper Permian Bogan Gap Group (Barton *et al.*, 1970). This mudstone crops out on the lower slopes and largely underlies the stream dissected Unit 5. The Permian rocks have horizontal to subhorizontal bedding and are generally much harder and less friable than the Triassic sandstone. Jointing is well developed in the Permian rocks and the rock breaks easily into roughly square blocks, enabling easy quarrying. The harder nature of the mudstone renders it suitable for road surfacing. Soils developed on the Permian mudstone are thin, with bedrock often less than one metre from the surface. Soils are generally stony and less susceptible to instability than the deeper clayey sands and sandy clays developed on the Triassic sediments.

The youngest rock of the region is dolerite talus of Quaternary age. A veneer of dolerite talus of varying thickness overlies part of the Jurassic dolerite and Triassic sandstone. The talus is also variable in composition, consisting of angular dolerite boulders up to several metres in diameter in a matrix of silty clay in varying proportions. The presence of dolerite boulders in underlying talus cannot be totally assumed from the surface occurrence of such boulders. Often a surface veneer of boulders is present which may have its origin as a lag deposit produced by removal of the silty clay matrix by erosion. The surface boulder veneer may also be

GEOLOGY – WESTS BLOCK CLUAN TIERS
(OVERLAID ON MORPHOLOGY)



KEY

- QUATERNARY DOLERITE TALUS
- TRIASSIC SANDSTONE
- UPPER PERMIAN MUDSTONE (BOGAN GAP GROUP)
- JURASSIC DOLERITE
- FAULT

SCALE 1:50000

GEOLOGIST J.SLOANE

Fig. 2

5 cm

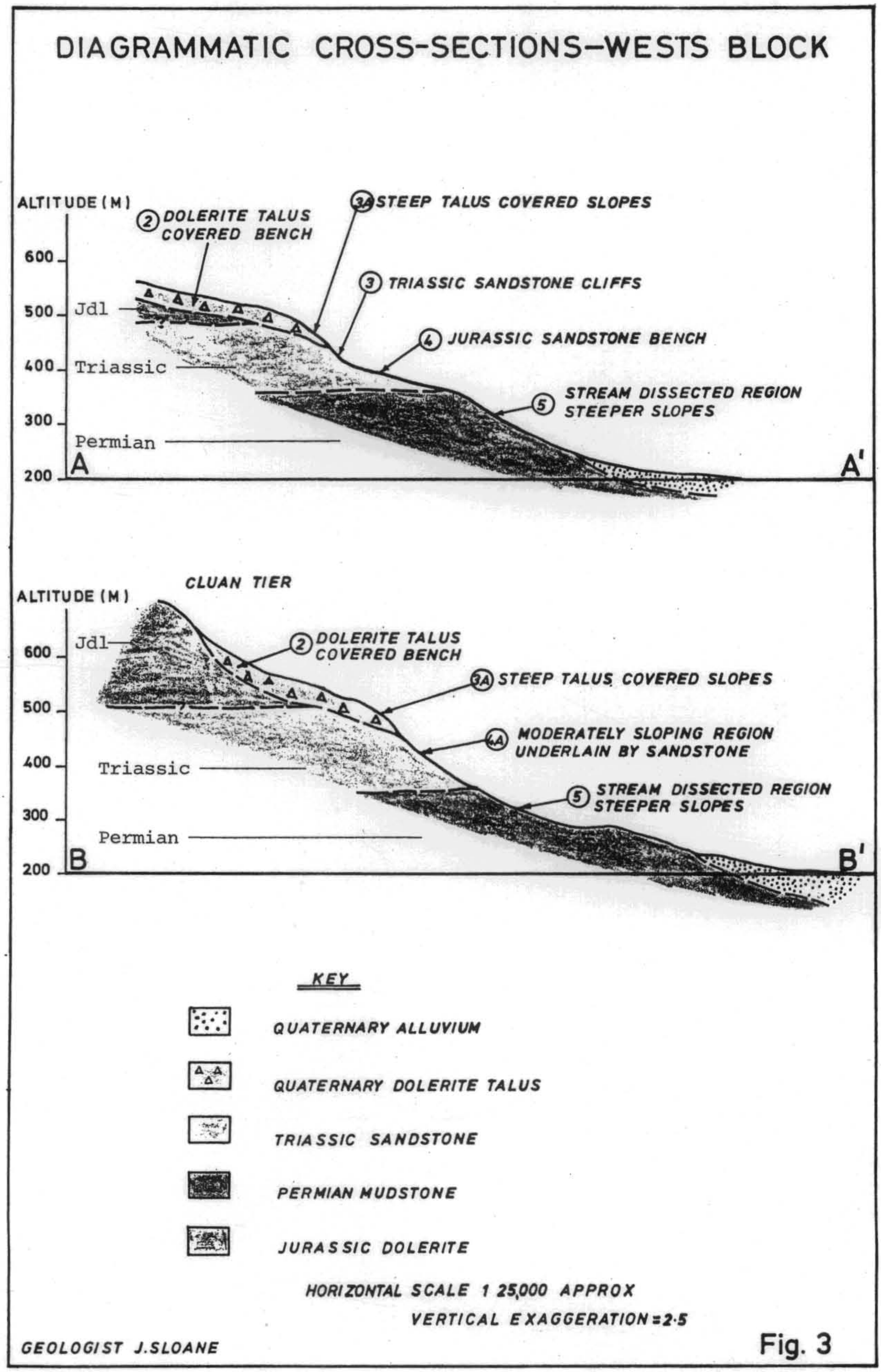

DIAGRAMMATIC CROSS-SECTIONS—WESTS BLOCK
ALTITUDE (M)
600
500
400
300
200
② DOLERITE TALUS COVERED BENCH
3A STEEP TALUS COVERED SLOPES
③ TRIASSIC SANDSTONE CLIFFS
④ JURASSIC SANDSTONE BENCH
⑤ STREAM DISSECTED REGION STEEPER SLOPES
Jdl
Triassic
Permian
A
A'
CLUAN TIER
ALTITUDE (M)
600
500
400
300
200
Jdl
② DOLERITE TALUS COVERED BENCH
3A STEEP TALUS COVERED SLOPES
4A MODERATELY SLOPING REGION UNDERLAIN BY SANDSTONE
⑤ STREAM DISSECTED REGION STEEPER SLOPES
Triassic
Permian
B
B'
KEY
QUATERNARY ALLUVIUM
QUATERNARY DOLERITE TALUS
TRIASSIC SANDSTONE
PERMIAN MUDSTONE
JURASSIC DOLERITE
HORIZONTAL SCALE 1 25,000 APPROX
VERTICAL EXAGGERATION = 2·5
GEOLOGIST J.SLOANE

Fig. 3

5 cm

a more recent deposit produced largely by physical processes such as freeze-thaw activity. The dolerite talus has most likely formed during cold climatic conditions, probably during or towards the end of the last glacial period. At this time vegetation was sparse and physical weathering and mass movement were the dominant processes. The talus is thought to have formed as a solifluction deposit which moves by creep and flow in a near water saturated condition. The angular boulders present in the talus would have been supplied by freeze-thaw activity on dolerite outcrops and the silty-clay matrix probably originates from material formed by deep weathering of the dolerite during warmer interglacial periods. Some of the boulders in the talus are very large and have, in places, been rafted considerable distances from the nearest dolerite outcrop.

SLOPE INSTABILITY

One active landslip occurs in an area on Cluan Tier to the south of West's Block and at a slightly higher altitude. The failure has occurred where the road passes around the toe of a talus lobe. Several other features attributable to old landslips occur in this area. No other examples of instability were observed, despite the presence of some moderately large road cuttings where both dolerite talus and deeply weathered Triassic sediments are exposed. The stability of these cuttings is partially attributed to good embankment construction, with batters of approximately 1:1 slope in places. The West's Block access road is well located, in the main part traversing the Triassic bench in Unit 4 and thus minimising embankment excavation.

Without extensive and detailed mapping of the area reference must be made to experience gained from studies of areas with similar topography and geology. Experience gained from investigations of slope stability for the Forestry Commission in the Fingal-St Marys-East Coast region indicates initially that potentially unstable areas occur in Units 3 and 3A, 4 and 4A, and to a minor extent in Unit 5. Unit 3A has probably the highest potential instability, with dolerite talus overlying Triassic rocks on steep slopes. These areas often have underground drainage with a large amount of rainfall infiltrating through the talus and draining along the talus-Triassic bedrock interface. Several examples occur elsewhere where road excavation has exposed the underlying Triassic rocks with numerous springs occurring along the bedrock interface. The concept of a threshold slope angle is important in planning the development of an area with respect to potential slope instability. This threshold slope value is a slope angle above which the potential instability is very high, if slope disturbance occurs. Fortunately the maximum slope angle at which most logging machinery can operate is about 20° (35%) which closely corresponds to the threshold slope angle of a dolerite talus covered terrain. This figure has been deduced by investigation of several areas where dolerite talus overlies Triassic bedrock. The figure of 20° is understandably not an exact figure but more an indication of the sort of angle above which disturbance should not occur. As in all situations there are probably many slopes above this figure which would remain stable if disturbance occurred and there are probably several slopes below this figure which may fail. The reason for this is simple in that the prediction of groundwater conditions is virtually impossible without obtaining subsurface information from drill holes. There is therefore a need for a buffer zone around this threshold slope angle. This zone must be treated with caution, especially where road construction is envisaged. In the talus situation, a buffer zone between 15° and 20° (25% to 35%) is proposed. Similar slope angle guidelines should be applied to Unit 4A, where steeper slopes are underlain by Triassic sediments. As mentioned previously, the

Triassic rocks are deeply weathered in places to sandy clay. The clayey weathering products are derived from mudstone and often contain montmorillonite, a clay with high shrink-swell properties and prone to landslip where underlying steep slopes.

Unit 5, underlain by Permian mudstone, may have isolated instability problems on steep slopes underlain by deeply weathered materials. Landslips associated with Upper Permian sediments occur in several parts of the state. From a brief field inspection, it appears that soils are thin and stony with only isolated horizons susceptible to weathering, especially those horizons that are friable and easily break into small lumps. An example of this breakdown of the mudstone occurs in road cuttings on the lower slopes of West's Block, adjacent to the quarry on the main access road. Generally, the Permian mudstone is less susceptible to weathering, hence its use as road material, and the stream dissection and erosion in Unit 5 has probably removed a large amount of weathered material. Areas requiring inspection and possible caution exist on steep slopes above 17° (30%).

From the topography and geology of the region, areas of potential instability have been outlined and guidelines concerning the use of slope angles to further delineate areas have been presented. Areas such as Units 4A and 5 cannot be excluded on the basis of the brief investigations described above. Field inspection with measurement of slope angles will be required to accurately assess slopes and to subsequently apply the slope criterion described above. The other major input into the decision making process will be the evidence of previous instability in such areas. The presence of old landslips indicates that failure of a region has occurred and disturbance, especially by road construction, should be avoided. The use of slope angle criteria and field evidence of instability generally indicates areas to be avoided. Features associated with old landslips have been described and indicated to APPM officers during the field inspection. In summary, the morphological features to be recognised as indicative of old landslips are the following (fig. 4):

Drainage

Stream flow or gully depressions aligned along the slope rather than across the regional contours. Caused by drainage disruption by landslips.

Swampy depressions, especially where associated with backsloping slope segments. Caused by ponding of runoff on slip masses or may be fed by aquifers exposed at head scarps after failure.

Slip morphology

Head scarp regions - arcuate areas of steeper slope on an otherwise uniformly sloping area.

Toe regions - 'bulges' or hummocky ground. Convex profile humps on an otherwise even or concave slope profile. Often an area where flow of slip materials is dominant. Sometimes exhibit seepages at toe front. (Examples of the above features were indicated in the field in the area adjacent to the active landslip).

Slip mass region - often hummocky and ridged across the slope. The slip mass may have a 'back slope' caused by rotation along a near-circular slip plane.

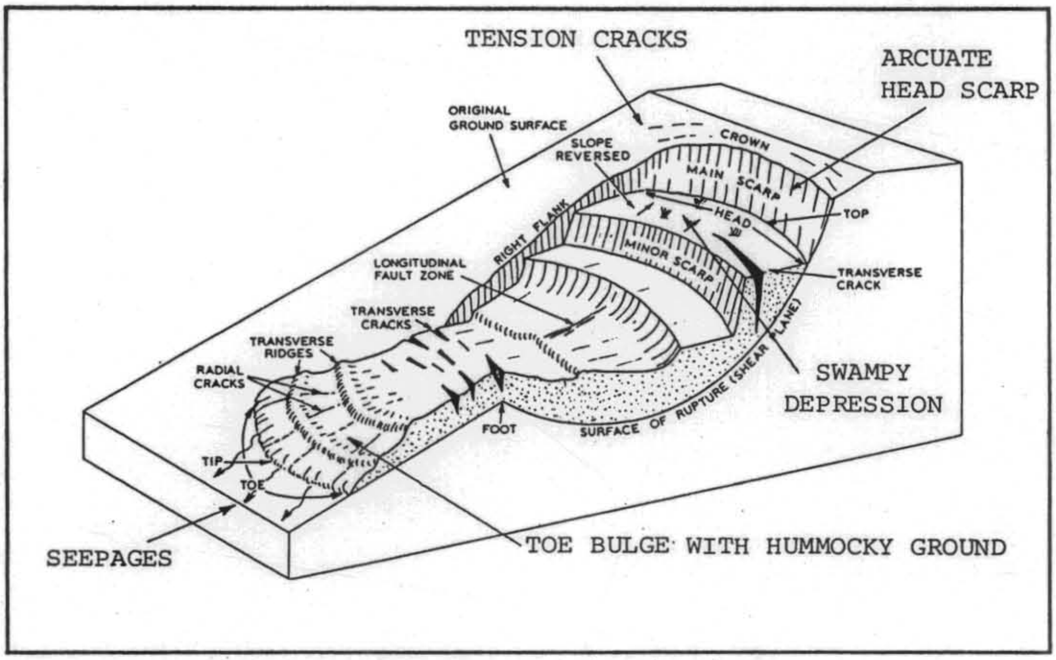


Figure 4. *Essential features of a rotational landslip.*
[*Adapted from Cooke and Doornkamp 1974 (after Varnes, 1958)*].

Note: All of the above features may not be present, depending on the type of failure. The failure plane may not be circular. The slip may have more of a flow component resulting in a long, narrow failure with few of the slip mass features described above. With increasing age, the slip features become more subdued due to erosion.

Slope complexity - often used as an indicator of previous instability. Can be identified in the field or from good, close interval, contour maps. Outline areas of complex or varying slope segments on an otherwise uniform or simple regional slope profile.

Other features

Tension cracks above head scarp features, on toe bulges and slip masses. Generally associated with active or recently active landslips, but may still be preserved in older slips.

Leaning or 'kinked' trees. Caused by instability during the growth of trees resulting in trunk deformation.

These features should not be considered in isolation as indicative of old failures. Several features will usually be associated, giving greater confirmation of past instability. Once both active and old landslip features are located on the map, together with slope and pertinent information such as depth of soil, seepages, swampy depressions *etc.*, a decision can be made for the exclusion of areas on the basis of the instability criteria.

The areas of low potential for slope instability are Units 2 and 4, the talus covered bench and the Triassic sandstone bench, obviously because of their low slope.

SUMMARY AND CONCLUSIONS

From a brief field inspection and aerial photograph interpretation, West's Block has been divided into five topographic units. An overlay of the topography and geology has been prepared and from experience gained from stability investigations elsewhere, areas of varying potential instability can be outlined.

Steep slopes underlain by dolerite talus are potentially unstable (Units 3 and 3A). Slopes above 15° (25%) should be treated with caution, with modification or careful planning of operations on slopes of between 15° and 20° (25% to 35%). Slopes above 20% should remain untouched. Most of Units 3 and 3A will probably be unsuitable for clear fell forestry operations.

Steep slopes underlain by deeply weathered Triassic sandstone and mudstone are also potentially unstable. The same slope criteria indicated above should be applied in these areas, which are largely covered by Unit 4A. This area requires further field inspection to determine slope angles and the possible presence of old or active landslip features before a planning decision is made. The area is most likely to be marginally suitable for plantation operations.

Sections of Unit 5 may be suitable for plantation depending on further inspection of slopes as outlined previously. The suitable sections of Unit 5 may be too fragmented to allow suitable plantation organisation. Areas of slope greater than 17° (30%) should be avoided and potential problem areas are likely to be isolated and restricted to areas of thicker soils and deeper weathering.

On the basis of slope and geology, the areas most suitable for clear fell operations and plantation development appear to be the Triassic and dolerite talus bench areas of Units 2 and 4.

Any future road construction should be carefully planned and preferably located along hill slope benches to minimise embankment excavations. Embankments are areas of maximum slope disturbance and hence have a higher instability potential. A vegetation retention strip 30 m in width should be retained above embankments where roads traverse steeper slopes. A retention strip is considered advisable where the West's Block access road traverses Unit 4A. A 10 m retention strip should be retained on the lower side of roads where fill embankments are large. Good standards of road construction should be maintained, especially with regards to embankment batters.

Using topographic and geologic inputs, broad zones of potential instability can be recognised, enabling an initial selection of suitable areas. Some regions require field inspection to determine their topographic characteristics before stability guidelines can be applied. Planning decisions can then be made on the basis of this information. It should be recognised that these are guidelines and due to the variable nature of any topography, all possible situations cannot be covered. In this case, the intuitive feelings of field officers about the instability of an area should not be ignored. Delineation of areas requires a 'common sense' approach and it is hoped that the field inspection conducted in the presence of Company officials in conjunction with the guidelines described above will aid in the planning of forestry operations in West's Block.

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43/64

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Potential landslide and erosion problems, Great Western Tiers and Mt Barrow.

by D.J. SLOANE

TASMANIA DEPARTMENT OF MINES

(60-43)

44

1986/67. Potential landslide and erosion problems, Great Western Tiers and Mt Barrow.

D.J.Sloane

Abstract

Geological and topographical maps covering areas of Forestry Commission operations have been examined in order to provide a preliminary indication of areas of potential erosion and landslide risk.

The areas examined, on the slopes of the Great Western Tiers and South Barrow escarpment, have topographic features which strongly reflect the varying resistance to erosion of the underlying bedrock. The salient features are steep talus and scree covered upper escarpment slopes below cliffs of erosion resistant dolerite, and pronounced slope benches with associated steep slopes at their margins, located on the middle to lower escarpment profile. In some areas the slope benches have been dissected by streams with associated steep head and valley slopes.

Slopes steeper than 20° (35%) on most rock types have the highest risk of potential erosion and landslide problems, and should therefore remain undisturbed. Slopes between 15° (25%) and 20° (35%) are known to have failed elsewhere and therefore are at high risk. Slopes between 15° (25%) and 12° (21%) have been known to fail in some cases, particularly where embankments have been excavated. Slopes below 12° (21%) are considered stable.

Soils developed on sandstone and granodiorite on slopes above 12° should be recognised as particularly sensitive to erosion. Other soils, especially on Triassic and Permian mudstone and siltstone, may be prone to tunnel erosion.

In order to assess the potential hazards, areas of proposed operations should be compared with regions of similar topography and rock type where forestry operations are currently proceeding or have been completed. This should be followed by inspection of the potential problem areas in the region where operations are proposed. This assessment should result in the planning of operations with regard to the perceived hazards.

Forestry Commission guideline procedures for erosion control should be implemented during, and immediately after, forest operations.

INTRODUCTION

The guidelines presented in this report are based on a background of investigations of landslide and erosion problems in many parts of the State. The majority of investigations involve slopes of the Tamar Valley and the North-west Coast which are underlain by Tertiary basalt and clay. Several investigations have been conducted elsewhere, including Quaternary talus and Triassic and Permian rock slopes of the East Coast, Fingal area and Cluan Tier. Permian and Triassic slopes and landslides have also been investigated in the Lilydale, southern Midlands and southeastern parts of the State. Erosion problems have been investigated on several of these rock types, as well as on areas of the North-east, underlain by highly erodible granite soils.

The relationship between topography and the underlying geology, as well as an understanding of the nature of the rock types, their weathering products and susceptibility to erosion and landsliding, are important starting points towards an understanding of the behaviour of slopes after the removal of vegetation. The potential effects of erosion processes can therefore be anticipated and appropriate forestry practices adjusted. The planning of all operations should acknowledge the sensitivity of the landscape to accelerated erosion and potential mass movement.

For the purposes of this report the terms erosion and landslides have been separated. The term erosion will be used to cover sheet, rill, gully and tunnel erosion forms and processes.

EROSION AND LANDSLIDE HAZARDS

Soil erosion is a particular hazard associated with forestry operations in the areas under investigation. The hazard must be assessed according to the critical land features such as topography and geology. Once the hazards have been assessed operations can be planned according to the assessment. However, operation planning must be sufficiently flexible in order to allow adjustment if further hazards occur or increase.

Accelerated erosion of the soil by rainfall and runoff, in the form of sheet, gully, rill and tunnel erosion, as well as landslide mass movement, are all considered to be potential hazards in areas of forestry operations. The rate of erosion is governed by the length and steepness of slope, surface roughness, the intensity of rainfall runoff, the nature of the soil or rock weathering products, the vegetative cover, and land use and management (Sloane, 1983a). The soil is considered to be the weathered products of the *in situ* bedrock and includes unconsolidated deposits such as talus. In many instances these deposits will vary in thickness on a local scale, according to such things as the nature of the bedrock, groundwater conditions, and slope aspect.

A brief outline of erosion forms and known landslide occurrences will be presented, together with a summary of the potential erosion susceptibility of rock types. It should be noted that this advice is generalised, as this is not a field assessment report, and the information scale is based on 1:50 000 and 1:63 360 geological and topographic maps.

SOIL EROSION

Sheet Erosion.

Sheet erosion is considered by Pinkard (1980) to be the greatest hazard, as a large part of the area has steep or long slopes and relatively unstable soils. Pinkard (1980) and Ritchley (1978), consider that sheet erosion is most severe on the upper slopes and crests of hills and mountains in the higher rainfall areas. All soils are susceptible to some extent, but a ranking in order of decreasing susceptibility related to rock type would be; granodiorite, Triassic sandstone and sandstone talus, Permian sandstone, Permian mudstone, dolerite talus and dolerite.

Sheet erosion is an insidious process and usually progresses unnoticed until more serious effects such as rilling and gullying occur. The net result is a loss of topsoil and associated soil nutrients.

Rill and Gully Erosion.

Rill and gully erosion is a further development of sheet erosion and forms where concentrated runoff erodes to form well defined channels or rills and gullies. Sloane (1983a) considers that gullying develops on middle to lower slope areas where soils are often thickest. Continued concentration of runoff into the gullies leads to rapid progression upslope by headward extension. Soils which are prone to gullying are generally unstable with sandy surface layers. The rilling and gullying of roadside embankments and gravel pits is a major problem as siltation of drains may occur, resulting in road damage and a ready source of sediment for further transport by runoff. A similar ranking in terms of rock type can be used as that suggested for sheet erosion.

Tunnel Erosion.

Tunnel erosion is a potential problem where subsoil clays have dispersive properties. Deeply weathered profiles developed on Permian and Triassic shale and mudstone may be prone to this form of erosion, as tunnel erosion is prevalent on these rock types elsewhere in the State. Tunnelling usually results in deep gullying due to tunnel collapse.

In summary, potential hazards include sheet, rill, gully and tunnel erosion. Long steep slopes are potentially highly prone to erosion, as well as areas of major soil disturbance such as roads, snig tracks and landings. Granodiorite and Permian and Triassic sandstone are rock types of highest potential risk. The potential for tunnel erosion is highest on Permian and Triassic mudstone where the subsoil contains a high proportion of clay with dispersive properties. A detailed discussion of erosion forms and processes is presented by Sloane (1983a).

LANDSLIDES

Landslides have occurred elsewhere in the State on most of the rock types that are present in the areas under investigation. Long steep slopes with high groundwater tables are particularly susceptible. Landslides on Permian and Triassic rocks usually occur on deeply weathered profiles with high clay contents. From investigation of landslides elsewhere in the State, slopes above 15° have a high potential for failure. Slopes below 12° are considered stable, while slopes between 15° and 12° are potentially unstable and must therefore be treated with some caution.

Slopes underlain by dolerite talus are known to have failed in several parts of the State. Landslides have been inspected for the Forestry Commission in the Fingal and Mount Punter region as well as other areas of the East Coast (Sloane 1978, 1982.) Failures commonly occur where dolerite talus overlies sandstone bedrock and especially where the talus is thin and road embankments have been excavated to bedrock. Landslides in dolerite talus have also been seen in undisturbed areas with natural vegetation. Slopes greater than 15° have a high potential for failure (Sloane, 1978). Slopes between 12° and 15° are known to have failed in some cases and therefore slopes in this category must be treated with some caution. Slopes less than 12° are considered stable, unless excavation results in embankments with bedrock exposed at the base.

Several landslides are shown on the Lake River and Middlesex geological maps. Other landslides have been located by the Forestry Commission. The landslides and associated topographic and geological locations are summarised below. The adjacent coupe reference is given.

LT 10. Middlesex geological map. Adjacent landslides on Permian Woodbridge Glacials and dolerite talus. Upper and middle escarpment slopes and steep slopes at the edge of major benches.

WC 2. Forestry landslide A. Dolerite talus overlying Triassic sandstone. Upper escarpment slopes.

HU 6. Forestry landslide F. Dolerite talus overlying Triassic sandstone. Upper escarpment slopes.

LR 1. Forestry landslides B,C,D,G. Dolerite talus overlying Triassic sandstone. Steep slopes at edge of major sandstone bench. Forestry landslide B has been inspected by B.D. Weldon and a report is included in Appendix 1.

LR 3. Forestry landslide E. Permian Poatina Group sediments. Steep slopes at incised edge of major bench.

LR 5. Lake River geological map. Landslide on adjacent slopes. Dolerite talus overlying Triassic sandstone. Upper escarpment slopes.

The evidence of previous instability is an important input in determining landslide risk. The morphological features associated with old landslides are summarised below.

Drainage.

Stream channels or gully depressions aligned across the slope rather than in a downslope direction. Swampy depressions, especially when associated with 'backsloping' slope segments, are caused by ponding of runoff by ground disturbance or fed by seepage from landslide headscarps.

Landslide morphology.

Head scarp- Arcuate area of steeper slope on an otherwise uniformly sloping area.

Slide mass- Often a semicircular 'backsloping' area caused by rotation during failure. May be hummocky and ridged across the slope. Ponding or swampy depression may be associated.

Toe region- Often lobate or tongue shaped in plan. Hummocky or bulged in profile. Seepages may be present at toe front.

Other features.

Slope complexity is often a good indicator of previous instability. This can be identified in the field or from topographic maps with a small contour interval. Areas of complex slope on an otherwise uniform or simple slope profile should be outlined.

Tension cracks are generally associated with active or recently active landslides and can occur in toe or slide mass regions or above head scarps.

Leaning trees or 'kinked' sections of trees often indicate slope instability during growth.

Several of these features may be associated, providing greater confirmation of previous instability.

In summary, landsliding may occur in dolerite talus, particularly on steep slopes at the edge of Triassic sandstone benches. Landslides may also occur on steep slopes underlain by thick mantles of weathered Permian and Triassic mudstones. Slopes greater than 20° are considered to be highly likely to fail and therefore should remain undisturbed. Slopes between 15 ° and 20° have a high potential for failure, particularly where the water table is high. Extreme caution must be exercised when disturbing slopes of this grade as the majority of landslides on these rock types occur on slopes above 15°. Slopes between 12° and 15° have a moderate risk of failure and therefore must be appropriately considered, particularly where roading results in embankment excavation. Slopes less than 12° are considered stable, although large excavations must be treated with caution.

RECOMMENDATIONS

The accompanying coupe maps (Appendix 2) have been enlarged from 1:50 000 topographic maps. The areas have been slope classed into three basic classes; greater than 20°, between 20° and 12°, and less than 12°. The topographic base was considered unsuitable to allow further subdivision and the classes were chosen to provide a broad outline of the salient topographic features described previously.

It is suggested that the initial input in outlining potential erosion and landslide hazard areas should be the slope classing of each area at the best topographic scale available. The suggested slope classes are described in the previous section on landsliding. This will initially identify the basic topographic units which can then be related to the geological information. This procedure will highlight those areas of potential erosion and landslide hazard and allow a ranking in order of potential severity.

The methodology of further investigations should be similar to that employed by Sloane (1982, 1983*a*,*b*,*c*). The initial topographic and geological inputs will highlight potential problem areas, at a scale dependent on this baseline information scale. Similar areas already subjected to forestry operations should then be inspected in the field. This will improve the assessment of the erosion and landslide susceptibility of the various rock types, on the basis of previous experience. The final step should involve field inspection of the potential problem areas after the above steps have been implemented. During this assessment process all known occurrences of active landslides and erosion areas should be plotted on the coupe maps, together with areas which have been identified as old landslide areas. This will highlight sensitive topographic units which can be avoided and will also indicate similar topographic units which may be at risk. These similar topographic units may have no evidence of erosion or previous instability but if, for example, they are a continuation of a slope segment which has failed, then by inference the unfailed slope segment must be considered to be marginally stable. An example of this approach is provided by Sloane (1982), from brief investigations at Cluan Tier.

The end result of the above investigations should provide a basis for the planning of forestry operations with regard to the potential geological hazards described in this report. Sensitive areas will be indicated and therefore roading and clearfelling can be arranged in order to minimise potential hazards and the visual impact of these hazards. Despite a concern with visual impact, the overriding concern should be the minimisation of accelerated erosion in order to protect and preserve the soil for further operations. Sloane (1983*c*), considers that if large scale erosion occurs then not only is there a loss of soil, and consequently soil nutrients, but access to the area for the next cycle of forest harvesting may also be seriously affected.

Some of the field guidelines used in the Mount Punter and Cluan Tier areas (Sloane 1978, 1982) may also apply to the areas under investigation, particularly as there are basic topographical and geological similarities. In this region clearfelling and roading was restricted to the topographic benches wherever possible. Areas which were avoided included the steep slopes at the edge of the first major Triassic sandstone bench, especially where the dolerite talus mantle was thin. Road routes which traversed this slope were carefully chosen, as evidence of old landslides was common. The preferential location of access roads along ridges and benches was also considered by Sloane (1982, 1983*c*) to be a useful technique to avoid large scale excavation, as well as minimising the effect of roads as a main source of sediment for transport by rainfall runoff.

It is also recommended that there be a strict adherence to the Forestry 'Guidelines' (1981) in terms of the implementation of erosion control procedures during or immediately after clearfelling operations. The guidelines should not be strictly adhered to in the sense that once an area is classed in terms of erosion then the procedures to be followed are rigidly set. If local problems occur, the erosion class may require upgrading and this should be done at the field or district forester level. Field investigations with Forestry personnel have shown them to have an excellent local knowledge of the soils and their behaviour in relation to forestry operations. To a large extent therefore, decision making in respect to geological hazards should be made by field staff at the local level.

Ranking of proposed forest areas with reference to potential geological hazards.

The logging coupes under investigation have been ranked in decreasing order of potential geological hazard. To a large extent this is related to the percentage of the area with slope greater than 20°. Those areas which are deeply dissected by streams are considered more at risk than areas with simple benched profiles reflecting the underlying geology. Dissected regions may have a higher potential for groundwater seepage. The potential areas of hazard are summarised below.

BA 5. Large percentage of steep slopes. Only approximately one square kilometre of a major sandstone bench remnant with low slope and low hazard in western part of area. Remainder of area is deeply dissected with long steep slopes adjacent to streams and at the margin of the major sandstone bench below 750 m contour. Steep Triassic sandstone slopes at edge of bench may have high erosion potential. Steep slopes near the dolerite talus fringe have potential for failure. Steep lower slopes underlain by Permian Ferntree Mudstone have moderate to low erosion and landslide hazard unless soils are thick or the rock is deeply weathered.

HU 10. Deeply dissected Triassic sandstone bench. Sandy soils of high erosion class can be expected. Particular problems may occur on steep slopes at valley sides and heads, especially as long slopes are apparent. Remnant steep slopes at edge of Triassic sandstone and Permian Jackey Formation (sandstone) bench, approximately below the 750 m contour. Moderate to high erosion class if soils are sandy and thick. Moderate to low landslide risk unless deeply weathered and clayey. Lower areas underlain by Permian Bogan Gap Group siltstone have low erosion and low landslide risk unless deeply weathered.

BA 3. Deeply dissected. High proportion of area has steep long slopes. Some steep upper slopes on Triassic sandstone may have high erosion class due to sandy soils. Majority of slopes underlain by Permian Bogan Gap Group siltstone with low to moderate risk of erosion and landslide unless deeply weathered.

LR 1. Higher areas have locally steep slopes on dolerite talus with moderate landslide risk. The steep slopes at the edge of the Triassic sandstone bench below 720 m contour have sandy soils with potentially high erosion class. Steep lower slopes underlain by Permian Ferntree Mudstone have moderate to low erosion and low landslide risk unless deeply weathered.

WC 2. Major steep slopes are underlain by Quaternary gravel and Triassic sandstone. High erosion class on sandstone slopes. Quaternary gravels are similar to dolerite talus with moderate landslide and low erosion risk. Steep slopes between 600 m and 700 m underlain by Permian mudstone and sandstone. High erosion risk if soils are sandy. Moderate to low landslide risk unless deeply weathered.

LT 10. Major area of steep slopes underlain by Permian Ferntree Mudstone and Woodbridge Glacials. Low to moderate erosion and low landslide risk unless deeply weathered and sandy soils. Long steep slopes common.

HU 6. Steep upper slopes underlain by dolerite talus, Triassic sandstone and Permian Jackey Formation. Edge of major bench between 800 m and 600 m has high erosion potential due to sandy soils. Moderate to high landslide risk at talus fringe at edge of major bench. Moderate mid-slopes underlain by Permian Bogan Gap Group siltstone have low erosion and low landslide risk unless soils are sandy or deep weathered.

BS 11. Steep slopes, above approximately the 900 m contour, are underlain by dolerite talus with low erosion risk and moderate landslide risk, especially where the talus is thin at the edge of Permian rock benches. Minor areas of high erosion risk include steep and moderate slopes adjacent to streams and underlain by granodiorite.

LR 3. Minor areas of steep and moderate slope on dolerite talus and Permian Bogan Gap Group siltstone. Low erosion and low landslide risk unless deeply weathered. Highest landslide risk on steep slopes at talus fringe.

HU 7. Minor areas of steep and moderate slope are underlain by dolerite talus and Permian sediments. Low to moderate landslide and erosion risk unless soils are sandy. Higher landslide risk where talus veneer is thin, especially adjacent to Warners Creek in the southern part of the area.

LR 14. Minor steep slopes underlain by dolerite talus with low landslide and low erosion risk.

TU 11. Low erosion and low landslide risk.

LR 5. Low erosion and low landslide risk.

TU 3. Low erosion and low landslide risk.

TU 7. Low erosion and low landslide risk.

CONCLUSIONS

The aim of this report has been to provide a broad overview of potential geological hazards in areas of forest operations on the Great Western Tiers and South Barrow escarpments. These potential geological hazards include sheet, rill, gully and tunnel erosion, and landsliding. The hazard risk is considered to be closely related to the topography and geology. The topography strongly reflects the resistance to erosion of the underlying rock types. These concepts are considered to form the basis of the risk assessment, in terms of erosion and landsliding.

All rock types in the areas under investigation are subject to the landslide risk, depending on the steepness of slope, the presence and nature of the soil and weathered bedrock, and groundwater conditions. The slope criteria which should be used in assessments has been outlined in this report.

In summary, slopes greater than 20° (35%) have a very high potential for failure and erosion and should therefore remain undisturbed. Slopes between 15° and 20° (25% to 35%) are potentially unstable and should be treated with caution by modifying operations and careful planning. Slopes between 15° and 12° (21% to 25%) are known to have failed in some cases, particularly where roading has resulted in the excavation of steep embankments, and therefore consideration of this risk should be included in the assessment. Slopes below 12° (21%) are considered to be stable.

The soils and weathered bedrock in each area are all subject to erosion, to a varying extent. Accelerated erosion will occur after forest clearfelling, and operation planning and erosion control measures should be designed to minimise this. The potential erosion susceptibility of the various rock types has been discussed elsewhere in this report and slopes greater than 12° (21%) may be considered to be potentially sensitive.

Increased runoff can be expected for a period of approximately five years after forest clearfelling (Sloane 1983a). This increase is related to a reduction in rainfall infiltration, interception and evapotranspiration, compaction of soils, and alteration of drainage due to ground disturbance. The overall effect may result in accelerated erosion with an associated deterioration of water quality in adjacent streams through increasing the sediment yield. The Forestry Commission 'Guidelines' (1981) are designed to minimise these detrimental effects of forestry operations.

The main sources of erosion and sediment yield to streams are caused by ground disturbance, particularly from roads, access and snig tracks. Therefore the careful planning of roads and snig track systems is essential. Some suggestions include the location of tracks along ridges or benches or at the base of slopes. Midslope or upper footslope locations are to be avoided wherever possible as these areas are sensitive to erosion. Uphill snigging is advised on moderate slopes, wherever practical, as the divergent pattern of tracks tends to disperse runoff.

Soil is the most important basic resource of the forest and soil conservation is highly important in order to minimise erosion and preserve the capacity of the area for reafforestation and further harvesting.

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[21 November 1986]

APPENDIX 1.

INSPECTION OF FORESTRY LANDSLIDE 'B' - GREAT WESTERN TIERS.

B.D. Weldon.

A landslide on the slopes of the Great Western Tiers was inspected with APPM representatives and several officers from the Forestry Commission on Wednesday 25 June 1986. A logging road traverses a 'bench' on the slopes of the Great Western Tiers. The landslide is located on the edge of this bench and is some 60 m north-east of the logging access road.

The landslide is relatively narrow (about 30 m across), affecting a long slope segment (estimated at 120-140 m long). Splash marks on trees adjacent to and within the path of the landslide mass indicate that the landslide was apparently quite fluid at the time of failure.

The surface geology consists of boulders of Jurassic age dolerite in a clayey matrix. These are talus deposits overlying the bedrock. Fragments of sandstone were observed within the landslide mass. Toward the north-western edge of the landslide, a large mass of Triassic age sandstone crops out. Green/blue, highly plastic clays were observed both above and below the sandstone mass.

The headscarp of the landslide is located within a natural drainage path which leads from the bench (variable slopes 4-10 degrees) to the steep slopes (16-22 degrees) of the Tiers. This natural drainage path is now fed with water collected by the roadside table drains. The Forestry and APPM personnel were concerned that this roadside water may have been a trigger for landsliding. This is probably the case. However, because the natural drainage path feeds the head scarp area of the landslide, it may merely have accelerated the occurrence of the landslide. Without the benefit of watershed mapping it is difficult to assess the role that roadside water played in initiating the landslide.

The slope on which the landslide has occurred is potentially unstable. Topographic maps show irregular contours, the slope is steep and landslides have occurred in the past. The geological setting of a dolerite veneer overlying Triassic sandstone is known to be unstable elsewhere in Tasmania.

After discussing the above mentioned points in the field, it was agreed that some guidelines were required to assist the foresters to identify areas where the local conditions were unfavourable with respect to slope stability.

57/64

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The potential effect of forestry operations on slope stability and springs in the Mt Clark - Mt Koonya area

by D. J. SLOANE

TASMANIA DEPARTMENT OF MINES

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1987/56. The potential effect of forestry operations on slope stability and springs in the Mt Clark - Mt Koonya area.

D. J. Sloane

Abstract

The geological configuration of this area is similar to other areas previously investigated for the Forestry Commission with regard to potential instability problems. The main Mt Clark - Mt Koonya plateau is underlain by Jurassic dolerite, with Triassic sandstone and mudstone rocks forming topographic benches at the base of steep, talus-covered escarpment slopes.

Old and recently active landslide areas have been observed in the region. It is considered that if the steep, talus-covered escarpment slopes are clearfelled, potential instability problems could occur.

Springs occur near the base of the escarpment. Their origin is considered to be partially related to rainfall infiltration and joint directions of the dolerite underlying the higher plateau region. If clearfelling occurs on the plateau, it is suggested that spring flow should increase initially. The increased flow may occur for a period of up to five years. If the new forest regrowth is denser than the existing vegetation, the long-term effect may be a reduction in spring flow.

The most essential aim concerning proposed forestry operations in the area is to minimise soil compaction in order to maintain the infiltration capacity of the soils.

INTRODUCTION

At the request of the Forestry Commission, areas of the Mt Koonya - Mt Clark State Forest on the Tasman Peninsula were inspected on 20 October, in the company of Mr Paul Smith. The Forestry Commission was concerned that forest harvesting may have a deleterious effect on slope stability and spring water supplies. Several properties rely on the water from springs for domestic supplies.

GEOLOGY AND TOPOGRAPHY

The geological configuration of this area is similar to other areas previously investigated for the Forestry Commission with regard to potential instability problems. The main Mt Clark - Mt Koonya plateau is underlain by Jurassic dolerite. The dolerite was originally intruded in the form of a sheet or sill. The major escarpments in the area represent the edge of the dolerite outcrop (fig. 1). Slopes are up to 30° (60%) and commonly between 18° (32%) and 25° (47%) on the northern, eastern and southern-facing escarpment slopes of Mt Clark.

Underlying the dolerite is Triassic sandstone and mudstone which commonly forms benches at the base of the escarpment. Dolerite talus and scree deposits mantle the escarpment slopes.

An examination of the topography of the region indicates some NNE-SSW structural control, with a secondary control at right angles. This can be deduced from escarpment and stream directions. Dominant subvertical joints with a spacing of 1.0 to 0.3 m can be seen in dolerite outcrops adjacent to the Mt Clark access track. Some of the dolerite cliffs associated with the slopes above Grooms Hill Road show joint spacings greater than one metre. The size of scree boulders also tends to reflect a wide, rather than platy, joint spacing. Joints are generally open where observed in outcrops, indicating relaxation due to stress release.

DRAINAGE AND GROUNDWATER SEEPAGE

The drainage divide above the escarpment slopes occurs close to the track running along the slope crest (fig. 1). Seepages are evident along the talus slopes, particularly along the northern face, with occasional ponding at the base of the escarpment. The seepages often appear close to the contact between the dolerite and the underlying sandstone and mudstone. The seepage origin is often masked by the talus cover, with the seepages sometimes appearing lower on the slopes. Seepages often appear and disappear intermittently in the talus cover.

If the talus seepages are purely associated with rainfall infiltration along this slope, it appears unlikely that constant seepage flow can be expected during dry periods, despite the ponding of water in isolated places at the escarpment foot.

The dominant NNE-SSW trending, open vertical joints appear to be related to the predominance of springs on the steep slopes on the northern side of Mt Clark. Some of the groundwater undoubtedly originates from rainfall infiltration on the plateau area to the south of the watershed. The salinity of two seepages tested was 250 mg/l and 150 mg/l. These salinities indicate that the groundwater is not entirely fresh but also indicate that the water has not been in the dolerite bedrock and talus for a long period of time. Therefore the salinities also tend to indicate that the groundwater seepages originate, at least in part, from near-surface dolerite jointing.

The result of forest clearfelling can now be considered in relation to the potential effect on groundwater seepages. It is widely considered that clearfelling will increase rainfall infiltration, provided soil compaction is minimised. This increased infiltration is due to reduced evapotranspiration and interception by vegetation, an increase in depression storage from ground disturbance, and a reduction in litter and resulting increase in the area of bare soil. This effect is likely to occur for a period of approximately five years after clearfelling and reseeding until the new forest has grown sufficiently for the hydrological balance to be restored to a state similar to pre-clearing levels.

Theoretically, the seepages at the base of the Mt Clark escarpment should increase in flow for several years after clearfelling. However the Melbourne Metropolitan Board of Works has prevented the logging of their water supply catchments, not because of increased runoff and sediment yield to streams, but because they consider that the new forest cover will be denser and result in an eventual 25% reduction in runoff. There is not a lot of evidence to support this theory but if it is correct, infiltration on the Mt Clark plateau will eventually be reduced, resulting in a reduced or nonexistent seepage flow.

POTENTIAL INSTABILITY PROBLEMS

With respect to potential instability problems it is probably unwise to clearfell the steep escarpment slopes. The higher scree slopes are considered to be surficially stable due to a high permeability and a lack of clay matrix. However, it is uncertain if the grain-supported structure of the rock scree extends to depth. In other parts of the State exposures in road cuttings have shown that the surface occurrence of boulders does not always reflect the rock component of the underlying talus.

Old landslide features are apparent on the talus-covered northern face of Mt Clark. Inspection of the contour map shows that the talus slopes are topographically complex, indicating a history of previous instability. The presence of seepages on the talus slopes indicates that the moisture content of the talus is probably high. The presence of sandstone boulders on the middle to lower talus slopes indicates that the underlying Triassic rocks are probably at shallow depth. Previously investigated landslide problems occur in similar situations elsewhere in the State, and at these locations, slopes steeper than about 15° (27%) are considered to be potentially unstable (Sloane 1978; 1982; 1986).

Existing landslides have been mapped at the northern end of Grooms Hill and at locations adjacent to the Nubeena Back Road (Cromer *et al.*, 1979). The landslides are associated with both the Jurassic dolerite and Triassic sandstone and mudstone, including the talus and scree deposits derived from the parent bedrock. Cromer *et al.* (1979) considered that most earth movements tend to develop either in the head region of gullies or on more moderate slopes lower down the hillside. At these locations a thicker accumulation of weathered material, soil or talus, combined with the emergence of springs and seepages issuing onto the slope, is prone to instability.

RECOMMENDATIONS

The geological configuration of the steep escarpment slopes of Mt Clark and Mt Koonya is similar to other areas of the State where instability problems have occurred. Old and recently-active landslide areas have been observed in the region. It is therefore considered that if the steep, talus-covered escarpment slopes are clearfelled, potential instability problems could occur. For planning purposes elsewhere, slopes steeper than 15° (27%) are considered potentially unstable. Figure 1 indicates those areas steeper than this angle. The areas considered to be underlain by Jurassic dolerite have been indicated. These areas are considered to be more stable than areas underlain by talus and located close to the dolerite-sandstone and mudstone boundary. Cable logging methods are possibly more suitable in these more stable regions.

The origin of springs near the base of the escarpment is considered to be partially related to rainfall infiltration and joint directions of the dolerite underlying the higher plateau region. If clearfelling occurs on the plateau, and the theory of the spring origins is correct, then spring flow should initially increase. The increased flow may occur for a period of up to five years. If the new forest regrowth is denser than the existing vegetation, the long term effect may be a reduction in spring flow, again provided that the dolerite joint control theory of some component of the spring water is correct.

The most essential aim concerning proposed forestry operations in the area is to minimise soil compaction in order to maintain the infiltration capacity of the soils.

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Slope stability in an area of the Douglas - Apsley State Forest

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1987/58. Slope stability in an area of the Douglas - Apsley State Forest.

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Abstract

A section of the Douglas - Apsley State Forest known as Coupe 50 has similar topographic features and geology to previously inspected areas where known instability problems exist. Instability problems usually occur along the steep slopes at the edge of topographic benches underlain by Triassic sandstone and mudstone, where the dolerite talus veneer is thin.

Slopes steeper than about 15° (27%) and underlain by dolerite talus are considered to be potentially unstable. These areas have been outlined and inspected. Road routes and areas of forest clearing have been planned in order to avoid these potentially unstable areas.

INTRODUCTION

Geologist D. J. Sloane has inspected an area of the Douglas - Apsley State Forest at Mt Andrew, near Bicheno, in the company of J. Cunningham of the Forestry Commission and W. Robbie of Tasmanian Pulp and Forest Holdings. The purpose of the field inspection was to determine the stability of steeply sloping areas, as well as to assess the suitability of an extension to 'O' Road into an area of Coupe 50.

GEOLOGY AND TOPOGRAPHY

The Coupe 50 area has similar topographic features and geology to previously inspected areas where known instability problems exist. These areas have gently sloping topographic benches beneath dolerite-capped hills. The benches usually have a thin veneer of dolerite talus overlying Triassic sandstone, mudstone and coal measures. Instability problems usually occur along the steep slopes at the edge of the benches, where the dolerite talus is very thin (Sloane, 1978; 1982; 1986). The steep slopes at the edge of the benches are usually a result of the resistance to erosion of the underlying sandstone and mudstone.

Good geological maps of the area are available, and part of a map covering the Coupe 50 region has been reproduced as a transparent overlay (fig. 1). The accompanying section of the topographic map has been marked with the proposed road route, and areas of slope greater than 15° (27%) have been outlined. This slope angle is considered to be a threshold slope angle for dolerite talus overlying Triassic rocks. Previous investigations show that instability problems have occurred above this angle.

PLANNING AND SITE INSPECTION

The combination of the transparent geology overlay and the topographic map indicating the steep slopes is very useful for initial planning. These indicate that the safest route is in fact the route planned by Mr Robbie, and visual inspection confirms this. Site inspection has also confirmed that the steep bench edge in the southern part of the coupe has slopes up to 24°(40%), and weathered mudstone is also exposed in places. The dolerite talus along this slope is therefore extremely thin.

It is difficult to determine positively if old landslides are present on the steeply sloping area of the coupe. Several small benches were observed, together with small talus lobes and minor areas of possible drainage disruption. The areas of weathered mudstone outcrop are considered to be moderately to highly erodable.

RECOMMENDATIONS

It is recommended that the steeply sloping area outlined on the topographic map should be avoided with regard to roading and conventional harvesting methods. The boundary to this area is approximately at the 300 m contour level. It is considered that the area could probably be logged by cable methods at a later date, as this method minimises ground disturbance. Field discussions indicated that it is also advisable not to continue the coupe road beyond point A on the accompanying map. Beyond this point the proposed route traverses the foot of steep slopes before reaching a lower bench. The area of suitable forest in this area is small, and therefore roading is considered uneconomic.

The main access road from 'O' road is considered well planned and is not likely to be affected by potential instability problems. Mr Robbie has previously recognised areas of potential and old instability and avoided them in planning the road route.

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