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Geological Survey of Victoria

ANZ Slide '87

Field workshop on Landslides
Victorian Section
August 4 - 5, 1987

P G Dahlhaus
A M Cooney
J L Neilson

Unpublished Report 1987/38

DEPARTMENT OF INDUSTRY, TECHNOLOGY AND RESOURCES

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1 MELBOURNE TO PORT CAMPBELL

From Melbourne Airport the route follows the Tullamarine Freeway south to the western edge of the City of Melbourne before joining the Princes Highway to Geelong.

1.1 Melbourne to Geelong

Between Melbourne Airport and Geelong the route crosses a volcanic landscape known as the Werribee Plains, comprising a Plio-Pleistocene sheet of basaltic materials that extends westwards almost to the South Australian border (Fig 1). The Werribee Plains are mainly underlain by extensive sheet flows of basaltic lava with some beds of ash and other pyroclastics. A few eruption points rise above the Werribee Plains as mounds, including Mt Cottrell (a lava cone) near Melbourne, and the Anakies (three scoria cones) near Geelong. The Princes Highway crosses a number of basalt tongue flows with their distinctive topography: these rest on the prevalent sheet flows and can be traced to eruption points. The volcanic materials of the Werribee Plains are quite commonly veneered with a reddish brown loess-like material.

The western limit of the Werribee Plains is marked by the prominent Rowsley Fault Scarp. To the south this becomes a monocline with the basalt warped across it; elsewhere the feature is marked by scoria cones (the Anakies). The largest and by far the highest group of hills present are the You Yangs, a residual of Devonian granite which projects sharply through the basalt plains.

Halfway to Geelong the highway crosses the alluvium of the Werribee Delta, here about ten kilometres across. The river has cut into the delta sediments, forming terraces and vertical cliffs.

Geelong is the major port on Corio Bay, which was partly formed by down faulting. Tertiary calcareous clays underlie basalt along its western shore. Both the Barwon and Moorabool Rivers have cut deeply into the basalt flows, to expose the Tertiary sedimentary rocks. Both ancient and still-developing river terraces occur along the valleys.

Last century, the open volcanic plains quickly attracted pioneering pastoralists who used Geelong as the port to export their wool. When gold was discovered at Ballarat in 1851, both the commerce and the population of Geelong leapt as it became a favoured port of entry for the diggings. By 1854, Geelong's population of 23,000 made it Australia's third largest town. Today with a population of approximately 140,000 it is an important industrial and commercial centre. Major industries include cement manufacture, aluminium smelting, automotive manufacturing and oil refining.

1.2 Geelong to Port Campbell

The Princes Highway crosses sub-basaltic Tertiary limestones and other sedimentary materials outcropping along the eastern margin of the Otway Basin and then the lower slopes of the Cretaceous sediments forming the Barrabool Hills to the north. From there, the route follows the southern edge of the volcanic plains to Colac.

The southern skyline is formed by a low, broad range - the Otway Range - with a maximum elevation of 670 m. Lower Cretaceous sediments - the Otway Group - comprising lithic sandstones and siltstone underlie the range (Fig. 2). Fringing foothils and flats are underlain by Tertiary sediments including the Wangerrip Group and Nirranda Group (Palaeocene - Eocene) and the Heytesbury Group (Oligiocene - Miocene). The base of the sequence includes various sandy units such as the Dilwyn Formation as well as some fine grained units. Calcareous sediments are more common higher in the sequence and the Heytesbury Group includes the Gellibrand Marl comprising interbedded calcareous clays and silts with very minor clayey sand. This formation is covered with a sand unit, the Moorabool Viaduct Formation, or a limestone unit, The Port Campbell Limestone.

Although landslides occur in all units, they are most frequent in the Otway and Heytesbury Groups. A summary of relationships is as follows:

Geological Group	Typical failure types	Slopes (°)	Lithology
Heytesbury	Earth flow	9.5-16.5	Calcareous clay & silt
Nirranda	Earth block	14	Calcareous clay & silt
Wangerrip	Earth slump	19.5+	Sand & silt
Otway	Complex slump, Earth flow, topple	22-37	Lithic sandstone & siltstone

From Colac the journey leaves the Princes Highway and the volcanic plains, and crosses south-west over the Tertiary sediments of the Otway Basin. These sediments mostly comprise limestone, calcareous clay, clay and silt which make up the Heytesbury Group. One of the formations in this group is the Gellibrand Marl which comprise interbedded black clays and dark olive green silts, both highly fossiliferous; these are mottled yellow, grey and tan in outcrop, with frequent calcareous nodules, powdery calcareous patches and sometimes ironstone deposits occur along joints and bedding indicating a high degree of weathering. They underlie an elevated flat to undulating surface which is about 160 m above sea level. Valleys, some 80 to 100 m deep are incised into this surface. Most trend northwest and have a distinctly curved outline; Scotts Creek, however, runs more or less east-west, cutting across them.

Numerous flow failures can be seen along the northern wall of Scotts Creek Valley. Many farms in this area (known as the Heytesbury area) were developed since 1960 and much of the native vegetation was cleared since that time. At least some of the slope failure had occurred prior to that clearing. Figure 3 shows a failure just south of Scotts Creek (along Bucks Rd); Figure 4 shows a cross section of that slide. Overall area affected by the failure is 15 ha although part (2 ha) has been active recently. Failure was in gently dipping interbedded calcareous clays and silty clays and minor clayey sand bands of the Gellibrand Marl; this was weathered to a depth of 9 m. Failure was on slopes of 7° to 9° (12% - 16%) and occurred at or near the weathered - unweathered contact. Both the weathered and unweathered materials were CH soils but, in general, the weathered material was finer grained overall and a little more plastic than the unweathered material.

Mean annual rainfall at Timboon (13 km to the west) is 971 mm. Historic failures seem to be related more to anomalously high monthly rainfall than to annual peaks. In some cases the failure year is preceeded by below average annual rainfall.

At a deep road cutting in Heytesbury Group sediments about 1.5 km north of Timboon, silty clays have been weathered from grey to yellow to a depth of about 10 metres.

The Gellibrand Marl outcrops between Timboon and Port Campbell. Slumps and earth flows become common just north of Port Campbell, even on the gentle slopes. Along the coastal zone near Port Campbell it is overlain by the Port Campbell Limestone. Both formations are of Miocene Heytesbury Group.

Lunch will be taken at Port Campbell.

2. PORT CAMPBELL TO PRINCETOWN

2.1 Description of the Port Campbell Coastal area.

A limestone plain 45 m above sea level stretches from near Warnambool to Port Campbell. West of Port Campbell, numerous sinkholes up to 270 m in diameter have developed and surface drainage is absent. Heathland and low clumps of Casuarina (sheoak) and Eucalypt (brown stringybark) trees grow on the surface cover of residual clay and siliceous sand.

The Port Campbell Limestone is thinly bedded, with concretions and secondary limestone along the bedding, and dips of 1° to 5° seaward. Jointing is prominent striking NW - SE (parallel to the coast), NE - SW (controlling gorge and promontory formation) and both vertical and at 45° (controlling cliffs, cave roofs and arches).

The coastline runs NW - SE, but is crenulated with gorges, small bays and promontories. A platform extends up to 1.2 km offshore with reefs and rock stacks. Cliffs are close to vertical, and include sections which overhang to 8°. Generally the cliffs are between 30 m and 60 m high.

The local annual rainfall is 50 to 115 mm and falls mainly from May to October, so that small streams dry up in the summer. Currents for most of the year are to the east, but from January to March run to the west, and build sand barriers across the mouths of the creeks. Storms are mainly from the southwest, and swell periods of 14 to 16 seconds are most common. The mean rise of tide in Port Campbell harbour is 1.2 m.

The first settlement in this area was 1846. During the 19th century the rugged coastline was the site of many shipwrecks. The limestone coastline was proclaimed a National Park in May, 1964.

2.2 Route from Port Campbell to Princetown

The road follows close to the cliff top along an old coastal plain formed in the Port Campbell Limestone. This formation will be viewed at a stop where the "Twelve Apostles" - a series of rock stacks - extend approximately two miles along the coast east of Port Campbell. The taller stacks are about 45 m high.

Approaching Princetown, the road passes on the landward side of prominent Quaternary cemented dunes or dune limestones rising approximately 50 m above sea level. Princetown is simply a place name; there is no town. Near Princetown, the route takes the road to Simpson for several kilometres across a hilly landscape in the landslip-prone Gellibrand Marl.

3. BOUWMAN'S LANDSLIDE, PRINCETOWN AREA.

This landslide (Figs. 5a, 5b, 5c)occurs at Mr J A Bouwman's property, Princetown to Simpson Road, approximately 6 km north west of Princetown, in the Shire of Otway.

Mr Bouwman recollects that the landslide began in the early 1970's (possibly 1972) in the south west corner of the paddock now fenced off. Although a rather minor feature at the time, it continued to move for three years. Following this there was a period of dry winters for about three years during which no movements occurred.

However, in October 1979 the landslide became active again and the road surface was cracked. At this stage the area affected was triangular shaped and about one hectare in size.

In early August 1980 movement was more extensive and a crack traversed the garage just north of the dairy causing vertical displacement of the garage floor by about 0.3 metres. The effected area had now grown to about three hectares.

In 1981 movement occurred over three weeks between the end of August and mid September. In late September drilling was carried out to investigate the mechanism of the slide and formulate stabilisation measures. Included in the investigation program was the installation of piezometers and some soil testing. In April 1982 a detailed topographic survey was carried out over the area and a number of steel rods were located on and near the slide as monitoring stations in September 1982. These were resurveyed in late 1984 and the results showed substantial movement had occurred.

The failure occurs in weathered interbedded calcareous clays and silty clays of the Gellibrand Marl formation. There is no outcrop, but the drill core shows that the dip of the beds is either horizontal or only a few degrees. The direction of the dip is unknown. The failure is translational with the slip plane being at 3 - 4 metres deep. The failed mass is moving as two blocks.

The effect of the weathering has been to increase the plasticity of the soils and also their permeability (through the development of powdery carbonate patches). Once failure occurred, the permeability of the failed material was increased by fissuring and fracturing resulting from movement.

The landslide becomes mobile when the groundwater table rises so that there is both hydraulic uplift to de-stabilise the landslide mass and saturation of the soil to weaken it. Groundwater is derived from local infiltration. Although the natural catchment to the landslide site is small, the roadside drainage system and, in the past, the dairy waste water have substantially increased water discharge onto the area. Furthermore, the porous road embankment acts as both a dam wall, ponding surface water at the head of the slide, and as a permeable medium whereby the surface water is conveyed into the landslide mass.

Suggested remedial work is to prevent as much water as possible from reaching the landslide, and the diversion of the surface runoff well away from the failed area. The trees on the slide were planted by the owner as a means of reducing infiltration of direct precipitation and removing groundwater by transpiration. Although trees have been planted now for several years, movement again occurred last year.

4. PRINCETOWN TO APOLLO BAY

The route again passes over Gellibrand Marl before crossing the ferruginous sands of the Lower Tertiary Dilwyn Formation. Immediately east of the Gellibrand River, a faulted boundary marks the beginning of the Lower Cretaceous rocks in outcrop.

5. THE OTWAY RANGES

5.1 Geology and Geomorphology

The Otway Range is composed of Mesozoic (Lower Cretaceosu) sediments that have been uplifted into a complex domal structure. The elevation along the main ridge is about 500 metres, with the highest point (Mount Cowley) reaching 670 metres. In general, the range is closely and deeply disected with the stream pattern generally radial, reflecting the structural control.

Inliers of ferruginous sands of the Dilwyn Formation occur south of Lavers Hill. At Glen Aire a system of streams has been dammed behind a coastal barrier of Pleistocene dune limestone and Holocene mobile sand barriers to produce wide river flats which the road follows upstream before climbing again into the Otway Ranges and finally dropping to reach the coast at Apollo Bay.

Although deeply and intricately dissected, the range still shows the form of the pre-Tertiary surface. Structures associated with the late Cainozoic uplift are still evident topographically and the valleys of the main streams are in a large measure structurally controlled. The coastal streams, constantly rejuvenated by coastal erosion, contain numerous waterfalls. Landslides are commonplace on the steeper slopes.

The Otway Group is a monotonous sequence of fluviatile lithic sandstones, siltstones and minor thin beds of coal. The sequence has been measured up to 1500 metres thick. Montmorillinite is an important component of the siltstones. The rocks can occur in three associations: massive lithic sandstone, massive siltstone or thinly interbedded lithic sandstone and siltstone units. In general, they are gently folded with dips ranging up to 20°; very steep dips occur in places (eg. Skenes Creek just east of Apollo Bay). Pronounced lineaments occur (Fig. 6) reflecting the generally fractured nature of the unit.

They are often fresh to moderately weathered along the coastline and highly to completely weathered inland. The lithic sandstones are greenish grey when fresh and weather to yellowish brown; the siltstones are black to dark grey and weather through grey to very light grey.

5.2 Landslide History, Rainfall and Seismicity

Numerous landslides can be seen in the area, although there is very little historical information available about them.

The largest documented historic landslide in the region was near Forrest, some 30 km south of Colac, when an estimated 6,000,000 m^3 block of Otway Group sediments with a surface area of some 48 ha slid into the East Branch of the Barwon River; failure was along the bedding which dip 12° to 20° towards the river. The toe of the slide about 400 m wide at river level and formed a 35 m high wall of a natural dam (Figs 7 & 8).

Failure occurred during winter in late June 1952 following the wettest monthly rainfall - 415 mm (June mean 113 mm). The same year (i.e. 1952) also had the wettest annual rainfall - 1683 mm (mean annual rainfall 1037 mm). High rainfall also occurred in 1951 (1637 mm) and 1953 (1203 mm).

The natural dam was breached on 5 August 1953 and a wall of water - still some 7 m high about 10 km downstream - passed down the river. Damage was done to fencing etc. and extensive one metre layer of silt was deposited over the fields. Luckily, there were no significant buildings along the river flats and the damage was relatively slight.

Many small landslides have occurred during historical times, but unfortunately, there is no complete record of these events although aerial photographs have provided information over the past 30 years.

Average annual rainfall in the Otway Range varies from about 1100 mm along the coast to over 1900 mm on the crest of the range. The wettest period is late winter to early spring. Intense rainfall events of 233 mm for one day, 587 mm for three days, and more than 2700 mm per year have been recorded.

Many seismic events (earthquakes), some of considerable intensity (5.2 on the Richter scale), have occurred offshore since records have been kept. Most events are thought to be associated with movement along the Torquay Fault, which runs more or less parallel to the coast. However, onshore seismicity over the same period has been much less frequent and of lower intensity. There is no known association between slope failure and seismicity in the area.

5.3 Factors Conducive to Landsliding

From a general study of the region, the following factors were deduced as being conducive to landsliding in the Otway area:

1 The presence of a previous failure
2 high annual rainfall
3 coastal erosion
4 moderate to steep topography
5 suitable sediments such as:
   * Tertiary sediments (particularly the Heytesbury Group), including calcareous clays and silts.
   * Cretaceous sediments, including lithic sandstones and siltstones
6 deep weathering in Cretaceous rocks
7 "favourable" orientation of discontinuities
8 ion exchange between the groundwater and some clays (possibly in the Heytesbury Group).

Triggering mechanisms may be:

intense rainfall
road, or other, construction resulting in the removal of slope support
earthquakes (no known case)
high energy coastal storms
inappropriate development on steeper slopes.

5.4 Shire of Otway - Planning Controls

In Victoria, the Ministry for Planning and Environment (MPE) is the authority responsible for planning issues. In the Shire of Otway, the responsibility for planning has been delegated to the Shire's Planning Officer for primarily residential areas ("Village" zones), and to the MPE in all other areas. The "Village" zones are affected by the Shire of Otway (Ocean Road) Interim Development Order (IDO), approved by the Government in August 1984. Under the conditions of the IDO, applications for planning permits in areas which are prone to landslides are required to be referred to the Geological Survey and the Land Protection Service for comment.

Town	Total allotments	Number developed	Percentage developed	Number vacant	Percentage vacant
Apollo Bay	800	656	82	144	18
Marengo	210	133	63.4	77	36.6
Skenes Creek	300	162	55.4	134	44.6
Kennett River	155	79	51	76	49
Wye River	460	239	52	221	48

Town	Permanent residents
Apollo Bay	63%
Marengo	14.2%
Skenes Creek	8.6%
Kennett River	3.5%
Wye River	5.7%

5.5 Apollo Bay

At Apollo Bay sealers and whalers first made temporary selltlemnts in the early 1800's, but permanent settlement of this coast was slow because of poor accessibility from land and sea and its limited pastoral potential. Conditions changed in the 1850's when milling of the Otway forests commenced. At its peak around 1860 there were 1000 timber-cutters at Apollo Bay, but this industry declined rapidly once railway contracts were completed.

The opening of the Great Ocean Road in 1932, greatly improved accessibility and promoted development of this seaside resort.

7. WILD DOG CREEK VALLEY

7.1 Major slope failure zone

The eastern walls of this stream exhibit slope failures on a massive scale. The Geological Survey believes that mountain spreading is in operation, forming ridge top depression. Major slump earth flow failures are characteristic of this valley. One destroyed the Wild Dog Creek Road in 1952 and another constantly encroaches upon it. Others have scarred the hillside without damage to roads or structures. Signs of extensive small scale active movement abound.

7.2 Geology and Geomorphology

Wild Dog Creek flows into Bass Strait about 3 km north-east of Apollo Bay. Along the creek, the valley walls are very steep (up to 45° or 100%) and bedrock comprises sedimentary rocks of Lower Cretaceous age. The beds are composed of alternating dark siltstone and lithic sandstone with some thin coal seams. A massive sandstone unit forms a steep-sided, narrow gorge about 600 m from the mouth of the creek. Thickly bedded sandstone also predominates in the northern part of the valley. Elsewhere the rocks contain alternating sandstones and siltstones with either rock type dominating locally. Bed thicknesses range from a few centimetres to about 5 m, but more commonly are about 0.5 m. The shale beds tend to to be weaker and erode more rapidly than the sandstone and, occassionally, continuous thin (1 - 2 cm), clay beds occur in a sequence of shales and/or sandstones. The degree of weathering increases with elevation and the only outcrops of fresh rock are in the creek bed (Fig. 9).

Bedrock is generally overlain by a soil profile that consists of a thin topsoil horizon and a variable zone of soil and rock fragments that have suffered a certain amount of creep. A characteristic profile would comprise:

- 0 - 20 cm Medium to dark greyish brown, friable, fine sandy or clayey loam, plant roots.
- 20 - 100 cm Pale yellow brown, sandy clay loam with numerous highly weathered rock fragments becoming more common with depth. Clay content is related to the parent rock. The zone grades into weathered bedrock.

The structure of the soil throughout is highly porous, and severe tunnel erosion can be observed at many sites.

It is useful to compare the geomorphology of the Wild Dog Creek valley to that of the smaller catchment immediately to the east. The latter is a short creek, generally at an elevation of 100 m to 150 m higher than Wild Dog Creek, until the creek cascades down a sheer waterfall about 700 m upstream from the mouth. The waterfall is formed by the same massive sandstone bed that has been bisected by Wild Dog Creek in the gorge, however, the smaller catchment has provided insufficient flow for the stream to erode a channel.

In contrast, Wild Dog Creek has carved a very steep gorge through the sandstone and then the valley widens rapidly upstream. It is thought that in geologically recent times Wild Dog Creek was also at a substantially greater elevation cascading over a sandstone waterfall, and has only "recently" cut its channel through. The interbedded sediments immediately upstream are much softer and rapid degradation then took place. The convex shape of the stream profile would suggest that the creek is still actively degrading.

The major consequence of this process would have been rapid steepening of the lower parts of the valley sides. This is one of the major contributing factors to the deep seated instability along the valley.

The large landslide at the northern intersection of Busty Road and Wild Dog Creek Road - known as the "1952 slide" - has its failure plane at up to 26 m deep; the failed material is dominantly highly weathered, extremely fractured, lithic sandstone which has slipped on siltstone dipping 15° towards the creek (Fig. 10). A similar set of conditions occurs at the Cape Patton slide (Fig. 11) - although this is a considerably larger feature - with the failure plane at 45 m depth. It is also apparently stabilised and the brecciated mass is weakly recemented with clay in places.

7.3 Slope Stability and Landslide Risk

From a surface study of the landslides along this valley the following general conclusions were drawn:

* The smaller slides comprise surficial materials and the larger slides extend into bedrock.
* The smaller slides occur on steeper slopes than the larger slides.
* Most of the slides involving bedrock comprise mostly sandstone, probably with failure occurring on siltstone beds and sometimes on very thin clay bands.
* Failures along bedding planes are important but many large failures occur where the bedding is oblique to the slope. In these cases, jointing, creep failure or failure through the rock mass must be significant.
* Most slides are recent or old, active or dormant, but few are fossil or stabilised. This indicates the factors contributing to landslide development still exist.
* Both surface and groundwater are very important factors
* The most critical slope angles are 36-55% and 76-85%; no slides occur on slopes <25%.

* Slides rarely occur on slopes that are concave in the vertical direction or convex in the horizontal direction.
* Most large slides probably develop progressively from small slides at the toe.

The landslide risk map (Fig. 12) defines three categories.

1 No landslide risk, no restrictions on development.

2 Landslides are possible, proposed development sites should be assessed individually and adequate design precautions taken

3 High landslide risk, development should not be permitted unless under special circumstances.

Criteria

Zone 1
slopes less then 25% (14°)
no active or dormant landslides.

Zone 2
slopes between 25% and 35% (19°)
no active or dormant landslides.

Zone 3
All slopes steeper than 35% (19°)
all slopes containing active or dormant landslides.

The term 'dormant' relates to whether or not the causes of failure are still present. This is often not known and so it may be best to describe the state of erosion of the feature.

Additional observations made in the region as a whole are:

. major failures require a continuous discontinuity, such as bedding, dipping at a low to moderate angle out of the slope. Jointing is more likely to be associated with toppling.

. lineaments on sattelite images indicate that as yet unmapped major geological structures such as faults are present and probably influence slope stability.

These studies were carried out in order to map areas for planning purposes. It has however, been found that while they provide a firm basis on which to give advice, inspection of individual proposed development sites is required in most cases along the coast. Inspections are carried out by geologists of the Geological Survey of Victoria at the request of the Shire of Otway or the Ministry for Planning and Environment.

One of the problems which is becomming increasingly apparent is the determination of whether or not the current climate regime is typical or atypical for the area; a related matter is the age of the major landslides. Geological and geomorphological studies of a lake system in Victoria indicate that the last 100 years is, indeed, atypically dry and that lake levels prior to this time were substantially higher. If this is the case, the "abnormal" 1951 - 1953 rainfall pattern may be the more appropriate one on which to base recommendations. At that time the low intensity rural development in the area meant that the damage, although locally very significant, was not a disaster. However, nowadays there are pressures to develop areas which, if the 1951 - 1953 conditions return would result in considerable losses.

8. GREAT OCEAN ROAD, APOLLO BAY TO ANGLESEA

8.1 History and Construction

The Great Ocean Road was built during the economic depression of the late 1920's and early 1930's as one of the Government employment schemes. Many of the men who worked on the road construction were returned soldiers from the Great War (1914 - 1918), and many of the place names along the road reflect this association. The road was opened in 1932.

8.2 Geology and Stability

The Great Ocean Road from Apollo Bay through Lorne to Eastern View is formed as a bench cut into Lower Cretaceous sandstone and mudstone beds of the Otway Group. These rocks are well-bedded and jointed. The bedding planes commonly dip seaward at about 40° and are not particularly well cemented. Intersecting joints are commonly uncemented. The sandstone as a material is intrinsically strong but the siltstone is structurally weak, crumbles easily and where weathered, breaks down into clay.

It is therefore not surprising that with the bedding dipping down out of the high cuttings frequently necessary on the landward side of the road, sliding failures are common. Such failures are mostly isolated blocks and fragments of rock, but on occassions, particularly after prolonged heavy rain, they can be more serious and may even block the road. Saftey measures such as steel mesh attached to rock bolts and barrier walls have not been constructed. This is probably because rock falls are still relatively uncommon and resulting accidents are rare. The danger remains, however.

8.3 Windy Point Rockslide

At Windy Point and its vicinity the rock structure is potentially one of the least stable along this coast. The factors that combine to cause this are: the seaward (southerly) dip of about 27°; the two prominent and persistent sets of near-vertical joints that intersect at approximately 90° in plan; the presence of at least two thin (12 cm and 40 cm) silty clay beds that underlie the massive beds of sandstone and intersect the lower part of the the steep natural slope near road level; numerous minor joints at various angles; surface fissures and craters that resulted from slide movement; and the substantial winter and spring rainfall.

The Windy Point rockslide commenced when a relatively minor quantities of rock were removed during road construction in late 1968. Several rock slides that occurred after 1968 were treated by pushing the fallen rock off the seaward side of the road. During this period, evidence of larger scale movement was observed on the slope to elevations of 30 to 40, and later, 70 m above the road. During 1970 and 1971 the rate of movement increased to a maximum of 2 cm per day, and a mass of 3000 tonnes of rock began sliding towards the road.

The condition of the slide at that time involved up to 150,000 tonnes of sandstone, consisting of large and small discrete blocks, moving down dip on silty clay slip planes; some shear failure in the sandstone; major fissures and joints were opening to depths exceeding 15 m; and the surface soil was extensively fissured (Fig 13).

The Great Ocean Road was closed in July 1971. A cable anchoring system was prepared and the contractor commenced work in September. Movement ceased soon after the first 7 anchors were tensioned in October, notwithstanding the heavy rain at the time. The road was re-opened in December 1971.

8.4 Eastern View to Anglesea

Slope stability problems in the road cuts ease in this section of the road. At Eastern View, the gravels, sands, clays and minor brown coal beds of the Eastern View Formation (Palaeocene) unconformably overlie the Lower Cretaceous rocks. Within about 5 km further east, the Eastern View Formation is in turn overlain conformably by the Demon's Bluff Formation (Eocene - Lower Oligocene), comprising fossiliferous clays and sands, carbonaceous in part and commonly stained and partly cemented by non oxide minerals; this formation continues to Anglesea.

8.5 Point Roadknight (Melba Parade) Landslide, Anglesea

This major cliff failure occurs on the coast approximately 500 m north of Point Roadknight. It is about 300 m wide and threatens a residential street named Melba Parade.

The geological material present are two parts of the Eocene - Lower Oligocene Demon's Bluff Formation which shows a gentle seaward dip of approximately 6° - 9° (Fig 14).

Slope failure has been caused by sliding along the contact between the two parts of the formation:

. a yellowish green slippery bentonic clay containing fragments of decomposed basalt and pieces of mudstone (weathered ashes and agglomerate) known as the "Soapy Rocks" forms the lower unit and on its upper surface sliding has occurred.

. reddish brown cohesive clayey sands and very stiff sandy clays have failed by a mechanism of sliding on the shearing surface beneath, assisted by toppling along sub-vertical joints and probably some rotational failure. The failed material has flowed towards the coast, with an irregular hummocky surface.

The impermeable clay of the Soapy Rocks forms a barrier to the downward percolating water, thereby maintaining saturated conditions in the clayey sands/sandy clays overlying them. The resulting high pore water pressures lower internal friction and reduce shear strength have helped to mobilise the clayey sands/sandy clays on the failure surface of the Soapy Rocks and led to their internal failure by secondary shears and toppling with final flowage.

Remedies proposed 14 years ago were:
i) a sea barrier to prevent constant removal of flowed material from the toe of the flow zone.
ii) drainage of the flowage zone, assisted by tree planting and
iii) drainage behind the slip face.

Measure (i) has been taken, (ii) has been done in part and (iii) has not been attempted.

The flowage of material has been slowed considerably and recession of the cliffs appears to have been halted, though probably only temporarily. Slow sliding at reduced velocity is still in operation.

9. MELBOURNE

Situated at the mouth of the Yarra River on the northern shore of Port Phillip Bay, Melbourne has grown from a town of fewer than 30,000 people in 1851, to a major metropolis of approximately 3 million in the 1980's.

Until the beginning of the 1970's Melbourne's growth was rapid and continuous, but more recently the growth has slowed. However, over 70% of Victoria's population lives in Melbourne.

In order to rationalise development and prevent desecration of the countryside, the Melbourne and Metropolitan Board of Works (MMBW) was granted powers over the planning of Melbourne in 1949. Using established corridors, this body attempted to guide the growth of the city by the establishment of preferred development areas.

These notes were compiled from:

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Neilson, JL	Geol. Surv. Vict. Unpub. Repts.
Wood, PD	Geol. Surv. Vict. Unpub. Repts.
Duncan, S (ed.)	Atlas of Victoria.
McAndrew & Marsden	Regional guide to Victorian Geology

These notes were compiled by:
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Werribee
Mt. Cotteril
Melbourne
Brisbane Ra.
The Anakies
You Yangs
Geelong
0 10
miles
N
Stawell
Maryborough
Castlemaine
Kyneton
Daylesford
Beaufort
Gisborne
Ballarat
Skipton
Bacchus Marsh
Hamilton
Penshurst
Hopkins
MELBOURNE
Werribee
Portmoor
PORT PHILLIP
BAY
Mortlake
Geelong
Heywood
Camperdown
Terang
Point Lonsdale
Colac
Portland
Cape Nelson
Port Fairy
Warrnambool
Timboon
Lorne
Port Campbell
Cape Otway
Quaternary
Sediments
Newer Volcanic
Tertiary
Sediments (marine and non marine)
Older Volcanic
Mesozoic
Arkose, sandstones and mudstones
Upper Palaeozoic
Glacial sediments, sandstones rhyolites etc
Lower Palaeozoic
Metamorphics, slates and sandstones
Granitic rocks
SCALE OF MILES
0 10 20 30 40
BASS
STRAIT
38°
141°
142°
143°
144°
145°
Prepared by Department of Mines, Victoria

FIG. 1

CORIO BAY
GEELONG
BARRABOOL HILLS
BARWON R.
L. CONNEWARRE
L. MURDEDUKE
WINCHELSEA
MT. GELLIBRAND
L. CORANGAMITE
WARRION HILL
L. COLAC
COLAC
BIRREGURRA
MT. NOORAT
L. COLONGULAC
L. GNOTUK
CAMPERDOWN
MT. LEURA
L. KEILAMBETE
TERANG
MT. EMU CK.
L. BULLENMERRI
MT. EWEN
L. PURRUMBETE
MT. PORNDON
COBDEN
SCOTT'S CK.
CURDIE'S R.
TIMBOON
TOPAHAWK CK.
KAWARREN
GELLIBRAND
FORREST
DEAN'S MARSH
BARWON R.
TURQUAY
ANGLESEA
PT. ADDIS
PT. ROADKNIGHT
EASTERN VIEW
AIREY'S INLET
LORNE
CUMBERLAND R.
GELLIBRAND R.
BARONGAROOK
MT. SABINE
WYE R.
C. PATTON
BEECH FOREST
LAVER'S HILL
PETERBOROUGH
PORT CAMPBELL
FERGUSON HILL
PT. HESSE
PRINCETOWN
GELLIBRAND R.
JOHANNA R.
AIRE R.
BARHAM R.
SKENES CK.
APOLLO BAY
MOONLIGHT HD.
ROTTEN PT.
PARKER R.
C. OTWAY
0
5
10
MILES
QUATERNARY
QUATERNARY NEWER VOLCANICS
PLIOCENE NEWER VOLCANICS
OLIGOCENE - MIOCENE
OLDER VOLCANICS
PALEOCENE - EOCENE
MESOZOIC
CAMBRIAN

FIG. 2

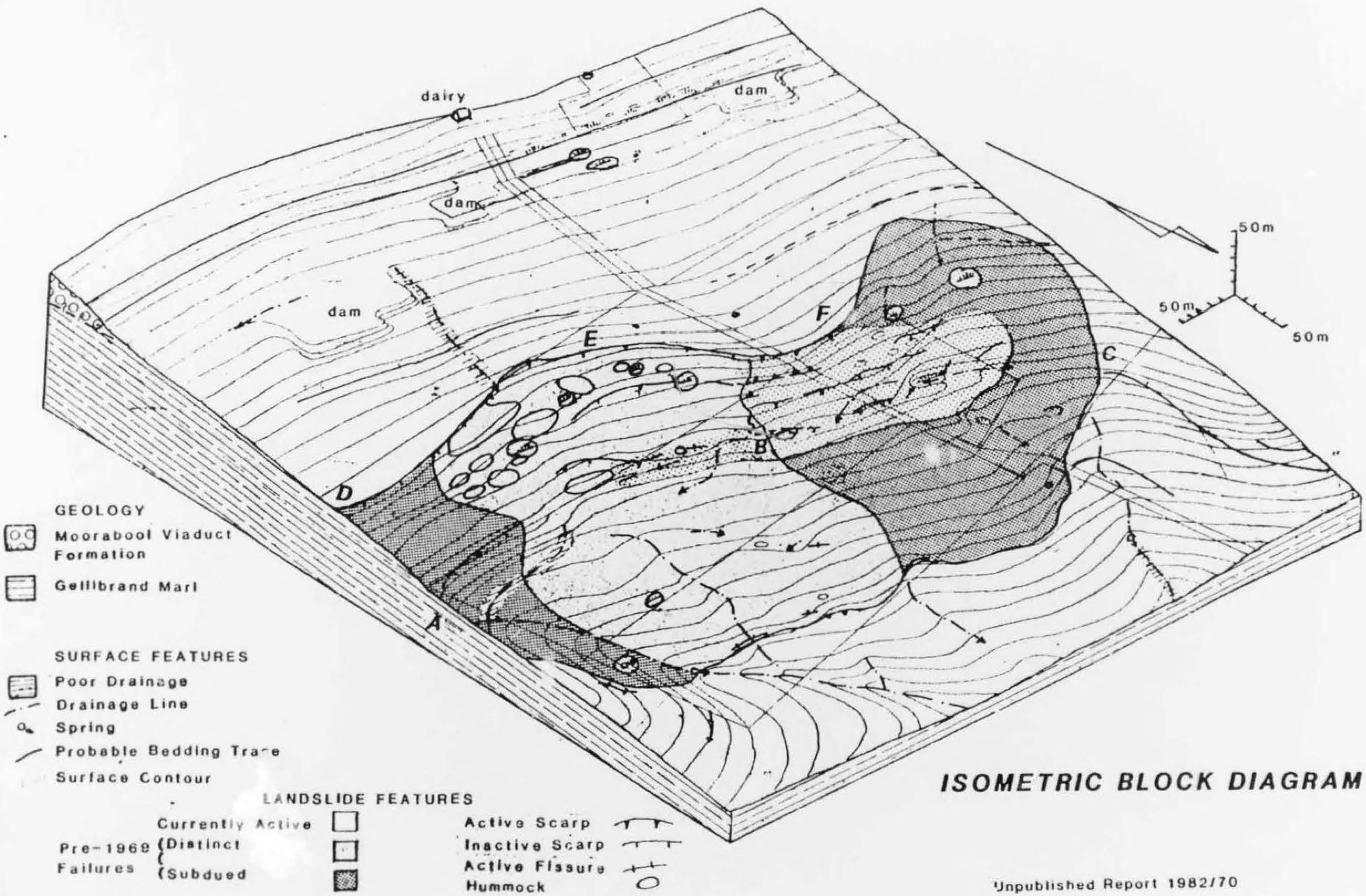
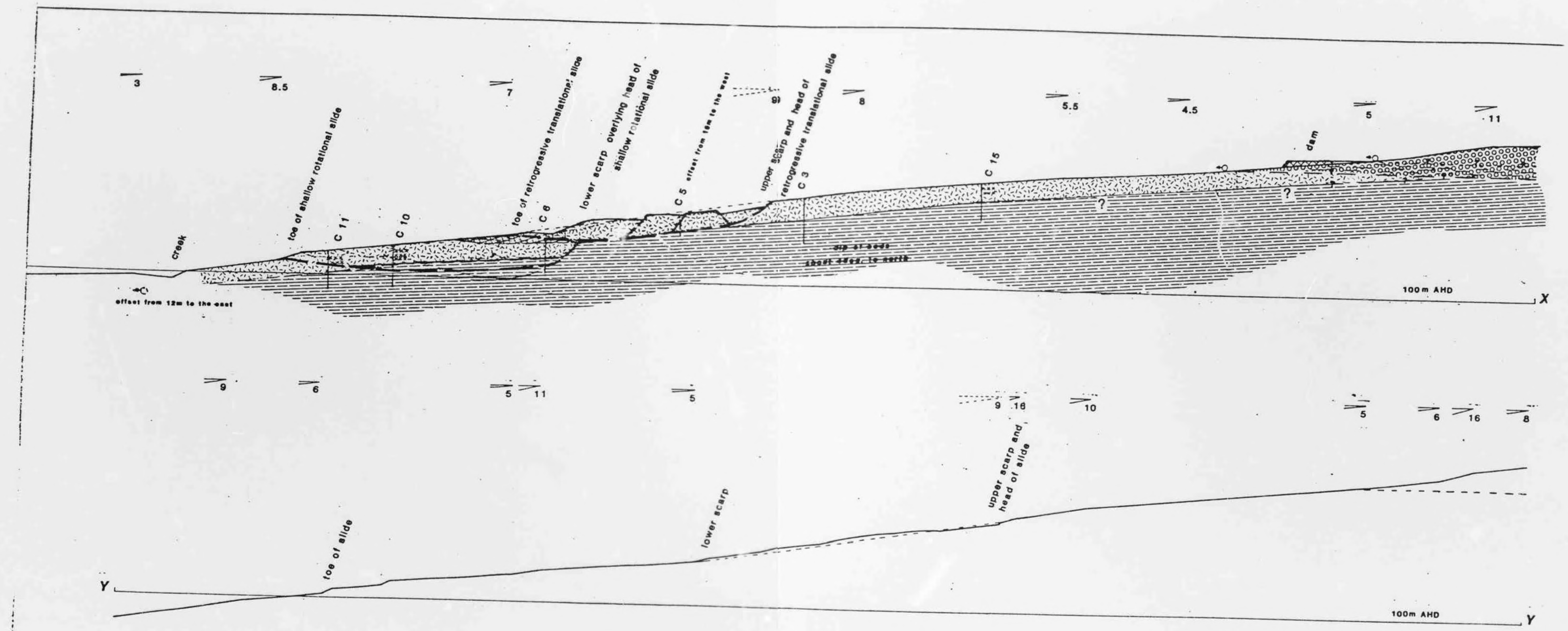

dairy
dam
dam
dam
50m
50m
50m
A
B
C
D
E
F
GEOLOGY
Moorabool Viaduct Formation
Gellibrand Marl
SURFACE FEATURES
Poor Drainage
Drainage Line
Spring
Probable Bedding Trace
Surface Contour
LANDSLIDE FEATURES
Currently Active
Pre-1969 Failures (Distinct
(Subdued
Active Scarp
Inactive Scarp
Active Fissure
Hummock
ISOMETRIC BLOCK DIAGRAM
Unpublished Report 1982/70

FIG. 3

36516

17



GEOLOGICAL SURVEY OF VICTORIA

Drill Hole -'C': Corrlejong

Fissures

Spring

Hillslope in degrees

Inferred slip plane

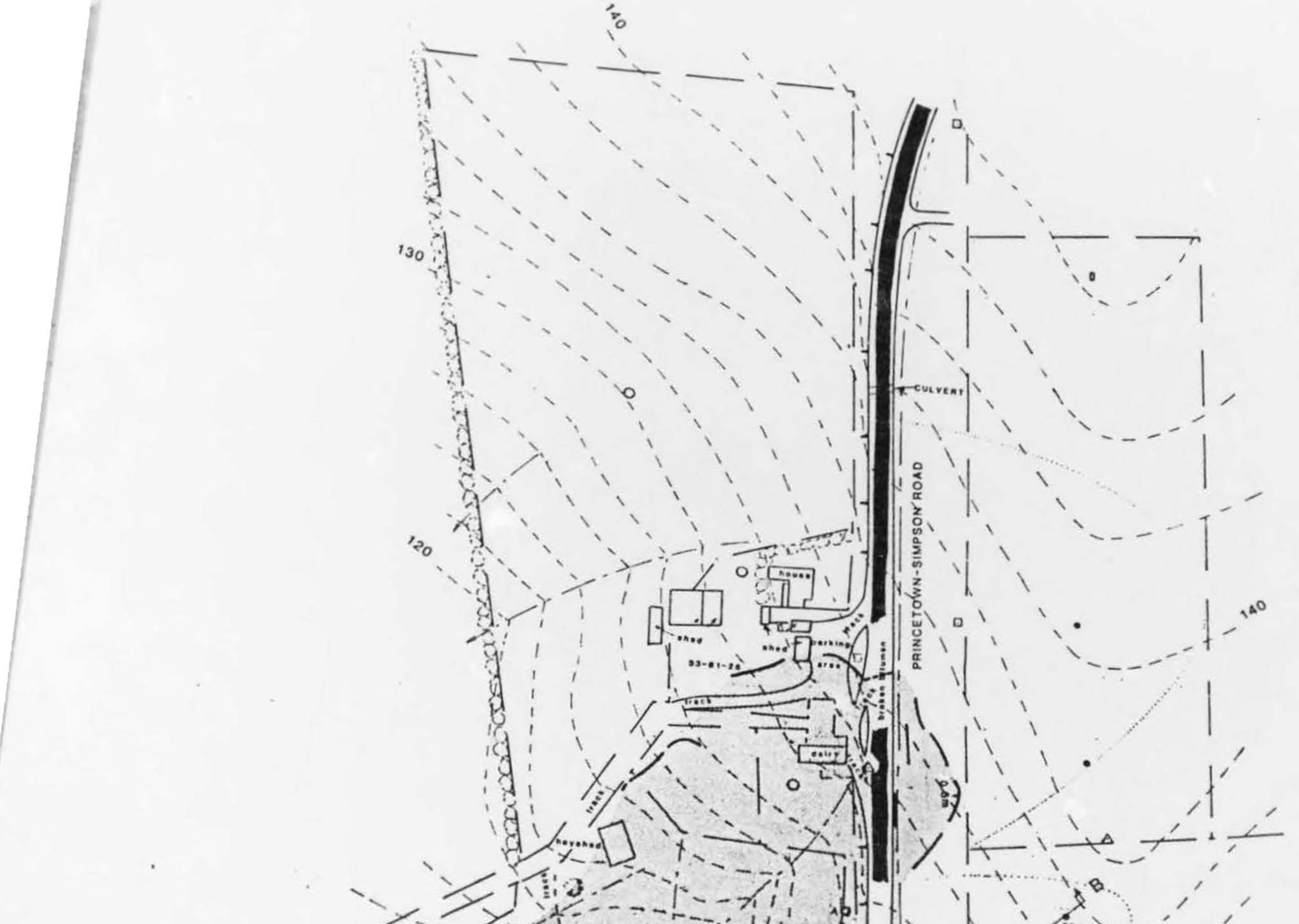
Fill — sand, sandy clay, sandstone fragments, [illegible]onal charcoal fragments - *CL soil*

Moorabool Viaduct Formation — ferruginous sandstone and gritty sandstone.

Gellibrand Marl — weathered clay - generally calcareous yellow clay:frequent carbonate nodules and powdery patches - *CH soil*

unweathered clay - interbedded calcareous black and olive grey clays and silty clays, some sandy silts and clays, minor sand lenses, highly fossiliferous - *CH soil*

FIG. 4



PRINCETOWN-SIMPSON ROAD
CULVERT
DESTROYED CULVERT
CULVERT
house
shed
shed
parking area
dairy
hayshed
track
old road
broken bitumen
33-81-28
140
130
120
110
90
90
100
110
120
140
130

FIG. 5a

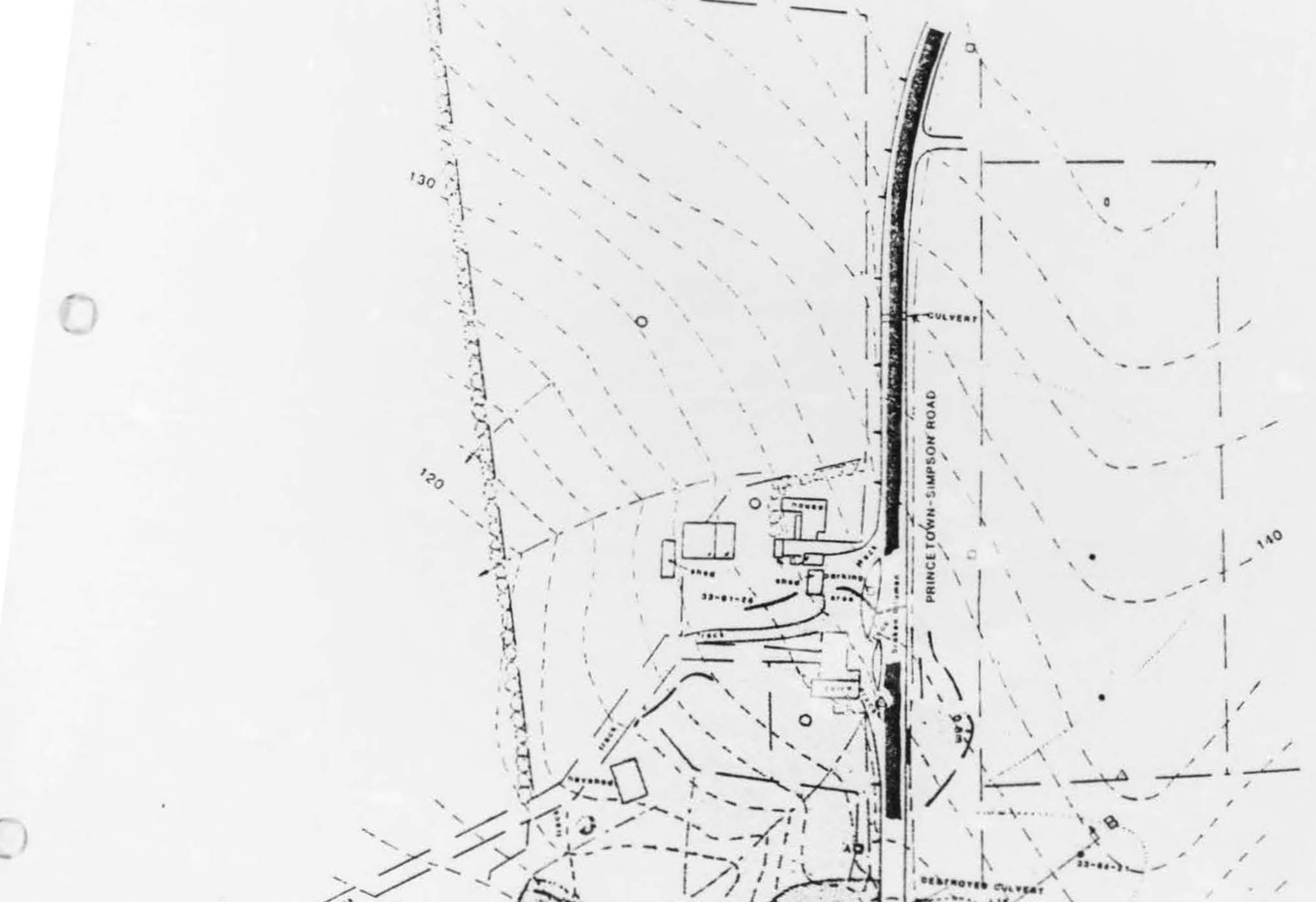
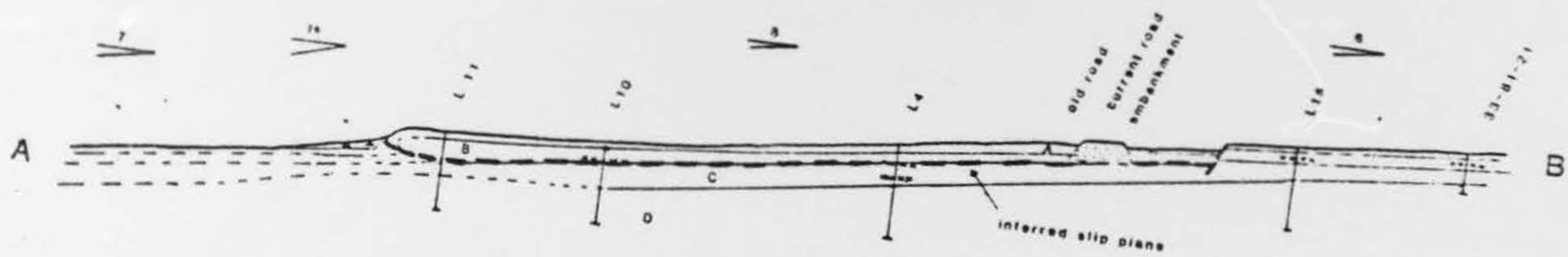

PRINCETOWN-SIMPSON ROAD
CULVERT
DESTROYED CULVERT
CULVERT
140
130
120
110
100
90
90
140
130
120
110
100

FIG. 5a

CROSS SECTION



SOIL PROFILE
- A Noncalcareous clay
- B Calcareous clay with powdery carbonate patches
- C Calcareous clay without powdery carbonate patches

BASE OF WEATHERING
- D Calcareous clay and silty clay

25 Hill slope in degrees

Fissures

FIG. 5b

GEOLOGICAL SURVEY OF ICTORIA

LANDSLIDE MAP

0 100 m

contour interval 2m

LEVEL DATUM-AHD

Surveyed by R F Fox assisted by A M Cooney and and R L Luxmoore

Drawn by A M Cooney Unpublished Report No. 82/114

Corrections 26/11/84

GENERAL SURFACE FEATURES

- Fence
- Concrete water tank
- Water trough
- SEC pole
- Survey Station
- A Monitoring Station
- Drill Hole — 33-&1-28 - field number; L9 (Latrobe 9) - registered number
- Surface Drainage
- Area of Poor Drainage
- Trees
- Embankment
- Cutting

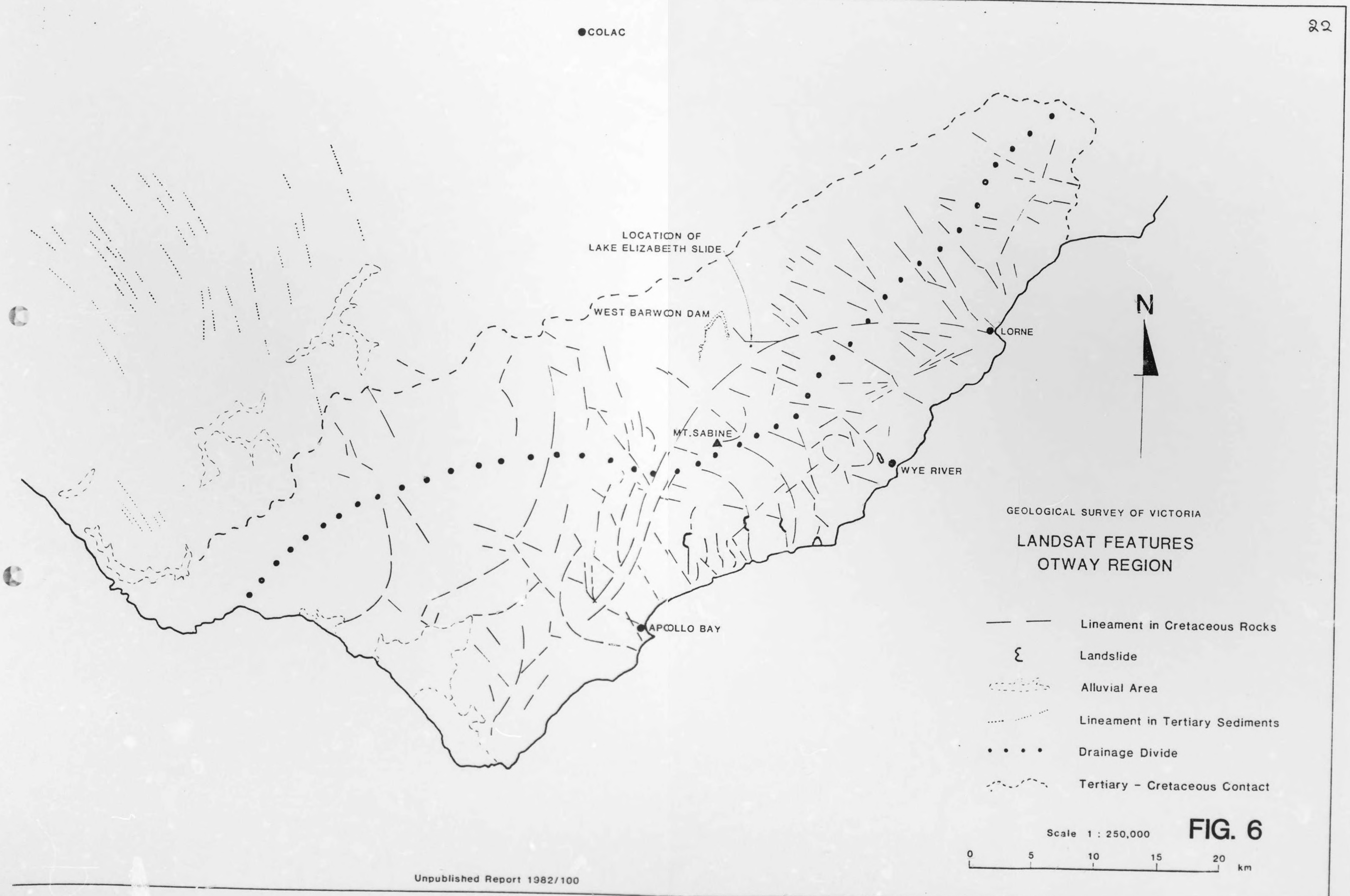
LANDSLIDE FEATURES

- Major Fissure
- 0.3m Scarp - barb to downthrown side with magnitude shown in metres
- Landslide Area
- Area with substantially finely fissured ground surface
- Faint aerial photograph pattern which may be due to an ancien

CROSS SECTION LINE

A B

FIG. 5c



GEOLOGICAL SURVEY OF VICTORIA

LANDSAT FEATURES
OTWAY REGION

FIG. 6

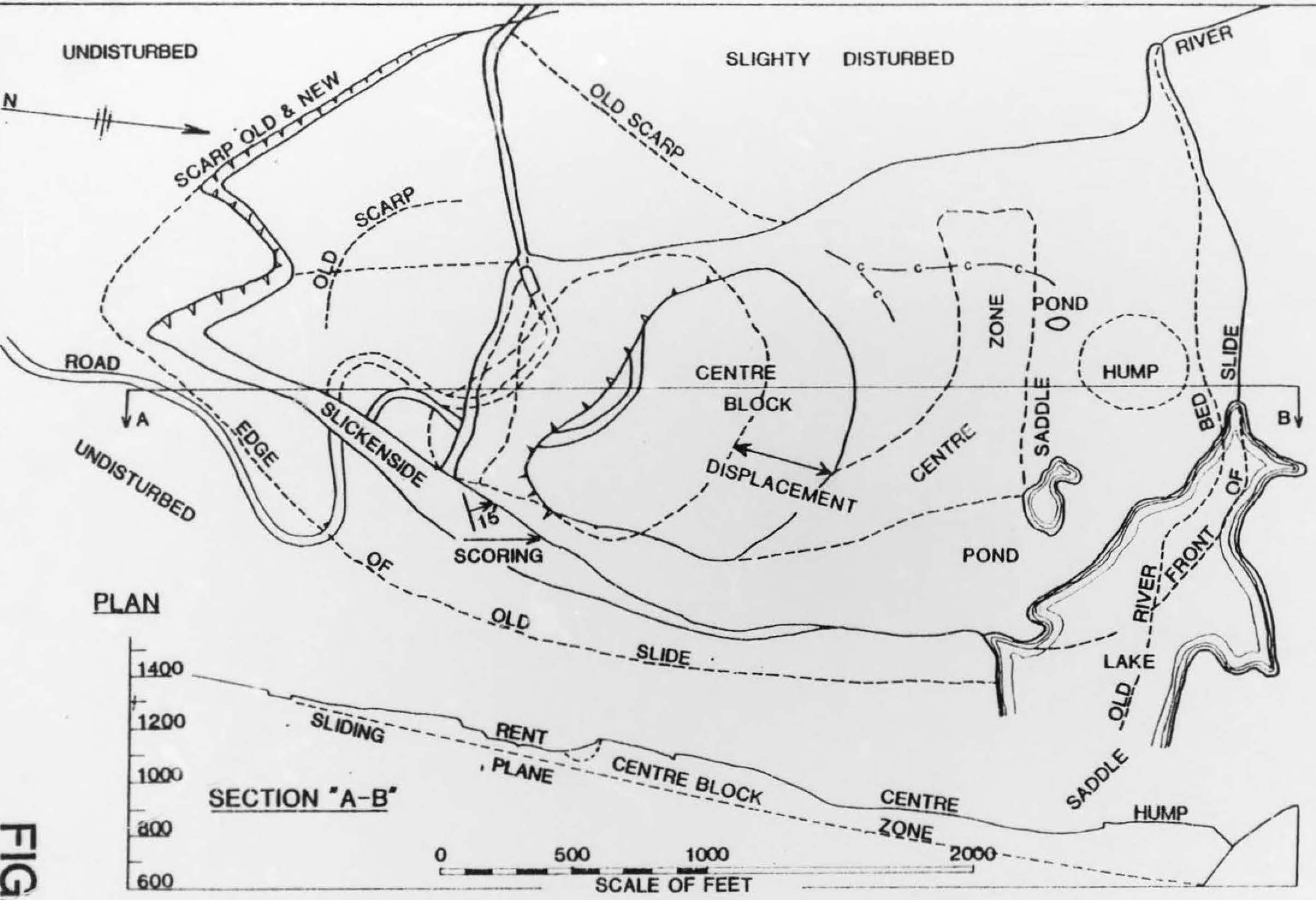
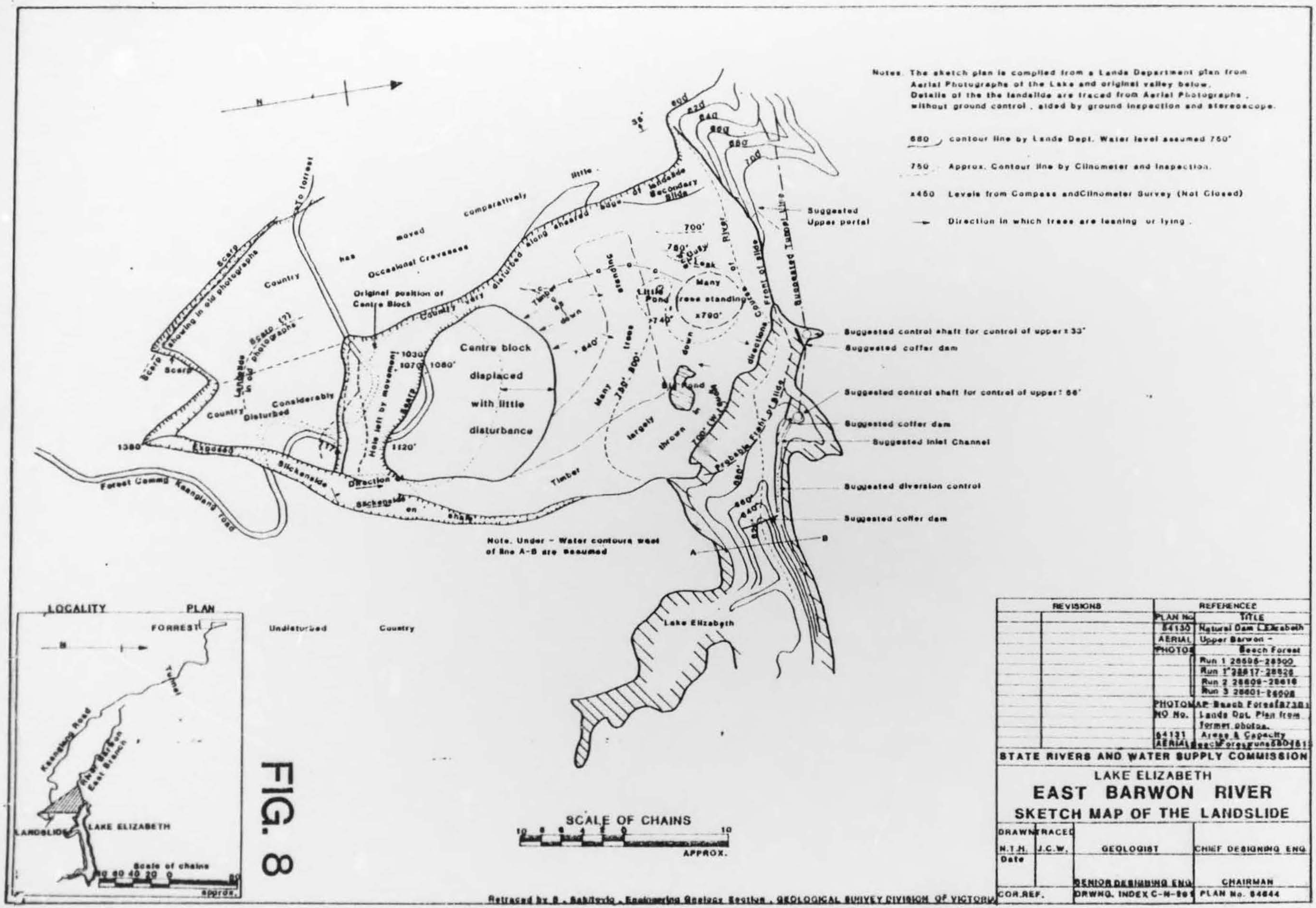


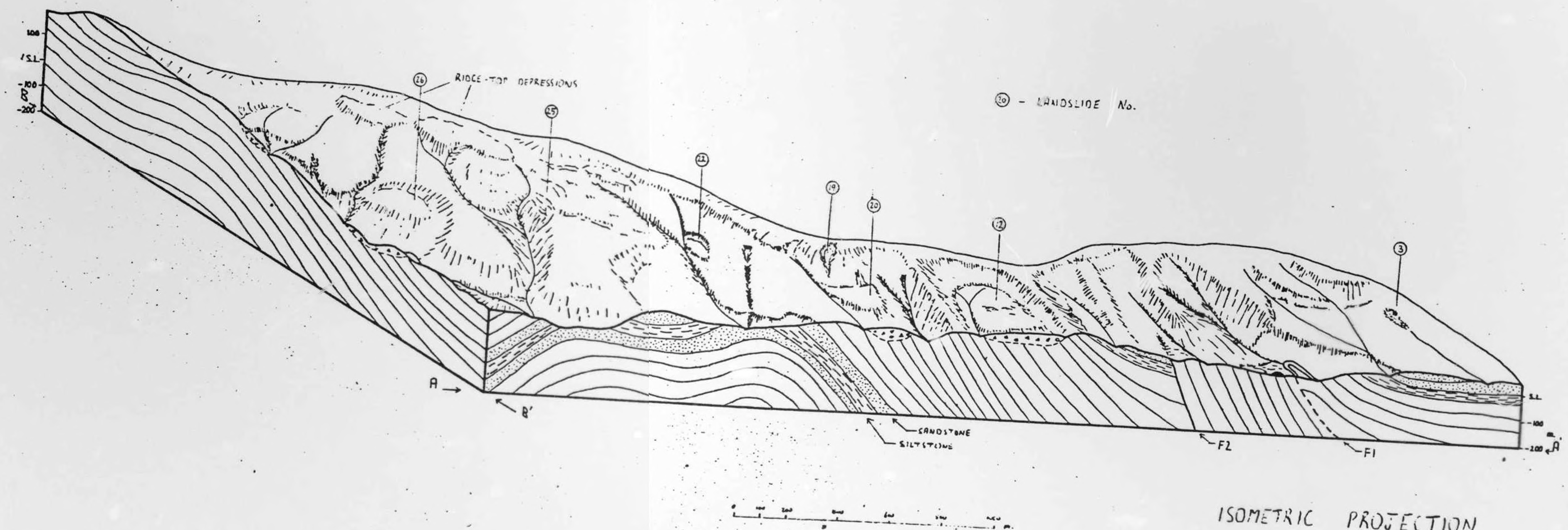
FIG. 7

LANDSLIDE ON THE EAST BARWON RIVER 1952



Notes. The sketch plan is compiled from a Lands Department plan from Aerial Photographs of the Lake and original valley below.
Details of the the landslide are traced from Aerial Photographs, without ground control, aided by ground inspection and stereoscope.
680 contour line by Lands Dept. Water level assumed 750'
750 Approx. Contour line by Clinometer and Inspection.
x450 Levels from Compass and Clinometer Survey (Not Closed)
Direction in which trees are leaning or lying.
N
Suggested Upper portal
Suggested Tunnel Line
Suggested control shaft for control of upper ± 33'
Suggested coffer dam
Suggested control shaft for control of upper ± 66'
Suggested coffer dam
Suggested Inlet Channel
Suggested diversion control
Suggested coffer dam
Country has moved comparatively little
Occasional Crevasses
Original position of Centre Block
Centre block displaced with little disturbance
Considerably Disturbed Country
Hole left by movement
Many trees standing
Little Pond
Big Pond
Many trees 780'-800'
largely thrown down
Probable Front of Slide
Course of River
Front of Slide
Slickenside
Forest Commn Kaanglang Road
To Forrest
Scarp showing in old photographs
Note. Under - Water contours west of line A-B are assumed
Lake Elizabeth
Undisturbed Country
LOCALITY PLAN
FORREST
Tunnel
Kaanglang Road
River Barwon East Branch
LANDSLIDE
LAKE ELIZABETH
Scale of chains
approx.
SCALE OF CHAINS
APPROX.
REVISIONS
REFERENCES
PLAN No. TITLE
54130 Natural Dam L. Elizabeth
AERIAL PHOTOS Upper Barwon - Beech Forest
STATE RIVERS AND WATER SUPPLY COMMISSION
LAKE ELIZABETH
EAST BARWON RIVER
SKETCH MAP OF THE LANDSLIDE
DRAWN TRACED
N.T.H. J.C.W.
GEOLOGIST
CHIEF DESIGNING ENG.
SENIOR DESIGNING ENG.
CHAIRMAN
COR.REF.
PLAN No. 54644
Retraced by B. Sabitovic, Engineering Geology Section, GEOLOGICAL SURVEY DIVISION OF VICTORIA

FIG. 8



ISOMETRIC PROJECTION

Unpublished Report 1982/85

FIG. 9

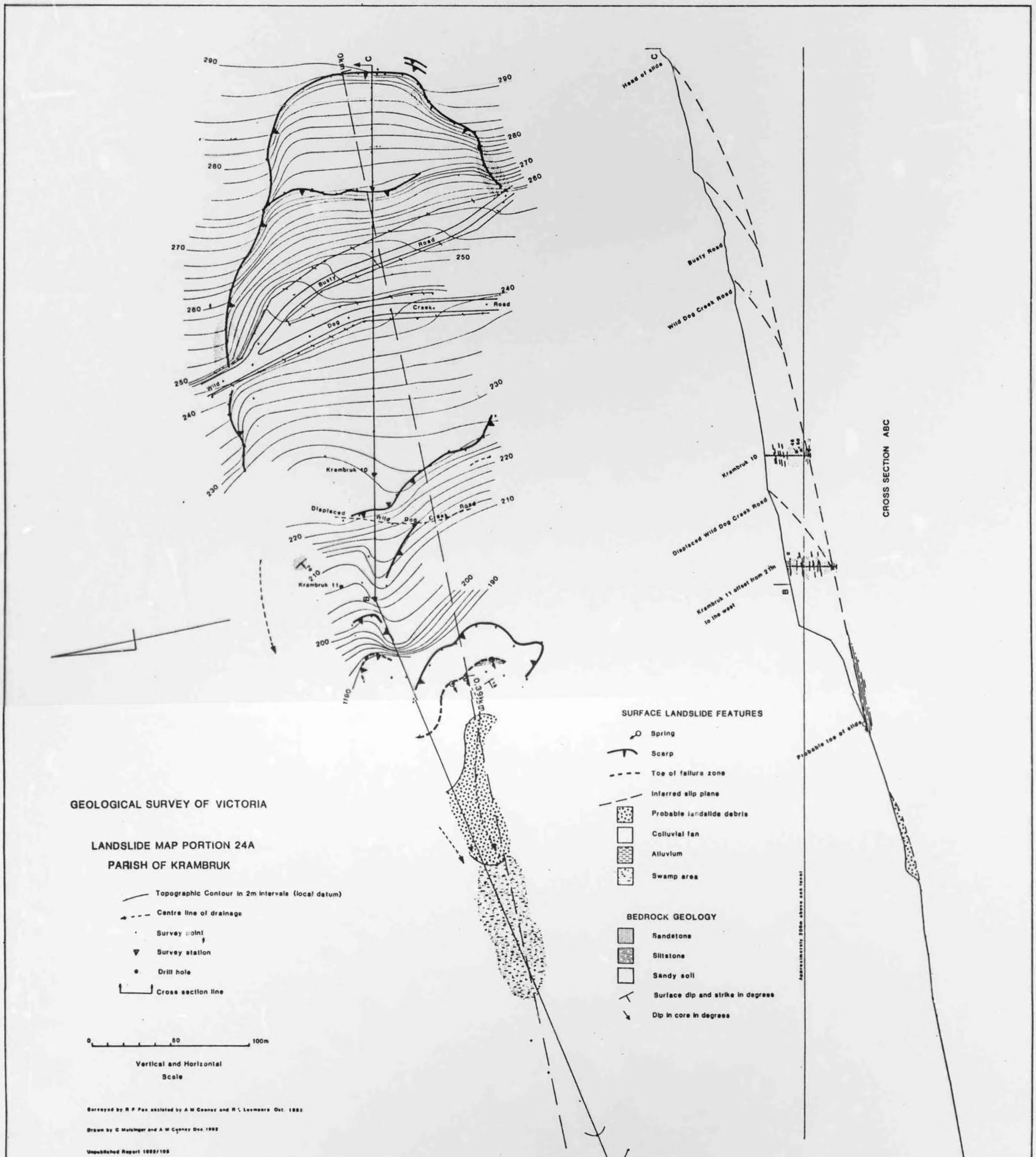

GEOLOGICAL SURVEY OF VICTORIA
LANDSLIDE MAP PORTION 24A
PARISH OF KRAMBRUK
Topographic Contour in 2m intervals (local datum)
Centre line of drainage
Survey point
Survey station
Drill hole
Cross section line
Vertical and Horizontal Scale
SURFACE LANDSLIDE FEATURES
Spring
Scarp
Toe of failure zone
Inferred slip plane
Probable landslide debris
Colluvial fan
Alluvium
Swamp area
BEDROCK GEOLOGY
Sandstone
Siltstone
Sandy soil
Surface dip and strike in degrees
Dip in core in degrees
CROSS SECTION ABC
Head of slide
Busty Road
Wild Dog Creek Road
Krambruk 10
Displaced Wild Dog Creek Road
Krambruk 11 offset from 21m to the west
Probable toe of slide
Wild Dog Creek
CROSS SECTION DE
Wild Dog Creek

FIG. 10

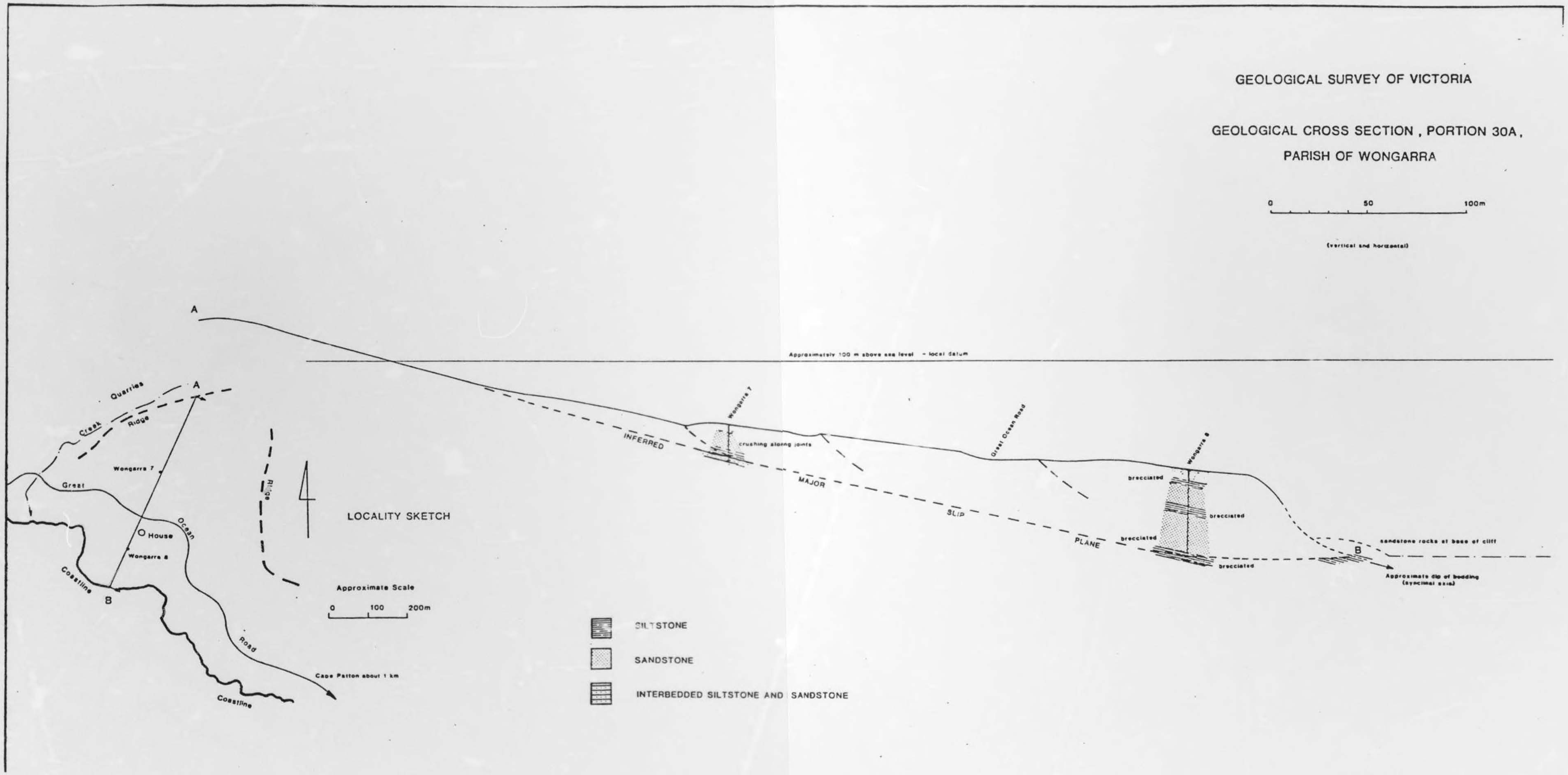
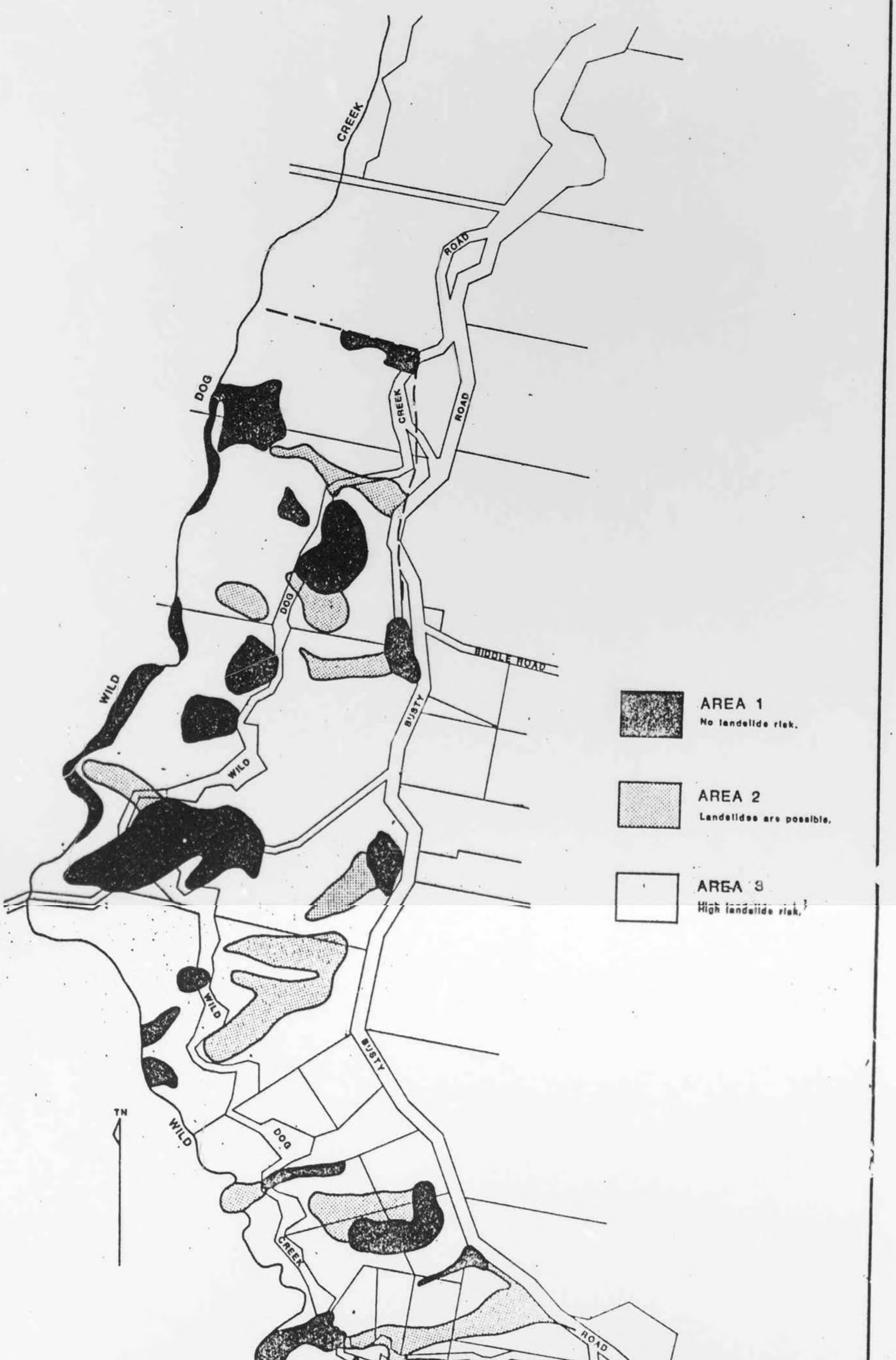

GEOLOGICAL SURVEY OF VICTORIA
GEOLOGICAL CROSS SECTION, PORTION 30A, PARISH OF WONGARRA
0
50
100m
(vertical and horizontal)
A
Approximately 100 m above sea level - local datum
Wongarra 7
crushing along joints
INFERRED
MAJOR
SLIP
PLANE
Great Ocean Road
Wongarra 8
brecciated
brecciated
brecciated
brecciated
sandstone rocks at base of cliff
B
Approximate dip of bedding (synclinal axis)
Quarries
Creek
Ridge
A
Wongarra 7
Great
Ocean
Road
House
Wongarra 8
Coastline
B
Ridge
LOCALITY SKETCH
Approximate Scale
0
100
200m
Cape Patton about 1 km
Coastline
SILTSTONE
SANDSTONE
INTERBEDDED SILTSTONE AND SANDSTONE

FIG. 11



GEOLOGICAL SURVEY OF VICTORIA

WILD DOG CREEK
LANDSLIDE RISK ZONATION

FIG. 12

Mapped by P. D. Wood.

Drawn by A. E. Webster. Dec 1982. Unpublished Report 1982/105

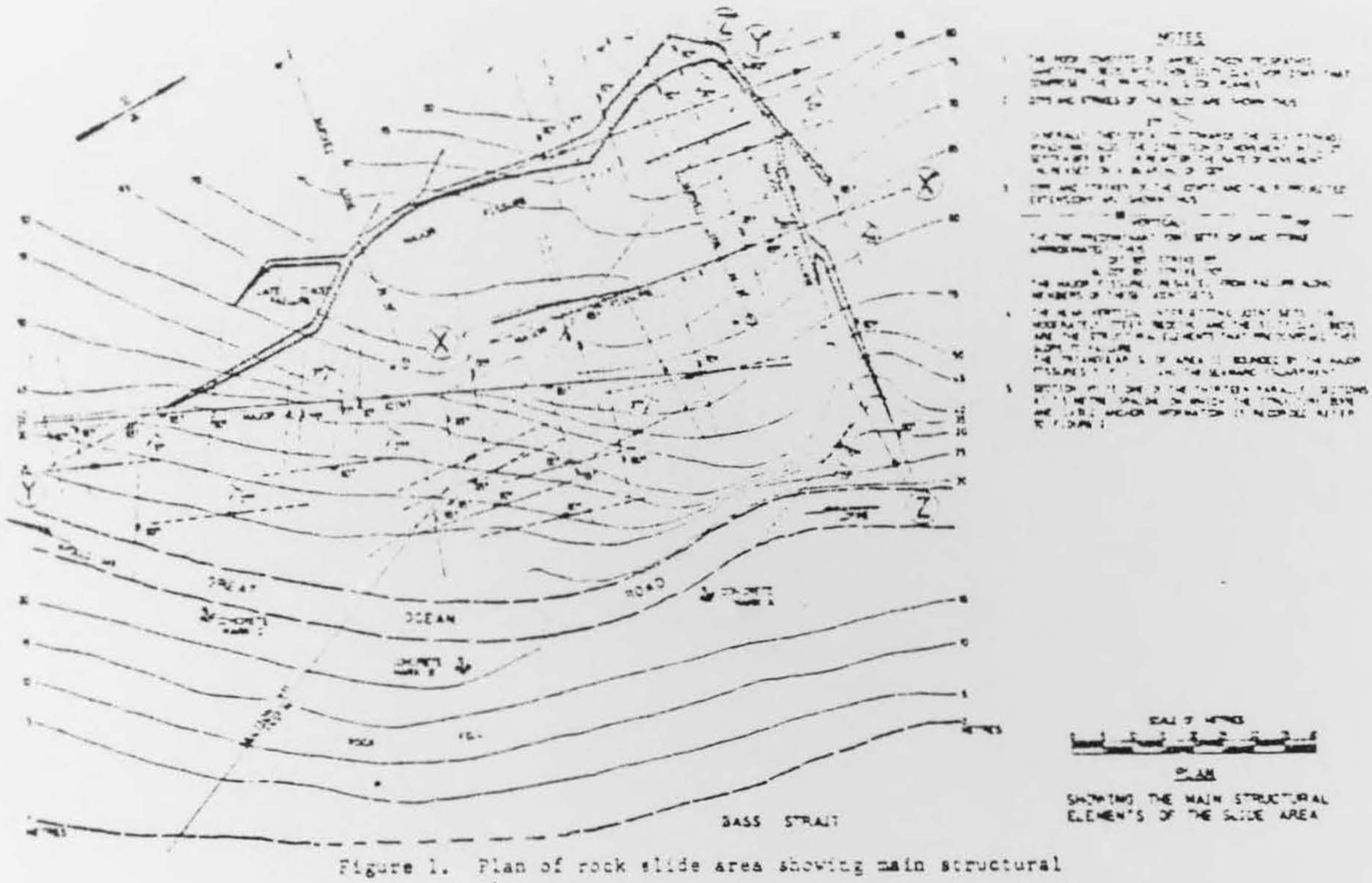


Figure 1. Plan of rock slide area showing main structural elements.

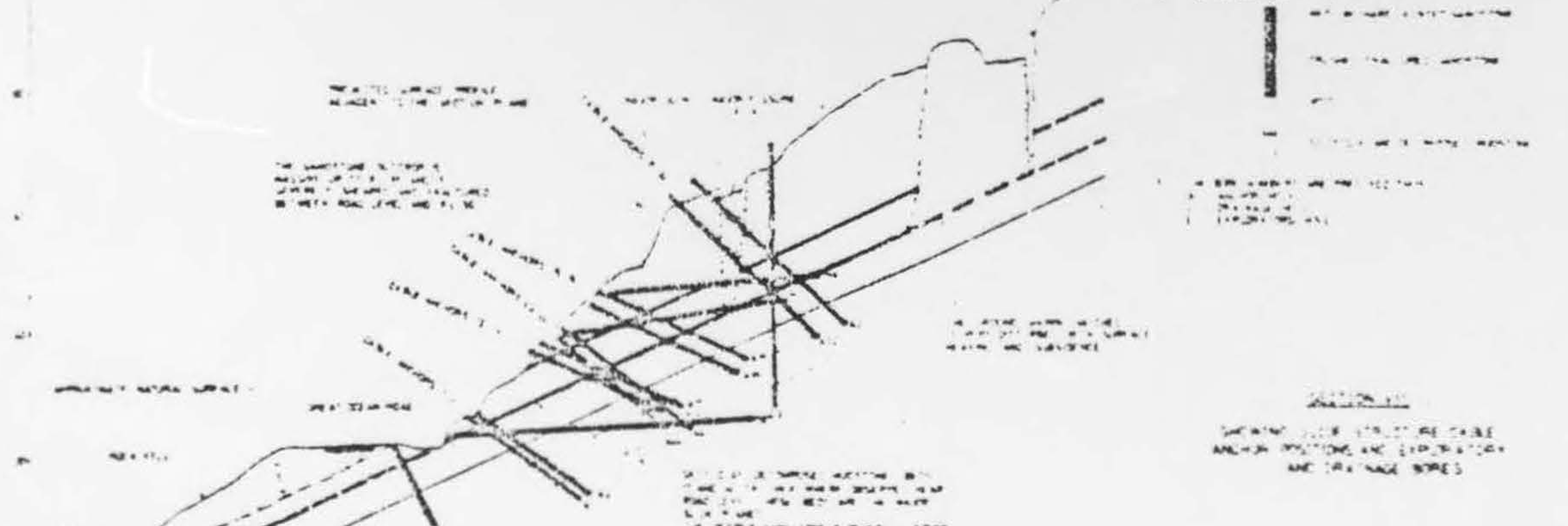


FIG. 13

Figure 2. Vertical profile of rock slide showing slide masses and anchor positions near centre of slide.

Landslide at Point Roadknight, Anglesea

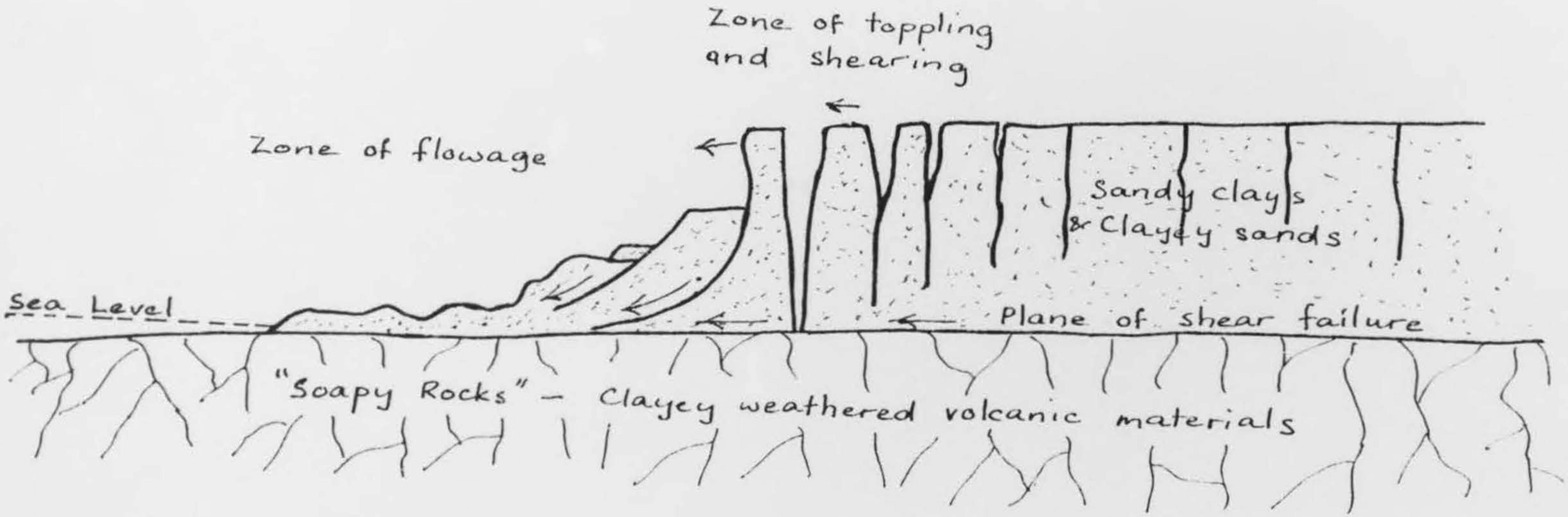


FIG. 14

S T A R T

ITR

1987/38

Geological Survey of Victoria

ANZ Slide '87

Field workshop on Landslides
Victorian Section
August 4 - 5, 1987

P G Dahlhaus
A M Cooney
J L Neilson

Unpublished Report 1987/38

COPY 2

P.G. DAHLHAUS, A.M. COONEY,
J.L. NEILSON

DEPARTMENT OF INDUSTRY, TECHNOLOGY AND RESOURCES

ANZ Slide '87

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1 MELBOURNE TO PORT CAMPBELL

From Melbourne Airport the route follows the Tullamarine Freeway south to the western edge of the City of Melbourne before joining the Princes Highway to Geelong.

1.1 Melbourne to Geelong

Between Melbourne Airport and Geelong the route crosses a volcanic landscape known as the Werribee Plains, comprising a Plio-Pleistocene sheet of basaltic materials that extends westwards almost to the South Australian border (Fig 1). The Werribee Plains are mainly underlain by extensive sheet flows of basaltic lava with some beds of ash and other pyroclastics. A few eruption points rise above the Werribee Plains as mounds, including Mt Cottrell (a lava cone) near Melbourne, and the Anakies (three scoria cones) near Geelong. The Princes Highway crosses a number of basalt tongue flows with their distinctive topography: these rest on the prevalent sheet flows and can be traced to eruption points. The volcanic materials of the Werribee Plains are quite commonly veneered with a reddish brown loess-like material.

The western limit of the Werribee Plains is marked by the prominent Rowsley Fault Scarp. To the south this becomes a monocline with the basalt warped across it; elsewhere the feature is marked by scoria cones (the Anakies). The largest and by far the highest group of hills present are the You Yangs, a residual of Devonian granite which projects sharply through the basalt plains.

Halfway to Geelong the highway crosses the alluvium of the Werribee Delta, here about ten kilometres across. The river has cut into the delta sediments, forming terraces and vertical cliffs.

Geelong is the major port on Corio Bay, which was partly formed by down faulting. Tertiary calcareous clays underlie basalt along its western shore. Both the Barwon and Moorabool Rivers have cut deeply into the basalt flows, to expose the Tertiary sedimentary rocks. Both ancient and still-developing river terraces occur along the valleys.

Last century, the open volcanic plains quickly attracted pioneering pastoralists who used Geelong as the port to export their wool. When gold was discovered at Ballarat in 1851, both the commerce and the population of Geelong leapt as it became a favoured port of entry for the diggings. By 1854, Geelong's population of 23,000 made it Australia's third largest town. Today with a population of approximately 140,000 it is an important industrial and commercial centre. Major industries include cement manufacture, aluminium smelting, automotive manufacturing and oil refining.

1.2 Geelong to Port Campbell

The Princes Highway crosses sub-basaltic Tertiary limestones and other sedimentary materials outcropping along the eastern margin of the Otway Basin and then the lower slopes of the Cretaceous sediments forming the Barrabool Hills to the north. From there, the route follows the southern edge of the volcanic plains to Colac.

The southern skyline is formed by a low, broad range - the Otway Range - with a maximum elevation of 670 m. Lower Cretaceous sediments - the Otway Group - comprising lithic sandstones and siltstone underlie the range (Fig. 2). Fringing foothils and flats are underlain by Tertiary sediments including the Wangerrip Group and Nirranda Group (Palaeocene - Eocene) and the Heytesbury Group (Oligiocene - Miocene). The base of the sequence includes various sandy units such as the Dilwyn Formation as well as some fine grained units. Calcareous sediments are more common higher in the sequence and the Heytesbury Group includes the Gellibrand Marl comprising interbedded calcareous clays and silts with very minor clayey sand. This formation is covered with a sand unit, the Moorabool Viaduct Formation, or a limestone unit, The Port Campbell Limestone.

Although landslides occur in all units, they are most frequent in the Otway and Heytesbury Groups. A summary of relationships is as follows:

Geological Group	Typical failure types	Slopes (°)	Lithology
Heytesbury	Earth flow	9.5-16.5	Calcareous clay & silt
Nirranda	Earth block	14	Calcareous clay & silt
Wangerrip	Earth slump	19.5+	Sand & silt
Otway	Complex slump, Earth flow, topple	22-37	Lithic sandstone & siltstone

From Colac the journey leaves the Princes Highway and the volcanic plains, and crosses south-west over the Tertiary sediments of the Otway Basin. These sediments mostly comprise limestone, calcareous clay, clay and silt which make up the Heytesbury Group. One of the formations in this group is the Gellibrand Marl which comprise interbedded black clays and dark olive green silts, both highly fossiliferous; these are mottled yellow, grey and tan in outcrop, with frequent calcareous nodules, powdery calcareous patches and sometimes ironstone deposits occur along joints and bedding indicating a high degree of weathering. They underlie an elevated flat to undulating surface which is about 160 m above sea level. Valleys, some 80 to 100 m deep are incised into this surface. Most trend northwest and have a distinctly curved outline; Scotts Creek, however, runs more or less east-west, cutting across them.

Numerous flow failures can be seen along the northern wall of Scotts Creek Valley. Many farms in this area (known as the Heytesbury area) were developed since 1960 and much of the native vegetation was cleared since that time. At least some of the slope failure had occurred prior to that clearing. Figure 3 shows a failure just south of Scotts Creek (along Bucks Rd); Figure 4 shows a cross section of that slide. Overall area affected by the failure is 15 ha although part (2 ha) has been active recently. Failure was in gently dipping interbedded calcareous clays and silty clays and minor clayey sand bands of the Gellibrand Marl; this was weathered to a depth of 9 m. Failure was on slopes of 7° to 9° (12% - 16%) and occurred at or near the weathered - unweathered contact. Both the weathered and unweathered materials were CH soils but, in general, the weathered material was finer grained overall and a little more plastic than the unweathered material.

Mean annual rainfall at Timboon (13 km to the west) is 971 mm. Historic failures seem to be related more to anomalously high monthly rainfall than to annual peaks. In some cases the failure year is preceeded by below average annual rainfall.

At a deep road cutting in Heytesbury Group sediments about 1.5 km north of Timboon, silty clays have been weathered from grey to yellow to a depth of about 10 metres.

The Gellibrand Marl outcrops between Timboon and Port Campbell. Slumps and earth flows become common just north of Port Campbell, even on the gentle slopes. Along the coastal zone near Port Campbell it is overlain by the Port Campbell Limestone. Both formations are of Miocene Heytesbury Group.

Lunch will be taken at Port Campbell.

2. PORT CAMPBELL TO PRINCETOWN

2.1 Description of the Port Campbell Coastal area.

A limestone plain 45 m above sea level stretches from near Warnambool to Port Campbell. West of Port Campbell, numerous sinkholes up to 270 m in diameter have developed and surface drainage is absent. Heathland and low clumps of Casuarina (sheoak) and Eucalypt (brown stringybark) trees grow on the surface cover of residual clay and siliceous sand.

The Port Campbell Limestone is thinly bedded, with concretions and secondary limestone along the bedding, and dips of 1° to 5° seaward. Jointing is prominent striking NW - SE (parallel to the coast), NE - SW (controlling gorge and promontory formation) and both vertical and at 45° (controlling cliffs, cave roofs and arches).

The coastline runs NW - SE, but is crenulated with gorges, small bays and promontories. A platform extends up to 1.2 km offshore with reefs and rock stacks. Cliffs are close to vertical, and include sections which overhang to 8°. Generally the cliffs are between 30 m and 60 m high.

The local annual rainfall is 50 to 115 mm and falls mainly from May to October, so that small streams dry up in the summer. Currents for most of the year are to the east, but from January to March run to the west, and build sand barriers across the mouths of the creeks. Storms are mainly from the southwest, and swell periods of 14 to 16 seconds are most common. The mean rise of tide in Port Campbell harbour is 1.2 m.

The first settlement in this area was 1846. During the 19th century the rugged coastline was the site of many shipwrecks. The limestone coastline was proclaimed a National Park in May, 1964.

2.2 Route from Port Campbell to Princetown

The road follows close to the cliff top along an old coastal plain formed in the Port Campbell Limestone. This formation will be viewed at a stop where the "Twelve Apostles" - a series of rock stacks - extend approximately two miles along the coast east of Port Campbell. The taller stacks are about 45 m high.

Approaching Princetown, the road passes on the landward side of prominent Quaternary cemented dunes or dune limestones rising approximately 50 m above sea level. Princetown is simply a place name; there is no town. Near Princetown, the route takes the road to Simpson for several kilometres across a hilly landscape in the landslip-prone Gellibrand Marl.

3. BOUWMAN'S LANDSLIDE, PRINCETOWN AREA.

This landslide (Figs. 5a, 5b, 5c)occurs at Mr J A Bouwman's property, Princetown to Simpson Road, approximately 6 km north west of Princetown, in the Shire of Otway.

Mr Bouwman recollects that the landslide began in the early 1970's (possibly 1972) in the south west corner of the paddock now fenced off. Although a rather minor feature at the time, it continued to move for three years. Following this there was a period of dry winters for about three years during which no movements occurred.

However, in October 1979 the landslide became active again and the road surface was cracked. At this stage the area affected was triangular shaped and about one hectare in size.

In early August 1980 movement was more extensive and a crack traversed the garage just north of the dairy causing vertical displacement of the garage floor by about 0.3 metres. The effected area had now grown to about three hectares.

In 1981 movement occurred over three weeks between the end of August and mid September. In late September drilling was carried out to investigate the mechanism of the slide and formulate stabilisation measures. Included in the investigation program was the installation of piezometers and some soil testing. In April 1982 a detailed topographic survey was carried out over the area and a number of steel rods were located on and near the slide as monitoring stations in September 1982. These were resurveyed in late 1984 and the results showed substantial movement had occurred.

The failure occurs in weathered interbedded calcareous clays and silty clays of the Gellibrand Marl formation. There is no outcrop, but the drill core shows that the dip of the beds is either horizontal or only a few degrees. The direction of the dip is unknown. The failure is translational with the slip plane being at 3 - 4 metres deep. The failed mass is moving as two blocks.

The effect of the weathering has been to increase the plasticity of the soils and also their permeability (through the development of powdery carbonate patches). Once failure occurred, the permeability of the failed material was increased by fissuring and fracturing resulting from movement.

The landslide becomes mobile when the groundwater table rises so that there is both hydraulic uplift to de-stabilise the landslide mass and saturation of the soil to weaken it. Groundwater is derived from local infiltration. Although the natural catchment to the landslide site is small, the roadside drainage system and, in the past, the dairy waste water have substantially increased water discharge onto the area. Furthermore, the porous road embankment acts as both a dam wall, ponding surface water at the head of the slide, and as a permeable medium whereby the surface water is conveyed into the landslide mass.

Suggested remedial work is to prevent as much water as possible from reaching the landslide, and the diversion of the surface runoff well away from the failed area. The trees on the slide were planted by the owner as a means of reducing infiltration of direct precipitation and removing groundwater by transpiration. Although trees have been planted now for several years, movement again occurred last year.

4. PRINCETOWN TO APOLLO BAY

The route again passes over Gellibrand Marl before crossing the ferruginous sands of the Lower Tertiary Dilwyn Formation. Immediately east of the Gellibrand River, a faulted boundary marks the beginning of the Lower Cretaceous rocks in outcrop.

5. THE OTWAY RANGES

5.1 Geology and Geomorphology

The Otway Range is composed of Mesozoic (Lower Cretaceosu) sediments that have been uplifted into a complex domal structure. The elevation along the main ridge is about 500 metres, with the highest point (Mount Cowley) reaching 670 metres. In general, the range is closely and deeply disected with the stream pattern generally radial, reflecting the structural control.

Inliers of ferruginous sands of the Dilwyn Formation occur south of Lavers Hill. At Glen Aire a system of streams has been dammed behind a coastal barrier of Pleistocene dune limestone and Holocene mobile sand barriers to produce wide river flats which the road follows upstream before climbing again into the Otway Ranges and finally dropping to reach the coast at Apollo Bay.

Although deeply and intricately dissected, the range still shows the form of the pre-Tertiary surface. Structures associated with the late Cainozoic uplift are still evident topographically and the valleys of the main streams are in a large measure structurally controlled. The coastal streams, constantly rejuvenated by coastal erosion, contain numerous waterfalls. Landslides are commonplace on the steeper slopes.

The Otway Group is a monotonous sequence of fluviatile lithic sandstones, siltstones and minor thin beds of coal. The sequence has been measured up to 1500 metres thick. Montmorillinite is an important component of the siltstones. The rocks can occur in three associations: massive lithic sandstone, massive siltstone or thinly interbedded lithic sandstone and siltstone units. In general, they are gently folded with dips ranging up to 20°; very steep dips occur in places (eg. Skenes Creek just east of Apollo Bay). Pronounced lineaments occur (Fig. 6) reflecting the generally fractured nature of the unit.

They are often fresh to moderately weathered along the coastline and highly to completely weathered inland. The lithic sandstones are greenish grey when fresh and weather to yellowish brown; the siltstones are black to dark grey and weather through grey to very light grey.

5.2 Landslide History, Rainfall and Seismicity

Numerous landslides can be seen in the area, although there is very little historical information available about them.

The largest documented historic landslide in the region was near Forrest, some 30 km south of Colac, when an estimated 6,000,000 m^3 block of Otway Group sediments with a surface area of some 48 ha slid into the East Branch of the Barwon River; failure was along the bedding which dip 12° to 20° towards the river. The toe of the slide about 400 m wide at river level and formed a 35 m high wall of a natural dam (Figs 7 & 8).

Failure occurred during winter in late June 1952 following the wettest monthly rainfall - 415 mm (June mean 113 mm). The same year (i.e. 1952) also had the wettest annual rainfall - 1683 mm (mean annual rainfall 1037 mm). High rainfall also occurred in 1951 (1637 mm) and 1953 (1203 mm).

The natural dam was breached on 5 August 1953 and a wall of water - still some 7 m high about 10 km downstream - passed down the river. Damage was done to fencing etc. and extensive one metre layer of silt was deposited over the fields. Luckily, there were no significant buildings along the river flats and the damage was relatively slight.

Many small landslides have occurred during historical times, but unfortunately, there is no complete record of these events although aerial photographs have provided information over the past 30 years.

Average annual rainfall in the Otway Range varies from about 1100 mm along the coast to over 1900 mm on the crest of the range. The wettest period is late winter to early spring. Intense rainfall events of 233 mm for one day, 587 mm for three days, and more than 2700 mm per year have been recorded.

Many seismic events (earthquakes), some of considerable intensity (5.2 on the Richter scale), have occurred offshore since records have been kept. Most events are thought to be associated with movement along the Torquay Fault, which runs more or less parallel to the coast. However, onshore seismicity over the same period has been much less frequent and of lower intensity. There is no known association between slope failure and seismicity in the area.

5.3 Factors Conducive to Landsliding

From a general study of the region, the following factors were deduced as being conducive to landsliding in the Otway area:

1 The presence of a previous failure
2 high annual rainfall
3 coastal erosion
4 moderate to steep topography
5 suitable sediments such as:
  * Tertiary sediments (particularly the Heytesbury Group), including calcareous clays and silts.
  * Cretaceous sediments, including lithic sandstones and siltstones
6 deep weathering in Cretaceous rocks
7 "favourable" orientation of discontinuities
8 ion exchange between the groundwater and some clays (possibly in the Heytesbury Group).

Triggering mechanisms may be:

intense rainfall
road, or other, construction resulting in the removal of slope support
earthquakes (no known case)
high energy coastal storms
inappropriate development on steeper slopes.

5.4 Shire of Otway - Planning Controls

In Victoria, the Ministry for Planning and Environment (MPE) is the authority responsible for planning issues. In the Shire of Otway, the responsibility for planning has been delegated to the Shire's Planning Officer for primarily residential areas ("Village" zones), and to the MPE in all other areas. The "Village" zones are affected by the Shire of Otway (Ocean Road) Interim Development Order (IDO), approved by the Government in August 1984. Under the conditions of the IDO, applications for planning permits in areas which are prone to landslides are required to be referred to the Geological Survey and the Land Protection Service for comment.

Town	Total allotments	Number developed	Percentage developed	Number vacant	Percentage vacant
Apollo Bay	800	656	82	144	18
Marengo	210	133	63.4	77	36.6
Skenes Creek	300	162	55.4	134	44.6
Kennett River	155	79	51	76	49
Wye River	460	239	52	221	48

Town	Permanent residents
Apollo Bay	63%
Marengo	14.2%
Skenes Creek	8.6%
Kennett River	3.5%
Wye River	5.7%

5.5 Apollo Bay

At Apollo Bay sealers and whalers first made temporary selltlemnts in the early 1800's, but permanent settlement of this coast was slow because of poor accessibility from land and sea and its limited pastoral potential. Conditions changed in the 1850's when milling of the Otway forests commenced. At its peak around 1860 there were 1000 timber-cutters at Apollo Bay, but this industry declined rapidly once railway contracts were completed.

The opening of the Great Ocean Road in 1932, greatly improved accessibility and promoted development of this seaside resort.

7. WILD DOG CREEK VALLEY

7.1 Major slope failure zone

The eastern walls of this stream exhibit slope failures on a massive scale. The Geological Survey believes that mountain spreading is in operation, forming ridge top depression. Major slump earth flow failures are characteristic of this valley. One destroyed the Wild Dog Creek Road in 1952 and another constantly encroaches upon it. Others have scarred the hillside without damage to roads or structures. Signs of extensive small scale active movement abound.

7.2 Geology and Geomorphology

Wild Dog Creek flows into Bass Strait about 3 km north-east of Apollo Bay. Along the creek, the valley walls are very steep (up to 45° or 100%) and bedrock comprises sedimentary rocks of Lower Cretaceous age. The beds are composed of alternating dark siltstone and lithic sandstone with some thin coal seams. A massive sandstone unit forms a steep-sided, narrow gorge about 600 m from the mouth of the creek. Thickly bedded sandstone also predominates in the northern part of the valley. Elsewhere the rocks contain alternating sandstones and siltstones with either rock type dominating locally. Bed thicknesses range from a few centimetres to about 5 m, but more commonly are about 0.5 m. The shale beds tend to to be weaker and erode more rapidly than the sandstone and, occassionally, continuous thin (1 - 2 cm), clay beds occur in a sequence of shales and/or sandstones. The degree of weathering increases with elevation and the only outcrops of fresh rock are in the creek bed (Fig. 9).

Bedrock is generally overlain by a soil profile that consists of a thin topsoil horizon and a variable zone of soil and rock fragments that have suffered a certain amount of creep. A characteristic profile would comprise:

0 - 20 cm Medium to dark greyish brown, friable, fine sandy or clayey loam, plant roots.

20 - 100 cm Pale yellow brown, sandy clay loam with numerous highly weathered rock fragments becoming more common with depth. Clay content is related to the parent rock. The zone grades into weathered bedrock.

The structure of the soil throughout is highly porous, and severe tunnel erosion can be observed at many sites.

It is useful to compare the geomorphology of the Wild Dog Creek valley to that of the smaller catchment immediately to the east. The latter is a short creek, generally at an elevation of 100 m to 150 m higher than Wild Dog Creek, until the creek cascades down a sheer waterfall about 700 m upstream from the mouth. The waterfall is formed by the same massive sandstone bed that has been bisected by Wild Dog Creek in the gorge, however, the smaller catchment has provided insufficient flow for the stream to erode a channel.

In contrast, Wild Dog Creek has carved a very steep gorge through the sandstone and then the valley widens rapidly upstream. It is thought that in geologically recent times Wild Dog Creek was also at a substantially greater elevation cascading over a sandstone waterfall, and has only "recently" cut its channel through. The interbedded sediments immediately upstream are much softer and rapid degradation then took place. The convex shape of the stream profile would suggest that the creek is still actively degrading.

The major consequence of this process would have been rapid steepening of the lower parts of the valley sides. This is one of the major contributing factors to the deep seated instability along the valley.

The large landslide at the northern intersection of Busty Road and Wild Dog Creek Road - known as the "1952 slide" - has its failure plane at up to 26 m deep; the failed material is dominantly highly weathered, extremely fractured, lithic sandstone which has slipped on siltstone dipping 15° towards the creek (Fig. 10). A similar set of conditions occurs at the Cape Patton slide (Fig. 11) - although this is a considerably larger feature - with the failure plane at 45 m depth. It is also apparently stabilised and the brecciated mass is weakly recemented with clay in places.

7.3 Slope Stability and Landslide Risk

From a surface study of the landslides along this valley the following general conclusions were drawn:

* The smaller slides comprise surficial materials and the larger slides extend into bedrock.
* The smaller slides occur on steeper slopes than the larger slides.
* Most of the slides involving bedrock comprise mostly sandstone, probably with failure occurring on siltstone beds and sometimes on very thin clay bands.
* Failures along bedding planes are important but many large failures occur where the bedding is oblique to the slope. In these cases, jointing, creep failure or failure through the rock mass must be significant.
* Most slides are recent or old, active or dormant, but few are fossil or stabilised. This indicates the factors contributing to landslide development still exist.
* Both surface and groundwater are very important factors
* The most critical slope angles are 36-55% and 76-85%; no slides occur on slopes <25%.

* Slides rarely occur on slopes that are concave in the vertical direction or convex in the horizontal direction.
* Most large slides probably develop progressively from small slides at the toe.

The landslide risk map (Fig. 12) defines three categories.

1 No landslide risk, no restrictions on development.

2 Landslides are possible, proposed development sites should be assessed individually and adequate design precautions taken

3 High landslide risk, development should not be permitted unless under special circumstances.

Criteria

Zone 1
slopes less then 25% (14°)
no active or dormant landslides.

Zone 2
slopes between 25% and 35% (19°)
no active or dormant landslides.

Zone 3
All slopes steeper than 35% (19°)
all slopes containing active or dormant landslides.

The term 'dormant' relates to whether or not the causes of failure are still present. This is often not known and so it may be best to describe the state of erosion of the feature.

Additional observations made in the region as a whole are:

. major failures require a continuous discontinuity, such as bedding, dipping at a low to moderate angle out of the slope. Jointing is more likely to be associated with toppling.

. lineaments on sattelite images indicate that as yet unmapped major geological structures such as faults are present and probably influence slope stability.

These studies were carried out in order to map areas for planning purposes. It has however, been found that while they provide a firm basis on which to give advice, inspection of individual proposed development sites is required in most cases along the coast. Inspections are carried out by geologists of the Geological Survey of Victoria at the request of the Shire of Otway or the Ministry for Planning and Environment.

One of the problems which is becomming increasingly apparent is the determination of whether or not the current climate regime is typical or atypical for the area; a related matter is the age of the major landslides. Geological and geomorphological studies of a lake system in Victoria indicate that the last 100 years is, indeed, atypically dry and that lake levels prior to this time were substantially higher. If this is the case, the "abnormal" 1951 - 1953 rainfall pattern may be the more appropriate one on which to base recommendations. At that time the low intensity rural development in the area meant that the damage, although locally very significant, was not a disaster. However, nowadays there are pressures to develop areas which, if the 1951 - 1953 conditions return would result in considerable losses.

8. GREAT OCEAN ROAD, APOLLO BAY TO ANGLESEA

8.1 History and Construction

The Great Ocean Road was built during the economic depression of the late 1920's and early 1930's as one of the Government employment schemes. Many of the men who worked on the road construction were returned soldiers from the Great War (1914 - 1918), and many of the place names along the road reflect this association. The road was opened in 1932.

8.2 Geology and Stability

The Great Ocean Road from Apollo Bay through Lorne to Eastern View is formed as a bench cut into Lower Cretaceous sandstone and mudstone beds of the Otway Group. These rocks are well-bedded and jointed. The bedding planes commonly dip seaward at about 40° and are not particularly well cemented. Intersecting joints are commonly uncemented. The sandstone as a material is intrinsically strong but the siltstone is structurally weak, crumbles easily and where weathered, breaks down into clay.

It is therefore not surprising that with the bedding dipping down out of the high cuttings frequently necessary on the landward side of the road, sliding failures are common. Such failures are mostly isolated blocks and fragments of rock, but on occassions, particularly after prolonged heavy rain, they can be more serious and may even block the road. Saftey measures such as steel mesh attached to rock bolts and barrier walls have not been constructed. This is probably because rock falls are still relatively uncommon and resulting accidents are rare. The danger remains, however.

8.3 Windy Point Rockslide

At Windy Point and its vicinity the rock structure is potentially one of the least stable along this coast. The factors that combine to cause this are: the seaward (southerly) dip of about 27°; the two prominent and persistent sets of near-vertical joints that intersect at approximately 90° in plan; the presence of at least two thin (12 cm and 40 cm) silty clay beds that underlie the massive beds of sandstone and intersect the lower part of the the steep natural slope near road level; numerous minor joints at various angles; surface fissures and craters that resulted from slide movement; and the substantial winter and spring rainfall.

The Windy Point rockslide commenced when a relatively minor quantities of rock were removed during road construction in late 1968. Several rock slides that occurred after 1968 were treated by pushing the fallen rock off the seaward side of the road. During this period, evidence of larger scale movement was observed on the slope to elevations of 30 to 40, and later, 70 m above the road. During 1970 and 1971 the rate of movement increased to a maximum of 2 cm per day, and a mass of 3000 tonnes of rock began sliding towards the road.

The condition of the slide at that time involved up to 150,000 tonnes of sandstone, consisting of large and small discrete blocks, moving down dip on silty clay slip planes; some shear failure in the sandstone; major fissures and joints were opening to depths exceeding 15 m; and the surface soil was extensively fissured (Fig 13).

The Great Ocean Road was closed in July 1971. A cable anchoring system was prepared and the contractor commenced work in September. Movement ceased soon after the first 7 anchors were tensioned in October, notwithstanding the heavy rain at the time. The road was re-opened in December 1971.

8.4 Eastern View to Anglesea

Slope stability problems in the road cuts ease in this section of the road. At Eastern View, the gravels, sands, clays and minor brown coal beds of the Eastern View Formation (Palaeocene) unconformably overlie the Lower Cretaceous rocks. Within about 5 km further east, the Eastern View Formation is in turn overlain conformably by the Demon's Bluff Formation (Eocene - Lower Oligocene), comprising fossiliferous clays and sands, carbonaceous in part and commonly stained and partly cemented by non oxide minerals; this formation continues to Anglesea.

8.5 Point Roadknight (Melba Parade) Landslide, Anglesea

This major cliff failure occurs on the coast approximately 500 m north of Point Roadknight. It is about 300 m wide and threatens a residential street named Melba Parade.

The geological material present are two parts of the Eocene - Lower Oligocene Demon's Bluff Formation which shows a gentle seaward dip of approximately 6° - 9° (Fig 14).

Slope failure has been caused by sliding along the contact between the two parts of the formation:

. a yellowish green slippery bentonic clay containing fragments of decomposed basalt and pieces of mudstone (weathered ashes and agglomerate) known as the "Soapy Rocks" forms the lower unit and on its upper surface sliding has occurred.

. reddish brown cohesive clayey sands and very stiff sandy clays have failed by a mechanism of sliding on the shearing surface beneath, assisted by toppling along sub-vertical joints and probably some rotational failure. The failed material has flowed towards the coast, with an irregular hummocky surface.

The impermeable clay of the Soapy Rocks forms a barrier to the downward percolating water, thereby maintaining saturated conditions in the clayey sands/sandy clays overlying them. The resulting high pore water pressures lower internal friction and reduce shear strength have helped to mobilise the clayey sands/sandy clays on the failure surface of the Soapy Rocks and led to their internal failure by secondary shears and toppling with final flowage.

Remedies proposed 14 years ago were:

i) a sea barrier to prevent constant removal of flowed material from the toe of the flow zone.
ii) drainage of the flowage zone, assisted by tree planting and
iii) drainage behind the slip face.

Measure (i) has been taken, (ii) has been done in part and (iii) has not been attempted.

The flowage of material has been slowed considerably and recession of the cliffs appears to have been halted, though probably only temporarily. Slow sliding at reduced velocity is still in operation.

9. MELBOURNE

Situated at the mouth of the Yarra River on the northern shore of Port Phillip Bay, Melbourne has grown from a town of fewer than 30,000 people in 1851, to a major metropolis of approximately 3 million in the 1980's.

Until the beginning of the 1970's Melbourne's growth was rapid and continuous, but more recently the growth has slowed. However, over 70% of Victoria's population lives in Melbourne.

In order to rationalise development and prevent desecration of the countryside, the Melbourne and Metropolitan Board of Works (MMBW) was granted powers over the planning of Melbourne in 1949. Using established corridors, this body attempted to guide the growth of the city by the establishment of preferred development areas.

These notes were compiled from:

Cooney, AM	Geol. Surv. Vict. Unpub. Repts.
Neilson, JL	Geol. Surv. Vict. Unpub. Repts.
Wood, PD	Geol. Surv. Vict. Unpub. Repts.
Duncan, S (ed.)	Atlas of Victoria.
McAndrew & Marsden	Regional guide to Victorian Geology

These notes were compiled by:
J L Neilson, A M Cooney and P G Dahlhaus of the Geological Survey of Victoria.

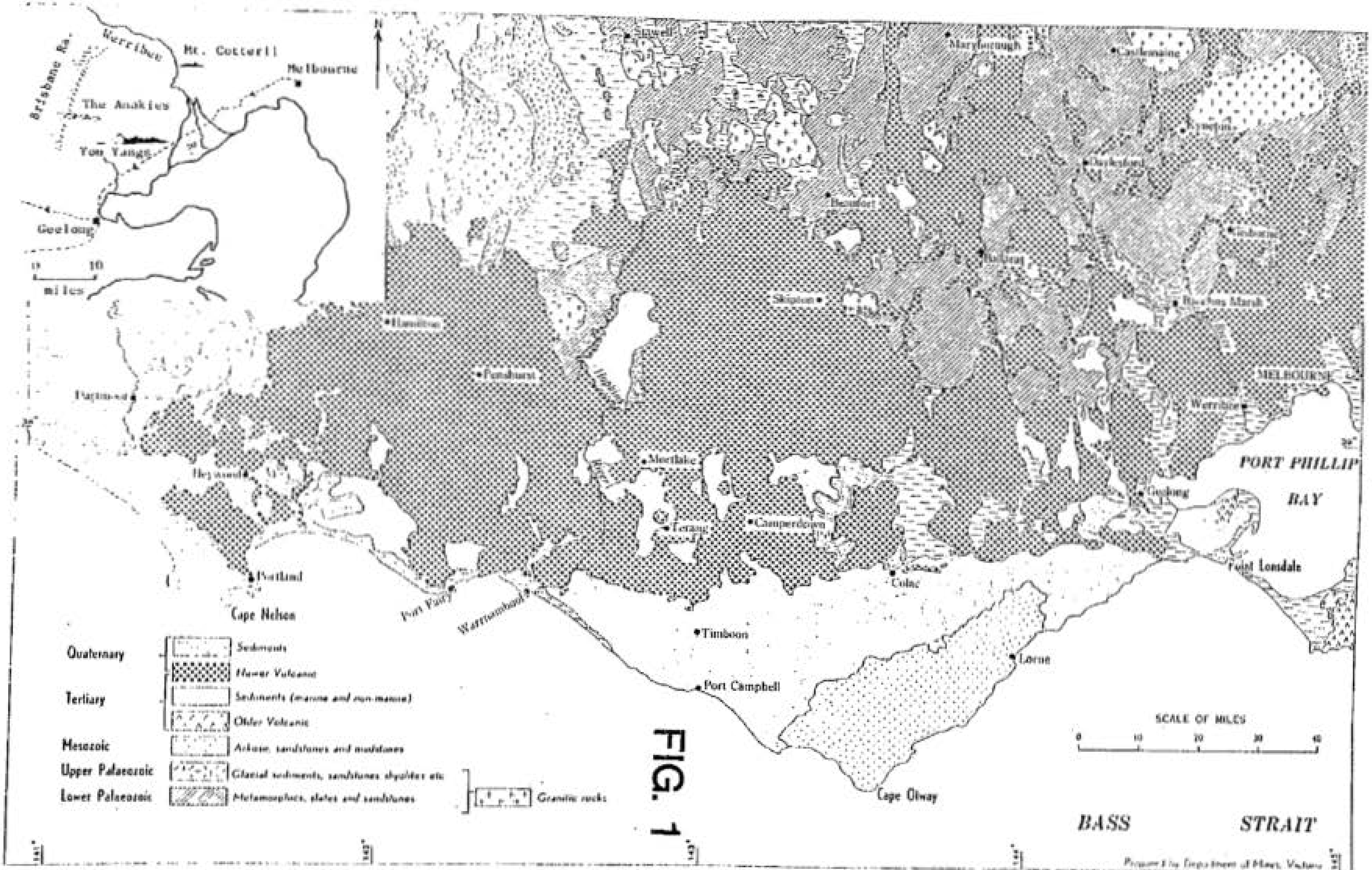

Werribee
Mt. Cotterill
Melbourne
Brisbane Ra.
The Anakies
You Yangs
Geelong
0 10
miles
N
Stawell
Maryborough
Castlemaine
Kyneton
Daylesford
Beaufort
Ballarat
Gisborne
Skipton
Bacchus Marsh
Hamilton
Penshurst
MELBOURNE
Werribee
Mortlake
Heywood
Terang
Camperdown
Geelong
PORT PHILLIP
BAY
Portland
Colac
Point Lonsdale
Cape Nelson
Port Fairy
Warrnambool
Timboon
Lorne
Port Campbell
Quaternary
Sediments
Newer Volcanic
Tertiary
Sediments (marine and non-marine)
Older Volcanic
Mesozoic
Arkose, sandstones and mudstones
Upper Palaeozoic
Glacial sediments, sandstones shyolites etc
Lower Palaeozoic
Metamorphics, slates and sandstones
Granitic rocks
SCALE OF MILES
0 10 20 30 40
Cape Otway
BASS
STRAIT

FIG. 1

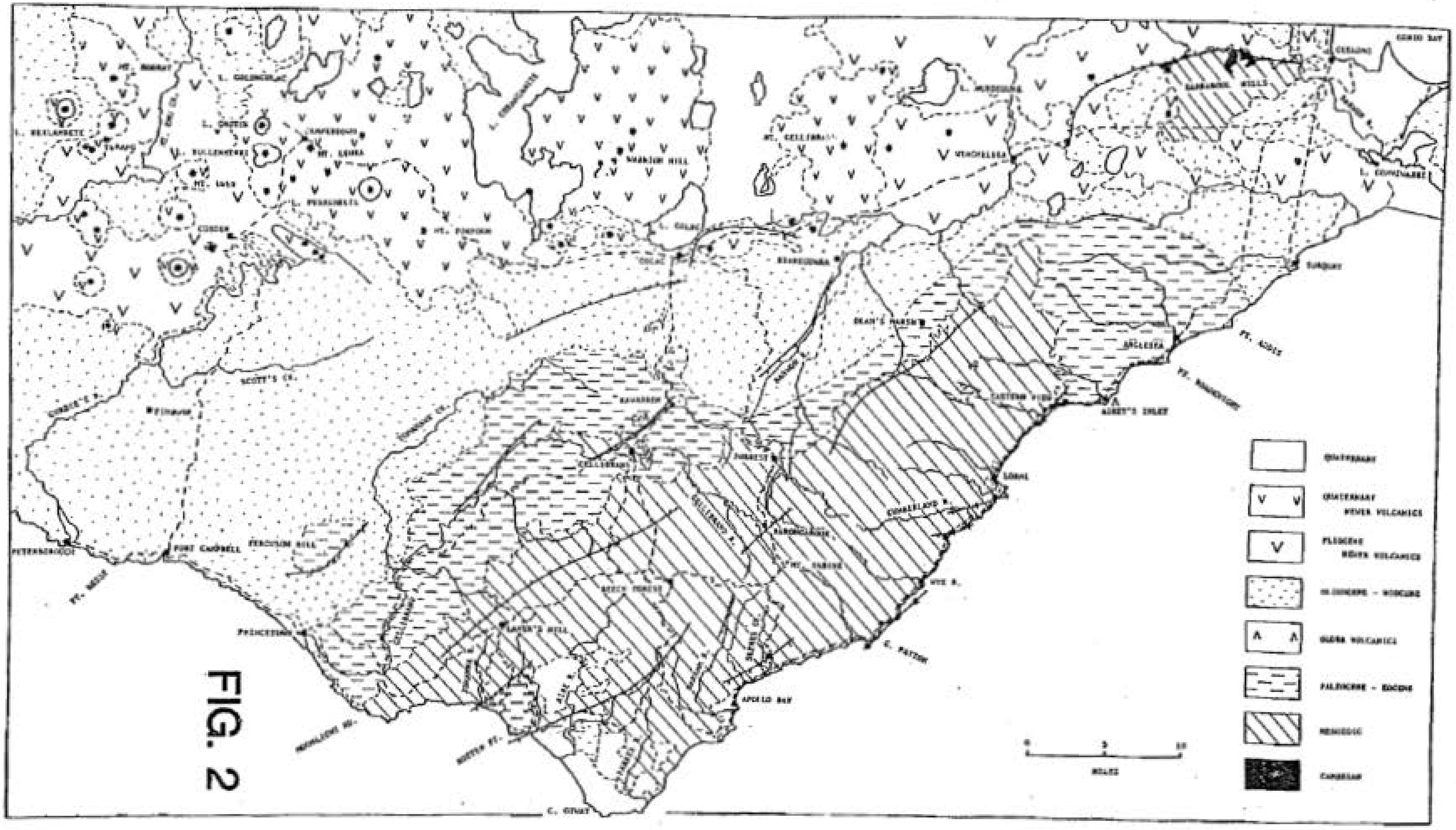

QUATERNARY
QUATERNARY NEWER VOLCANICS
PLIOCENE NEWER VOLCANICS
OLIGOCENE - MIOCENE
OLDER VOLCANICS
PALEOCENE - EOCENE
MESOZOIC
CAMBRIAN
MILES
PETERBOROUGH
PORT CAMPBELL
APOLLO BAY
LORNE
ANGLESEA
TORQUAY
GEELONG
C. OTWAY

FIG. 2

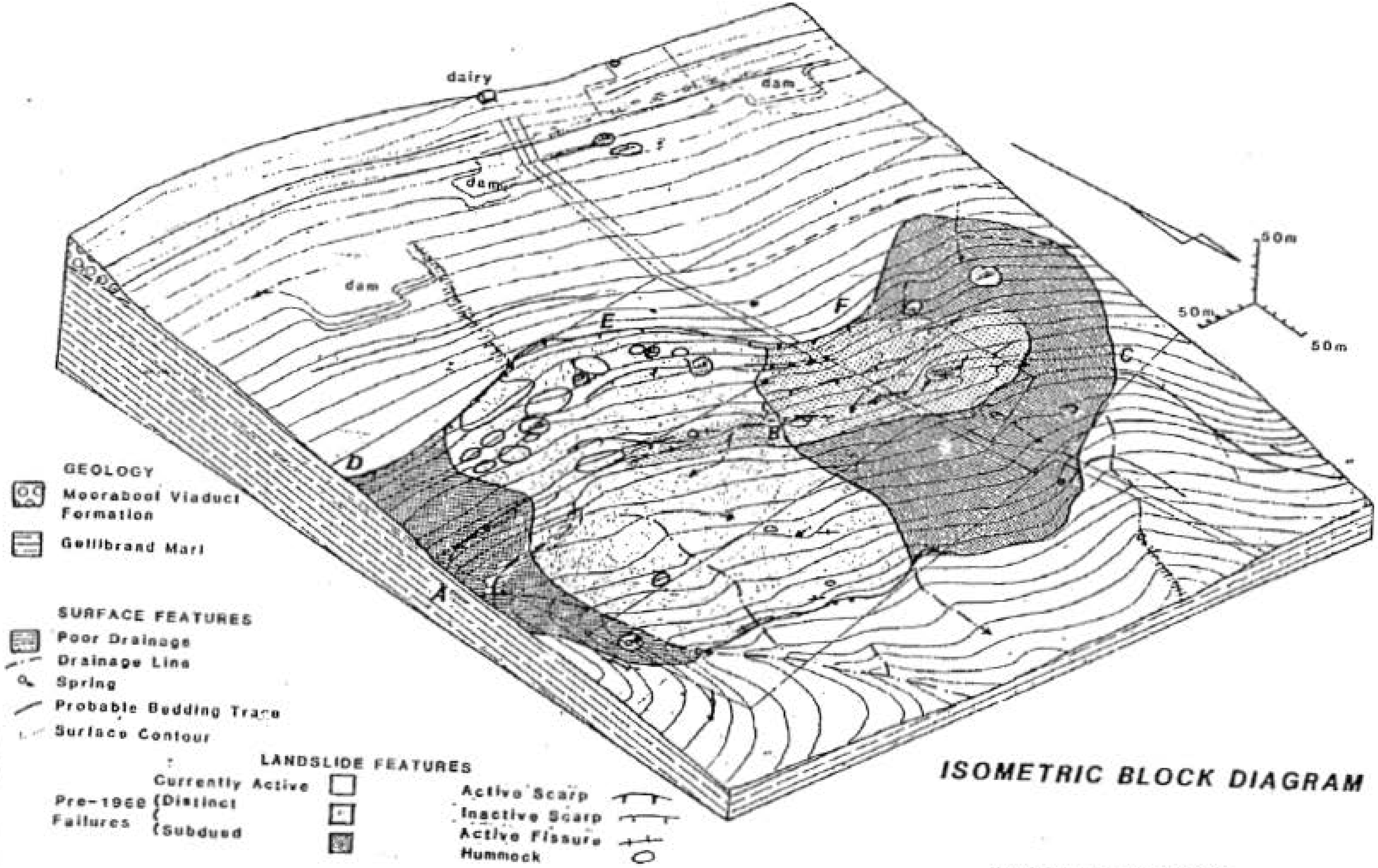


FIG. 3

ISOMETRIC BLOCK DIAGRAM

Unpublished Report 1982/70

36576

17

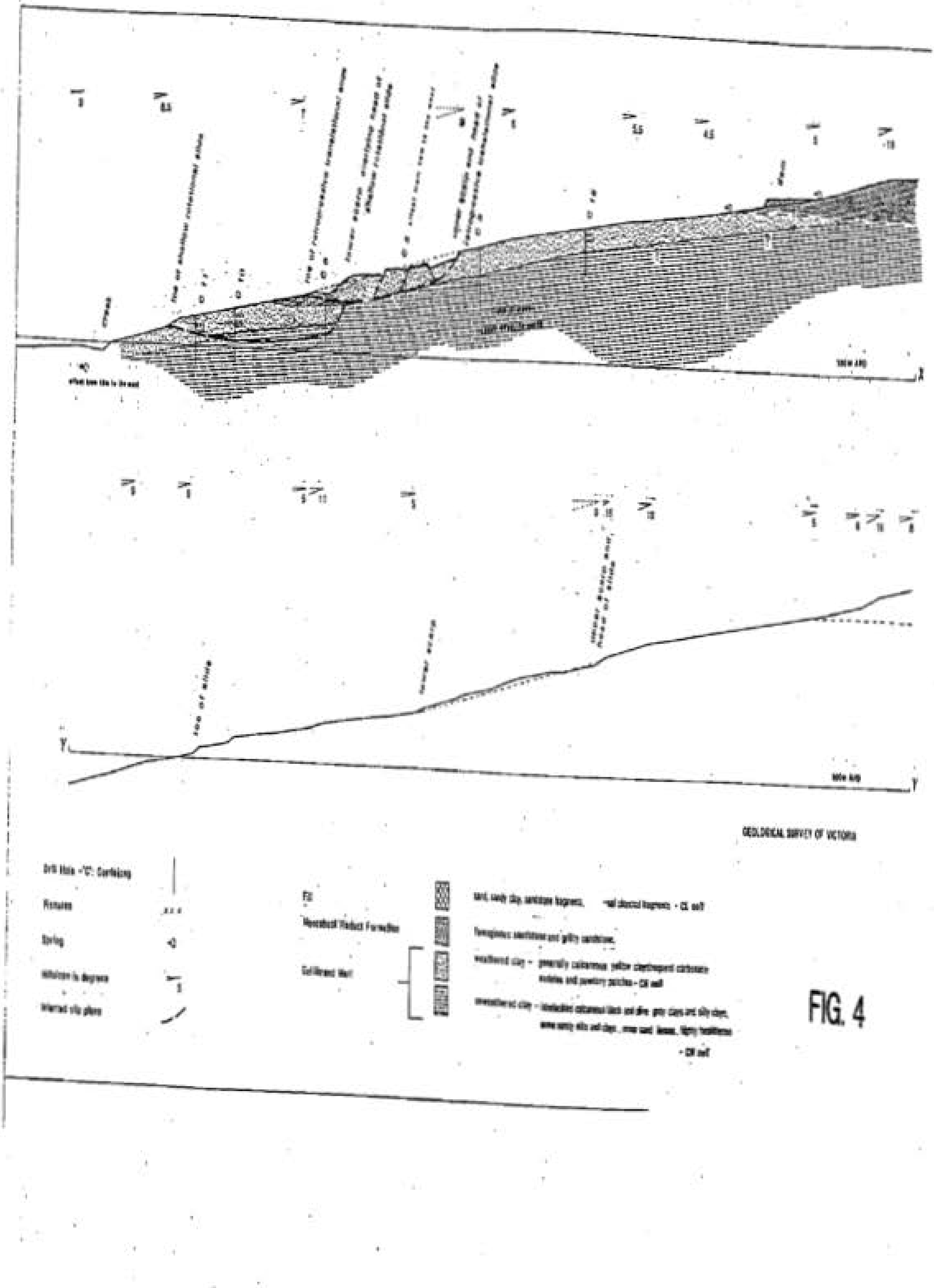


FIG. 4

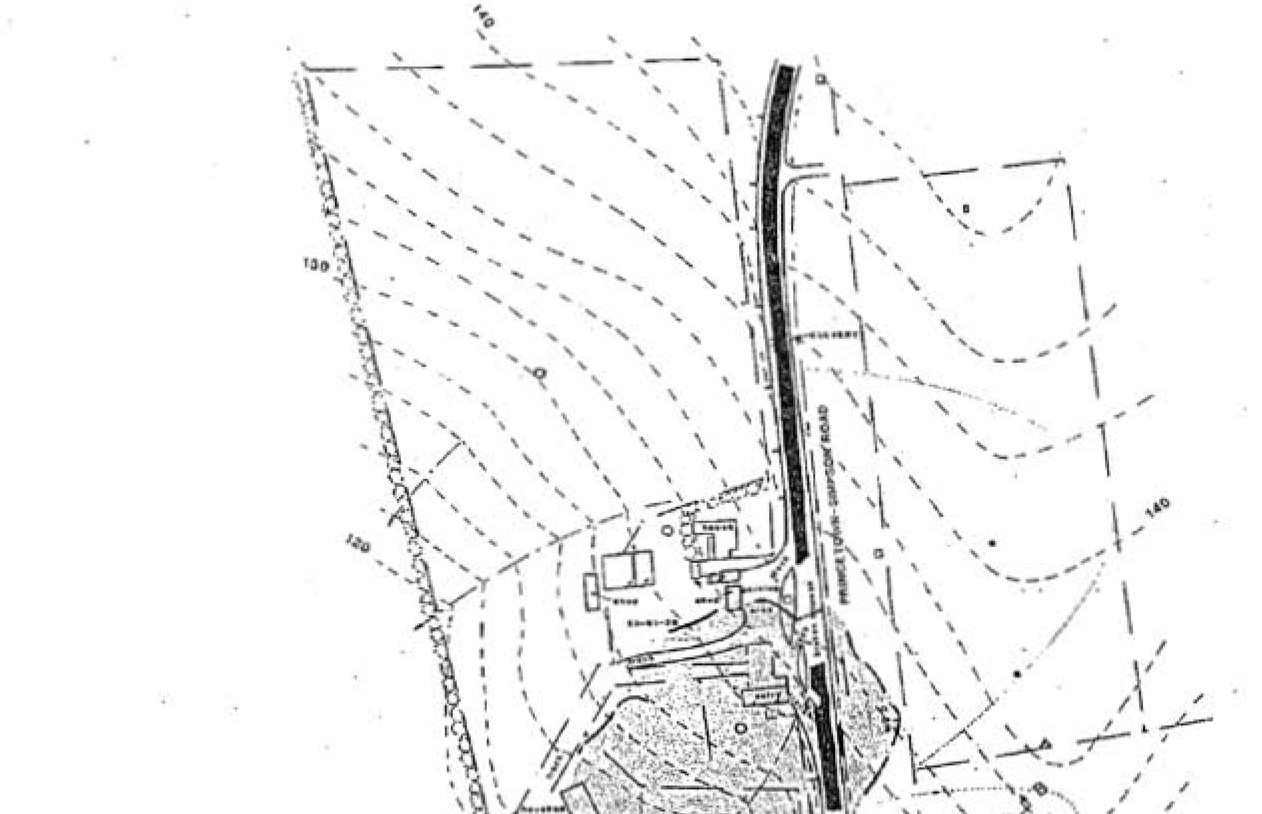
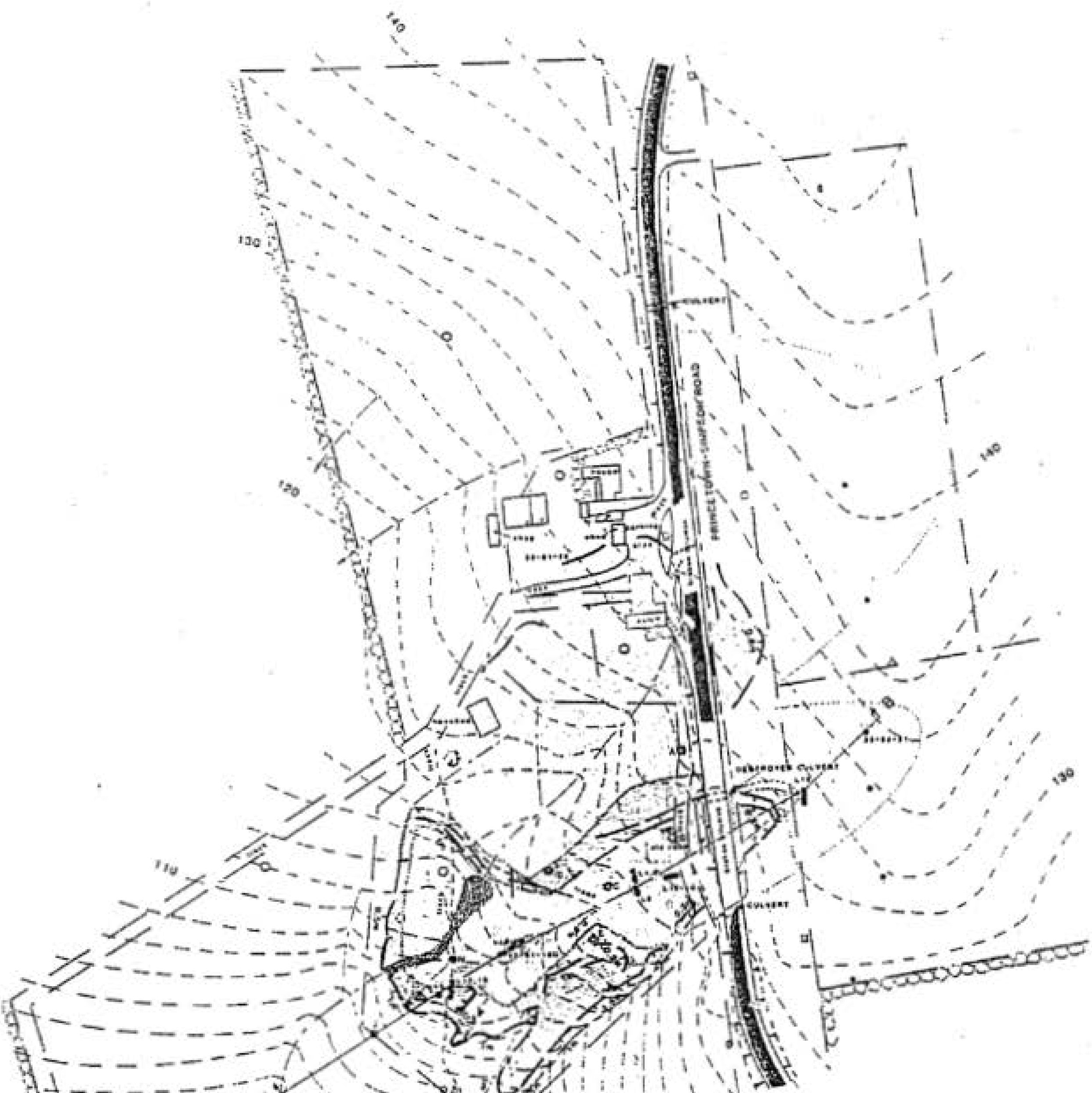


FIG. 5a

19.



140
130
120
110
100
90
PRINCETOWN-SHIPTON ROAD
CULVERT
DESTROYED CULVERT
B
A

FIG. 5a

CROSS SECTION

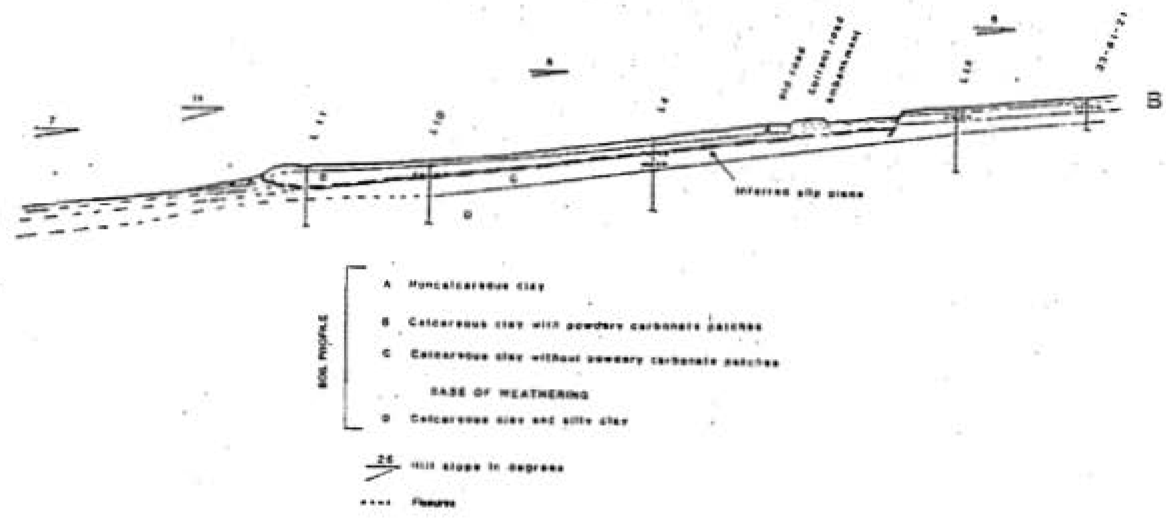


FIG. 5b

21

GEOLOGICAL SURVEY OF VICTORIA

LANDSLIDE MAP

0 ———— 100 m

Contour interval 2m

LEVEL DATUM-AHD

Surveyed by R. F. Fox assisted by A. M. Cooney and and R. L. Luxmoore

Drawn by A. M. Cooney Unpublished Report No. 82/114

Corrections 20/11/84

GENERAL SURFACE FEATURES

Fence

Concrete water tank

Water trough

SEC pole

Survey Station

A Monitoring Station

Drill Hole — [illegible] – field number; L8 (Latrobe 8) – registered number

Surface Drainage

Area of Poor Drainage

Trees

Embankment

Cutting

LANDSLIDE FEATURES

Major Fissure

0.3m Scarp – barb to downthrown side with magnitude shown in metres

Landslide Area

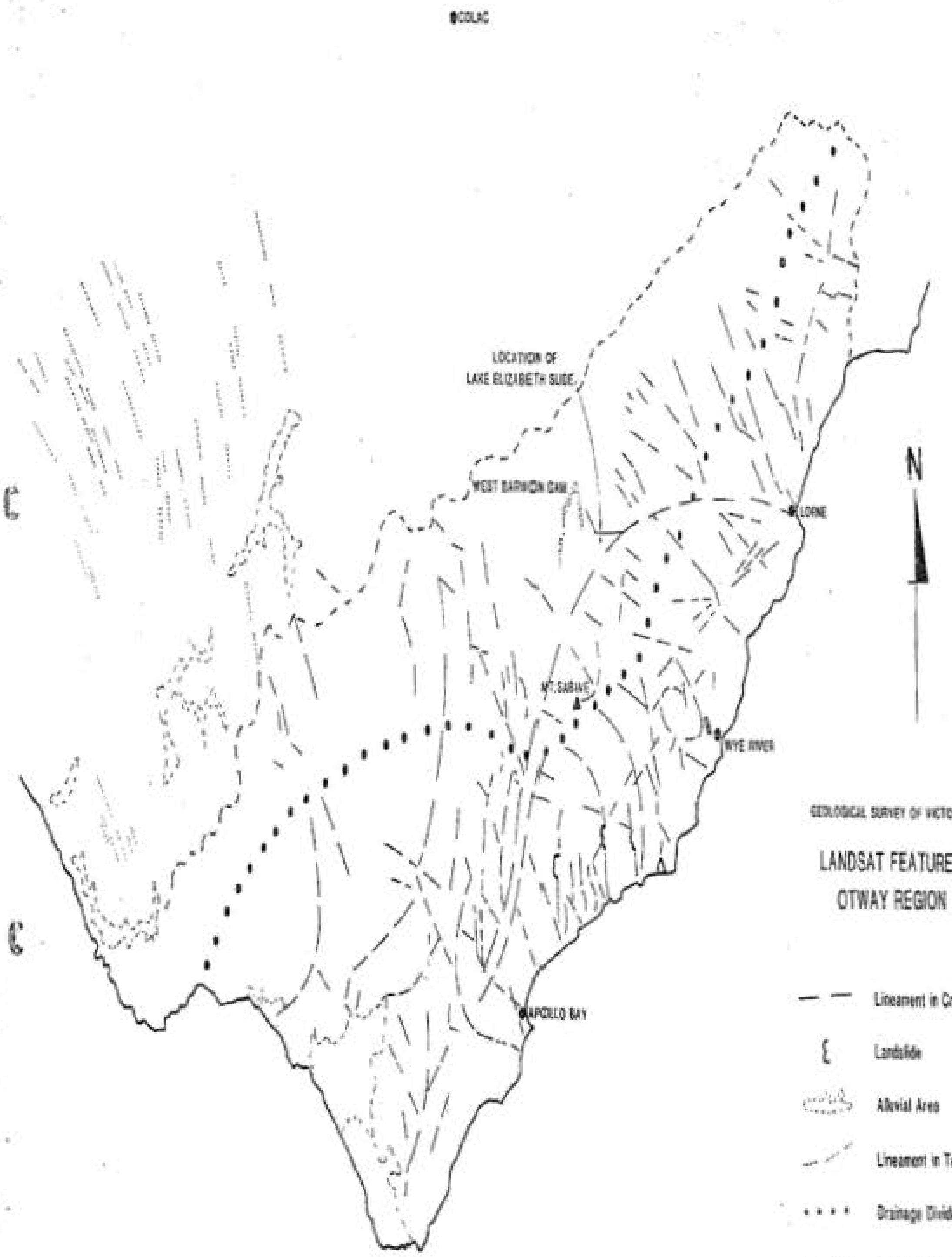
Area with substantially finely fissured ground surface

Faint aerial photograph pattern which may be due to an ancien

CROSS SECTION LINE

A ———— B

FIG. 5c



GEOLOGICAL SURVEY OF VICTORIA

LANDSAT FEATURES
OTWAY REGION

— —	Lineament in Cretaceous Rocks
{	Landslide
	Alluvial Area
	Lineament in Tertiary Sediments
• • • •	Drainage Divide
	Tertiary – Cretaceous Contact

Scale 1 : 250,000

FIG. 6

0 5 10 15 20 km

Unpublished Report 1982/100

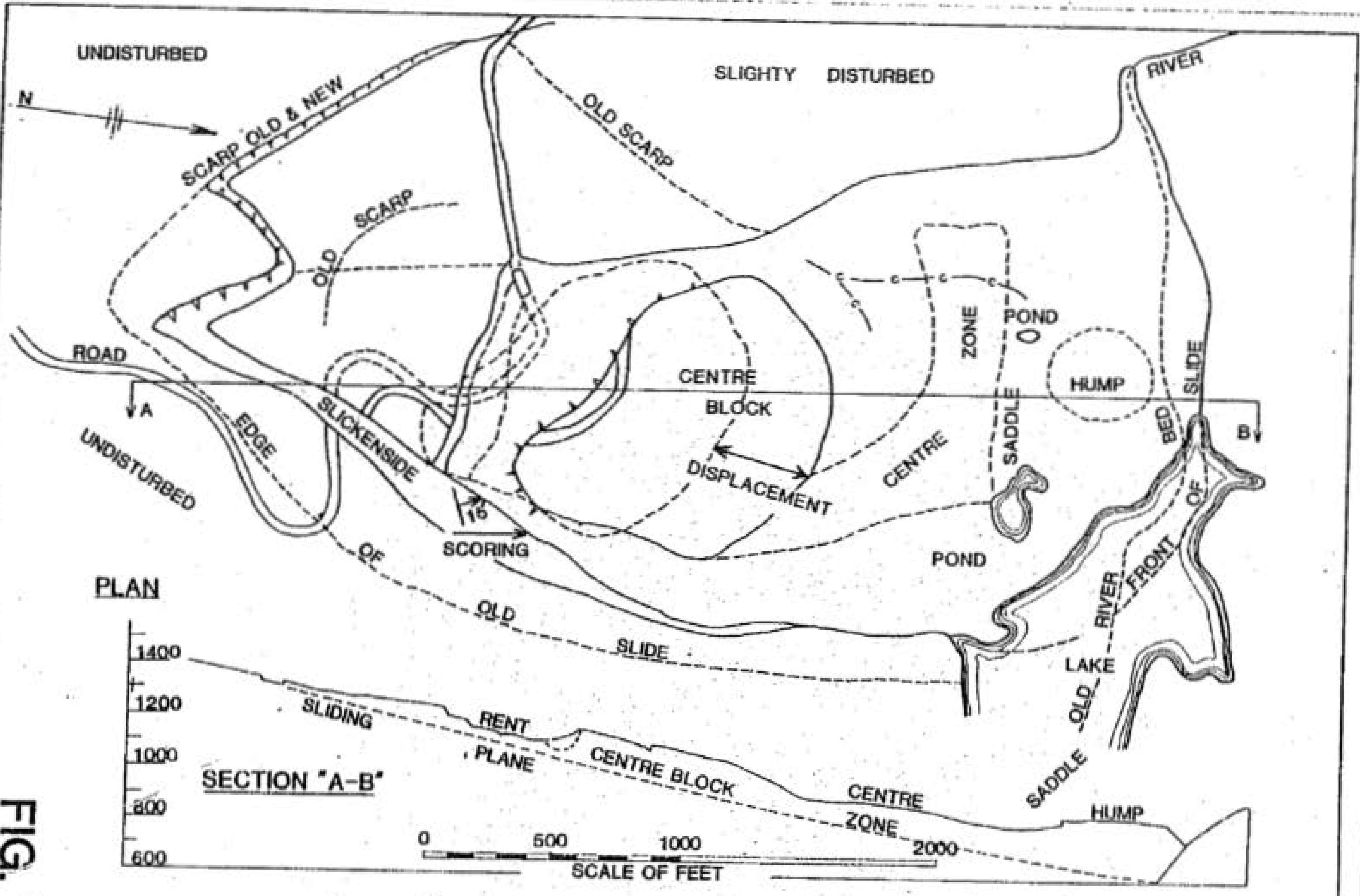


FIG. 7

LANDSLIDE ON THE EAST BARWON RIVER 1952

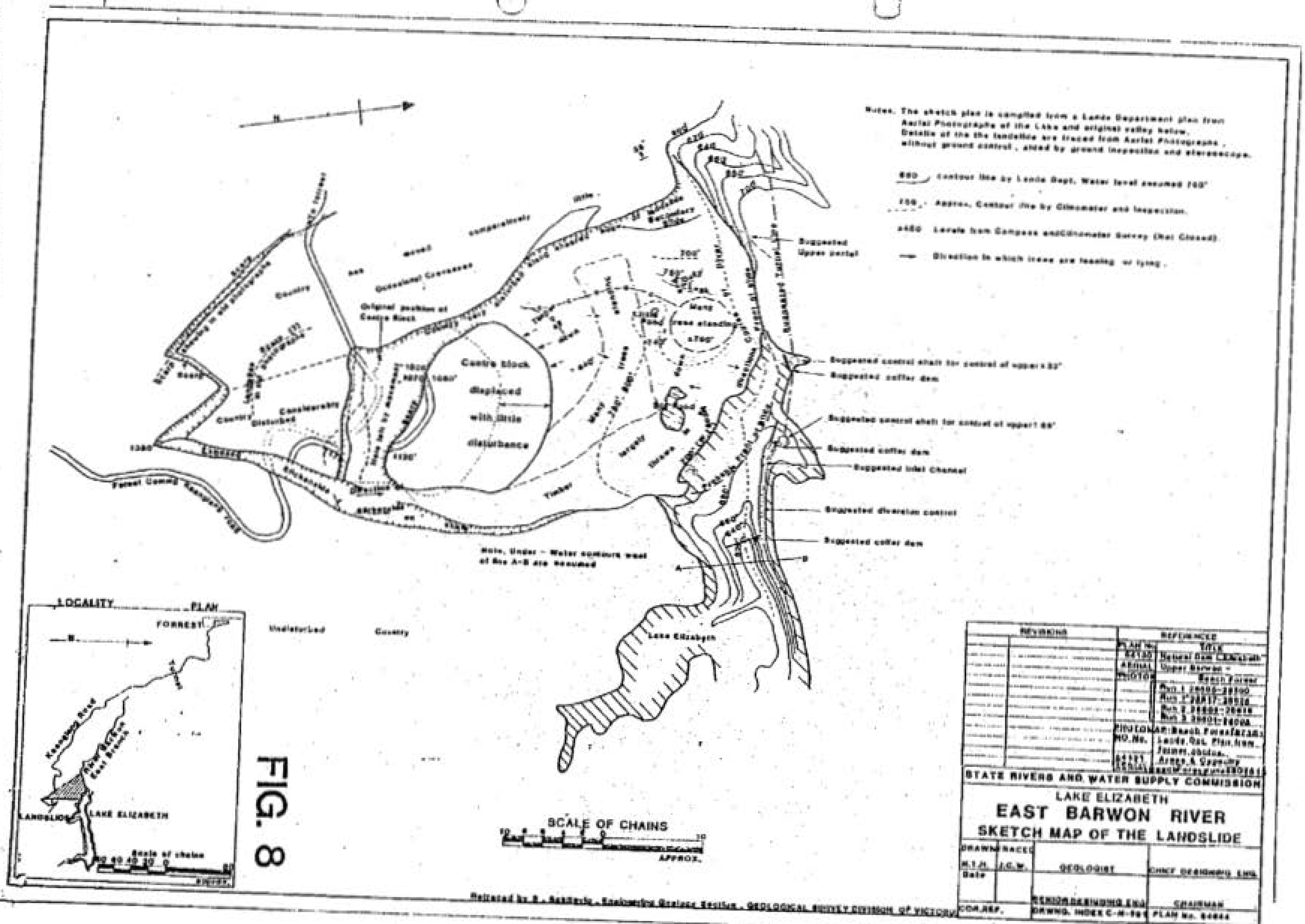

N
Centre block
displaced
with little
disturbance
Original position of
Centre Block
Suggested
Upper portal
Suggested coffer dam
Suggested inlet Channel
Suggested diversion control
Timber
Lake Elizabeth
Undisturbed
Country
LOCALITY
PLAN
FORREST
LANDSLIDE
LAKE ELIZABETH
SCALE OF CHAINS
APPROX.
REVISIONS
REFERENCES
STATE RIVERS AND WATER SUPPLY COMMISSION
LAKE ELIZABETH
EAST BARWON RIVER
SKETCH MAP OF THE LANDSLIDE
GEOLOGIST
CHAIRMAN

FIG. 8

25

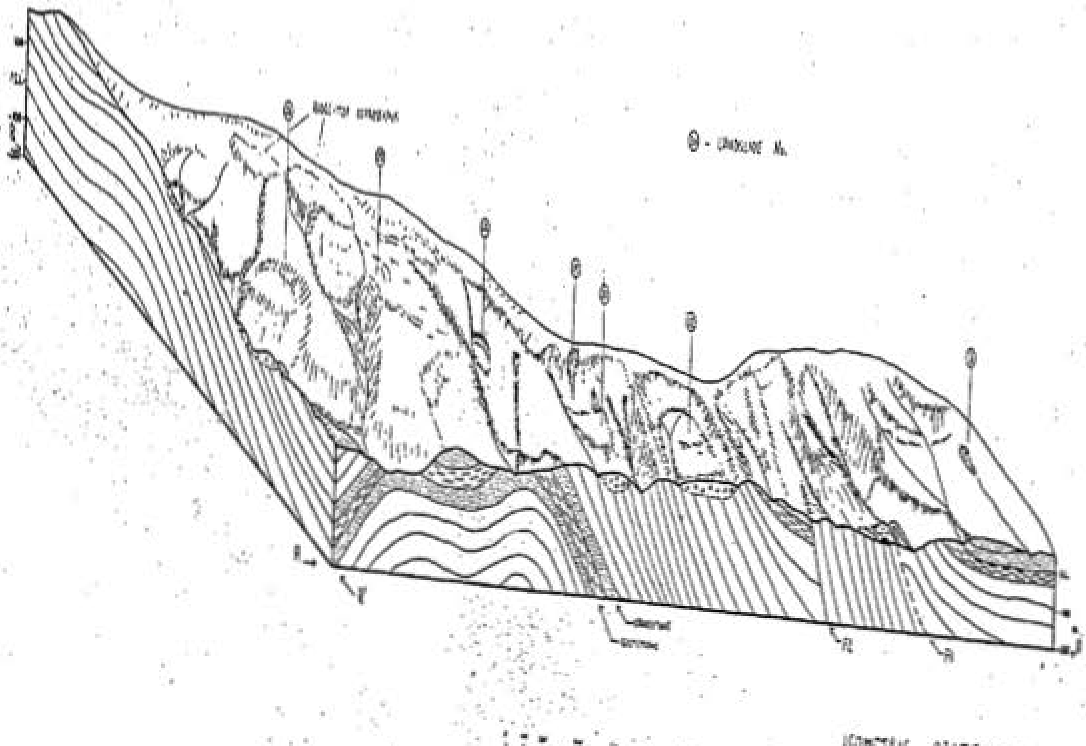


FIG. 9

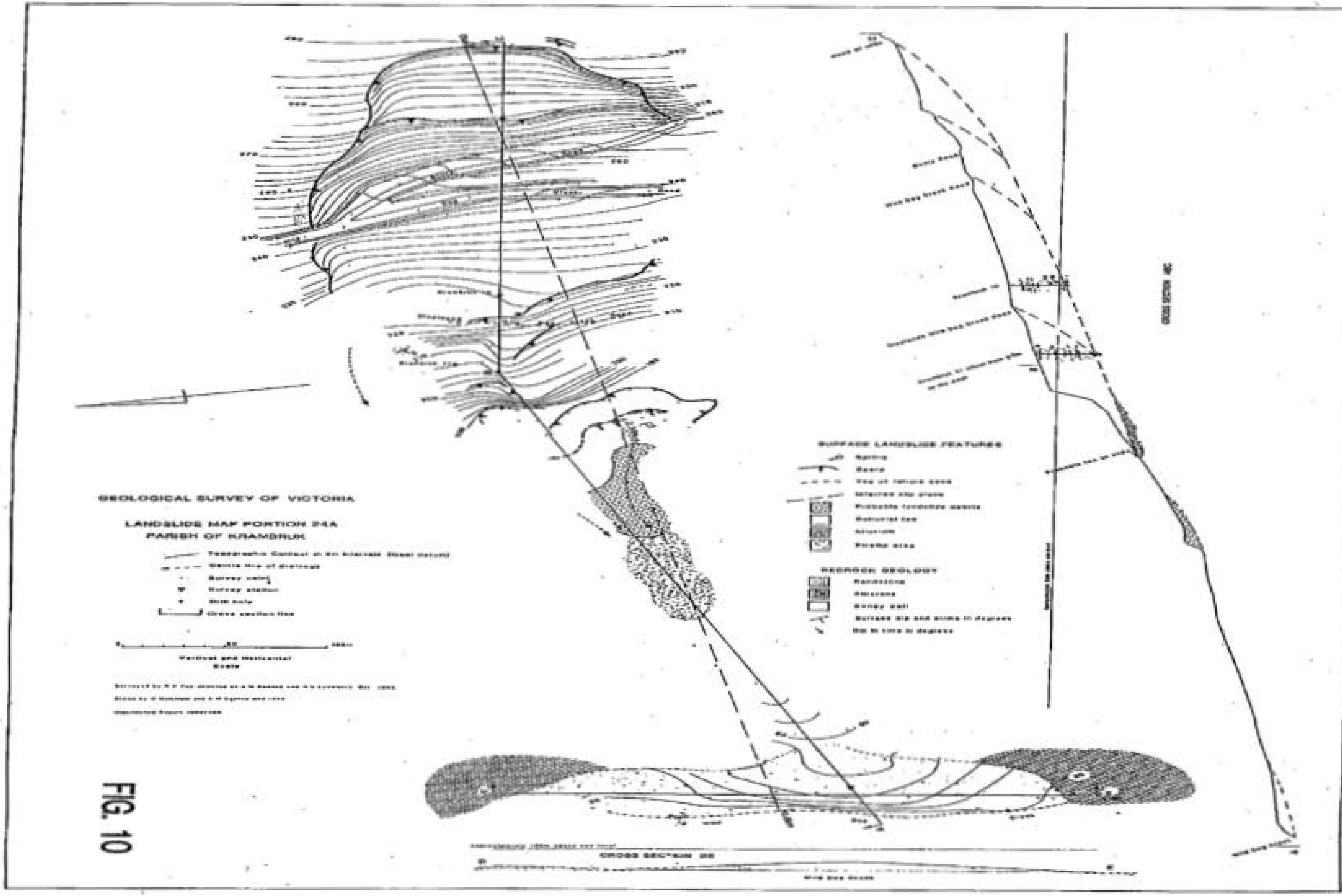

GEOLOGICAL SURVEY OF VICTORIA
LANDSLIDE MAP PORTION 24A
PARISH OF KRAMBRUK
Cross section line
Vertical and Horizontal
Scale
SURFACE LANDSLIDE FEATURES
Spring
Scarp
BEDROCK GEOLOGY
Sandstone
CROSS SECTION

FIG. 10

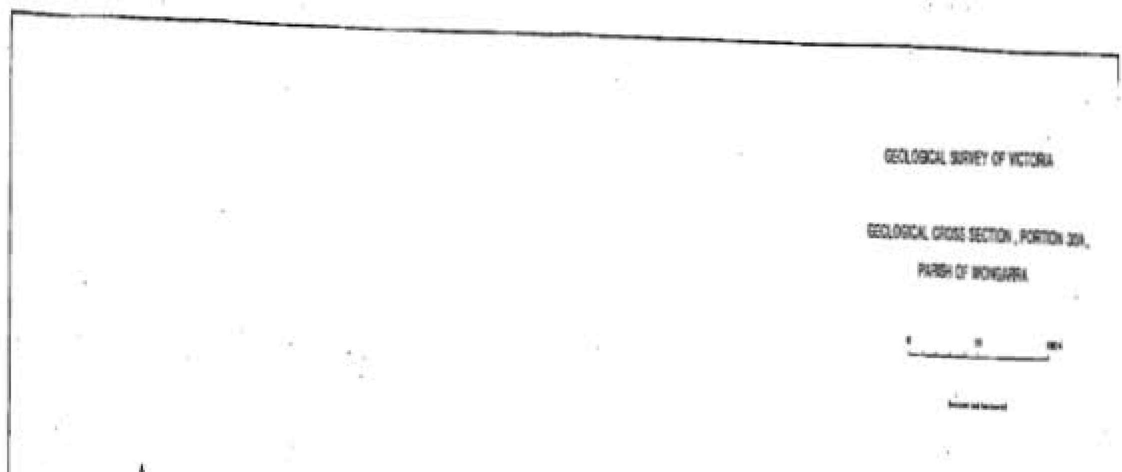

GEOLOGICAL SURVEY OF VICTORIA
GEOLOGICAL CROSS SECTION, PORTION 20A,
PARISH OF WONGARRA
LOCALITY SKETCH
SILTSTONE
SANDSTONE
INTERBEDDED SILTSTONE AND SANDSTONE

FIG. 11

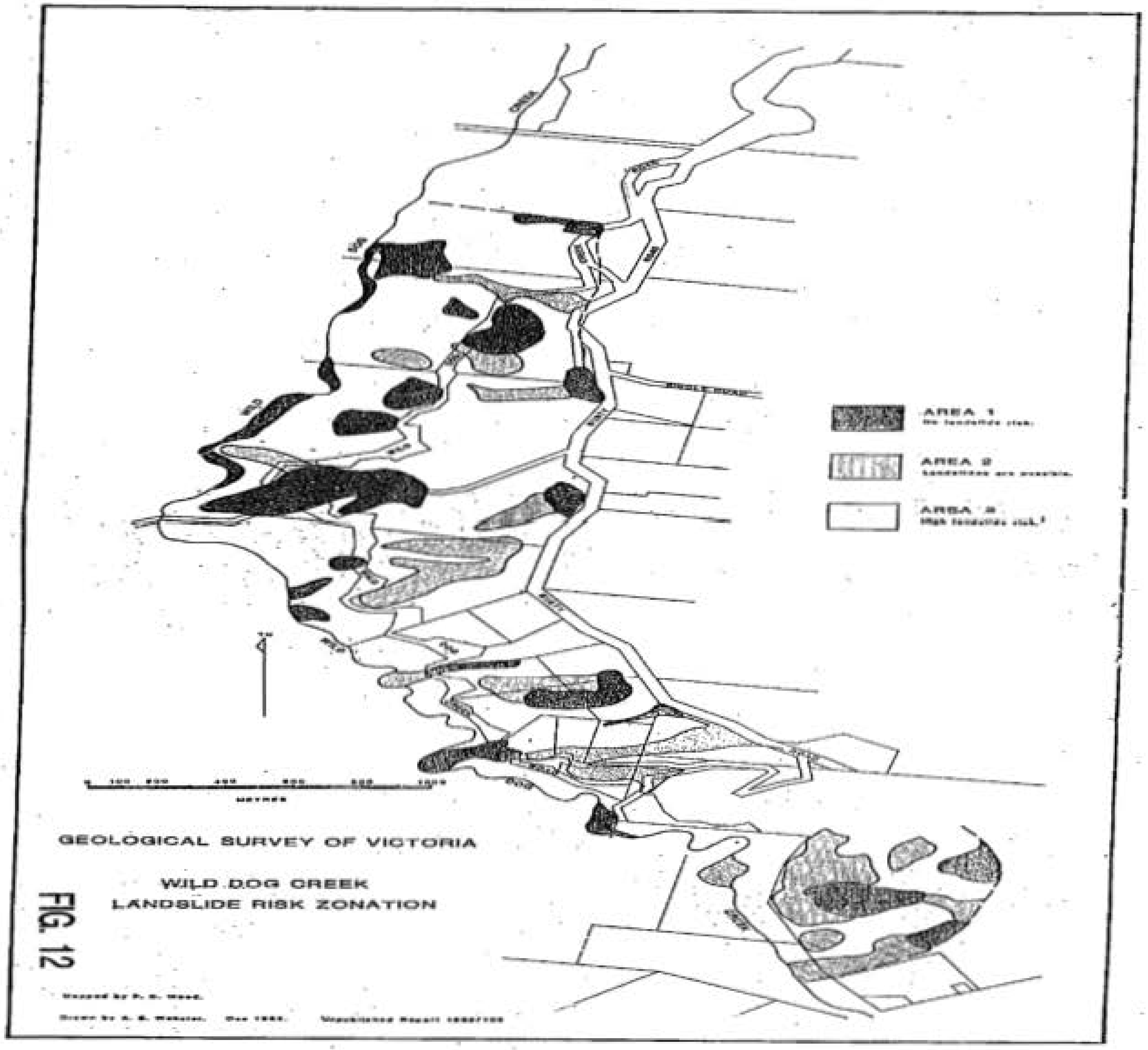

AREA 1
AREA 2
AREA 3
GEOLOGICAL SURVEY OF VICTORIA
WILD DOG CREEK
LANDSLIDE RISK ZONATION

FIG. 12

29

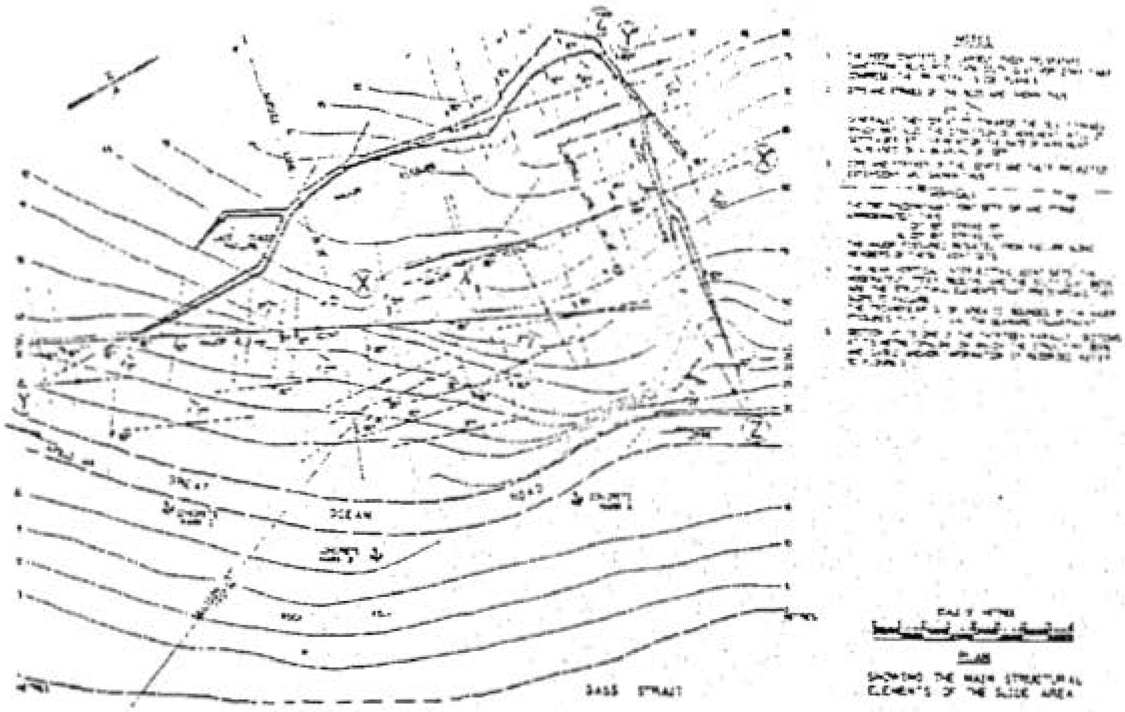


Figure 1. Plan of rock slide area showing main structural elements.

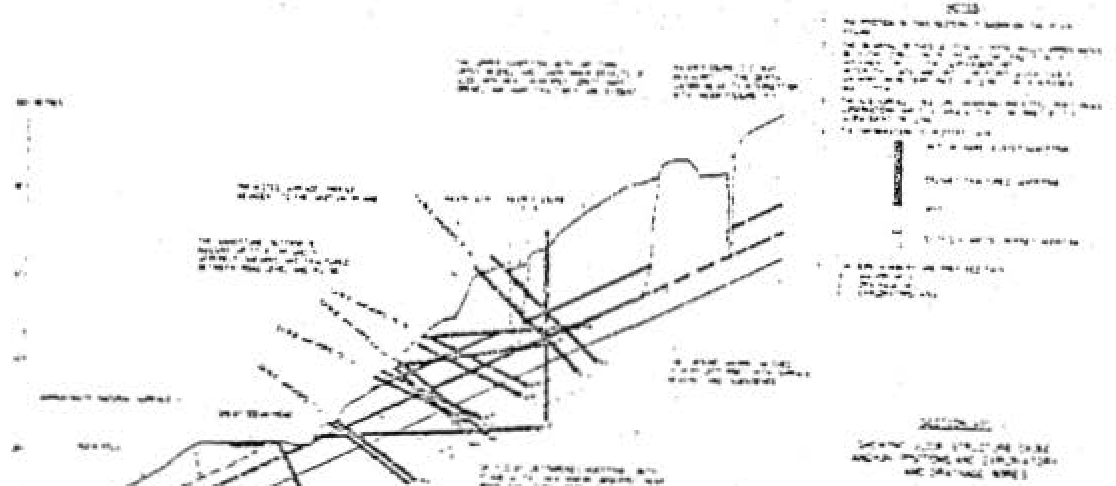


FIG. 13

Figure 2. Vertical profile of rock slide showing slide masses and anchor positions near centre of slide.

Landslide at Point Roadknight, Anglesea

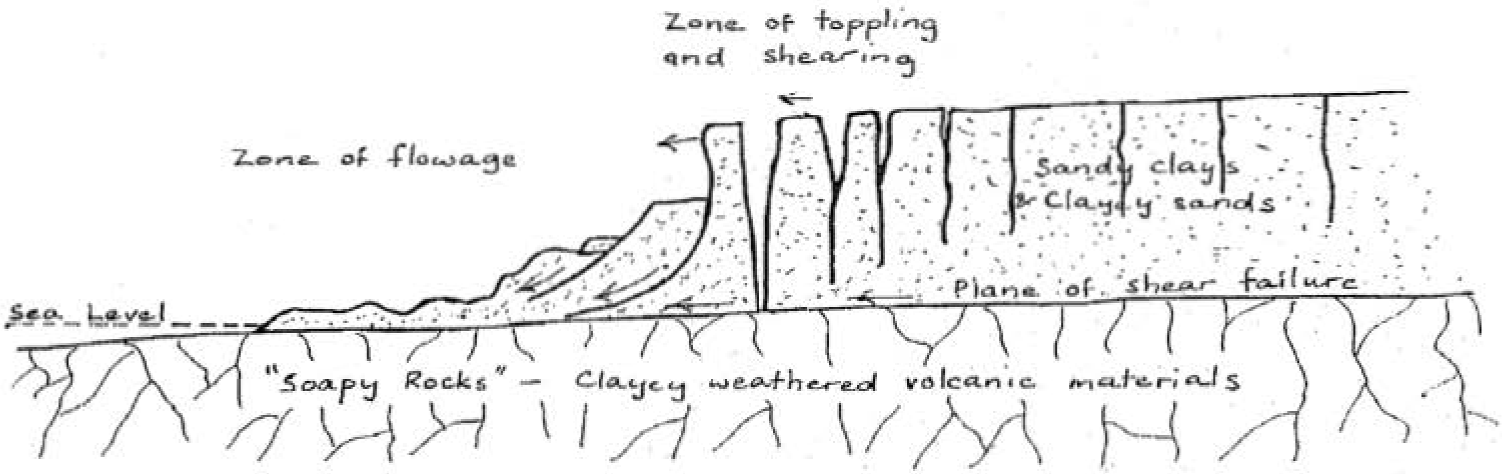


FIG. 14