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Abstract

The Illawarra escarpment is one of the most striking features of the N.S.W. coast, for it runs like a great unbreached wall for some 120km, and dominates the narrow plains below. Vet little hes been written about it, and some of the brief commentaries that have appeared are incorrect. This account outlines the major feature. of the escarpment, its origins, and also the hazards of land slip encountered on its slopes.

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THE ILLAWARRA ESCARPMENT – R. W. YOUNG

The Illawarra escarpment is one of the most striking features of the N.S.W. coast, for it runs like a great unbreached wall for some 120km, and dominates the narrow plains below. Yet little has been written about it, and some of the brief commentaries that have appeared are incorrect. This account outlines the major features of the escarpment, its origins, and also the hazards of land slip encountered on its slopes.

Although the escarpment is often regarded as beginning at Stanwell Park, it extends farther northwards forming the sea cliffs of the Royal National Park (Fig. 1). Along this northern extremity cliffs of 200 to 300m are broken only by short valleys and small bays. South of Coal Cliff the shoreline and the escarpment diverge until the coastal plain reaches a width of some 20km near Albion Park. Over this same section the height of the escarpment increases from about 350m to 650m; thereafter it remains fairly constant between 650 and 700m. South of Albion Park the escarpment swings eastward until its foothills reach the sea between Kiama and Gerrigong. Although an outlying line of hills continues southwards within a few kilometres of the coastline, the main escarpment swings again to the southwest, then near Nowra turns westward. It can be traced as far as the junction of the Kangaroo and Shoalhaven Rivers where it becomes indistinguishable in a complex network of canyons and cliffs.

ORIGINS AND DEVELOPMENT

The rocks from which the escarpment has been carved were deposited in an ancient area of subsidence known as the Sydney Basin (see Branagan et al., 1976 for detailed accounts of the deposition). At the close of Triassic times, about 180 - 200 million years ago, these layers of sedimentary and volcanic rocks began to rise above sea level. Earth movements on the southern side of the Sydney Basin took the form of broad warping upwards towards the south and southeast, so that beds like the Hawkesbury Sandstone which still lie near sea level in the centre of the basin can be traced to elevations of 600 metres in the vicinity of Kiama and Nowra (Fig. 1). The extremely straight, wall-like sections near Wollongong and Nowra prompted some early researchers to attribute the escarpment to large scale faulting with the plateau being uplifted and the coastal lowland left near sea level. But this idea is obviously wrong because individual beds of rock can be traced from the lowland right in under the escarpment without any evidence of faulting (Fig. 2). The small faults that are encountered in the region tend to run at right angles to, rather than parallel to, the escarpment, and detailed stratigraphic studies show that most formed long before the uplift of the plateau. If major faulting did accompany the uplift of the Sydney Basin rock strata, then it must have been located east of the present shoreline, perhaps beyond the edge of the continental shelf.

The escarpment that we see today is the product of erosion and the gravitational movement of debris downslope. Moreover the denudation of the eastern edge of the plateau has gone on over an extremely long period of time. The escarpment was long thought to be a young geological feature for most of the uplift of the rocks of the Sydney Basin was considered to have occurred only a few million years ago. However, recent radiometric dating of basalts on the coastal lowland near Ulladulla indicate that virtually all uplift along the southeastern margins of the N.S.W. highlands had occurred by at least 25 to 30 million years ago (Wellman and McDougal, 1974; see also Young, 1978). Occasional earthquakes centred in the Robertson district suggest that some minor earth movement might still be taking place, but this seems to be negligible in the long-term history of uplift.

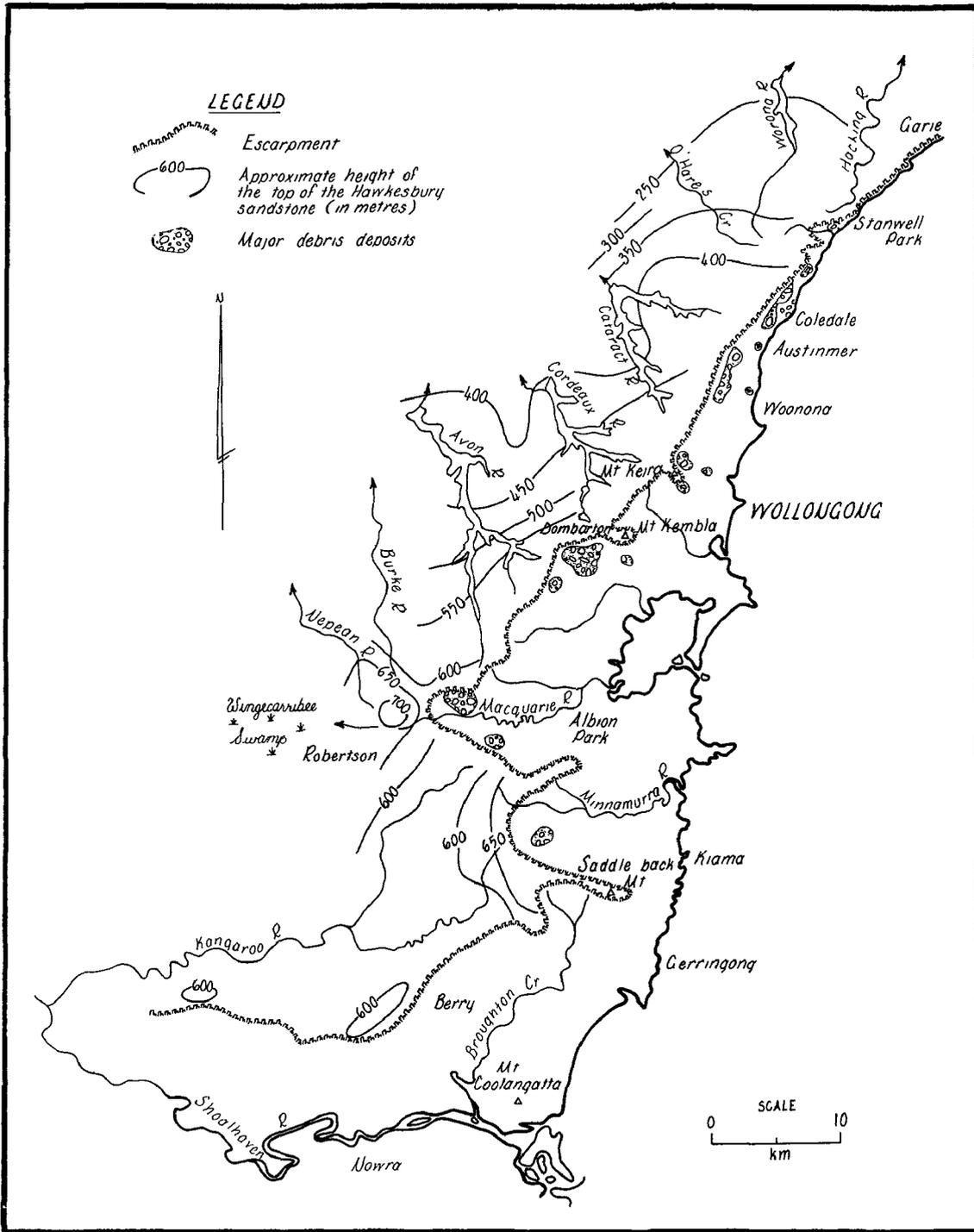
Some parts of the escarpment have been worn back much farther from the coast than have others. At first sight this seems, as Griffith Taylor (1923) argued, to be simply a matter of the differential resistance to erosion of the varied rocks exposed along the escarpment. Taylor considered that the great increase in the width of the coastal lowland between Coal Cliff and Albion Park was due to the southward increase in the thickness of the weak Illawarra Coal Measure beds exposed to erosion, and that the narrowing of the lowland near Kiama could be attributed to the outcrop of tougher volcanic rocks around the old volcanic plug of Saddleback Mountain. The increasing thickness of shales exposed under the volcanics as the escarpment again swings away from the coast south of the Kiama-Gerrigong district would seem to add additional weight to Taylor's idea. But as plausible as this idea may seem, it does not stand up to close inspection.

Taylor cited the increase in height of the top of the Coal Measures as evidence supporting his claim that greater thicknesses of weak rock were exposed in the southern part of the region. Unfortunately he overlooked the fact that the Coal Measures actually become thinner towards the south. The weakness of his argument is clear when the thickness, rather than the height of the Coal Measures is compared to the distance of the escarpment from the sea (Table 1). Moreover the argument fares no better when the thickness of exposed beds of the Narrabeen Group, which also contains some very weak claystone beds, is added to that of the Coal Measures. They too become thinner towards the south. Indeed the sea cliffs in the far north around Garie Beach, where there the escarpment comes right to the sea, include substantial beds of Narrabeen claystones. Finally, it should not be forgotten that thick outcrops of the tough volcanic latite (a rock akin to basalt) and tuffaceous sandstones (derived from volcanic rocks) occur on the widest parts of the coastal lowland in the valleys of the Macquarie Rivulet and Minnamurra River.

TABLE 1

Locality	Coal Measures Exposure (m)	Narrabeen Group Exposure (m)	Distance of Scarp Crest from Sea (km)
Bulli Pass	120	200	4
Mt. Kembla	210	165	9
Wongawilli	150	150	16
Macquarie Pass	110	105	25

The weakness in arguments like Taylor's is that they consider only variations in resistance to erosion without taking into account variation in the distribution of erosive forces. The key to the latter lies, of course, in the pattern of streams, for the greater discharge of large streams enables them to more readily cut into the escarpment than can small ones. Perhaps the most curious feature of the Illawarra escarpment is that the major streams rising near its crest almost invariably flow inland to the Nepean, Wingecaribee and Shoalhaven drainage systems. With the exception of the Macquarie Rivulet and the Minnamurra Rivulet, only very small streams flow directly to the Illawarra coast. This curious pattern can be readily explained by reference to the geological structures of the region (Fig. 1). The rivers flowing inland follow the fall of the Hawkesbury Sandstone which forms the plateau surface, while the Hacking River that flows to the Northeast parallel to the coast follows a variation in the direction of the dip of the sandstone - for a detailed account of the relation between structure and drainage in the region see Young and Johnson (1977) and Young (1978). Even the orientation of the Broughton Creek system which flows southward parallel to the coast from Saddleback Mountain to join the Shoalhaven River can perhaps be attributed to local warping caused by the intrusion of the volcanic plug (Fig. 2) and to depressions in the Hawkesbury Sandstone in the Berry district; unfortunately not enough of the sandstone capping survives to provide conclusive evidence.



The significance of the concentration of erosive energy along the major streams is readily seen in the contrast between the deep valleys cut behind the escarpment by the tributaries of the Nepean and the much smaller valleys cut into the face of the escarpment by the tiny coastal streams. In the extreme north the Hacking River has eroded a long valley parallel to, and only a few kilometres or so behind the sea cliffs, while none of the coastal streams has been able to breach the intervening divide. Only in the vicinity of Otford, where Stanwell Creek cuts a few kilometres back into the escarpment and where the Hacking Valley lies immediately behind the sea cliffs, has even the sandstone capping of this divide been removed. Farther south much larger coastal streams such as the Macquarie Rivulet have worn the escarpment well back from the shoreline. Then behind Kiama, where the major drainage lines

run south and southwest to the Shoalhaven River, the escarpment again swings close to the sea. However the concentration of erosion is probably best illustrated in the far south where great gorges have extended almost to the headwaters of the Kangaroo River and its tributaries. These gorges completely outflanked the narrow section of the escarpment known as the Cambewarra Range. In fact, the real edge of the highland lies farther to the east, along the ridge which runs from Saddleback Mountain to Coolangatta Mountain. There, where surface runoff has been funnelled parallel to the coast down Broughton Creek, steep hills rise immediately inland from the coastal dunes. It is thus the pattern of drainage, rather than the distribution of rock types, that has played the main role in determining the position of the escarpment.

SLOPE FORM AND SLOPE DEPOSITS

The main expression of the varied resistance of rock types to erosion is in the benched topography of the escarpment, for some rocks can support much steeper slopes than can others (Fig. 2). Along almost its entire length the escarpment is capped by a prominent cliff line of Hawkesbury Sandstone. Even where little of the sandstone remains it still forms near-vertical faces. The small flat-topped sandstone residuals on the Cambewarra Range between Berry and Nowra, for example, are strikingly reminiscent of the mesas of arid lands, and incidentally demonstrate that mesas are by no means limited to dry climates as many textbooks would have us believe. The cliffs seem to be retreating very slowly for, with the exception of the great rock fall at Dombarton near Dapto where subsidence due to mining may have had some effect, there is evidence of only a few quite small contemporary collapses along the entire escarpment.

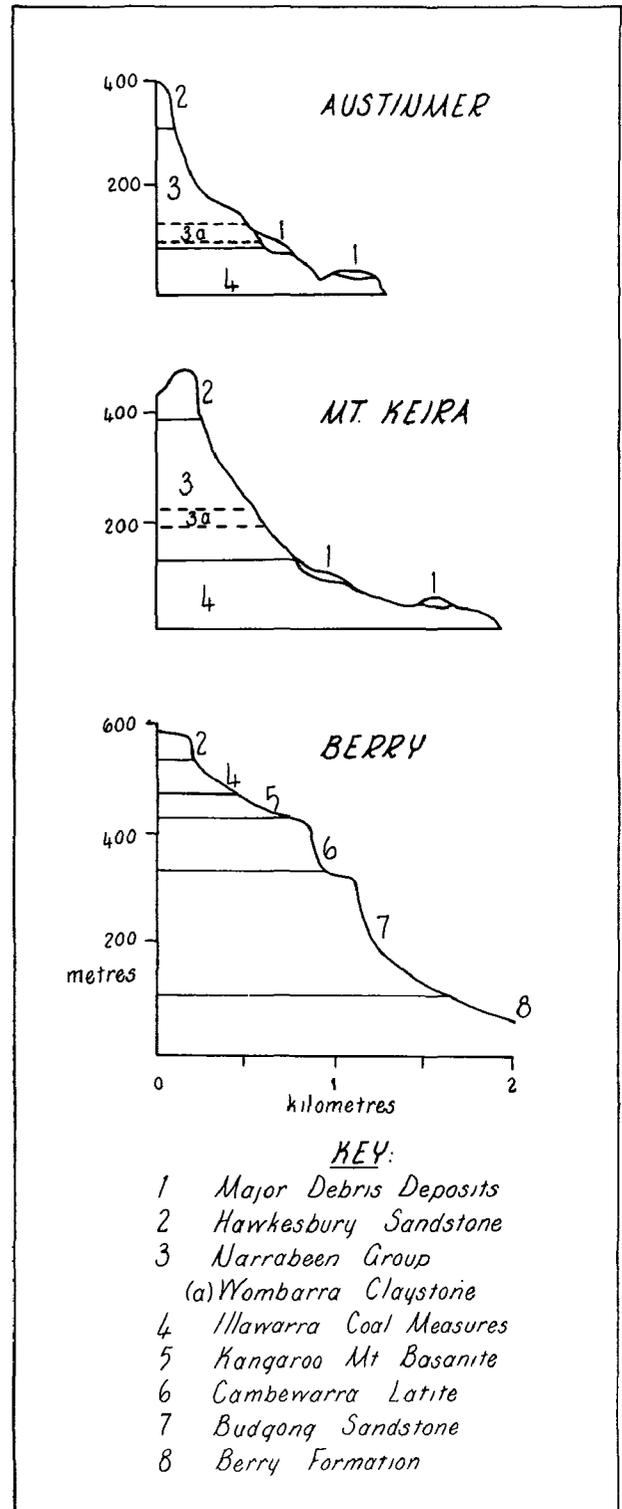
It seems likely that the Hawkesbury Sandstone now forming the top cliffline was once itself capped by at least thin beds of Wianamatta shale which has since been stripped by erosion. Small patches of shale still survive behind the crest north of Wollongong and larger residuals form prominent hills above the sandstone behind Jamberoo are in turn capped by basalt which has been dated at about 35 million years (Wellman and McDougall, 1974).

Not only do the slope forms change vertically on the escarpment, they also change laterally along its length as additional beds are exposed. For example on the northern sea cliffs, where the Narrabeen Group is thick and is being undercut by wave erosion, the Bulgo, Scarborough and Coal Cliff Sandstones form bold vertical faces. Farther south these three sandstones form only small, discontinuous cliff lines. In contrast to the steep slopes on the sandstones, the claystones of the Narrabeen Group support much gentler slopes. There are two prominent claystone benches north of Wollongong, one lying on the Stanwell Park Claystone and a generally larger one lying on the Wombarra Claystone. The Wombarra Claystone bench has been the site of recent residential development and, as is discussed below, the weakness of the rock poses serious land slip problems.

As exposures firstly of the Coal Measures and then on the Gerringong Volcanics increase, the pattern of benching becomes more and more complex. Excellent examples of these numerous breaks of slope can be seen around Kiama and Jamberoo, where the latites and some of the tougher sandstones stand in quite steep faces. South of Saddleback Mountain secondary cliffs, especially those developed on the Cambewarra Latite and the Budgong Sandstone, become increasingly prominent on the middle slopes of the escarpment. In fact the Budgong Sandstone forms by far the most prominent cliffs on the escarpment west of Nowra. In contrast to cliffs developed on this sandstone, much gentler slopes are found on the shales of the Berry Formation in the Berry and Nowra districts, though thin sandier beds in the shales do form small sharp breaks of slope north of Nowra. Yet of all the slope forms in the entire region probably the most visually striking are the steep convex slopes formed on the volcanic agglomerate (a rock composed of fragments of volcanic material) of the old plug at Saddleback Mountain. Saddleback looms large from virtually all sections of the escarpment and the coastal lowlands.

The characteristics of the mass movement of debris vary from one rock type to another. Rockfalls are the most common type of movement on the Hawkesbury Sandstone cliffs and also on the sea cliffs that are prominent north of Austinmer. Debris slides are the main type of movement on the latites and weaker sandstones, while mud flows and slumps (with some rotational movement in the debris) are characteristic of the claystones. While rock type is a reasonable guide to slope form and processes, other factors exert an influence. For example, the steepness of slope developed on the sandstones depends to a large extent on whether softer rocks have been exposed beneath them; under-cut sandstone slopes are generally near vertical, but those which are not generally have slopes of lesser declivity.

There is considerable diversity in the character of the debris mantling the slopes of the escarpment. Very little debris occurs on the steep slopes immediately below the upper cliff line, the thick talus deposits (coarse rocky material) referred to by several authors simply do not exist. The mantle of debris and soils on these slopes is rarely deeper than 0.5m and bedrock frequently outcrops. Material falling from the cliffs cascades down to lower slopes. The large blocks which tumbled down in the Dombarton fall carved a swath through the forest and stripped off the soil leaving a straight bedrock slope.



The debris on the lower slopes can be classified into two types. The first, which consists of rock fragments in variable amounts of a sandy or clayey matrix, shows little sign of weathering and was probably associated with relatively recent mass movement (Young, 1977). The second consists of abundant sandstone boulders set in a finer matrix with very striking red and white mottling (Young, 1977). As the mottling is clearly the result of prolonged weathering, the latter group of deposits must be relict features that came down in ancient slides or falls. Their age is uncertain, but, as the mottling is far stronger than that in river terraces dated at 29,000 years (Walker, 1962), they are almost certainly much older than 30,000 years. Given that mottled deposits cap an isolated hill at Austinmer, and occur several kilometres out from the foot of the scarp at Campbell Street Woonona, their age might well be measured in hundreds of thousands of years. Even the eroded remnants of the old mottled deposits are far larger than the debris mass from the biggest contemporary fall - i.e. Dombarton. Moreover they lie on quite low slopes, whereas the Dombarton debris did not even reach the first major bench on the escarpment's face. Thus the mottled debris deposits seem to have been associated with movements far larger than we now experience in the region. They may well have been triggered by truly catastrophic rock falls from the cliffs perhaps under climatic conditions much wetter than those of the present day.

Both the mottled and unmottled types of deposit are encountered frequently between Mt. Keira and Stanwell Park. Good exposures can be seen on the lower parts of Mt. Ousley Road, in the rail cutting at Campbell Street, Woonona, in the Bulli brick pits, just north of Headlands Hotel, and in the rail cutting at Denmark Street Coledale. The deposits are less common south of Wollongong, but excellent examples occur on the lower part of Jamberoo Pass, and smaller exposures can be seen at Minnamurra Falls Reserve and on Macquarie Pass. There are few large debris deposits south of Kiama, apparently because the generally smaller cliffs and the more well developed benches have a retarding effect. However, remnants of a fairly large fall can be seen at the southern end of Kangaroo Mountain on the scenic road north of Cambewarra Lookout.

SLOPE STABILITY

The steep slopes, weak bedrock, thick debris deposits and high rainfall encountered on sections of the Illawarra escarpment pose serious problems for the construction of transport lines and especially for residential development. Detailed studies near Wollongong (Bowman, 1972; Young, 1978) revealed that while many failures occurred on very steep slopes, the majority of serious failures occurred on the more gently sloping benches and foot-hills. When the location of the failures was plotted it became clear that two rock strata, the Sydney Subgroup of the Coal Measures, and the Wombarra Claystone, were the most hazardous in the area. However many of the failures have occurred in the debris deposits covering the bedrock because, as Young (1978) notes, this debris "often contains expansive clays" and "its shearing resistance is low." Major failures in the Sydney Subgroup rocks

and overlying debris occurred on Mt. Ousley Road, while very serious ones on the Wombarra Claystone bench occurred at Morrison Avenue Coledale. Many major failures can also be seen on the Kiama Sandstone between Kiama and Gerringong.

The triggering of slope failure by prolonged or intense rainfall has been demonstrated in many environments. For the Wollongong area the critical minimum monthly rainfall needed to trigger such movements is about 250mm; failures were reported in 40% of months with rainfall in excess of this threshold level (Young, 1978). On the escarpment there is a 30-50% chance that this threshold will be exceeded in February alone, and a 10-30% chance that it will be exceeded in any of the months in autumn, winter and early summer. "Rainfalls likely to induce landslip are clearly a normal and, in historical time, not an infrequent feature of the climate of the Illawarra" (Young, 1978).

The threat of slope failure increases with height of the escarpment because of increasing rainfall as well as steepening of slopes. Annual rainfall on the coastal lowland at Wollongong is 1100-1200mm but near the escarpment crest it reaches about 1600mm. For the standard period 1931-60 the rainfall gradient from the coast to Mt. Keira was 72mm/km. In the wettest year on record, 1950, this gradient increased to 96mm/km, with 2250mm falling on the coastal lowland and over 3000mm on the Escarpment. What is more, the lower temperatures towards the crest reduce evaporation thereby making more water available for runoff and infiltration into the soil. An estimated 55% of the rainfall on the higher slopes becomes available for runoff and infiltration, whereas on average only 15% is available on the lowlands.

Residential expansion has itself increased the hazards of slope failure. Slopes have been oversteepened by excavation for roads and foundations. Natural drainage has been disrupted by buildings and roads, and the input of water has been increased from domestic supplies especially where no integrated drainage or sewerage system is available. A significant step towards controlling the problem of damage from land slip in Wollongong was taken when H. N. Bowman (1972) mapped the urban area into six zones of relative stability. The city council now requires stability assessments for any development proposed in the unstable zones, but unfortunately the zoning was not linked to a specific building code. The need for more detailed research became startlingly clear in 1974 when failures encroached on several areas mapped as relatively stable. Yet more than additional research is needed: the information needs to be made available to the general public. Unfortunately the existing legal codes hamper the dissemination of the facts known about the hazards of slope failure in the urban area, and there is no compensation available to those whose property is damaged. In this regard, New South Wales lags years behind many other places - including Tasmania which has tied building codes to its stability zoning. The final decisions must be made, and the burden of any damage resulting from what are legally classified as "acts of God" carried by the individual homebuyer, who is almost invariably totally untrained in assessing the hazards of the natural landscape.

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