

The Deterioration of a Dolerite Escarpment

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SUMMARY A dolerite escarpment above a mountain road near Hobart may pose a threat to tourist traffic, and a study has been made of several modes of deterioration. Relaxation, weathering and slow movement of dolerite columns leads to several kinds of instability, some of which can be dangerous. One phenomenon, the hinge block is of particular interest as its origin is obscure, but it does not present any danger.

1 THE IMMEDIATE AND BROADER PURPOSES OF THE STUDY

The writer is a geologist concerned with the geology of urban areas in Tasmania. This State has some pretensions as a tourist area, and Mt Wellington, the large mountain very close to Hobart is on the route of many tours by car and bus. The road to the summit passes diagonally across the mountain face as seen from Hobart, and close under the high cliffs just beneath the Pinnacle. In discussion with officers of the Hobart City Council, the question of rock-falls blocking the road and of the safety of traffic arose. The immediate aim of the study has been to examine the erosion processes operating on the mountain face, their nature, range, velocity and controls, so as to be able to form some idea of the hazard and risk. The broader purpose is to study the erosion processes of dolerite escarpments in general (and Tasmania has some 1 000 km of them) and perhaps shed some light on more complex hard rock escarpment failure. Little indeed has been written on the subject, and it is hard to find much outside general textbook accounts. Fairbridge (1968) gives some references but it is plain that the details of the mechanism from undisturbed rock to talus slope are largely unknown. Accounts mention isolated processes such as ice-wedging or the influence of water pressures, but the discrete stages in the process are not well known and in particular cases the rate of processes is usually guessed. Terzaghi (1967) gives an account of rock and rock joints, but is mainly interested in the stability afforded by cohesive and frictional properties and its maintenance rather than deterioration. Indeed he specifically says that his paper does not cover "rock slopes in (an) advanced stage of development". Yet this is the normal stage of a rock escarpment. New scarps are rare. Price and Knill (1967) is a detailed account of a particular investigation with a useful blend of geology and engineering, but is not much concerned with time-dependent mechanisms of deterioration. de Freitas and Watters (1973) deal with toppling failure and give some interesting examples, but do not deal with rock slope failure in general. Rock slopes in Tasmania have been dealt with by Hale (1957) who deals particularly with weathering and toppling is closely studied by Caine (1979).

2 THE DOLERITE SILL

Any visitor to Hobart immediately becomes familiar with Mt Wellington. The summit of the 1 270 m

mountain is only 7 km from the city centre and it forms an impressive backdrop to the city.

The dolerite sill lies sub-horizontally on the top of the mountain more or less conformably on Triassic sandstones and fine Permian quartz mudstones (Leaman 1976). The sill is about 210 m thick and the upper part, judging from the mineralogy and crystallinity is missing. It was perhaps 300 m thick originally.

The dolerite is of tholeiitic basalt magma composition and is a complex intrusion, much faulted in the Hobart area (Leaman 1974). The mass capping Mt Wellington is however almost a simple slab and is thought to be distant about 5 or 6 km from each of three feeders.

The most prominent feature of the escarpment face overlooking Hobart is the Organ Pipes, a face formed of dolerite columns 100 - 200 m high, but even the less prominent parts of the face are columnar also. The rock being almost constant in composition, with little gross variation even in grain size and a consistent columnar jointing makes it a good subject for a study of erosional deterioration.

3 STAGES OF DETERIORATION

A full account of the deterioration process must encompass every stage from the erosional uncovering of the dolerite slab from its sandstone roof-rock right through to the development, weathering and final disposal of the taluses. This ideal is not possible here and this paper should be regarded as a preliminary attempt to examine some of the questions raised by this very large phenomenon. Three in situ stages will be described, corresponding to the degree of confinement of the rock columns. The slab stage shows three-dimensional confinement with more or less retention of elastic stresses. The screen stage shows rows of columns standing free of the main mass, and the pillar stage shows remaining columns standing free of each other. Each stage has characteristic features which pose fascinating questions.

The intact slab was intruded into its Triassic sandstone-mudstone host rock in early Jurassic times (Leaman 1974) without catastrophic distortion, although some undoubtedly contemporaneous faulting occurred. No erosion can take place without uplift and this took place to expose the edge of the slab, on one of the many faults mapped in the Hobart area. No trace of this first cause of the escarpment now

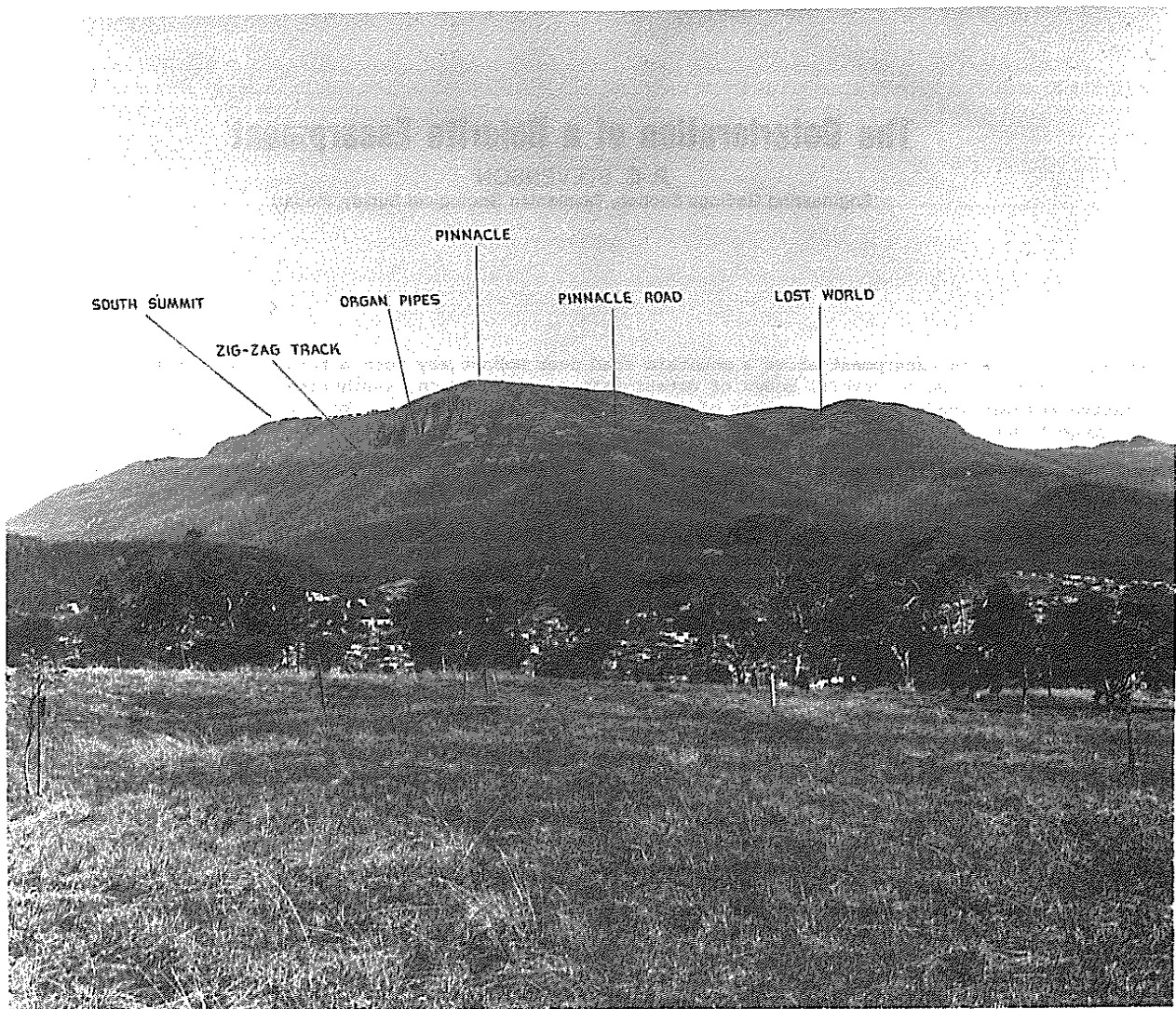


Figure 1 Mt Wellington seen from Hobart Domain. Localities mentioned in the text are indicated.

remains, and we can only consider the erosion as a continuing process. We can deduce that the uplifted slab retained its sedimentary cover for some time, but this was removed by erosion as were some scores of metres of the dolerite and the erosion process then took roughly the form we see in operation today.

3.1 The Role of Relaxation

We would expect the slab to contain some in situ stress. A major part, that arising from its thermal origin, would be lost in the development of the columnar joints but it appears to retain considerable tectonic as well as lithostatic stresses (A.J. Bowling, pers. comm.). Such results as exist parallel closely the work of Lee (1978) on the Niagara escarpment. The formation of a scarp face allows stresses to dissipate locally and this may be shown by seismic traverses observed on top of the mountain normal to the scarp face. These show that a higher velocity zone may be detected becoming shallower as one moves away from the scarp.

The relaxed edge of the slab is attacked by processes to be described in the next section, but the top surface is also attacked by weathering down

the lines of weakness created by the thermal columnar joints. The rock is not chemically very stable and in the presence of water easily weathers it to a reddish (or in reducing conditions) a greenish clay. This material is fairly impermeable and expansive, and readily blocks the joints, so that weathering penetration is limited vertically to a few metres where columns are well confined. Clay mineralogy is variable (see Hale 1957) but kaolin and montmorillonite are usually present, the latter particularly in ill-drained situations (W.L. Matthews, pers. comm.).

The simple picture of a relaxing slab edge is confused by the great variety of resulting effects, but two localities may be described to illustrate it. The back face of the Lost World (Fig. 1 and Fig. 2(a)) consists of a row of columns 1 - 2 m across and standing about 30 m high.

In many places this now stands a metre or so clear of the main slab behind so that a chasm is formed 30 m or so deep and often bridged by fallen blocks. It is difficult to see how this chasm can form except by slight outward toppling of the screen or by bodily translation outward. Time and again one

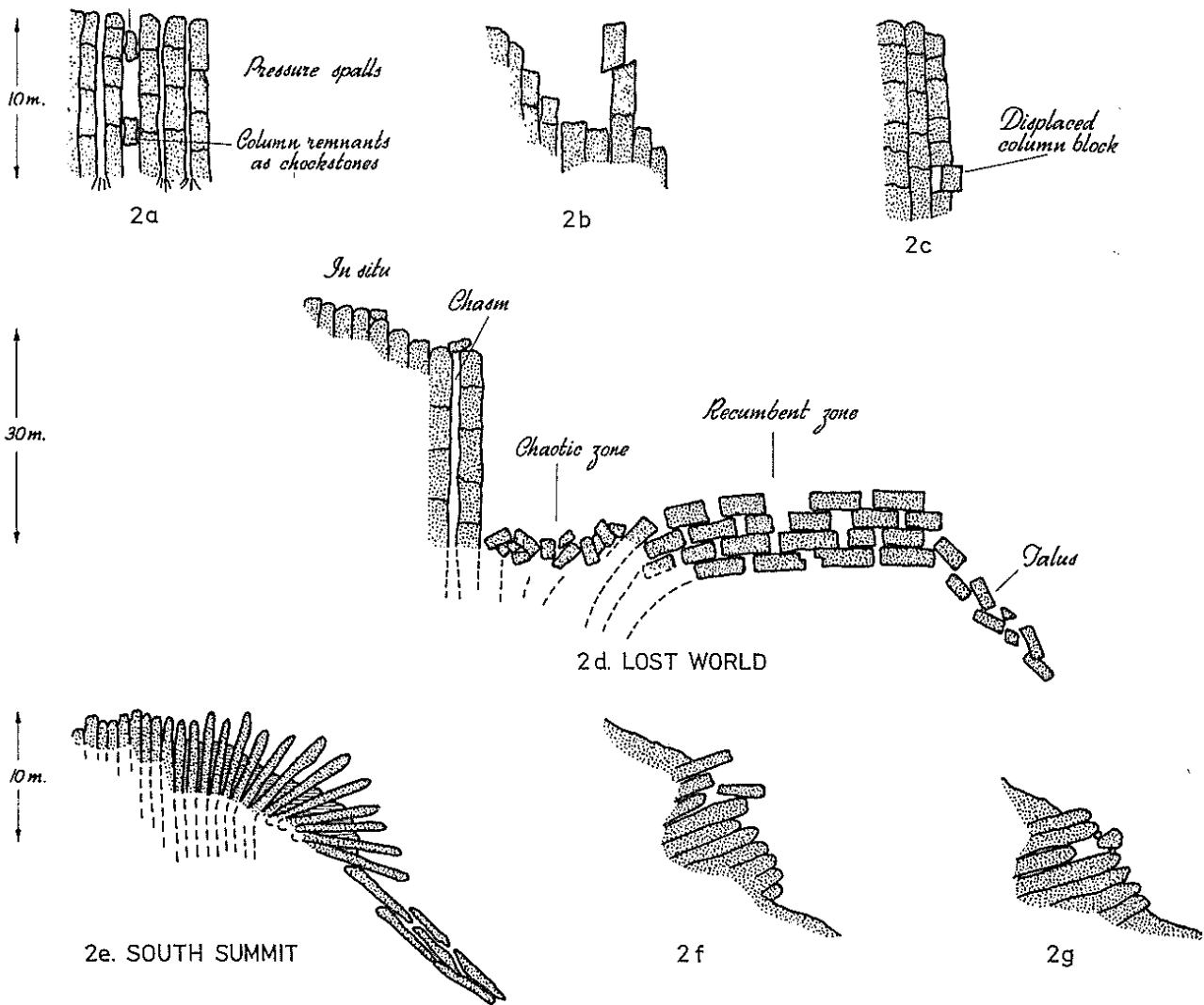


Figure 2 Features of dolerite escarpment deterioration

is confronted by dilemmas of this kind where no reasonable explanation seems possible and one has to choose the least unreasonable one. In this case the toppling explanation seems possible and we shall return to it. The second localities where one may see the effect of slab-edge relaxation are those mountain slopes to the north and south of the Zig-zag Track where vertical columns stand in turreted formations, apparently becoming more and more isolated from one another. It is not clear whether this increasing isolation is all caused by lateral movement of columns or partly by the weathering process described in the next section.

3.2 The Role of Weathering

The impact of weathering on the top of the slab has been mentioned. Decreasing confinement means that more faces are exposed to weather. Two modes of weathering are evident on the dolerite of the mountain. These might be called the high- and low-exposure modes. The first is seen on rock faces well-exposed to the rain, snow, wind, and frost of the alpine climate. The surface of the rock turns brown and becomes very rough from the evident etching-out of more vulnerable minerals. A skin of brown oxidised and hydrated rock forms up to 20 mm thick but normally much thinner. A dimensional

change occurs in this skin so that it readily spalls off, exposing unweathered blue dolerite beneath. Measurements with a Schmidt hammer show that a reduction in strength also occurs. The shed spalls collect at the foot of the surfaces, breaking up into a gritty crystal sand which soon disintegrates into clay soil. The spalling process is obviously a rapid one, as spalls may be seen lying on vegetation, and the fresh blue dolerite soon becomes brown. The process is a potent one in geological and even shorter time scales and results in thinning columns. It is of interest that the spalling phenomenon is not obvious on the rocks at Mt Wellington Pinnacle and only becomes common at distances of about a kilometre from it. The reason seems to be that the Pinnacle rocks are climbed on by a great number of visitors and the fragile spalls never grow to any size before being broken off.

The clay soils produced from the disintegrating spalls and from the rain-washing of weathering rock faces accumulate round the bases of columns and faces and become insinuated into the opening joints below. This is the low-exposure weathering situation. High exposure implies large and rapid temperature and moisture variations wind and rain splash, free access of air, sun and frost.

Low exposure implies fairly constant temperature high and constant moisture, water and snow ponding, and protection from frost and sun with rock faces mantled in clay and vegetation. In such conditions the proportion of montmorillonite increases and expansion and contraction of clay becomes important.

When weathering and relaxation act on screens or rows of columns the spaces between them increase from about 1 mm to perhaps as much as a metre. This appears to be brought about by lateral translation of the columns but probably to a greater extent by column thinning. At 1 mm per year the column will be drastically modified, so that individual columns may drop out of their row. Evidence that this has happened is provided by those cases illustrated in Figure 2(a) where column sections are left suspended as chock-stones while the remainder has disappeared. The increasing instability of the remaining columns enables them to grip the chock-stones firmly.

When columns become isolated either on top of the slab as tor-like masses, or on the slopes as castellated areas, the effect of high exposure weathering is fully felt. The thinning-down columns become increasingly unstable as their aspect ratio increases. Angular faces become increasingly attacked and therefore more rounded and the articulating joints of each column become rounded also. The rainwash is carried down each column and readily enters sub-horizontal joints providing a clay pad in the joint. Increasing instability produces slight toppling and the increase of pressure on the side of the column towards which it is moving spalls off a part of the corner (Fig. 2(a)).

The clay pad in an articulating joint may aid what appears to be a slow creep process on inclined joints when the upper part of a column becomes increasingly eccentric on the lower part (Fig. 2(b)). The reality of high-stress accelerated weathering in this situation is an unanswered question. The situation illustrated in Figure 2(c) is not unique and if it were not for the sizes of blocks involved one might suspect the hand of the practical joker.

Weathering, the resulting thinning and loss of confinement and the failure of joint surfaces will finally bring about the fall of individual columns, triggered perhaps by snow loading, wind, the swelling of clay in joints or growing vegetation. These processes are understandable and the probability of failure of columns could be mapped. But this course to failure is not universal and at least two other processes are illustrated on a large scale on Mt Wellington.

4 HINGE BLOCKS

The area known as the Lost World illustrates the feature named a hinge block by Prof. J.L. Davies. The essential elements are as shown in Figure 2(d). The in situ slab and the free standing screen have already been mentioned. Below this 30 m high face lies a jumbled mass of column sections, the chaotic zone, and outward again the recumbent zone, where 30 - 40 m of disarticulated but still easily matched columns lie almost horizontally in a stack at least five high. It is as if a section of the scarp face about 120 m long had fallen outward but had miraculously remained almost intact. Towards the scree slope the columns tilt over and fall to become incorporated in the random tumble of blocks.

How does it happen?

Could the columns actually be in situ? The orientation of columns is generally accepted to be the result of the heat-flow during cooling, so that columns form normal to isotherms. This could hardly be the case at the Lost World for it would imply a sharp discontinuity in the heat flow. Horizontal and vertical columns exist alongside each other at the sides of the structure. Neither does it seem possible that the fall was catastrophic. Any rock fall involving a mass of columns five deep, falling fifty metres and rotating through a right angle could hardly fall so as to retain mutual relationships. The block glide process could deal with this mass, but could not produce the rotation.

We do not see any process operating today which could form the hinge block, unless it were very slow, too slow to be deduced or detected by observation. We must look for a powerful but slow agent not presently active and an obvious one is the harsh climate of the last glacial maximum. This may be assumed to have produced thick though not necessarily permanent mantles of snow and ice particularly on the lee sides of mountain tops. Ice consolidating around barely stable groups of columns could have cemented them together and not only caused them to topple but also cushioned their fall. The columns would have bent over and been lowered into their present position to be subsequently freed from their jacket of ice. If this picture is true then the presence of more inclined columns and possibly talus under the chaotic zone would confirm it.

The Lost World is an excellent and well exposed example but recumbent columns are common elsewhere on the mountain face. Above the Zig-zag Track they are very common and exist in hundreds, inclined at about 10° into the face. There the upper surface is not clearly exposed, being mantled in blocks and soil from above. Nevertheless the column ends project from the slope and climbing amongst them reveals the same disarticulated but still recognisable columnar mass. In this location too, no vertical back face is apparent, as if the chaotic zone had expanded to fill the void and mantle the whole structure.

5 TILTING

The South Summit of Mt Wellington shows another process of deterioration, illustrated in Figure 2(e). The nature of weathering and the production of clay soils has been mentioned. Where vertical columns become thinned down the resulting clay may accumulate round column bases so that each becomes clay-socketed. In these low-exposure conditions the column bases may be strongly attacked. When toppling finally supervenes, columns can move individually but are restrained by the clay socket, and by interference of the column roots in the clay matrix. Seasonal wetting and drying of the clay enables periodic movement to take place and the result is the slow-motion falling illustrated. An abundance of long thin columns provides ample space for the clay bed to form and control the process.

Soils, both as expansive clays and as hosts for vegetation appear to be important in many parts of the deterioration process. When a spring thus occurs after snowfall, a soil scar is apparent under almost every rock on soil mantled slopes. Its appearance is as if the soil and vegetation had moved 20 or 30 mm down slope leaving a bare soil rim below every rock. The reality of this movement has yet to be demonstrated.

6 PERCHED AND TRAPPED BLOCKS

Of the many peculiar items of dolerite escarpment deterioration, two others deserve mention. Rocking boulders are quite common in other rock terrains, particularly granites, and one is illustrated, from east of the Pinnacle in Figure 2(f). The other item is shown in Figure 2(g). This 8 m³ boulder is trapped between two projecting recumbent columns and is retained by two hand-sized chocks, one on each side. Were it not for the size and precarious position of this rock and the sheer difficulty and danger of making this arrangement one might again suspect a practical joker. As it is, the explanation offered for both these items is a more prosaic one, where boulders becoming buried either in ice or soil are subsequently exhumed by melting or rainwash and the random contacts made while buried become temporary supports for a few.

7 CONCLUSIONS

From the descriptive work that has been done, it will be obvious that the aim of estimating risk of danger from rock fall is still far off. Nevertheless, if these are the sorts of mechanisms that operate they could perhaps be arranged in order of hazard. Perched and trapped blocks though unsafe are not usually large. Thinning, isolated columns constitute a much greater mass, and although they fall with less frequency are many times greater in number. Clay socketed columns and hinge blocks though interesting in their geomorphic implications are not an appreciable danger.

Such an ordering, combined with a locality map and a fall track map as has been used by D.G. Price (pers. comm.) would be a further stage on the way to a practicable risk estimate. In spite of the spectacularly precarious appearance of many blocks on the mountain, risks to persons and vehicles do not appear to be great, possibly because the rolling range of column sections is not as great as might be expected because of their elongated shape. The investigation is however too incomplete for complacency and work will continue.

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