The Evolution of Landslide Slopes in Dorset [and Discussion]

D. Brunsden, D. K. C. Jones and Muriel A. Arber

Phil. Trans. R. Soc. Lond. A 1976 **283**, 605-631
doi: 10.1098/rsta.1976.0097

Phil. Trans. R. Soc. Lond. A. **283**, 605–631 (1976) [605]
Printed in Great Britain

The evolution of landslide slopes in Dorset

By D. Brunsden
Department of Geography, King's College London

and D. K. C. Jones
Department of Geography, London School of Economics

[Plates 12 and 13]

The form and evolution of Fairy Dell, an active landslide complex on the Dorset coast, is described using a combination of cartographic, air photograph and field survey techniques. Erosion rates for the main landslide scars, undercliffs and sea cliffs are calculated and the spatial patterns of landslide evolution demonstrated by the use of sequences of maps and geological cross sections. Two dominant mechanisms are identified and described: (1) rotational landsliding and (2) block disruption, the breakup of originally large landslide units as they move downslope and over time. The role of small-scale erosion, in combination with the infilling of depressions by scree, wash debris and mudslides so as to produce an increasingly subdued topography as the landslides degrade, is emphasized and simple evolutionary models are proposed. The active landslide complex is then compared with the now stable, degraded landslide slopes inland. It is shown how the spatial patterns of landforms recognized in these areas on morphological maps and the complex subsurface forms revealed in sections can be better understood by reference to the suggested evolutionary sequence developed for the active complex. The sections in the stable but degraded slopes clearly support the idea of retrogressive rotational landsliding followed by block disruption, infilling and the downslope reduction of topographic expression of landslide units. Finally, it is suggested that this evolutionary interpretation might assist in the understanding of similar areas elsewhere and, if used in conjunction with geomorphological surveys, could result in the planning of more efficient site investigations.

1. Introduction

Many escarpments in Britain have suffered from long-term instability, especially those where a permeable arenaceous layer overlies less permeable strata. Under such circumstances morphologically complex slopes have been developed on extensive spreads of landslide debris which may extend for several hundred metres downslope. Two downslope trends are generally discernible in such areas: a decrease in average slope angle toward a state of ultimate stability against landsliding and a reduction in the topographic expression of individual mass-movement units (Hutchinson 1967; Chandler 1970; Brunsden & Jones 1972). These areas clearly represent 'potential hazard zones' for construction. It is important, therefore, that more information be obtained on their topographical characteristics, distribution and evolutionary development so as to reduce the costs resulting from the renewal of landsliding activity, either during building programmes or subsequent to completion.

In a recent paper (Brunsden & Jones 1972) the pattern of landslides on degraded hillslopes in Dorset was investigated by means of geomorphological mapping techniques. As the methods employed led to the clear identification of the extent of disturbance, it was suggested that they could usefully be employed as reconnaissance procedures before site investigation, as has subsequently proved to be the case (Brunsden *et al.* 1975). In the example investigated, the Char Valley flanks of Stonebarrow Hill (figure 1), the characteristic sequence of rotated blocks and subdued undulations were identified lying beneath steep upper slopes and large arcuate coombes; the latter appearing to be the product of 'zones of aggression' which migrated upslope as a chain reaction from points of initial disturbance at lower elevation. The spatial distribution of morphologically distinguishable landslide units led to the suggestion that the lower slopes had evolved through the interaction of two mechanisms. First, that as the slipped masses continued to settle slowly downslope, new landslides occurred in the degradational zone above, thus resulting in a sequence of rotational landslides with time. Secondly, that the large blocks produced by these initial failures subsequently disintegrated into smaller and smaller units which became increasingly subdued morphologically as they moved downslope. The term 'block disruption' was adopted to describe this latter process.

In the present paper the morphological patterns observed on the valley-side slopes of Stonebarrow Hill, including the area previously described, will be compared with those being currently produced within the adjacent active coastal mass-movement complex of Fairy Dell (figure 1). This exercise has three main objectives. First, to bring forward further evidence in support of the 'block disruption' hypothesis. Second, to argue that the mechanisms and evolutionary patterns identified in the presently active coastal complex greatly assist in the interpretation of landform development on the inland slopes, all of which are underlain by similar stratigraphic successions. Third, the postulated evolutionary sequence together with sections in the degraded landslide slopes will serve to indicate the complexity of subsurface conditions likely to be encountered in such areas and therefore the necessity for both 'extensive' as well as 'intensive' site investigations prior to engineering work.

2. Topography and geology

Stonebarrow Hill is a broad and prominent NE–SW oriented ridge located on the west Dorset coast between Charmouth and Golden Cap (figure 1). Its inland slopes descend to the River Char on the northwest and to several smaller streams on the southeast, and are extensively mantled by superficial spreads of landslide debris, scree and 'head' (Brunsden & Jones 1972). The southern end of the ridge has been truncated by marine erosion and forms one of the varied landslide complexes that fringe Lyme Bay (figure 2, plate 12). Here the 40–50 m high sea cliffs are overlooked by a large amphitheatre 1400 m long, a maximum of 350 m deep and up to 85 m high, known as Fairy Dell (Arber 1941), which is the scene of current mass movement activity.

The hill mass consists of a thick capping of arenaceous Lower Cretaceous sediments (Upper Greensand and Gault) resting uncomfortably on predominantly argillaceous Middle and Lower Liassic strata (Wilson, Welch, Robbie & Green 1958) (figures 1 and 4). The Lias generally dips ESE at 2–3° although locally disturbed by minor intra-Jurassic folds and faults, while the overlying Cretaceous deposits and the plane of unconformity dip SW at approximately $2\frac{1}{2}°$.

The ridge summit is developed on Upper Greensand chert beds and declines in elevation southwestwards with the dip. This capping stratum is composed of up to 9 m of closely jointed chert separated into two or three major beds by narrow layers of coarse dark green quartz sand. The remaining 30 m of the Upper Greensand formation consists of a yellow-orange fine sand known locally as Foxmould, composed predominantly of particles in the size range

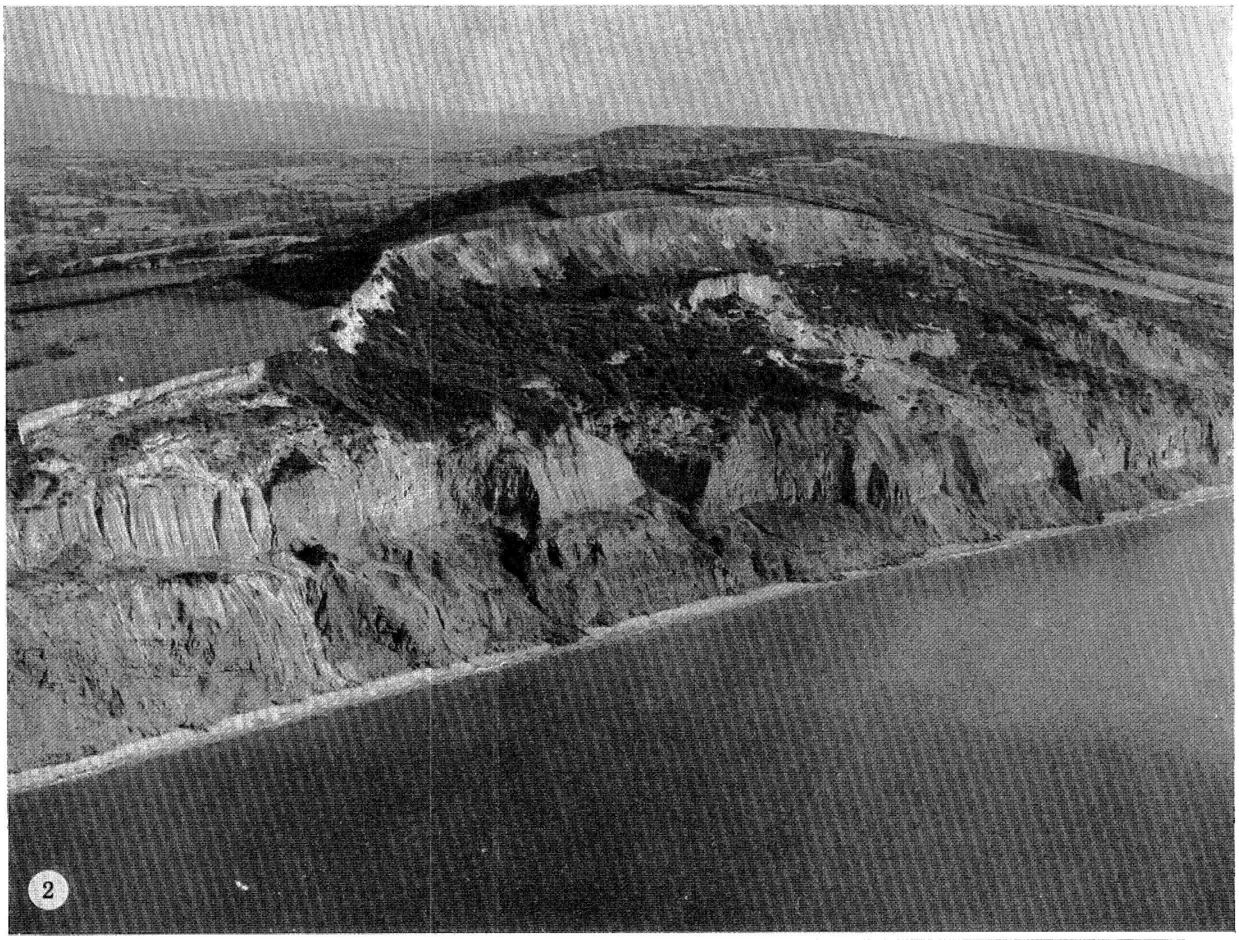


FIGURE 2. Oblique air photograph of Stonebarrow Hill, the Fairy Dell landslide complex and the degraded, inland landslide slopes (copyright N. Barrington, 1969). Photograph date: 9 August 1969.

FIGURE 3. Vertical air photograph of Stonebarrow Hill, the Fairy Dell landslide complex and part of the degraded, inland landslide slopes described in an earlier paper (Brunsden & Jones 1972) and compared with the active slopes in this paper. (Copyright D. Brunsden, Fairey Aviation, 1969). Attention is drawn to the irregular topography near the houses to the west (left) of Fairy Dell and the areas of woodland which conceal the large landslide coombes at the head of the degraded slopes.

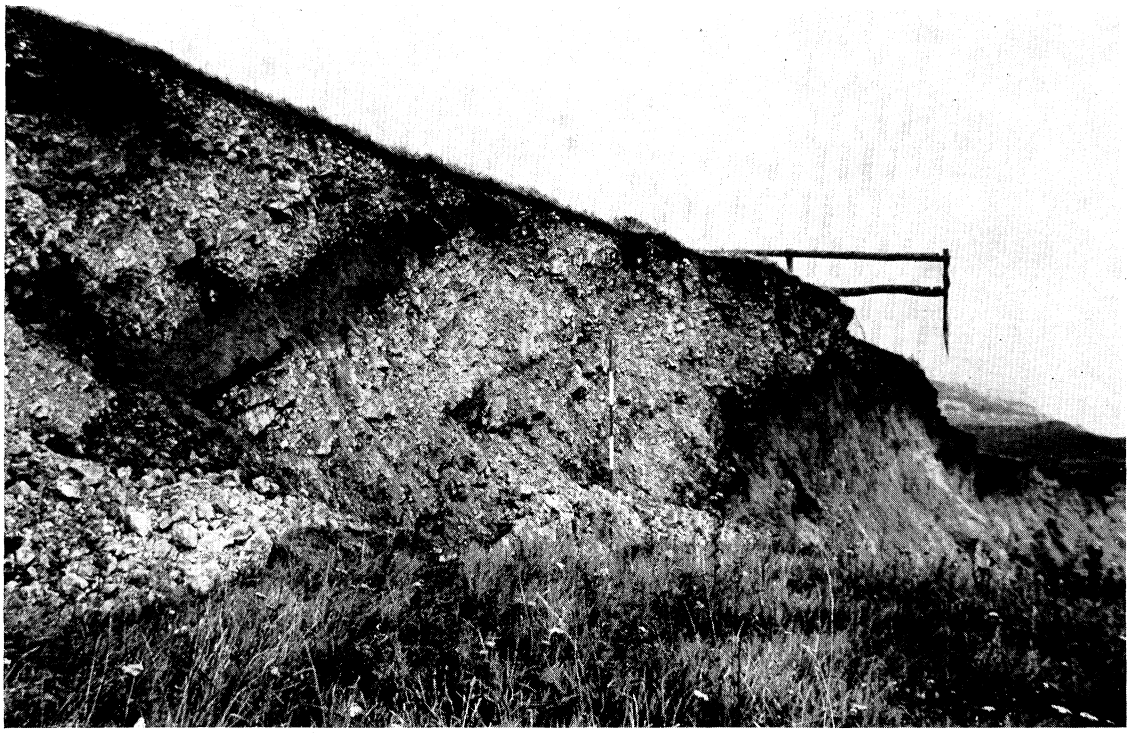


FIGURE 15. Photograph of the degraded landslide block exposed in the coastal section near Westhay Farm. The backtilted Upper Greensand cherts are clearly visible and should be compared with the upper portion of the Fairy Dell section (figure 4).

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

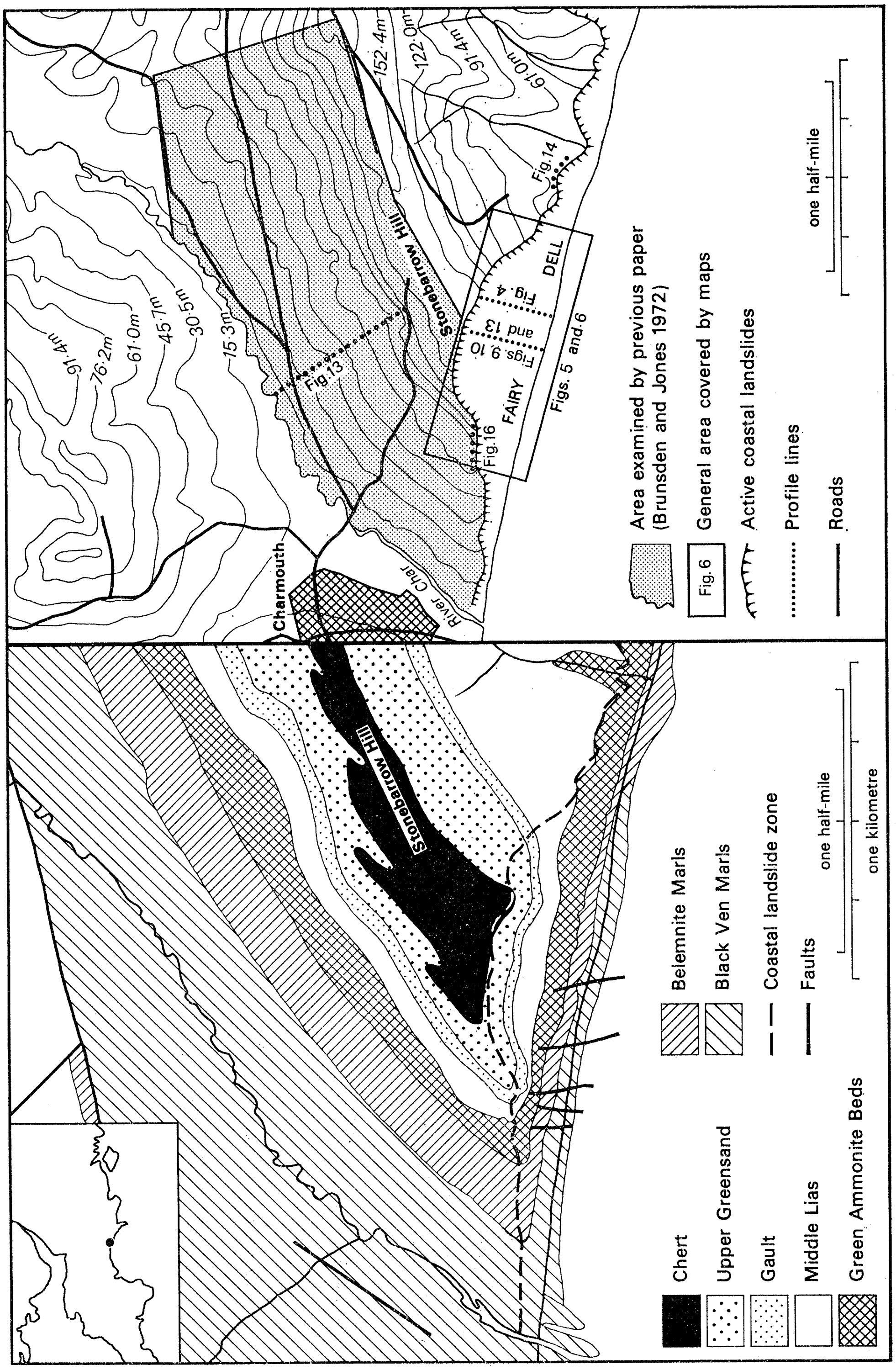


Figure 1. Geology, topography and location of the study area. Sources: Institute of Geological Sciences, Memoir, and 1:63360 survey sheets (sheets 327 and 312), Ordnance Survey 1:25000 maps.

0.06–0.2 mm and having average liquid and plastic limits of 37 and 22 % respectively. The underlying Gault is considered to consist of approximately 12 m of fine blue-green sandy-clay with occasional pebble beds, although exposures are rare and almost certainly out of position due to landsliding (Lang 1914).

The Middle and Lower Lias deposits beneath the sub-Albian unconformity consist mainly of silts and fissured clays interbedded with thin bands of limestone, calcareous sandstone and layers of limestone nodules. Although the composition of the upper portion of the Stonebarrow sequence is difficult to determine due to the lack of exposures, it is generally considered to include a westward thinning wedge of Middle Lias (Wilson *et al.* 1958). Thus in Fairy Dell, a variable thickness of Three Tiers (Middle Lias) overlies 20 m of Green Ammonite Beds, 68 m of Belemnite Marls and a variable exposure of Black Ven Marls due to the east-southeast dip (figures 1 and 4). The Lower Lias shales are overconsolidated and densely fissured. They have grain-size characteristics of fine silts and clays, 0.001–0.02 mm, while samples obtained from typical mudslide areas show average liquid and plastic limits of 48 and 24 % respectively.

3. The Fairy Dell landslide complex

(*a*) *Sources and methods*

A considerable volume of data concerning the distribution of land forms, interrelationship of mass movement processes and short-term evolutionary developments has been obtained from geomorphological surveys and observations carried out since 1964. For longer term changes two additional sources of information were utilized so that the spatial pattern of slope evolution could be revealed.

First, detailed Ordnance Survey plans on a scale of 1:2500 were examined. These are available for 1887, with revisions in 1901, and 1921, and for 1953 with boundary revisions in 1960. Although these plans do not show the individual landslide units, steep slopes are depicted by hachuring and can therefore be used to indicate gross form and to provide some indication of the extent of movement. Further, the boundary survey repetitions provide a useful picture of the changing position of high water mark and the retreat of both the sea-cliffs and the main landslide scar which defines the landward margin of the Fairy Dell amphitheatre (figure 5).

Second, vertical air photographs for 1946, 1948, 1958 and 1969 (figure 3, plate 12) are available at scales ranging from 1:4000 to 1:16000, together with oblique air photographs for 1946 and 1969. With the exception of the 1958 photograph, these are of good quality and allow the clear identification of such geomorphological features as landslide units, mudslides and gullies, as well as the accurate determination of the pattern of cliff retreat. The 1958 photograph is, unfortunately, rather heavily distorted and was therefore used only to obtain a rough guide of the evolutionary development during the period 1948–69.

Three maps (figure 6, *a–c*) were prepared from these photographs but lack of suitable equipment and the non-availability of stereo-cover made it impossible to correct for scale distortion. No measurements of movements within the landslide complex are therefore available. It is intended that these maps should be compared with each other for the purpose of identifying the general evolutionary pattern, and with the previously published survey of inland slopes shown in figure 11 (Brunsden & Jones 1972).

Before considering in detail the evolutionary patterns displayed in Fairy Dell, it is necessary to add a few words of caution concerning the use of map evidence. It has been found that early maps are often inaccurate in the depiction of areas of 'marginal importance' situated away from settlements (Carr 1962). Although the Ordnance Survey has a good record in this respect, it seems unlikely that the accurate representation of relief in an active landslide complex would have held a high priority in the minds of most nineteenth century surveyors. It should also be noted that the depiction of steep slopes by means of hachuring often owes more to artistic licence than to topographic form. Several major discrepancies were found in the 1:2500 plans used in the first geomorphological field survey of Fairy Dell, which were not explicable in terms of mass-movement activity. A comparison of figure 5*b* with the map derived from the 1969 aerial photograph (figure 6*c*) clearly demonstrates how inaccurate this data source can be. It is therefore suggested that although plans may yield reasonable figures on cliff retreat rates, especially if produced from boundary revisions, hachuring can at best only give a very general indication of the changing topographic pattern. Where possible aerial photographs should always be used for this purpose.

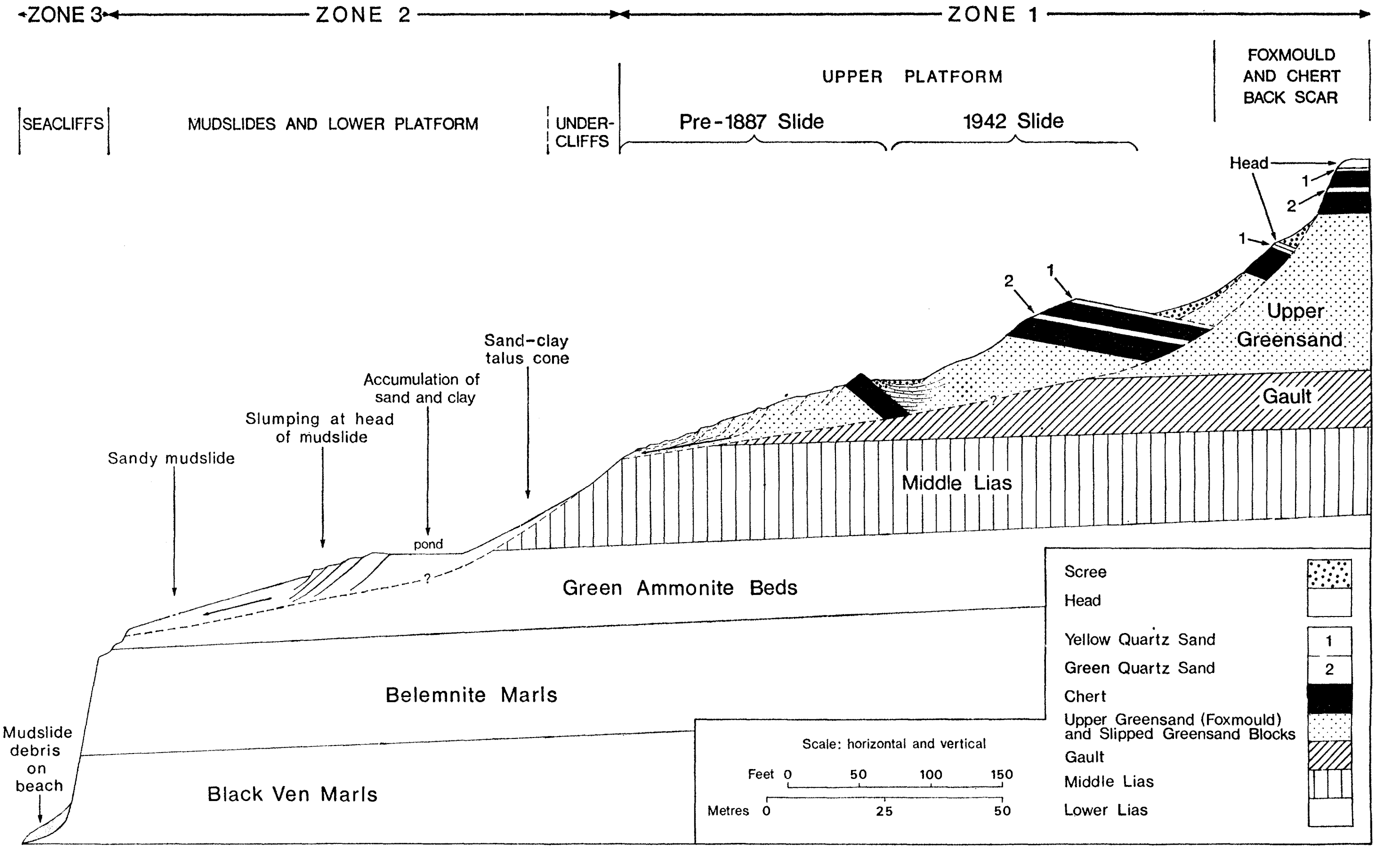


FIGURE 4. Geological section through the Fairy Dell landslide complex showing the interrelationship of morphodynamic zones (for location see figure 1).

(*b*) *General description*

Fairy Dell consists of three subparallel cliff lines separated by debris covered benches (figure 4). These features are broadly the product of lithological variations, the upper and lower 'platforms' being respectively associated with the sub-Albian unconformity and the outcrop of the Green Ammonite Beds. Geomorphological mapping techniques were used to establish the spatial distribution of landforms in this densely vegetated complex terrain, and resulted in the identification of three morphodynamic zones, each of which is characterized by a particular assemblage of morphological features and mass-movement processes (figures 4 and 6*c*). The seaward progression of these zones is as follows:

(i) *Zone* 1. This uppermost zone consists of three major geomorphological units (figure 4). The inland margin of the complex is defined by a steep (50–70°) arcuate scar up to 45 m high, developed in Foxmould and chert. The lowest parts of the scar are blanketed by a sparsely vegetated scree slope of variable extent with a surface inclination of approximately 35°. The Upper Platform forms the third unit and is located at the base of these features. It consists of a number of large rotated landslide blocks separated by spreads of chert scree and largely concealed beneath a dense cover of broom, bramble and gorse.

(ii) *Zone* 2. The seaward margin of zone 1 is demarcated by a minor undercliff of variable height (up to 20 m) developed in the Middle and Lower Lias, which overlooks the Lower Platform (figure 4). This latter area has an exceedingly complex topographic form. Four dominant geomorphological features can be distinguished; large V-shaped gullies cut by streams which cascade over the sea-cliffs; rotated landslide blocks produced by failure of the undercliffs; low relief debris accumulation areas, and mudslide basins which transport debris to the cliff edge where it falls on to the beach below (see figure 6*c*).

(iii) *Zone* 3. The near vertical sea-cliffs, up to 50 m high, form the lowest zone of the coastal landslide complex. Their base is normally covered by a bank of debris which shows an annual pattern of volumetric fluctuation. This basal sediment store appears to experience net accumulation during the winter months so as to attain maximum volume in late spring, and then diminishes in bulk through the summer as the material is redistributed by marine processes to reach a minimum volume in the late autumn.

(*c*) *Evolution of the morphodynamic zones*

(i) *Zone* 1. Map evidence indicates that the main arcuate landslide scar has retreated by up to 55 m in the period 1887–1964 (figure 5), which represents an average rate of 0.71 m/a. This figure was recorded near the centre of the scar, retreat rates diminishing to 22 m (0.29 m/a) and 28 m (0.36 m/a) at the western and eastern ends respectively. Scar retreat appears to be achieved in two ways. First, by large-scale rotational landsliding, and secondly, by slower degradation during the intervening periods between major failures.

Map and field evidence suggests that the products of two phases of large-scale failure can still be distinguished on the Upper Platform. The first (marked by numbers 1, 4, 6 and 10 in figure 5) occurred at some time before the 1887 survey, when a considerable length of cliff subsided. The scar is thought to have retreated by up to 90 m as a direct consequence of this failure, but this should be considered an approximate figure since it is based on the hachured areas shown on Ordnance Survey plans. Although the large landslide blocks are still present in zone 1 they cannot be used accurately to calculate the magnitude of the failures, for they have suffered erosion since their original displacement and have therefore been reduced in size by an unknown amount. It is, however, possible to suggest that between 25000 and 30000 m² of land was involved in these movements.

The second major failure phase can be more precisely dated and measured. It happened at 8.0 a.m. on the 14 May 1942 (Lang 1942, 1944), when two large slides occurred in the central part of the scar (C and D in figure 5*b*), carrying away a radio-location station and a grove of

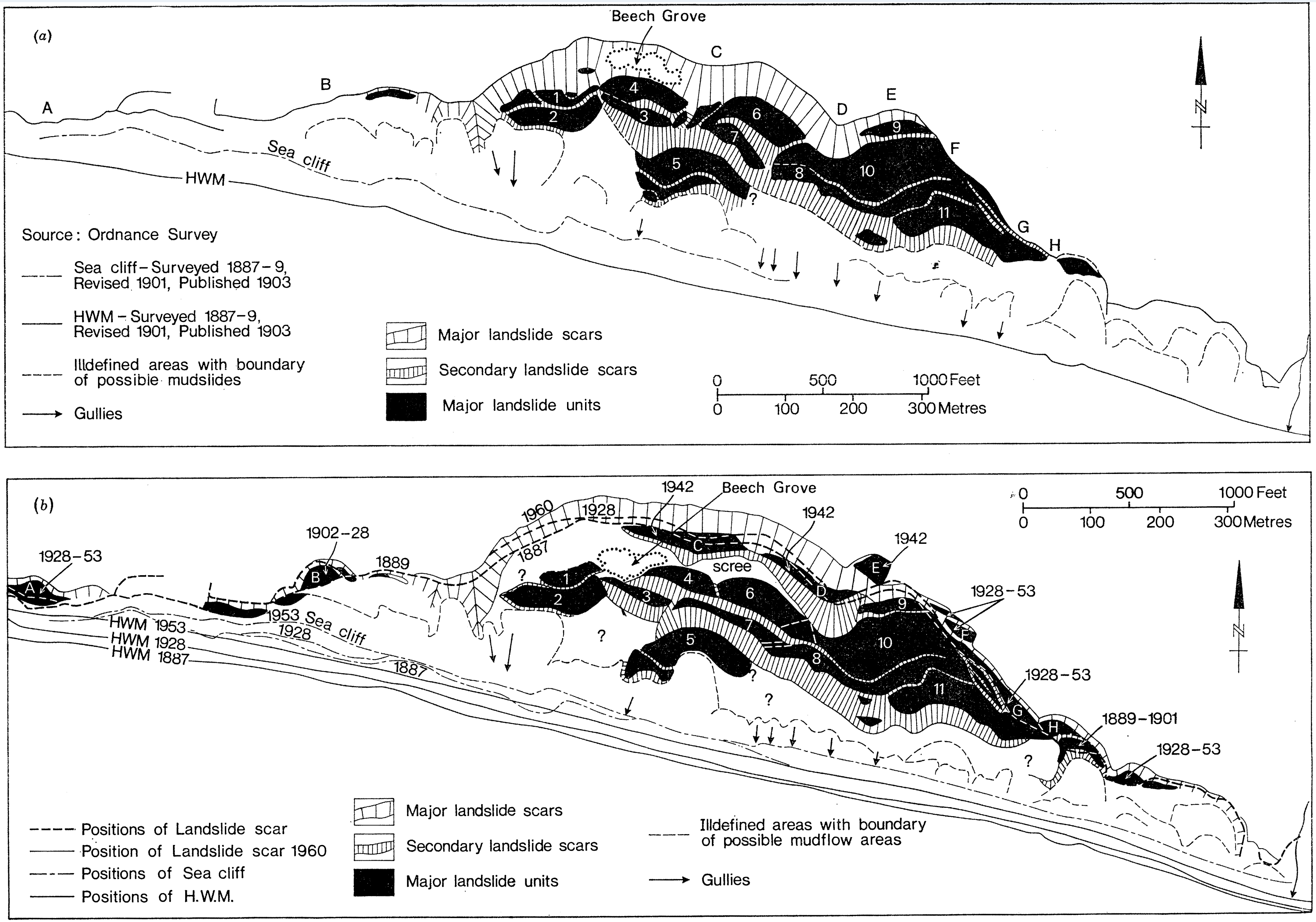


Figure 5. Maps showing the approximate boundaries of landslide units derived from Ordnance Survey 1:2500 plans. (*a*) The pattern identified on plans based on surveys carried out during the period 1887–1901. (*b*) Map showing the retreat of the sea cliffs and main landslide scar, prepared from surveys and boundary revisions carried out over the period 1887–1960. It is important to note that although certain new landslides can be identified (A–H), the pattern of large blocks (1–11) shows little change over this period. This is almost certainly due to a lack of detailed revision and should be compared with the pattern shown on figure 6.

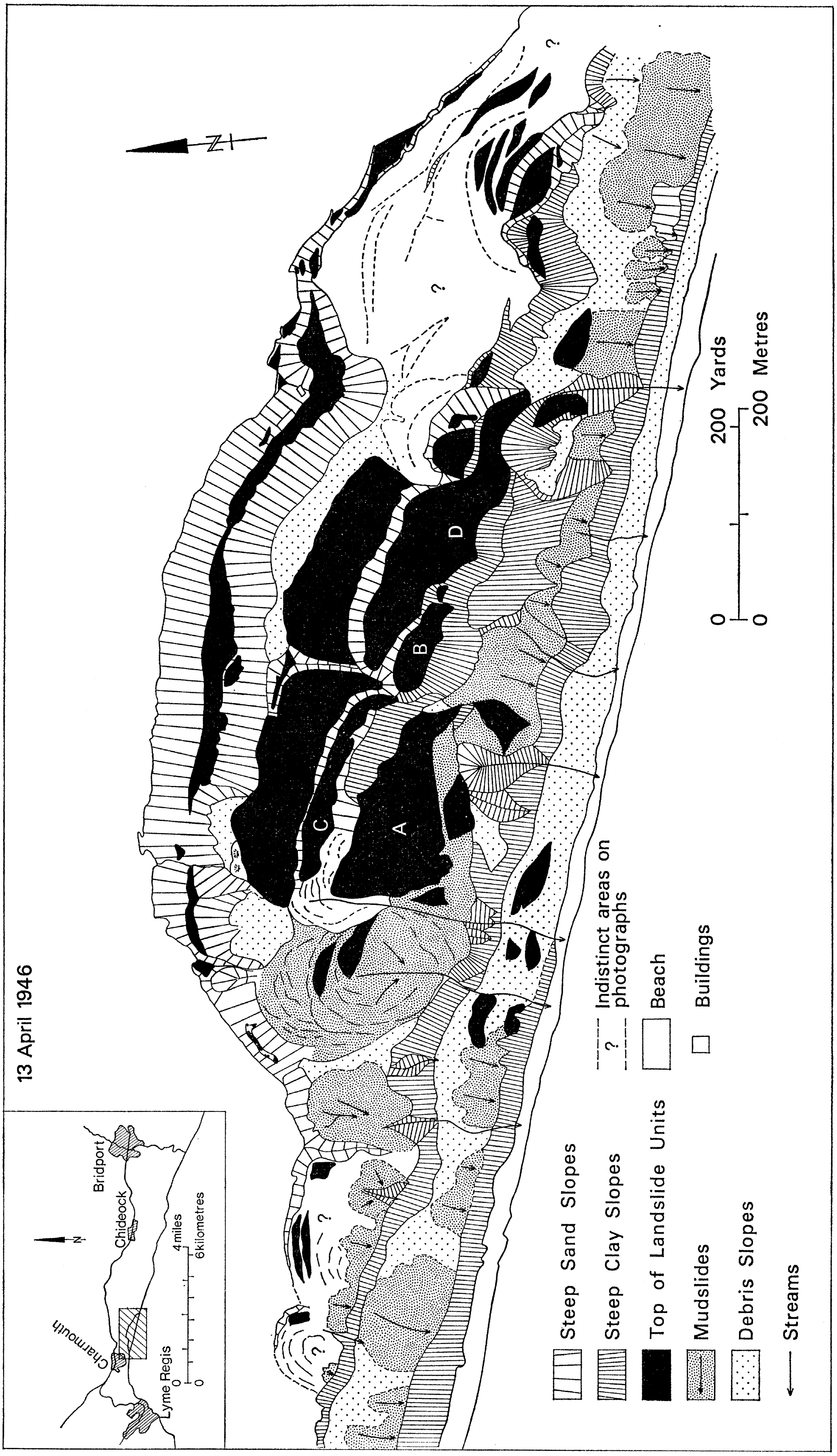


FIGURE 6 (*a*). For description see p. 614.

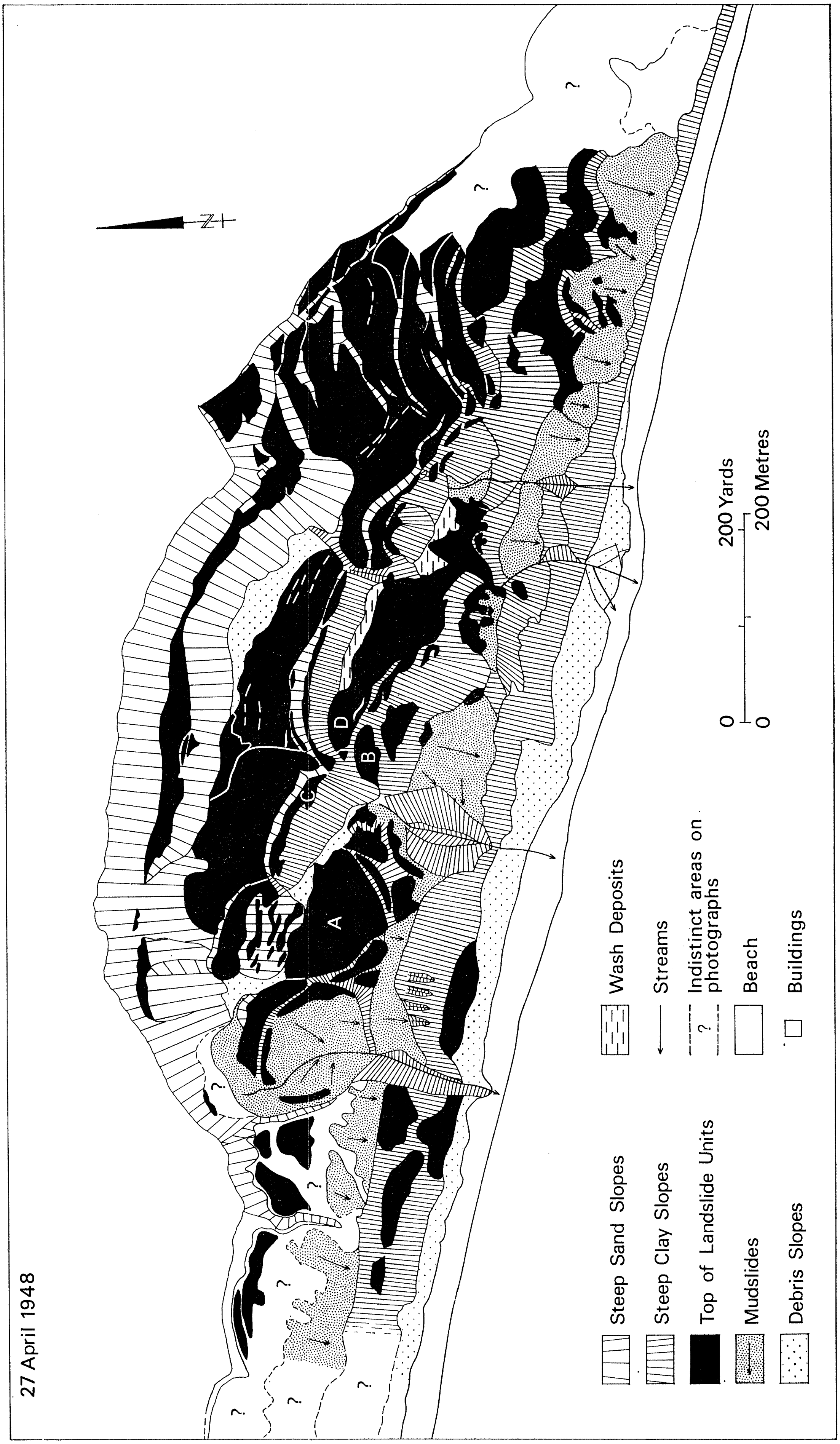


FIGURE 6 (*b*). For description see p. 614.

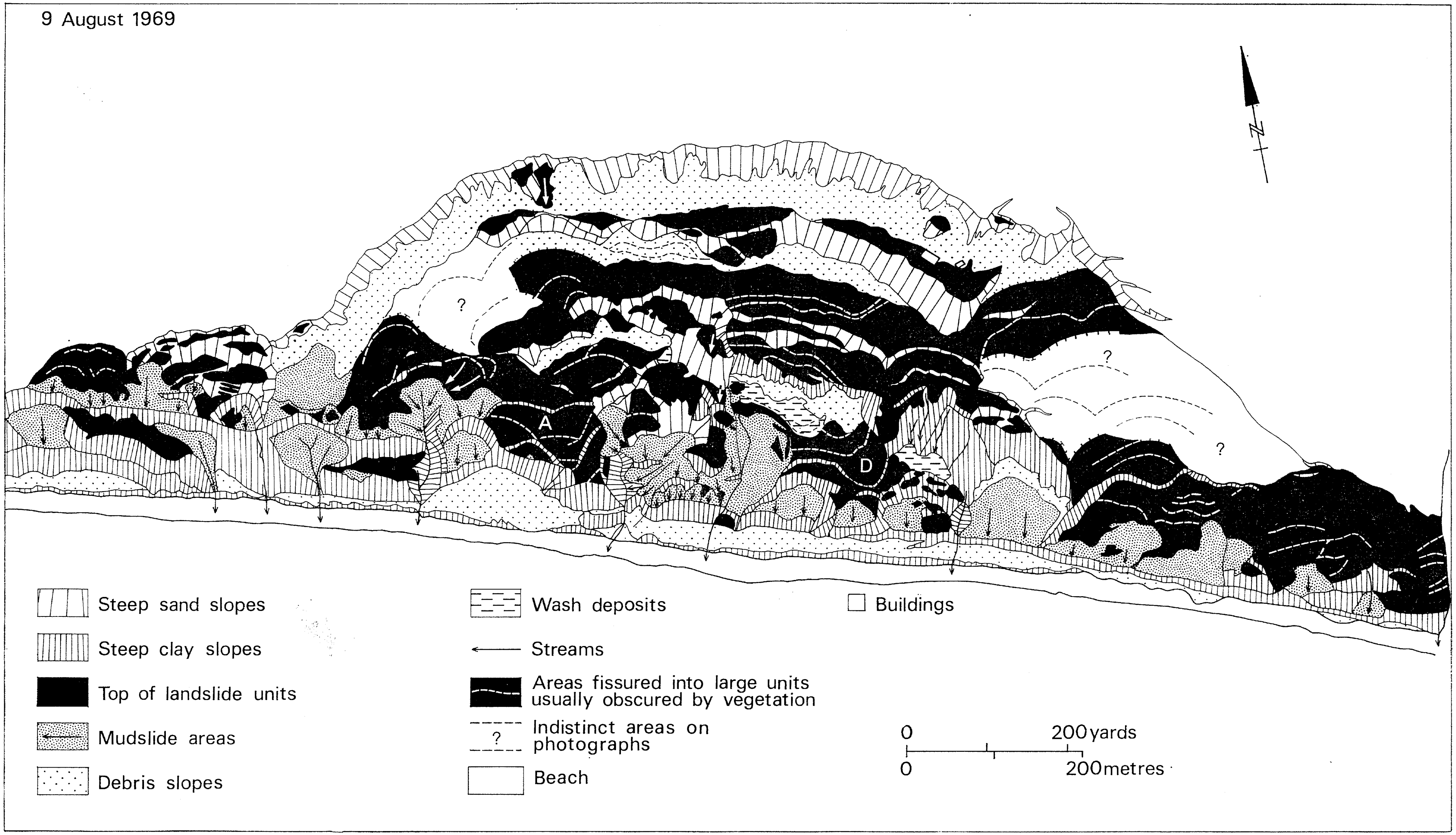


FIGURE 6 (*c*). Geomorphological maps of the Fairy Dell landslide complex derived from air photographs and ground surveys. These maps demonstrate the evolution of the area by deep-seated rotational landsliding, block disruption and mudslide development. It must be emphasized that these maps are derived directly from the photographs and for technical reasons have not been corrected for scale distortion.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

mature beech trees which had become established on the scar. Up to 28 m of cliff-top was lost in these failures, which were also accompanied by several smaller slides in the east (E, F, G and H in figure 5*b*), one of which (E) is still only partially detached from the scar. It is estimated that about 7500 m^2 of cliff-top was displaced by these 1942 movements.

The quiescent periods between major phases of landsliding appear to be characterized by sporadic small failures (figure 5*b*). These vary considerably in size, ranging from blocks which are recognizable for a number of years, to small masses which rapidly disintegrate during their passage down the scar, thereby contributing directly to the talus accumulation. Many of the larger blocks fail to reach the base of the slope, but come to rest at some intermediate position. Such 'perched blocks' subsequently become loaded by scree debris and move progressively down the scar with time. Map evidence indicates the occurrence of at least seven small failures during the period 1887–1953 (figure 5*b*), although the actual number, including those that disintegrated while moving or were too small to distinguish, is likely to have been considerably greater. The presence of a number of well-developed tension cracks in the vicinity of block E in figure 5*b* indicates one area where such failures are likely to occur in the relatively near future.

The role of minor failures in scarp retreat should not be over-emphasized, as weathering processes are also of considerable importance. The weak calcareous cement of the Foxmould weathers rapidly upon exposure so that the deposit readily disintegrates into individual grains which will flow in sand-runs when wet. The overlying chert beds are also easily disrupted by both frost action and the undermining effect of the retreating Foxmould face. Both weathering and minor failures combine to provide the bulk of the talus materials as well as forming a significant proportion of the total scar retreat. It is calculated that during the period 1928–60 the cliff-top retreated by between 11 and 45 m (0.34–1.4 m/a), figures that include the effects of the major 1942 failure which involved up to 28 m of ground. Approximately 17 m (0.53 m/a) of the maximum figure must therefore be accounted for by weathering and small scale failures. However, during the period 1946–69 the cliff-top only appears to have retreated by approximately 3 m, or about 0.13 m/a, which is comparable with rates of up to 0.15 m/a recorded on erosion pins set into the sandstone face of the scar and measured since 1968. The marked difference between these latter figures and the longer-term maximum rate of 0.53 m/a. is problematic. It can be argued that retreat rates due to small-scale processes are likely to be relatively rapid immediately following a major phase of landsliding and subsequently to diminish with time. Thus the 1928–60 maximum rate would be expected to be greater than that recorded for the period 1946–69. However, the degree of difference would suggest that cartographic and surveying errors may well account for much of the discrepancy.

The morphology of the landslide accumulation zone or 'Upper Platform' clearly indicates the episodic nature of major slope failure events. The dominant relief features are two distinct ridges developed on the rotated blocks created by the two most recent phases of major failure, which are separated by an irregular but continuous spread of chert blocks. This material can be identified on photographs taken prior to the 1942 slides as an almost completely stable and vegetated scree slope. When the 1942 failure occurred, this talus deposit was crumpled up and over the backslopes of the pre-1887 landslide blocks. The resultant loading effects may well have caused the pre-1887 units to move forward, and may provide an explanation as to why the 1942 movements were associated with extensive failures in the undercliffs of zone 2, although there is no evidence available to confirm which movements occurred first.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Photographic evidence indicates that movement of the 1942 units were initially rapid but became slower both with time and as the base of the scarp was approached. Thus, by 1946 the top of the main slide was some two-thirds down the scarp (approximately 25 m), a further 12 m of movement occurring between 1946 and 1969 (figure 7). Although present settlement rates are not easily gauged as the area is being rapidly colonized by vegetation, slow seaward movement is to be expected due to the effect of continued scree-slope development behind. It is therefore suggested that after initial rapid failure rotated blocks tend to settle slowly over a long period of time, the rate of movement diminishing as they approach a stable position. Thus the two points for the 1942 slide (figure 7) would be expected to lie close to a curve flattening with time, similar to that indicated for the zone 2 failures for which there are more data available. Such a pattern of settlement may be interrupted as a result of changes in environmental conditions which initiate more rapid movements. There appear to be two such mechanisms operating in zone 1 of Fairy Dell; first, the removal of mass from the toes of rotated blocks as a result of erosional processes operating in zone 2, and second, the loading of the tilted backslopes of the blocks by talus and further landslide units. The large landslide blocks in zone 1 may therefore experience several phases of rapid movement before they are finally destroyed.

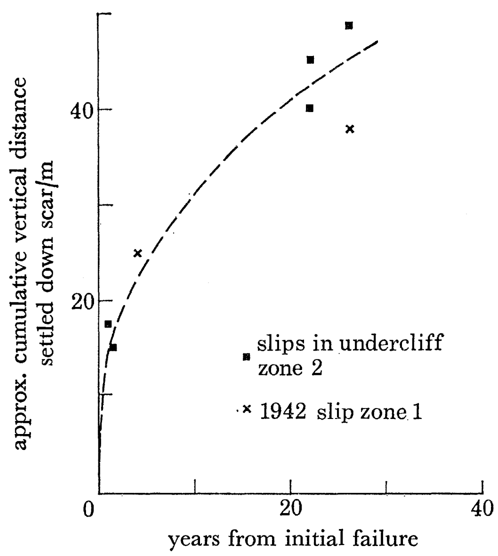


FIGURE 7. The approximate rate of settlement of landslide units in years from initial failure. The pecked line represents the generalized rate for zone 2 settlements.

There is thus in zone 1 a seaward succession of (*a*) degraded 1942 landslide scar, (*b*) the post-1942 scree slope and wash deposits, (*c*) the 1942 landslide units together with the remains of a beech grove and radiolocation station, (*d*) the pre-1942 scree slope now greatly disturbed, and (*e*) the remains of the pre-1887 landslide blocks. A considerable portion of these latter blocks and the major part of the earlier scree accumulations are missing from the area as they have been removed by the processes operating in zone 2. The same is also true of the earlier phases of landslide evolution, evidence for which has subsequently been totally destroyed.

(ii) *Zone* 2. Examination of Ordnance Survey plans proved of little value in distinguishing the changes which have taken place on the undercliffs and Lower Platform, because these features are not accurately depicted. Fortunately, the aerial photographs provide a detailed picture of the area's evolution over the period 1946–69 (figure 6) and therefore augment the surveys undertaken by the authors since 1964.

The undercliffs consist mainly of Middle Lias overlain by a capping of Cretaceous materials which represent the remains of the pre-1887 landslide blocks. Their form varies considerably depending on the geomorphological character of the Lower Platform at that point. At the head of active mudslide basins they tend to be steep (30–45°) and fairly free of debris, for material is being continuously removed from the slope base. Elsewhere, the undercliffs are fronted by landslide blocks which rapidly degrade into irregular mounds of Liassic material through the action of further rotational movements, mudslides, mudflows, creep and surface wash. The intervening depressions become quickly filled with talus and laminated wash deposits largely derived from the Cretaceous cappings of the rotated blocks, so that the topography becomes increasingly subdued with time. If the seaward movement of blocks is slow, this redistribution of sediment leads to the formation of low relief debris accumulation areas which will eventually be destroyed by the encroachment of adjacent mudslide basins. In the case of the latter situation the originally steep undercliffs rapidly lose their fresh appearance and degrade through the action of minor slumps, surface wash and weathering processes. The accumulation of debris in coalescent alluvial fans along the base of the slope results in the eventual development of a subdued convexo-concave form.

During the period 1946–69 the undercliffs retreated by between 33 and 60 m (1.5–2.6 m/a), most of this movement being achieved by rotational landslides of variable size. Instability is caused by the transport of detritus across the lower platform by a variety of sliding and flowing mechanisms induced by the continuing retreat of the sea-cliffs at approximately 0.4–0.5 m/a. Rotational landsliding is of great importance, individual blocks having been observed to move seawards at rates of up to 18.3 m/a (Brunsden 1974), undergoing break-up during their progress. However, it appears likely that the most important sediment transport mechanisms are the perennial mudslides which occupy well-defined basins that can exceed 100 m in length. Depths of material vary considerably depending largely on the size of the mudslide basin, but usually lie in the range 1–2 m although over 10 m of sediment has been recorded in the upper parts of a centrally located basin (figure 8). These features remove material at fairly rapid rates; for example, an annual movement of 91.4 m was recorded for one mudslide in 1968–9, with most of the activity taking place in the period January–March.

The available evidence suggests a cyclical evolutionary pattern for zone 2. Retreat of the sea-cliffs causes gully incision and accelerated mudslide activity, thereby maintaining a gradient across the Lower Platform. The removal of debris by the mudslides eventually leads to the undermining of the undercliff so that it becomes increasingly convex towards its base and fails. Details of this mechanism have been published elsewhere (Brunsden 1974). It is, however, worth noting in the present context that small-scale failures (1–100 m^3) increase in frequency as the undercliffs steepen, until large-scale failure, or failures, takes place. The blocks thus formed tend to slide towards the sea, breaking up and becoming degraded in the process. If the former mudslide basins have survived, they will continue to operate as a transport mechanism. However, in the event of a mudslide basin being overwhelmed by rotated blocks, one of three changes may occur; the adjacent basins will become the focal points of the transport system or new mudslides will develop, either between the newly rotated blocks or between these blocks and the margins of the original basin. The cycle then begins again, eventually resulting in failures at other points, a mechanism which is similar to that proposed for London

Clay cliffs by Hutchinson (1973). Thus, overall parallel retreat of the undercliffs is mainly achieved by large failures, the location of which varies through time. The 1946–9 average retreat rates of 1.5–2.6 m/a, however, obscure the fact that in the short term the headwalls of the mudslide basins retreat more slowly (1.5–1.7 m/a), until major failures recur.

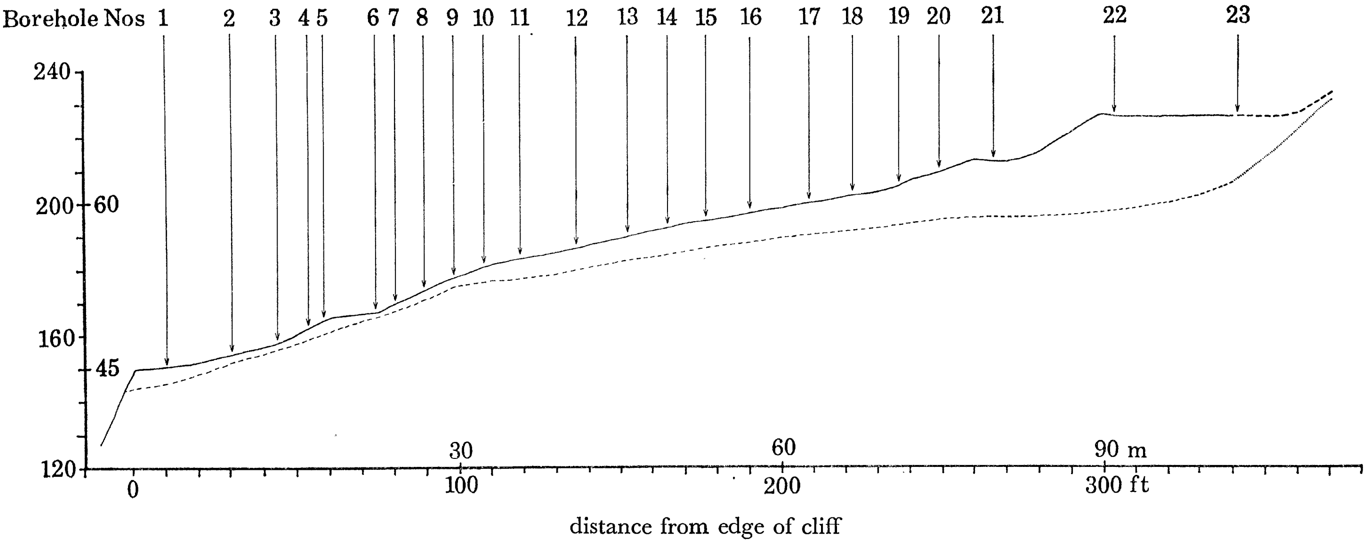


FIGURE 8. Section of a mudslide basin in the centre of the Fairy Dell complex (see figure 6). This illustrates the general morphometry of the Fairy Dell mudslides and especially the unloading of the toe by cliff retreat which leads to both recurrent and sudden movements. —, surface of mudslide; ---, base of mudslide.

The general pattern of development for the period 1946–69 is readily illustrated by the maps that form figure 6. These maps, along with other records (Lang 1942), show that the major zone 1 landslides of 14 May 1942 were accompanied by at least four large rotational slides in zone 2 (figure 6*a*, A–D). The later air photographs indicate that these blocks subsequently broke up into smaller and smaller units as they moved downslope and were eroded on their seaward margins. Thus, by 1948 (figure 6*b*) slides A and B had been broken into at least five and two units respectively. Slide C had lost a considerable proportion of its mass through the effects of small-scale failures, while slide D had settled markedly and suffered disruption along its leading edge. It is also important to note that the seaward movements of slides A and D resulted in further failures of the undercliffs behind. The 1958 photograph shows that slide B had ceased to exist by this time and that a further failure had occurred inland of its former position. By 1969 (figure 6*c*) the pattern of blocks had become exceedingly complex with several new failures having occurred on the undercliffs, while of the original four slides, remnants of only two could still be distinguished with any certainty (figure 6*c*, A, D).

This series of maps clearly indicates the importance of block disruption in the continuing development of the Fairy Dell complex, and it may be noted that two categories of disruptive mechanism can be distinguished. The first is clearly illustrated by the major rotated blocks in zone 1 which eventually become involved in failures of the undercliffs, there being a considerable interval of time between initial failure and subsequent disruption. In this case the blocks produced in one degradation zone (the rear scar) are disrupted by the failures associated with a second such zone at lower elevation (the undercliffs). The second type of block disruption involves the rather more rapid break-up of blocks following initial failure and forms an essential

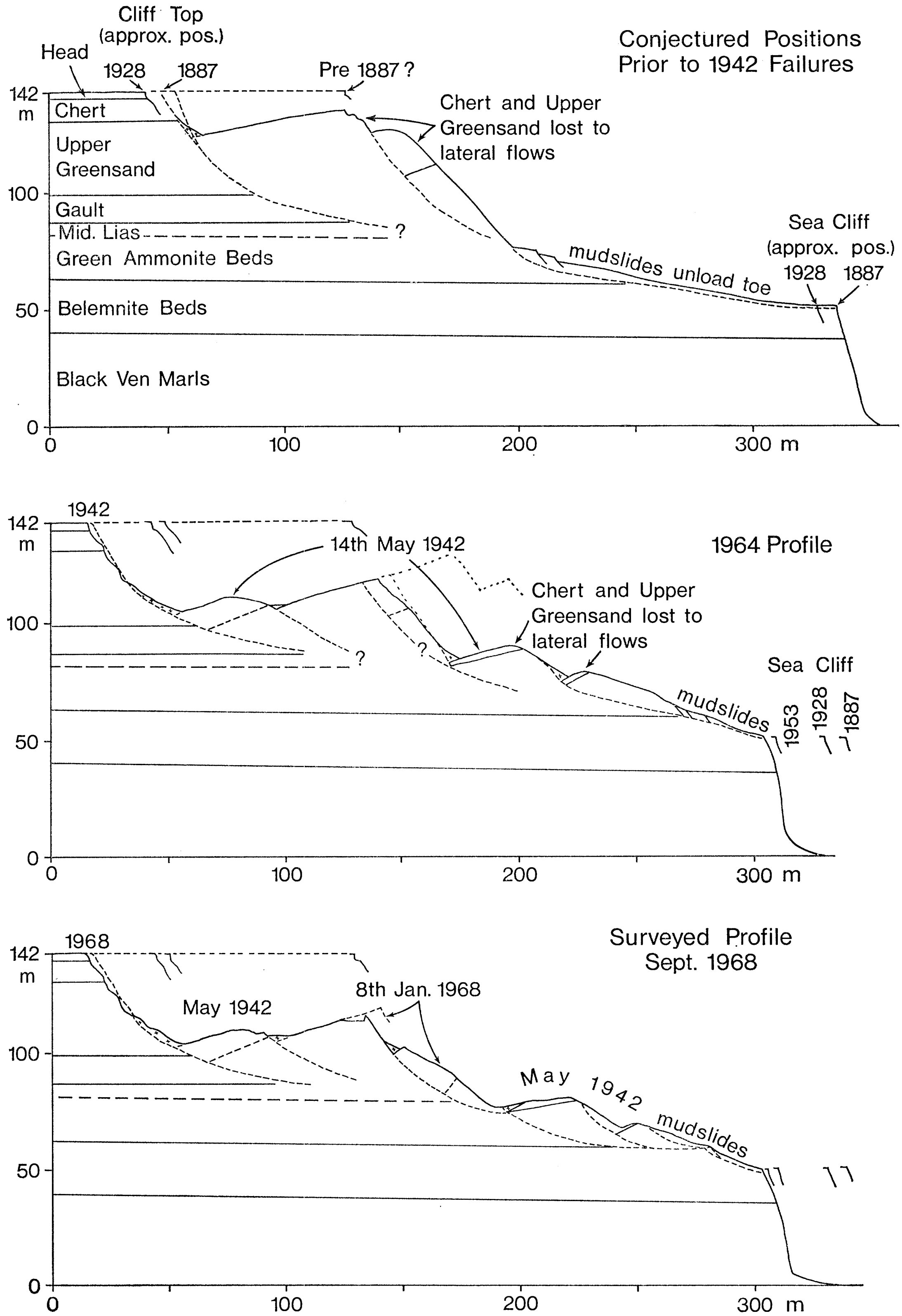


FIGURE 9. Schematic sections of Fairy Dell to illustrate the historical sequence of rotational landsliding and subsequent block disruption, with cliff and ground loss since 1887. Sources: Ordnance Survey 1:2500 plans; air photographs, R.A.F. 1946, 1948, Fairey Aviation 1969; field surveys 1964–9. The location in plan of these sections in approximately the same as for figure 12 (see figure 1).

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

mechanism in the evolution of landslide slopes towards a state of ultimate stability against land sliding (figure 9). Examples of this disruptive process have already been cited for zone 2 and inspection of figure 6c shows that the western part of the 1942 slide in zone 1 has been similarly affected.

It should be clearly apparent that the landslide processes of zone 2 differ from those operating in zone 1 in three main respects. The first and most obvious of these concerns the frequency

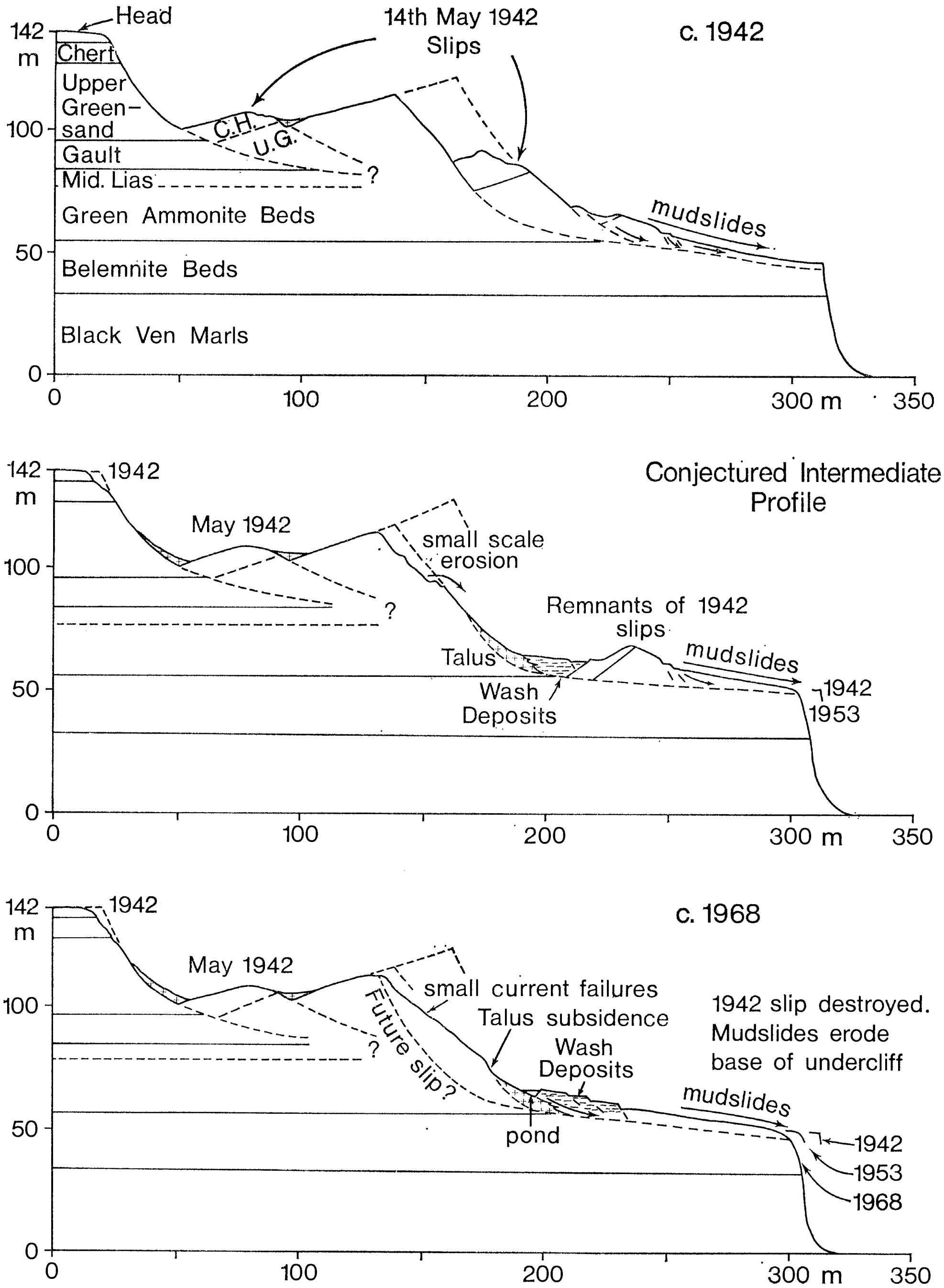


FIGURE 10. Schematic sections of Fairy Dell to illustrate the historical sequence of failures where mudslides operate in the lower areas of the landslide complex. Sources as for figure 9 and Brunsden (1974). The location in plan of these sections is approximately the same as for figure 12 (see figure 1).

and magnitude of landslide events for, while the largest slides occur in zone 1, the frequency of failures is greatest in zone 2. Second, there are differences in settlement rates (figure 7), photographic evidence indicating that the zone 2 blocks settle at a faster rate through time than those associated with the Upper Platform. Third, the throughput time for landslide debris appears to be different for each subsystem. Thus, the large blocks produced by the relatively infrequent zone 1 failures remain on the Upper Platform for periods of at least 100 years according to present evidence. By contrast, the more frequent smaller scale events in zone 2 produce blocks which are broken down and rapidly moved to the cliff edge, throughput time for these materials appearing to lie in the range 20–40 years, although it may be longer in the sediment accumulation areas (figure 9). It is important to note that this rapid movement and fragmentation in zone 2 is largely due to the continual removal of material along the margin of the blocks by mudslides (figure 10).

(iii) *Zone* 3. The near vertical sea cliffs of Lower Lias cannot degrade to stable slopes because of marine erosion at their base and therefore undergo parallel retreat at between 0.4 and 0.5 m/a, an average total retreat along the cliff of 35 m over the period 1887–1969. Retreat is mainly achieved through falls, although rotational movements and large-scale settlement do occur, the debris becoming incorporated in a basal accumulation bank which is also fed by the gullies, mudslides and rotational movements in zone 2 above. The importance of these sea-cliffs to the landslide complex lies in the fact that their retreat with time leads to the rejuvenation of the higher inland zones and also enables the zone 2 mechanisms to operate at a rapid rate because of the lack of a lower accumulation zone.

(*d*) *An evolutionary model of the landslide complex*

Fairy Dell can be subdivided into two degradation zones and two transport slopes above a receding marine cliff-line. Examination of figure 6, shows that the deep-seated rotational movements taking place along the two scars produce blocks which are subsequently broken down through time by 'block disruption' to produce a varied assemblage of small units.

Detailed examination of this complex suggests the following evolutionary model. Marine erosion not only removes debris, thereby preventing the development of a lower aggradation slope, but also leads to a reasonably rapid and continuing rate of cliff retreat. This has the effect of increasing the rate of debris transport across the Lower Platform (zone 2) and results in the eventual undermining and failure of the undercliffs, thus causing arenaceous Cretaceous materials to move down from zone 1 to zone 2 where they form an important constituent of the mudslides. Undercliff retreat and the removal of mass from the toes of the zone 1 blocks (in this case the pre-1887 slides) causes them to move slowly seawards. This results in further failures of the undercliffs as well as major failures in the backscar because of the removal of support at the base of the Foxmould slope. Thus cliff retreat activates a 'zone of aggression' that subsequently works its way inland (figures 9 and 10). The resultant major failures in zone 1 may cause an impulse which is transmitted in the opposite direction, for the settlement of the newly created blocks contorts the talus materials over the blocks in front, and loads the pre-existing landslide units. These may even be shunted forward short distances by a large failure, thereby producing further failures in the undercliffs (zone 2), as appears to be the case for the 1942 movements. The debris thus supplied to the Lower Platform would then have to be transported seawards to the cliff-edge. Only when a considerable proportion of this material has been removed is it possible for a new cycle to begin. In the case of Fairy Dell it seems that the products of the 1942 movements have only recently been evacuated from the Lower Platform, for the growing relative relief of the mudslide basins and the recent increase in the number of rotational failures in the undercliffs suggests that an 'aggressive phase' is once more working inland.

4. Comparison of the coastal and inland slopes

There are severe dangers inherent in attempting to relate landslide evolutionary sequences that are separated both in space and time and for which there is no information concerning the variability of causative mechanisms. Nevertheless the close proximity and similar geological and ground-water conditions of the inland and coastal areas, the one nearly stable at present, the other still very active, is felt strong enough in this case to suggest that useful ideas can be derived from such a comparison. Even though the two areas appear at first sight morphologically very different in profile (figure 13), the plan form and relationships of the geomorphological features of both areas contain sufficient points of similarity to justify a direct comparison. It can therefore be argued that examination of the presently active mass movement complex can provide valuable information concerning the evolution of landforms on the inland slopes, although it would be unwise to assume that the rate of operation of the causative processes displayed the same frequency and magnitude. While the development of a marine cliff-line obviously has no inland equivalent, it is possible to relate the forms observed in zones 1 and 2 of the coastal complex, with the down-slope sequence previously described for the Char Valley (Brunsden & Jones 1972), which was as follows (figure 11):

(i) *Zone A*. The steep uppermost slopes developed on the Cretaceous deposits. Three subzones were distinguished, stepped slopes developed on the chert cappings of rotated blocks which have only moved a short distance (zone A1), convexo-concave slopes developed on landslide units concealed beneath a thick mantle of head and scree (zone A2) and a number of large steep sided (30–45°) arcuate embayments or 'coombes' (zone A3) (figure 12).

(ii) *Zone B*. Beneath the steep slopes of zone A lies an irregular mosaic of rotated blocks separated by marshy depressions (zone B1). The blocks, some of which showed reversed slopes, are particularly well developed in front of the coombes. At two points this pattern is modified by the occurrence of large amphitheatre shaped hollows (zone B2) (figure 12).

(iii) *Zone C*. The lower half of the slopes are characterized by an irregular 'rippled' topography developed on landslide debris. Two subzones were distinguished according to the orientation of the undulations, an upper area where they show elongation along the slope (zone C1) giving way to a more lobate pattern at lower elevation (zone C2).

The most obvious correlations are to be found within the upper slopes of the two landslide complexes. Thus the steep arcuate Foxmould embayments on the Char Valley slopes (zone A3) (figures 11 and 12) are considered the direct but smaller equivalents of the Fairy Dell main scar, while zones A1 and A2 represent degraded scar forms where the bedrock outcrop is concealed by variable amounts of regolith. Similarly, the large elongate blocks (zone B1) lying in front of the 'coombes' are considered the equivalents of the rotated landslide units located on the Upper Platform. The spatial arrangement of these masses (figure 11) clearly suggests that the block disruption process observed in Fairy Dell also operated on the upper parts of the Char Valley slopes as was previously suggested (Brunsden & Jones 1972).

Comparison of the lower areas is more difficult because of the very different general slope forms (figure 13), the Char Valley slopes displaying an overall gentle convex profile while

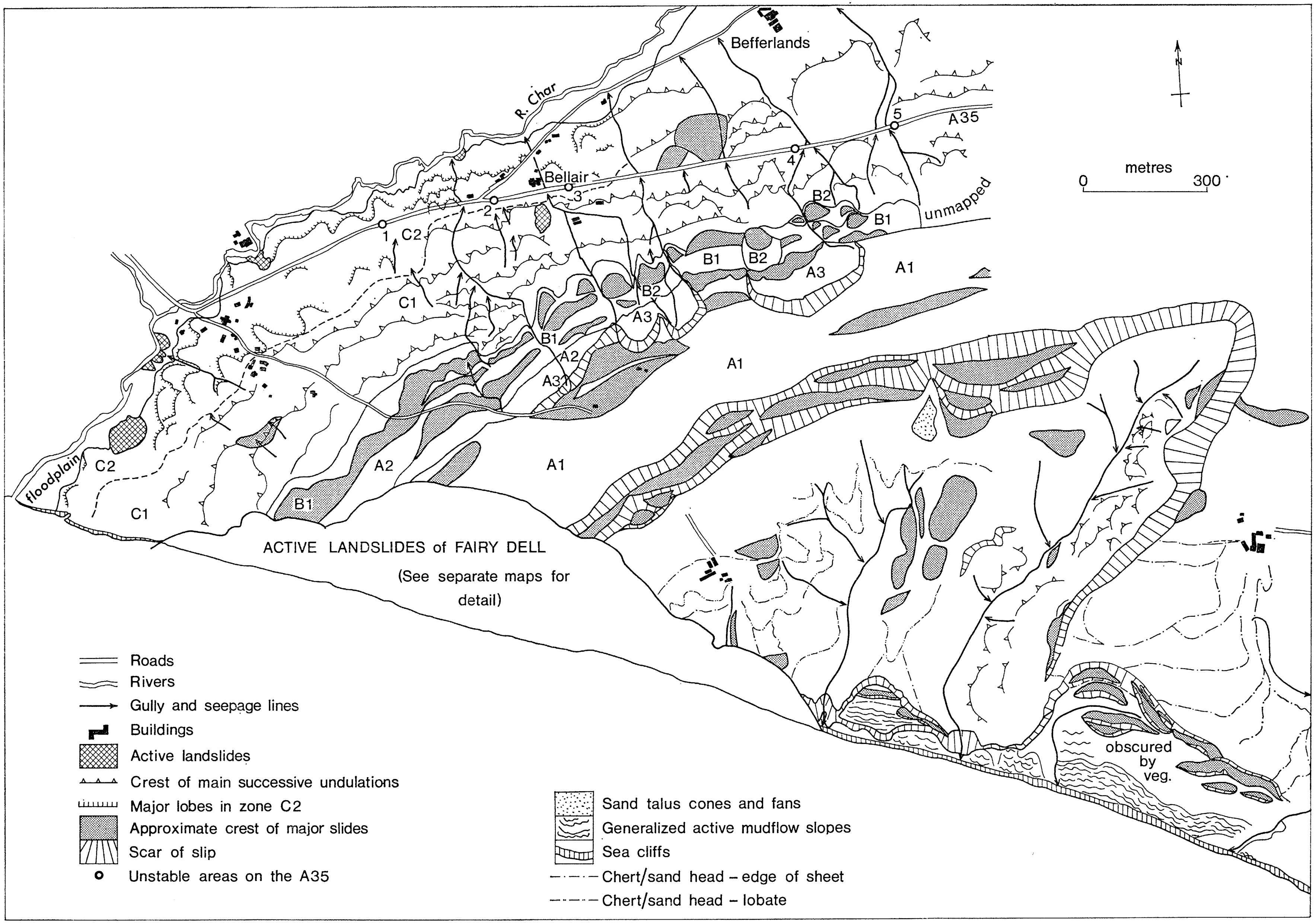


FIGURE 11. Geomorphological map of the degraded inland slopes of the Char Valley (based on Brunsden & Jones 1972) and the slopes between Stonebarrow Hill and Golden Cap (field survey). The arcuate embayments and landslide patterns should be compared with those shown on figure 6.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Fairy Dell is composed of two transport slopes separated by the undercliffs. It can be argued, however, that much of this difference is due to the contrasting states of activity, which is largely the product of the different conditions at the base of the two slopes. Thus the magnitude and freshness of the undercliff feature in Fairy Dell directly results from intense mass movement activity which is maintained by marine cliff retreat. However, where sliding is slow, or has ceased altogether, the undercliffs become both degraded and subdued. It is, therefore, suggested that the stepped profile displayed in Fairy Dell, could be changed into a convex form similar to that of the Char Valley slopes through degradation under conditions of little or no sediment removal from the base of the slope.

Detailed examination of the Char Valley slopes revealed the presence of a second and lower set of 'coombes' (zone B2, figure 12), located where the Middle Lias would outcrop if there was no cover of landslide debris. It is considered that these features represent surviving remnants

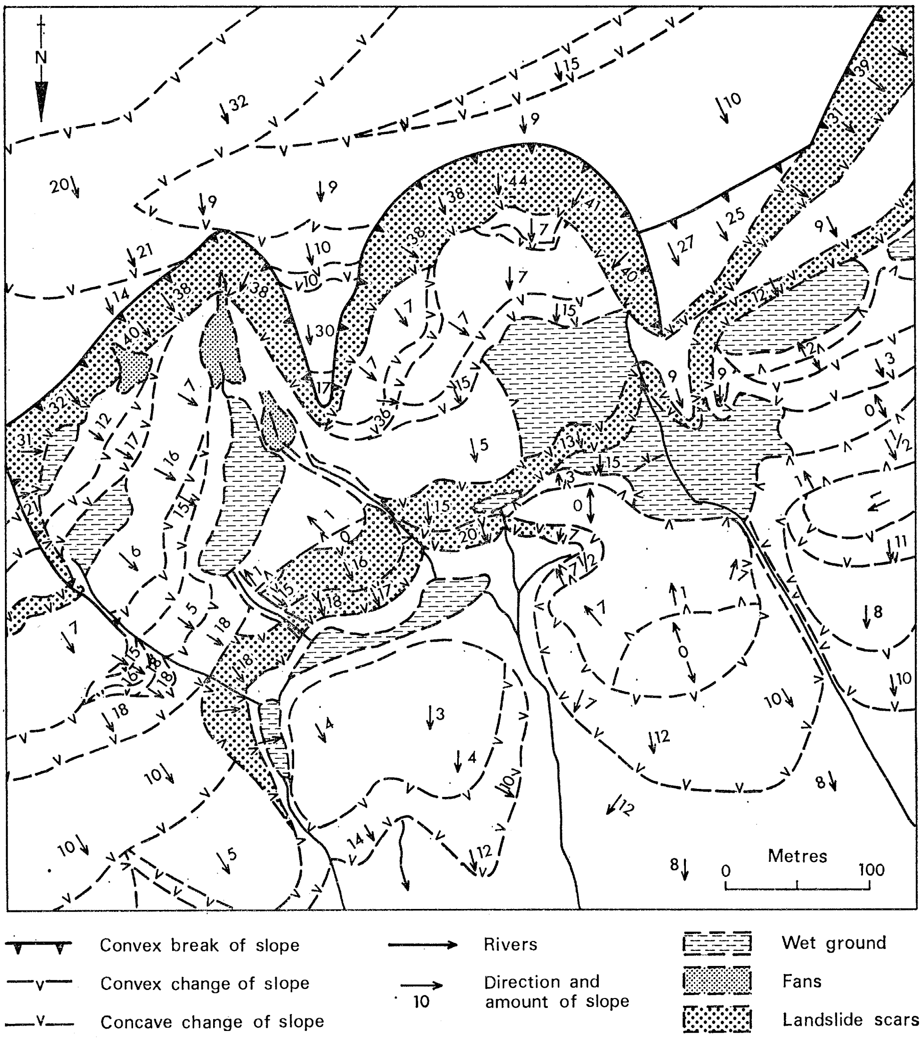


FIGURE 12. Morphological map of a portion of the Char Valley slopes showing (*a*) one way in which degraded landslide topography can be portrayed using geomorphological techniques, (*b*) the form of the arcuate embayments (zone A3), which are cut into the 'stepped slopes' (zone A1) forming the upper parts of Stonebarrow Hill and (*c*) the lower coombes (zone B2), the floors of which are occupied by two obvious landslide blocks. For location and zone lettering see figure 11 but note the change in orientation.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

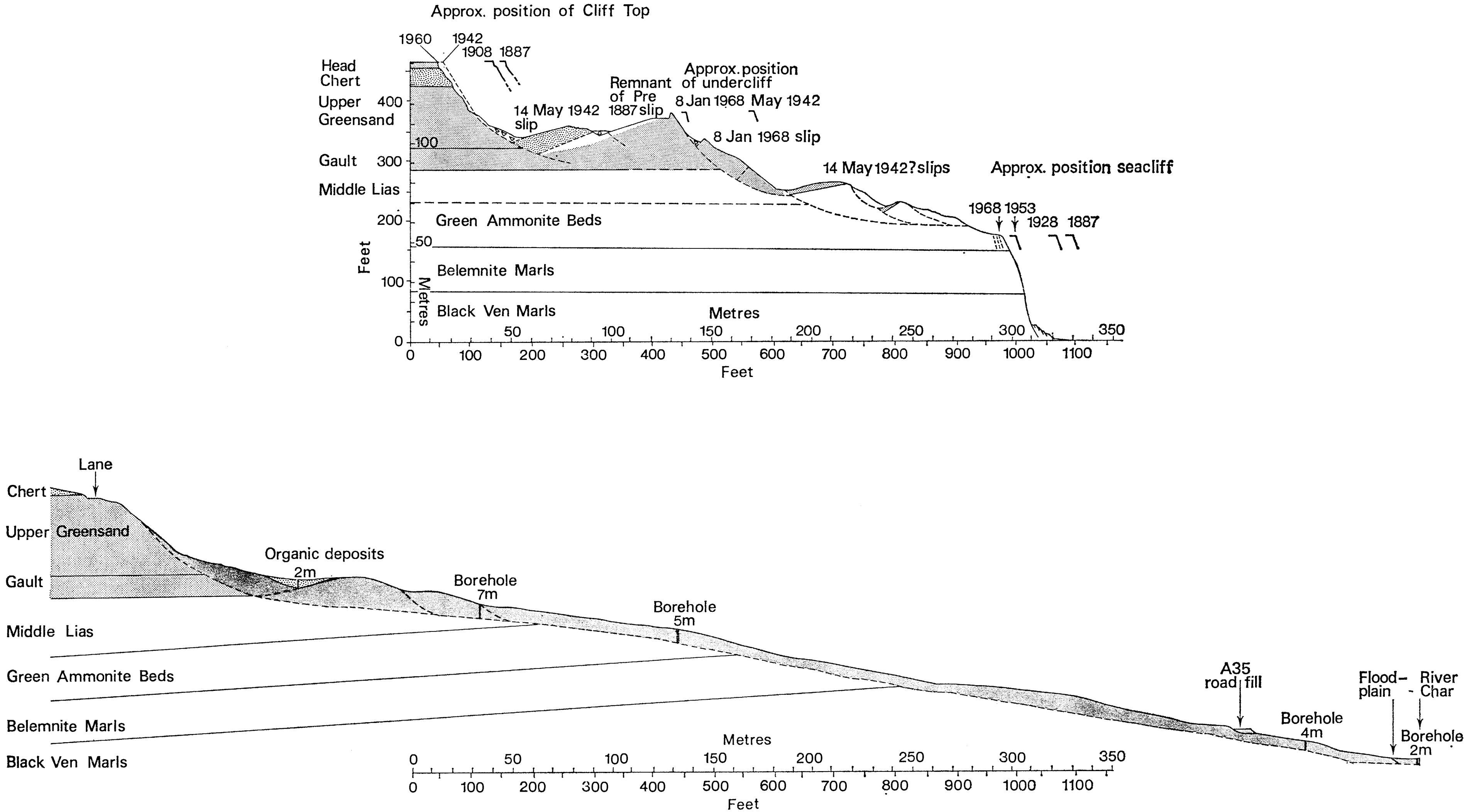


FIGURE 13. Comparative sections through the Fairy Dell landslide complex and the degraded slopes of the Char Valley.

of the valley-side equivalent of the Fairy Dell undercliffs which were either not developed elsewhere or have subsequently been obliterated. Further support for this interpretation can be derived from the morphological plan patterns displayed on the lower slopes. Thus the irregular mosaic of subdued elongate blocks which decrease in size downslope (zone C1), is very similar to that produced by block disruption beneath the undercliffs of Fairy Dell, while the gentle lobate forms (zone C2) can be explained as the produce of shallower sliding mechanisms, including mudslides, which would be expected to develop as a result of the break-up of larger landslide units. This latter zone is, therefore, seen as equivalent to the lowest part of the Lower Platform in the truncated Fairy Dell sequence.

The Fairy Dell and Char Valley sequences can also be compared with the slopes to the east of Stonebarrow Hill. Here the Cretaceous outcrops have been stripped back to form a large steep-sided embayment floored by Middle Lias and drained by two small southward flowing streams (figures 1 and 11). These streams have become deeply incised into the Middle Lias outcrop to produce a markedly polycyclic topography. The slopes are in general simpler, smoother and less steep than those of the Char Valley, consisting in the main of gentle convexo-concave elements. Four major geomorphological units were identified (figure 11), which tend to occur in the following downslope sequence:

(i) A degradational zone of steep slopes developed on the flanks of the Cretaceous outcrop containing numerous steps and benches which were interpreted as slipped blocks. These slopes are reasonably straight in plan and do not contain any of the coombe features noted on the western side of Stonebarrow Hill. Their form in profile thus represents a combination of the characteristics displayed in zones A1 and A2 of the Char Valley.

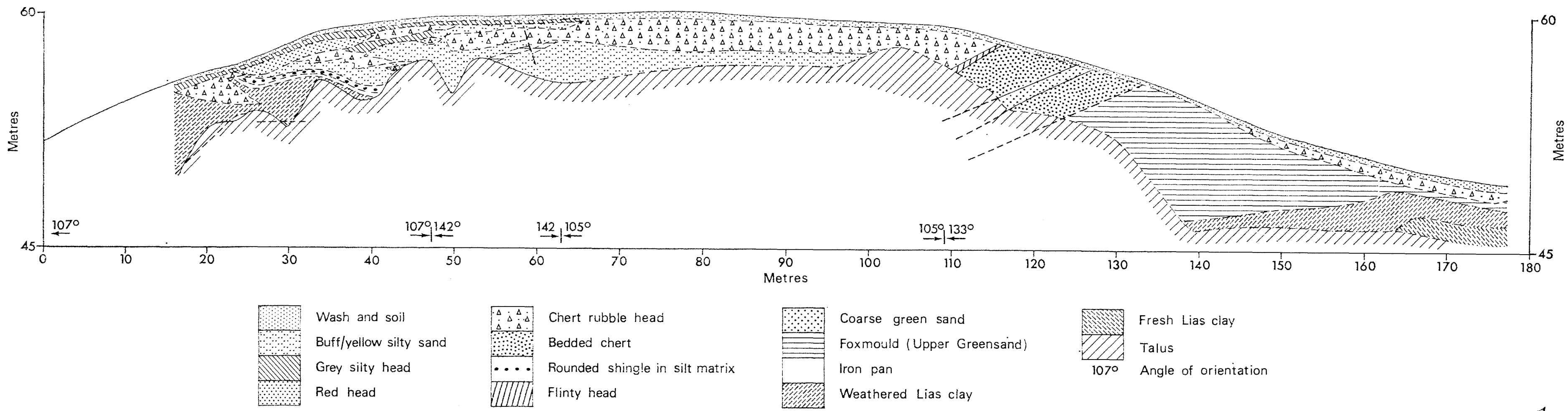
(ii) Beneath part of the former degradation zone occur broad smooth concave slopes. The surface character, position and exposed sections in the flank of Fairy Dell, indicate that this is an area of landslide blocks buried by an extensive accumulation of head, scree and wash deposits. There is no true equivalent of these slopes in the other areas described in this paper.

(iii) Relatively smooth convexo-concave slopes containing some clearly definable 'flats' and topographic bulges. This was interpreted as an area where large landslide blocks were only partially buried by superficial accumulations and therefore still had some topographic expression. The form of these areas is broadly similar to zone B of the Char Valley.

(iv) Steeper valley-side slopes associated with the incision of the two streams and containing numerous signs of shallow instability which occur in the same form and location as the recent instability on the lower slopes of the Char Valley.

Confirmation of the origin and evolution of the inland slopes on both sides of Stonebarrow Hill would depend upon detailed subsurface information being obtained from a network of boreholes and trial pits. As this proved impracticable due to financial constraints, subsurface data were obtained by inspecting the backscars produced in the active coastal landslide belt on either flank of the Fairy Dell complex. Here current rotational movements towards the south have revealed discontinuous sections through a thick cover of superficial deposits mantling the inland slopes. Two of these exposures are particularly worthy of note in the context of this paper.

The first of these sections is located near West Hay Farm to the east of Fairy Dell (figure 1). Here a phase of very active coastal landsliding which began in 1966, has temporarily revealed a section in one of the topographic bulges which shows a complex series of interbedded deposits banked up against the tilted backslope of a large rotated block (figure 14). This block consists of Foxmould (Upper Greensand) with a substantial capping of chert, the latter still including



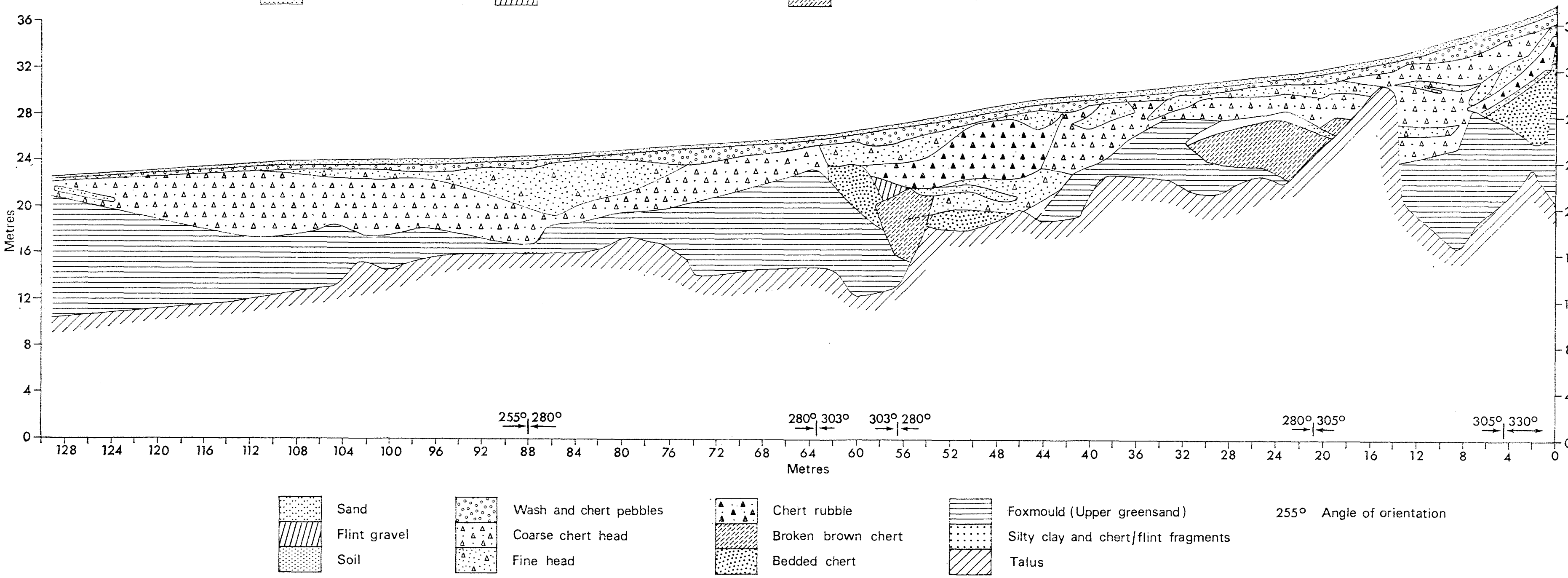


Figure 14. Coastal section located to the east of Stonebarrow Hill near Westhay Farm (see figure 1). The topographic expression of the subdued ridge is clearly related to the degraded remains of a large rotational landslide, which is now partly concealed by angular scree, bedded heads and wash deposits. The geological succession preserved in the slide block should be compared with that shown in figure 4. The block is estimated to be displaced 600 m horizontally and some 70–80 m vertically below its original position (see figure 1 for location).

Figure 16. Coastal section exposed on the western side of Stonebarrow Hill (see figure 1). The 'rippled' topography suggests the presence of degraded landslides. The section reveals a very complicated pattern of partially disrupted blocks with infillings of angular chert scree, flint head, wash and soil deposits. The section emphasizes the care which is required in interpreting subsurface form from topographic detail.

the layer of coarse, dark green sand observed to outcrop in the backscar of Fairy Dell (figure 15, plate 13). Measurements of dip in the chert capping and associated sandmember give an average inclination of 20°, orientation 355°, which differs substantially from the dip of the Cretaceous deposits in this area ($2\frac{1}{2}$° towards SW). The base of Foxmould in this rotated unit lies at approximately 47 m O.D., some 54 m below the local *in situ* Upper Greensand–Gault boundary, while the bed of dark green, coarse sand occurs nearly 80 m below its outcrop in Fairy Dell. The horizontal component of displacement is equally dramatic, for the chert beds are located approximately 600 m from the outcrop on Stonebarrow Hill. As such a movement is unlikely to have been achieved in one phase of activity, it is suggested that this block has slowly settled over quite a considerable period under the combined influence of downslope slope steepening due to river incision and loading on its back-slope margin. The complicated interdigitation of deposits behind the block is, therefore, interpreted as the product of fans, Greensand slumps, chert scree, head and wash; an assemblage similar in many respects to that observed to occur today in zone 1 of Fairy Dell. This downslope movement was almost certainly accompanied by a reduction of mass due to block disruption, the original failure being considerably larger than that preserved today. The accumulation of debris on the upslope margin, coupled with the action of creep and wash, has had the effect of modifying the topographic expression of the block, the original rather angular ridge and reversed slope, similar to those noted in zone 1 of Fairy Dell (figure 4), being replaced by a smooth convexo-concave profile. Nevertheless, this feature still retains sufficient morphological expression to be both recognized and mapped (see figure 11).

The second section is located on the western flank of Stonebarrow Hill (figure 1), and shows the deposits underlying a part of zone B1 (figure 11) of the Char Valley slopes. Here Foxmould blocks with an irregular upper surface (figure 16), are overlain by a complex series of chert rubbles and head deposits. Relatively undisturbed masses of bedded chert can be identified in three areas, which together with the pattern of bedding displayed by the superficial deposits and Foxmould, indicate that disruption has occurred (figure 16). These units are buried by spreads of chert rubble, head and wash deposits which produce a very subdued surface topography.

Inspection of these sections reveals that the irregular topographic forms previously mapped by using geomorphological methods (Brunsden & Jones 1972) reflect the presence of a cover of mass movement debris including rotated blocks. They further indicate that the evolution of such slopes involves a combination of both slow downslope settlement of large rotated masses, together with the break-up of such units by block disruption, so as to produce an overall decrease in unit size downslope. Finally, they clearly illustrate how spreads of surface debris have the effect of reducing the topographic expression of landslide units both downslope and over time.

Two further general points are worthy of note. First, that although there is a good general correspondence between slope morphology and the occurrence of degraded landslide units, it is not a constant one. In the case of large landslide units, such as that revealed in the West Hay section (figure 14), the topography appears to clearly reflect the presence and form of an underlying block. However, the relationship becomes less obvious where the original landslide units have been fragmented by block disruption and then buried by extensive spreads of head and wash (see figure 16). In such areas the resulting 'rippled' topography can be used to map the occurrence and extent of past landsliding activity, but cannot form the basis for defining the landslide block boundaries with precision. Second, both sections demonstrate the complexity of subsurface conditions likely to be encountered in areas that have been affected by landsliding. The variation in discontinuities, landslide remnants, scree deposits and head and wash in-fills can only be interpreted with difficulty from full sections. Any attempt to determine such patterns by conventional methods of investigation must therefore be based on very closely spaced boreholes and trial pits, and even then the results treated with caution.

5. Discussion

The geomorphological maps and sections suggest that the inland slopes of Stonebarrow Hill were produced by mass movement processes similar to those operating in Fairy Dell today.

The major differences concern the age of the mass movement and the nature of the relief producing mechanisms. Unfortunately, there is no evidence in terms of absolute dates to establish the age of the inland mass movement features. Circumstantial evidence was presented in a previous paper (Brunsden & Jones 1972) which indicated that in the case of the inland slopes 'vertical' incision by drainage lines, including the River Char, during the Pleistocene was a major factor in the generation of instability. Mass transport systems were established which moved material derived from degrading deep-seated failures, across broadly convex 'transport slopes' to the rivers. These systems continued to operate for as long as material was removed from the slope base by fluvial erosion. The most recent phase of alluviation associated with the latter stages of the Postglacial (Flandrian) Transgression, coupled with the effects of Postglacial climatic change, probably resulted in steadily diminishing activity as the slopes tended toward a stable condition. The present morphology (figures 12 and 13), therefore, is largely fossil, though currently being modified by creep and wash processes.

By contrast, the Fairy Dell complex has continued to be the site of landsliding activity due to the effects of 'lateral' marine erosion, thereby accounting for the greater clarity and sharpness of the constituent landforms. However, the complex topographic form of this area clearly indicates that marine erosion is not the only cause of instability, but works in combination with the effects of the variable and fluctuating groundwater conditions in Stonebarrow Hill. Marine influence is almost wholly confined to the maintenance of a constantly steep and unstable lower slope, thus preventing the development of an accumulation zone at the ultimate angle of stability of the debris materials. This landslide system is, therefore, being continually rejuvenated due to lateral unloading initiated by coastal erosion, parallel retreat of the cliff-line causing accelerated mudslide and block disruption activity which eventually leads to failures in the undercliffs and main scar. The Flandrian Transgression has in this instance not only caused the prolongation of activity through time, but may well have increased its rate of operation due to accelerated coastal erosion. There are, however, no grounds for suggesting that the nature and interrelationship of the mass movement processes presently visible in Fairy Dell are radically different from those that once operated on the adjacent inland slopes, though it is probable that the frequency and magnitude of failures would show a different distribution.

The differences in morphology displayed by the Char Valley slopes and those to the east of Stonebarrow Hill can be explained in terms of variations in both stratigraphy and the intensity of former landsliding activity. The Cretaceous deposits that form the eastern slopes of Stonebarrow Hill are underlain by a thick sequence of Middle Lias strata (figure 1), much of it arenaceous in character, so that shale horizons do not outcrop until the vicinity of West Hay

Farm. The increased thickness of permeable strata, together with the fact that the production of relief was limited to the effects of incision by two small streams, led to the slow development of large landslide blocks along a broad front. There are no signs of the most recent intense phase of landsliding which produced the steep arcuate scar embayments of the Char Valley (zone A3) (figures 11 and 12). The creation of major blocks in the degradation zone seems to have been followed by slow settlement; movement being dominated by loading on the upslope margins rather than erosional unloading of the toes through the mechanism of block disruption. Thus the major blocks have not only tended to survive as fairly large units which contain much of their original structure (figure 14), but have also moved considerable distances due to the loading effects of scree and head, which have resulted in a marked reduction in topographic expression, and in certain cases, complete burial.

The contrasting morphology of the three areas described in this paper are thus in large part due to the differences in intensity of landsliding processes, and in particular the scale of block disruption. Fairy Dell with its angular forms and second degradation zone (undercliffs) represents one extreme condition with widespread fragmentation of blocks and rapid throughput times. The eastern flanks of Stonebarrow Hill, by contrast, are near the opposite end of the spectrum, with large blocks suffering little disruption and having been moved downslope and buried by head and scree. The Char Valley slopes represent an intermediate position, certain areas being similar to those on the eastern flanks of Stonebarrow Hill, while others display the effects of more rapid downslope movement and block disruption associated with the incision of the River Char. The mechanisms are thus seen to be broadly comparable, the variations in form being due to the intensity of the differing mass movement processes involved.

The general evolutionary model described in this paper would appear widely applicable in Dorset, where similar geological conditions occur over extensive areas, although the presence of a second, or lower, degradation zone would depend on topographic and stratigraphic controls. It should also prove possible to modify this model to suit other situations, for the general pattern of large multiple landslides fronted by aprons of disrupted blocks and mudslides would appear accurately to describe the landslide slopes reported from a number of areas where coherent arenaceous sediments overlie less permeable argillaceous deposits. These areas are always variable in surface form, sub-surface conditions and drainage characteristics, and can only be well understood by the use of 'extensive' as well as 'intensive' investigations which will place a specific site within the context of its geomorphological situation, including its evolutionary history. This can be most efficiently achieved by the use of geomorphological surveys, similar to those referred to in this paper, at an early stage in the investigation.

The authors wish to thank the many colleagues and students of the Joint School of Geography who assisted with the field work necessary for this study. Particular thanks are due to Professor J. C. Pugh for surveying assistance, together with G. Butcher, D. Maugham, P. Parkinson, J. Petch, J. Pittam, D. Weyman and J. Wood.

The financial support of the Natural Environment Research Council who awarded a generous grant, and King's College who assisted with travel and equipment, are most gratefully acknowledged.

We also thank the Captain of H.M.S. *Osprey*, Mr N. Barrington, Mr C. R. Polglaze, Miss P. Roberts, and the cartographers Mrs J. Baker (London School of Economics), Miss D.

Orsanic, Miss R. Beaumont and Mr G. A. Reynell (University of London, King's College). for invaluable technical assistance.

We gratefully thank Miss M. A. Arber, Professor A. W. Skempton, F.R.S., and Dr J. N. Hutchinson for their constant interest and encouragement.

References (Brunsden & Jones)

Arber, M. A. 1941 The coastal landslips of West Dorset. *Proc. Geol. Ass.* **52**, 273–283.

Brunsden, D. 1974 The degradation of a coastal slope Dorset, England. *Progress in Geomorphology* (eds E. H. Brown & R. S. Waters), pp. 79–98. *Inst. Br. Geogrs. Spec. Publ. No.* 7.

Brunsden, D. & Jones, D. K. C. 1972 The morphology of degraded landslide slopes in South West Dorset. *Q. J. Eng. Geol.* **5**, 205–222.

Brunsden, D., Doornkamp, J. C., Fookes, P. G., Jones, D. K. C. & Kelly, J. M. H. 1975 Large-scale geomorphological mapping and highway engineering design: general concepts and case histories. *Q. J. Eng. Geol.* **8**, 227–253.

Carr, A. P. 1962 Cartographical error and historical accuracy. *Geography*, **47** 135–144.

Chandler, R. J. 1970 The degradation of Lias clay slopes in an area of the East Midlands. *Q. J. Eng. Geol.* **2**, 161–182.

Hutchinson, J. N. 1967 The free degradation of London Clay Cliffs. *Proc. Geotech. Conf. Oslo*, **1**, 113–118.

Hutchinson, J. N. 1973 The response of London Clay cliffs to differing rates of toe erosion. *Geologia Applicata e Idrogeologia*, **8**, 221–239.

Lang, W. D. 1914 The geology of the Charmouth Cliffs, beach and foreshore. *Proc. Geol. Ass.* **25**, 293–360.

Lang, W. D. 1942 Geological Notes, 1941–42. *Proc. Dorset Nat. Hist. Archaeol. Soc.* **64**, 129–130. Also in *Geol. Notes* 1944, **66**, 129.

Wilson, V., Welch, F. B. A., Robbie, J. A. & Green, G. M. 1958 Geology of the country around Bridport and Yeovil. (Sheets 327 and 312). *Mem. Geol. Surv. Gt Br.* (England and Wales). H.M.S.O. 238 pp.

Discussion

Muriel A. Arber (18 *Sherlock Close*, *Cambridge CB*3 0*HW*)

Dr Brunsden suggested that degraded landslides, similar to those in the Char valley, might be found elsewhere in west Dorset. That they occur in the valley of the River Lim, on the border of Dorset and Devon, is indicated both by the contours of the hillside slopes and by occasional temporary sections in what appears to be Upper Greensand further downhill than its solid outcrop; for instance, at SY338929, I have seen it at least 55 m below its junction with the Lias. The instability of the land in this valley, as in that of the Char, should be appreciated by all would-be developers.

The National Grid is of particular value in maps of landslides, not only because it gives a precise basis for the measurement of future movement, but because the character of the terrain makes it difficult otherwise to fix localities, which may even cease to exist when further slipping has occurred on the cliffs.

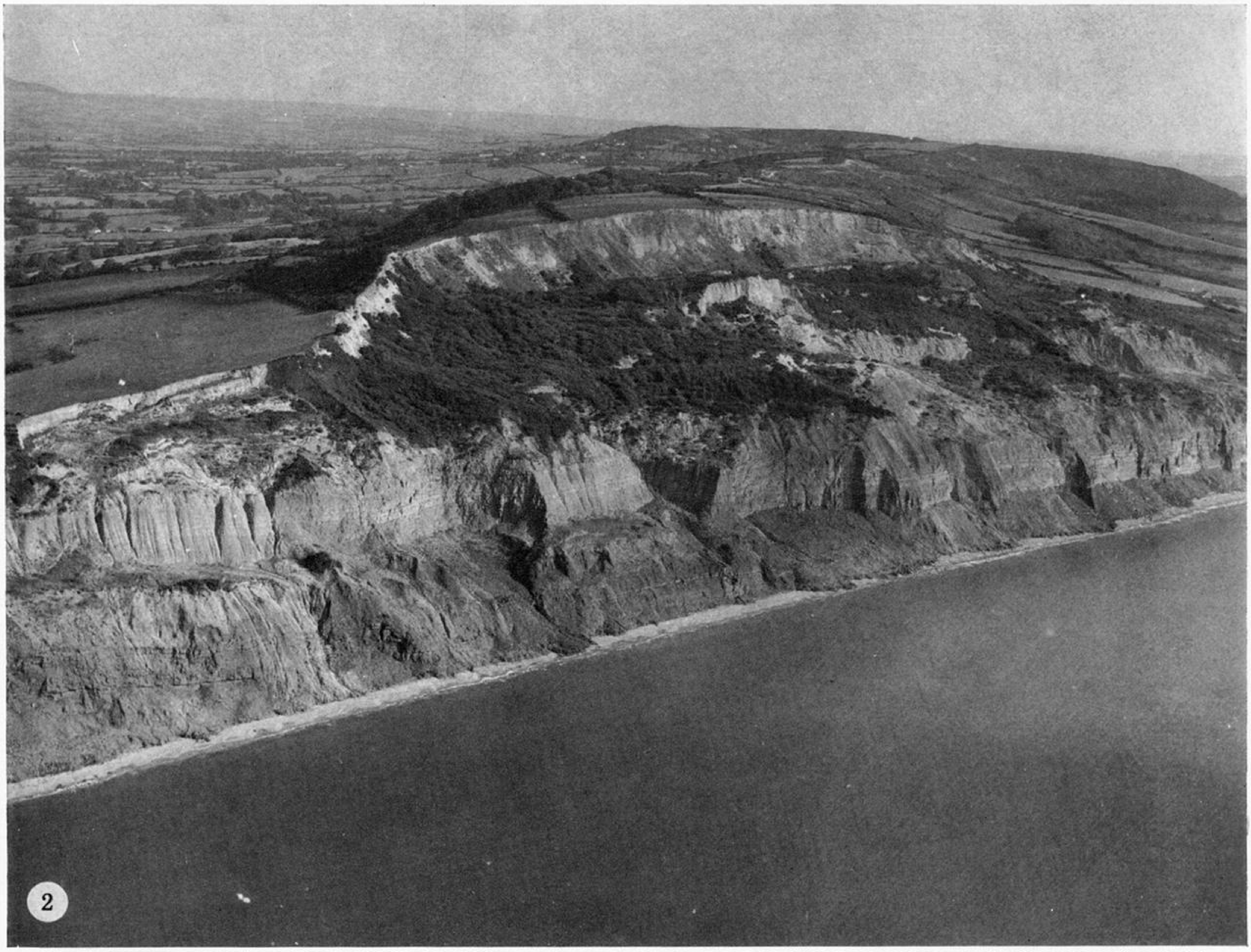


FIGURE 2. Oblique air photograph of Stonebarrow Hill, the Fairy Dell landslide complex and the degraded, inland landslide slopes (copyright N. Barrington, 1969). Photograph date: 9 August 1969.

FIGURE 3. Vertical air photograph of Stonebarrow Hill, the Fairy Dell landslide complex and part of the degraded, inland landslide slopes described in an earlier paper (Brunsden & Jones 1972) and compared with the active slopes in this paper. (Copyright D. Brunsden, Fairey Aviation, 1969). Attention is drawn to the irregular topography near the houses to the west (left) of Fairy Dell and the areas of woodland which conceal the large landslide coombes at the head of the degraded slopes.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

IGURE 15. Photograph of the degraded landslide block exposed in the coastal section near Westhay Farm. The backtilted Upper Greensand cherts are clearly visible and should be compared with the upper portion of the Fairy Dell section (figure 4).