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ASYMMETRICAL SLOPE DEVELOPMENT IN THE CHILTERN HILLS

Abstract

The asymmetrical nature of Chalk dry valleys in Southern England is discussed with reference to some of the Chiltern valleys. The periglacial origin of the asymmetry is not disputed. Instead, a model of asymmetrical slope and valley development is proposed in which the importance of fluvial processes in periglacial environments is stressed. Some implications with respect to the origin of chalk dry valleys are outlined. It is argued that while the major valleys may very well be explained in terms of a ground water hypothesis in accordance with a progressively falling watertable throughout the Pleistocene, the periods of periglacial conditions promoted: (a) the asymmetrical modification of the slopes of already existing valleys and (b) the initiation of the periglacial valleys and gullies – les vallons en berceau – upon the frozen subsoils existing at that time.

INTRODUCTION

It has been widely assumed that the Chalk landscape of Southern England is essentially a "fossil" periglacial landscape, fashioned by processes of a cryonival and niveo-fluvial nature. Williams (1968) has recently, in this journal, reviewed much of this evidence. Additional support for such an interpretation has been provided by the recognition of the widespread existence of periglacially modified asymmetrical valleys (Ollier & Thomasson, 1957; French, 1967). Such an asymmetry expresses itself in a steeper slope orientated towards the SW or W and is suggested to be directly comparable to that which characterises the dry valleys of North France (Gloriod & Tricart, 1952), of Belgium (Grimberieux, 1955), and of the Muschelkalk Plateau of Germany (Helbig, 1965). The asymmetry is thought to be the result of differential insolation and freeze-thaw processes operating upon slopes of varying orientations during the fluctuating climates of the Pleistocene. Similar asymmetry also exists upon other lithologies in France (Taillefer, 1944; Cavaillé, 1953), Belgium (Alexandre, 1958), the Netherlands (Geukens, 1947), Germany (Büdel, 1953), Czechoslovakia (Czudek, 1964) and Poland

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(Dylik, 1956). This asymmetry is regarded as the "normal" asymmetry for W-Europe.

Areas in Southern England where this asymmetry is particularly well developed are not only the Chiltern Hills, as Ollier and Thomasson have described, but also the North Wiltshire Chalklands and the North Dorset Downs (French, 1967). In these three areas, the well developed but simple NW–SE alignment of the valley patterns has been favourable for the development of the asymmetry. In other areas, structural and lithological considerations, together with rather more complex valley pattern have operated to disguise or negate the development of this asymmetry.

In the Chiltern Hills, the simple asymmetry pattern is complicated by the fact that there would appear to be at least two different types of W-facing asymmetrical valleys existing in close juxtaposition to symmetrical valleys. For this reason, the area offered special problems of explanation as regards asymmetry. This paper is an attempt to establish the relationship between these various forms as a contribution towards an understanding of the origin of such valleys. Emphasis in this paper is upon the forms of these valleys since the significance of the deposits has already been discussed by Ollier and Thomasson (1957), Avery (1959) and others. The resultant model of asymmetrical slope development is suggested to be applicable to the other areas of the Chalklands possessing the "normal" asymmetry.

THE SETTING OF THE PROBLEM

The majority of the valleys which dissect the dip slopes of the Chalklands of S. England do not posses surface streams. It is possible to distinguish two types of dip-slope dry valleys: (1) the large valleys which constitute the major drainage lines and valley patterns and (2) the numerous small tributaries and gullies which feed into the large valleys and which often produce asymmetrical tributary patterns. Such a distinction is similar to that made by Klatkowa (1965) in Poland between the *vallons en berceau* (niecki denudacyjne) and the *vallées sèches* (doliny denudacyjne). This study is primarily concerned with the asymmetrical form of the large valleys – les vallées sèches. In the Chiltern Hills at least four different types of valley forms can be recognised:

(1) Small shallow symmetrical valleys and gullies, often elongated or "paddle-shaped". These are found at the extreme heads of the larger valleys and on the gentle slopes of the asymmetrical valleys. These are analogous to the *vallons en berceau*.

(2) Normal Asymmetrical Valleys, Type I. On a much larger scale, valleys exist possessing a broadly U-shaped, yet asymmetrical, cross-profile.

Examples are the Radnage, Little Hampden and Callow Downs valleys (pl. 1). This form of asymmetry is regarded as the Type I asymmetry in the Chiltern Hills and may be contrasted with the Type II asymmetry existing in the same area.

(3) Normal Asymmetrical Valleys, Type II. This type of asymmetry is rather more striking than Type I since the valley is rather more clearly defined. The cross-profile is asymmetrical, but basically V-shaped. Such valley forms are found in the Chesham and Hughendon areas (pl. 2).

(4) Symmetrical U-shaped Valleys. These are broad flat valleys such as the Great Missenden valley and the "through" valleys of the region. The three latter types constitute the *vallées sèches* or *doliny denudacyjne* of the English Chalklands.

Because both symmetrical and asymmetrical valleys are present in the Chiltern Hills, the problem is not merely to explain asymmetry but also it is to establish why some valleys are not asymmetrical. Any hypothesis must be of general applicability to the whole area if it is to be anything but special pleading.

The problems posed by symmetrical valleys are exemplified by examining the broad "through" valleys. They lack any noticeable slope asymmetry throughout their lengths. This could be the result of either the size of the valley limiting any cross-valley variations conducive to asymmetry formation or the eradication of asymmetry by glacial meltwater modification from the Vale of Aylesbury (Brown, 1964). However, the nature of these valleys is rather more complex than this, for Ollier and Thomasson (1957) note that the asymmetrical pattern of soils found in all the asymmetrical valleys is also present in these large "through" valleys, (see soil survey map "Aylesbury" for many examples, e.g. Gt. Missenden Valley). If meltwater had indeed acted to modify the slope forms of these valleys one would have expected it to have also destroyed the much more delicate soil asymmetry. Furthermore, the very presence of an asymmetrical development of soil types implies differential cross-valley variations of some sort. For several reasons, therefore, it is clear that the symmetrical nature of the broad valleys poses rather more difficult problems of explanation than are, at first, appreciated.

The existence of "paddle-shaped" symmetrical valley heads is also problematical. Is there, for example, a "threshold" of some sort at which such a form changes to an asymmetrical one? If so, the establishing of this is essential to understanding the development of asymmetry. Helbig (1965), for example, has suggested a depth as small as 15′ (4.5 m) for the initiation of asymmetry. Alternatively, one can ask: what conditions are exclusive to these extreme valley heads?

Thus, in examining the asymmetrical nature of the Chiltern valleys, one is inevitably committed to a consideration of the symmetrical valleys also. If asymmetry is a climatic phenomena, the location of the areas of no asymmetry may be just as revealing as those with asymmetry. Finally, a given sequence of asymmetrical slope development must be able to incorporate symmetrical forms if it is to be considered as representing any sort of reality for the Chiltern Hills.

ASYMMETRICAL SLOPE DEVELOPMENT

In the past, many slope studies have been conceived of within a cyclic or stage dependent conceptual framework. Thus, a downvalley slope sequence may be thought to be an indirect reflection of stage. However, it is also possible to examine a downvalley sequence of slopes without any implication of stage. Instead, the various downvalley profiles are considered in relation to such variables as slope height, distance from source, and valley dimensions in general.

Slopes profiles were measured by the author in dry valleys on the Chalk possessing the "normal" asymmetry[1]. The fieldwork was carried out in the Chiltern Hills, the Marlborough Downs, the N. Dorset Downs, the South Downs and the Southern Hampshire Chalklands.

Distinctive slope angles were found to characterise the valleys. Maximum slope angles had major peaks of 7–11° (41%) and of 19–23° (15%) which correspond to the gentler and steeper slopes respectively of these valleys. Secondly, the gentle slopes were characterised by long R. segments of a constant angle between 5–9°.

The interaction of these characteristic angles to produce the asymmetrical forms is clearly of importance. Consequently, a detailed analysis of the slopes of two valleys in the Chiltern Hills is outlined. The two valleys chosen were those of Little Hampden and Bryant's Bottom which correspond, respectively, to the two types of asymmetrical valley already recogn sed.

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[1] The slopes were measured by means of an Abney level, a tape and a pair of ranging poles. Analysis was made first, of the maximum slope angles measured and secondly, of the frequency of rectilinear segments within the profiles. The following terminology was decided upon: a *measured length* – the distance over which each slope measurement was taken (a constant interval of 30'); a *rectilinear segment* (R) – at least 3 measured lengths having an interval variation of no more than 1° (plus or minus ½°); a *maximum angle* – the highest slope angle recorded over one measured length for one complete profile. The index of asymmetry, Id, as defined by Tricart (1947) was used to describe the degree of asymmetry present. However, it was defined with respect to maximum angles and the resultant index was given the title of the *Asymmetry Index*, A/I.

TYPE I ASYMMETRY – THE LITTLE HAMPDEN VALLEY

(fig. 1)

This valley was the subject of a previous examination of slopes and deposits by Ollier and Thomasson (1957). The sequence of soils and deposits as outlined by these authors was verified in the field. However, the ambiguous relationship between slopes and deposits is such that this was an incentive to examine and isolate only slope form in this paper. The surveyed profiles (fig. 2, table I) enable the following conclusions to be made.

Firstly, with the exception of profile 1 which had insignificant asymmetry development, all of the steeper slopes are orientated facing 240°–270°. Secondly, asymmetry gradually develops in magnitude from a negligible state at profile H1 to an important dimension at profile H4 (A/I=2.15). Beyond profile H4 the asymmetry declines slightly but still remains a strong characteristic of the cross profile. This suggests that profile H4 represents the maximum development of asymmetry after which, in response perhaps to environmental slope factors concerned with valley dimensions, the asymmetry becomes stabilized.

One such factor is that of slope height. In Little Hampden, the maximum A/I coincides with a depth of encasement of about 100–150′, a value which is considerably in excess of the 45–60′ suggested by Gloriod and Tricart (1952). On the other hand, the value of 45–60′ appears to coincide with the depth at which asymmetry begins to develop, thus agreeing rather more with Helbig's evidence. Another valley dimension of reputed importance is that of distance from source. In the Little Hampden Valley, the maximum asymmetry is reached at a distance of approximately 1.6 miles from the head. This relates well to a maximum at 2–3 kilometers for Artois (Gloriod & Tricart, 1952). The maximum angle is also of importance. On the steeper slope it increases steadily downvalley until the maximum of 22° is reached at profile H4 coinciding with the maximum development of asymmetry. By contrast, the maximum angles of the gentle slope displays a remarkable uniformity and are closely grouped in the angle range of 8–11°. Such consideration of maximum angles suggests that the gentle slope maintains an approximately constant angle while the steeper slope develops to a maximum of between 19–22°.

In order to examine such an hypothesis, the relationship of R-segments to maximum angles was investigated. It is assumed that the nearer is the maximum angle to the base of the slope, the more active is some form of downcutting or basal undercutting in fashioning the overall form of the slope. On the other hand, a maximum angle situated at some distance away from the valley bottom,

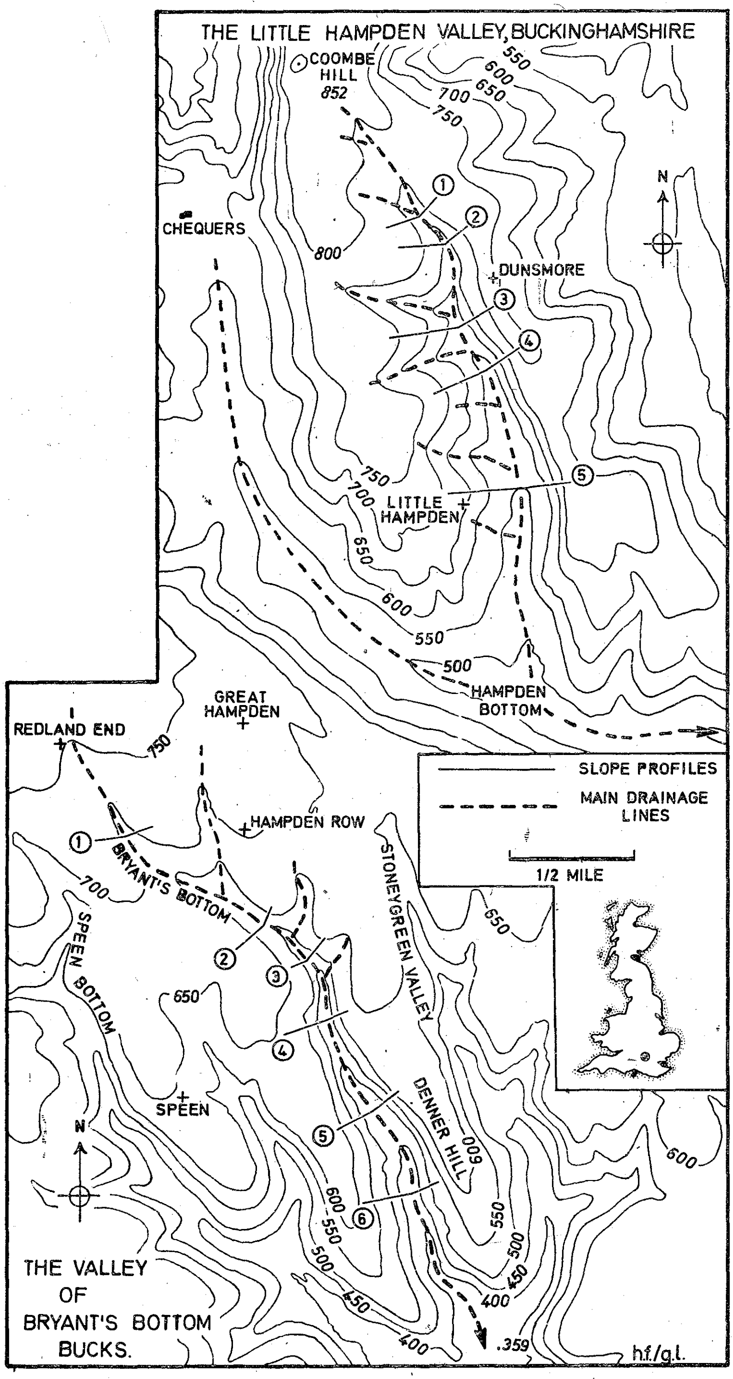

Fig. 1. Location map and position of slope profiles

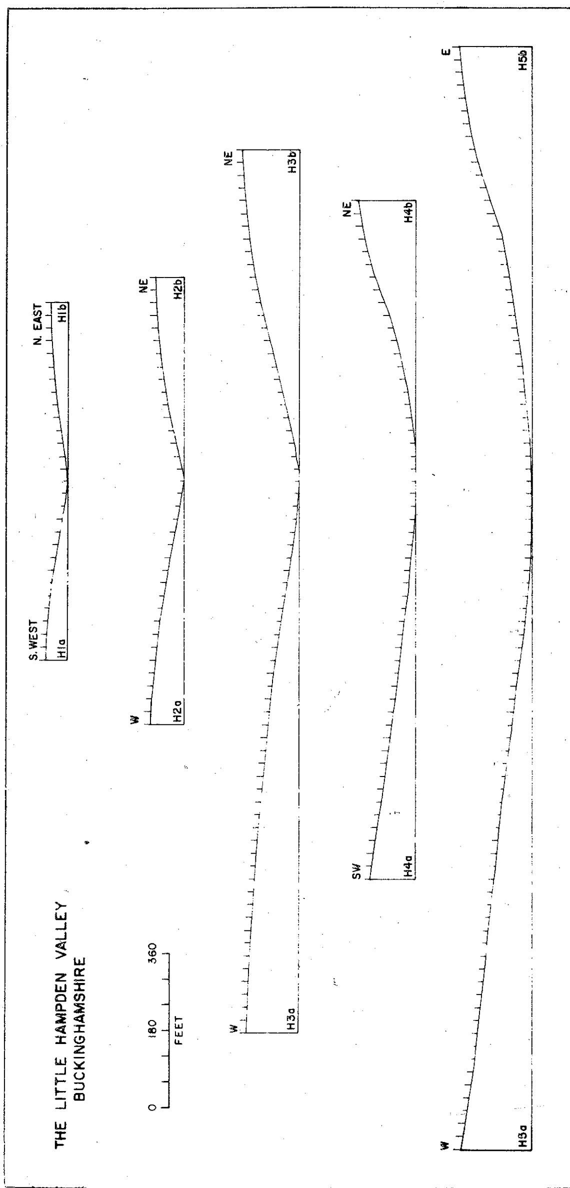

Fig. 2. Surveyed slope profiles: The Little Hampden Valley, Buckinghamshire

upslope, implies the development of a broad concavity of some form beneath the maximum angle, a morphological feature which could only be developed if downcutting was relatively unimportant. Concerning the steeper slope, two points are of note: Firstly, the % R increases downvalley to profile H3 (71%) but falls off at profiles H4 and H5, where the asymmetry is in fact best developed. Secondly, the maximum angle moves progressively upslope further down the valley and at profile locations H4 and H5 over 50% of the slope lengths are beneath this angle.

These two trends can be reconciled in the following manner. They suggest that, to begin with, the development of the steep slope takes the form of the extension of the R-segments, ogether with the maximum angle towards the bottom of the slope in response to downcutting. The % R reaches a maximum of about 70% of the total slope. After this stage has been reached, the slope suffers modification. Firstly, the slope continues to steepen to a maximum angle of 22°, secondly, there is an increase of slope length beneath the maximum angle and thirdly, there is a marked decrease in the total % R segments in favor of convex, concave, or complex forms. Finally, the maximum angle, having hithertoo undergone steepening, becomes adjusted to a maximum angle of 18–22°. This is associated with an increase in the extent of lower angled slopes beneath the maximum angle which is in contrast to the previous extension of R segments.

Such an interpretation implies two things for the steep slope of the Little Hampden Valley. Firstly, downcutting was associated with the steepening of the slope and an extension of the R segments in the upper part of the valley. Secondly, with the attainment of a maximum angle somewhere in the region of 19–22° and the maximum extension of R segments, the whole slope experiences parallel retreat. At this point, the slope form is regarded as being of extreme relevance. Theoretically, 3 components of a retreating slope can be recognised in a situation involving no downcutting: the free face, the debris slope, and the footslope (fig. 3). In the Little Hampden Valley, only the first two components are recognised. The maximum angle segment of 18–22° constitutes the free-face and beneath it, there is a debris slope of 8–10° angle. The role of the debris slope is to allow the transport of material from the free-face to pass into the basal channel and to be subsequently removed from the system. The angle of any such slope of transport is related therefore to (1) the processes acting upon it and (2) the nature of the material being moved across it. No footslope is present since, as Ollier and Thomasson have pointed out (1957, p. 78), this slope would inevitably have to be lower in angle than the opposite gentle slope. This is demonstrably not the case in the situation being considered. Some degree of downcutting is therefore involved. However, the extent and development of this debris slope implies that this downcutting was not necessarily so important as was suggested for the steeping of the slope in the upper reaches of the valley. Such downcutting would hinder the extension of the debris slope unless the slope was retreating at an exceptionally fast rate and this has yet to be demonstrated.

There are many other localities upon the Chalklands of S. England where debris slopes possessing R-segments of between 8–10° in angle can be recognised on the steeper SW facing slopes of asymmetrical valleys (fig. 4). Examples are the Radnage & Callow Downs Valleys (pl. 1), Buckinghamshire, the West Woods Valley, Wiltshire, the Devil's Brook, near Dewlish, Dorset, and some of the valleys of the Eastern South Downs, Sussex. In all cases, the slope forms cannot be related to lithological differences in the Chalk.

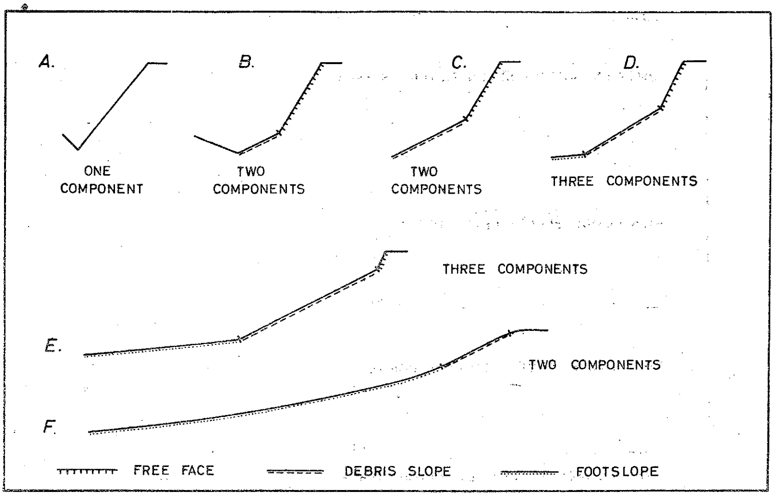

Fig. 3. Morphological components of a retreating slope, after Penck (1924) and Wood (1942)

In many respects the gentle slope of Little Hampden Valley can be contrasted to the steeper. Firstly, the maximum angle suffers no drastic change in angle downvalley. Secondly, with the exception of profile H1, there is a high % R segments (60–80% total slope length) in all the profiles which serves as an important form characteristic of the gentle slope. The majority of these R segments are 5.0–8.9° in angle, and they would appear to be intimately related to the degree of asymmetry since there is a direct relationship between the degree of asymmetry and the % R segments of that angle range. Thus profile H4, for example, corresponds to both the highest degree of asymmetry (A/I = 2.75) and the greatest % R segments of this angle.

It seems likely that the gentle slope, in contrast to the steep slope, develops at a constant angle. The growth of the gentle slope coincides both

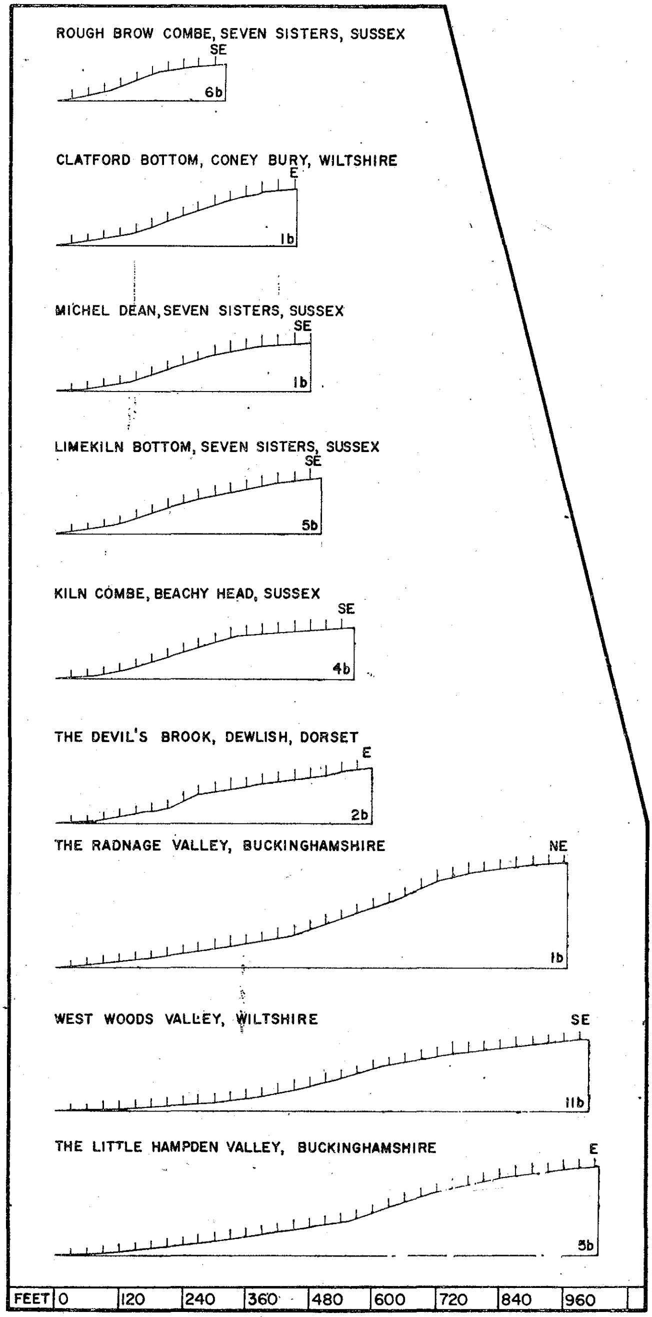

Fig. 4. Selected south-west facing slope profiles on the Chalklands of Southern England

with the development of asymmetry and the increase in importance of R segments of 5.0–8.9°. It is significant that Winchester soils occur widely upon this slope in spite of the fact that the parent material for this soil (clay-with--flints) is derived from near the top of the slope thereby indicating downslope movement to be important on this slope. Thirdly, as for the W facing slope, it seems that downcutting was more important in the upper reaches of the valley.

TYPE II ASYMMETRY – THE BRYANT'S BOTTOM VALLEY (fig. 1)

Barely three miles from the Little Hampden Valley, the valley of Bryant's Bottom is strikingly asymmetrical. However, it is narrow and V-shaped and is regarded as an example of the second type of slope asymmetry present in the Chiltern Hills (pl. 2). The valley runs SE from Green Hailey towards lower Warren farm where it joins the N-S Hughenden vale. The M. Chalk is exposed in the valley bottom in its lowest part and the valley follows the dip precisely.

In summary, there would appear to be certain similarities between the two valleys as regards slope development (fig. 5, table I). In particular, criteria such as the maximum angles of the steep slope (21–22°), the orientation of the asymmetry (SW), the depth at which asymmetry begins (50′), and the distance from source at which the asymmetry reaches its maximum, about two miles, are surprisingly similar. R-segments of 5.0–8.9° are certainly not unimportant upon the gentle slope of Bryant's Bottom. In profiles 4 and 5, where asymmetry is well developed, the extent of the R-segments of 5.0–8.9 as a % of the total R-segments is appreciable (38 & 54% respectively). In fact, it can be argued that the R-segments of 5.0–8.9° are just as important in the form composition of the gentle slope of this second type of asymmetry. But there are several important differences between the valleys. Firstly, in Bryant's Bottom, the maximum angle of the gentle slope does not remain so remarkably constant as it does in the Little Hampden Valley but increases downvalley. Thus, although the steep slope reaches a maximum angle of 22° in profile B4a, the maximum A/I obtained is lower (A/I = 1.95), because the maximum angle of the gentle slope is higher. Secondly, in Bryant's Bottom the asymmetry decreases very sharply after the attainment of maximum asymmetry. Moreover, this is interesting because the asymmetry decreases downvalley from the point of maximum asymmetry not so much as a result of the decline in angle of the steeper slope but rather through the increase in angle of the gentle slope. Thirdly, the examination of the R-segments in conjunction with the position of the maximum slope angles show no discernible relationship, similar to that found in Little Hampden. There does not appear to be any comparable development of a debris slope.

A MODEL OF ASYMMETRICAL SLOPE DEVELOPMENT

Using the evidence which has been presented above, it is possible to develop an inductive model within which all of these observations can be incorporated.

The association between asymmetry development and the existence of R-segments of 5.0–8.9° upon the gentle slope would appear to be crucial. The evidence suggests that asymmetry develops in response to the increasing

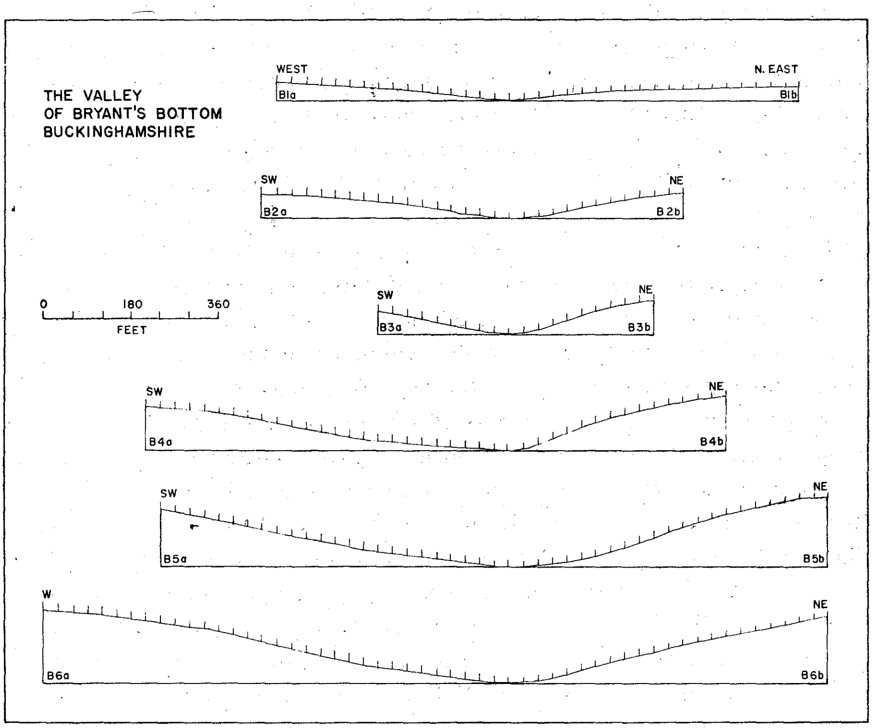

Fig. 5. Surveyed slope profiles: The Bryant's Bottom Valley, Buckinghamshire

extent of such slope angles upon the gentle slope. It seems probable that the major asymmetry forming process in the Chiltern operates most effectively upon the gentle slope at that angle. Thus, not only may 5.0–8.9° be a characteristic angle of the Chalk but it may also be a limiting angle for asymmetry processes.

It may therefore be possible to postulate a threshold angle, rather than a threshold depth, below which asymmetry does not develop. The evidence

Table I

Slope profile data for the Little Hampden Valley (H) and the Bryant's Bottom Valley (B), Bucks.

Profile	Orientation	Height in feet	Max. angle	Max. A/I	Distance from source in metres	% R Ground length	% R between 5.0–8.9°	% slope beneath max. angle
H1a	235°	38	9.00°	1.12	0.6	61.52	30.76	23.07
H1b	065°	48	10.25°			30.76	–	23.07
H2a	230°	63	14.00°	1.25	0.9	43.75	25.00	6.25
H2b	080°	75	11.25°			77.77	42.85	10.52
H3a	248°	135	14.50°	1.53	1.4	71.10	14.28	38.46
H3b	080°	115	9.50°			86.94	55.00	15.38
H4a	240°	136	22.00°	2.75	1.6	12.50	–	58.33
H4b	060°	105	8.50°			83.94	100.00	36.36
H5a	270°	175	19.00°	2.37	2.2	39.27	13.88	54.28
H5b	085°	155	8.00°			68.00	88.23	46.00
B1a	260°	30	7.00°	1.07	0.8	68.41	–	6.25
B1b	080°	36	7.50°			81.25	31.25	31.25
B2a	210°	50	13.00°	1.24	1.6	27.27	25.00	27.27
B2b	045°	48	10.50°			57.88	36.84	31.25
B3a	210	72	20.00°	1.60	2.0	–	–	40.00
B3b	055°	48	12.50°			33.30	–	44.44
B4a	250°	112	22.50°	1.95	2.4	37.50	–	18.79
B4b	070°	94	11.50°			70.92	38.71	45.16
B5a	240°	144	21.00°	1.61	3.0	29.16	–	37.50
B5b	040°	120	13.00°			29.00	54.16	58.33
B6a	250°	138	16.00°	1.06	3.25	30.43	–	52.17
B6b	070°	156	15.00°			64.68	29.41	66.66

indicates that this angle is approximately 7–9°. On the Chalk, it would appear that a depth of encasement of approximately 40–50′ is necessary for the normal attainment of this angle. Upon reaching 7–9°, the asymmetry forming processes begin to operate upon the slopes; to smooth out, to lower slightly in angle, and to extend the gentle slope at this constant angle of 5.0–8.9°. With the continued downcutting of the basal channel asymmetry subsequently begins to develop. This is because the gentle slope extends itself constantly at 5.0–8.9° and there is, therefore, an inevitable lateral movement of the basal channel to the foot of the other, now steeper, slope. It must be emphasised that this latter slope begins to develop in response to two factors; firstly, the lateral movement of the basal channel to the foot of the slope, and secondly, the continued downcutting of the valley. Lateral movement and downcutting are thus synonymous at this stage of development. On the steeper slope, the R-segments extend downslope and the maximum angle, as well as increasing, does likewise.

Continued downcutting affects the steeper slope even more, however, and the R segments of this slope increase to perhaps, a maximum of 70% of the total slope length. At the same time a maximum angle is reached of about 19–22°. Contemporaneously, the gentle slope still extends itself at its constant angle and, as downcutting is still operating in the valley, the extension of this slope and the steepening of the SW facing slope result in a continued lateral movement of the basal channel. At about this stage, the maximum asymmetrical development will be reached for the steeper slope will have obtained its maximum angle. An A/I of between 2.0–3.0° will be typical at this point. With the development of this stage of maximum asymmetry, subsequent slope development will depend to a large extent upon the efficiency of the basal channel to cut downwards. It would appear that it is this criteria which differientiates the Little Hampden Valley from Bryant's Bottom, and thus the form of the Type I asymmetrical valleys from that of the Type II asymmetrical valleys.

There are many reasons why the downcutting of a valley may become less important. While many of them are connected with increasing valley dimensions (e.g. lowering of channel gradients, increasing proximity to base level) some are associated with decreases in the debris *production : removal* ratio. In the latter case, an increase in the volume of weathered material arriving at the basal channel will leave the stream with less available energy to erode, either laterally or vertically. Moreover, any increase in slope length as the valley deepens will provide more debris even if the slope angle remains constant. It may be, therefore, that as the steeper slope increases to 19–22° in angle, the amount of weathered material arriving at the foot of this slope becomes sufficient to reduce, and finally negate, any further downcutting of the basal channel. If this is the case, the asymmetrical valley form, at its maximum

Pl. 1. Chiltern Hills asymmetry, type I. The Callow Downs Valley, looking SE from Slough Hill

Pl. 2. Chiltern Hills asymmetry, type II. The Bryants' Bottom Valley, looking N

asymmetrical development, suffers modification. The gentle slope remains constant in angle and the basal channel does not move laterally in either direction since a state of adjustment or balance has been attained between the stream and the debris being supplied by the two slopes. The steeper slope, having attained its maximum angle, continues to retreat parallel to itself. This results in the development of a lower angled debris slope between the maximum angle and the basal channel (fig. 3).

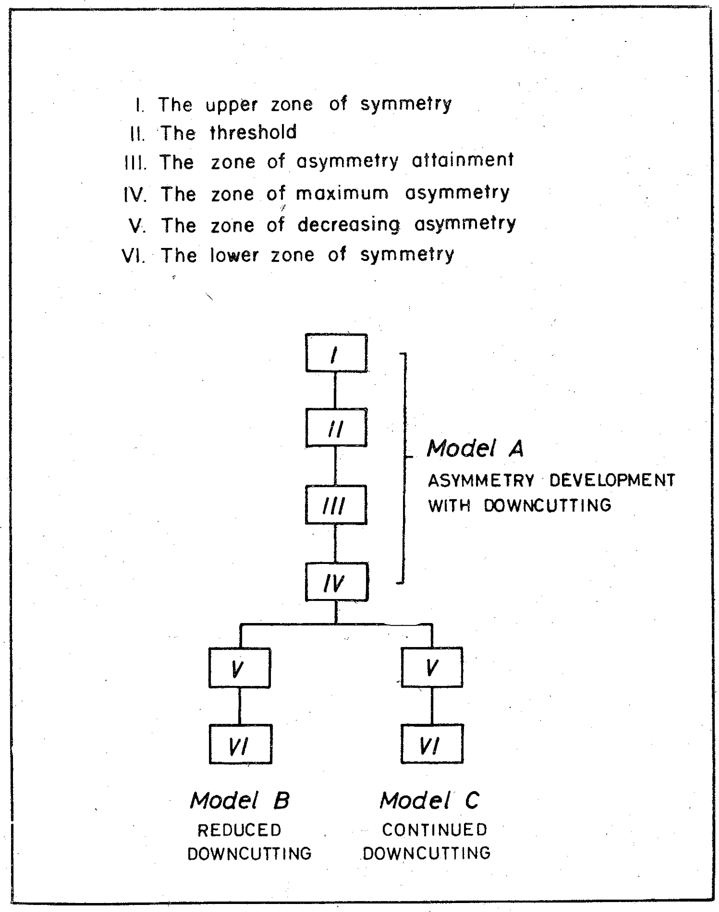

Fig. 6. Sequential model of asymmetrical valley development in the Chiltern Hills

If, however, downcutting is not impeded to the extent which has been implied, the slope development is slightly different. Asymmetry decreases owing to an increase in the angle of the gentle slope and, perhaps, a slight decline of the steeper slope. It is suggested that this decline in angle of the steep slope is associated with impeded basal removal, for any further undercutting of the maximum angled steep slope (22°) will produce a totally disproportionate amount of debris to be removed from the base. Only an exceptionally large stream would have the power to do this and, at the same time, have excess energy available for lateral erosion. If downcutting continues, therefore, the gentle slope will begin to suffer modification and steepen in angle for the simple reason that it cannot extend itself at a constant angle because the position of the basal channel is relatively fixed. With the increase in angle of the gentle slope, the asymmetry decreases. Moreover, it may well be that, with the disappearance of the R segments of 5.0–8.9° the asymmetry-forming processes would also diminish in importance.

In the case of those asymmetrical valleys where downcutting is unimportant, and the steep slope is beginning to retreat parallel to itself, the asymmetry also decreases after a time and eventually disappears. The lack of any surveyed profiles at this point makes the following evolution rather conjectural, but it may be tentatively proposed that continued parallel retreat of the steep slope and a diminution in the extent of the maximum angle results, ultimately, in the 'steeper' slope being composed of a lower angled debris slope and/or footslope. The asymmetrical distribution of deposits within the large symmetrical valleys of the Chiltern Hills rules out the alternative possibilities of either increasing valley dimensions reducing crossvalley variations or increasing discharge acting to modify the slopes.

It is now possible to summarise the manner in which the normal asymmetry develops, maintains itself and then diminishes, by recognising a sequence of stages of downvalley development of an asymmetrical valley (fig. 6):

Stage I: The Upper Zone of Symmetry. In the shallow weakly incised heads of valleys where the slope angles have not reached the 'threshold' angles of 7–9°, there is a symmetrical development of both slopes of the valley.

Stage II: The 'Threshold'. This is reached when both slopes attain angles of 7–9°. This usually coincides with a depth of incasement of approximately 40–50′.

Stage III: The Zone of Asymmetry Attainment. After reaching the threshold angle, the gentle slope suffers very little modification, remaining constant in angle with R segments of 5.0–8.9°. Continued downcutting and a subsequent lateral movement of the basal channel to the foot of the steep slope promotes an increase in angle length and rectilinearity of that slope. Asymmetry, therefore, begins to appear in the cross-profile.

Stage IV: The Zone of Maximum Asymmetry. The steep slope reaches a maximum angle of 19–22° in response to downcutting and a lateral movement of the basal channel. The gentle slope has a uniform angle of 5.0–8.9°. The A/I reaches a maximum of 2.75–3.00. Asymmetry is maintained f (1) downcutting ceases or is reduced in importance, for the steep slope then begins to retreat parallel to itself producing a lower angled debris slope (e.g. Little Hampden) or (2) the basal channel is particularly strong in its erosive power to undercut the steep slope even further and to transport material away at the same time. This produces 24–25° meander bluffs' as the steeper

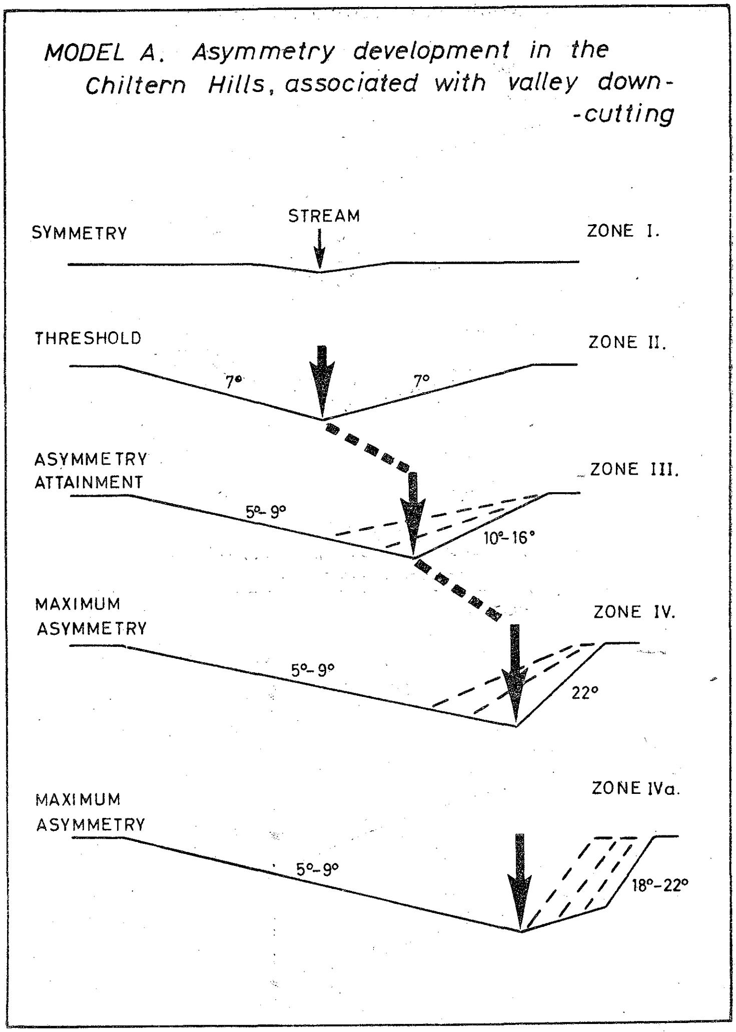

Fig 7. Model A. Asymmetry development contemporaneous to downcutting

slope. (This feature is not present in the Chiltern Hills but is found in Dorset where powerful scarp foot springs cross the dip-slope, e.g. the Devil's Brook, Dorset).

Stage V: The Zone of Decreasing Asymmetry. Asymmetry decreases owing to (1) the continued retreat of the maximum angle if downcutting has ceased or (2) an increase in the angle of the gentle slope if there is a continuance of downcutting (e.g. Bryant's Bottom).

Stage VI. The Lower Zone of Symmetry. Symmetry again becomes established in the valley (e.g. the large 'through' valleys). In these cases, the retreating steeper slope would have ultimately 'consumed' its free face. This

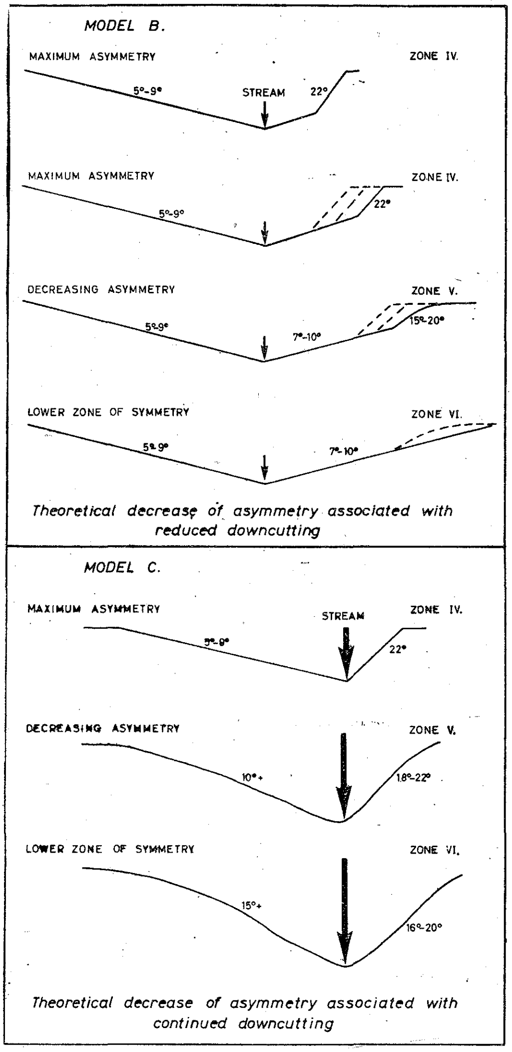

Fig. 8. Models of decreasing asymmetry

slope would consist of the debris and/or footslope components which would approximate in angle to the gentle slope.

There are certain aspects of this sequence which warrant further comment.

It would appear that, in many of the Chiltern valleys, slope development has proceded to the stage of Maximum Asymmetry. The development towards this stage is conceived of as model A (fig. 7). The Zone of Maximum Asymmetry reflects a change in the environmental slope conditions from those of downcutting and lateral migration of the stream to those of an equilibrium between the debris arriving from both slopes and the erosive powers of the basal stream. The manner in which asymmetry disappears suggests two further models. Asymmetry may decrease in one of two ways: (1) a continued retreat

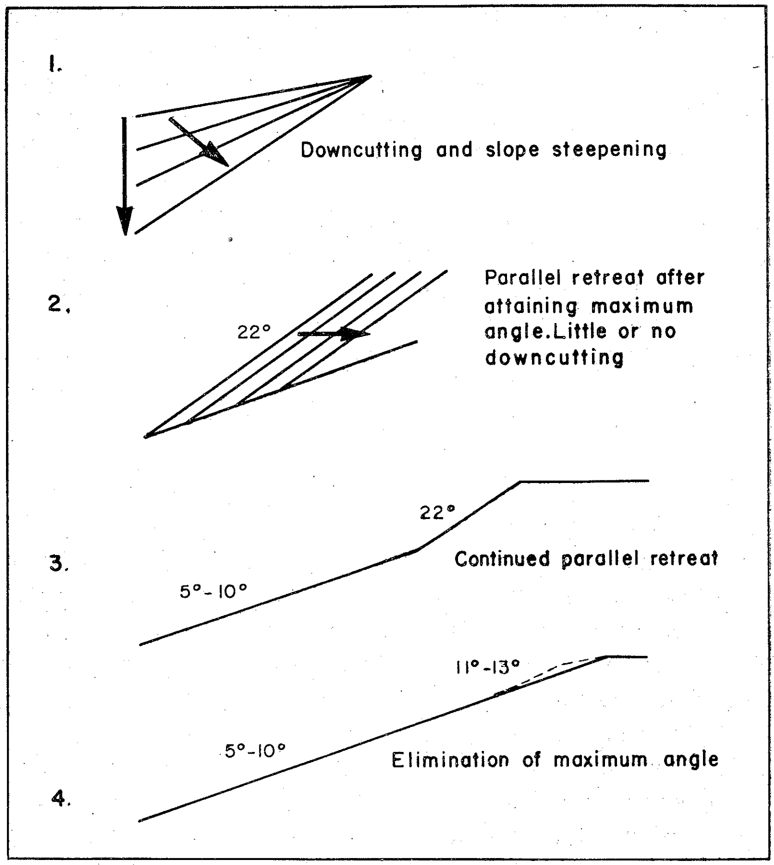

Fig 9. The evolution of the steeper west-facing slope in the Chiltern Hills

of the steep slope – Model B (fig. 8) and (2) a renewal of downcutting – Model C (fig. 8). In model B a broad shallow valley would be the end result which would be approximately symmetrical in cross-profile and in model C a deeply incised V-shaped valley would develop.

It may very well be that the form of the large 'through' valleys of the Chiltern Hills, such as the Gt. Missenden Valley with the symmetrical cross-

-profiles but asymmetrical pattern of soils and deposits is the end result of this slope sequence. How else, it must be argued, can an asymmetrical pattern of soils and deposits be present in both symmetrical and asymmetrical valleys? Thus, it can be visualised that the three rather different valley forms of, for example, Bryant's Bottom, Little Hampden and the Great Missenden Valley are reflections of but one sequence of asymmetrical slope development (fig. 9) which has become arrested and fossilised with the drying up of the valleys and the eradiction of conditions conducive to asymmetry formation. It is suggested that this sequence is applicable to those areas of the Chalk of Southern England which possess the 'normal', W-facing asymmetry. However, there are many instances where it is inapplicable. For example, the E-facing asymmetry of the valley NW of Brighton, the randomly orientated asymmetry of S. Hampshire, and the predominantly N-facing asymmetry of Salisbury Plain (French, 1967) are of a different nature. Finally, the rather unique, 'abnormal' asymmetry of Clatford Bottom, N. Wiltshire (Clark, *et al.*, 1967) and "The Valley of Stones" in S. Dorset finds no place within this model. To all of these, other explanations of a lithological, structural or different climatic nature are necessary (see French, 1967; Williams, 1968).

CONCLUSIONS

There are several observations of general relevance to periglacial problems which may be drawn from this study. Firstly, the morphologically more active slope is the SW-facing slope and it appears to undergo a process of parallel retreat as Ollier and Thomasson (1957) concluded. The recognition of the existence of debris slopes beneath the free face operating as slopes of transport for material from the free face is further confirmation of this mechanism. Secondly, the importance attached to the gentle slopes in the development of the asymmetrical valleys is considerable. Although little morphological modification takes place upon this slope, it would appear that the extension of this slope often at an angle of between 5–8° is instrumental in the lateral movement of the basal channel and the promotion of the steeping of the other slope. A 'threshold' angle of about 7° may very well be a valid concept for the initiation of asymmetrical valley development.

Thirdly, the importance of linear erosion and its relationship to the production of weathered material is basis to this model of asymmetry development. The efficacy of erosion by running water in periglacial regions has often been underestimated in the past. Peltier (1950), for example, does not give it the mportance which it deserves. However, recent work in the

Canadian Arctic is indicating that stream erosion is probably more effective in a periglacial region than in any other morphoclimatic region (St-Onge, 1964) since the stream flow is highly concentrated and there is an absence of a continuous vegetation cover (Robitaille, 1960). Running water in the valley bottom and solifluction and creep acting upon the gentle slope with freeze-thaw processes upon the steeper slope were the most likely combination of processes operating to produce the asymmetry.

Finally, there are the implications of this study to the problematic origin of the dip-slope dry valleys of the Chalk. The interpretation given here to the existence of the 'normal' asymmetry implies that a surface water hypothesis may be valid (i.e. higher surface run-off in the past due to e.g. frozen sub-soil, Bull, 1940). However, many of these valleys are undoubtedly polycyclic, since different stages of evolution of the steeper slope are found in different valleys within the same area. Furthermore, their long profiles give evidence of successive rejuvenation (Culling, 1956). A surface water hypothesis is not completely adequate, therefore, and it is probable that the major dry valleys – les vallées sèches – were cut by stream action resulting from the existence of a higher water table at the time (i.e. a groundwater hypothesis, Fagg, 1954). In all probability, the valleys became successively drier from the headwater downwards, as the water table fell during the Pleistocene. If this were so, the downstream sections could have been formed and modified while upstream parts were dry and fossilised. The influence of the periglacial asymmetry-forming processes upon the Chalk landscape may therefore have been twofold; firstly, to modify the slope forms of already existing valleys and secondly, to initiate true periglacial valleys and gullies – les vallons en berceau – upon the frozen subsoils existing at that time. Such periglacial conditions probably recurred several times throughout the fluctuating climate of the Pleistocene and the Chalk landscape of today is, essentially, a reflection of the latest of these periods, preserved by the progressive desiccation of the Chalk.

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