Notes on Two Transverse-Profile Geomorphic Problems.

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[*Read before Wellington Branch, October 10, 1940; received by the Editor, October 10, 1940; issued separately, June, 1941.*]

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I.—RIVER TERRACE PROFILES.

A DIAGRAM of the development of river terraces published recently by Lobeck and another produced by Hills* draw attention to a necessary deduction from Davis's hypothesis of terrace-development during restrained downcutting. The abandonment of unmatched terraces alternating in level on opposite sides of a valley calls for a to-and-fro swinging of a river across the valley during slow degradation; and generally it is assumed that a whole meander belt so swings.† Lobeck's diagram shows this process as cutting successive flood-plain floors which slope alternately right and left across the valley; and the conclusion that something of the nature of slip-off slopes must be left during combined across-valley migration and downward cutting is inescapable. It is very doubtful, however, whether these floors are usually sloping plains which are smooth for their whole width except for the usual swells and swales and other inequalities of flood-plains. If such is the case, the treads of broad terraces that result from swinging may be expected to have continuous slopes of measurable declivity away from the valley sides, these being, of course, distinct from and beneath any surface slopes that have resulted from the accumulation of valley-side talus and fans on the terraces. Every terrace tread of this kind would be itself a polygenetic terrace, as defined by Chaput. It does not appear that any precise measurements are on record which would prove that terrace treads commonly slope in this manner; but the hypothesis is worth testing, and examination of terrace treads with the object of detecting any systematic across-valley slopes may be recommended to observers in New Zealand.

In most cases it may be expected, however, that a meander belt migrating sideward and downward instead of developing a smooth slope (polygenetic terrace) would carry down with it a strip as wide as the belt itself, which would have a floor approximately horizontal in transverse profile, while at the same time leaving behind on the slip-off slope of abandoned flood-plain strips an irregular flight of low terraces with level treads. Should the river not degrade in

* A. K. LOBECK, *Geomorphology*, p. 238, 1939; E. S. HILLS, *Physiography of Victoria*, p. 109, 1940.

† W. M. DAVIS, River Terraces in New England, *Bull. Mus. Comp. Zool. Harvard*, vol. 38, pp. 281–346, 1902.

well-defined free-sweeping meanders, however, but be either confined to a restricted channel or spread in a braided course over a somewhat wider strip, it is possible that in some cases the minor slip-off slope terraces on a future major terrace tread may be lower and more numerous, thus producing a closer approximation to a smooth slope.

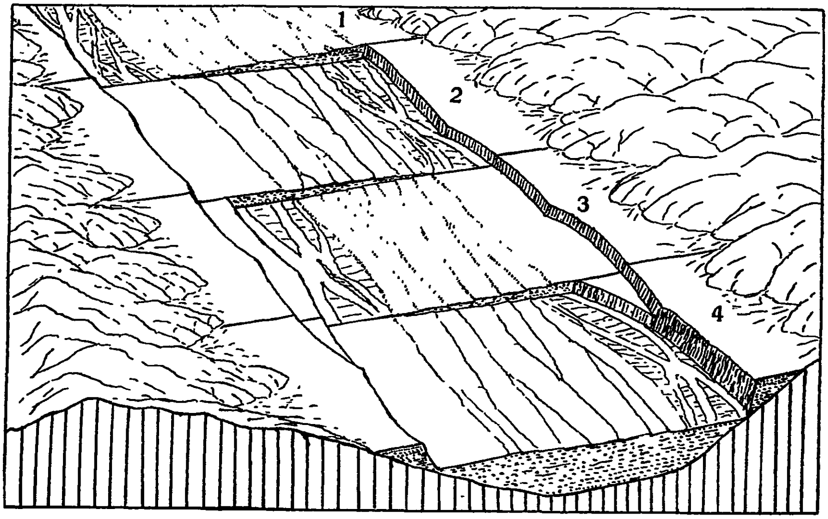

FIG. 1.—Diagram illustrating the development of river terraces by a degrading river swinging from side to side of its valley.

In any case only exceptionally broad terraces may be expected to exhibit on their treads either minutely terraced or smooth transverse slopes, and where valley-side terraces are relatively narrow they may be expected to preserve only parts of the floors that were developed as level plains, these being either parts of the meander belts or perhaps of rather broad strips that may have been occupied by channels in braided patterns. It would appear, therefore, that level across-valley profiles will be most often found on terrace treads, and, indeed, the treads are shown level in all Davis's diagrams. In such cases the hypothetical slip-off slopes, either smooth or minutely terraced, down which successive lateral migrations have taken place, have been destroyed by later swings of the river, as suggested in Fig. 1.

The diagram drawn by Hills is apparently based on that of Lobeck, of which it may be regarded as a simplified version. It frankly deduces strong slip-off slopes on terrace treads. The photograph of terraces in the valley of an Australian river which accompanies the diagram on the same page fails, however, to support the slip-off slope deduction, for the indication of level afforded by standing water on the terrace in the foreground of the view makes it very clear that the slope of the tread is not towards the valley axis, as shown in the diagram, but rather away from it, though the actual departure from the horizontal may be explained as due to the presence of an abandoned stream channel.

II.—How Does Transverse Tilting Affect Valley Erosion?

In a book recently published the statement appears that lateral "displacement [of rivers] can . . . be caused by young movements of the earth's crust. . . . It is known that petroleum is only to be found in the crests of local folds in the earth's crust. When these crests are formed the rivers are shifted sideways along the upfolded strata [surface?]. And, conversely, such valley displacements assist in the search for geological structures suggestive of petroleum."*

This sounds helpful, but the reader is not informed how the petroleum geologist recognises that lateral displacement of rivers resulting from local surface tilting has taken place, and the author has apparently failed to realise that this problem is quite distinct from that presented by simple cases of homoclinal shifting.

Hanson-Lowe has ventured the more cautious statement that "rivers flowing parallel to the hinge [of surface tilting] would probably show a tendency to lateral displacement";† while another geologist has expressed to me his opinion that a river flowing along or parallel to the hinge-line of a strong tilt of the land surface will be thrown by the tilting against that side of its valley which is thereby depressed, and that, as a result, undercutting will develop there a conspicuous line of bluffs to the extent of causing the valley to assume a distinctly asymmetrical cross profile.

In view of the foregoing assertion and opinions it seems worth while to examine how, if at all, transverse tilting will affect the form of a valley already in existence.

Different conceptions are possible of what constitutes the valley. If it be taken to include the whole valley system, or strip between divides on either side more or less parallel with the river and extending around the heads of its tributaries, Campbell's law of migration of divides is applicable to it; and the divides on either hand, if both are situated on the same tilted strip, will both eventually migrate towards the axis of uplift; while an obvious corollary to this is eventual migration of the axis of the valley system in the same direction. These migrations will be long delayed, however, and early stages of the process will be characterised only by the appearance of rejuvenation features in the tributaries on the upheaved side and of aggradation in those on the other side.

Enlarging upon Campbell's law, I have made the ambiguous statement that "streams shift towards and tend eventually to coincide with the axes of downwarping."* I believe that the statement is true in the long run of drainage lines, though transfer of these will not be brought about by lateral shifting of pre-existing valleys towards the depressed side. The eventual transfer of drainage to new lines in or near axes of downwarping will be delayed until it is effected by captures stimulated by the tilt. On the west side of

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* R. GHEYSELINCK, *The Restless Earth*, p. 145, 1939.

† J. HANSON-LOWE, Theoretical Reflections on the Geomorphology of China from the Viewpoint of Glacio-eustatism, *Bull. Geol. Soc. China*, vol. 15, pp. 119–29, 1936.

* C. A. COTTON, *Geomorphology of New Zealand*, p. 249, 1922; also "valley lines shift slowly . . . towards axes of downwarping," *Landscape*, p. 230 (in press).

the Port Nicholson depression, for example, captures have been made by the Kaiwarra and Ngahauranga Rivers which have added to the area drained into and through that depression.

In the present discussion attention may be directed more particularly, however, to the immediate valley of a river, which, if fairly mature, will consist of a more or less well-developed flood-plain, forming its floor, and sides which are generally in the main bluffs truncating the ends of the valley-side spurs between minor tributaries.

There is no difficulty in postulating conditions under which very gradual tilting will fail to cause a river that flows on the floor of such a valley in a well-defined channel to change its course at all, at any rate if the general effect of the accompanying earth movement is to bring about some degradation in the valley. This is the familiar case of vertical incision of the kind that results in superposition of rivers. Rapid tilting, on the other hand, or a cumulative succession of intermittent small movements each of which is instantaneous (or at least very rapid) will generally cause a river to take a new course along what is henceforth the low side of its former flood-plain, which is now transversely tilted.

There is no reason why the river, as it re-shapes its valley after this event, should undercut more vigorously on one side than on the other, but owing to asymmetry of the cross profile after tilting (Fig. 2, A) a profile with higher bluffs on the side that has been depressed may be expected to appear in the early youth of the post-tilting epicycle. This will be so because the now transversely tilted floor of the pre-existing valley will still be in evidence; and early stages of post-tilting valley development will be characterised by the presence along one side of the valley of a sloping terrace, the surface of which is the now transversely tilted floor of the former valley. The terrace-edge will be bordered at first only by a line of low undercut bluffs contrasting with the higher bluffs on the opposite (depressed) side of the valley (Fig. 2, A, 11); but the erosion scarp forming the front of the terrace will become higher as the new valley is widened by lateral stream corrasion (stage 22). When the sloping terrace which is a remnant of the former valley floor has been destroyed by this process (33, 44), the valley will assume a typical mature cross profile, and the bluffs will now probably be higher on the upheaved than on the depressed side because of the uplift of the whole land surface in that direction.

In the deduction of the foregoing hypothesis no appreciable change of gradient or load in the river has been allowed for. It is more than probable, however, that immediately after the occurrence of the tilting movement the river will aggrade or degrade its course. If the latter is the case, a stage of valley-in-valley rejuvenation will be followed (after grade is attained) by stages similar to those already outlined (Fig. 2, B). If, on the other hand, an aggradational phase is passed through, and is followed by stages of lateral cutting at constant level after the valley has become graded, the successive profiles will be of the general nature of those numbered 11–44 in Fig. 2, C. As the diagrams suggest, the valley will be bordered in all cases by bluffs, and these will probably be of greater height on the upheaved than on the depressed side.

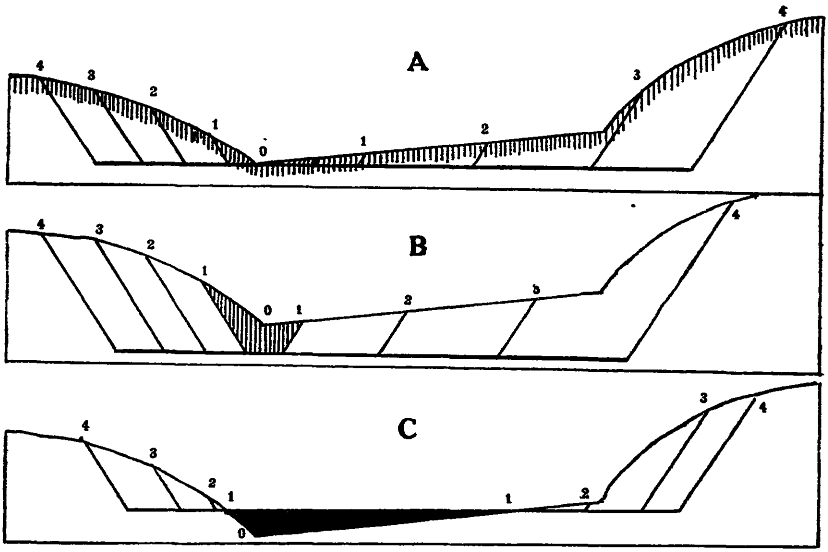

FIG. 2.—A: Initial and sequential cross profiles after transverse tilting of a valley. O, initial position of the stream; 11, 22, 33, 44, successive profiles developed by lateral corrasion.

B: Initial, O, and sequential profiles, of which 11 is developed in a phase of vertical corrasion, and 22, 33, and 44 are the results of lateral corrasion at later stages.

C: Initial, O, and sequential profiles, of which the profile 11 is developed in an aggradational phase.

Evidence of change of form as a result of transverse tilting might be sought in the valley of the Wainui-o-mata River, which flows southward at right angles to the westward direction of regional slope from the crest-line of the Rimutaka Range towards the axis of the Port Nicholson depression, the stream course being parallel to the assumed hinge-line of the tilting that has produced this regional slope.* The valley of this river yields no positive evidence of change of form, however, as a result of the transverse surface tilt. The explanation of this is satisfactorily found in the fact that the valley is now fully mature in the post-tilting epicycle. So, as may be expected when this stage is reached, the tilted floor of a former valley characteristic of a hypothetical initial or infantile stage from which this mature sequential valley has been shaped by erosion has been destroyed, and no traces of the initial form survive. Thus the landscape forms of the main Wainui-o-mata valley (as distinguished from its westward-branching headwater tributaries) afford at the present day no positive evidence regarding the tilt of which other features in the vicinity seem to offer proof.

* C. A. COTTON, The Warped Land-surface on the South-eastern Side of the Port Nicholson Depression, Wellington, N.Z., *Trans. N.Z. Inst.*, vol. 53, pp. 131–43, 1921.