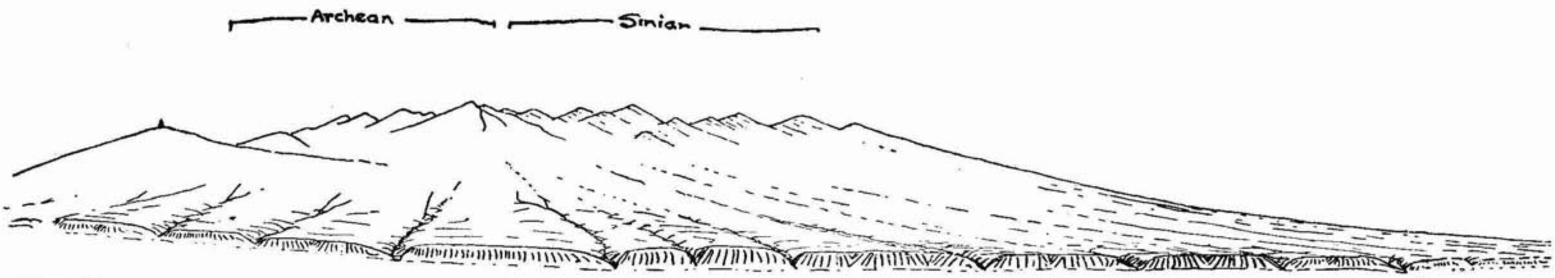
CORRELATION BY FLUVIATILE TERRACES

By

George B. Barbour

REPRINTED FROM THE
BULLETIN OF THE GEOLOGICAL SOCIETY OF CHINA
VOL. XIV, NO. 4, 1935.



Dissected
Alluvial Fan looking North and
East from above Tungkuan to the Southern flank of Feng-Huang-Shan . Note unbroken profile of skyline extending right to

Dissected
Alluvial Fan looking North and
East from above Tungkuan to the Southern flank of Feng-Huang-Shan. Note unbroken profile of skyline extending right to

CORRELATION BY FLUVIATILE TERRACES

By

GEORGE B. BARBOUR

Visiting Physiographer, Cenozoic Laboratory

INTRODUCTION

The use of landforms as a means of correlation to supplement palæontological and stratigraphic evidence has recently been receiving increasing attention in connection with problems of Cenozoic research in China.

Recognition of the importance of the method in Europe and America is shown by the existence of the Commission on Pliocene and Pleistocene terraces which has already presented three reports to successive meetings of the International Geographical Congress. The underlying principles embodied in the arguments of many of the papers contributed to those reports are of general application. But the physical conditions ruling in South-east Asia during the last three geological periods have been sufficiently different from those obtaining in most of the areas covered by reports to justify a brief statement of those principles that are of special concern to geomorphologists working in China.

The term "terrace" is applied to a landform of a recognized type, irrespective of the material composing it. It is therefore a mistake, as Johnson points out in discussion, to extend its use to the material itself, and only confusion can result from such a misuse of the term:

> "The term terrace is essentially a morphological term, and long widespread usage has given it a fairly definite meaning: a flat or moderately inclined surface terminated in front by a steeper descent to lower ground, and at the rear by a steeper rise to higher ground.

The term has no proper geological significance, since it may be composed of rock or of alluvium, may be a depositional or an erosional feature and may have a variety of origin. For this reason it seems to me a confusion of terms to apply the name "terrace" to the material instead of the form, and misleading to speak of a gravel deposit as a terrace when it exhibits no trace of the terrace form."[1]

It is only necessary to add that in China the "steeper rise to higher ground" in the rear of the higher depositional terraces often involves no sharp discontinuity of slope, but is part of a catenary curve which steepens gradually, passing insensibly into the slopes of the flanking ranges or the subdued ridges of the local divides.

The combination of the upper surface with the steep front face of the terrace is therefore the critical element in the feature. Its presence implies a relative lowering of the level of action of the eroding agent, whether fluviatile or marine.

As far as marine action is concerned, this lowering of level implies the emergence of a previously submerged fringe of coast. It may be the result either of crustal uplift, or of withdrawal of the sea from the margin of a stationery land mass, or from both causes acting concurrently in such a manner as to leave a net balance in favour of emergence. The causes need not be considered for the moment. The fact is recognized from the finding today of ancient strandline features at elevations above the reach of present-day wave action.[2]

The case of river terraces is more complex, and it is with these that the present paper is more directly concerned. The development of fluviatile terraces may arise from a variety of causes and it is important from the point of view of correlation to determine which of these is involved in any given

1 Douglas Johnson, Commiss. pour l'etude des Terrasses, 3rd Report, 1933, p.180.

2 For a discussion of the principles of marine terrace correlation the reader is referred to Douglas Johnson, Comm. pour l'etude des Terrasses, 3rd. Rept. 1933, pp.42-54. See also H. Baulig "The changing sea-level", Instit. Brit. Geographers Pub. 3, 1935.

instance. The brief summary which follows is restricted to river terraces and does not attempt to deal with terraces of other types (e.g. lake terraces, fault terraces, etc.) from which they must be carefully distinguished.

TYPES OF RIVER TERRACE

(1) The existence of a terrace need not imply rejuvenation, because channel degradation does not cease when a stream attains maturity. After a river has developed a wide floodplain it may happen that alluvial fans, built out by its tributaries opposite points where it is hugging, say, the right margin of its floodplain, are later cut back into terraces when the channel swings across to the left. These meander swing terraces, however, owing their formation to the gradient of the tributaries, do not show uniform elevations and are therefore not precisely matched on opposite sides of the main channel. Examples of such "unmatched" swing terraces occur on both banks of the Huangho between Tungkwan and Sanmen. They must be carefully distinguished from the "matched" terraces which are connected with definite stages of rejuvenation of the main river itself.

(2) In general, matched terraces may be taken to indicate rejuvenation of the river concerned, and the possible causes of increased erosive ability call for special consideration.

These causes may for convenience be grouped as follows:

(A) Increased volume of water,
(B) Decreased volume of water,
(C) Increased gradient of channel, and
(D) Lowered base-level.

(A) The volume of a stream may be augmented in several ways.

(i) Increased precipitation due to climatic change may be expected to show its effects in the channels of all streams drawing their supply from the area affected by the change. In the case of long trunk rivers like the Huangho or the Colorado which pass from their gathering grounds across desert regions of low rainfall qualifications are necessary. But in general we may assume that the effects of any marked increase in humidity are recorded, whether by degradation or by aggradation, throughout the mature stretches of trunk and tributaries alike.

The late Pleistocene rejuvenation following the Malan stage of loess accumulation was of this type and has left its record as matched terraces throughout the highlands of North China. The same is true of the Chingshui dissection which preceded the Malan Stage.

(ii) In many parts of northern Europe the rivers show a record of fluctuation directly related to the flow of meltwater from glacial sources. While this factor may need to be taken into account in dealing with the glaciated alpine border of western China, it does not have to be reckoned with in the case of the central, eastern or coastal provinces.

(iii) Another cause of increased supply is involved in case of river capture. As is suggested in Fig. 1, the master stream (1) augments its flow at the expense of its beheaded competitor (3) by stealing its former headwaters (2), while its own tributaries share the advantages of the resulting degradation of the trunk channel. The topographic effects will thus be localized relative to the drainage basins involved, and the distribution of the effects gives a clue as to the cause of any terraces which may result. In the hypothetical case illustrated, capture is supposed to have occurred, with diversion at the point 2, terraces have begun to extend headwards in the streams of the enlarged drainage basin and have reached as far as the point 1 on the master stream, while the beheaded river is now an underfit.

It would seem as if such evidence of capture is to be most clearly displayed in cases where two conditions are satisfied, viz. after the master stream has reached maturity, and when the added volume of water must be sufficient to affect appreciably the equilibrium profile of the master stream for regrading of the latter to involve detectable rejuvenation. When these conditions are not present, the only place where well-developed terraces will occur is in channel 2 and then only if that channel had attained first-cycle maturity or been aggraded.

(iv) In the case of North China a further minor factor may occasionally need to be taken into account, namely the effect of artificial deforestation. Lowdermilk found that the rate of run-off from two comparable mountain slopes in Shansi, the one timbered, the other recently deforested, was in the ratio of 1 to 51. Since the greatest amount of erosion is done during the brief periods of heavy rain, the removal of the retarding cover of vegetation must involve a regrading of the mature stretches of the rivers which carry off the water.

(v) It would seem that under somewhat exceptional circumstances decreased humidity could also increase the volume of immediate run-off entering a stream and thus lead to terrace cutting. Where precipitation is only just sufficient to keep vegetation alive and bind the soil cover on a surface of

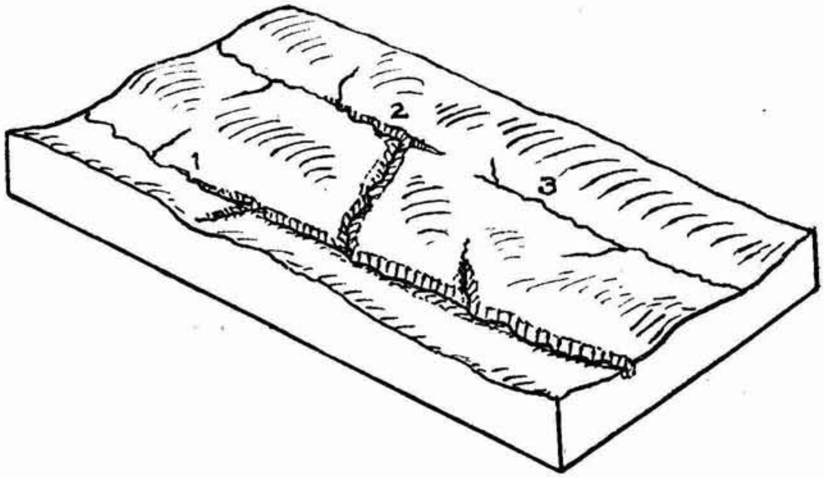


Fig. 1. Terraces produced by capture.

mature relief a nice balance of conditions exists which would be easily disturbed by change of precipitation in either direction. Destruction of the plant cover would mean failure to retard the run-off and increase the immediate discharge into the channels following each downpour. In certain cases this must undoubtedly involve slight regrading of the channels either with silting or with the production of low terrace features.

(B) Dr. K. S. Sandford has drawn my attention to terraces of a type investigated by him in Egypt which, though not hitherto recognized in China, may later prove to be present here too. These are the result not of increased run-off but of *decreased* precipitation. Owing to the lessened volume of water to be dealt with, the streams narrow their channels so that as degradation proceeds the restricted channel becomes entrenched. In a personal communication Dr. Sandford writes, "I think from experience that the factor of decrease is quite as important as increased".

(C) Where rejuvenation is due to increased gradient resulting from uplift, the distribution of effects will be related to the character and extent of the crustal movement. Tilt to the south will assist south-flowing streams, but will be unfavourable to north-flowing ones, while those which flow east or west may show little or no effect, being influenced only in so far as the major streams into which they drain have their channels deepened or not as the result of the movement.

(i) In particular, if upwarp happen to take place along an eastwest axis through the heart of an area of intricate drainage pattern, significant changes may occur along all channels whose courses cross that axis. A river of sufficient volume and energy may continue to degrade and keep its channel open in face of unfavourable uplift, becoming thus an antecedent stream. A stream of lesser competency may find the adverse rise of the barrier too rapid and suffer decapitation, the upper waters being diverted to a new outlet and the flow between the points of decapitation and diversion being reversed.

These features are illustrated in Fig. 2 where an upwarp (indicated by an arrow) across two south flowing streams had rendered one antecedent and has reversed the flow in R, the upper course of the smaller beheaded parallel stream B. As far as the terraces of the antecedent river A are concerned, if the latter has attained or nearly attained maturity, the elevation of the old above the new profile should reach a maximum near the axis of upwarp.

Localized increase of terrace elevation is observable in the gorges of the Huangho[1] and of the Fenho in Shansi, thus supporting the inference that the Fenho rejuvenation was due primarily to warping rather that to climatic change or other factors. The inference is corroborated (a) by two recognized cases of capture behind the same axis and (b) by the absence of any physiographic separation of the deposits immediately older or younger than the Fenho epoch in areas outside the influence of this upwarp. Further confirmation is seen in

1 Teilhard and Young, Geol. Surv. China, Mem. A 8 1930, p. 14.

the presence of a complementary zone of aggradation, if not actual downwarp, found on the Huangho above Sanmen.[1] (See Fig. 2 dotted area.)

The fine-grained Pliocene fluvio-lacustrine deposits of the eastern Ordos margin are doubtless the result of the reduced channel gradients above the zone of maximum upwarp.

(ii) Rejuvenation as the result of faulting has been noted in several North China localities. The terraces at Taiku owe their origin to this cause, and it is likely that further study will show that this factor been more generally operative than was formerly recognized.

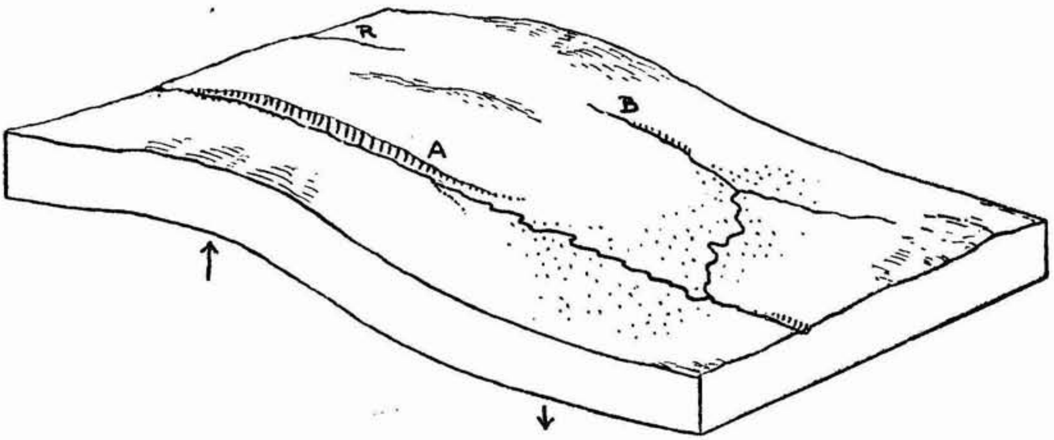


Fig. 2. Upwarp producing antecedence and diversion respectively in parallel rivers.

(D) Lowering of base-level may be of two kinds:

(i) Marine and

(ii) Local.

(i) Any seaward retreat of the strandline will affect all streams draining to the part of the coast affected. The effect of the emergence will be to cause regrading of the channels, a process which will start at the mouth and extend

1 M. N. Bien, Bull. Geol. Soc. China, vol. 13, 1934, p.433.

headwards. This is illustrated in Fig. 3, where the retreat of the sea from position 1 to position 2 has been shown as sufficiently recent for regrading only to have reached the point X. Theoretically the maximum terrace elevation should occur near the dotted line marking the former position of the strandline.

(ii) In the process of regrading their courses, streams not infrequently discover barriers of resistant bedrock which yield less rapidly than the stretches of country immediately upstream. The latter may thus exhibit mature channel forms while the barrier itself shows only youthful stream profiles. In time however the level of outflow across the barrier is cut down and the sinking of the local base-level rejuvenates the upper stream, leaving its old floodplain standing as a dissected terrace feature.

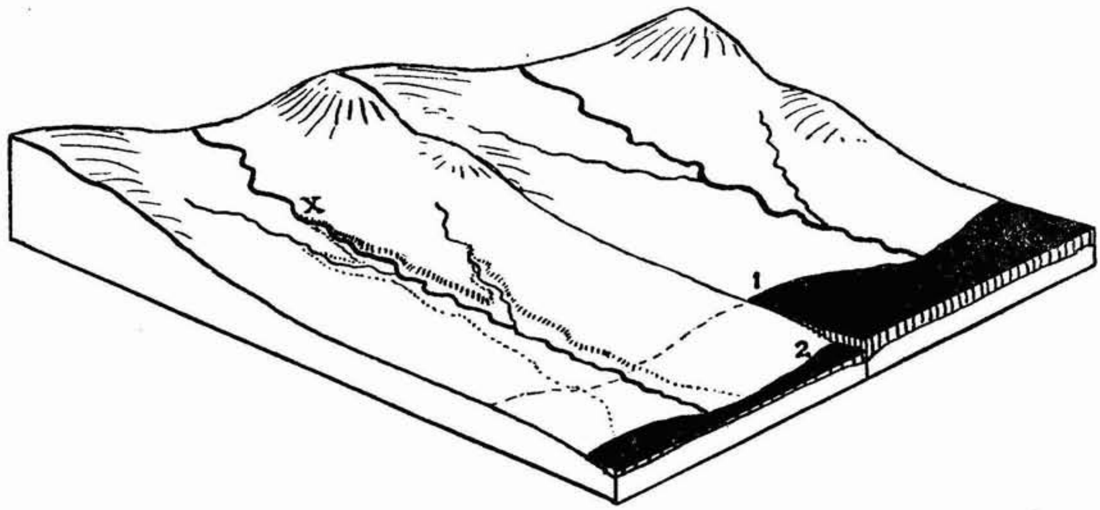


Fig. 3. Terraces produced by strandline shift.

Cases of this kind are known from the Huailai basin, the Upper Sangkanho, and others of the structural depressions of North China. An example of the regrading through local base-level reduction may we seen in the Kalgan area. Erosion of weak gravel and conglomerate beds has disclosed a once buried porphyry barrier on which a stream channel was superposed close to the district town of Wanchuan.[1] This barrier retarded the process of

1 G. B. Barbour, Geol. Surv. China Mem. A 6, 1929, p. 101.

degradation so that the streams outflanking the end of the ridge are about to capture part of the headwater drainage which is here perched 50 feet above the corresponding thalwegs of the streams which work unimpeded entirely in the softer formation. Meanwhile the spillway across the barrier has been slightly reduced so that the upper basin of the superposed stream shows traces of slight rejuvenation with subdued terrace features, illustrated in Plate IX, Fig. 1 of the Geology of the Kalgan Area.[1]

The barrier of igneous rock at the Sanmen rapids of the Huangho must have had a similar effect on the topography of the valley between Lingpao and the rapids, though the scale of the resulting features is so dwarfed by the elevations of the magnificent major stage terraces that the local base-level effects are liable to be overlooked.

A specially important type of terrace due to lowered base-level develops during the process of integration of previously unconnected units in an interior drainage system, which in contrast to exterior drainage has no common ultimate base-level at the coast. This process, however, involves capture of the waters of one basin by those of another having a lower base, and is therefore virtually covered by what has already been said in speaking of stream piracy terraces in general.

Before summarizing the critical points bv which these various types of terrace are to be identified, reference must be made to two further criteria which necessarily play important roles in the identification of terraces in connection with problems of correlation.

One is the necessity of distinguishing depositional from erosional terraces. It is of course true that most terraces have at least a surfacing of deposited material, but in many cases the basis of the feature responsible for its tabular form is an erosion surface on which the deposit is merely a veneer.

The second point is that of the lithological character of the material building the terraces, which is often sufficiently diagnostic to allow of a positive correlation when the landform itself has been so dissected that little if any of the terrace feature has survived. It will suffice here to mention some of the

1 Op. cit. p.112.

more characteristic types which, for all their wide range of local variation, can still frequently be used as a basis of correlation in areas where the stratigraphy of the surface deposits is known. The chief recognizable units are: the Malan loess (Upper Pleistocene), the banded loams (Upper Pliocene—Lower Pleistocene), the "laterized" deposits of Central and South China (Pliocene). Under suitable conditions further units are identifiable, viz. the early Poliocen red clays and the late Pleistocene or Recent Laoho deposits of the Jehol area. Taken in conjunction with the associated landforms these lithological criteria become of peculiar importance.

TERRACE DESIGNATION

The current practice is to use the height of terraces as a basis for their correlation until their identity in terms of physiographic stages has been established. In following this convention, two points must be kept in mind.

(1) The significant elements is the difference between the two levels at which the river has flowed in the locality under consideration. Hence the altitude of the terrace above sea level is usually irrelevant[1] except in the immediate vicinity of the coast. What matters is the actual vertical elevation of the terrace, that is to say, the height of its front face.

(2) If the terrace is a depositional one, it usually has both a gentle downstream slope and a transverse slope towards the thalweg. In broad open valleys such as the aggraded structural depressions of North China, the transverse slope is usually of considerably greater gradient than the upstream slope of the terrace surface, so that if in a later erosion cycle it is trimmed back unequally, the resulting terrace height may shown considerable variation which must be taken into account in designating the terrace in terms of its elevation above the younger channel.

CRITERIA FOR DISTINCTION OF TERRACE TYPES

The following types of terrace have been enumerated:—

(1) Unmatched terraces due to meander swing

1 G. Dubois, Méthodes de recherches dans l'étude des anciennes lignes de rivages quaternaires, Commiss. pour l'étude des Terrasses, 3rd Rep. 1933, p.34.

(2) Matched terraces due to rejuvenation

(A) Resulting from increased volume of water

(i) Due to increased precipitation
(ii) Due to glacial meltwater fluctuations
(iii) Due to river capture
(iv) Due to artificial deforestation
(v) Due to natural devegetation through dessication

(B) Resulting from decreased volume of water

(C) Resulting from increased gradient

(i) Due to upwarp
(ii) Due to faulting

(D) Resulting from lowered base-level

(i) Due to emergence
(ii) Due to local base-level reduction.

No attention is paid here to non-fluviatile forms, viz.

(3) Marine Terraces

(4) Lake Terraces and

(5) Terrace features of extraneous origin, e.g. fault-scarp terraces, nor to certain rarer types that belong properly in the group of matched terraces above but which, while theoretically possible, have not been noted in China. These latter include for instance rejuvenation terraces due to failure of detrital supply causing a stream, previously fully loaded, to become underloaded: alluvial fan terraces of tributary streams, and the like. When the modes of origin of the various terrace types are taken into account, it is possible to deduce the following criteria for differentiating them.

(1) Where terraces are unmatched, the first hypothesis to be tested is that they are swing-terraces and therefore of no value in regional correlation. Care must however be taken to rule out the possibility of the unmatched character being only apparent and due to assymetrical erosion of a previously matched system.

(2) Where matched terraces are involved, the following points are to be noted:

(a) Lowering of marine base-level may cause terracing in a mature river system, the process starting at the river mouth and working headward. The effects may thus be recognizable along the lower course without their having had time to extend to the upper reaches. This is specially liable to occur if resistant barriers impose local base-levels. Such barriers are therefore specially deserving of study in attempts to work out the history of any particular stream, the more so since rock-defence assists the preservation of records of mature stages of earlier erosion cycles which may have been entirely destroyed in less resistant terrains.

(b) Local base-levels play a specially prominent part in the river systems of the block-fault basins of North China where broad aggraded depressions are drained by streams flowing out through antecedent gorge channels. Each of these basins may have, superposed on the effects of the major regional physiographic stages local ones due to the role played by barriers at the points of outflow. Each such basin must therefore be considered separately on its own merits before attempting to correlate its terraces with those of adjoining basins, even where similarity of terrace elevations at first sight suggests a common history.

(c) Climatic change towards greater humidity on the other hand will affect all streams within the drainage basin involved, right to their headwaters. Moreover since no marine base-level change is involved, the resulting terraces will not be prominent near the coast and will tend, theoretically, to attain their maximum elevation along the lower middle length of the stream where the new equilibrium profile due to the stronger stream flow falls farthest below the old one.

(d) Where rejuvenation results from crustal uplift, the distribution of effects will be directly related to the character and distribution of the vertical movements, being greatest where uplift has raised the old thalweg most above the new stream level in the case of antecedent rivers, and sinking to zero where movement has been negative or in areas upstream from axes of upwarp. In both these latter cases, aggradation may for a time replace degradation as the dominant process, older terraces in consequence losing elevation and even becoming finally entirely buried.

(e) Where drainage adjustment has involved capture, minor complications are introduced which must be given independent study.

Thus far the discussion has tacitly assumed that the various causes of terrace development operate independently. The problem becomes more complicated when more than one cause has been operative simultaneously. If, for instance, warping is associated with strandline shift or happens to coincide in time with an epoch of climatic change a corresponding complexity of effects must ensue. The various factors can only be unravelled by careful study of individual areas in the hope of eliminating those elements which are of purely local significance and thus isolating the factors which are of regional importance. The method is of necessity one calling for prolonged detailed study and much patience. Only thus, however, can reliable conclusions be obtained.