The Taiku Deposits and The Problem of Pleistocene Climates

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PLEISTOCENE CLIMATES

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Abstract.

A brief description is given of fossiliferous continental deposits of late Pliocene and early Pleistocene age discovered near Taiku, Shansi. They are of value for correlation purposes, in that remains of mammals, fish, plants and mollusca occur in closely associated horizons. In addition, the structural relationships of the series afford new precise data regarding the physiographic and tectonic history of this sector of Shansi and fix within narrow limits the age of the youngest major diastrophic movement along the great Taiku fault-line. This movement took place early in Lower Pleistocene times.

The contrast in character between the lower and upper members of the series points to a distinct change in conditions of weathering and throws light on the climatic fluctuations of the early Quaternary. The structural relationships amplify
our understanding of the evolution of the present land-surface and accord precisely with the stages of development recognized in other localities.

Three systems of stage correlation are discussed and the conclusion is reached that the facts are unexplainable without appeal to a shift of the earth's axis of rotation. The choice seems to lie between alternative correlations which differ mainly in the exact date at which the Malan loess conditions took hold in Pleistocene time. The problems raised by each hypothesis are considered and directions suggested in which solutions may be looked for. The evidence appears to support Simpson's theory of solar radiation control as a cause of climatic fluctuation.

INTRODUCTION

A snow-storm on New Year's Eve 1930 cut short a trip into southern Shansi, leaving me marooned at Taiku. Going for a stroll outside the compound to work off annoyance at the delay, I came on some piles of green-grey and buff coloured clay-shale. In answer to a shout of enquiry, a voice from a tunnelled gallery under the loess-covered field on which I stood informed me that the clay was to be used for making pottery. The general appearance of the material, the abundant small crystals of gypsum and broken bits of plants stems recalled so strongly the character of certain horizons of the Nihowan beds* that the source of the shale had clearly to be tracked down, snow or no snow.

The material was traced to a dump beside a trench on a hill-face in the mountainous country behind the great Taiku fault-scarp, which dominates the plain some four miles east of the city (see Fig. 1). The brief daylight and short time available yielded unexpectedly encouraging results, largely thanks to the help of my host, Mr. Raymond Moyer. On my return to Peiping, the mammal remains were submitted to Dr. C. C. Young and Mr. W. C. Pei of the Geological Survey, who corroborated the provisional identification. Their conclusions were amply borne out by the study made in the Laboratory of Cenozoic Research of further fossil material secured during a second less hasty visit a month later. The fossil plant material is being studied by Dr. Ralph Chaney in the University of California.

I am glad of this chance to acknowledge the help of those who have contributed to results now reported.

THE LOCALITY.

The great high-road from Taiyuan to the interior—followed by Marco Polo and famous travellers, imperial and foreign, before and since—goes down the middle of the upper Fenho basin, but the new motor road skirts the edge of the plain and passes through Taiku about 10 miles due east of a point midway between the provincial capital and the gorges of the Fenho. Most of the great geological reconnaissances* seem to have followed the line of the old highway, but even from the new road one might be forgiven for not suspecting the presence of a dissected basin of late Tertiary sediments hidden behind the rampart of the fault-scarp, especially in the blue haze that frequently obscures the distance during the bright hours of the day.

Several prominent landmarks will serve as useful reference points in describing the locality. Looking from Taiku towards the south-east (Fig. 1), two distinct crestlines are seen, one behind the other. Even at a distance of several miles, the nearer one can be recognized as a fault-scarp, with triangular facets of text-book perfection (see Fig. 5). The top of the scarp sags a little in the centre rising gently on the left to the summit of Ta-Fu-Shan crowned by its blue pagoda, and running up more steeply on the right to a point below the lofty Feng-shan, whose three towers dominate the entire district. The farther skyline lies some two miles beyond, but swings forward on the right to unite with the front ridge farther south. Feng-shan-ssu crowns the actual spur which connects the two.

Access to the hidden basin behind is gained only by clambering up rocky gorges in the V-shaped gaps between the fault-facets. Between two such adjoining gaps, springs come up along the fault fissure, and the famous temple of Shen-t'ou built over them clings to the steep outer rock face overlooking the plain. Behind the precipitous fault-scarp, the ground continues to rise for a short distance but much more gently, to a summit crowned by the village of Pan-tao-ts'un, and then falls away abruptly into the deeply dissected basin beyond.

Fig. 2 Simplified Block-diagram of the structural relationships of the Taiku deposits after the faulting but before the completion of the later extensive dissection. (Appropriate symbols mark the positions of the Blue Pagoda, the village of Pan-tao-ts'un, the three towers of Feng-shan-ssu, the temple of Shen-t'ou, and Taiku city. Viewed from north-west.)

**General Geological Structure.**

Careful study of a simplified block-diagram will give a clearer idea of the fundamental structural setting than can be grasped from a verbal description. In Fig. 2 only the southern portion of the dislocated sedimentary basin is shown; the complications of later erosional effects are largely neglected, but
the surface of the downthrow block is shown buried by the superficial deposits which have built up the Taiku plain to its present relative level. It is apparent that the basin sediments must have been laid down before the movement along the great fault placed them in the relatively elevated position they occupy today—otherwise their material would have been thrown out instead in a series of alluvial fans along the front of the fault. Moreover, it is only the fortunate presence of the hard-rock foundation forming the fault-face itself that has prevented these soft sediments from suffering the same fate since the dislocation.

In actual detail, the history subsequent to the faulting is more complex than this simplified reconstruction suggests. But the complexity itself is of value, since there is present evidence for each one of the series of later physiographic stages recognized in other North China localities, thus confirming in a very pretty fashion generalizations based on findings made elsewhere.

STRATIGRAPHY.

(A) The underlying bedrock floor is composed of an alternation of blue-grey shales and mottled cross-bedded sandstones. The former look as if they should be fossiliferous, but no plant or other fossils were found. The sandstones are of medium grain, regularly cross-bedded, sometimes weathering out in thin plates, sometimes in courses of one to two or more feet thickness separated by layers of shale, sometimes in massive beds many feet thick. The mottled appearance is given by oval or sub-rectangular flesh-coloured spots on a green-grey ground; the spots are of such uniformity that from a distance they give the appearance of felspar phenocrysts in a subacid porphyry. But the colour pattern is apparently a secondary effect due to some control of the distribution of chlorite.

The country-rock of this entire sector of the range is indicated as Triassic on the one-millionth geological map of central Shansi. I had no means of checking the identification. The formation does not look like any of the Triassic rocks exposed along the line of the Chengtai Railway, nor does it answer to the description of any Triassic rock given in the Explanation to the Taiyuan-Yulin sheet. On the whole, it seems to correspond rather to some of the Permian, or even possibly Carboniferous, horizons established by Norin.
As its identity has no bearing on the problem of the Taiku deposits, the matter was left sub judice.

(B) The name *Taiku Series* is proposed for the overlying succession of poorly consolidated freshwater sediments and loams, 400 or more feet thick, which rest on a very uneven bedrock surface.

I had time to trace the configuration of the original depression only along the southern region of the basin. It undoubtedly has a considerable extension both backward into the range and paralleled with the fault-line to the north-east. Hence it is not certain whether the local difference in direction of dip between the basal and the topmost members of the series (see Fig. 3) is the result of a change in drainage conditions due to tectonic movement, or whether the depression is really only a lateral embayment of a larger basin whose master drainage westwards took control once the lower ridges encircling the basin on that side were buried beneath the immense apron of outwashed sand, mud and gravel.

Though no sharp division can be observed in the series of deposits, three facies are present and on the whole they tend to predominate in the lower, middle and upper levels respectively. They are (i) a clay, (ii) a sandy and (iii) a loam facies, which intergrade in a manner suggesting gradual transition rather than abrupt change of conditions.

(i) The lowest horizons presumably lie buried in the centre of the basin and are not exposed. At many points near the margin, however, the basal contact is marked by a thick boulder deposit or a coarse breccia with angular blocks several feet in diameter. Thereafter the main lower division of the
series is an alternation of grey and buff laminated clays with sandier intercalations of brown or yellow. At two levels the clays show a pale yellow-green tint which allows the horizons to be easily recognized at distances of many hundred yards across the basin. When saturated with groundwater the clays cut like cheese, but on drying out in the air the material hardens and cleaves with the bedding, often with the perfection of a true shale.

This tendency to split is emphasized by the presence of layers of gypsum crystals which occur at all levels of the series. Remains of plants—chiefly leaves of trees and shrubs, and fragments of plant-stems—are found from the lowest to the highest horizons of this fine-grained facies, while in the lowest levels fish skeletons occur beside leaf-prints on the same piece of shale. A single insect impression was found. The sandy element increases towards the margin and towards the top of the deposit.

(ii) In the higher sandy horizons, mammal bones occur in a thoroughly silicified condition. In only three localities were they recovered in situ, but at six other points they were picked up on slopes below weathered outcrops of the same general level. In addition, in this zone, and slightly nearer the top of the series, small freshwater gastropods and brachiopods occur, usually restricted to rather definite horizons but fairly abundant where present at all. Throughout the formation, but increasingly in these sandy members, the succession of incoherent sediments is interrupted by layers of large projecting concretions and tough fluted cornices of cemented sandstone an inch or two thick. The colour of this facies varies from yellow-brown to buff and redder tints of brown.

(iii) Towards the top of the series the sharply bedded character is lost, the brown sands grading up into a red clay loam facies which thickens towards the mountains, attaining ultimately depths of over 80 feet. Locally it becomes somewhat loessic though distinctly redder than true loess. It lies in poorly defined layers two or more feet thick, marked by faint but distinct colour changes and bands of concretions. These latter often attain surprising uniformity, varying from two to eight inches (average four inches) in maximum diameter, frequently set with long axes vertical in layers about two feet apart and sometimes with intermediate layers of embryo concretions where the process of cementation was evidently arrested at an earlier stage. The red loam itself is usually paler just round the concretions and for an inch or two
below. The layers have a distinct westerly dip which is clearly related to an old surface of deposition still preserved in a few places as a prominent high platform with a westerly slope of about three-and-a-half degrees (see Fig. 4 below).

No fossils were recovered from this facies, but it is evidently a distinct slightly younger deposit—it certainly implies a marked change in conditions of aggradation the significance of which will be discussed below.

Dr. C. C. Young has made a preliminary study of the mammalian fossils from the sandy members near the middle of the series and has kindly furnished the following provisional list of types represented:

- *Carnivora* indet. fragments of large canine tooth; one phalanx, perhaps of *Hyæna*.
- *Rhinoceros* sp. fragments of teeth.
- *Equus* cf. *sanmeniensis*, one broken skull, a broken right lower jaw, some isolated lower teeth, vertebrae, pelvis, metacarpalia and some other fragments.
- *Cervus* cf. *boulei*, a fragment of antler, one right lower jaw, one proximal end of radius; one calcaneum, and one claw. The teeth are somewhat smaller and the proximodistal length of the series shorter than *C. boulei*; *P* 4 complicated.
- *Gazella* sp. (probably *G. sinensis*), 3 fragments of horn-cores, one proximal end of ulna, and one proximal end of (?) tibia.
- *Bison* cf. *palæosinensis*, some isolated upper and lower teeth, the size and the structure being apparently the same as *B. palæosinensis* of Nihowan.

The assemblage is sufficiently diagnostic to date the beds as of Sanmenian age, and, further, to place it in the *Nihowan* or lower division, which is regarded as belonging to the very close of the Pliocene. (The *Choukoutien* or upper division of the Sanmenian, of presumed basal Pleistocene age, is the horizon to which *Sinanthropus* belongs.)

The identification of the fish, mollusc and plant remains has not yet been completed. But from a preliminary examination of the floral association Dr. Ralph W. Chaney of the Carnegie Institution of Washington, Palæobotanist to the Central Asiatic Expedition, draws the following significant conclusions:

"The flora is definitely like that of the semi-arid type found today in the Great Basin where the rainfall is 15 inches a year or less. The small size of the leaves and the genera represented both fit in well with a cool semi-arid
climate such as we have reason to expect was present in north-eastern Asia and western America during the Pliocene."

(C) The Taiku beds are capped with a veneer of aeolian loess which lies on all horizons of the older series, showing that the basin sediments were deeply dissected in Lower Pleistocene times—a point of significance in considering the stages in the evolution of the present topography and their bearing on the problem of the age of the faulting.

PHYSIOGRAPHY AND STRUCTURE.

As the result of observations in many North China localities, a succession of stages of physiographic development has been detected in the present land-surface and in the structural relationships of the superficial deposits.† The perfection with which each stage of cut or fill has left its record on the landscape varies greatly in different places, but the sequence of major events appears to be the same in each case.

It is important to see how far the study of a new area confirms the general standard succession. The series is given chronological order beginning with the oldest, epochs of aggradation being inset to the right;—

1 Peital Peneplane
2 Tanghsien mature erosion
3 ......Paote red clay deposits
4 Fenho dissection
5 ......Sanmen lake and river deposition
6 Chingshui trenching
7 ......Malan loess epoch
8 Panchiao regrading (erosion and ......gravel deposition)
9 Present stage

It should be added that the Sanmen Stage (5) is divisible into two sub-stages, Nihowan and Choukoutien; that in this region the Panchiao deposits are insignificant; and also that that the present stage (9) into which the Panchiao stage merged is dominantly erosional, although involving local flood-plain deposition.

* Personal communication. See also note on page 104.
The first three stages are clearly observed just outside the area under discussion, but are not preserved within the limits of the basin itself. The distant sky-line of the main ridge still shows remnants of the dismembered peneplane, while the summits of the lateral spurs often accord with the profile of late Tanghsien times.

Directing attention therefore to the later stages, it will be seen that the diagrammatic section already given (Fig. 3) embodies both the structural relationships between the various units and the topographic surface associated with each. The formations are given on the right of the diagram and the physiographic stages on the left. The section is drawn through one of the fault-facets, a dotted line indicating the parallel thalweg section up an adjoining gap. The right half of the section corresponds more or less to that of the terrain shown in Fig. 4.

The age of the Taiku freshwater beds is fixed palaeontologically as lower Sanmenian (Nihowan substage) and this represents stage 5. The uneven basal contact is therefore presumably the Fenho erosion surface (stage 4).

The contact surface of the loess on the underlying Taiku beds is one of sharp relief, comparable to that of the present day (see Fig. 4). The extremely superficial character of the loess itself is a fact that is usually overlooked just on this account. The way in which the material forming the walls of the gullies and ravines stands up as erosion proceeds is itself significant enough to attract attention. It is usual to find such walls begin with a vertical drop from the top for the first five to fifteen feet and then continue down as a steep or moderate declivity to the bottom. The feature is readily seen in the left foreground of the sketch. Here as often this change of slope is not primarily, as its appearance at first suggests, that of a talus slope formed of material split off from the vertical face above and now lying at the angle of rest, but is due to the difference of internal structure and cohesion of two entirely distinct deposits causing their exposed surfaces to assume characteristic slopes under the influences of weathering and erosion. On account of the sharp relief of the surface on which the loess came to rest, the feature occurs at all heights above the valley bottoms; but it is apt to be most marked lower down—as shown in the sketch—because the loess itself lay thicker in the base of the depressions.
Fig. 4 Erosion Effects in the Taiku Deposits. Note (1) present dissection of (2) artificially terraced remnants of loess veneer resting on (3) sub-loess erosion surface cut in (4) gently sloping basin deposits of the Taiku Series.
A further point to note—and one which bears on the whole problem of the origin of loess and the manner in which it came to rest—is also well exemplified in the same sketch (Fig. 4). This is the contrast between the smoothly rounded upper surfaces of the loess deposits, even where this has been partly destroyed by the terracing and regrading of generations of farmers, and the abrupt vertical walls in which it falls away under erosion. The present sloping surfaces of loess deposits where these attain any thickness are essentially constructional forms due to deposition, upon a pre-existing rugged topography rather than erosional forms developed since the loess itself came to rest.

Judging from the distribution and present position of the loess in the basin where this sketch was made, it is clear that the Chingshui erosion (stage 6) which carved the sub-loess surface cut almost as deep as the present trenching. The loess itself belongs to the Malan epoch (stage 7), while the Panchiao and recent erosion (stage 8) is represented by the dissection of the loess and by a slight overdeepening of the gorges piercing the fault-scarp—shown by clearly defined rock-terraces and platforms at the gorge mouths.

Thus not only does the order of the stages exactly tally with that observed elsewhere, but the feature representing each stage is precisely typical of the process normally associated with that stage where developed most clearly.

**AGE OF THE TAIKU FAULT.**

Referring again to Fig. 4 and the structure section (Fig. 3), it is at once clear that the gently sloping upper surface of deposit 5 is dislocated by the fault and corresponds without question to a landsurface of much more subdued relief than has existed since the subsidence of the graben floor. The fault is therefore post-Nihowan in age. At the same time, the Chingshui pre-loess erosion, as indicated by the dotted thalweg on the structure-section, could only have developed after the subsidence. Hence the fault is pre-Chingshui. Whether the fracture was a newly developed rift or whether movement was revived along an old line of collapse is still uncertain. The basal breccia of the Taiku Series and the coarseness of the boulder bed may indicate a pre-Sanmen dislocation. But in either case the last great movement responsible for the present physical features was of early Pleistocene age.
Anticipating conclusions which will be put forward below, we are probably correct in assigning an Upper Sanmenian age to the red loams. On this dating, the age of the fault is still more precisely determined since the subsidence must have occurred almost exactly at the transition from the Sanmenian to the Chingshui erosion period. In fact the crustal movement itself was probably the cause of the rejuvenation which ushered in the new epoch.

Fig. 5 Triangular facets of the Taiku fault-scarp. (View looking south towards the three towers of Feng-shan-ssu)

THE BEARING OF THE CHARACTER OF THE TAIKU DEPOSITS ON THE
PROBLEM OF SANMENIAN CLIMATIC CONDITIONS.

Until comparatively recently, the exact status of the Choukoutien fauna was somewhat of an open question. At no place have deposits with Choukoutien types of fossils been found in contact with undoubted Nihowan horizons. There was therefore for a time uncertainty as to whether they were almost of the same age but developed in different localities, or were upper and lower divisions of the one major Sanmen unit, or were even separated by an intervening episode of erosion.

From palæontological study, however, Teilhard and Young conclude that, although the two associations have almost enough in common to have
passed at first sight for contemporaries developed in slightly different environments, each has distinctive elements not entirely explainable on this basis and indicating a definite difference in evolutionary advance. The Nihowan fauna is apparently slightly more archæic than the Choukoutien.* In conversation P. Teilhard de Chardin has informed me that these mammalian faunal differences are insufficient to warrant the assumption of any climatic change between the lower and upper divisions of the Sanmenian.

Now the members of the Lower Taiku (freshwater) series are lithologically exactly like the sediments of the Nihowan type locality, † and evidently developed under similar conditions. They have the same range of variation in colour, texture and coherence, the same gypsum content and behaviour on weathering, as well as the same mammal types and general forms of small mollusca and plant-life. In both localities the fine-grained facies predominates in the lower horizons in the series and the concretionary and sandier facies in which the mollusca and mammal fossils occur seems to develop towards the top and marginally.

On the other hand, the banded loams above clearly formed under different conditions. Their whole appearance suggests old imperfectly developed lateritic soils. In his treatise on the great soil types, Glinka ‡ points out that in the formation of both red loams and laterites the colour of the iron oxides, once established, remains. The correct interpretation of the red loam facies of the Taiku deposits will therefore throw light on the question of the climatic conditions at the time of its formation.

The roughly layered character and relation to the topographic surface of deposition show that the loams are not residual soils, but a secondary deposit of material carried down from the upper slopes—at least colluvial, if not transported to any great distance. The faint but definite colour-banding and the concretionary horizons conforming to the gentle catenary surface of the high terrace can mean only a succession of ancient soil layers ("fossil soils") whose subaerial surfaces were darkened by exposure to vigorous insolation and oxidation in presence of moisture, while the lower horizons of the successive soil profiles suffered less and became instead the sites for concretionary

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‡ Die Typen der Bodenbildung, Berlin, 1914.
cementing, the latter action often taking place along the older buried soil surfaces themselves.

It may be noted that such red loams are of frequent occurrence immediately under the true loess wherever the highest members of the Sanmenian series have been preserved. They are well developed in the Shouyang Basin especially around Lung-Chia-Nao two miles north of Ma-Shou-Tsun Station. They occur in the Tatung graben in Northern Shansi. Many of the so-called “red-clays” of the mountain areas of Hopei, Chahar and Jehol are of the same character. At times the material of the highest layers of this facies becomes loessic in character. V. Richthofen comments on the fact that such red loams produce deep furrows and gullies like true loess. Though the Sanmenian loessic facies is redder and more clayish than the pure aeolian loess overlying it, it is impossible to resist the conclusion that wind-blown material has been added to the reworked products of local weathering and that this deposit is in fact of composite origin.

The chemical composition of the material itself still awaits determination. Older analyses labelled “red loess” and the like from Honan and Shansi were carried out on samples taken from unidentifiable horizons. Hence the exact chemical relationship of the weathering process involved to that of typical lateritization and red loam development as studied in Java*, Malaya† and elsewhere awaits further research. The process, even if similar in character to that giving rise to true laterite as an end product, is clearly very much less in degree, as the induration hardly exceeds that of loess and the highly porous character is not developed. Moreover the typical hardpan constituent of laterite is iron, whereas in the Taiku red loams the concretions are mainly calcareous. The thorough silification of the Sanmenian vertebrate fossils is characteristic and in marked contrast to those of the loess and younger deposits. But these differences may be in part due to the continuous accretion of new layers of material as the result of the topographic relief (assisted by wind-action) which recurred before the weathering had reached an advanced stage. Moreover Dr. R. L. Pendleton, Chief Soil Technologist of the Geological

* Van Baren, Mitt. des Geol. Inst. der Landbouwhoogeschool in Wageningen, No. 16, 1930, p. 86
Glinka, op. cit. p. 57ff.
Survey of China, has spoken to me of how when, as Director of Agriculture of Gwalior State, Central India, he was mapping soils in the Mandsaur region of that State, he found instances on low basaltic buttes of what may be regarded as relics of true laterites, which at a depth of about two meters below the surface had considerable quantities of calcareous concretions, there known as "kankar." The laterite, which is of the hard, porous, tubulated sort, must have developed under a humid climate from the Deccan trap, which is the country rock of that region. Subsequent erosion occurred and a change of climate, for the present climate is distinctly arid for most of the year, with about 600 mm of rainfall in the summer months from July to September inclusive. The genesis, therefore, of the calcareous layers lying between the hard laterite and the relatively unweathered basalt a meter or so deeper is unexplained.

It is at any rate clear that the red loams and clays of the later Tertiary and early Quaternary of North China could only have formed under climatic conditions more nearly tropical than those of today. This is corroborated by the major differential weathering effects of that period as shown in the surface relief of today which assumed its main features before the opening of the Pleistocene Period. Thoroughly decayed granite and diorite intrusives are found weathered down to low rolling hummocks in depressions between projecting limestone ridges. The bedrock in such mountain basins as the Peipiao coalfield which suffered lightly from the excavations of the Fenho and Chingshui stages are lined with a thick cover of rich red-brown residual clay. The faunal evidence points in the same direction.

According to our reconstruction of the subdued land surface relief of those days, the layered loams collected on the gentle slopes below the faintly projecting decayed and well-nigh buried remnants of the old mountain ridges. Similar soil-material, reworked and water-laid, came to rest in the bottoms of the shallow intermontane basins, and today forms imposing stratified deposits along the lower Fenho, well exposed for example southeast of the river bend between Hou-ma and Chiang-chow. The low topographic relief must have been exactly like that still preserved today in places where later crustal movement has not caused its destruction, as for instance in many areas along the south-eastern border of Mongolia, or in such more limited localities as the slope directly across the Yu-ho from Tatung city or on the broad southern flank of Feng-Huang-Shan near the bend of the Yellow River at Tung-kuan.
But though such surfaces exist today, the red loams which veneer them are clearly not the products of the present day conditions of weathering. The effects of the action of present day climate on loess, bedrock or on the soils themselves are notably different from those which produced the red loams. The latter could only have formed under conditions of greater moisture and higher temperature than now rule—in fact under a subtropical climate.

In this connection the climatic implications of the lower members of the Taiku series is of significance. According to Chaney the flora implies a cool semi-arid climate, with which the lithological character of the fine-grained facies and the presence of gypsum are in accord. As already noted, Teilhard and Young find no indication of climatic change between the Nihowan and Choukoutien faunas, but the mammalian fossils occur mainly at the slightly higher predominantly sandy horizon which may on careful study prove to be more closely linked with the overlying red loams than with the underlying freshwater members. The significance of this possible relationship was not fully recognized when the Nihowan and Taiku areas were visited. Until the evidence from the plant fossils was forthcoming, it seemed as if the transition from gypsiferous sediments to red loams might conceivably have been accounted for by the change from conditions of a small interior drainage basin ponded by faulting to those of a marginal slope after the spurs separating the basin from the main Fenho valley were buried by subaerial deposits. But the floral evidence seems conclusive. In addition the development of the characteristic megalodont unionids found in the lower Sanmenian is accepted by Grabau as implying unfavourable conditions of the kind a less genial climate would offer.

It is generally assumed that the famous caves at Choukoutien received their quota of fossils during a period of aggradation, are younger than the Nihowan horizons and are older than the loess. On this assumption, the Taiku red loams are the equivalent of the Choukoutien phase in this area, and in the Taiku deposits as a whole we have preserved a series covering much of both lower and upper subdivisions of the Sanmenian.

However a possible alternative, not so far suggested elsewhere, should not be overlooked. Under suitable topographic conditions the filling of an underground channel in limestone may occur also at a time when the predominant process above ground is erosion. In that case the Choukoutien fauna might really belong to the first stage of the post-Sanmenian erosion
epoch (Chingshui stage). This would account for the slightly more advanced evolution of some of the species, for the scarcity of deposits of this precise age, and for the fact that all the fossils of this horizon so far found have been in cave-fillings or allied types of deposits, and yet are plentiful where they do occur. Since the structure of the Taiku series shows that the effective cause of the Chingshui rejuvenation, in this locality at least, was diastrophic rather than climatic, the persistence of Nihowan mammalian types into Choukoutien times is entirely natural. But the depth of the cave filling and general physiographic considerations prevent the Choukoutien deposits from being younger than very early Chingshui. Moreover with their slow rate of accumulation, the thick red loam deposits probably account for the full lapse of time between the two Sanmenian mammalian horizons.

On either assumption—that is to say, whether the Choukoutien horizon is precisely equivalent to the Taiku red loams or to the opening phase of the Chingshui erosion which dissects them—the locality retains a record of each element in the physiographic evolution of the area from Middle Pliocene to the present time.

In addition there is preserved evidence of a hitherto unsuspected minor climatic change from cool semi-arid conditions to those of increased temperature and greater moisture in late Pliocene times.

CORRELATION OF PLEISTOCENE CLIMATIC FLUCTUATIONS.

The problem of linking the post-Miocene history of North China with that of Europe and North America has till latterly been impossible. The meagre fossil evidence was inadequate to correlate deposits in an ice-free region with those of a glaciated area separated by the width of a continent. Even our knowledge of the succession of stages through which the region came to its present condition was too scanty. The gaps in the sedimentary record seemed to represent longer time-intervals than were needed for the amount of intervening erosion observed.

But, as noted in an earlier section of this paper, we seem at last to have laid hold of a fairly complete series of physiographic stages—confirmed in an increasing number of localities—which, though needing much further study in detail, does account for the major features observed and reconciles elements which previously seemed discordant.
Attempts to connect these stages with any recognized succession of events elsewhere—especially in glaciated regions—through appeal to some direct common control for both series of changes have until recently been out of the question for lack of data.

Three general systems of correlation may be considered.

I. Correlation of Malan Stage with Riss-Würm double glaciation.

In a previous paper I tried to relate the period of loess development to the second twin-glaciation (Riss-Würm).* This offers a solution for the Malan stage itself, but suggests no satisfactory correlation for the earlier stages.

"The conditions of loess accumulation are specialized enough to demand climatic influences of an abnormal kind, suggesting a more than regional control likely to be of world-wide character.

"A connection with some phase of the Pleistocene Ice-age at once suggests itself. No direct link has been established between the loess and the two valley-glaciations of the Altai recorded by Berkey and Morris, nor with Dainelli’s four glacial stages of the Karakoram, nor with similar events in the Tibetan Alps.

"But if the times of greatest ice-extension accompanied an accentuation of the winter pressure-distribution and a corresponding waning of the summer monsoon effect, the general conditions for loess development can be accounted for.

"This would make the times of loess generation coincide with the glacial maxima, or at least with the periods of lowest mean temperature within the glacial cycles. Two such periods are called for—corresponding to the loess deposits of the later Sanmen and of the Malan Stage. The loessic facies of each of these formations appears to be an indivisible unit and so far careful study reveals no other loessic horizons. †

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* Barbour, Loess Problem of China, Geol. Magazine, vol. 67, p. 472. It is important to note that in a recent paper Teilhard and Young appear to adopt this general correlation by indicating the period of loess-deposition as "Middle Pleistocene (Riss-Würm)" on their table of formations, without however discussing its implications. Vida Bull. Geol. Soc. China, vol. 9, 1930 p. 125.

† If further study proves that the loess was not all deposited more or less continuously at one epoch, but is actually a compound formation with elements of slightly different ages, the problem will of course be immediately simplified. At present, however, there is no warrant for this assumption.
"The Sanmen deposits yield fossils of Villefranchian type. Whatever views are held as to the identity and independence of the Günz Glaciation, the Sanmenian cannot be younger than the Mindel Glacial Stage, so that the loessic deposits at the top of the formation can be correlated with the peak of that glaciation.

"On faunal grounds the Malan Stage might be either of Riss or of Würm age. If it is limited to either one, we may ask why no corresponding deposits have been anywhere found for the other. Since the accepted place for the Mousterian cultures has been in the Riss-Würm Interglacial Epoch, the discovery of quasi-Mousterian implements at the base of the Malan loess presented a dilemma with no obvious solution, unless:—

"(1) The Riss glaciation had no loessic counterpart in this area—a hypothesis for which there is no ground—or

"(2) The period of loess accumulation lasted through both Riss and Würm Glacial epochs, but for some reason was unevenly distributed, or locally scoured, so that the areas of the quasi-Mousterians foyers were free of Rissian loess—or

"(3) The Loess represents both the Riss and Würm Epochs, but the cultures evolved in the East (or spread thither from an intermediate dispersal centre) before their appearance in Europe displaced the more primitive industries.

"With regard to the last explanation, it should be noted that the fossil types present all belong to a single natural association. In fact the work of Teilhard, Young and others brings out clearly the fact that the Pleistocene of China shows only two groups—the warm Sanmen association followed by the cold Malan one. Recent studies of the European Pleistocene associations point to a similar sequence for the two main groups—warm followed by cold. There is increasing ground for the conviction that the Riss and Würm Glacial epochs were closely linked and represent essentially a double advance within a single relatively cold period. On this interpretation, the Malan loess is the representative of this Riss-Würm twin-group.

"With regard to the date of the Chinese Palæolithic and the problem this raises in relation to the loess, recent revisions by Breuil and others place the Chellean well back in the Mindel-Riss Interglacial, so that a somewhat greater antiquity for the Mousterian in Europe is now more
generally conceded than was formerly granted. Even if it is allowed that
its appearance there does not go back much beyond the close of the Riss,
its origin farther to the east may well have been considerably earlier. For,
as Boule has it, "Western Europe......is only an advanced cape of Eurasia,
a kind of cul-de-sac where the successive waves of many human tides come
to break and die out." Even if the dispersal centre in this case lay in some
intermediate region, so that the culture did not reach China at once, it still
may well have done so long before it came to Europe. In addition, it would
thus have only an indirect relationship with the classic Mousterian through
their common mid-Asiatic ancestor, a fact explaining its somewhat anoma-
lous character.

"The Malan Stage was preceded and followed by the periods of greater
precipitation of the Chingshui and Panchiao Stages. The latter corresponds to
the post-Würm transition to present-day conditions, the former apparently
to the Mindel-Riss Interglacial. It thus seems that the pluvial periods do not
correspond to glacial stages, nor are the arid days of the loess the counterpart
of the warmer interglacial epochs. Instead, the prime control of both loess
and glaciation seems to have been the slight but world-wide fall in tempera-
ture."*

II. Correlation of Malan Stage with Mindel-Riss Interglacial.

The formulation recently of Simpson's Solar Radiation Hypothesis of
glacial control offers a new line of attack on the problem. By applying to
North China the consequences of his theory as developed for Europe, it is
possible to suggest two alternative explanations which seem better to account
for the facts on the basis of the evidence of the deposits and related structures
of the Taiku area.

In attempting to interpret the record of erosion and deposit in terms
of diastrophic movement and climatic change, it must be understood that
North China probably underwent no rapid alternations of heat, cold,
drought or moisture during the Pliocene or Pleistocene Periods. Climatic
changes are to be thought of rather as those from warmer to cooler, more
humid to more arid, rather than as glacial, tropical, pluvial or desert. It must
also be emphasized that the dating of deposits in this region necessarily
calls for some latitude of interpretation. The extreme paucity of fossiliferous

* loc. cit.
horizons, the superficial character of the deposits and our general ignorance of
the exact relationship between faunal groups here and those elsewhere, make
it at present impossible to set exact time-limits in terms of European glacial
stages to any one formation in China.

The succession of events to be accounted for is as follows:

1. The *Paote Stage* of warm moist climate with extensive development on
   red clays. Fossils of Pontian (*Hipparion*) type point to an early Pliocene age,
   though the same conditions probably set in before the close of the Miocene
   Period and may have persisted locally long after Lower Pliocene.

2. The *Fenho Stage* of vigorous erosion. This cannot be explained without
   some appeal to vertical movement, as bedrock was dissected in places to depths
   of several hundred feet below the older thalweg profiles. No climatic change
   need therefore be invoked.

3. The *Sanmen Stage* of fluvo-lacustrine deposition, which began under
   cooler and drier conditions (as indicated by the lower horizons of the Taiku
   deposits) and then returned to warmer conditions of greater moisture, and
   latterly with development of impure loess. Palæontologically this stage has been
   divided into the lower or Nihowan Sub-stage (regarded as late Upper Pliocene)
   and the upper or Choukoutien Sub-stage (basal Pleistocene), but as has been
   pointed out above, strict correspondence of the palæontological and the climatic
   sub-stages may not exist.

4. The *Chingshui Stage* of revived stream activity. This erosion was
   vigorous but much briefer than the Fenho Stage.

5. The *Malan Stage* of decreased moisture and lower temperature with
   evanescent stream action and extensive loess deposition. The fauna of this
   colder climate is of Middle or Upper Pleistocene age and it is important to note
   that the Palæolithic culture sites of the Ordos region occur in gravels near
   the base of loess deposits of this age.

6. The *Panchiao Stage* of increased precipitation. Though predominantly
   erosional, the regrading of this stage involved local deposition. In the maritime
   belt there were sharp alternations of vigorous torrential action and fierce winds,
   for lenses of loess are interlayered with coarse deposits of angular gravel. The
   Panchiao stage spans the transition from the Pleistocene to present conditions
   of more temperate monsoon climate, with erosion and deposition of marked
   seasonal character.
In the Table below this sequence of stages is set opposite the succession of glacial epochs recognized in Europe. The relative characteristic of each Chinese stage (as compared with those that precede and follow) is indicated in the second column, while the third gives the climatic conditions deduced by Simpson for the glacial epochs of the fourth column, as represented in the diagram illustrating his paper.

**COMPARATIVE TABLE OF CHINESE AND EUROPEAN STAGES**

(Not to scale)

<table>
<thead>
<tr>
<th>Geological Period</th>
<th>Chinese Stage</th>
<th>Chinese Conditions</th>
<th>European Conditions</th>
<th>European Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pliocene</td>
<td>PAOTE</td>
<td>warm wet</td>
<td>warm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FENHO</td>
<td>wet</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NIHOWAN</td>
<td>cool dry</td>
<td>cold dry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CHOUKOUTIEN</td>
<td>warm wet</td>
<td>warm wet</td>
<td>GUNZ</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>CHINGSHUI</td>
<td>wet</td>
<td>warm wet</td>
<td>MINDEL</td>
</tr>
<tr>
<td></td>
<td>MALAN</td>
<td>cold dry</td>
<td>cold dry</td>
<td>RISS</td>
</tr>
<tr>
<td></td>
<td>PANCHIAO</td>
<td>wet</td>
<td>warm wet</td>
<td>WURM</td>
</tr>
<tr>
<td>Recent</td>
<td>PRESENT</td>
<td>cool</td>
<td>cold dry</td>
<td></td>
</tr>
</tbody>
</table>

Simpson adopts Köppen and Wegener's form of the Polar Shift Hypothesis as an integral part of his explanation of the European Pleistocene climatic changes. According to their calculation, the pole lay between Hudson Bay and the 75th parallel at the close of the Pliocene Period and thereafter swung to its present position after a detour across Greenland. On this assumption North China lay nearer the Equator than it does today from before the Fenho until late in the Panchiao Stage. According to a calculation kindly made for me by Dr. Simpson, the latitude of Peiping at the end of the Pliocene Period was about 22°N. and subsequently even lower.† The whole region must therefore have been subtropical throughout the Sanmenian epoch, actually reaching a

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† Personal communication from the Director of the Meterological Office of the British Air Ministry, London.
latitude corresponding to that of Canton or Calcutta today, thus bringing it well within the range of the climatic conditions needed to produce the soil-effects described.

The problem is complicated by uncertainties regarding the behaviour of the monsoons under conditions then obtaining. Cammiade and Burkitt have recently* tried to show that during the glacial periods the strength of the monsoon was lessened, while it increased during the interglacials. Just how this would affect North China is not easy to predict, but it would suggest that in epochs when the balance was slightly in favour of greater moisture this effect would be heightened; thus perhaps explaining the vigour of the Chingshui and Panchiao epochs of erosion. On the other hand when the trend was towards lower precipitation as in Malan times, the winter monsoon with its burden of loess dust would be exaggerated. Moreover, the glacial periods, on this explanation, would correspond to times of less pronounced monsoon effects and hence in this case exert a moderating effect mostly along the line of producing somewhat less marked seasonal changes, perhaps distributing the precipitation a little more evenly through the year.

The glacial periods of Europe would thus correspond to the times of transition between periods of greater and less precipitation in North China, and as such would leave more obvious traces when the trend was towards a drier rather a wetter epoch.

A further uncertain element in the situation is the question of change in elevation of the Mongolian landsurface, which must have had a marked effect on the pressure distribution.

Taking the table as it stands however, there is a sufficiently striking coincidence between the climatic conditions of the right and left halves of the page. Moreover it will be noted that so far nothing has been said regarding the diastrophic factor as a determinant in the erosion cycles. We have already pointed out that vertical movement of the earth's crust was certainly a factor in the Fenho rejuvenation, so that no climatic change need be assumed at that point. Similarly the evidence from the Taiku fault-line recorded in an earlier section of this paper makes it clear that crustal readjustment marked the incep-

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tion of the Chingshui rejuvenation.* In both cases a new erosion cycle could have started under existing climatic conditions, and in both cases the cycle was interrupted before reaching maturity by a change towards greater aridity, when erosion gave place to deposition.

Thus in both cases it would probably be safe to assume the persistence of warmth as well as of moisture, in which case the parallelism between Europe and China would be almost perfect. But in neither case has this second meteorological element been inserted in the table because the latter records only those elements for which there is actual evidence.

On the other hand the Panchiao stage does not seem to have been associated with any such crustal adjustment. But as its deposits indicate moister conditions than those of the loess days (Malan Stage), the rejuvenation in this case is unquestionably due in part at least to increased precipitation.

THE PROBLEM OF POLAR SHIFT.

It seems impossible to account for the red loams without appeal to climatic conditions of definitely more tropical character than rule today. An increase in solar radiation of the kind postulated in Simpson’s theory only makes the weathering effects more pronounced. The warm faunal association points in the same direction.

Moreover the characteristic red-clays of the earlier Pliocene show evidence of the same type of warm-climate weathering which seems to have persisted through the later Tertiary with the single exception of the lower Nihowan horizons which could be explained by a decrease of solar radiation just at the time when it is demanded by Simpson’s hypothesis.

At first sight the most serious objection to the polar shift assumption is that the cold loess fauna has no business to be down near the Tropic of Cancer at a time when solar radiation was perhaps not so great or even less than today. Leaving the temperature factor out of account, the other feature of the Malan climate—aridity—is unquestionably assisted by a shift which brings the Equator well over the continental mass of Eastern Asia. In a personal communication received since the earlier part of this paper was written, Dr. Simpson points out that south-east Asia would then have a relation to the

* It is probable that the pre-Chingshui movement was part of the general uplift which raised Mongolia to its present elevation.
Equator comparable to that of north-east Africa and Arabia today. "The southern border of the desert in that part of the world now approaches within 15 degrees of the Equator. In its new position the Equator would actually pass over part of the continent of Asia south of Peking, and it is almost certain that this would cause the edge of the desert to approach the equator and so the region near Peking would become more arid than it is at present. In other words we should expect to get the arid conditions found during the mid-Pleistocene if the pole shifted to the position it is supposed to have had during that epoch."

The unexplained element in the Malan Climate, then, is the low temperature. Part of it could be accounted for by decrease in solar radiation, part certainly by elevation—the Mongolian border stands at 5000 feet above sea-level and two periods of Pleistocene valley glaciation have been recognized in the Altai ranges. The palæontological evidence, on the basis of which a cool climate has been assumed, must be scrutinized to see what further light can be thrown on this point and to determine whether the loess fauna is incompatible with a latitude some fifteen to twenty degrees nearer the Equator.

THE PROBLEM OF PALÆOLITHIC CULTURE

The second serious objection to the interpretation given here is the position of the Palæolithic foyers found by Teilhard and Licent near the base of the loess in the Ordos region. This would seem to imply a Mindel-Riss Interglacial horizon for this Mousterian (?) culture, whereas the classical place for Mousterian Man is after the Riss. Unless a revision of the European dating is possible, it becomes necessary to assume that the Palæolithic cultures evolved in more genial surroundings farther to the east some time before their spread to Europe on the retreat of the ice.

As noted above however there is already a growing body opinion that would extend the Mousterian considerably further back than onset of the Würm glaciation. In his *Eiszeit und Urgeschichte*, Bayer definitely correlates the Mousterian advance with the Riss glaciation. Incidentally, he refers to Eurasia as the centre of origin of the "broad blade" industry characteristic of the Neanderthal race.

At any rate there is enough uncertainty with regard to the exact relationship between the Ordos 'flints' and the European cultural succession to justify our refusal to regard the presence of these Palæolithic foyers as an
insuperable objection to a Mindel-Riss date for the horizons at which they occur provided all the other facts can be reconciled.

III. Indirect correlation without reference to European Stages.

On the other hand, it may be urged that the earlier observations were made without full appreciation of certain significant details now better understood; that in the absence of fossil evidence errors may have been made in correlating deposits of identical lithological character; that the Pleistocene standard column of Europe is itself sufficiently open to dispute on many points of detail; that there is no a priori reason why the two curves of radiation variation should be as nearly equal in amplitude or span as Dr. Simpson's diagram suggests; and, finally, that there may in fact have been no exact correspondence at all between any given stage in China and one in Europe, the climatic fluctuations in China being due essentially to local controls, independent of, or at least only indirectly connected with, the Ice-age changes of Europe.

In this case we may disregard any apparent parallelism between the climatic fluctuations in western Europe and eastern Asia suggested above, and readjust the position of the Chinese stages so as to avoid any possible apparent conflict with the palaeontological and cultural evidence. We can then see in what respects it fits in with the climatic probabilities deduced from Simpson's hypothesis and consider in what direction a solution may be found for discrepancies with the latter.

The mammalian faunas fall into three groups which afford fixed points for the readjustment;

(1) The Pontian warm climate association, with the extensive development of red residual clays and allied transported deposits definitely indicates a tropical climate for the early Pliocene.

(2) The Sanmenian association, belonging to a warm climate (following a minor cool fluctuation in Upper Pliocene) indicates a general persistence of tropical or subtropical conditions well into the Pleistocene. (The recognition of two separable horizons (Nihowan and Choukoutien) may indicate that these conditions held for long enough for a distinct evolutionary advance to take place.)
(3) The Malan loess fauna of Middle or Upper Pleistocene age, which belongs to a cool dry climate followed by a period of increased moisture.

To avoid the conflict with the evidence of palæolithic culture however, the Malan stage must be limited to Upper Pleistocene and made to cover the time of the Riss-Würm Interglacial and part of the Würm. This restriction of the Malan Stage also fits in with the fact noted above that the physiographic and faunal gap between the Sanmenian and the Malan epochs,—i. e. the time occupied by the Chingshui Stage—is of greater importance than the post-loess Panchiao interval.

Even with this revision of the dating, the fact still stands out prominently that the Pontian and Sanmenian call for a sub-tropical climate whereas the Malan and later deposits accumulated under conditions more nearly characteristic of their present latitude. Since increased radiation as a sole explanation for the Sanmenian conditions would fail to explain the non-occurrence of similar conditions during the loess epoch, we seem driven to assume a shift of the polar axis.

Until the complicated meteorological effects of this shift have been worked out in detail it seems impossible to fit the North China stages into the European chronology with any certainty. But it is worth while seeing how far this third method of dating the Chinese Pleistocene may be correlated with the probable consequences of Dr. Simpson's hypothesis as applied to this part of Asia.

This correlation is suggested in a generalized manner in Fig. 6 where Curve 2 is the solar radiation curve taken directly from Fig. 3 of Dr. Simpson's paper on "the Climate during the Pleistocene Period,"* to which have been added as reference points the initial letters of the European glacial stages. Curve 1 gives the relative variation of mean annual temperature due to polar shift only. For simplicity this variation has been assumed to be directly proportional to the change of latitude and the curve was therefore obtained by inverting the latitude-variation curve for Peiping on the Köppen-Wegener hypothesis as most kindly calculated for me by Dr. Simpson. As the relative importance of the two variable elements—latitude and radiation—are at present unknown, the resultant plotted as Curve 3 must be interpreted as indicating

* Simpson, op. cit. p. 167.
only the probable relative trend of climatic change, the absolute magnitude of individual fluctuations being a matter of conjecture. Moreover in view of the subtropical position and the complex monsoon influences, the maxima and minima were certainly less regular and in some cases less pronounced than the curve suggests. But the general tendencies are clear and seem to be in accord with the succession and relative importances of the physiographic stages indicated at the bottom of the diagram. The characteristic of each stage is noted, the precise position of the Choukoutien horizon being regarded as uncertain.

**Fig. 6** Hypothetical Correlation of North China Stages with Climatic Tendencies on assumption of (1) polar shift and (2) varying radiation. (Not drawn to Scale).

Comparing this result with Simpson’s curve of radiation, it then appears that, according to his hypothesis, the Sanmenian might have persisted throughout the time allotted to the Günz and Mindel glaciations — giving the time needed for slight faunal changes to develop. But the Malan loess then comes only after the second radiation maximum. In this case then the necessary factor in the fall of temperature of the loess epoch must have been the change of latitude, aided perhaps by increased elevation. As a corollary of this is the deduction that, so long as the polar axis remains where it is and the continental outline retains its present configuration, a future change in radiation could of itself cause a recurrence of loess conditions.
One effect of adjusting the stages to fit Curve 3 is that the Malan loess epoch appears to fall so late that it extends to the close of the Pleistocene, thus still further compressing the Panchiao stage—in conformity with the recent tendency to regard the latter as of less importance than was formerly supposed. The Chingshui erosion may have to invoke diastrophic movement to explain why it did not merely repeat the effects of Middle Sanmenian times. But the Taiku area structures now give warrant for this assumption in any case.

**EVALUATION OF THE THREE SYSTEMS OF CORRELATION.**

In trying to see which of the three systems accords best with facts, the difficulties inherent in each must be frankly faced again. Considering first correlation I—the one involving close parallelism of climates developed on the radiation hypothesis—the following points have to be remembered:

1. The loess fauna is not critical enough in character to allow of discrimination between closely set horizons, even, for instance, between the Mindel-Riss Interglacial and the early Würm.

2. It may put an undue strain on the archaeological possibilities to extend the cultural stages back as far as the interpretation seems to require.

3. From the point of view of geomorphological effect, the results of the Panchiao Stage are so insignificant compared with those of the Chingshui erosion that to assign comparable spans to time to these two stages seems hardly warranted. This latter point, perhaps, cannot be stressed as it involves too many uncertain factors—the question as to whether the presence of the porous loess blanket may not have made run-off less rapid and hence reduced erosion in Panchiao times, lack of knowledge as to the exact amount and distribution of rainfall during the two epochs and as to the complicated effects upon the prevailing humidity of evaporation under different conditions, uncertainty as to monsoonal behaviour, and the like. But as P. Teilhard has pointed out in conversation, faunally too the Chingshui lacuna is more imposing than the Panchiao. So the difficulty still remains.

The system of correlation I, which equates the Malan loess epoch with the Riss-Würm double glaciation, is equally dogged by the uncertainty (1), but does not put such a strain on the archaeological evidence (2). This latter aspect has been considered already. Nor is the correlation so liable to the criticism inherent in (3), because on this assumption the Panchiao Stage is entirely post-glacial in age.
But the correlation in itself offers no assistance with regard to the pre-
loess stages and raises the difficulty already noted of the absence of any true
loess deposits corresponding to the Günz-Mindel—unless the locally developed
loessic phase of the Sanmenian loams is all that remains of a once more widely
developed early Pleistocene loess. Polar shift becomes essential to explain the
earlier more tropical conditions indicated by the character of the sediments.
And a further cause has to be sought for the brief cooler semi-arid phase of the
early Nihowan epoch coming between the vigorous Fenho erosion and the warm
moist times of the later Sanmenian.

The last approach (III) makes no demands of this kind because it is pur-
posely framed to avoid the difficulties inherent in the other two. But it leaves
the onus of proof on the development of a satisfactory meteorological system
to account for the development of the moist conditions of the Chingshui and
Panchiaoy Stages and the aridity of the Malan loess Stage. It was noted above
that, according to Cammiade and Burkitt, the vigour of the monsoon abated
during the glacial periods. If then the Malan loess is more or less equivalent
to the Würm, the decrease in force of the summer monsoon would account for
the greater aridity, while the shift of the equator towards Australia would
produce the fall in temperature. The reinvigoration of the monsoon with the
recession of glacial conditions would be partially offset by the diminution in
solar radiation, thus prolonging the effect somewhat. The increase of monsoon
effect in the Mindel-Riss Interglacial would explain the Sanmenian loessic
phase. It may be supposed that earlier minor fluctuation, for instance in the
Günz-Mindel occurring in a cycle region then more tropical in its general con-
ditions, have left evidence of a kind which we have so far failed to detect.

The third system is entirely consistent with a Pleistocene glaciation of
New Zealand. It does not however suggest the occurrence of two pluvial periods
nicely adjusted to the chronology of the ice-advances of Europe and
America. We still lack data as to how far the effective cause of the
Fenho, Chingshui and Panchiaoy rejuvenations were climatic and how far
tectonic. The presence of a well-defined raised planation surface at Peitaiho,
Shanhaikuan and other points along the north shore of the Gulf of Peichihli
may indicate that a strandline shift involving emergence of the order of
fifty feet occurred well before the close of Pleistocene, but it is not clear whe-
ther this is of Fenho or Chingshui date, so that the factors of vertical movement and increased precipitation cannot be isolated as yet. We must leave it as a problem for future research to show how far this question of the pluvial stages and other related consequences of this third system of correlation are in accord with meteorological probabilities. Summing up, then—if the palaeontologists and archaeologists can be satisfied—the first by the discovery of further fossil data allowing a more precise dating of the Malan deposits, the second on the score of the antiquity of palaeolithic man—it would seem that the direct parallel correlation of stages is possible. Otherwise we must adopt the third general correlation leaving the adjustment of details until we are in possession of a better understanding of the climatic controls of Eastern Asia during the Pleistocene Period.* In any case, explanation of the facts seems only possible on the assumption of a shift of the earth's axis of rotation.

FURTHER LINES OF ATTACK.

The final solution of the problem may ultimately be achieved in any one of a number of ways. It may prove possible to link the Malan deposits with a stage of valley glaciation in Tibet or the Altai, with the help of fossiliferous sediments or physiographic criteria. Or studies at present in progress on the past climates of Inner Asia may furnish the key. Comparison of climatic fluctuations in India and other intermediate points may supply a link with Europe and Africa. New discoveries may be made regarding the early history of Man in Central Asia.

Meanwhile as to further lines of detailed attack which must be followed up to establish the truth of the explanation advanced here, two may be mentioned as relatively easy of achievement in the near future.

One is the study of the fossil leaves recently recovered from the lower members of the Taiku formation, which should confirm the assumption regarding the climate during the early part of the Nihowan substage. Along with this must go a critical review of the Lower Sanmenian mammalian fauna to determine how far it is compatible with the deductions from the floral evidence of the lower horizons.

The other will be a chemical study of the loams of the upper members of the Taiku series, which should throw light on the conditions of weathering in

* see Note at end of paper.
early Pleistocene times. The fact that there appears to be a repetition of the general character of the soil profile, as indicated by the banding and concretionary layers, points to a steadily operative process of alteration acting on fresh supplies of soil material laid down in successive layers on the top of already weathered soil surfaces; since this accretion was probably not strictly uniform, the buried soils may show variations which would be instructive if considered in relation to their varying thickness, the thoroughness with which alteration occurred before it was interrupted by burial and the extent to which concretionary processes had gone in each instance. It is quite possible that an analysis of the concretions may show some significant variations, and it would certainly be of value to compare the concretions recovered from the distinct formations—Paote, Sanmen (Upper and Lower) and Malan. In any case, a comparison of the compositions of the Paote red clays, the Sanmenian red loams and the loess of Malan and Panchiao times should prove particularly instructive.

It would seem, moreover, that a careful quantitative study of the heights of river terraces and platforms, taken with the character of their distribution, should yield important additional data concerning the nature of the various rejuvenations and hence the cause of the inception of each of the different erosional stages. It ought to be possible, for instance, to distinguish entrenchment due to increased rainfall from that due to warp or to shift of strandline. In the latter case, regrading starts from the coast and works headward up the water-courses. In the case of tilting, the amount of incision should vary with the relation between the general trend of the stream and the direction of warp. Whereas with increased precipitation all streams are liable to affected throughout their whole length. But this last mode of attack is one of extreme complexity, especially if, as seems likely, more than one cause has been operative.

**CONCLUSION**

The character and structure of the Taiku deposits described in the first section of this paper amplify our understanding of the history of North China from late Pliocene to Recent times. In so doing, they furnish a useful means of connecting previously uncorrelated stages in the evolution of the landsurface.
Three systems of correlation are outlined, two of them equating the Malan stage of loess-accumulation (i) to the Riss-Würm double-glaciation and (ii) to the Mindel-Riss Interglacial respectively. The latter seems in close accord with Simpson’s radiation control hypothesis, but involves difficulties with regard to the age of palæolithic man and to the time-limits of the loess-fauna. A third “nonparallel” correlation avoids these difficulties and appears the most reasonable at present.

The assumption of polar shift accounts for certain warm-climate features inferred from a study of the fossils and the lithological character of Pliocene and early Pleistocene deposits.

Corroboration of the interpretation advanced is to be sought by a study of the fossil soil profiles and a chemical comparison of the typical weathering-products of the different epochs.

NOTE

1. Since this paper was prepared for the press I have had an opportunity of seeing an important contribution by Dr. Davidson Black, prepared for this same volume, which suggests a meteorological explanation of precisely the kind required for the third system of correlation put forward in this paper.

2. A further interim report on the Taiku flora has been received from Dr. Ralph Chaney;

"It contains the following new species....

*Acer taikuensis* cf. *Acer palmatum*

*Acer plicocenicum* cf. *Acer henryi*

*Leguminosites climensis* cf. *Albizzia corniculata*

*Ribes barbouri* cf. *Ribes aciculare*

*Ulmus Shansiensis* cf. *Ulmus parviflora*

".....The species with which the fossils are compared are species living for the most part in northern China. Their occurrence in a comparatively cool, dry climate indicates a climate during the Pliocene not unlike that of today. Such a conclusion is in full accord with Dorf’s recent discussion of the Pliocene floras of California (see Carnegie Institution Publication No. 412, 1930). The comparatively small size of several of the species as compared to the normal leaves of their living equivalents may also be interpreted as an indication of low rainfall and of a comparatively short growing season."