THEORETICAL REFLECTIONS ON THE GEOMORPHOLOGY OF CHINA FROM THE VIEWPOINT OF GLACIO-EUSTATISM.*

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It is quite generally accepted that the growth of the Pleistocene ice-caps demanded world-wide depression of mean sea-level; indeed, as Henri Baulig says, "it expresses a physical necessity." There is striking evidence, moreover, for such a recent depression in the extension of river systems across the continental shelf as submarine trenches of dendritic pattern, a feature met with on most shores of the world and whose localised absence is usually to be explained along simple physiographic lines, such as the lack of streams capable of incising to this extent (*e.g.* desert shores).

Further, the gradual recession of the ice after each glacial maximum must have entailed a slow rise in sea-level. This is remarkably clear in the case of the last (Würmian) glaciation through such widely spread features as drowned shorelines and river estuaries, the aggradation of river-beds due to the rise in baselevel, and the associated sedimentary infil of the Würmian trenches cut into the continental shelf. The rise in mean sea-level since the commencement of the melting of the Würmian ice will be referred to, for the purposes of this paper, as the post-Würmian transgression.

The purpose of this paper is not, however, to examine the abundant evidence for such eustatic oscillations since this has already been dealt with in numerous papers of which H. Baulig[1] has recently given a critical résumé. The evidence for these movements is so convincing that their actuality will be assumed in this discussion and attention will be concentrated upon China in the light of glacio-eustatism.

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1 H. Baulig: "The Changing Sea-Level," Inst. Brit. Geographers, Pub. No. 3., London, 1935.

In the first place the youthful, submerged type of shoreline shown by the 'South China Block' is remarkable.[1] Before seeking what information the eustatic factor can throw on this ria coast it is instructive to consider certain tectonic hypotheses. Perhaps the drowned coast is due to downfaulting on the seaward side together with partial submergence of the landward (upthrow) block. In this case the faulting cannot have taken place in a remote geological period since the shoreline is so youthful; further, two main divisions of such possible faulting may be discussed: a) that in which the fault zone is some distance inland with resultant drowning of the down-faulted region between the fault-zone and the sea. In this case the fault zone should be clearly visible in the field; the majority of rivers should show profile breaks of slope when the faulting has taken place in rocks of high resistance to fluvial erosion; there may even be waterfalls. If in addition there were partial submergence of the landward block then the sub-aequeous profiles of most rivers would be expected to show breaks of slope (unless sedimentation had been very rapid) at that part of their bed crossed by the fault or faults. b) that in which the sea is brought to rest against the fault-face, producing a compound shoreline with partial submergence of the landward block. In such a case the fault-face should be recognizable throughout much of the shoreline affected by faulting, since owing to the reflection of waves from such a face and the initial absence of really effective material for the waves to fling against the cliffs erosion is for some time unusually slow. Moreover the sub-aequeous contours would clearly reveal such faulting if it were of any considerable extent, which is our supposition.[2] However, the irregular pattern shown by this south-east coastal region of China is certainly not characteristic of fault coasts.

In the second place downwarping may have caused the drowning. In this case important river profile modifications must have taken place, and these changes should be clear in the case of rivers that had reached the graded

1 A recent paper dealing with the question is by C. Y. Lee; "Study on the submergence or emergence of the shoreline of China," J. Geog. Soc. China., vol. 2, June 1935.

2 For discussion on fault coasts see particularly, Cotton: "Fault Coasts in New Zealand," Geog. Rev., No. 1., Pgs. 20-47. 1916.

stage before the warping took place, since:—those that flowed seawards at right-angles to the hinge of warping would start downcutting at a rate greatly superior to that they assumed during the graded state, and this increased incision would be greater downstream, where the increase in slope is greatest; those rivers flowing for a part of their courses at right-angles to the hinge of warping, but in a direction away from the sea, would have their slopes decreased and, given identical conditions with regard to load and volume, would start aggrading their beds, (in the case of really violent downwarping their direction of flow might be reversed, etc., conditions which are outside the scope of this paper as regards discussion); rivers flowing parallel to the hinge would probably show a tendency to lateral displacement in a seaward direction.

In all these cases the simplest, symmetrical type of down-warping has been considered; departure from symmetry would naturally demand modifications more or less easily determined. Moreover, the determination of such profile modifications would demand contoured maps of high accuracy, not to mention a knowledge of the geological structure (in its widest sense) and extended field-work, for a critical examination of the warping hypothesis.

If we go beyond simple warping and suggest broad negative (i.e. downward) epeirogenic movement—a possibility that, frankly, must be faced—then difficulties abound, i.e. in the mere determination of the limits of the area affected.

But there is another side to the latter question: there is a youthful shoreline and therefore the supposed epeirogenic movement cannot have taken place in the remote past. If then it took place comparatively recently it can hardly have done so very slowly, for in that case active marine erosion, and sedimentation would have kept pace with the gradual drowning and so prevented the characteristics of a submerged shoreline from obtaining. Thus the movement must have been recent and of no small magnitude; and in that case the limit of the area involved in the downward movement should be clearly defined in that area's peripheral morphology.

It must be stressed that whatever tectonic hypothesis (especially that of faulting) or combination of hypotheses be favoured, a "tangent" shoreline of very great length is here involved, quite apart from the *actual* endlessly ramified shoreline. Should such as hypothesis be proved correct, then the recent

activity of such widely-spread tectonic forces will demand an explanation from geophysics.

We have still, however, to consider the eustatic factor. What has been the effect of the Würmian depression plus the post-Würmian transgression? It seems inevitable that, since we are dealing with a shoreline of immense length, unless tectonic movements have so closely simulated eustatic movements as to nullify their effect, traces must abound of a recent downcutting of the rivers into the continental shelf with the later drowning of the coastal region and the development of youthful, submergence type coastal forms such as rias, bay-head beaches, spits, etc. But this is precisely the shoreline type that is observed. The presence of sediment-filled trenches in the continental shelf in continuation of the river systems, and the discovery that most rivers are underfit (i.e. below-grade) and engaged in aggrading their beds seem, to the author, to be expected; it is unreasonable to suppose 'oscillatory' tectonic movements capable of simulating eustatic pulses through such a length of coast. At the same time the length of shoreline is quite immaterial, since the depression of sea level was world-wide.

There is the further point that Pleistocene glaciations earlier than the Würmian must also have had their effect on sea-level, and that the depression at the maximum of those glaciations must have been considerably greater than the Würmian. And furthermore the possibility of tectonic movements locally affecting areas must be allowed for. Before going further the magnitude of these depressions must be briefly discussed.

Ernst Antevs[1], neglecting the effect of downwarp of the glaciated areas due to ice-load, and considering the ice-caps to be plano-convex instead of bi-convex as well as taking no account of the gravitational effect of the ice-masses insisted upon by Daly,[2] gives an estimate based upon the most careful analysis of glacial data of 93 metres for the maximum of the Würmian glaciation (assuming exact contemporaneity of the maximum in each hemisphere), and 88 metres if there were not exact contemporaneity.

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1 Ernst Antevs: "The Last Glaciation," New York, 1928.

2 Daly: "The Changing world of the Ice Age." New York, 1934.

Daly (loc.cit.), allowing for what may be termed deformational and gravitational corrections, gives 75 metres for the Würmian and 90 metres for the maximum depression during the Pleistocene. Moreover he stresses the complicated effects of the earth's elasticity and plasticity on strandline positions in non-glaciated regions, particularly in relation to ocean-bed depression due to increase in post-glacial water-load increase. At the same time it does seem that these estimates are too low; or, in other words, that the applied corrections are too great. It would seem that Daly's depression values are necessary to support his coral-reef theory, rather than that the theory rests upon more generally accepted depression values.

Dubois,[1] neglecting 1) isostatic adjustment of the ocean bed with varying water-load, 2) modifications of the oceanic basins following upon glacial variations themselves, upon the sediments brought by the glacial débâcle, or upon reactionary movements of the continents due to glacial isostatic adjustments, 3) local deformation of the sea-surface caused by variations in the attraction of the glacial masses, gives the following figures:—90 to 100 metres for the Würmian depression, assuming exact contemporaneity in each hemisphere, and 131 metres for the maximum Pleistocene depression, under the same conditions.

Baulig (loc. cit.) commenting on Antevs' figures, stresses the fact that the considering of the ice-masses to have been planoconvex lenses instead of biconvex ones, etc., means that there was more ice, by an indefinite amount, than Antevs allowed for, and that therefore, in the case of the Würmian glaciation, the sea-depression must have been greater than his 88-93 metres; similarly comparable figures, or even larger ones, must naturally be accepted for each of the previous glaciations. In support of this statement it is noteworthy that the Würmian bed of the Rhône-Durance, for example, plunging beneath the delta, the Camargue, would indicate a sea-level of from 100 to 140 metres below that of to-day; the continuation of the profile clearly shows this.[2]

1 Georges Dubois: "Essai statistique sur les états glaciaires quaternaires et les états correspondants du niveau marin," Ann. de Geographie, XL, 1931, pp. 655-658.

2 H. Baulig: "La Crau et la Glaciation Würmienne," Ann. de Geog., XXXVI, 1927, pp. 499-508.

In the light of these figures it is instructive to consider the "geosynclinal" region to the north of the South China block, that is to say, the Yangtze & N. China Plains of G. B. Cressey.

Well logs show beach deposits at Shanghai at 900 feet below ground-level.[1] The deepest Peiping well records 708 feet of deposits, and Dr. W. H. Wong[2], critically examining well-log evidence in the northern 'alluvial' plain, concludes that it is definitely proved that the delta plain is characterized by great depth of sediments.

The generally accepted opinion regarding such deposits is that a typical geosynclinal region is being dealt with; and, indeed, this solution has much to support it, and in the main would appear to be sound. Barbour[3] mentions that poor preservation of fossil content from various horizons makes dating impossible, and judging from the volume of sediments deposited, and general physiographic considerations, he would say that unquestionably subsidence has been the dominant movement in the main delta of the Yangtze since well before the close of the Tertiary, and that this movement may have halted for a time or had its effect negatived by warping early in the Pleistocene, and has proceeded at an extremely slow pace since. Whether it has ceased or not at the moment cannot be determined with certainty.

On applying the conception of glacio-eustatism to the geosynclinal region one has first to countenance an important query: what was the development of the region before, say, the beginning of the onset of the Würmian glaciation compared with the region's present development? It is clear that, in the present state of our knowledge, this question cannot be answered with certainty, and that arguments will have to be based upon reasonable assumptions and simplifications. Let it be supposed, therefore, that the area occupied by the delta during the Riss-Würmian interglacial times was comparable with that occupied to-day; further let it be supposed that there was some considerable

1 Walker: Pro. Eng. Soc. China, Vol. 25, Paper 7, 1926, p. 14.

2 W. H. Wong: Sediments of the North China rivers and their Geological Significance," Bull. Geol. Soc. China, Vol. 10, 1931.

3 Barbour: "The geomorphology of the Nanking area," Contrib, Nat. Res. Inst. Geol., Acad- Sin., No. 3, 1933.

depth of sediments—say 150 metres in the thicker, seaward part. Finally, for the purpose of initial simplification, suppose all purely tectonic movements of the area under consideration to be non-existent. Then with the onset of Würmian glacial times there would be a gradual eustatic depression to a maximum of some 100+ metres. This would lead to:

a) The shifting of the strandline very far to the East. The present 100 metre isobath extends, very roughly, from Quelpart Island in the north to Formosa in the South, with an eastward bulge half-way simulating the general curve of the coast. It seems to the author, therefore, that during the maximum of this glaciation the Gulfs of Pechihli and Liaotung, Korea Bay and the Yellow Sea must have been above sea-level; indeed, to take but 100 metres depression for the Würmian is almost certainly too low a figure, so that the strandline must have been even further east, whilst during the maximum Pleistocene glaciation it must have been even further east still. It may be objected in this connection that no allowance has been made for deposition during and since the Würmian recession, and that therefore during the Würmian Maximum the 100 metre isobath must have been much further to the west than it is to-day. On the other hand the sea area considered is so vast that it does not seem to the author that the shift can have been of a magnitude likely to affect the major question. Also, with regard to the shore-forms developed during the maximum depression, the bearing on the present discussion is so slight that reference to these emergence shoreline forms will be omitted.

b) A greatly increased land surface now available for aeolian deposition, such as loess.

c) A probable change in the volume of river water owing to climatic change.

d) The extension of the river systems over what was the submarine delta. Rivers formerly sub-parallel may even become tributaries the one of the other.

e) Owing to base-level depression the rivers will steadily incise their beds, and a wave of retrogressive erosion will pass upstream. Given the low resistance of the sediments to erosion it would appear that this retrogressive wave must have moved rapidly, a point to which we shall later return. Further, it is

significant that during this phase of incision there will be the smallest possible tendency for rivers to change their courses.

It is unlikely that during the period of maximum sea-level depression the shoreline would be very greatly pushed back towards the west; certainly not far enough to be worth considering its effect on present conditions in the Great Plain.

With the waning of the ice-sheets the sea-level gradually rose—the post-Würmian transgression. This would lead to:

a) The gradual submergence of land consisting of deltaic sediments formed beneath the sea during the Riss-Würm interglacial epoch, incised by the continuation of mainland rivers, and probably by little developed consequent streams, and probably covered by aeolian deposits whose thickness increases westward.

b) Drowning of the incised river valleys.

c) Sedimentary infil of the now submarine trenches, and the initiation of fresh deltaic deposits at river mouths.

d) The passage upstream of a wave of retrogressive aggradation in the river system due to the rise in base-level.

e) Change in volume of water in the rivers due to climatic change.

f) Finally present-day conditions are reached, with overladen rivers, flooding, and consequent immense river migrations, as in the case of the Hwang-ho; also a tendency to delta extension.

Now it would appear[1], empirically, that a graded river in flood can shift alluvium to a depth below the low-water plane equal to the height of the river at flood above that plane. . .and this is but a minimum value, and it is at flood that the great migrations take place. It follows, therefore, that the depth to which such a great river as the Hwangho can shift alluvium at flood must be very great, and so a great depth of material must have been "refashioned" as well as removed during these wanderings. It is therefore clear that, considering solely the period from Riss-Würm times till to-day, the variety of horizons through which any boring might conceivably pass is not small. . . . even under geological conditions intentionally simplified. It might pass through:

1 H. Baulig: "The Changing Sea-Level", p. 11, footnote.

1) Sediments of Rissian and pre-Rissian age, 2) Riss-Würm interglacial material, 3) Würmian æolian material; (4) Post-Würmian infil of Würmian trenches, 5) Silt of more recent times, 6) Early post-Würmian transgression beach material now covered by more recent delta alluvium due to delta advance: there is even a seventh division if "refashioned" material, due to river migrations, be counted.

Is it to be wondered, therefore, that there is very great difficulty in correlating horizons between wells that are even relatively close to each other?. . . .and this quite apart from the varied facies characteristic of any single horizon.

If one goes back to earlier Pleistocene times it is logical to ask if there may not also be found evidence for the Günz, Mindel or Riss glaciationsr or even for all three. If so then such record as here is much be preserved in division 1) above; and when one considers that the eustatic depression during the maximum Pleistocene glaciation was much greater than during the Würmian, and further that the series of events outlined for the Würmian would be repeated for each of the earlier glaciations, the complexity the existing record must have is certainly not encouraging to the investigator.

And it is less encouraging still if the conclusions of Maurice Gignoux[1] and other investigators be valid, namely that the mean sea-level at each inter-glacial stage was progressively lower than at the previous inter-glacial stage. Moreover, we have purposely neglected negative or positive epeirogenic or warping movements accompanying the glacial cycles sketched above; but it would seem to the author that such movements are unlikely to have been of such magnitude and contemporaneity that the effects of the glacial cycles could have been nullified.

But there is another line of investigation: it has already been stressed that eustatic depression has as a corollary the origination of waves of retrogressive erosion passing up the river systems. Now the waves initiated by a base-level depression of considerably more than 100 metres during the Würmian, and of even more than that during the maximum Pleistocene glaciation, can have been by no means insignificant, and given at first unresistant deposits to pass through

1 M. Gignoux: "La Géologie Stratigraphique", Paris, 1926 (giving the results of his own work and of that of others).

they must rapidly have moved upstream and so reached the delta hinterland of more resistant rock in which river trenches had already been cut.

Now in a very great number of papers recently published in China and dealing with more or less large regions attention has been drawn to recent downcutting of the rivers followed by aggradation. Further, it has been natural to infer that such similarity of action probably occurred more or less contemporaneously, and so an attempt has been made to view synchronically such stages as the Yangtze of Willis, Chao and Huang[1], the Pukiang of Barbour[2]; the North China Panchiao of Willis, Andersson, Barbour and Teilhard[3]; etc. In each case the main reason for increased downcutting is given as "warping"; and the wider the observations are extended the more synchronous cases of warping we seem likely to be presented with.

It would seem to the writer that the Würmian eustatic depression with the associated retrogressive erosion might very well account for this increased and ubiquitous incision, and do so, moreover, in a very simple and "expected" way. And besides, should this suggestion be proved correct, a date has been found for the period of the downcutting. Similarly the aggradation would be a consequence of the eustatic rise since the beginning of the recession of the Würmian ice-sheets.

And further, it is to be expected that previous waves of retrogressive erosion occurring during pre-Würmian Pleistocene glacial maxima must have left their mark in the same way—that during the greatest ice-extension should be conspicuous, considering the depth of the eustatic depression—and each followed by an aggradational wave. Is it possible that such stages as, e. g., the Chingshui [3,4,5] have some such origin?

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1 Chao & Huang: "Geology of Tsinlingshan & Szechuan", Geol. Sur. China Mem. A. 9.

2 Barbour: "Geology of the Nanking Area", (loc. cit.)

3 Barbour: "Geology of the Kalgan Area", G. Sur. C. Mem. A. 6.

4 C. C. Sun: "Geol. of Suiyuan & S.W. Chahar", G. Sur. C. Mem. A. 12.

5 Teilhard & Young: "Some Correlations between the Geol. of China and the Geol. of Mongolia", B.G.S.C., vol. 9, no. 2.

At the same time it is quite within the realms of possibility that such general downcutting in, say, Würmian times has been locally hindered or aided by crustal movement. In any case the investigator must be prepared for this probability.

No attempt has been made in this paper to solve problems; indeed, its aim has been to be suggestive rather than conclusive. Attention has been directed upon those world-wide eustatic movements of Pleistocene times which much necessarily have left their trace on Chinese morphology. In addition, certain probable results of these movements have been suggested, and certain major lines of attack have been touched upon.