THE LAST "PLUVIAL" PHASE OF THE EURAFRICAN SUB-TROPICS

by

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INTRODUCTION

One of the most important palaeoclimatic problems of the sub-tropics is the character and chronology of what have been described as "Mediterranean pluvials" (see Zeuner, 1953). There is little doubt on the part of specialists today that the poleward margins of the sub-tropical high pressure cells enjoyed extended periods of moister climate during parts of the Pleistocene. There is widespread agreement that these morphologically conspicuous phases of ameliorated hydrological balance were broadly associated with glacial episodes. Two fundamental problems have, however, received but incidental attention and no unanimity.

"Pluvial" periods have been defined as periods of wide-spread, long-term rainfall increase of sufficient duration and intensity to be of geomorphic significance. Basic phenomena employed to ascertain the presence of pluvials have usually been limited to high lake levels and greater fluviatile activity. Conceivably misunderstandings have resulted, and dissident opinions have been voiced whether or not a true rainfall increase is implied. Specifically it is argued that a zonal lowering of temperature by 4°-5° C. during various glacial phases would automatically reduce evaporation sufficiently so as to permit higher lake levels or greater stream discharge. Consequently it is argued that the term "pluvial" is inappropriate, and that such phases are little else than "fluvial" periods. Admittedly such arguments have been loosely used for distinct geographical regions, and they may be better founded in the case of inner-tropical or equatorial phenomena. Yet they have also been frequently employed to discredit truly rainy phases in northern Africa and the Mediterranean area.

Closely associated with this problem of physical geological interpretation is another of stratigraphical character. The precise chronological position of "pluvial" phenomena is absolutely essential if conclusive argumentation is to be attempted. It is climatologically quite unrealistic to assume or state that glacials and pluvials are contemporary or not. Classical stratigraphical methods, whereby periods of many million years are considered quite homogeneous, are disastrous when applied to the Pleistocene. Furthermore such long- and short-term fluctuations of climatic elements as are known from the instrumental and historical record are incredibly complex and incompatible with the oversimplification of sedimentary processes so often made by earth scientists.

A historical review of Upper Pleistocene climatic interpretation may be useful in actually defining the problems to be discussed here. After the existence of widespread glacial epochs had been conclusively proven during the later nineteenth century, many decades of argument were devoted to the problem of many versus one, single glaciation of Pleistocene date. Although A. Penck and E. Brückner's classical alpine study (1900) generally bore out the polyglacial interpretation, some so-called monoglacialists still publish today. But after 1920 the problem of immediate controversy shifted from the plurality of glaciations to the uniformity of each glacial epoch. Interstadial interruptions were recognized or disputed, exhumed or interred. With the successful application of radio-carbon dating, it has now become almost obvious that what was previously considered to be the Würm-Weichsel glaciation in Europe was interrupted by at least several warmer episodes.

With the realization that there were several and not only one Pleistocene glaciation, and that glaciations consisted of several and not one stadial phase, general opinion seems to have been susceptible to accept further complications. In 1950 J. Büdel, an apparent opponent of subdivided glaciations, and I. Schaefer, both outlined significant climatic phases recognizable in the sequence of interglacial-glacial. More precisely Büdel and Schaefer independently showed that major Pleistocene solifluction and river aggradation preceded the maximum extent of the glaciers, and that loess and sand deposition with linear erosion followed under drier conditions during the period of glacial standstill and ultimate dissipation.

RÉSUMÉ

La dernière phase « pluviale » de la zone subtropicale eurafricaine (K. W. Butzer)

Lorsqu'on étudie, d'après les récents relevés géologiques, les climats qui ont été autrefois ceux des régions arides du monde, l'un des problèmes fondamentaux qu'on rencontre est celui des périodes « pluviales ». Aucune série d'anomalies climatiques n'a eu, sur les zones désertiques subtropicales et à leurs lisières, des effets comparables à ceux de plusieurs périodes d'humidité plus grande. La configuration terrestre du Sahara, du Proche-Orient et même des régions adjacentes telles que le bassin Méditerranéen est parsemée de particularités géomorphiques dues à des périodes anciennes de précipitations plus importantes. En fait, dans beaucoup de régions prédominent des fossiles caractéristiques de la période pluviale du pléistocène : on y trouve des sculptures fluviatiles impressionnantes, alors qu'il n'y pleut presque pas aujourd'hui.

En concentrant son attention sur une seule zone climatique, à savoir l'Afrique du Nord et la région méditerranéenne, et sur une seule période qui correspond *grosso modo* à la dernière glaciation, on peut dégager de cette étude plusieurs caractéristiques paléoclimatiques assez précises. Certains sédiments, trouvés associés à la plus ancienne oscillation régressive de la mer Méditerranée qui date de la glaciation de Würms, sont considérés comme l'indice de pluies violentes du type torrentiel. Ces dépôts comprennent les limons colluviaux du bassin Méditerranéen (dus à une érosion laminaire et à des dépôts locaux) et les graviers des oueds ou des torrents qu'on trouve tant dans la région méditerranéenne qu'en Afrique du Nord. La comparaison de ces dépôts d'alluvions avec les processus fluviatiles de l'époque actuelle montre sans aucun doute possible qu'il y a eu augmentation en valeur absolue de la quantité des précipitations, bien qu'une saison sèche d'intensité comparable ait dû persister. Des caractéristiques analogues sont associées à diverses oscillations du niveau de la mer dans le bassin Méditerranéen et, par conséquent, aux fluctuations des glaciers continentaux aux latitudes plus hautes.

Les périodes de régression maximale (correspondant à la pleine période de glaciation de Würms) et de transgressions ultérieures (correspondant à la dernière phase glaciaire) ont néanmoins été principalement sèches. Sur les côtes de la Méditerranée, le développement intensif des dunes entraînant la régression du littoral n'a été que faiblement empêché par la végétation, et l'activité fluviatile en Afrique du Nord s'est fortement réduite ou bien a complètement cessé. Il en résulte une succession d'initiales phases glaciaires humides avec des maximums d'humidité secondaires aux divers moments où les glaciers reprennent leur avance graduelle, et de phases glaciaires complètes ou tardives, mais sèches.

L'association que cela implique n'est évidemment pas fortuite : il doit y avoir un phénomène de circulation primaire qui explique l'avance simultanée des glaciers situés à de hautes latitudes et l'apparition des phases pluviales dans la zone subtropicale. Cela tend à montrer que ces périodes pluviales ne sont pas simplement des phénomènes secondaires résultant d'une déflexion mécanique des perturbations occidentales par les souches continentales existantes de glace. Du point de vue météorologique, la question se pose aussi de savoir comment les changements fondamentaux de la circulation et les formes d'équilibre et d'échanges thermiques latitudinaux se sont trouvés associés à l'abaissement général de la température dont témoigne la période glaciaire maximale.

DISCUSSION

L. B. Leopold. It is requested that Dr. Butzer explain by simple sketches or by a few sentences, what he means, in connexion with his Table 2, by "sheet-flood erosion", "limited surface washing", "incision of valley margins". Also, it would be valuable to the audience if he would explain briefly why he believes "vertical erosion" is associated with "cool, frequent frosts, subhumid winters, and extended dry season" (see Table 2), and further why "valley alluviation" is associated with "temperate, heavy torrential rains, moderately extended dry season".

K. W. Butzer. In a few words, what is meant by "sheet flood erosion" is areal denudation, particularly of irregular terrain or slopes, with mass transfer of soils and regolith on to lower slopes, into topographic hollows or drainage channels.

"Limited surface washing" should simply mean analogous processes of very limited intensity.

"Incision of valley margins" should mean linear erosion of lateral margins of existing torrents or canyons, with accumulation along the soles.

"Vertical erosion" associated with "cool, frequent frosts, etc." is meant in the sense that areal denudation had declined or ceased entirely during the Full Glacial. Various deposits

present are of more local origin, and more angular, being derived from limited erosion of adjacent surfaces. These processes cannot compare with the wholesale denudation and alluviation or colluviation associated with preceding "pluvial" conditions of rather more frequent and intense torrential rains.

R. C. SUTCLIFFE. Does the kind of evidence described by Professor Butzer enable us to say whether the climate of the Mediterranean has remained "Mediterranean" in character, that is, whether in all phases the rainfall was mainly in the winter with relatively dry summers?

K. W. BUTZER. The seasonality of climate seems, from all available evidence, to have remained analogous to that of today. A dry season very probably persisted throughout the Pleistocene. The question of temperature, as defining the other statistical element employed to define a "Mediterranean" type climate, is different. A general lowering of temperature means by some 4°-5°C. can be safely assumed for glacial maxima from various lines of evidence. This would then reduce large parts of the Mediterranean Basin to "submediterranean" or "temperate" conditions in the thermal sense.

H. BOBEK. While congratulating Professor Butzer on his paper, I should like to make a warning remark against too early and too much generalization. All the phenomena involved are dependent not only on climate, but also on a host of other factors which certainly have to be taken into consideration and make generalization a very precarious thing.

As to quantification of controlling factors otherwise not determinable, the comparative method should, I feel, be much more used; e.g., the "sheet-flood erosion" was classified in Table 2 under "Pluvial Glacial" whereas "vertical erosion" should belong to the "Dry Glacial". Accordingly pediments, or *glacis d'érosion*, in the western Mediterranean have been attributed by many scholars to the Pluvial periods. However, in Persia (which I have known for years) the Central Plateau is certainly a region where sheet-flood erosion, i. e., pedimentation, is active today as it has been for ages, at a precipitation range of 100(50)-300 mm. Why, then, should one claim a still more humid pluvial in the western Mediterranean to explain the pediments there instead of a drier climate?

Aggradation and degradation have their specific place in a river system. They should not be labelled in terms of climate only without referring to their specific situations in the respective river systems, or to other important co-factors (tectonics, etc.). The same applies to the size and form of materials.

General statements of the type made in Table 2 may all too easily prove dangerous.

K. W. BUTZER. I would like to emphasize that in my paper I have attempted to single out very specific phenomena and outline these in such detail as is possible here. The tables presented were simply offered as a systematic organization of materials and suggestions, and to consider one column as reference to areal erosion as opposed to vertical erosion in another, is to misunderstand and misinterpret their purpose. Reference is made specifically to the phenomena discussed in the background paper.

So, for example, pedimentation, a phenomenon not typical of the "Mediterranean" climates of the Mediterranean Basin, was not considered, and is a topic on the genesis of which I offer no opinion. The sheet-flood erosion mentioned was specifically directed towards the genesis of colluvial silts. I then feel quantitative or semi-quantitative study of pediments to be decidedly more significant than general morphological study in palaeoclimatic interpretation.

Professor Bobek's statements about solifluction or cold climate phenomena being responsible for upstream aggradation do not apply to the areas described, namely the Mediterranean lowlands. I feel very strongly that cold climate transport hypotheses are unwarranted unless solifluction or cryoturbation features can be demonstrated in questionable pediments. Specific reference has already been made to the lower limits of cold climate ("periglacial") transport in the areas considered. The catchment basins studied were chosen to be free from such phenomena.

As regards localization of aggradation and erosion in a stream system, I believe that sufficient description is given in the background paper and in details given above in reply to Dr. Leopold. It was indicated that the contrast of pluvial and dry glacial or dry interglacial is fundamentally one of morphogenesis as opposed to quasi-equilibrium, excepting of course man-induced erosion. Furthermore the local catchment basins of the Mediterranean littorals are generally small so that particular longitudinal differentiation patterns do not occur other than already indicated. "Other factors" such as tectonics are insignificant as regards aggradation problems in Spain and Egypt for the Upper Pleistocene and Holocene.

H. FLOHN. Referring to the questions at the end of Professor Butzer's paper I would like to formulate, in a quite preliminary way, some suggestions from the viewpoint of a meteorologist.

1. It seems most likely that at the last glacial epoch the surface temperature of the Mediterranean sea was not lowered more than 4°-5°C. as compared with the recent value. The existence of the Alpine glaciation, however, indicates a larger decrease of the temperature in the middle troposphere which may be estimated to 7° or 8°C. in the area of a rather persistent upper-air trough. Under such conditions the average vertical lapse rate of temperature was substantially larger than it is today, frequently conditionally unstable, which favoured torrential cloudbursts. To support this there is evidence of an extremely rainy and cloudy climate of the French and Italian Riviera, near Genoa, during the last glaciation, where these conditions—due to the vicinity of the warm sea to the glaciated Alps—are expected to be most pronounced.

2. A predominance of "low latitude low index" circulation types (Willett, 1958) seem to coincide, from a geographical view point, with the distribution of high latitude glaciations and subtropical pluvials. However, these circulation types are nowadays apparently more or less related to lower temperatures, at least in middle latitudes.

3. Taking into account the fact that the heat content of the oceans is several orders of magnitude higher than that of the atmosphere, we have to expect a phase shift between the temperature of the oceans t_w and that of the air t_a. Thus, at the beginning of each glaciation, during a fairly long period t_w-t_a can be expected to remain substantially greater than today, accompanied by instable conditions in the lower atmospheric layers and by increased evaporation at the oceans. Vice versa, at the end of each glaciation t_w-t_a might be substantially smaller, largely negative, and therefore accompanied by stable conditions and decreased evaporation. It seems not unlikely that the total water-vapour content of the atmosphere may have varied largely during this cycle. Since the average residence time of a H_2O molecule in the atmosphere is not greater than 11 days, the global annual

precipitation amount must be equal to the annual evaporation, and this lag effect may have influenced markedly the global water budget.

4. If the coincidence of moist periods in subtropical latitudes with warm and dry climates in temperate latitudes is established beyond any doubt, we ought to consider how far equatorial disturbances may have extended to the north during the summer at least over the continents, as suggested by H. H. Lamb for the postglacial optimum.

During the war, in one case a cloud system from the equatorial summer rains reached the Mediterranean coast of Egypt, even producing some rain-drops (H. G. Koch). As quoted from C. E. P. Brooks, during the Roman era of Egypt, summer rains were nearly as frequent as winter rains. Thus it might be conceivable that during an Interglacial of the Postglacial optimum a semi-arid climatic type similar to that near Peshawar (northern Pakistan) may have governed large parts of the Near East, with two short (and weak) rainy seasons of 2-3 months each in winter and summer, and with two intermediate dry seasons.

K. W. Butzer. I thank Professor Flohn for these stimulating and valuable remarks.

W. L. Kubiena. I am very grateful to our chairman for his very valuable and detailed presentation of the subject and I am particularly grateful that he used paleosoils for his synthesis to such an extent. As to the question of the character of the humid interglacials, I would like to make a remark. We have tried to date *terra rossa* formations in Spain. Pleistocene and Tertiary formations were found but it has not been possible as yet to find a *terra rossa* which could be dated as a recent formation. This is very strange because the *terra rossa* has been regarded up to now as the most typical Mediterranean soil. We are still looking for the recent *terra rossa*. In this connexion I might mention that I prepared a soil map of Spain pointing out the possible recent *terra rossa* areas which, however, could not be proved up to now. It it turns out definitely that a recent *terra rossa* does not exist in the Mediterranean, it would mean that the present climate is different from that of the humid interglacials the latter having had perhaps a greater African influence with much warmer and much more humid winters.

M. Kassas. 1. The stabilized sand dunes (Qoz) of Kurdufan (Sudan), may be taken to indicate a more arid climate in the time of formation as compared to the present-day climate which makes the growth of stabilizing vegetation possible.

2. On the plain at the base of the Qoz, extending to Omdurman, numerous fossil ant hills are found. These may be taken to indicate a wetter climate previous to the arid climate of the dune formation.

3. Concerning the gypsum layers in desert soils, one may refer to the presence of a surface layer of amorphous powder gypsum and a deeply seated layer (usually thicker) of crystalline gypsum. The former layer is formed by capillary rise and is typical of the present arid climate. The deeper bed may indicate a less arid climate where a water-table is developed.

4. The study of wadi development may provide evidence on the climatic change. There are two types of wadi cutting: downward cutting of long channels (wet climate) and backward cutting of gullies (arid climate). The pattern and interrelationships of the two types may bring the required evidence.

K. W. Butzer. As regards the Qoz I do not claim any authority other than to confirm the existence of patterns such as Dr. Kassas described from most of the Sahelian belt. The younger Qoz presumably indicates phases of even drier climate than today, although the basic genesis of the Qoz appears very complex according to Professor Monod's work.

The two varieties of gypsum crusts so well observed by Dr. Kassas are familiar to me. I have not, however, found the latter in stratigraphic context. As to its interpretation, I would prefer to refer the issue to Professor Kubiena.

The wadis of Egypt are from all evidence Upper Miocene to Lower Pliocene, forming under moister conditions during the Tertiary. Presumably both agencies mentioned by Kassas are responsible. Although both headward erosion (on a very limited scale by talus development) and linear incision and gullying do occur today, the latter is more significant. It is, however, very localized indeed and confined to soft, fine sediments.

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