MEDITERRANEAN PLUVIALS AND THE GENERAL CIRCULATION OF THE PLEISTOCENE

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The pluvials of the Mediterranean Basin, North Africa and the Near East are generally conceded to be the consequence of a local intensification of the westerly circulation accompanying the glacial phases of the Pleistocene. However, very little attention has ever been paid to the possibility of identifying distinct stages of pluviation corresponding to the periods of ice formation, the duration of the glacial maximum and to the retreat of the continental glaciers. The recent reclassification of the Würm-Weichsel chronology in Central Europe as particularly carried out by P. WOLDSTEDT (1956) and H. GROSS (1956) is in full accord with the Wisconsin stratigraphy of North America (R. F. FLINT 1956) and is substantiated by a large number of radiocarbon datings. This classification associates the main period of solifluction with the Early Würm and with the Main Würm readvance after the Göttweig Interstadial; the chief periods of loess deposition fall along with the Stettin, Brandenburg and Pommeranian stadia. In effect, the periods of glacial advances and readvances were, from all considerations of the evidence, moist and cool in Europe, those of the glacial maxima and standstills, cold and dry. In other words there must be two distinct types of general atmospheric circulation associated with the phases of semi-equilibrium accompanying the standstills of the continental glaciers as well as with their advance and formation. Apart from the factor of increased temperatures, the general circulation accompanying the retreat of the ice sheets appears to belong within the former category.

Such a distinction of two quite different general circulation types has not been made for the pluvials, largely because the phenomenon of long-term periods of increased annual precipitation on the northern margins of the Saharo-Arabian desert belt was never accredited to a primary change of the general circulation. The Mediterranean pluvials have always been passed off as a secondary effect of the presence of a continental glaciation in northern Europe, the ice sheet supposedly acting as a thermal and baric agent dynamically deflecting the moist westerlies with their associated depressions southward. If this were the case, the Early Würm phase that was predominantly oceanic and moist in Europe (to permit the formation of the glaciers and account for the large-scale solifluction), should have corresponded to a comparatively dry climate in the Mediterranean Basin. Similarly the Main and earlier Late Würm phases which were predominantly continental and dry in Europe (simultaneous with the glacial maximum and initial retreat) should correspond to the actual Mediterranean pluvial phase.

Recent detailed study of the stratigraphy and climatic chronology of the Near East, very particularly of the Upper Pleistocene and Holocene (K. W. BUTZER 1957, a, b), does not confirm this hypothesis in any way. In fact it looks very much like that the Early Würm phase was temperate but decidedly moist in northeastern Africa and southwestern Asia; the Main Würm phase was quite cool but only moderately moist, and almost exclusively so only at the very onset of the Würm maximum, at a time corresponding to the readvance of the continental glaciers after the Göttweig Interstadial. It appears that in both cases pluviation was concentrated on the advance phases, and with some justice the Early Würm pluvial subphase can be designated as the Würm Pluvial *par excellence* in the Mediterranean Basin.

A few brief examples drawn from analyses of cave sediments at different points in the Mediterranean area illustrate this point well, but it cannot be attempted to outline or enumerate the large amount of geological material substantiating these results here. The interpretation of the cave deposits is largely given as according to R. LAIS (1941), and the chronological position of the prehistoric industries as determined glacio-eustatically and more recently by radiocarbon is outlined in D. A. E. GARROD (1956), BUTZER (1957 b) and others. Specifically the Mediterranean Levalloiso-Mousterian for the greater part belongs to the Early Würm, the Upper Palaeolithic to the Main and Late Würm, similar to their stratigraphic position in Europe as reviewed in detail by P. WOLDSTEDT (1956).

The cave sediments of the Grotte de l'Observatoire, Monaco, excavated by BOULE & VILLENEUVE (1927) date back farther than the Würm, but only those of the Upper Pleistocene are considered here. These deposits begin with an undescribed cave-earth, a fauna devoid of cold-loving biotypes with Acheulian and what appears to be developing Levalloiso-Mousterian industries. This appears to qualify for the Riss/Würm Interglacial and the layer is overlain by a thick stalagmitic horizon. Above this an earthy section with small limestone fragments, a number of cold forms and an Upper Levalloiso-Mousterian industry suggests a cool Early Würm ushered in by a very humid phase. Stalagmites necessitate a good amount of water seepage through the roof of the cave and are not forming in Mediterranean caves to-day. Similarly small, uncorroded angular limestone fragments are an indication of frost shattering and implicitly of a considerably cooler climate, as such weathering is also not taking place at present. A similar complex of stalagmites and cave earth with an even greater number of cold types and an Aurignacian industry lie above this, and imply the Main and Late Würm. Apparently both subphases of the Würm were inaugurated by very moist phases.

The Grotta Romanelli in Apulia has been thoroughly excavated by G. A. BLANC (1921). The deposits begin with a Monastir II beach conglomerate at 7—8 m above sea-level. From 5.5—4.6 m coarse angular rock-debris with *Hippopotamus*, *Rhinoceros merckii* and other thermophile faunal elements, overlain by a lower horizon of stalagmitic concretions (20 cm) containing traces of a more temperate fauna. A terra rossa layer from 4.4—3.6 m contains *Hippopotamus*, *R. merckii* and suggests a warm Mediterranean climate. Above

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this are the upper stalagmite horizon (some 5 cm), a number of large fallen limestone blocks (loosened by percolating water?) and 3.5 m of brown earth with a temperate fauna. The industry is Upper Palaeolithic in character, and from 3.0—0.8 m there is a great abundance of small, angular limestone fragments suggesting frost-shattering. Apparently the stalagmite horizon following upon the Riss/Würm Interglacial 8 m raised beach can be assigned to a very moist and more temperate phase during the Early Würm; the terra rossa zone suggests a Mediterranean climate during an interstadial; the brown earth with initial stalagmites, a temperate fauna, frost debris and an Upper Paleolithic industry must belong to the Main and Late Würm. Apparently the Early Würm was very moist but not particularly cool, the Main and Late Würm cold but moister only at the outset.

In the Haua Fteah Cave west of Derna, Libya, the Levalloiso-Mousterian is represented in a horizon of red clay and very frequent stalagmitic concretions and zones of cementation (C. B. M. McBurney 1953). The red clay must be the product of decalcification *in situ*, while the stalagmite and breccia horizons point to considerable percolating water, processes that both point to a much moister climate than that of the present. This horizon from 8.4—4.8 m is overlain by a level from 4.7—2.6 m characterized by angular limestone fragments and large uncorroded limestone blocks due to frost shattering, especially between 4.5—3.0 m. Obviously this horizon was little effected by greater water-seepage, the highest stalagmite zone occurring at 4.4 m. The radiocarbon datings by H. E. Suess (1954) make the suggested dating of McBurney unlikely, and one can safely date this phase of colder climate associated with an Upper Palaeolithic blade-industry, from c. 25000 to 8000 B.C. on the basis of C_{14}. This confirms a cold climate in Libya during Main and Late Würm, of which only the initial phase (level 4.7—4.4 m) was appreciably moister than the present. It also bears out how well the Upper Palaeolithic, and by extension, the Levalloiso-Mousterian delimit the Main-Late and Early Würm periods respectively. Obviously the 'pluvial' Levalloiso-Mousterian phase represents Early Würm.

The graphic representation of the relative frequency of the steppe biotype gazelle and the woodland form red deer occurring in the various culturally-dated layers of the Tabun and Wad caves of Mt. Carmel, Palestine (Garrod & Bate, 1937), can unfortunately not be regarded as a precipitation curve as some authors have tried to do. A number of authorities have spoken against this approach, and particularly A. Rust (1950, p. 140) stresses that different cultural groups would possibly have quite different tastes and hunting methods, giving a striking example from the Yabrud Cave, Syria. The latter cave likewise shows a quite similar stratigraphy (Rust 1950, p. 139—41). A Riss/Würm horizon (Acheulio-Yabrudian) from 9—5 m is composed of breccia-free, very loose materials with an intercalation of aeolian desert sand. From 5—2 m there are frequent hard breccia layers (stalagmitic concretions) and large, fallen limestone blocks. The last Palaeolithic level is composed of loose calcareous rubble with remnants of cementation zones. Apparently we again meet a pluvial horizon immediately following the Riss/Würm Interglacial-Interpluvial whereafter the rainfall once more decreased during the advanced stages of the Würm.

As a last example the deposits of the rock-shelter at Ksar Akil, Lebanon, excavated by

J. F. EWING (1947), can be cited. From 17—15 m two complexes of compact angular limestone fragments (due to frost-shattering) overlying a layer of red clay (due to greater humidity) indicate greater precipitation and a more continental, cooler climate during the Levalloiso-Mousterian (Early Würm). Above a depth of indifferent sediments another stone bed—red clay complex occurred with an Upper Palaeolithic industry at 11—10 m. A last stone layer at 2.0—1.5 m with a final Palaeolithic industry suggests the last glacial relapse of the Upper Dryas. This again bears out the characteristic Mediterranean cave stratigraphy with greatest moisture during Early Würm and associated with a Levalloiso-Mousterian industry. In each case greater moisture strikingly precedes greater cold.

How then can one explain that the Early Würm was predominantly a moist phase, the Main Würm predominantly a cooler phase, and that specifically maximum moisture always preceded maximum continentality—in the micro-case of each stadial as in the overall picture of the Würm glacial phase? Firstly, as in northern Europe, there must have been two types of general circulation in the Mediterranean Basin: one circulation associated with greater precipitation, and a second circulation pattern, more closely resembling that of the present in principle, but associated with a lower planetary temperature. The former circulation predominated at the onset of each glacial relapse in particular, and during the period of the glacial advance in general. Maximum pluviation clearly appears to have preceded the maximum lowering of world temperatures, and a great change in the general circulation must therefore have set in at the very beginning of the glacial phase, before any appreciable world-wide lowering of temperature. Consequently the circulation pattern changes of the Pleistocene were no secondary effect of a planetary temperature decrease and the appearance of continental glaciers. Temperature was apparently not the initial primary factor involved in the changeover from interglacial to glacial, which supports the suggestion of H. C. WILLETT (1950) that the primary ultimate cause of glaciation is to be sought in variations of solar ultra-violet or in particle emissions of the sun, not in absolute variations of insolation.

The change of the general atmospheric circulation at the beginning of the Würm was most probably towards a very pronounced, long-term low index or meridional pattern in the sense of WILLETT (1949) and H. FLOHN (1952). During such low index phases the circumpolar westerlies are weakened and dominated by very extensive quasi-stationary wave movements. Extensive upper air troughs extend far equatorwards and introduce polar airmasses into the tropics, while tropical air reaches far poleward in compensation. In the lower atmosphere the zone of maximal frontal activity is shifted equatorwards, the subtropical high pressure cells are weakened and separated by discernible troughs disturbing the normal trade wind circulation, permitting deep cold waves to invade the tropics (FLOHN 1952). On the other hand, during periods of high index or zonal circulation the jet-stream is well developed and little disrupted by wave movements. The zone of maximum frontal activity is shifted polewards, the subtropical high pressure cells are well developed and the trade winds are only disturbed by occasional shallow cold waves. The former circulation pattern is now generally considered as characteristically glacial in character, the latter, as interglacial. As noted above, the circulation of the Würm cannot be accounted for by the gradual predominance of a low index circulation: there are two distinct circulatory types inherent within the glacial phase proper. The first of these could very well have been a pronounced period of low index circulation, but the circulation of the glacial maximum and early retreat was somewhat different, and complicated by the presence of the ice sheets as well as a lower planetary temperature. Even apart from these necessary limitations, the actual situation shows further complications as general moisture tendencies in Europe and the Near East appear to have been largely similar during the Würm, and also during the Holocene (cf. BUTZER 1957 a, b). This could suggest world-wide accelerations or slackenings of the condensation cycle.

A word could also be said with regard to the reconstruction of an interglacial-interpluvial as a phase of pronounced high index circulation. For while world temperatures were 2—3° higher during the Climatic Optimum the Saharan area and the Near East (BUTZER 1957 a) enjoyed an appreciably moister period c. 5000—2400 B.C. This cannot be explained by either a high or a low index circulation pattern. S. A. HUZAYYIN (1936) proposed two distinct types of interglacial circulation connected with *warm* and *cool* interglacials, of which the former are humid and the latter dry in subtropical latitudes. However all the interglacials were 'warm' as is witnessed by the raised beaches which, apart from subsequent uplift, in all probability indicate a greater melting of the residual ice masses. And that the interglacials were simultaneously interpluvials is also borne out by the geological evidence. Possibly the solution is to be found in a more complicated process of 'blocking action' than the simplified notions of high and low index patterns allow. Objectively speaking there does not appear to be any coherent division between the Mediterranean and temperate European climatic provinces from the patterns of zonal rainfall increase or decrease associated with upper air 'blocking' analyzed so far (e.g. REX 1950). Further research in that direction may prove to be of great value to palaeoclimatology.

In summary, we stress that the Mediterranean pluvials cannot be explained as a secondary effect of the presence of the ice sheets, these pluvials being essentially limited to the advance phases of the glaciers and especially to the very onset of the glacial periods. Consequently the Mediterranean pluvials must be the direct result of primary changes in the general atmospheric circulation, probably in the form of a pronounced low index pattern, and they are not secondary effects of the presence of continental glaciations. However there appear to be two main circulation types associated with the advance phases and stand-stills or retreats of the glaciers respectively. The last cannot have been characteristically low index due to the sharp decrease in Mediterranean precipitation. Lastly another problem is presented by the presence of a moist phase in the Sahara and Near East during the first half of the Climatic Optimum. These questions may be solved as our understanding of long-term anomalies of the general circulation improves in the light of further meteorological research.

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