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Erratum

In Table II, page 300, A3 Dating of Pekin man, for *c* 400-200 read *c* 300,000–200,000

Preface

THIS BOOK HAD its inception in 1958, the Darwin Centenary year, when Sir Gavin de Beer urged me to undertake such a work. Most of the script here used had been written by early 1961, when on account of ill health it was shelved. My intention was eventually to increase its scope considerably, perhaps quadrupling its length, before embarking on publication. However, early in 1963, Dr Errol White, Keeper of the Department of Palaeontology, persuaded me that I would be better serving the interests of all those concerned with dating fossil men if I revised the existing script in readiness for immediate publication.

On his recommendation the first part of the script, an historical review of attempts to date the earliest remains of man, was published in a number of the *Bulletin of the British Museum (Nat. Hist.), Palaeontology Series*. In the opinion of my professorial colleagues the remainder of the script, dealing with the bases of stratigraphical and cultural dating of early man, sufficed to form a book, without extensive further work being required. Messrs Weidenfeld & Nicolson agreed with this view and undertook publication.

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As REGARDS THE details of this book the author owes much to those who supplied information or gave him their advice, notably Dr Karl Adam, the late Dr Alberto Blanc, Dr Bernard Campbell, Dr L. Cardini, Professor Desmond Clark, Mrs Sonia Cole, Professor G. W. Dimbleby, Mr Percy Evans, Professor H. Godwin, Professor R. F. Flint, Dr D. A. Hooijer, Professor Clark Howell, Dr Maxine Haldemann-Kleindienst, Dr G. H. R. von Koenigswald, Dr Björn Kurtén, Mrs Mary Leakey, Dr Susan Linbrey, Dr Charles McBurney, Professor Karl Narr, Mr Derek Roe, Mr Gale Sieveking, Dr Ralph Solecki, Dr J. C. Vogel, Dr John Waechter and Dr Richard West. The author hastens to add here that he alone accepts responsibility for any errors of fact and faulty synthesis that this book contains.

In the final stages of preparing the script for publication the author owed much to Mrs Sonia Cole and Mr Richard Carrington for practical advice; to Mrs Elizabeth Gardiner for her help in checking references and in preparing the stratigraphical bibliography; to Mrs Robin Kenward for help with the archaeological bibliography; to Dr Andrée Rosenfeld for her painstaking assistance in preparing the radiocarbon-dating charts; to Mr David Sisman and his able staff in the Art Department of the Reader's Digest for the final artwork and type-setting of these charts; and to Miss Theya Molleson for her unstinting and capable help in preparing the whole script for publication and finally in compiling the sixteen tables at the end of the book which apply stratigraphical, cultural and chronometric dating to the 300 or so more important specimens of fossil man now known.

The original manuscript of this book was typed by Mrs

Marjorie Nixon, and as this was a long continued onerous task my gratitude to her is considerable. I am also grateful to Lady Helen Greenfield who retyped those sections of the original script which required revision in 1963, to Miss Jane Beckett who prepared the index, to Mrs Valerie Vowles for help in revising the text in readiness for the second edition and to Miss Philippa Cullen for assistance in revision for the third edition.

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Lastly I wish to express my thanks to Dr E. I. White and to his successor, Dr H. W. Ball, for permitting some of the work connected with this book to be done in their Department of Palaeontology at the British Museum (Natural History).

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Introduction

THE CHRONOLOGICAL PLACING of fossils, whether they be early men or lower organisms, is fundamentally important for understanding their evolutionary relationships. Several distinct kinds of dating are involved. *Relative* dating* places an event with reference to some other event in a time-sequence. A fossil or a deposit can be regarded as representing an 'event': the interval of time when it was alive or being formed. In the relative dating of fossils reference is generally made to irregularly spaced, arbitrarily chosen events, which are geological, palaeontological or archaeological. For example in Europe the spread of the three mammalian genera *Elephas*, *Equus* and *Bos* has been chosen to mark the beginning of *Pleistocene* time; the ending of glacial conditions to mark the beginning of Recent, Post-Glacial or *Holocene* time, and the change from hunting to farming economy to mark the beginning of the *Neolithic* 'period'. In the sense that none of the events occurred everywhere simultaneously, the dating of a specimen by these criteria as Basal Pleistocene, Early Post-Glacial or Early Neolithic does not necessarily imply exact contemporaneity with specimens similarly dated in other parts of the world.

All dating is in a sense relative, but when it relates an event to a regular astronomical event-series, particularly the passage of years or solar time, it is commonly called *absolute* dating*. Thus, to date a skull as Early Neolithic is to place it in a sequence of archaeologically determined events; to date it as 6000 BC is to date it absolutely. Unfortunately the use of the term absolute dating as synonymous with dating in years has

* The current uses of the words *absolute* and *relative* dating were introduced by Oscar Montelius.

blunted the meaning of the word absolute, for it makes no distinction between referring an event to a span of years and referring it to a particular instant in time. Some authors (Ewer, 1956) have preferred to use the term absolute age with reference to contemporaneity between one deposit or species and another. For instance, if two deposits in widely separated regions were proved to be contemporaneous without being dated in years they could be said to be of the same absolute age. On the other hand, two deposits both dated as being 'between 20,000 and 25,000 years old' (so-called absolute dating) might not be contemporaneous. In such cases relative dating may be more informative.

To know the correct time sequence of the fossil remains of man and his ancestors is basic to interpreting their significance; but it is equally important from the point of view of understanding evolutionary process to obtain a measure of how much time separates one form from another. We are therefore concerned with two main classes of dating:

Relative Dating	the stratigraphical or archaeological age of a specimen or formation.
Chronometric Dating	(generally called Absolute Dating): the age of a specimen or formation measured in years.

In practice there are several kinds of relative dating, each depending on a different range of evidence. When a human skull, for example, is dug up in some ancient deposit, those interested in the discovery usually inquire at once: 'is it reliably dated?' The first question to be settled is whether the specimen is contemporaneous with the deposit in which it was found, or whether it has been instrusively buried, or whether (as sometimes happens) it has been derived from some older formation and redeposited. This primary dating, the age-relation of a specimen to its containing deposit and to the associated finds, has been termed for convenience *R.1 or first-order relative dating.** If the specimen is a bone (or tooth) determination of its chemical composition in comparison with that of other bones of known stratigraphical age in the same

* The author developed this dating terminology at the Wenner-Gren Symposium in New York 1952 (Oakley, 1953).

deposit is a valuable means of establishing whether it is contemporaneous, intrusive or derived, for the chemical composition of buried bone changes in course of time. The analytical methods of dating bones (Oakley, 1953, 1963, 1963a), including fluorine analysis, nitrogen analysis and radiometric assay, are mainly used for R.1 dating which is particularly important in connection with any doubtfully fossil human bones, because of man's long established habit of burying the dead.

It was this R.1 dating which was in doubt in all the discoveries of remains of *Homo sapiens* whose antiquity was controversial, as for instance in the cases of Moulin-Quignon, Calaveras, Galley Hill and Oldoway, which may be worthwhile summarizing briefly at this point.* The *Moulin-Quignon* jaw, found a century ago in the Somme terrace gravels, which contain Chellean hand-axes, was eventually shown by the 'gelatine' (= nitrogen) test to be not older than Neolithic, probably a fraudulent intrusion – really a predecessor of Piltdown.

The *Calaveras* skull, allegedly unearthed from a Pliocene bone-bed, was shown by means of an early application of the fluorine test to be relatively modern – probably planted in the mine-shaft by a cowboy as a joke.

The *Galley Hill* skeleton was found in 1888 in the Swanscombe terrace gravels containing Acheulian hand-axes. For some time it was regarded by Keith and others as an indication that *Homo sapiens* already existed in 'modern form' by Middle Pleistocene times. In 1948 Oakley and Montagu showed that comparison of its fluorine content with that of the fossil mammalia of the Swanscombe gravels indicated that it was an intrusive burial probably Post-Pleistocene and this was confirmed by radiocarbon dating of portions of the skeleton itself (Barker and Mackey, 1961, p. 41).

The '*Oldoway* human skeleton', discovered in 1913 by Professor H. Reck in what later became known as Olduvai Bed II, was for many years regarded by him as contemporaneous with the very ancient Bed II fauna. Later investigation (Boswell, 1932; Leakey *et al.*, 1933) showed that the skeleton

* All these controversial fossil *Homo sapiens* are discussed in detail by Oakley, 1964, and the revised dating of these and other remains is summarized in Table XVI at the end of this book.

was a burial, and mineral analysis of its matrix proved that the interment dated from a time after Beds III, IV and part of V had been eroded from the site, in fact from Epi-Palaeolithic times, the beginning of the Mesolithic Age.

However, in many discoveries of early human or pre-human remains there has been no reason to doubt their contemporaneity with the deposit in which they were found; for example the Swanscombe skull and the Olduvai fossil hominids found by the Leakeys. But in almost all cases the *stratigraphical* (including palaeontological) age or *archaeological* correlation has constituted a problem for discussion. The stage in the *local sequence* to which the deposit containing the fossil (or contemporaneous fauna or culture) is referable is called the *R.2 dating* of the specimen. The inferred position of that stage in terms of world, or at least *wider-scale* stratigraphy or culture sequence, may be called *R.3 dating*. The distinction between R.2 and R.3 dating may seem rather arbitrary, but the former is based on *fact* (*eg* item 2 opposite, associated industry: local Aurignacian), the latter on *inference* (*eg* item 2 below, stratigraphical stage: Mid–Würm in alpine sequence). There are of course some cases where R.2 dating and R.3 dating are synonymous. The eight examples of fossil man shown on the facing page serve to illustrate the distinction between the various orders of relative dating.

When a fossil bone or tooth (or indeed any fossil) is found in isolation unaccompanied by other organic remains serving to establish the R.2 or R.3 age, it can be sometimes dated by its form or morphology. This method of relative dating, which elsewhere (Oakley, 1953) I have termed *R.4 or morphological dating*, is reliable in some groups of fossils where the time-spans of the genera and species are relatively short and well known, but in other groups, particularly rare groups, it is very unreliable. It does not allow for unsuspected survivals. For example, before the discovery of a living coelacanth in 1938, any new fossil member of this group in rock of unknown age would have been dated. morphologically as 'unquestionably Cretaceous or earlier' whereas in fact, as we now know, it might be Tertiary or even Quaternary. Morphological dating of fossil Primates (the group which includes man) has also proved unreliable, but it will no doubt become less so with the increase of our knowledge

Names of Finds	*R.1* *age related to deposit**	*R.2* *stage in local archaeological or strati-graphical sequence*	*R.3* *position of stage in wider stratigraphy or archaeology*
1. 'Oldoway' skeleton (*Homo sapiens sapiens*)	In Olduvai Bed II *i*	Post basal Bed V (= Upper Capsian)	Early Meso-lithic Kenya
2. Cro-Magnon skeletons (*H. sapiens sapiens*)	*a c*	Aurignacian	Mid Würm
3. Spy skeletons (*H. neanderthalensis*)	*c*	'Cold' Mous-terian	Early Würm
4. Weimar–Ehringsdorf skeletons (*H. neanderthalensis*)	*c*	'Warm' Mous-terian	Riss–Würm (Eemian)
5. Swanscombe skull (*Homo of steinheimensis*)	*c*	Middle Gravel Acheulian	Mindel–Riss (Hoxnian)
6. Choukoutien Loc. I skulls (*Pithecanthropus pekinensis*)	*c*	Choukou-tienian	Mindel-Riss (Holsteinian)
7. Heidelberg jaw *Euranthropus* (*Homo heidelbergensis*)	*c*	Mauer Sands	Günz–Mindel
8. *Zinjanthropus* (*Paranthropus boisei*)	*c*	Olduvai Bed I (Oldowan 'floor')	Upper Villa-franchian

* Three R.1 categories are represented:

c – contemporaneous with deposit.

a c – approximately contemporaneous, *eg* Upper Palaeolithic interment in an Upper Palaeolithic deposit.

i – intrusive burial of appreciably later date than the deposit.

of the group. Few human palaeontologists would seriously question the correctness of inferring that the Neanderthal and Gibraltar skulls were of Upper Pleistocene age in view of their detailed similarity to the well-dated skulls of Spy, Le Moustier and elsewhere in Europe.

Morphological evidence is usually taken into consideration with other evidence bearing on the antiquity of fossil human remains of doubtful antiquity. Thus if a human skull is found in any early Pleistocene deposit and fails to pass any of the analytical tests for antiquity, the fact of its being indistinguishable from *Homo sapiens* would be regarded by most anthropologists as in keeping with the results of the tests; whereas if a skull found in similar circumstances were morphologically 'archaic', negative evidence of antiquity would be less convincing.

Establishing the R.2 and probable R.3 ages of human remains depends on the application of the usual methods of stratigraphical geology and archaeology: that is to say observing the stratification of the site where the remains have been found, noting any associated fauna, plant remains and artifacts, and comparing these with the contents of underlying and overlying deposits; and eventually comparing the sequence with that at other sites farther afield. The modern excavator pays particular attention to collecting shells and charcoal from the deposits under investigation, because these are likely not only to provide evidence of the climate prevailing when a deposit was being formed, but if found in sufficient quantities these materials can be chronometrically dated within limits by the radiocarbon method. The excavator also usually preserves samples of the deposits for mineral analysis (see above, p. 3) and pollen-grain analysis,* techniques which provide valuable evidence for relative dating of human remains at some sites.

In many parts of the world the sequence of land faunas through Tertiary and Quaternary times has been worked out in some detail, so that if a large assemblage of contemporaneous mammalian remains is found in association with a fossil human skeleton, or part of a skeleton, its stratigraphical age (R.2 or

* Pollen-grain analysis of matrices of the medullary cavities of one of the limb-bones of Tilbury Man showed in 1963 that this historic burial was not older than the Early Bronze Age; previously it had been regarded as possibly Mesolithic.

R.3 dating) is fairly easily determined within certain limits. Assemblages of molluscan shells sometimes provide valuable indications of the age of lake beds, river beds and aeolian or other terrestrial deposits. Land and freshwater molluscs are fairly sensitive climatic indicators, and therefore may show whether a deposit is periglacial, interglacial, interstadial or Post-Glacial, while many of the species have restricted time-ranges (either locally or universally).

In discussing the relative dating of fossil human remains in any detail, it is necessary to be familiar with current terms and methods of classifying and correlating Quaternary deposits. These matters form the subject of Part I of this book.

The *Absolute* or Chronometric dating of early human remains or other fossil bones provides the ultimate framework of hominid evolution, but it is important to recognize at the outset the differences between the various orders of absolute dating, which may be classified as follows:

A.1 dating: direct determination of the age of the specimen itself from internal evidence; for example by measuring the carbon-14 radioactivity of a sample of bone, as was done in the case of the Galley Hill skeleton, and in the case of the human skeleton found in one of the Dalkey Island shell-beds (Mesolithic), Northern Ireland (Barker and Mackey, 1961, p. 43).

A.2 dating: direct determination of the age of the source deposit; for example potassium/aragon (K/Ar) measurements of volcanic minerals in the beds which contained the Olduvai hominids (Leakey, Evernden and Curtis, 1961).

A.3 dating: the age of a specimen in years inferred by correlation of the source bed with a deposit whose actual age has been determined. Thus the original *Pithecanthropus I* remains from river gravel at Trinil, Java, can be dated as c 500,000 years old on the basis of the K/Ar age of leucite in volcanic rock found elsewhere in Java but containing Trinil fauna (von Koenigswald, 1968).

A.4 dating: the age in years inferred from some theoretical consideration; for example, dates obtained by expressing the local geological sequence in terms of climatic fluctuations, and matching these with the curve of past insolation as calculated by Milankovitch (the 'Absolute Chronology' of Zeuner). Thus, the Keilor skull in Australia was at one time dated as 150,000 years old on the basis of the Milankovitch age of the Main Monastirian beach with which the Keilor river-deposit was correlated (Zeuner, 1944). Later A.3 dating, based on radiocarbon measurements, indicate that it is probably less than 15,000 years old.

A more promising form of A.4 dating recently introduced is the matching of climatic fluctuations in the Pleistocene sequences on land with marine palaeotemperature changes recorded in ocean bed cores, and dating key layers of sediment in these cores by analysis of their content of uranium daughter elements.

It will be obvious that the validity of the A.2, A.3 or A.4 dating of a fossil is conditional on the contemporaneity of the specimen with the containing deposit (*ie* the R.1 dating) being assured. Recent studies have emphasized that attempts at chronometric dating (excluding the A.1 type) are often a waste of time unless the R.1 dating has been established beyond doubt.

The framework of relative chronology for Pleistocene deposits in Europe, Asia and Africa has become more dependable in recent years as a result of key points being dated chronometrically (*cf* Charts B–D). Already by 1957 (Gross, 1958) more than 120 samples of Upper Pleistocene deposits in Europe had been dated by the Carbon-14 method (limited to the last 70,000 years). Since 1958 the potassium/argon method of chronometric dating has been applied to numerous Lower and Middle Pleistocene volcanic deposits in Africa, Asia, Europe and America (Evernden and Curtis, 1965). Thus in future, so long as their relative ages (R.1, R.2 and R.3) are well established, the majority of fossil human remains will be quite reliably dated in years by the A.3 procedure, and in many cases even more closely by the A.2 procedure.

A remarkable number of chronometric methods have become available during the last few years (see Harland, 1964). With increased reliability and widened applicability of these methods, the time will come when most major stratigraphic boundaries will be defined in years. In the field of Upper Palaeolithic cultures, the relative dating of some industries remained uncertain until they had been dated absolutely by means of radiocarbon.

In spite of several attempts to subdivide the Pleistocene on a palaeontological basis, the glaciations have been regarded by most geologists as providing the ultimate basis of subdivision. As researches extended farther afield, particularly beyond the glaciated areas into subtropical and tropical realms the need for other means of classifying and correlating deposits of this period became more apparent. The recognition that pluvials took the place of glacials in many of these regions has not altogether helped correlation because of uncertainty as to the extent to which these climatic phases are synchronous.

The sequence of flora has served well enough for correlations within Europe, but in the deposits of Asia and Africa the botanical evidence discovered so far reflects climatic conditions usually without providing any direct means of relative dating. Fossil mammalia have supplied some important clues for the inter-continental correlation of deposits, but the magnitude of the time-lags involved in animal migrations on that scale is still largely unknown, and there are several cases on record of mammalian genera restricted to the Lower Pleistocene in one continent but surviving throughout the Middle Pleistocene in another.

Fortunately there is a further class of evidence available for determining the relative ages of Quaternary deposits which has some advantage over the palaeontological: namely *archaeological evidence*. The method of dating based on the spread of early human cultures is really an extension of palaeontological dating, for early industries (assemblages of artifacts) may be regarded as fossilized patterns of behaviour which changed ('evolved') at varying rates and which were acquired and transmitted by tradition. There are a number of reasons for inferring that the time-lag in the spread of palaeolithic traditions was small in relation to the measurable subdivisions of Pleistocene chronology.

At the present time, in almost all parts of the world, cultures of many kinds and varying levels of complexity occur within short distances of one another, but before the Neolithic stage this was not so. The cultures of the early hunters and food-gatherers evolved slowly and their traditions spread widely long before there was any marked change. Where a palaeolithic culture can be defined and identified on the basis of sufficiently large assemblages of artifacts, it is legitimate to regard its 'industries' as approximately contemporaneous throughout their area of distribution. Until recently this view was based wholly on theory, but radiocarbon dating of early archaeological horizons in Africa at least supports the conclusion that in pre-Neolithic times cultural evolution was proceeding contemporaneously over very large areas. To that extent palaeolithic industries may be used as means of approximate synchronic dating of Pleistocene deposits.

One of the advantages of archaeological dating of deposits as compared with the palaeontological is that a high percentage of the known early industries are in quartzite, flint or other almost indestructible stone, whereas in many regions plant and animal remains have only been preserved under exceptional conditions. In Africa, for example, the number of exposures of Pleistocene deposits in which palaeolithic artifacts can be found vastly outnumbers those containing fossils.

Where fossil human remains occur, associated artifacts are of course invaluable as dating evidence. The Rhodesian Skull found in the Broken Hill Bone Cave could 'not even be placed in one of the three major divisions of the Pleistocene' (Zeuner, 1946, p. 296) until its archaeological associations had been fully investigated (Clark, 1950).

As the cultures which provide the archaeological frameworks used in dating fossil men – in the sense of Pleistocene and Early Holocene hominids – are almost exclusively those of the Palaeolithic and Mesolithic stages of Old World Prehistory, these are the ones surveyed in detail in Part II of this book.

Part One

Stratigraphical Dating

Chapter 1

Relative Chronology of Quaternary Deposits

RELATIVE CHRONOLOGY IS closely linked with stratigraphy, the branch of geology concerned with the superposition of deposits or strata.[1]* In studying stratigraphy, the order of superposition is first observed, then the sequence is subdivided into natural groups of beds. The order of appearance of new organic forms – fossils – is noted and, in the case of Quaternary stratigraphy, the appearance of new types of artifacts. Finally, having established the order of organic or cultural succession, the sequence can be used as a guide to the relative ages of newly encountered formations.

It has seldom been possible to observe superposition on any considerable scale in Quaternary deposits and the sequence has had to be established and subdivided largely without such aid. Successive glacial moraines, raised beaches and river terraces, for instance, are quite different phenomena which do not necessarily occur in the same areas. Only on the floor of the oceans, and there only in some places, has there been a continuous sedimentary record of the whole of this period, although deposits accumulated on lake-beds and in caves at some localities represent fairly extensive sequences. The ideal stratigraphical column of the Quaternary has for the most part to be pieced together by correlating deposits and events of very diverse kinds.

We should recall at this point the view of some geologists that the conception of a Quaternary era is illogical, that the Pleistocene period should be regarded as a continuation of

*There are notes at the end of each part.

the Tertiary, and that there is no justification for separating so-called Post-Glacial time as Recent or Holocene since it is possible that we are living in an interglacial. However, it is convenient and probably less confusing to follow accustomed usage:

$$\text{Post-Pliocene} = \text{Quaternary} \begin{cases} \text{Holocene} = \text{Post-Glacial or Recent} \\ \text{Pleistocene or Great Ice Age}^{2} \end{cases}$$

The Pleistocene period has been defined on a palaeontological basis: by the proportion of extinct to living mollusca in its marine faunas, and by the presence of *Elephas*, *Equus* and *Bos* in its land fauna. It has also been defined on the basis of certain changes of sea-level. Nevertheless, the most outstanding fact about the period is its broad coincidence with the Great Ice Age. Consequently the successive glaciations have provided the most obvious means of subdividing the period, particularly in the higher latitudes.

Chapter 2

The Glacial Chronology

THE FOUR MAIN advances of glaciers in the Alps recognized by Penck and Brückner (1909), have been widely adopted as providing a convenient subdivision of the period, at any rate as far as Europe is concerned. In discussions during the Second Congress of the International Quaternary Organization (INQUA) at Leningrad in 1932 it was agreed to group these glacial subdivisions in terms of Lower, Middle and Upper Pleistocene as follows:

Würm Glaciation Riss-Würm Interglacial	Upper Pleistocene
Riss Glaciation Mindel-Riss Interglacial	Middle Pleistocene
Mindel Glaciation Günz-Mindel Interglacial Günz Glaciation	Lower Pleistocene

This scheme has become widely used in Europe,[3] but it does not fall into line with the classification used by vertebrate palaeontologists, which is based mainly on the succession of elephants. For example, *Elephas* (*Palaeoloxodon*) *antiquus*, regarded as typical of the Middle Pleistocene, had emerged and was spreading widely before the time of the Mindel glaciation. Following the decision of the International Geological Congress in 1948 to include the Villafranchian in the Pleistocene[4], a new classification of the Alpine stages was proposed in 1958 by the geologist Paul Woldstedt (1958, p.3). Later (1962) he modified the scheme by transferring back the Riss stage to the Middle Pleistocene, and as follows it finds wide acceptance:

Würm Riss-Würm	Upper Pleistocene
Riss Mindel-Riss Mindel Günz-Mindel	Middle Pleistocene
Günz and Pre-Günz (Donau) stages	Lower Pleistocene (Villafranchian)

Karl Adam (1964) introduced a further change which recognizes the need to distinguish the Villafranchian or *Basal Pleistocene* from the overtly *Glacial Pleistocene* (= *Diluvium* in Germany), which for him began with Günz. Alternative classifications which extend the Lower at the expense of the Middle Pleistocene are also in use (*eg* Howell, 1967). The position of the earliest Villafranchian has become *sub judice* (p.45, p. 100 note 66).

Glacial stages can be recognized far beyond the limits of the moraines and tills or boulder clays laid down by the glaciers and ice-sheets, for a region of glaciation is surrounded by a zone, sometimes several hundred miles wide, which is affected by intense frost and associated phenomena. This 'periglacial' area usually includes three main types of environment: *tundra*, with peat mosses and shrubs such as dwarf birch and dwarf willow; *taiga*,[5] with stunted forest, mainly coniferous; and *steppe*, dry grassland on which *loess* is liable to accumulate, that is to say the deposit of rock dust carried by wind from exposed glacial moraines and outwash deposits. Under periglacial conditions the subsoil is more or less permanently frozen, when it is termed *tjaele*,[6] or *permafrost*. In spring time the top layer of the *tjaele* thaws and forms a sludge of disintegrated rock which tends to flow down sparsely vegetated slopes and to accumulate on lower ground, for example in valley bottoms. The unstratified tumultuous deposits known as *head*, in many parts of Britain, or as *coombe-rock* in the chalk valleys, were formed by this process of *solifluxion* during glacial stages. Solifluxion has frequently caused a characteristic disturbance of the upper layers of stratified river deposits and lake-beds (Fig. 1). Loesses and solifluxion layers are valuable indicators of glacial horizons in Pleistocene sequences outside the areas of glaciation.

In their classic researches Penck and Brückner based their four-fold scheme partly on moraines but to a much greater

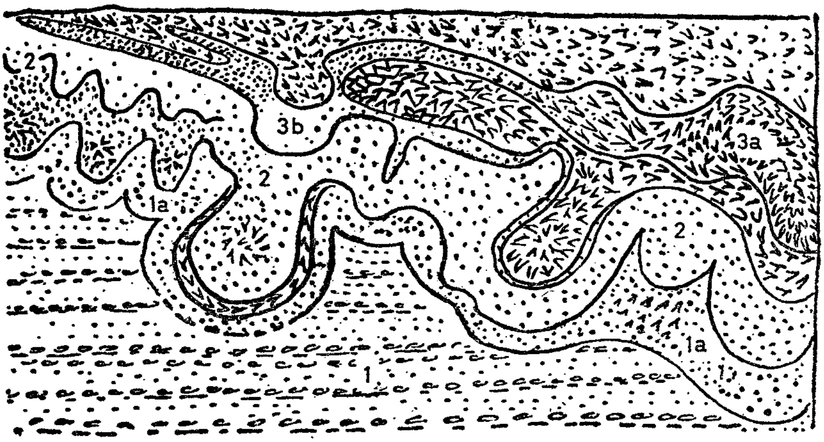


Figure 1 Section in 100-ft terrace gravels of the Thames, at East Burnham, Bucks, showing disturbance of the stratified gravelly sand by solifluxion and cryoturbation. *After Breuil.*

extent on fans and terraces of outwash gravel deposited by the rivers flowing from the glaciers which occupied the Bavarian valleys during Pleistocene times, as follows:

Low Terrace	representing the	Würm	Glaciation
High Terrace	,, ,,	Riss	,,
Younger Deckenschotter	,, ,,	Mindel	,,
Older Deckenschotter	,, ,,	Günz	,,

Subsequently, researches by Eberl (1930) showed[7] that the Low Terrace was composite and comprised deposits of three glacial phases. The second phase (Main Würm or Würm II), marked the peak of the glaciation. The readvancing glaciers extensively eroded the deposits of the much weaker Early Würm or Würm I advance, and converted them into hog-back hillocks of the type known as drumlins. The third phase (Würm III) is recorded by a belt of moraines which lie well within the limits of those of phase two. On the basis of terminal moraines, Penck and Brückner recognized a number of oscillations in the retreat of the Würm glaciers. The Laufen retreat (Fig. 12) in their classification has generally been identified with the main or Würm I/II interstadial of Eberl's classification.

Eberl confirmed earlier observations that the High Terrace was bipartite, and he found that the moraines which linked with the second phase of advance lay well within those of the first phase; that is to say Riss II was weaker than Riss I. He also found that the Younger Deckenschotter comprised two spreads of gravel but the second was much more distinct and linked up with the group of moraines representing the main Mindel Glaciation (= Mindel II). The Older Deckenschotter proved to comprise seven gravel-spreads, of which only the last two were identifiable with Penck's Günz-Deckenschotter. As all the older gravel-spreads showed the characteristics of glacial outwash, Eberl inferred that there had been five minor glacial advances before the Günz Glaciation and he named these the Donau (Danube) stages. Morainic deposits have been found below the till of Günz I, and there are deposits of weathered loess which can be correlated with the Donau stages.

The correlation between the Alpine glaciations with river terraces in Central Europe has been reappraised by H. Graul and K. Brunnacker (1962). Studies of the deposits of loess which overlie some of the glacial deposits and extend across the unglaciated Cental European plain almost to the shores of the Atlantic (Figs. 2 and 4), have provided useful confirmation of the subdivision of the glacial stages into stadia and *interstadia*[8]. The latter are represented in the loesses by zones of weathering or 'fossil soils'. Thus, when the geologist Soergel (1928) re-investigated the sections in the Mauer sand-pit he found that the Younger and Older Loesses, were subdivisible by levels of loamy weathering which represented mild intervals within the main glacial stages. In almost all areas where it is fully preserved the Younger Loess contains a well developed fossil soil horizon representing a major interstadial now presumed to correspond

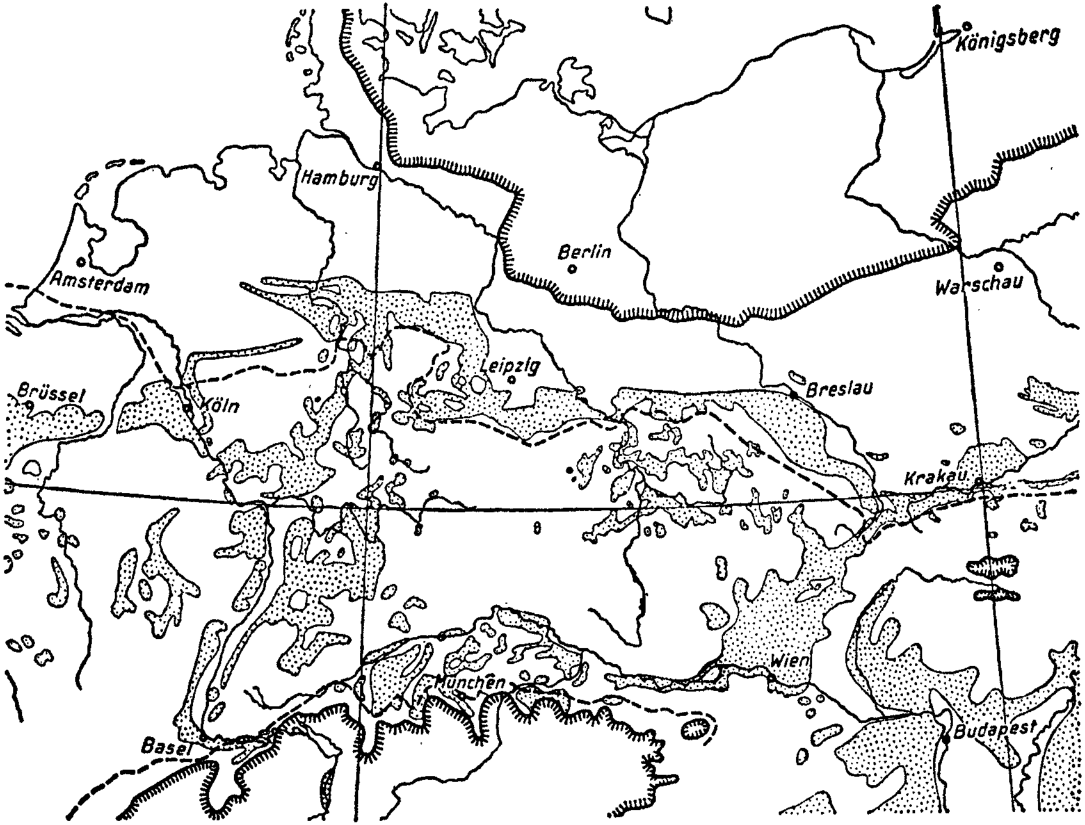


Figure 2 Distribution of loess on the European plain. *After Grahmann.*

with the Würm II/III interstadial in the Alps. In Austria two soil horizons have been recognized in the Younger Loess by Brandtner (1954), but only the Paudorf soil in the following sequence has been fully substantiated, and proves to have equivalents throughout central and north-western Europe.

Younger Loess III
Paudorf soil
Younger Loess I-II

In the Netherlands the Paudorf period is represented jointly by the Hengelo and Danekamp interstadials which have been closely dated by radiocarbon. Earlier and later Würm interstadials have been recognized on evidence from peaty deposits in this periglacial zone of the northwest littoral, and the subdivision of the Last Glaciation now in use is shown in Fig. 3. Radiocarbon dating has added precision to the use of interstadial horizons in the classification of Upper Pleistocene deposits in Europe and North America (de Vries, 1958; Woldstedt, 1960, van der Hammen *et al.*, 1967). The Brørup Interstadial, defined in Jutland (Trauber and de Vries, 1958), has sometimes been confused with the Göttweig[9], a temperate horizon in the Austrian sequence now recognized as antedating the onset of the Last Glaciation.

The Older Loess (= Riss) has in many regions been altered to a red clay to a considerable depth as a result of weathering under the warm climatic conditions of the Last Interglacial. In some areas the Older Loess also shows a thin buried zone of weathering corresponding to the Riss I/II interstadial. The Oldest Loesses (Donau, Günz and Mindel) are usually altered throughout their thickness, which is to be expected in view of their exposure to loamy weathering during two or three interglacials.

Loesses accumulated under intensely dry conditions which widely prevailed during glacial stages on account of the anticyclone associated with an ice-sheet; and in north-western Europe they generally contained a calcareous component. During warmer and moister interglacial periods, when the surface became more thickly vegetated, soil acids percolating downwards gradually converted the loess into loam. When the

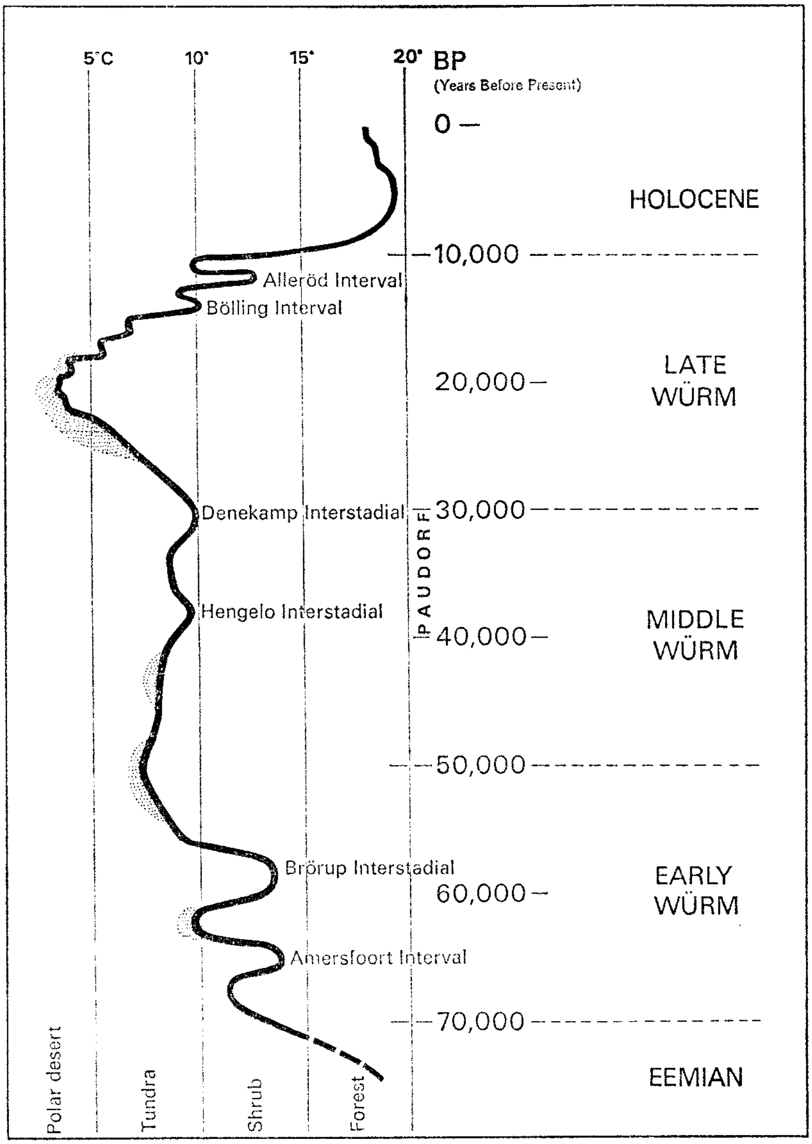


Figure 3 Undulations of the Last Glaciation in Europe (Würm=Weichselian) represented as a climatic curve, with main times of loess deposition (stippled), mean temperatures in July (Netherlands), stratigraphic subdivision and radiocarbon chronology. *Based on van der Hammen et. al., 1967, with addition following Woldstedt, 1960.*

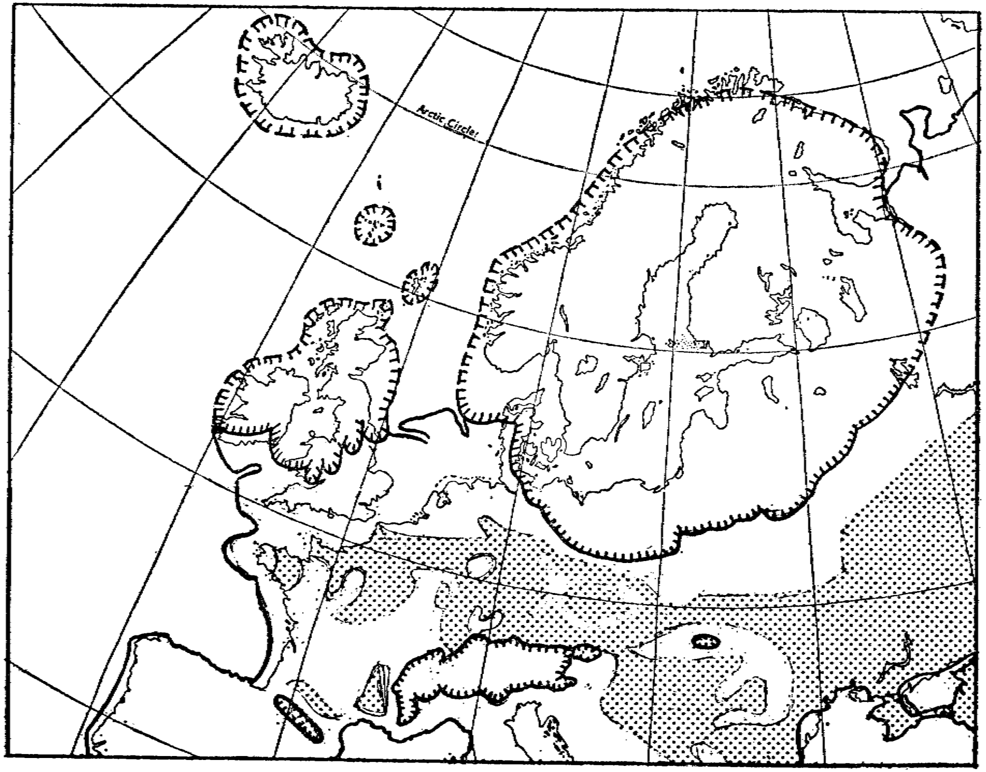
loess of one glacial stage overlies that of an earlier one, the junction between them is clearly marked by the zone of loamy weathering at the top of the older.

Largely on the basis of the amount of weathering and erosion which occurred between the formation of the Younger Deckenschotter and the High Terrace in the Bavarian valleys, Penck and Brückner considered that the Mindel-Riss or Second Interglacial was much longer than the other two, and consequently it became known as the Great Interglacial. In recent years, this view has been regarded as questionable (Flint, 1957, p. 385). Moreover, P. Beck (1937) discovered in some of the Swiss valleys evidence of two distinct glacial advances between the Deckenschotter and the High Terrace, leading him to infer that there had been two minor glaciations, which he named Kander and Glütsch, during the so-called Great Interglacial. These are now generally regarded as Pre-Rissian advances of the alpine glaciers.

The total areas covered by the drifts of the four main glaciations in the Alps indicate that the Riss advance was the most widespread, although the Mindel was equally extensive in some regions and less so in others. The Würm Glaciation was less extensive than either Riss or Mindel, and the Günz least of all. For reasons unknown, but possibly connected with the intensity of cold rather than the extent of the ice, the fauna of Europe suffered much greater changes in the course of the Würm Glaciation than during the two preceding ones. As we shall see, the extinction of Neanderthal man and his replacement by Modern man appears to have been closely linked with this ecological crisis.

Although the glacial advances and recessions in the foreland of the Alps have been used as the 'standard' for the glacial subdivisions of the Pleistocene, in fact the Scandinavian area of glaciation, which included Britain and Northern Germany, (Fig. 4) had a far greater influence on the unglaciated parts of Western Europe. As each advance of ice from the Scandinavian centre tended to destroy or at least considerably disturb the deposits of the preceding one, it has not been easy to establish beyond all doubt the number of separate ground-moraines in north Germany. In 1913 the geologist Gagel (1913), using weathering horizons as evidence of interglacials, concluded that

B



Loess Margins of land ice Margins of sea ice —— Ancient coast line

Figure 4 Distribution of ice in Europe at the maximum stage of the Last Glaciation.

there had been three major glaciations in that region, represented by two sheets of Older Drift (later called Elster and Saale) and the much less weathered Younger Drift which included the Baltic End Moraines. Further researches led to the subdivision of the main drifts and correlation with the Alpine stages as follows:[10]

	North Germany	*Alps*
Weichsel Drift	Baltic End Moraines	Minor readvances
	South Pomeranian Moraine	Würm III
	Frankfurt- Posen Moraine Brandenburg Moraines	Würm II
	Stettin Stadium[11]	Würm I
Warthe Drift[12]	.. ..	Riss II
Saale Drift	.. ..	Riss I
Elster Drift	.. ..	Mindel II

The period which has elapsed since the Scandinavian ice-sheet began its retreat from the Baltic End Moraines has been subdivided by the Swedish geologist de Geer as follows:

4 Post-Glacial (arbitrary, see Flint, 1957, p. 385.).
3 Finiglacial – stage during which Finland was freed from ice.
2 Gotiglacial – stage during which southern Sweden (Gotia) was freed from ice.
1 Daniglacial – stage during which Denmark (Dania) was uncovered.

These stages have been dated chronometrically mainly by varve-analysis (p. 77). See also Chart A.

The use of the Penck and Brückner terminology for Pleistocene deposits outside the Alpine region has proved difficult, and attempts to apply it throughout the world on the basis of inadequate evidence of correlation have probably actually hindered the progress of Pleistocene geology. Professor I. M. van der Vlerk (1955) has wisely recommended that, until glacial and interglacial deposits can be correlated over long distances more reliably than at present, it is better to establish the glacial/interglacial sequence in each region separately and to use local stage names (*cf.* R.2 dating) in preference to hypothetical alpine correlates (*cf.* R.3 dating). Professor F. E. Zeuner also urged caution and recommended that the Penck and Brückner terminology should be replaced as follows:

Würm – Last Glaciation (LGl.)
Riss-Würm – Last Interglacial (LIgl.)
Riss – Penultimate Glaciation (PGl.)
Mindel-Riss – Penultimate Interglacial (PIgl.)
Mindel – Antepenultimate Glaciation (ApGl.)
Günz-Mindel – Antepenultimate Interglacial (ApIgl.)
Günz – Early Glaciation (EGl.)

The view is sometimes held that Zeuner's terminology is less committal than that of Penck and Brückner, but both assume the correctness of deducing that there were four main glaciations during the Pleistocene period – and 'a rose by any other name. . . .'[13] To put the matter in another way, it is really no easier to establish that a deposit in some remote part of the world is of 'Antepenultimate Interglacial' age than to prove that it is of Günz-Mindel age. In this book local stage names have been used as far as possible in conjunction with provisional R.3 dating in whatever is judged to be the most appropriate general terminology.

Chapter 3

Interglacial Correlation and Palynology

THERE ARE FEW who would deny that the accumulated evidence from many areas indicates that the Pleistocene climatic fluctuations culminated in the higher latitudes with the formaation of continental ice-sheets on four occasions. On the other hand, cores from favourably situated localities on the ocean floors, providing a continuous record of past climatic fluctuations give a picture of very numerous and complicated temperature changes which can only be correlated with the latest phases of the known glacial sequence (Fig. 5; see also Wiseman, 1966). It is probable that on the land the glacial climaxes represented the summation of a complex succession of changes in the atmosphere and hydrosphere. The extent to which glaciers and ice-sheets advanced depended so much on local factors that whereas some areas bordering a centre of glaciation were overrun by ice-sheets during all four periods of glacial climax, other areas similarly situated were only glaciated during, say, one, two or three climaxes. In a number of regions, two advances or stadia of a single climax appeared as pronounced as two separate climax glaciations. In the latter circumstances, waterlaid deposits between two boulder-clays or tills would not be truly interglacial, but *interstadial*[8]. Indeed the 'Fourth and Fifth Interglacials' recognized by James Geikie (1877, p. 393)[14] were based on just such occurrences in Scotland. The deposits in question are now known to represent interstadials of the Last or Fourth Glaciation.

To a considerable extent the problem of Pleistocene correlation in the glaciated and periglacial regions depends on

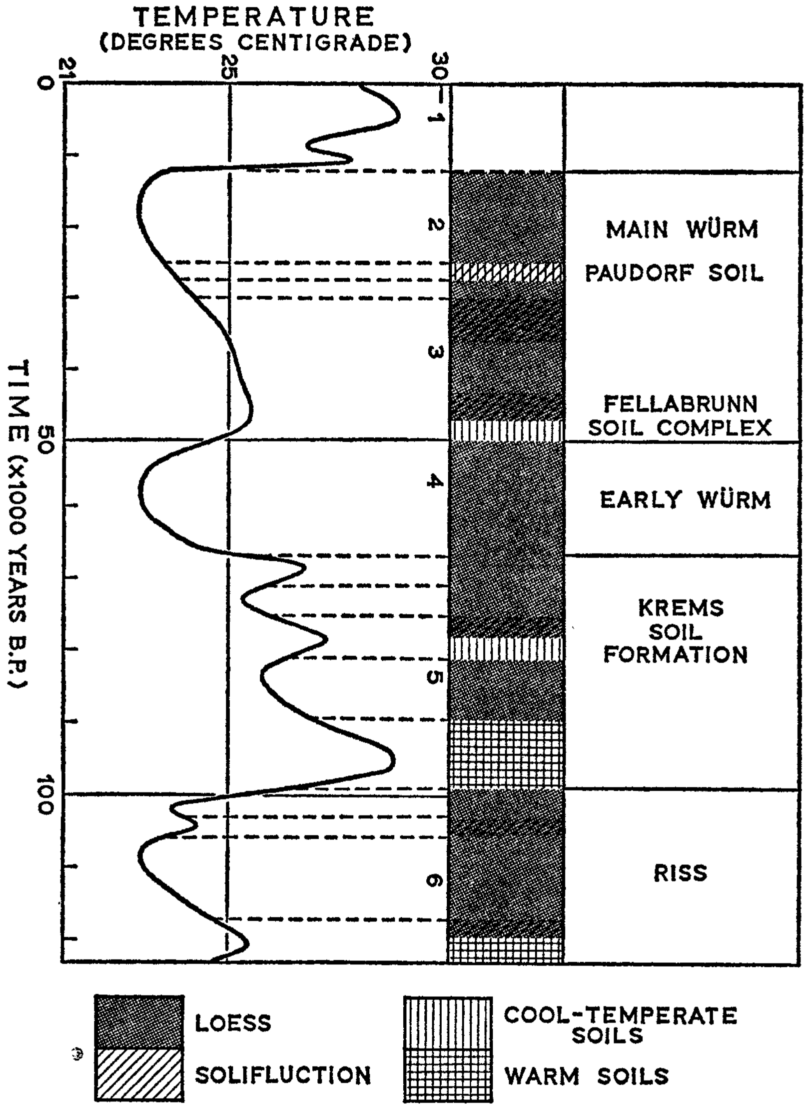


Figure 5 Correlation between palaeotemperature curve based on deep-sea cores, and loess/soil profiles in Austria and Moravia. *According to Emiliani.*