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PALAEOMAGNETIC CORRELATIONS OF PLEISTOCENE SEDIMENTS OF CENTRAL EUROPE

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INTRODUCTION

Within the scope of the UNESCO-IUGS IGCP project "Quaternary glaciations in the Northern Hemisphere" 73/1/24, the palaeomagnetic research in glacial and extraglacial areas of various regions of Europe was further developed. In order to obtain a palaeomagnetic base, continuous curves of magnetic declination and dip, characterizing continuously the detailed pattern and short-term variations of the Earth's magnetic field over the whole period of the Pleistocene and Upper Pliocene /the interval of the 2,300,000 years/ were constructed. Samples of continental sediments from Czechoslovakia /Bucha 1973, 1975/, Austria and the FRG /Kočí 1972, 1973, 1974/ and samples of marine sediments from Italy /Bucha 1975/ were investigated palaeomagnetically. Preliminary results obtained from the Italian samples, encompassing an interval of 550,000 to 2,300,000 years have shown that these types of rocks will be suitable for the investigation of a very detailed and practically continuous pattern of the variations of the geomagnetic field because they show expressive long sections with a positive or negative polarity, as well as shorter events which, as it seems, will prove very important for correlating the individual localities and determining their absolute age. To determine the continuous curves of the field for the said period appears to be the primary problem and the key condition to solving the problem as a whole.

EVALUATION OF THE CORRELATION METHODS USED

The present Quaternary systems are based essentially on facts obtained by three methods.

Lithostratigraphy - morphostratigraphy /sequences of various kinds of sediments or soils, usually related to the morphological development of the country - loess series, terraces, moraines, etc./.

This method still forms the basis of most systems.

Biostratigraphy /sequences of various faunas, particularly vertebral, possibly molluscan, and of flora/.

Geophysical methods /palaeomagnetism, radiocarbon method/.

Each of these methods works now with a certain system of facts which have so far been correlated only approximately, in many cases non-uniformly. This should be taken into account and one should proceed very carefully. The only reliable criteria are direct superposition, characteristic faunae or florae and palaeomagnetic or geochronological sequences from fully developed and quietly sedimented series. Various terms such as Würm, Günz Elster, Cromer, etc., are frequently given different meanings in various countries.

In general, the following holds true: Whereas profiles, reflecting well-developed younger sections are available, the continuity of the earlier periods is not clear yet. The controversial interval falls within the period of the Elster glaciation in North European chronology in a wider sense, in the Alps into the time-span between Mindel and Riss. However, what is lacking is the absolute determination of the ages of the individual intervals. Neither is this controversial period documented biostratigraphically, because no sequence is known which would be indicative in greater detail of the transition from the Biharium ["Cromer"] to modern faunae. There is practically no evidence of this period in karst cavities.

BIOTRATIGRAPHY OF THE MOLLUSCAN FAUNA

We can distinguish now three large sequential waves of molluscan fauna, characterized by a certain composition of the species.

The youngest wave, which may be denoted as modern, represents an alternation of cold associations of loesses of a similar nature as in the youngest loess, and of warm faunae, which display a composition similar to the fauna of recent times. These faunae are characteristic of the youngest cycles.

The middle wave includes associations which have preserved roughly their recent nature in the warm periods, however, comprise a series of extinct species /*Helicigona chapeki* /Pbk/. *Zonitoides sepultus* /Lzk/, *Acropis klemmi* /Schl. Lzk/. *Acicula diluviana* Hocker, etc./.

A classical example of these is the interglacial fauna from Stránská Skála near Brno and a series of cave discoveries /Zlatý Kun/.

The oldest, hitherto little known but very expressive wave is represented by the faunae with *Gastrocopta serotina* /Lzk/ and a whole series of other species, which are no longer identical with present species, from which they differ in various features. Neither is the ecological evaluation of these faunae always easy. A classical example are the faunae from the localities at Ctíněves-Hýkovina and the fauna of the Krems soil complex /Kr 7-8/ and lower.

N.B.:— The middle wave is identical with Kretzoi's Biharium which also includes the classical "Cromer" in Eastern England, the oldest wave is apparently Villeian or young Villafranchian /i.e. undoubtedly "pre-Cromer"/.

With a view to the marked changes of the geomagnetic field in the past and to the relatively accurate timing of the fundamental reversals by potassium-argon and palaeomagnetic age determination of the igneous rocks used on Cox's scale, the palaeomagnetic method is capable of determining the absolute age even of sedimentary formations. The dating may be carried out even in greater detail and more accurately than merely by reversals, if the palaeomagnetic base for the declination and dip curves has been investigated; this is carried out by comparing the curves at the locality investigated with the fundamental curves.

This, of course, requires that the variations of the geomagnetic field have first been investigated continuously over the whole period for which the geological correlations are to be carried out. The investigated sedimentary formations should be palaeomagnetically surveyed in greatest detail to obtain sufficiently long and accurate sequences of the D and I-variations of the geomagnetic field. Shorter-termed variations of the geomagnetic field were found to be more abundant than indicated by the data of Cox's scale. Therefore, only a few or one palaeomagnetic value is insufficient to determine the age of a locality, but whole D and I profiles with sampling steps of at least 10-20 cm must be available for comparison.

Another requirement is that highly sensitive magnetometers and reliable demagnetization equipment be used, because it was found that the unstable viscous magnetization, which must be eliminated from the samples, frequently represents more than 50 % of the overall magnetization. It was, therefore, possible that in the past quite distorted results were obtained, or only positive values even for periods with negative polarities, if the instruments used were not accurate enough. This also generated certain doubts about the method used. If detailed correlations are to be carried out, considerable attention should be devoted to investigating formations younger than 700,000 years, when the dip was essentially positive and when one may use different characteristics in the values of the positive inclination for purposes of dating. The declination also changed distinctly over this period, however, in cases where the values of the dip exceed 75° , the declination can only be determined with minor accuracy.

As regards the use of this method, it was found that correlations could be determined quite unequivocally if the profiles were sufficiently long and all the criteria adhered to. If the palaeomagnetic data are only known for shorter intervals of loess and soil sediments the results should be considered as tentative, because several alternatives of their dating may occur, as we shall see later.

PALAEOMAGNETIC SCALE OF THE PRINCIPAL REVERSALS DETERMINED BY POTASSIUM-ARGON AND PALAEOMAGNETIC STUDIES OF IGNEOUS ROCKS

The interval of the last 4.5 million years, investigated by Cox, Doell and Dalrymple, was at first divided into two intervals with a positive polarity [Brunhes 0 - 0.69 m.y., and Gauss 2.43 - 3.32 m.y.] and into two intervals with a negative polarity [Matuyama 0.69 - 2.43 m.y. and Gilbert 3.32 - 4.55 m.y.]. The gradual acquisition of new time data for a more extensive material implied [Cox 1968, Watkins 1971] that the number of reversals was much higher. The latest scale of reversals shows that there are 13 sections with positive polarity and 13 sections with negative polarity. These results and, in particular, the determination of the potassium-argon of the individual sections are very important and represent a base which can be used to determine the other data more accurately. On the other hand, this scale only indicates positive or negative values of the dip from the magnetic point of view, it does not determine its variations in the course of the positive and negative intervals and does not yield the values of the magnetic declination. Provided its pattern were finite and no other events were to occur, it could be used to correlate data, provided the occurrence of intervals

with periods of positive and negative dip of different duration were known. However, it was found that the geomagnetic field was more complicated. At certain times it was subject to considerable fluctuations /and many more events occurred than hitherto known/, and at other times the field was comparatively quiet. It is, therefore, necessary, particularly if we want to use the palaeomagnetic methods for geological correlations of Pleistocene sediments, to be acquainted with the detailed pattern of the variations of the magnetic declination and dip.

PALAEOMAGNETIC CHARACTERISTICS OF THE GEOMAGNETIC FIELD IN THE PLEISTOCENE AND THE UPPER PLIOCENE DETERMINED BY INVESTIGATING THE FUNDAMENTAL PROFILES OF THE CONTINENTAL SEDIMENTS FROM THE CSSR AND OF THE MARINE SEDIMENTS FROM ITALY

As Fig. 1, showing the curves of the variations of the declination D and the dip I for a period of about 1 m.y. [Bucha 1975], obtained by investigating the continental sediments at Czechoslovakian localities implies, the geomagnetic field displayed some marked changes in the period of positive polarity in the Brunhes epoch. The intensity of these changes is much higher in the interval between 600,000 and 1,800,000 years as can be seen from the tentative results of the palaeomagnetic investigations of the marine sediments from Italy [Fig. 2]. On the other hand, in the period prior to 1,800,000 years ago the geomagnetic field displayed a relatively calm pattern and only a reversed polarity. This character of the field seems to be similar back to about 2,300,000 years ago. The localities in Italy will also be investigated along a parallel profile, so that the results given should be considered tentative. Nevertheless, the results obtained, expressed in the form of curves of the variation of the magnetic declination and dip, allow to draw the following conclusions:

a/ The curves characterizing the variations of the geomagnetic field over the interval of the last 1 m.y. were obtained by investigating extraglacial sediments palaeomagnetically along several profiles, i.e. Kutná Hora, Chabry /Würm/ Sedlec U Prahy /Riss/, Červený kopec /Mindel/, Unětice, Stránská Skála /Günz/, and including them in a single graph [Fig. 1]. It should be pointed out beforehand that the pattern of the variations of the geomagnetic field, obtained from the overall sequence of sedimentary formations 70 m and more thick, may display a number of hiatuses because we know that loess series with soil complexes sediment non-uniformly in time and in some intervals the sedimentation may not have taken place at all. The presented results have already been analyzed in detail [Bucha, 1973], as regards the fundamental characteristics, it should be said that the declination displays values close to the present values /around 0° / in the principal interglacial periods, particularly in the Riss-Würm and Mindel-Riss interglacial stages. On the other hand, in the glacial stages the declination displays relatively large deviations into negative values /around 270 to 200° / in the younger period. The dip values are mostly positive in Europe during the Brunhes epoch. A short negative deviation was discovered about 12,000 years ago, however, this has not been proved unequivocally yet. In other areas of the Earth's surface reverse negative dip values may have been observed as a result of the fluctu-

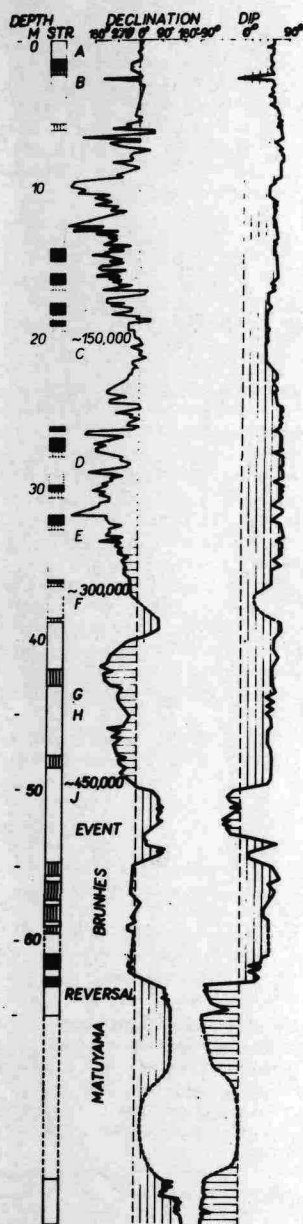


Fig. 1: Continuous changes in magnetic declination and dip as determined on Quaternary sediments from Czechoslovakia [according to Bucha (2)]. The values of D and I after a.c. cleaning in 200 and 300 Oe are given.

STIRONE

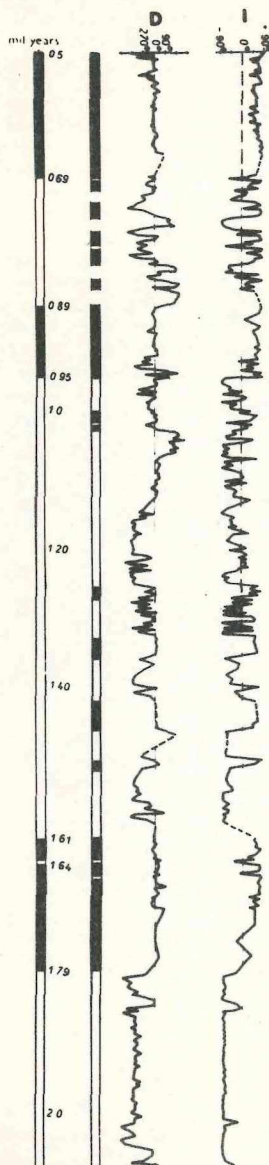


Fig. 2: Normal and reverse polarity intervals as determined in marine sediments along the river Stirone [preliminary results/. The profile was dated according to Cox's scale.

ation of the geomagnetic field and its poles, e.g., in America and Japan as indicated by the considerable deviations of the magnetic declination we have found. Otherwise the dip displays positive values again close to the present values, i.e. around 65° , in the interglacial periods, whereas in the Würm and Riss glacial stages the higher values are around 75° . For the older periods of Mindel and Günz lower values of I are displayed more markedly, and these were preceded by negative values [the Brunhes-Matuyama boundary and older]. For these older intervals the CS curves may no longer be considered as sufficient to express continuously the field owing to considerable hiatuses.

b) For this reason, within the scope of our project and as a result of the support of UNESCO it was decided to obtain such material for purposes of correlation, which would describe the geomagnetic field more continuously, in particular for the interval Mindel - lower boundary of the Pleistocene. As part of the co-operation with the Italian palaeontologists, Palosio, Iaccarino, Raffi, Rio from the Geological Institute of the University of Parma we were able to collect continuous profiles of marine samples in the basins of the Rivers Stirone, Crostolo and Vendina, which were also investigated palaeontologically. However, the upper boundary of the sediments was not known, but only the boundary between the Pliocene and Pleistocene, defined by the occurrence of *Arctica islandica*; the palaeomagnetic results obtained showed that, after correlation with Cox's palaeomagnetic scale, this continuous profile from Italy includes intervals between 550,000 and 2,300,000 years ago. The preliminary results, which will be supplemented and verified by measurements of other samples, yield a continuous pattern of the geomagnetic field [Fig. 2]. The younger interval, which is very important for correlating the sediments of Würm, Riss and Mindel age, no longer occurs at the localities in the neighbourhood of Parma. With a view to the positive results, yielded by the marine sediments, it should prove expedient to supplement these data also for the younger period by collecting samples from the basin of the river Santerno; this will enable us to obtain a detailed continuous profile for the whole Pleistocene and with its help solve a number of important problems.

As regards the results hitherto obtained with marine sediments from Italy [Fig. 2], it was found that the lower part of the Brunhes epoch [lower Mindel] displays positive values of I; the declination displayed a deviation into negative values in the uppermost interval investigated.

The period between the Brunhes-Matuyama boundary /690,000 years/ and the Jaramillo event /890,000 years/ is characterized by alternating negative and positive intervals, the dip displaying lower values in both polarities. The declination goes over into reverse values in the positive direction, i.e. over 90° . The Jaramillo event is displayed markedly positively with smaller fluctuations. For the even older period the dip is mostly negative, however, several positive events still occurred. The declination here is reversed rather in the negative values, i.e. between $180^\circ - 270^\circ - 300^\circ$. Since the absolute age of the principal events of Jaramillo and Gilsa [Olduvai] are known, one may date all intervals and events on our curves [Fig. 2]. The Gilsa event again displays very marked positive values, although on the whole the geomagnetic field displayed considerable fluctuations over the whole period between 690,000 and 1,790,000 years ago. However, the older periods are characterized, as can be seen in Fig. 2, by a relatively calm behaviour of the geomagnetic field in the declination, as well as in the dip.

As already mentioned, it will be necessary to carry out further research to obtain a comprehensive idea of the geomagnetic field in the Pleistocene. Nevertheless, the results achieved enable us to employ them for purposes of correlation.

CROSS-CORRELATION OF PLEISTOCENE SECTIONS AND THE DETERMINATION OF THEIR ABSOLUTE AGE

Let us summarize now some of the results and examples of palaeomagnetic correlations to support the validity of the correlation method, based on the curves of the magnetic declination and dip variations.

a/ Ostrava Region - sediments of the inland glaciations

Samples from the region of the northern glaciation were collected at the localities near Zábřeh nad Odrou, Dolní Lutyně, Slezská Ostrava and Bolatice. Stratigraphically the clay and varve sediments, from which the samples were collected, belong to the sediments of the Elster and Saale glaciation. The whole of the Ostrava region was investigated in detail and mapped on a scale of 1 : 25 000, the results have been summarized in a monography [Macoun, Šibrava, Tyráček, Knebllová-Vodičková, 1965/.

The locality near Zábřeh nad Odrou has preserved its stratigraphic sequence of the sediments from the Elster glaciation, represented by glacialacustrine sandy and clayey sediments. In the overlying rocks there are fluvial and sands gravels of the "Ostrava terrace" /pre-Riss/ of the River Odra, covered by Saalian and Weichselian aeolian sediments with fossile soils. A detailed profile is shown in the monography referred to [Macoun et al., 1965/.

In Dolní Lutyně the deposits of the Elster glaciation covered by fluvial and sands gravels from the late glacial phase, have been exposed. In the overlying rocks there is a complex system of layers of loess loams, separated by fossile soils, stratigraphically belonging to a younger temperature deviation of the Elster-Saale interglacial period and to individual Weichsel interstadials. The samples were taken from the clayey layers, stratigraphically placed into the period of the Elster glaciation.

In Slezská Ostrava glacialfluvial and morainic sediments of the Elster glaciation have been exposed. Two layers of dark grey faceted loams of the basic moraine of the Elster glaciation, separated by fossil soil of the pseudogley type, stratigraphically assigned to the warm interval between the first and second onset of the Elster glacier, have been proved.

In Bolatice sediments of the Saale glaciation, represented by glacialacustrine varved clays and glacialfluvial deposits, have been exposed. Stratigraphically these sediments are in the overburden of the so-called Main terr. the sedimentation of which immediately preceded the glaciation of the territory.

Several localities from the glacial region of Ostrava, represented by varves and clays, were investigated palaeomagnetically. Figure 3 shows the palaeomagnetic D and I curves for the locality of Bolatice. They imply that the magnetic declination in the upper part of the profile displays negative values between 340 and 360° and positive values between 0 and 25° in the lower section. However, the D-values do not

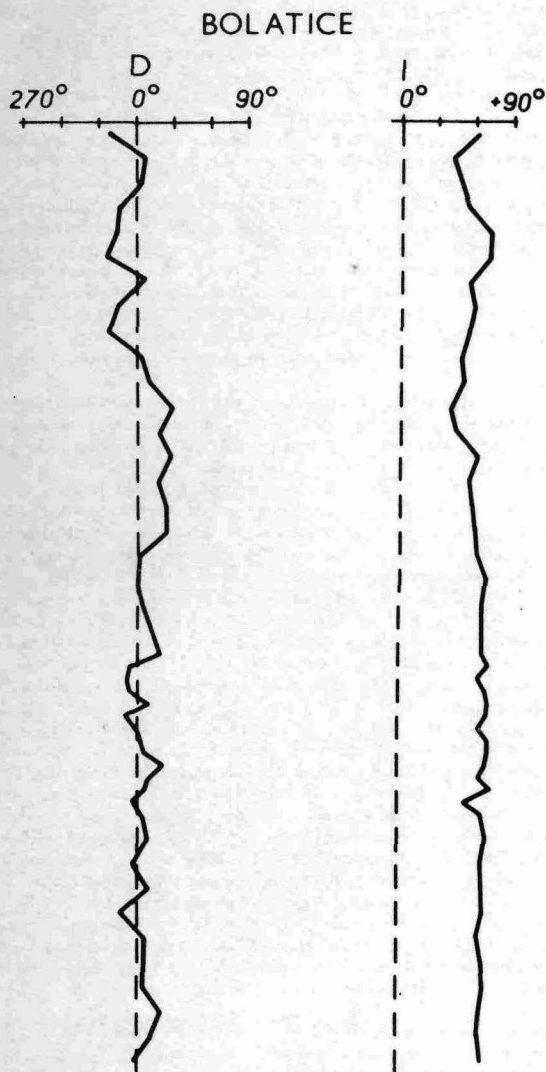


Fig. 3: Variations of the magnetic declination D and dip I at the locality Bolatice along the 2.5 m long profile sampled at steps of 10 cm.

mostly differ much from zero. The magnetic dip is completely positive, slightly lower [around 40°] than the dip in the upper part of the profile, whereas in the lower part it increases up to about 70° . Clearly, the varves were generated in the positive Brunhes epoch in the course of the terminating glacial [high values of I] and at the beginning of the interglacial. The comparison with the fundamental curve, obtained for this period so far only from continental sediments [Fig. 1], would most probably indicate a correlation with the terminating Saale glaciation, in which a similar character of the geomagnetic field appears on the fundamental curve from the extraglacial sediments. Another less probable alternative offers itself - the correlation between the M-R boundary, where the D-values are also close to zero, however, there is a hiatus on the fundamental curves here. The correlation within the Brunhes epoch is still difficult, because the dip was practically continuously positive and, in particular, because the fundamental curves do not describe this interval uniformly. It will be necessary to supplement them by other continuously collected profiles of marine sediments from Italy.

The Zábřeh locality [Fig. 4] displays highly anomalous values of D [around 200°] and low values of I [around 20°] in the upper part of the graph, whereas the middle and lower parts of the graph display weakly positive values of the declination and dip values in excess of 65° . Drawing on this, the locality could be of Upper Elster age.

The marked changes of the declination at the Ostrava locality [Fig. 5] and the low values of the dip seem to indicate that the locality falls within the Elster glaciation to Elster-Saale interglacial as a result of comparison with the fundamental curves.

The curves for the Dolní Lutyně locality [Fig. 6] show that the declination in the upper part of the profile was mostly negative and the dip markedly lower; in the lower part of the profile the declination was positive and the dip slightly higher than the present [higher than 65°]. It could again be assigned to the Elster-Saale interglacial.

The question remains open, of course, whether there was a hiatus just in the middle of the Elster glacial as indicated by sediments, used to construct the fundamental curves. It will, therefore, be necessary to check these results after curves from the marine sediments for the Brunhes epoch have been obtained, the more so because only the differences in the positive I -values can be employed here, and not the reversals which could have occurred here for very short periods of time at the most. This will be checked out in the next stage of research.

At this point we shall have to deal separately with the interval between 300 to 500 thousand years ago. The expressive M-R interglacial has been placed between 370 and 530 thousand years. The said interval may only be characterized palaeomagnetically by means of continuous marine profiles; it will then also be possible to decide which continental sediments fall within this period.

b/ Extraglacial area in Czechoslovakia

The palaeomagnetic investigations and the obtained fundamental curves allow us to carry out cross-correlations, in particular for localities older than the Brunhes-Matuyama boundary. This task has been simplified to a certain extent because the Earth's magnetic field displays negative values at certain periods and positive during others. Although frequent fluctuations of the field occurred, particularly between the Brunhes-Matuyama boundary and the Gilsa event, it is still possible to evaluate

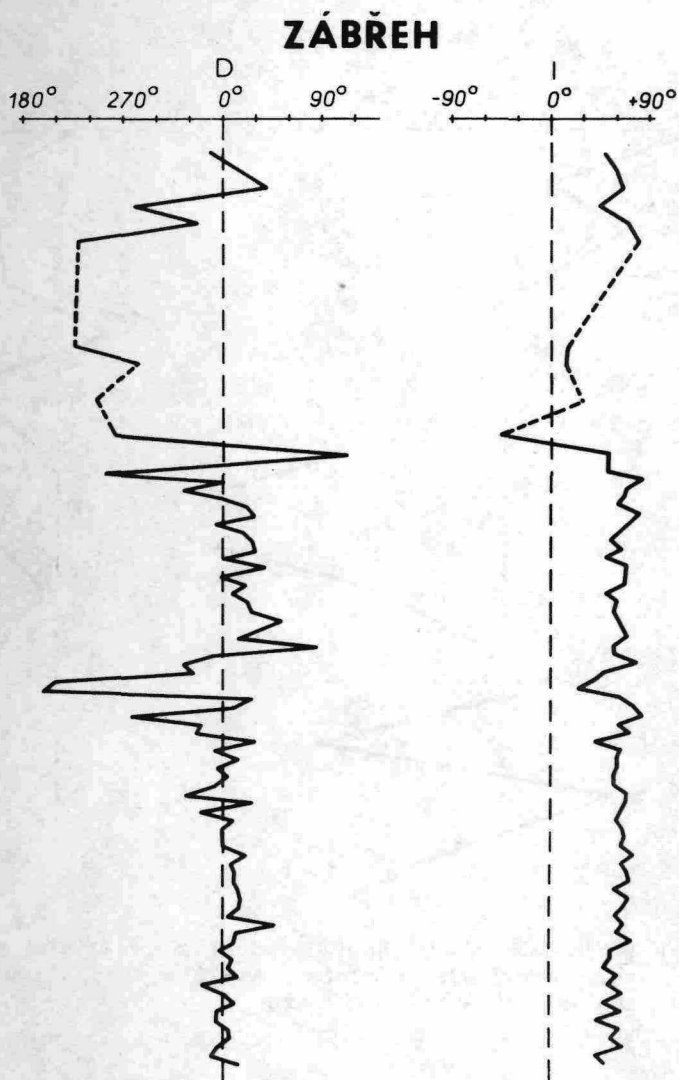


Fig. 4: Variations of the magnetic declination D and dip I at the locality Zábřeh along the 2.2 m long profile sampled at steps of 10cm.

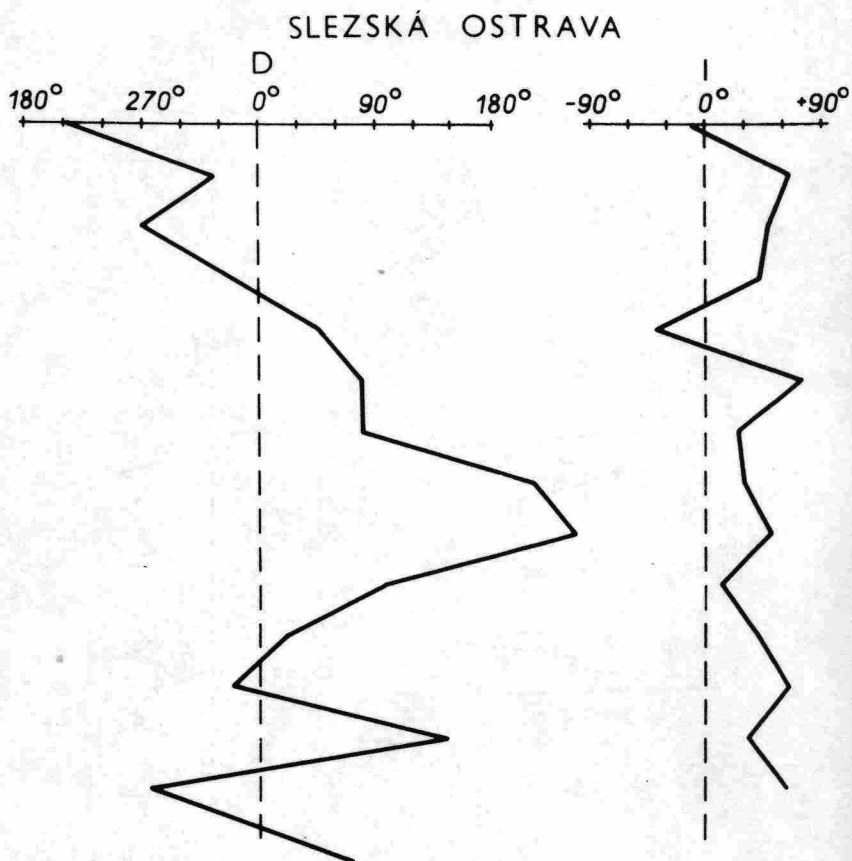


Fig. 5: Variations of the magnetic declination D and dip I at the locality Ostrava along the 2 m long profile sampled at steps of 10 cm.

DOLNÍ LUTYNĚ

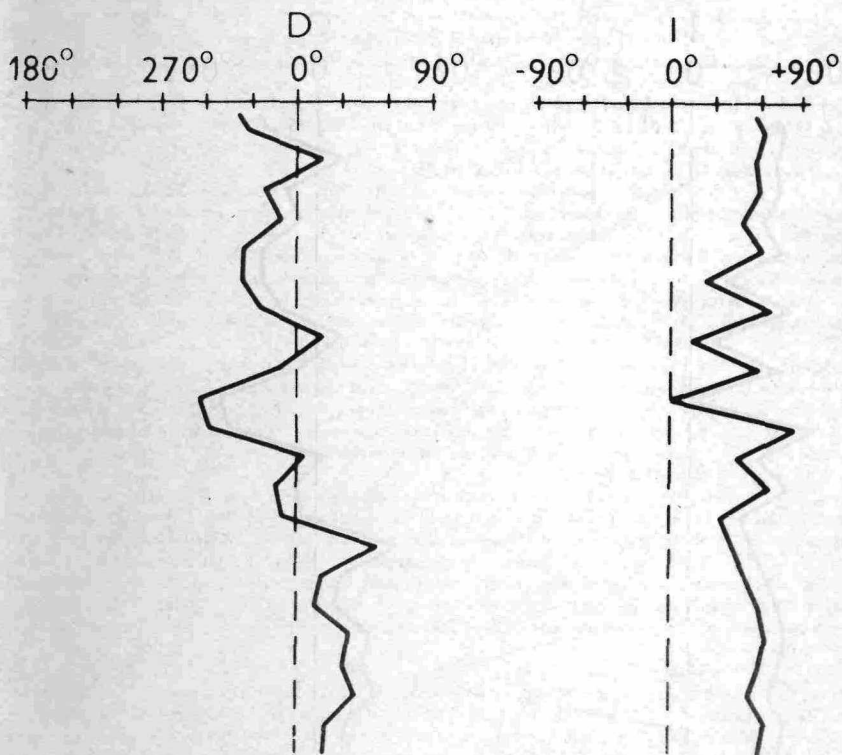


Fig. 6: Variations of the magnetic declination D and dip I at the locality Dolní Lutyně along the profile 1,2 m.

uniquely the intervals which were investigated palaeomagnetically for a sequence longer than 3-5 m.

Červený kopec

The loess series has two sections - a young at the bottom, corresponding to relatively completely developed upper up to middle Pleistocene and an old on the upper level, the relation of which to the younger cycles is not quite clear because both systems of layers are separated by erosive phases.

The fauna, found on the basis of soil PK X /originally, i.e. in Warsaw in 1961, PK VII/ belongs to the middle wave, however, it represents its younger section which is apparently younger than the faunae from the Stránská Skála or Krems 4.

Increased attention was devoted to the palaeomagnetism of the older section displaying positive I-values in the upper and lower parts, whereas low negative I-values were observed in the middle part. In order to verify the method, five parallel profiles /Fig. 7/ were palaeomagnetically investigated. All displayed a middle part with negative I-values and with positive D-values amounting to about 120° . The comparison with the fundamental scale, obtained from the Italian marine sediments in the Po valley /river Stirone/ allows us to correlate this middle part with the period between the B-M boundary and the Jaramillo event, i.e. between 690 and 890 thousand years. A less probable alternative still remains open to suggestion, in that no period with negative polarity occurred within the Brunhes epoch. This will have to be decided by a further investigation of marine sediments.

Stránská Skála

In the coarse colluvial deposits situated under the limestone rock there is a perfectly developed malacofauna of the Middle Biharian type - a typical representative of the middle wave of the molluscan fauna.

The palaeomagnetic investigation /Fig. 8/ determined reversed D and I-values, I attaining high negative values around 70° . This implies that the deposits in question sedimented either during some interval of reversed polarity below the B-M boundary or prior to the Jaramillo event.

Únětice

The system of layers, located concordantly /roughly parallel to the surface of the Suchdol terrace /90 m above the level of the river/, represents a quite complicated complex. The gravels are directly overlain by flood-plain loams, terminated by weathered decalcified soil, which corresponds to some warm period. The said niveau than moved outside the sphere of the activity of the flowing water, the river its way further into the terrain, and the water deposited sediments which correspond to a completely developed interglacial without substantiated hiatuses, onto the lower terrace which was created in this way. This system of layers, identical with strongly calciferous layers, includes roughly all phases of the warm period and its age amounts to about 20,000 years. The whole system of layers, including the basement loams and terraces, however, corresponds to at least 120,000 years. This is a rare locality, where the "Cromer" interglacial is represented by an exceptionally well-preserved and regularly deposited series of swamp layers.

Several palaeomagnetic investigations yielded the patterns of D and I-curves shown in Fig. 9. An attempt was made at correlating this locality with the Červený kopec locality /Fig. 7/, however, the marked negative dip along the Únětice profile rather indicates that the age of this locality is higher than the Jaramillo event. The comparison with the fundamental profile of the Italian marine sediments indicates that Únětice most probably includes the lower part of Jaramillo and older periods, i.e. between 940,000 and 1,100,000 years.

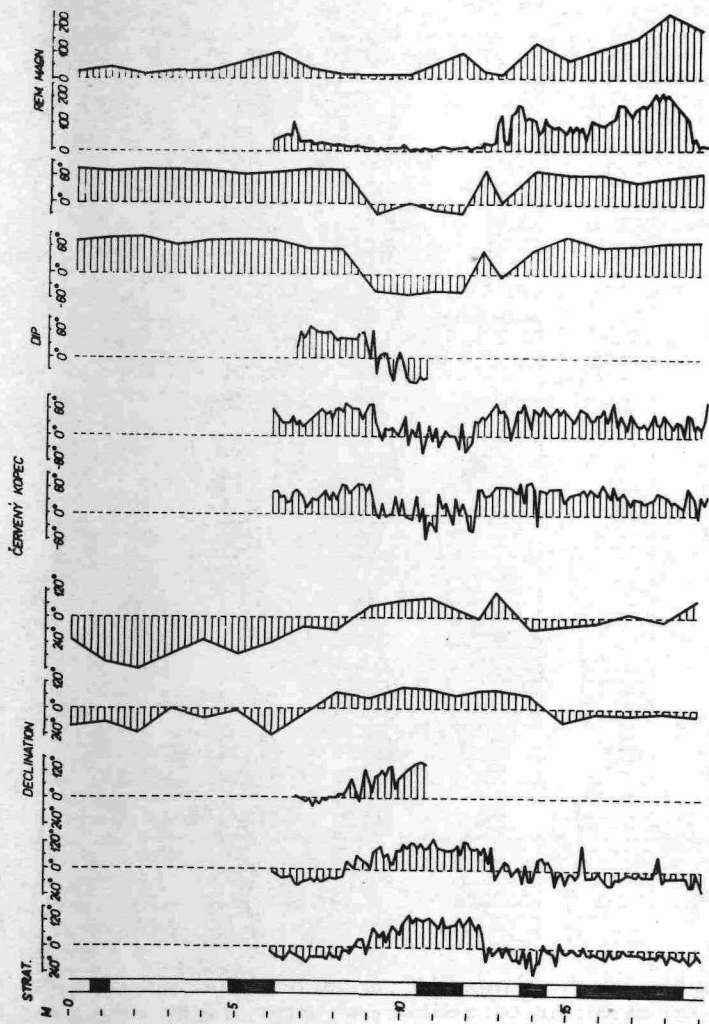


Fig. 7: Variations of the magnetic declination, dip and remanent magnetization at the locality of Červený kopec near Brno, and a comparison of the results using samples collected at five parallel profiles, 19 m long. The first three profiles were sampled at steps of 10 cm, profiles 4 and 5 at steps of 1 m. The results cover an interval of approximately 540,000 years. The sector between the 8th and 12th metre, characterized by declination values in the range from 80 to 150° and a negative, in some cases also very low dip, is markedly anomalous.

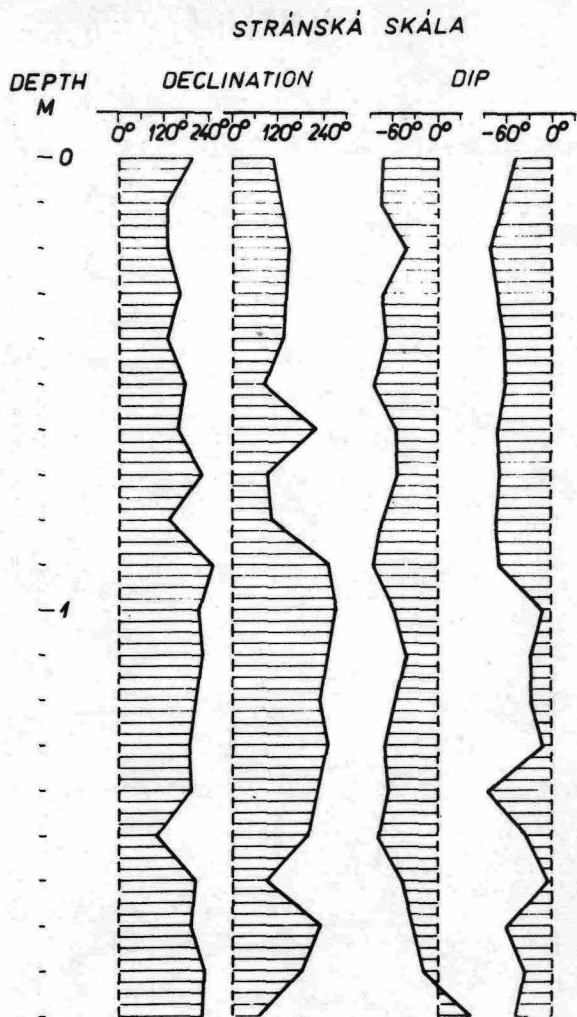


Fig. 8: Variations of the magnetic declination and dip at the locality of Stránská skála near Brno, older than 700,000 years. The samples of loess rocks were collected at intervals of 10 cm along two parallel profiles with an overall thickness of 2 m. As can be seen from the D and I values the magnetic field had an expressively reversed character.

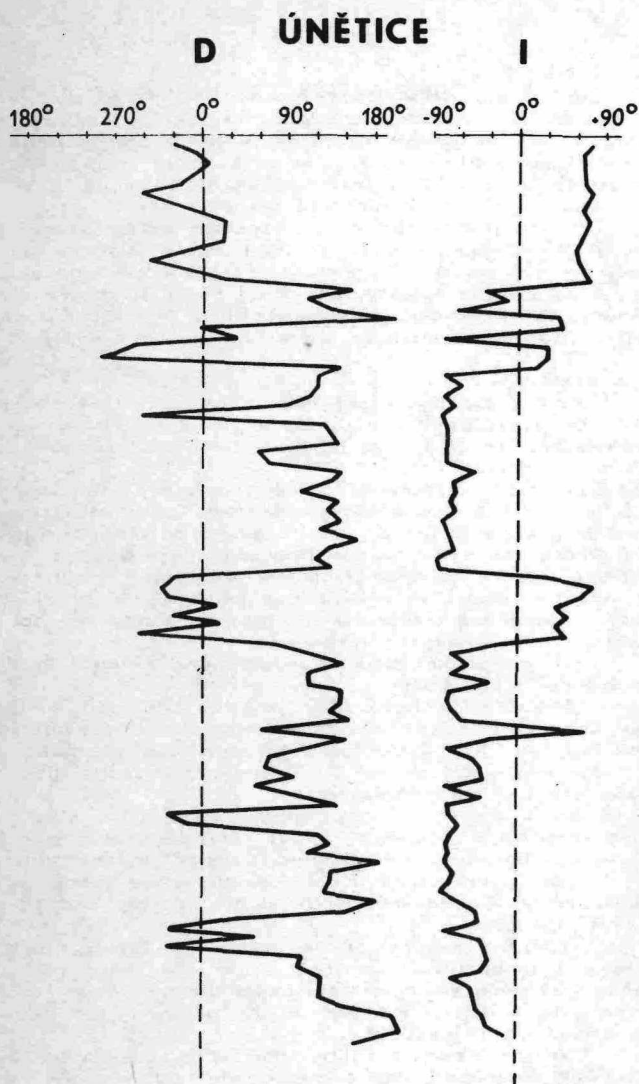


Fig. 9: Variations of the magnetic declination and dip at the locality Únětice. The samples were collected at steps of 5 cm along a profile 4.75 m long. The whole section correlated to the time interval between 940,000 and 1,100,000 years shows several transitions from negative polarity /negative dip/ to positive polarity.

Přezletice

In the lacustrine layers no marked changes of the fauna could be observed. The latter belongs either to the beginning or end of the warm period, or to the transition period to the glacial, and covers a relatively short period of time. A direct comparison, based on the molluscs, e.g., with Stránská Skála, was not possible, because the fauna belongs to a quite different climatic phase.

On the preliminary palaeomagnetic profile, shown in Fig. 10, the upper positive I-part is much younger, whereas the lower part, represented by the locustrine layers, probably corresponds to a section at the upper Jaramillo boundary, i.e. about 890,000 years. However, with a view to the short-termed sedimentation, Přezletice could also be correlated with some younger event between 750 and 890 thousand years.

Lysolaje

At this locality, representing the oldest Pleistocene Vltava terrace [Záruba 1942] we investigated the loess cover, younger according to palaeomagnetic data [Fig. 11], than the B-M boundary and the fine-grained sediments, located in the sandy layers of the Lysolaje terrace. A marked change in the polarity of the geomagnetic field between both, separated by a long hiatus can be observed. Older marly layers probably correspond in pattern of the D and I changes to the interval round 1,200,000 years, the more so that they are older than the sediments of the Únětice locality according to lithostratigraphic arrangement. However, accurate dating is still difficult because the profile could not be sampled in sufficient detail; coarse-grained sands are not particularly suitable for palaeomagnetic investigations.

c/ Extraglacial area in Austria and Federal Republic of Germany-Krems-Schiesstätte

The direct superposition of soils containing malacofauna of the middle and oldest waves has been proved at this locality [Fink, 1974]. In the soil horizon "Kr 4" the fauna is practically identical with the fauna of Stránská Skála, and in Kr 7 and lower associations of the oldest wave are present everywhere.

Kr 4 and Kr 4 both contain fauna of the middle wave. This proves that the so-called "Cromer" faunae belong to several different cycles, therefore, the notation "Cromer" is only general.

The layers above Kr 4, i.e. the whole middle and young Pleistocene are developed imperfectly at this locality and, therefore, they are not conclusive.

The development of the systems of layers below Kr 7 proves that a series of fluctuations occurred at the time of the oldest wave. The climatic and sedimentary conditions at this time were different from the later periods, which is reflected in the nature of the fauna, as well as in the conditions of deposition.

At the Krems locality, where the complex of soils and loesses is well developed, dating was carried out with the help of Cox's scale of the soils beginning with Kr 4 up to Kr 13. The B-M boundary was found, according to Kočí to be in the loess between Kr 4 and Kr 5 [Fig. 12]. With a view to the high viscous remanent magnetization the Jaramillo event cannot be distinguished well. Nevertheless, it can be distinguished between Kr 6 and Kr 7. The Olduvai [Gilsa] event begins before Kr 12. Assuming that the cold and warm periods alternated on the Earth's surface at regular intervals, the occurrence of 7 soils between

PŘEZLETICE

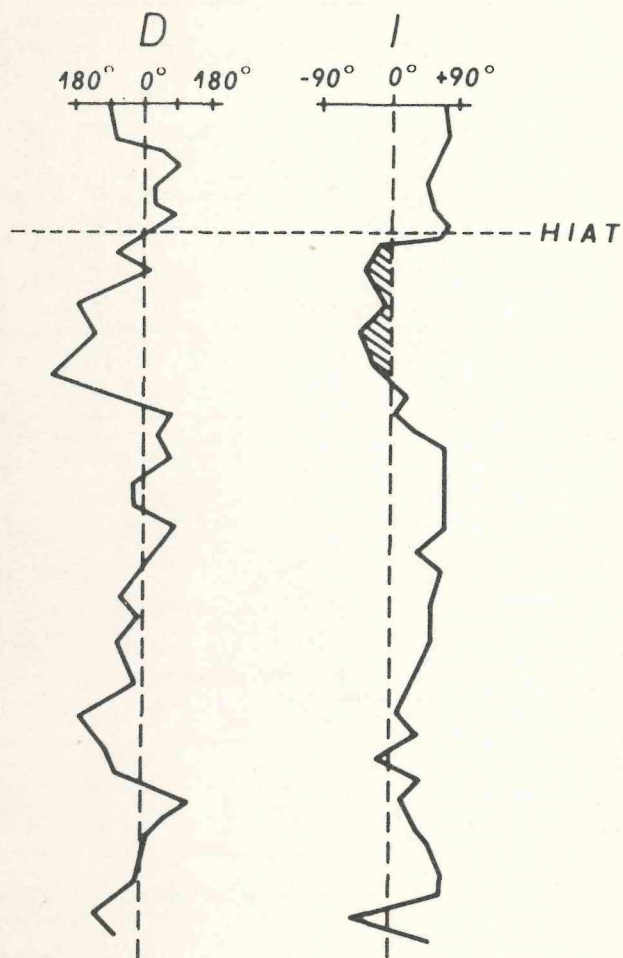


Fig. 10: Variations of the magnetic declination and dip at the locality Přezletice along the profile 2.4 m.

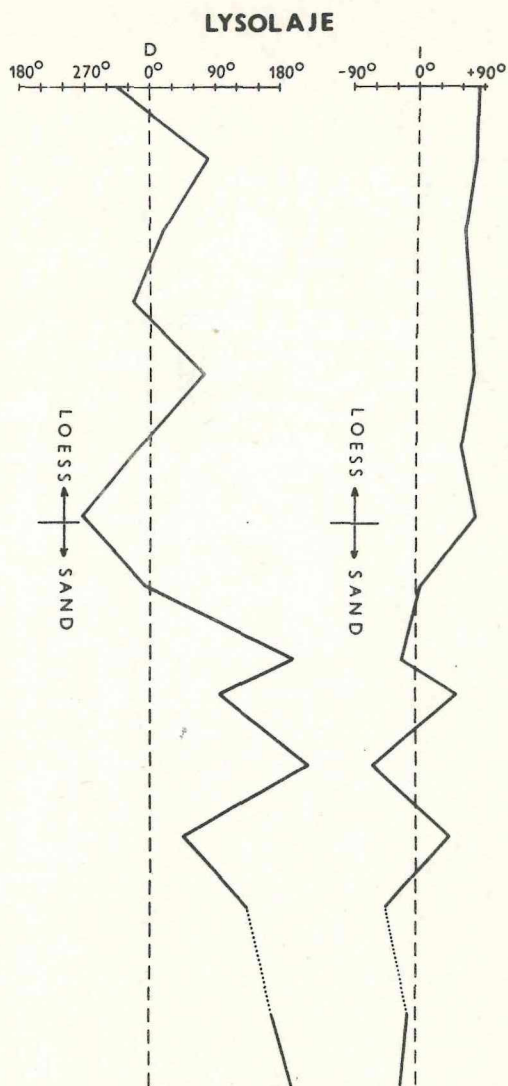


Fig. 11: Variations of the magnetic declination and dip at the locality Lysolaje representing in the upper part the loess cover /positive dip/ and in the lower part the fine-grained sediments of the Lysolaje terrace.

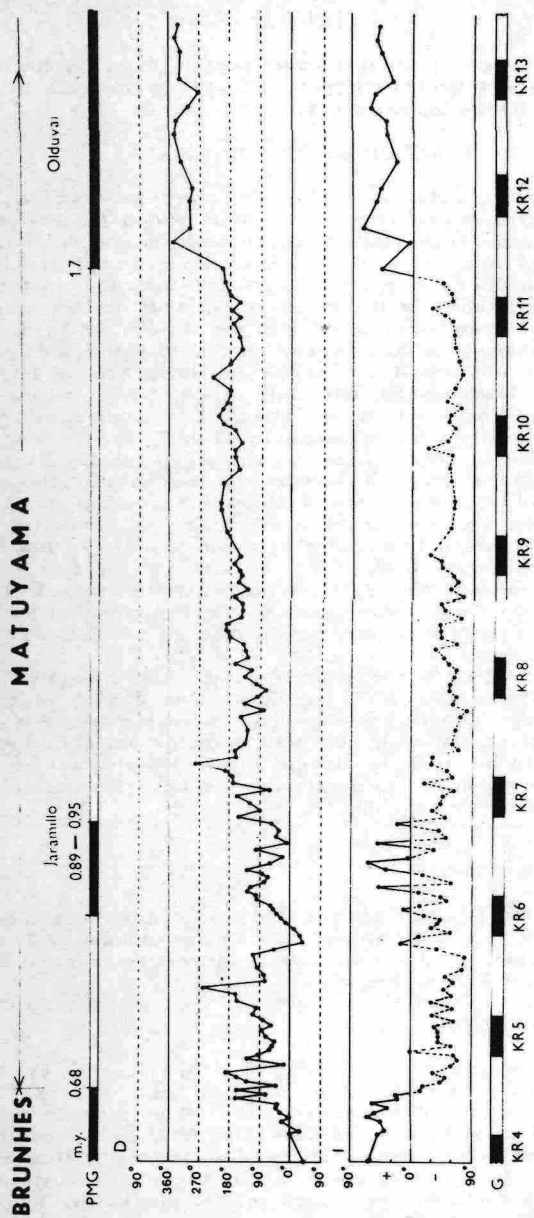


Fig. 12: Variations of the magnetic declination and dip at the locality Krems (Austria).
 PMG - palaeomagnetic time-scale; G - geological cycles /white-loesses,
 black-Krems red soils/.

the B-M boundary and the Olduvai event implies that 5 soils had to develop in the positive Brunhes epoch. This would indicate that one soil is missing in Krems above Kr 4.

BAD SODEN /FEDERAL REPUBLIC OF GERMANY/

The above conclusion would also correspond to the result of the palaeomagnetic investigation of the Bad Soden locality /Fig. 13/. Here the B-M reversal took place between soils 5 and 6. A considerable occurrence of rutile can be observed above soil 7 and this continues to the base of the profile. Rutile, to which the unstable component of magnetization is bound, is responsible for the considerable scatter of the palaeomagnetic results from the lower part of the profile, which cannot be interpreted well. Nevertheless, from the predominating number of negative I-values and from the D-values around 180° one may assume a negative Matuyama epoch. Only around soil 7 is the considerable occurrence of positive I-values around 0° conspicuous. This sections could correspond to the Jaramillo event.

The dating of clay V from the Brügggen locality Fig. 14a /Boenigk 1974/, where a reversal occurred at the base of the profile, is more difficult. With a view to the stratigraphic position this clay should belong to the sections where a reversal was observed at the localities mentioned above, however, the unique pattern of the D-variations from 0° to negative values through 270° to 280° at the time of the reversal does not indicate the B-M transition. With a view to the high positive I-values one could rather assume the beginning of the Jaramillo event. The B-M boundary would then be located above the said section.

The base of the Kärlich locality indicates a negative Matuyama epoch /Fig. 14b /Brunnacker, 1974/ the upper boundary of which may be expected in sands and in gravels of the main terrace. For this purpose samples of sands were collected here for palaeomagnetic investigation. Due to the well developed upper and younger part of the profile, it would be expedient to carry out a detailed palaeomagnetic survey of the whole profile at this locality.

ROSSHAUPTEN /AUSTRIA/

This locality is uniquely positive and it can be assigned to the Brunhes epoch /Fig. 15a/. With a view to the change of D from 0° to 270° and to I-values close to 60° , this section could have preceded by one cold period the B-M boundary.

GNEIXENDORF /AUSTRIA/

The palaeomagnetic data, obtained at this locality by the team of the Geophysical Institute CSAV, on the one hand, and by Pevzner of the Geological Institute in Moscow, on the other, indicate a transition from the positive section to the negative /Fig. 15b/. The positive I-values are very low, around $+40^\circ$. This fact could indicate that this was the beginning of the Gilsa Olduvai event in the negative Matuyama epoch /this event displays similarly low values of I at the Krems locality/, or the end of the negative event /Kaena/ in the positive Gauss epoch.

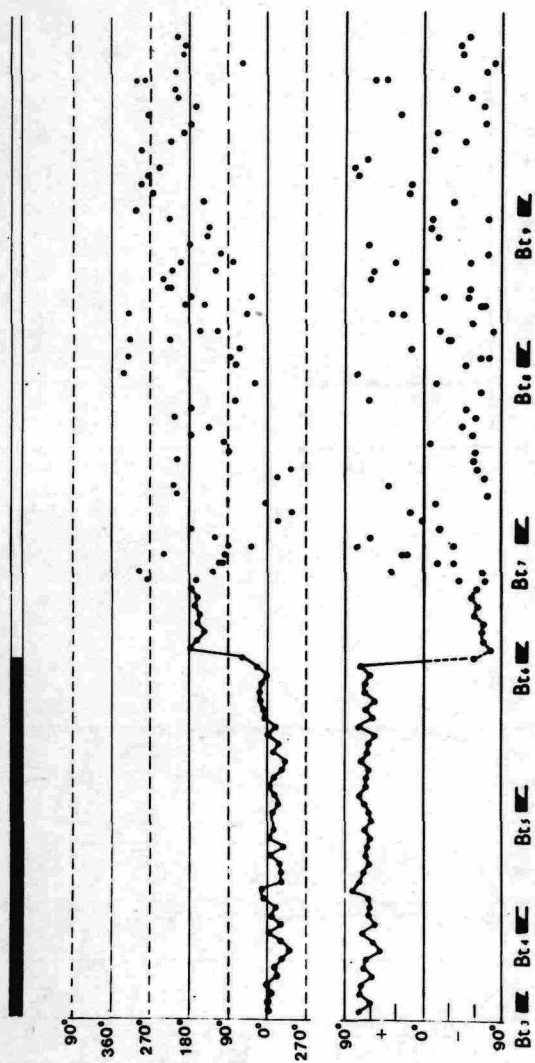
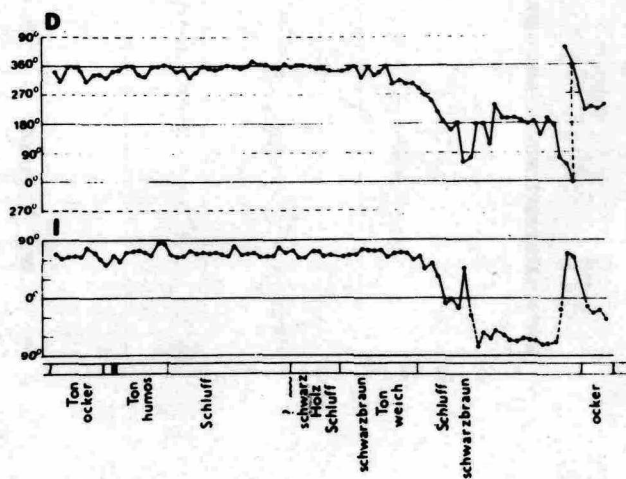
Brunhes
Matuyama

Fig. 13: Variations of the magnetic declination and dip at the locality Bad Soden /FRG/. Above-palaeomagnetic time scale; down -soils positions by Et marked.

Brüngen



Kärlich

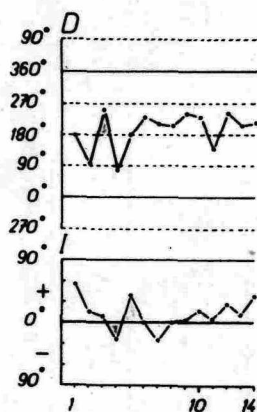


Fig. 14: a/ Reversal of the magnetic field in Ton V of the locality Brüngen /FRG/.
b/ Reversed magnetization of flood-loam of part A at the locality Kärlich /FRG/.

STRANZENDORF /AUSTRIA/

The uniquely positive pattern of I with values between 30 and 50° allows us to include this section in the positive Gauss epoch /Fig. 15c/. A more accurate dating of these sections /correlation/ will only be possible after palaeomagnetic investigation of the samples, collected at the Frechen locality /Germany/, where the most complete sequence of data from this period can be expected. The results of palaeomagnetic measurements, made at the localities of Brügggen and Frechen in the Federal Republic of Germany, have so far proved that Reuverin occurs in the positive Gauss epoch; this means that this formation is older than 2.5 million years.

FUNDAMENTAL PROBLEMS TO BE SOLVED

1. The most controversial section is the transition from the old to the middle Pleistocene because it is still not clear of how many cycles it consists and to which time interval it corresponds, i.e. how many years it lasted.

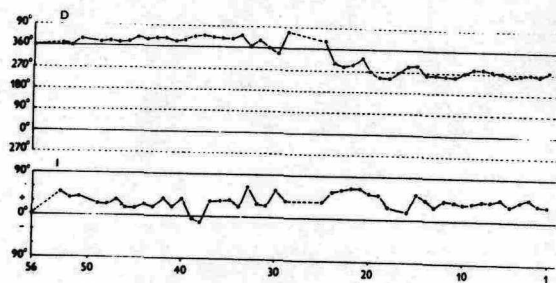
2. It is necessary to distinguish the individual interglacials, denoted by the collective name "Cromer", and in particular to identify the position of the warm period with the Stránská Skála - Krems type fauna, within the scope of the stratigraphic sequences, as well as of the stratigraphic sequences, as well as of the palaeomagnetic scale.

3. It is necessary to find and describe the faunas of the terminating Biharium and to determine their positions. It is most probable that the fauna, found in PK X at Červený kopec /which it is therefore unsuitable to parallel with the Stránská Skála, as attempted by Kukla/ belongs to this interval.

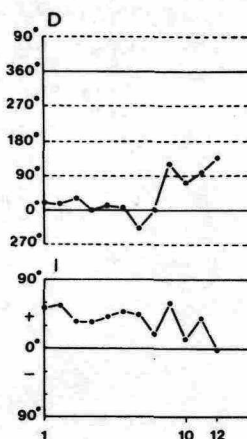
The results achieved over a relatively short period of a few years, prove the validity and expectancy of the application of palaeomagnetic methods to the geological correlation of the Quaternary sediments; they also indicate that conclusions can be drawn as set out in Project 73/1/24.

However, it is necessary for this purpose to investigate and verify the continuous fundamental palaeomagnetic D and I-curves, as well as the intensities of the geomagnetic field, characterizing in detail the variations of the field in the Pleistocene and Upper Pliocene. For this reason other investigations have to be carried out which are connected with the sampling of marine and continental sediments, from various areas of the Northern Hemisphere including also especially the North American Continent. On the basis of a detailed palaeomagnetic investigation of other type sections, using reliable instruments, it will then be possible to carry out the correlations, required for the accurate stratigraphical assignment of all Quaternary sediments and to draw satisfactory conclusions about the glaciations of the Northern Hemisphere and their causes.

Stranzendorf



Gneixendorf



Rosshaupten

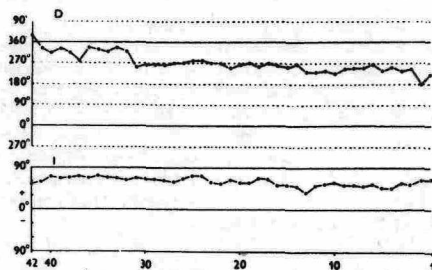


Fig. 15: Variations of the magnetic declination and dip at the localities a/ Rosshaupten; b/ Gneixendorf; c/ Stranzendorf

REFERENCES

- BOENIGK V. /1974/: Correlation of the Oldest Pleistocene of the Lower Rhine Basin with that of the Netherlands. Project 73/1/24 Quaternary Glaciations in the Northern Hemisphere, Report No 1 /1973/ 43 - 49, Praha.
- BOENIGK W., BRELIE G., BRUNNACKER K., KOČÍ A., SCHLICKUM W.R., STRAUCH F. /1974/: Zur Pliozän-Pleistozän-Grenze in Berich der Ville/Niederrheinische Bucht/, Newsl. Stratigr. 3, 4 /1974/, 219-241, Leiden.
- BUCHA V., /1970/: Geomagnetic Reversals in Quaternary Revealed from a Palaeomagnetic Investigation of Sedimentary Rocks. Journal of geomagn. and geoelectr. 22,3, 253-271, Tokyo
- BUCHA V. /1973/: The Continuous Pattern of Variations of the Geomagnetic Field in the Quaternary and Their Causes, Studia geoph. et geod. 17, 218-231, Praha.
- BUCHA V., HORÁČEK J. /1973/: Dynamic Manifestations of the Geomagnetic Field in the Quaternary Continental Sediments of Czechoslovakia. Studia geoph. et geod. 17, 321-336, Praha.
- BUCHA V. /1973/: Correlations between Variations of the Geomagnetic Field and Precession of the Earth in the Quaternary. Nature, Phys. Sc. V. 244 Aug. 13, 108-109, London
- BUCHA V., HORÁČEK J. /1975/: Continuous Changes of the Geomagnetic Field between 500,000 and 2,300,000 years. Studia geophys. et geod., Praha /in press/.
- BRUNNACKER K. /1974/: Results of Quaternary Stratigraphy on the Middle and Lower Courses of the Rhine. Project 73/1/24 Quaternary Glaciations in the Northern Hemisphere, Report No 1 /1973/ 16-33, Praha.
- COX A. /1968/: Lengths of Geomagnetic Polarity Reversals. J. Geoph. Res., 73, 3247-3253, Richmond
- FINK J. /1974/: Key Sites of Quaternary Stratigraphy in the Danubian Area. Project 73/1/24 Quaternary Glaciations in the Northern Hemisphere. Report No 1 /1973/, 50-68, Praha
- KOČÍ A., SCHIRMER W., BRUNNACKER K. /1973/: Paläomagnetische Daten aus dem mittleren Pleistozän des Rhein - Main - Raumes. N. Jb Paläont. Mh., H.9, 545-554, Stuttgart.
- KOČÍ A. /1972/: Ergebnisse paläomagnetischer Messungen und Sedimentproben von Frechen, Reuver, Belfeld und Tegele, /in W. Boenigk et al.: Zur Geologie des Altespleistozän der Niederrheinischen Bucht/ Z. Deutsch. Geol. Ges., B. 123, 119-161, Hannover.

- KOČÍ A. /1974/: Palaeomagnetic Investigation of Sediments. Project 73/1/24 Quaternary Glaciations in the Northern Hemisphere. Report No 1, 110-120, Praha.
- MACOUN J., ŠIBRAVA V., TYRÁČEK J., KNEBLOVÁ - VODIČKOVÁ V., /1965/: Kwartér Ostravska a Moravské brány NČSAV, Praha.
- WATKINS N.D. /1971/: Geomagnetic Polarity Events and the Problem od "The Reinforcement Syndrome", Comments on Earth Sciences: Geophysics, 2,2, 36-45, London
- ZÁRUBA Q. /1942/: Podélný profil vlávkými terasami mezi Kamýkem a Veltrusy. Rozpravy II. třídy české akademie, ročník III., 9, Praha.