TRACES OF ICE IN CAVES: EVIDENCE OF FORMER PERMAFROST

A. Pissart[1], B. Van Vliet-Lanoe[2], C. Ek[1] and E. Juvigne[1]

[1]Géomorphologie et Géologie du Quaternaire, Université de Liège, Belgique
[2]Centre de Géomorphologie du C.N.R.S., Caen, France

SYNOPSIS - Unconsolidated deposits in the Remouchamps Cave (Belgium) retain indisputable traces of segregation ice, confirming the presence of deep permafrost in the course of the late glaciation. When the ground warmed up once more, the permafrost considerably altered sedimentation conditions by blocking passages with ice. There is no doubt that the fusion of this ice caused significant mass movements in the sediments laid down. The study of segregation ice which may be detected in cavities will assist in the mapping of permafrost limits during the cold periods of the Quaternary and will without doubt provide fresh evidence on the depth it reached.

INTRODUCTION

Conditions necessary for the appearance of segregation ice are well established. It occurs in damp fine sediments subjected to slow freezing. Further, it is essential that pressure from the overlying land-mass is not too great, which implies that segregation ice cannot occur below a depth of some ten metres. In caves, however, sediments are not subjected to pressure from the ground within which the cavity has developed, so that segregation ice can occur irrespective of the depth of the cavity.

The occurrence of segregation ice in a sediment has the effect of structuring the earth : between the particles of ice, the earth is progressively distorted and dried; and since air cannot penetrate through, aggregates limited by the particles of ice are extremely compressed. In cross-sections through silt, the structuring of the earth which occurred in the course of the last glaciation is often clearly observable, at least when this structure was not destroyed by biological action or complete drying-out with subsequent rehydration. Indeed when this latter process occurs, it results in the aggregates exploding when the air inside the sediment is compressed by subsequent water penetration.

In caves where biological action is limited and where, particularly in the case of the climate of Western Europe, complete drying-out is almost impossible, the former presence of segregation ice can consequently be ascertained.It is especially apparent in the layout of residual spaces left open after fusion of the ice lenses.

If the layout of the cave does not allow circulation of the air to bring cold down from the surface, and if the cavity is located more than 20 m deep (the limit at which annual temperature variations occur), the presence of traces of ice, in other words of a temperature below 0°C, implies of necessity the presence of permafrost. In the present article, we show how the method can be applied in the study of a Belgian cave.

II. TRACES OF SEGREGATION ICE OBSERVED IN THE REMOUCHAMPS CAVE

Remouchamps cave is 20 km to the south east of Liège in paleozoic rocks. It comprises two horizontal corridors, the lower one being occupied by a subterranean stream (fig. 1). One of the authors (C. Ek, 1961) showed that these passages are connected with terraces of the river Ambleve which flows in the valley on the slope of which this cave has its entrance.

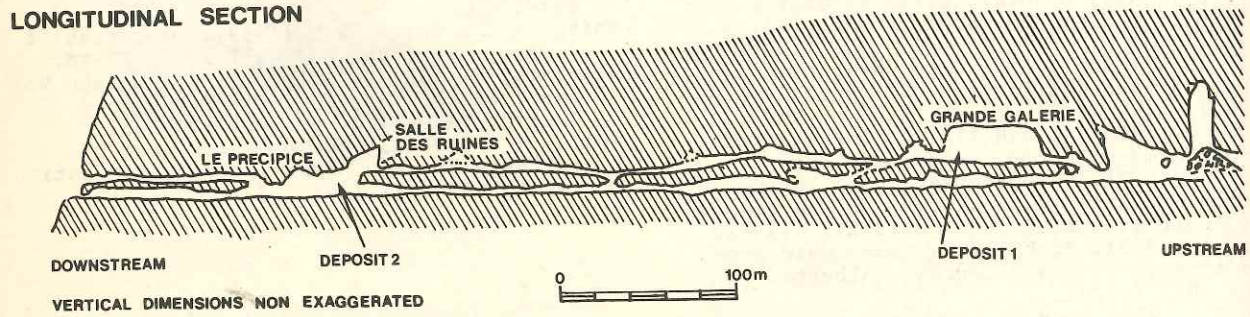

Fig.1 Longitudinal section of the Remouchamps cave with locations of the two deposits studied. Only passages accessible to potholers (speleologists) are shown (C. Ek, 1972).

Two distinct accumulations of sediments were studied in this cave. Their location is shown in figure 1 : the first is found in the "Grande Galerie" (Large Gallery); the second nearer the entrance 50 m upstream of the "Embarcadère" (pier).

a) The "Grande Galerie"

Situated some 500 m from the entrance, the "Grande Galerie" appears as a corridor with a height in excess of 20 m. The highest point of the roof is above 30 m below surface level.

Figure 2 indicates schematically the location within the cave of the deposits under investigation. Our examination was restricted to the upper part of sandy-silty sedimentation to be found at the SE end of this gallery; figure 3 shows in greater detail the presentation of these sediments.

The excavations which we have carried out did not reach the base of the sediments. They revealed finely stratified fine alluvial sands. Occasionally very thin clayey edgings provide evidence of brief periods of sedimentation in stagnant water.

Two distinct units are separated by a discordance in stratification testifying to erosive action before the sedimentation of the upper layers of sediment. The southeastern part of the lower deposits displays a sharply sloping stratification which is doubtlessly the result of sedimentation by a current of water in a drowned passage. The absence of cracks which could have provided evidence that these layers are a result of collapse, and also the presence of distorsions which appear to be due to syngenetic landslip of the deposit, prompt us to defend this interpretation.

Within the heart of the cross-section studied, traces of Rocourt tephra (enstatite, jagged green clinopyroxene and brown amphibole; E. Juvigné, 1977) were detected. Since such tephra fell on our country at an undeterminate time somewhere between 61.000 and 106.000 BP (E. Juvigné et M. Gewelt, 1987), these minerals prove that the laying down of this deposit occurred after the Eemian *sensu stricto*.

There was nothing to enable us to tell apart the deposits on either side of the discordance. Concretion debris found at the point of contact gave a Uranium-Thorium age of 195,067 (+28714, -21452) years (1), confirming that these were very ancient concretions which had undergone displacement, and therefore provided no useful data.

Twenty two thin-sliced sections were prepared for examination of the microstructures existing in these formations. Certain parts of the deposits already showed noticeable structuring which was clearly apparent on macroscopic examination of the sample blocks from the cross-section, but it was right and proper to check their nature under a microscope.

(1) Dating established at the "Centre for the study of Nuclear Energy" at Mol by Dr. G. Koch, Head of the Low-Level Measurement Department. Dating Nr 11.

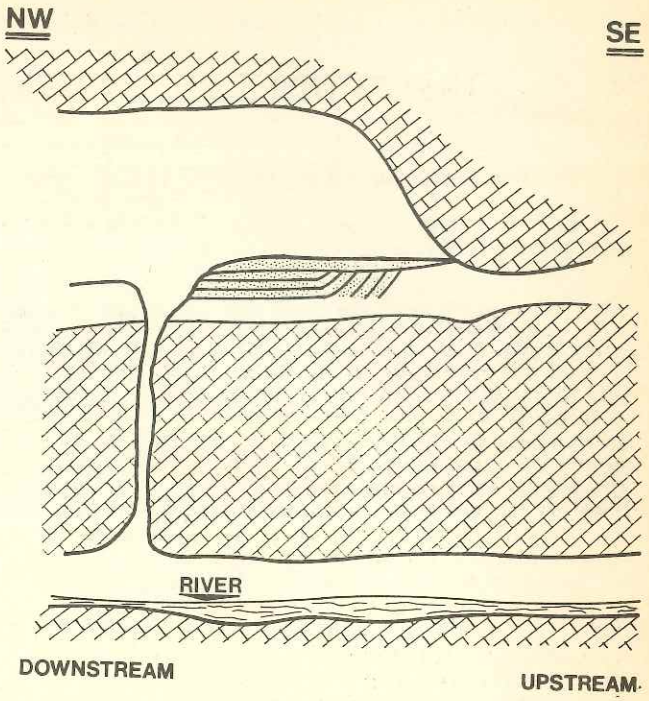

Fig.2 Diagram showing the location of deposits investigated in the S.E. part of the "Grande Galerie", and indicating the very probable hydrological relationship with the lower stream occupied by the river.

In 21 out of the 22 sections, traces of segregation ice are apparent, comprising :

(1) the arrangement of the empty spaces (hollows) present in the heart of the formation, the configuration of which evokes the distribution of segregation ice. Figure 4 provides a fine example.

(2) the nature of the walls of the hollows, the elements of which could not dovetail together if the fissure were closed. This lack of concordance between the two faces can be explained by pressure-thrust due to growth of segregation ice. It is particularly apparent in the presence of triangular hollows as shown in figure 6.

(3) the existence in the heart of the deposits of micro-thrust faults and ruptures in what were continuous strata, subsequent upon movement which occurred at the time of the fusion of the ice.

Since they have been subjected to only a very limited number of freezing-thawing cycles and probably, in the case of the upper formations, only a single cycle, it is futile to seek out in these sediments the traces of alternating freezing-thawing which the selected lamellar structures constitute (B. Van Vliet-Lanoe, 1976).

The sections examined do not reveal traces of ice in equal quantity. This may result from :

(1) the granulometry of the site material of each section studied.

(2) the amount of water present in the material at the time of freezing.

(3) refrigeration conditions which may have varied from place to place.

(4) the degree of compactness of the material before freezing.

The traces of segregation ice shown in figure 4 are very similar to those obtained when a muddy mass freezes shortly after being laid down (compare with photo 2 *in* Pissart, 1974). The like- lihood is that quasi syngenetic freezing of the deposit is involved here (B. van Vliet-Lanoe, J.-P. Coutard et A. Pissart, 1984).

Only one slide, the sample location of which is indicated in figure 3, does not show any other freezing activity. It may be testimony of the last deposits laid down at this location when the underlying formations were completely thawed.

The observations carried out lead to the following interpretation :

(1) underlying formations (that is to say those below the discordance in fig. 3) were placed on position at the time of disappearance of a permafrost. Indeed, it was necessary for the permafrost to disappear at the surface so that water and sediments might get down into the cavity. As they were laid down at a time when the cavity was still in permafrost, that is to say in a temperature below 0°C, syngenetic segregation icing of the deposit occurred.

(2) a period free of permafrost permitted the development of erosion wich truncated the formations laid down (discordance D in fig.3).

(3) the permafrost returned; at the time of its disappearance, sedimentation of fresh layers of alluvium/silt occurred while the ground was still below 0°C. The temperature of the substratum was still negative.

We surmise, without proof however, that these phases followed on in succession during the late ice-age and/or the Weichselien interpleniglacial.

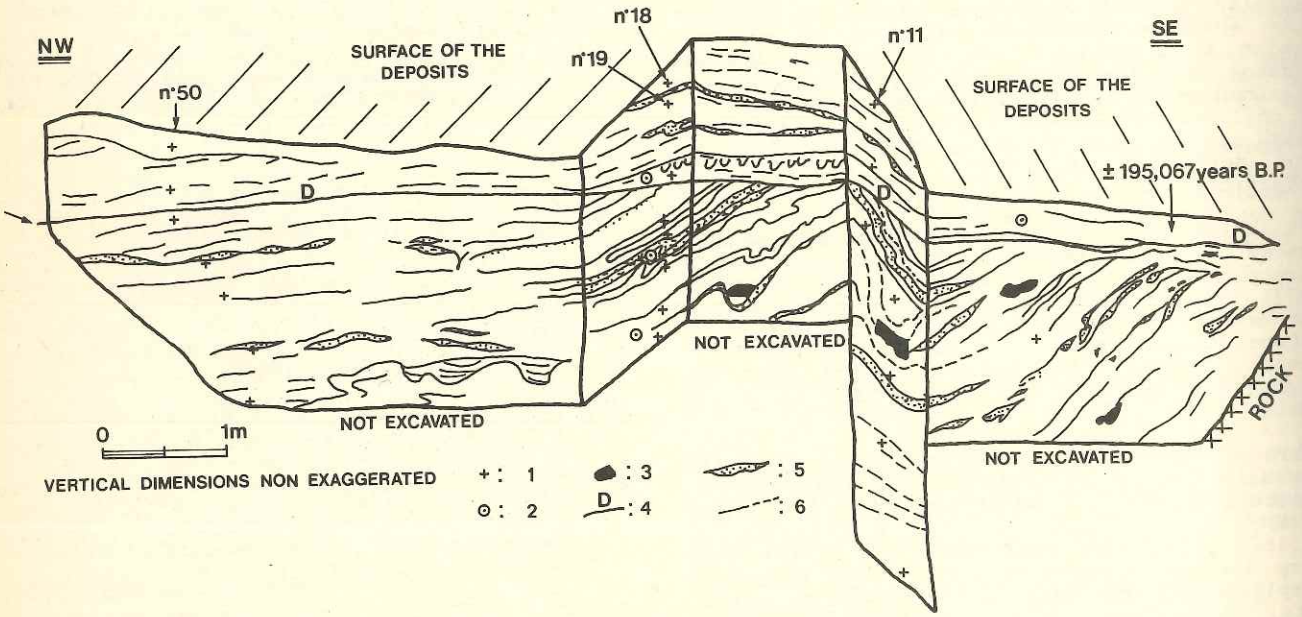

Fig.3 A cleared cross-section in the SE part of the "Grande Galerie" showing the lines of stratification.
1. Location of samples studied in respect of microstructures.
2. Idem in respect of dense minerals.
3. Blocks.
The letter D marks the position of the discordance in stratification.

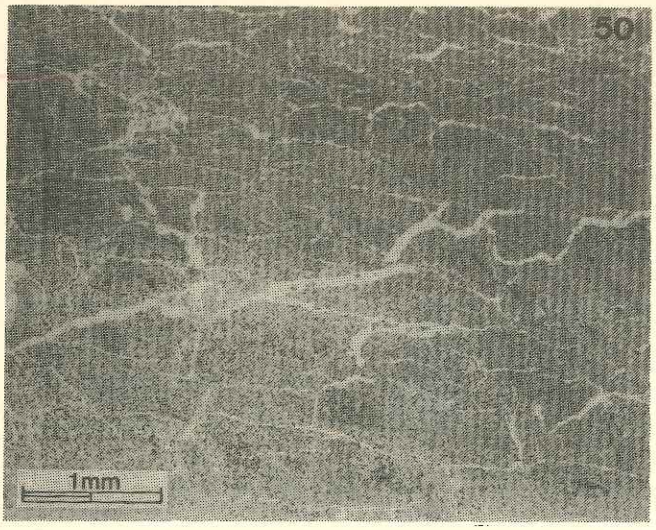

Fig.4 Traces of syngenetic segregation ice in the deposit. Sample 50 from the upper part of cross-section shown in figure 3.

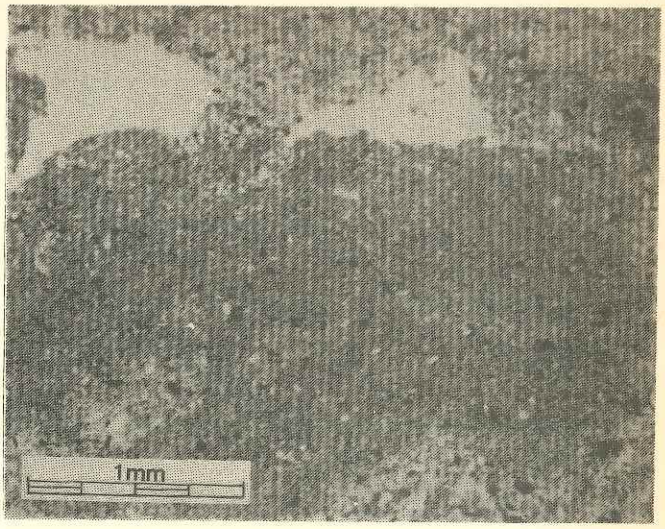

Fig.5 Triangular hollows testifying to the past existence of segregation ice.

b) Near the "Embarcadère" (pier)

A second, new accumulation of sediment was studied in the Remouchamps cave. Figure 6 pinpoints its location. For a description of all the features the reader is referred to Pissart *et al.*, 1987.

Two distinct formations are present. The lower formation is composed of sediments with very irregular outlines and a very heterogeneous nature. Along falls of large limestone blocks are found schist debris, the whole being enclosed in an extremely clayey matrix. The contact slope between these different materials is, at the right hand extremity of the cross-section, close to 35°. Up above, it opens into the "Salle des Ruines" (Hall of Ruins) previously referred to. Consequently it is clear that these materials are deposits which have slipped down the slope from this "Hall of Ruins" situated on the left bank of the stream.

The upper formation is made up of finely stratified fluvial deposits comprising silt and fine sand with, on rare occasions, some more clayey layers. These stratified deposits were laid down by the stream which presently flows a few metres below.

The associations of dense minerals show the presence throughout the deposits (except in the lower clayey layers) of Rocourt tephra (see above) which settled there during the last glaciation.

Traces of segregation ice are in evidence in the upper part of the fluvial deposit. The ice was there in abundance and subsidence due to fusion of this ice is very clear. However at a depth of one metre, one sample showed no sign of disturbance due to freezing. In the heart of the underlying formations laid down subsequent to mass transportations from the "Hall of Ruins", the effects of frost are also evident. The arrangement of fissures in the heart of blocks displaced by these agents of mass movement provides evidence of freezing prior to their slide down the slope.

Consequently we think we have discovered evidence supporting the following sequence of events :

(1) Unconsolidated sediments accumulated on steep slopes in the gallery extending above the present deposit.

(2) These sediments were frozen and an abundance of segregation ice occurred here.

(3) Fusion of this ice, during a period of climatic improvement, triggered mass movements which created the lower part of the accumulation. At the time when this occurred, the river was not flowing, no doubt owing to blocking of passage upstream.

(4) The river which resumed its flow found the passages downstream partially obstructed and accumulated fluvial deposits of a more loesslike character up to the level of the upper opening through which the water flowed out.

(5) A return of the frost, probably roughly contemporary with sedimentation of the upper layer occurred.

(6) The stream, rediscovering its lower outlet, rapidly incised the sediments laid down.

We surmise that these various stages all occurred at the end of the last glaciation, at the time of climatic fluctuations of the Weichselien late ice-age (tardiglacial).

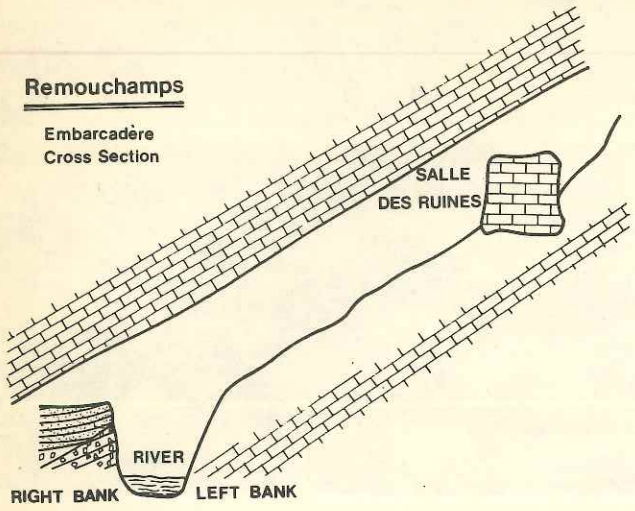

Fig.6 Diagram showing the location of the deposit accumulated upstream of the "Embarcadère" at the foot of the "Hall of Ruins".

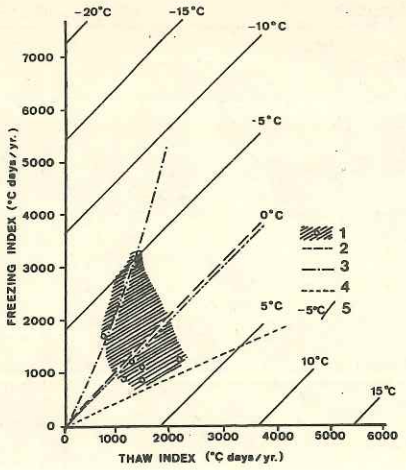

Fig.7 Relationship between temperature and ice-caves according to Harris (1982).

CONCLUSIONS

The discovery of traces of segregation ice in caves is of interest in two very different fields, namely :

(1) Sedimentology of deposits occupying karst cavities.

(2) Paleoclimatology.

The presence of ice in Belgian caves during the cold periods is thus demonstrated for the first time. This observation confirms that the blocking of swallowholes was not solely the result of the input into the thalweg of large quantities of unconsolidated sediments. The discovery of traces of syngenetic ice in the deposit, that is ice appearing immediately after sedimentation, can be explained by the fact that rewarming occurred from the surface downwards. In this way the upper ducts could be flooded while the lower ducts were still frozen. During what was probably a relatively brief period, sedimentation was not possible in the lower ducts which were blocked by ice, whereas it was occurring in ducts found nearer the surface that were already unfrozen. If this is in fact the case, it is somewhat hazardous, in regions where permafrost existed, to try to explain subterranean sedimentation by running water while taking into account definitive abandonment of upper ducts when lower ducts were well developed.

Furthermore it seems clear that at the time of thaw, the unfrozen masses of sediment became unstable and could slide on slopes while previously they were in equilibrium. This is how we explain the deposits we have described near the "Embarcadère". This accumulation, moreover, was formed at a time when the stream was no longer flowing; otherwise one would detect in the middle of it masses of layered sediments testifying to the action of a water course. Such thaws probably also caused the fall and simultaneous fracturing of a certain number of stalagmites standing on unconsolidated formations.

The study of traces of ice in caves in present-day temperate regions may well provide valuable evidence on the spread of permafrost during the cold periods of the Quaternary. The application is immediate if it is accepted that the temperature of the cavity corresponds to the annual mean temperature of the place where the cave is situated. It is however a well known fact that if movement of air is prevalent in the cavity, the temperature may deviate from the annual mean temperature. As shown in the figure provided by Harris (1982), ice caves may exist when the annual mean temperature reaches +3°C. However, by limiting our investigation to deposits a long way from cave entrances and well away from vertical shafts which might induce significant local freezing, the study of traces of segregation ice in caves constitutes a new tool in mapping the limits reached by the permafrost during the cold periods of the Quaternary. By studying deep cavities, one can thus hope to obtain direct evidence for depth attained by the permafrost, data that are totally lacking today in fossil periglacial regions.

REFERENCES

Dewez, M., Brabant, H., Bouchud, J., Calut, M., Damblon, F., Degerbol, M., Ek, C., Frère, H., Gilot, E. & GLIBERT, M. (1974). Nouvelles recherches à la Grotte de Remouchamps. Bull. Soc. Roy. belge Anthrop. et Préhist., (85), 5-161, Bruxelles.

Ek, C. (1961). Conduits souterrains en relation avec les terrasses fluviales. Ann. Soc. géol. Belg., (84), 313-340, Liège.

Harris, S. (1982). Identification of permafrost zones using selected permafrost landforms. C.R. de la 4e Conf. canadienne sur le Pergélisol, Calgary, Alberta, March 1981. National Research Council of Canada, Ottawa.

Juvigné, E. (1977). Zone de dispersion et âge des poussières volcaniques du tuf de Rocourt. Ann. Soc. géol. Belg., (100), 13-22, Liège.

Juvigné, E. & Gewelt, M. (1988). Intérêt stratigraphique réciproque des téphra et des dépôts de grottes. Ann. Soc. géol. Belg., (111), Liège.

Pissart, A. (1964). Contribution expérimentale à la connaissance de la genèse des sols polygonaux. Ann. Soc. géol. Belg., (87), B213-223, Liège.

Van-Vliet-Lanoe, B. (1976). Traces de ségrégation de glace en lentilles associées aux sols et phénomènes périglaciaires fossiles. Biul. Perygl., (26), 41-55, Lodz.

Van Vliet-Lanoe, B., Coutard, J.-P. & Pissart, A. (1984). Structures caused by repeated freezing and thawing in various loamy sediments : a comparison of active, fossil and experimental data. Earth Surface Processes and Landforms, (9) 6, 553-566, Wiley, Chichester.