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# RADIOCARBON DATING OF GROUND WATER IN CZECHOSLOVAKIA AND PALEOCLIMATIC PROBLEMS OF ITS ORIGIN IN CENTRAL EUROPE

**Abstract:** The results of radiocarbon dating of ground water in various deep hydrogeological structures in Czechoslovakia have been summarized in partial and total histograms. The resulting ground-water residence time usually exceeds one hydrological year. The origin of ground water can be linked quite accurately with the chronostratigraphic scale. Groud water of numerous hydrogeological structures does not belong to the present hydrological cycle but to longer hydrological cycles which started in the geological past at other climatic conditions than the later ones and perhaps also under other conditions for ground-water recharge. These facts show that the hitherto valid consideration of groud water as an automatically renewable natural resource should be revised.

## INTRODUCTION

At the Department of Hydrogeology and Engineering Geology at the Charles Univesity in Prague ground water has been dated using the radiocarbon method in order to provide information on the regional ground-water flow velocity in basins and other deep structures of the Czechoslovak territority with the aim to protect significant ground-water resources from mining activities and from the wastes of chemical industry. The then accepted opinions on ground-water flow velocity were based rather on transmitting of hydraulic impulses than on ground-water motion.

Already the first results of ground-water dating showed surprising high values of radiocarbon ground-water ages from which ground-water residence time in the range of tens of thousands years could be derived (Silar, 1976). Subsequently, data on ground-water ages in numerous hydrogeological structurs were gathered, especially in the deeper ones, in which the radiocarbon method is applicable. 177 data on radiocarbon ages of ground water were selected to be statistically processed and compiled to histograms. From the histograms, some interesting conclusions can be drawn about the time of origin of ground water explaining the paleoclimatic and paleogeographic circumstances of its recharge.

## METHODS

For determining the ground-water residence time in hydrogeological structures, the radiocarbon dating method developed by W. F. Libby (1952) and adopted by M. O. Münnich (1957) was used. The carbon necessary for measuring its beta activity was extracted in the field from bicarbonates dissolved in ground water either by trapping on strongly basic ion exchanger as developed by J. W. Crosby III and R. M. Chatters (1965) or by precipitating in forn of barium carbonate (Sampling of water for $^{14}C$ analysis, IAEA, without date). The concentration of radiocarbon was measured in the radiocarbon laboratory of the Department of Hydrogeology and Engineering Geology of the Faculty of Science of Charles University in Prague in proportional gas counter filled with carbon dioxide.

For calculating the radiocarbon ground-water age, the empirical consideration of the initial $^{14}C$ activity of ground water equal to 85 p.m.c. (Vogel, 1970; Geyh, 1972) was used which is frequent in isotope hydrology. I.e., ground water samples with measured activity higher than 85 p.m.c. can be considered as modern.

Radiocarbon dating of ground water proved to be aplicable especially in deep hydrogeological structures with a longer residence time (Silar, 1976) where the results can be used even for interpretation of the regional flow. Thus, the radiocarbon method was used for dating ground water in deeper basin structures in the Cretaceous fotrmation in northern and eastern Bohemia, in the Permocarboniferous, in the Neogene sediments of the Carpathian foredeep, in the Carpatian intermountains basins, in the carbonate rocks of the Carpatian Mesozoic and in deeper hydrogeological structures along faults in crystalline regions. The analysed group of data does not include samples from geological structures in which modern ground-water ages could have been expected in advance, i.e. from Quaternary alluvial plains and terraces within the Bohemian Massif.

The measured samples were collected in hydrogeological structures, which are significant from the water - management point of view, the grond water of which is either used or investigated because a sufficient volume of water could be obtained during pumping tests, from water supply plants, from natural artesian flow of wells or from outflow of springs.

The results of ground-water were illustrated in histograms for individual types of structures in different geological formations and summarized afterwards in a joint histogram.

The histograms were compiled on a computer according to a particular program (Jakub Silar, 1985). Each radiocarbon age is included in the pertinent histogram including its standard statistic deviation $\sigma_{tr}$ and is represented by a Gaussian curve which limits an area which is the same for all radiocarbon ages and which is equal to the area of the rectangle in the head of the histogram. More accurate measurements with a low statistic deviation are represented by lower and wide ones. Modern radiocarbon ages are represented as zero - age values. As the peak reaches beyond the figure, the number of modern - age data is given by a number (22 samples of modern age among 177 samples in the summarizing histogram). The summarizing histogramis constructed by summation by the heights of areas limited by the Gaussian curves of the individual measurements arranged along the horizontal axis of coordinates. The curve limiting the resulting area is a histogram the peaks of which indicate intervals with higher frequencies of radiocarbon ages of the ground-water samples.

The determining of the radiocarbon age and of the residence time makes it possible to refer the time of its origin, i.e. the time of its infiltration, to the chronostratigraphic scale. As the majority of the ground-water samples investigated so far originated during the Holocene and Upper Pleistocene, the dating of ground water makes it possible to confront its results with the results of the Quaternary geological research and to link the origin of ground water with the geological history and events in the Quaternary and with the global evolution of the environment.

## CHRONOSTRATIGRAPHIC ASSIGNMENT OF THE ORIGIN OF GROUND WATER

It follows from the histogram that the majority of ground water deep hydrogeological structures originated during the period of the last about 14,000 years BP. It follows that the majority of the dated ground-water samples originated by infiltration of precipitation during the warm period after the retreat of the periglacial climate from the teritority of central Europe, i.e. during the period of the Holocene. Older pre-Holocene samples from the interval 10,000 to 14,000 years BP, however, indicate that the water already infiltrated ealier, that is to say perhaps during interstadials Bölling and Alleröd and continued later after the final retreat of glaciation during the whole Holocene.

In the deep parts of the basin structures, however, older ground waters with radiocarbon ages as much as 40,000 years BP occur, i.e. at the limit of the applicability of the radiocarbon method. The existence of still older ground water is not excluded. Such ground waters originated under climatic conditions not yet cleared either under the periglacial climate during the Vistulianian glacial stage or more probably in the intervals of the transient warming up in the interstadial stages.

### Quaternary hydrological cycles

Ground water of the investigated deeper hydrogeological structures which is being developed is for the most part not linked with the short - term hydrological cycle (which, however, is not defined by time and is tacitly considered as being within the time scale of hydrological year), but with a long - term Quaternary cycle or cycles. This changes the opinion about ground water as a renewable natural resource because in numerous hydrogeological structures, its renewability can be considered in the time scale of geological periods but not years.

The space arrangment of the ground-water circulation, i.e. the flow net, developed during Pleistocene incission of streams into the surface of the platform sediments and basinal structures of the Carpathian system. It was a consequence of the continuing uplift of the majority of the area.

This uplift and erosion created the hydraulic gradient necessary for the ground-water flow and became impeuts for a gradual initation of a ground-water flow and for its shaping into its present form. It is probable that already the tectonic processes in the Tertiary had similiar results which could be determined by dating the evolution of karst hydrogeological structures in central Slovakia (Silar, 1968).

For considering the position of groud water in the hydrological cycle, it is necessary to consider even the relation of its age to the age of the space arrangement of hydrogeological structures by the mentioned geological and morphological processes. From this point of view, five cases can be distinguished:

1. The ground water is very old with a radiocarbon age of about 40,000 years or more, i.e. at the limit of application of the radiocarbon dating method and beyond it. The age of ground water in such cases is often not determinable but is very probably higher than the final shaping of the present relief and of the present hydrogeological structure. Waters of this type are preserved only in closed parts of deep structures where they stagnate. They reach the earth surfaceonly by means of boreholes, mining operations and similiar anthropogenic interferences. Such waters can be considered fossile in the proper sense of the word because they have not been yet part of the present hydrological cycle and they became a part of this cycle after having been tapped.

2. The ground water reveals a real radiocarbon age higher than about 10,000 years, i.e. higher than Holocene, and lower than 40,000 years, i.e. quite reliably determinable by radiocarbon dating. Such water originated during the late period of the Younger Pleistocene when the present shape of the Earth's surface already existed. The structural and morphological prerequisites for the geometrical space arrangement of the flow pattern including the area of ground water recharge, circulation pathways and drainage areas were the same as at the present time. The climatic conditions, however, differed from the present ones and consequently, also the conditions of infiltration, evapotranspiration, surface flow and other components of the hydrological cycle were different. Under the conditions of the Pleistocene periglacial climate, infiltration of precipitation can be considered only in limited areas of the Earth's surface and during limited time intervals. Thus, there were no prerequisites in the already existing hydrogeological structures for continuous ground-water recharge and for the origin of a hydrological cycle which would have fluctuated in one year periods but would have been steady in long - term effects and which would have been analogous to and a predecessor of the present hydrological cycle under the climatic conditions of that time. Due to the interrupted conditions of ground-water recharge, no continuous ground-water flow systems originated in the hydrogeological structures that would have persisted until the present time having preserved their original shape and which could hence be included into the present

hydrological balance. Because of this, the ground waters whose origin is late Pleistocene cannot be referred to younger ground waters of Holocene origin as they belong to different hydrological cycles.

3. The ground water reveals a radiocarbon age lower than 10,000 years but higher than zero. Such ground water originated during the Holocene when the present shape of the surface already existed and under climatic conditions similiar to the present ones. The morphological and climatic conditions remained stabilized on the whole and created the ground-water circulation which still persists with respect to its space arrangement and which at the long time scale is steady even in the hydraulic sense while at the short time scale it undergoes yearly periodic changes resulting from the local climate.

4. The ground water reveals a concentration of radiocarbon close to the standard modern activity and a high tritium activity. Such ground water can be considered modern, from the time after 1950 (due to the increase of $^{14}C$ and $^{3}H$ activities by nuclear tests). Water of this type is common in shallow or small hydrogeological structures with a fast ground-water circulation which is in a close contact with precipitation and surface water. It can be coordinated to the contemporaneus hydrological cycle which is modern in the sense of the isotopic hydrology, i.e. it can be attributed to the period after 1950. Sometimes the ground water can be identified and coordinated even to the current hydrological year.

5. The ground water reveals a low concentration of radiocarbon and a high concentration of tritum. This seeming paradox indicates mixing of ground waters of different origin.

It follows, when omitting the case of mixing components of ground water, that the ground waters of the hydrogeological structures in Czechoslovakia discussed so far can be attributed according to the time of origin to four periods the two oldest of which go back to the Pleistocene, the next one to the Holocene and the last one to the modern time. Ground water from different periods by origin belongs to different hydrological cycles which have a different duration and which all still continue because ground water of the oldest period issues to the surface at the same time with modern water which originated during the current hydrological year. Thus, while compiling hydrological balance and evaluating ground-water resources, it is right to approach different mentioned types of ground water in a different manner. As a consequence, the general opinion on ground water as a renewable natural should be reevaluated.

## PALEOCLIMATIC CONDITIONS OF GROUND-WATER RECHARGE AND ORIGIN

Observations in present Arctic regions, e.g. in the Rocky Mountains System in Alaska, show that the permafrost extends to depths as great as 600 m and is continuous except beneath deep lakes and in the alluvium beneath the deeper parts of the channels of streams (Heath, 1984). South of this area and north of the coastal strip, the permafrost is discontinuos and depends on exposure, slpoe, vegetation and other factors. The permafrost is highly variable in this zone is generally less than 100m thick.

Under such circumstances, the natural conditions for ground-water recharge during the periglacial climate of the Upper Pleistocene must be considered as very unfavourable. In the Bohemian Massif, there are not sufficient indications about the existence of large lakes and deep streams during this interval of time which would have made ground-water recharge possible. Their existence cannot be anticipated in the major part of the territory neither in connection with the orographic circumstances. Infiltration under the periglacial climate can be considered as possible only in the area of the lowermost gravel terraces in the middle reaches of the Labe River (Elbe) but we lack so far reliable isotopic data from the Cretaceous aquifers underlying these terraces. Some of the radiocarbon ground-water ages coincide with the interstadials Allerød (about 12,000 to 11,000 BP), Bølling (13,800 to 12,300 BP) (cf: Die Entwicklungsgeschichte der Erde, 1970) and Götaälv (about 30,000 to 24,000 BP, Lozek, 1973), the latter being also called Denekamp and corresponding to the Stillfried B interval of the Central European loess regions (V. Lozek, personal communications, 1989). The higher radiocarbon ground-water ages not exceeding 40,000 years indicate that the ground water of the present hydrogeological structures originated probably already during older periods of warming up within the Middle Vistulian stadial. This would be in agreement with radiocarbon dating and paleogeographic studies from the coast of the Northern Sea (Geyh, 1969) and other regions of Central Europe (Srdoc et al., 1983). Besides this, even ground waters older than 40,000 years BP were found less frequently which, in regard of the radiocarbon dating may be considered as fossile.

Among the radiocarbon ages of ground water of the deeper hydrogeological structures, some data occur which do not coincide with the present concept of the geological and climatic evolution during the Upper Pleistocene, e.g. the radiocarbon ages about 17,000 and 21,000 years BP. Such deviations can be effested by causes which secondarily changed the concentration of radiocarbon in ground water and thus also its resulting radiocarbon age (e.g. mixing of ground-water components of different origin). However, they also can be caused by lack of knowledge of paleoclimatic conditions during the Upper Pleistocene. To obtain more accurate data, radiocarbon dating of ground water will have to be cross - checked by analyzing stable isotopes $^{18}O$ and $^{2}H$ and by the radiocarbon dating of Quaternary carbonate sediments.

Should infiltration of precipitation and recharge of ground water be taken for ganted in Central Europe during the stadials under the periglacial climate, then such a hypothesis would have to be supported first by data from regions having similiar sedimentary geological structures as the basins of the Bohemian Massif which at the present time have a periglacial climate. The hydrogeological studies of the present - time periglacial climate in the Arctics seem to provide a clue to the knowledge of the paleohydrogeological conditions of the Central Europe.

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## DATOWANIE METODĄ $^{14}C$ WÓD GRUNTOWYCH NA TERENIE CZECHOSŁOWACJI I PALEOKLIMATYCZNA INTERPRETACJA POCHODZENIA WÓD GRUNTOWYCH EUROPY ŚRODKOWEJ

**Streszczenie**

Wyniki datowania metodą $^{14}C$ wód gruntowych z różnorodnych głębokich struktur geologicznych w Czechosłowacji zostały podsumowane w formie statystycznej. Oszacowany wypadkowy czas przebywania wód gruntowych przekracza zwykle jeden rok hydrologiczny. Pochodzenie wód gruntowych może być stosunkowo dokładnie powiązane z powszechnie znanymi skalami chronostratygraficznymi. Wody gruntowe różnorodnych struktur hydrogeologicznych nie są związane ze współczesnym cyklem hydrologicznym, lecz należą do znacznie dłuższych cykli hydrologicznych, które zostały zapoczątkowane w geologicznej przeszłości w znacznie różnych warunkach klimatycznych i prawdopodobnie przy zupełnie innych warunkach obiegu wód gruntowych. Fakty te wskazują, że należy zrewidować obowiązujący dotąd pogląd, że wody gruntowe należą do zasobów naturalnych łatwo odnawialnych.

## РАДИОУГЛЕРОДНОЕ ДАТИРОВАНИЕ ГРУНТОВЫХ ВОД ЧЕХОСЛОВАКИИ И ПАЛЕОКЛИМАТИЧЕСКАЯ ИНТЕРПРЕТАЦИА ИХ ПРОИСХОЖДЕНИА В ЦЕНТРАЛЬНОЙ ЕВРОПЕ

Резюме

Автор делает попытку систематического представления и интерпретации результатов радиоуглеродного датирования грунтовых вод из разных глубоких гидрогеологических структур Чехословакии. Оцениваемое среднее время пробывания грунтовых вод как правило провышает один гидрогеологический год. Происхождение грунтовых вод может быть сравнительно однозначно

связано с общепринятыми хроностратиграфическими шкалами. Обнаружено, что грунтовые воды различных гидрогеологических структур не связаны с современным гидрологическим циклом, но принадлежат к значительно более длинным гидрологическим циклам, которые начались в прошлом в других климатических условиах и, по видимому, при разных условиах кружения грунтовых вод. Эти обстаятельства указывают, что нужно изменить общепринятое утверждение что грунтовые воды принадлежат к классу скоро восстанавливаемых натуральных ресурсов.