# U-Series Dating of Speleothems Relevant to Cave Art

« The caves, those large cavities peculiar to limestone rocks, cut away by millennia of rainwater, have been favoured haunts of prehistoric man ».

## Introduction

A slight introduction is necessary before one goes on to explain the application of Uranium/Thorium (U/Th) to dating of caves dated within a range which encompasses the great cave paintings era of the Upper Palaeolithic.

Most of the applications of U/Th to caves have been concentrated on the Middle ($\simeq$ 150000 to $\simeq$ 40000 yrs BP) and Upper Palaeolithic ($\simeq$ 40000 to 10000 yrs BP). It is in the Upper Palaeolithic starting possibly as early as 38000 yrs BP that cave art both decorative and magical in character, develops. Along with the ceremonial burial of his dead, man at this time demonstrates how far he has progressed in conceptual thought. However, throughout this and the preceding period, he remains at the mercy of his environment (fig. 1).

Indeed, before the advent of absolute dating techniques, environmental changes in the « macro » scale provided the basic criteria with which quaternary scientists could provide a relative chronological scale.

Perspective and chronology for the Palaeolithic period is supplied by a series of vast climatic changes. Four main ice ages, called glaciations, are divided by warm periods called interglacials. Several sets of names are available for these. During times of favourable occupation Palaeolithic man lived and hunted.

The various tool types and remains found in deposits representative of different interglacial events provide a basic typology representing implements which range from the rudimentary pebble tools (starting around 2.6 million years ago in East Africa) to handaxes in the Middle Palaeolithic and blade tool and burin industries in the Upper Palaeolithic.

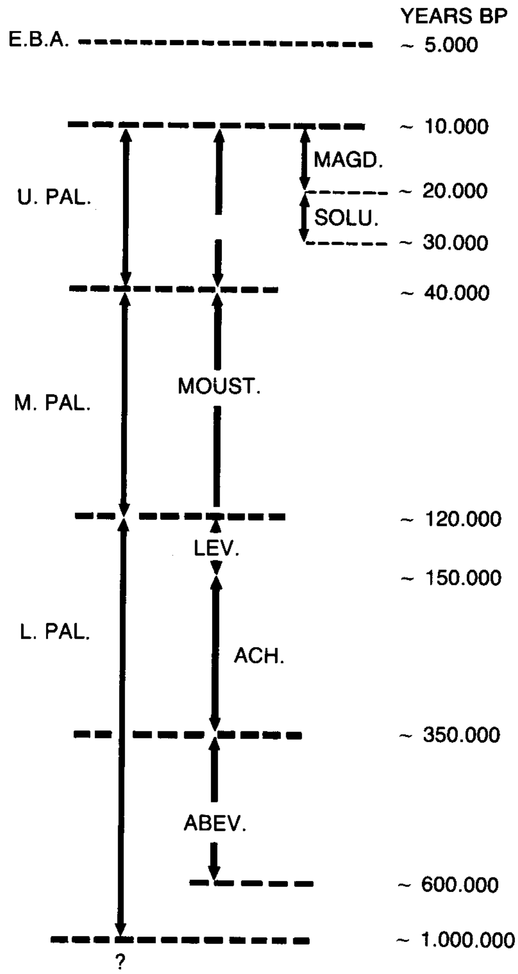


*Fig. 1. Approximate time scale of Prehistoric tool cultures in Europe. Abbreviations are : EBA = Early Bronze Age, U, M, L, PAL = Upper, Middle, Lower Palaeolithic, MOUST = Mousterian, LEV = Levallois, ACH = Acheulean, ABEV = Abevillian, MAGD = Magdalenian, SOLU = Solutrian.*

Often confusion is produced from the lack of some absolute dating method and nowhere is this more obvious than in the Middle-to-Upper Palaeolithic transitional phase. This is because the problem does not relate simply to the chronological changes in tool typology, but because the tool types of the Middle Palaeolithic are the work of a different species of *Homo*, that is *Homo erectus Neanderthalensis*, whereas the species which abruptly takes over at the begining of the Upper Palaeolithic is *Homo sapiens sapiens (Cro-magnon)*, the cave artist.

The tool culture of Neanderthal man is *Mousterian*. Its origins are still imperfectly understood. Often Neanderthal man would employ some of the techniques which originated in the preceding cultural phase, the *Levallois* phase. In such cases, the industry which resulted was simply called *Levallois-Mousterian*. The Mousterian type variants are three and differ for west and east of Europe.

The concern and focus of U/Th dating applications in archaeology is on the dating of different Palaeolithic cultures in various parts of the world and on the boundary between Middle and Upper Palaeolithic.

Dating of tools and primitive art of Middle and even Lower Palaeolithic helps probably in the understanding of art mobilization to later cultures as well. The object of dating, after all, a cave mural, is to date the cave painters, if not the cave paintings.

## A. THE BASIC PHENOMENA USED FOR DATING

### 1. FORMATION OF SPELEOTHEMS

The daughter isotopes of the uranium (U) and thorium (Th) are used to date speleothems *i.e.* stalagmites, stalactites, flowstones and travertines.

Three methods are used : 230-Th/234-U, 231-Pa/235-U and 234-U/238-U. These three ratios are each a measure of the age of a calcitic deposit.

In order to obtain a picture of the whole procedure, which leads to the development and dating of a speleothem, let us first examine the following schematic diagram (fig. 2). It is quite self-explicable : Rainfall precipitates-the water seeps into the soil, where it interacts with $CO_2$ which itself derives from a) organic matter in the soil, b) respiration of atmospheric $CO_2$ by the soil and c) acquisition of $CO_2$ from the chemical reaction of

$$C_6H_{12}O_6 + 6O_2 \rightleftarrows 6\ CO_2 + 6H_2O \quad (1)$$
$$hv\ \text{(photosynthesis)}$$

The boundary of the two media — soil and limestone — is basically a « closed system », in the sense that no flow of $CO_2$, $H_2O$ or U, Th isotopes occurs.

However some points, such as fissures and cracks, in the limestone rock, create small sections where there is an open system. It is through these cracks that the rainfall flows, seeping through $CO_2$ and U, Th in the overlying sediments and so on down into the limestone environment which is $CaCO_3$. The chemical reaction that takes place in this case then is :

$$H_2O + CO_2 + CaCO_3 + [UO_2\ (CO_3)_3] \rightleftarrows 2HCO^-_3 + Ca^{2+}\ \text{(or}$$
$$Ca(HCO_3)_2) + [UO_2\ (CO_3)_3] \quad (2)$$

calcium bicarbonate.

This equation shows the formation of stalagmitic materials carrying uranium ions (see fig. 2).

This carbonate bearing solution enters the caves and precipitation of $CaCO_3$, with some ions and U isotopes, is brought about by :

i : diminution in the amount of $CO_{2'atm.}$ present
ii : evaporation of $H_2O$
iii : bacterial or organic action and presence of certain ions.

There are various forms of speleothems depending on the shape of calcitic deposits which are formed from either dripping (stalactite, stalagmite) or running water (travertine, flowstones, rimstones). Of particular interest of our topic will be the flowstones and rimstones. Water flowing down the walls of caves or over the floor can produce flowstones in which the crystals are orientated perpendicular to the surface of deposition (see eq. 2 and fig. 2). If the surface is not smooth (irregularities), rimstones are formed. Flowstones formed in caves are normally crystalline, usually layered or bedded. When they occur in substantial deposits, they are known as travertines.

Having described the formation of the calcitic deposits or speleothems in caves, let us now see, how they can help in dating of materials and art of palaeoanthropological and archaeological significance. Figs. 2,6 show also various cases in which a human material may lay with respect to different calcitic forms which have been already mentioned above.

a. Cave wall paintings or engravings-partially covered by flowstone (Man in cave Art).
b. Bone or human tools covered by stalagmite or travertines.
c. Bones or human tools interlying between cave sediments and enclosed by two travertine layers.
d. Sandwich of bones or implements with stalagmitic material.
e. Partial coverage of a human skull by stalagmite.

## B. THE DATING METHOD AND TECHNIQUES

### 2. Dating of a speleothem

The isotopes of U series are the only ones that precipitated together with the carbonate bearing solution ; that is, the water which seeps through rock fissures. The Th isotopes do not get absorbed. However for other reasons Th is present in most travertins (see below).

Once a calcitic deposit is formed it becomes a closed system. This means the U starts to decay radioactively acting like a radioactive clock which is set at zero when the calcite is formed. The U decays slowly and in so doing the daughter products are formed (eq. 3). Measuring the U, Th daughter products today it gives basically the age of the speleothem formation.

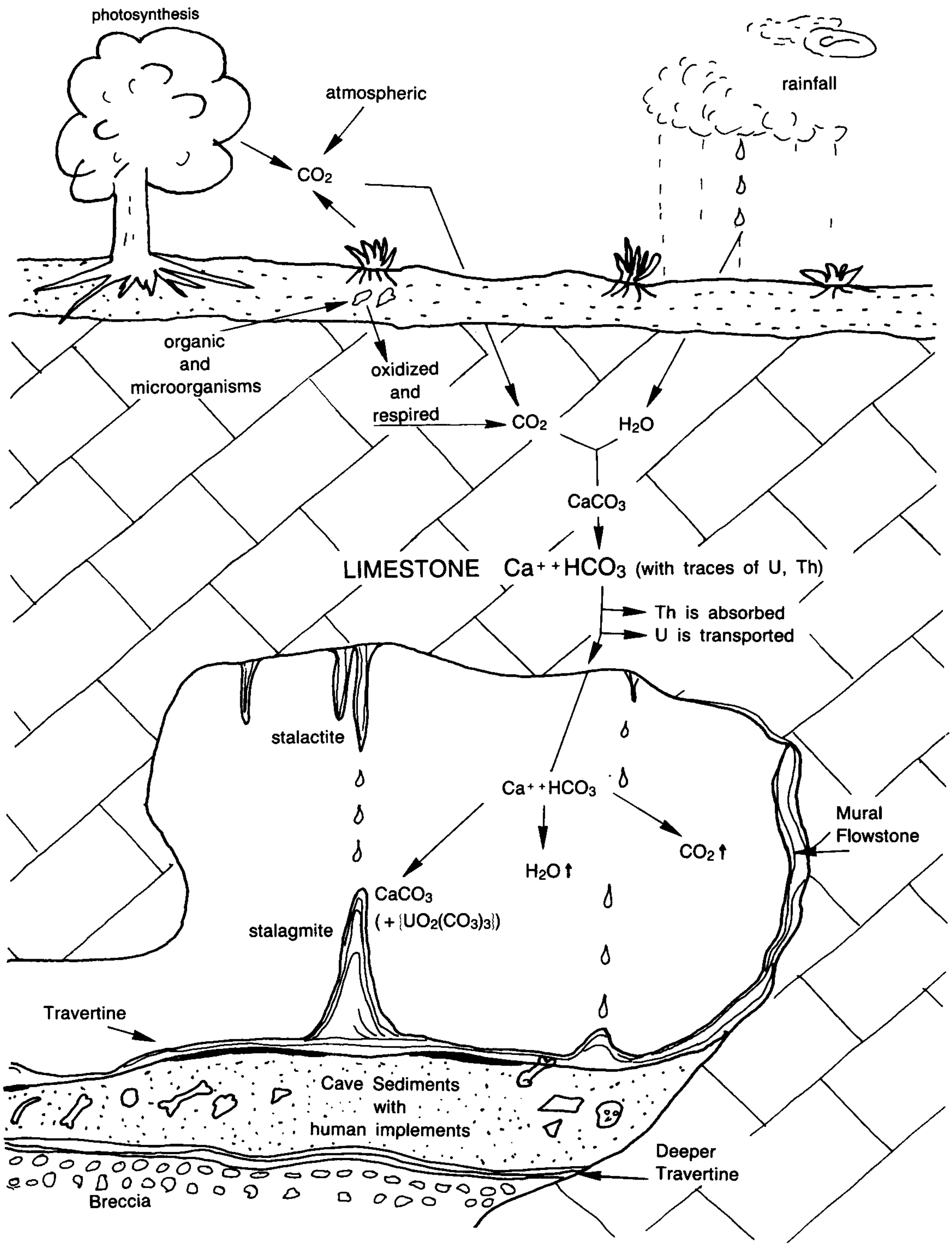


*Fig. 2. Schematic diagram of speleothem formation and human activities in caves.*

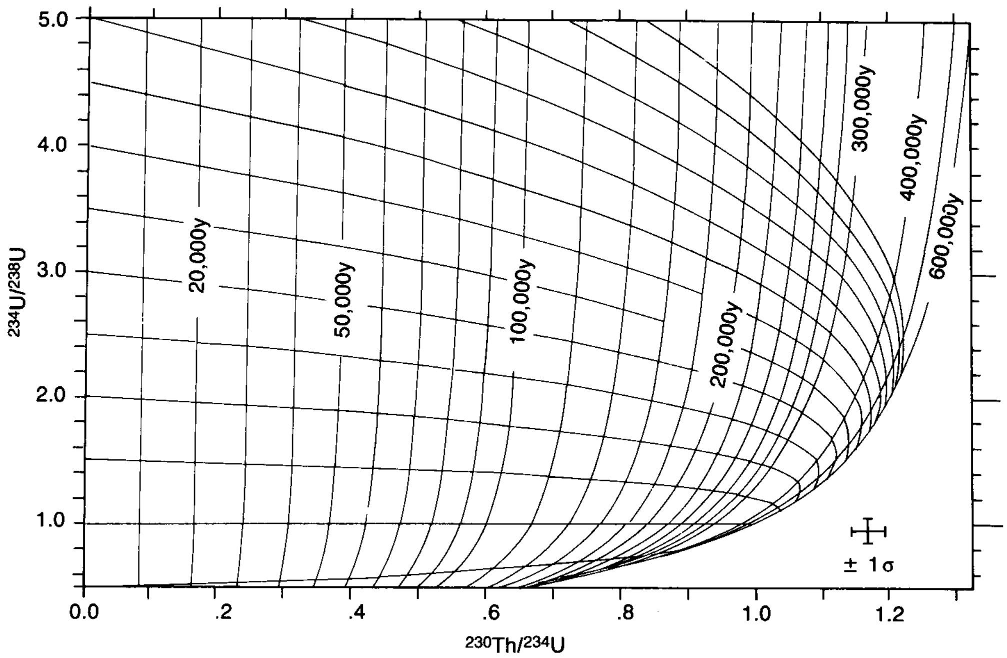


*Fig. 3. Isochron plot for « closed system » speleothems which contain initially U but no Th : The almost vertical lines are the isochrons* i.e. *the pairs of the two ratios that fall on these lines correspond to the same age of* e.g. *20.000, 100.000 yrs etc.*
*The age is found if one knows the pair of the two ratios, in the ordinates. For example for* $^{230}Th/^{234}U$ *= 0,85 and* $^{234}U/^{238}U$ *= 1.4 the age will be about 180.000 yrs.*
*The errors — lower right — are typical for such analyses containing 0.5-1 ppm U (Schwarcz* et al. *1980).*

The radioactive decay of U and Th is :

Parent $\longrightarrow$ Daughters...

a. U-238 $\xrightarrow[4.5 \times 10^9]{}$ U-234 $\xrightarrow[2.5 \times 10^5]{}$ Th-230 $\xrightarrow[7.2 \times 10^4]{}$ Ra-226 $\xrightarrow[1602]{}$

...... $\longrightarrow$ Po-210 ......

b. U-235 $\xrightarrow[7 \times 10^8]{}$ Pa-231 $\xrightarrow[3.2 \times 10^4]{}$ ....

c. Th-232 $\xrightarrow[1.4 \times 10^{10}]{}$ Th-228 $\xrightarrow[1.9]{}$ Ra-224 $\rightarrow$ ... $\rightarrow$ Po-212 ...(3)

The numbers (in years) are the half-lives of the left isotopes *i.e.*, the time that is required for half-the-nuclei of these isotopes to disintegrate. This quantity of time limits the time span of applications. These limits are : for the $^{230}Th/^{234}U$ method around 300-350.000 years, for the $^{231}Pa/^{235}U$ around 200.000 years, and for the $^{234}U/^{238}U$ around 1.5 million years.

The three methods of the U-series disequilibrum used to date speleothems are given in Table 1. Fig. 3 shows the relation between $^{230}Th/^{234}U$ and $^{234}U/^{238}U$ for closed systems, with varying initial U ratios. This figure is pertinent to the 230-Th/234-U dating method which is most widely used.

TABLE 1

Method : $^{230}Th/^{234}U$
Time range (yrs) : 1000-350.000
Formula :

$$\left(\frac{^{230}Th}{^{230}U}\right)_t = \left(\frac{^{230}U}{^{230}U}\right)_t (1 - \exp(-\lambda_{230}t))$$
$$+ \frac{\lambda_{230}}{\lambda_{230} - \lambda_{234}} \cdot \left(1 - \left(\frac{^{238}U}{^{234}U}\right)_t\right) \cdot (1 - \exp((\lambda_{234} - \lambda_{230})t)) \quad (4)$$

Comments : The λ's are the decay constants of the respective isotope *i.e.* $\lambda_{230}$ of the $^{230}Th$ and so on.
Initially the speleothem contains no $^{230}Th$.

Method : $^{231}Pa/^{235}U$
Time range (yrs) : 1000-200.000
Formula :

$$\left(\frac{^{231}Pa}{^{230}Th}\right)_t = 21.7 \left[\frac{1 - \exp(-\lambda_{231}t)}{(1 - \exp(-\lambda_{230}t)) + (r - 1)\,\frac{\lambda_{230}}{\lambda_{230} - \lambda_{234}}\,(1 - \exp(\lambda_{234} - \lambda_{230}) \cdot t)}\right] \quad (5)$$

Comments : r = $^{234}U/^{238}U$. The maximum $^{231}Pa$ activity observable in a given sample is only 1/21.7 times $^{235}U$ activity.

Method : $^{234}U/^{238}U$
Time range (yrs) : some thousands to 1.5 million
Formula :

$$\left(\frac{^{234}U}{^{234}U}\right)_t - 1 = \left(\left(\frac{^{234}U}{^{234}U}\right)_o - 1\right) \cdot \exp(-\lambda_{234}t) \quad (6)$$

Comments : $(^{234}U/^{238}U)_o$ = the initial ratio at the time of deposition.
This ratio must be known in order to use this method.

## 3. Radiochemical analysis

The extraction of U and Th from pure calcites presents a few problems, most of which concern the detrital or contaminated calcitic deposits. The chemical elements that are precipitated when a sediment-free solution loses $CO_2$ (outgasses) are those which form stable carbonates from bicarbonate solution *e.g.* Ca, Sr, Fe, Mn.

Many elements that are picked up in solution as a result of acid leaching in soil zone e.g. Si, Al, Na, K, will remain in solution when $CaCO_3$ is precipitated. A detrital calcite will contain soil particles and this imposes serious problems into the dating, as the condition of « closed system » is no longer valid and Th isotopes will participate in the initial calcitic deposit. The object of the chemical separation is to extract radiochemically pure U and Th from the $CaCO_3$ sample (fig. 4).

The ratios of eq. 4, 5, 6 are thus determined. Some samples contain appreciable amounts of 232-Th, indicating that 230-Th had probably also

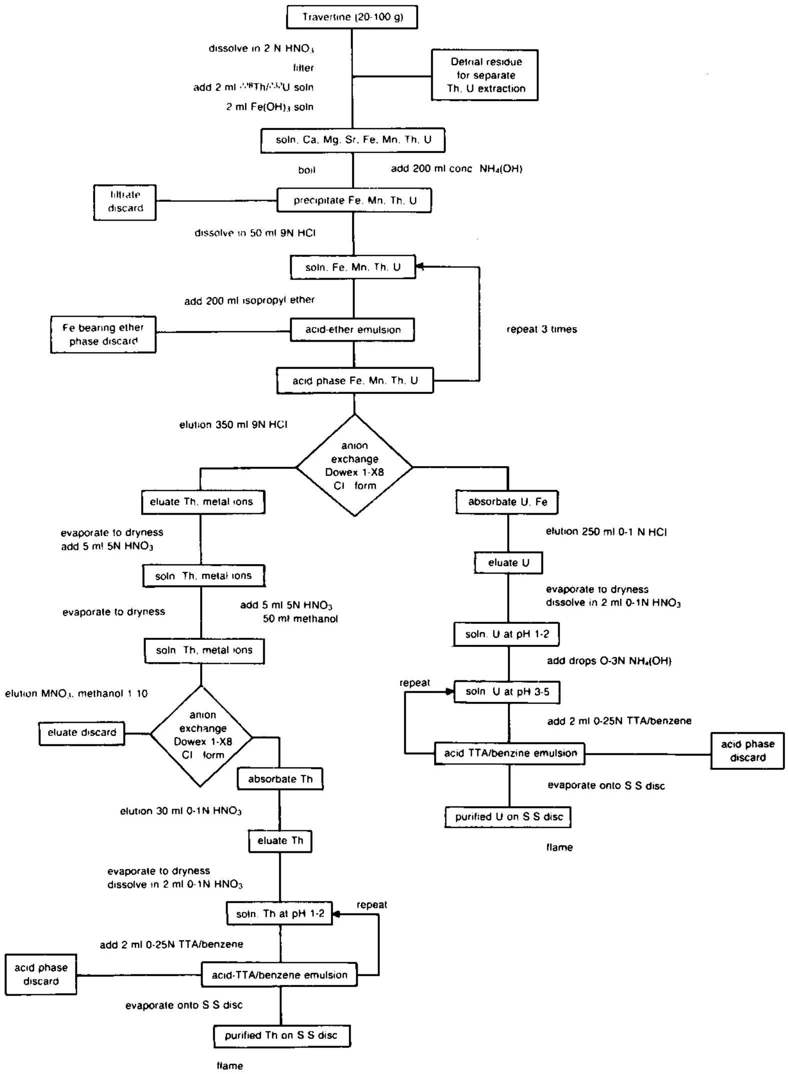


*Fig. 4. Stepwise procedure for the radiochemical analyses of calcites (Liritzis and Galloway, 1981).*

been deposited along with the speleothem, 230-Th, 231-Pa, 234-U isotopes that derive from the detrital phase of the carbonate, mixed with similar isotopes of the carbonate itself produce incorrect age results. Attempts to correct for this effect have been made (Turekian and Nelson 1976, Schwarcz 1979, 1980, Ku *et al.* 1977, Liritzis and Galloway 1981). Such contamination of calcites is the most serious problem in dating.

## 4. Alpha - Spectrometer

Once the chemically purified U and Th from each speleothem sample is plated out in stainless steel discs, it is alpha counted in an a-spectrometer, appropriately calibrated. Under vacuum conditions, the decay of the isotopes of interest $^{232}$Th, $^{230}$Th, $^{234}$U, $^{238}$Th, $^{232}$U, $^{231}$Pa, produce alpha particles which strike the surface barrier semiconductor detector with a characteristic energy.

This signal is analysed to produce a composite energy spectrum as illustrated in fig. 5. Peak amplitudes are related to the concentration of each isotope present and these peak ratios, corrected for background, are a direct measure of activity ratios.

## 5. Age programme errors

The Th and U isotope spectra accumulated in the multichannel analyser are fed into the computer for further processing. The errors in the age involved depend on the counting statistics. The magnitude of the errors are inversely proportional to the square root of the length of counting time.

The computer programme routine calculates the age of the sample, making the necessary corrections pertinent to the reduction of data that were fed to the computer.

The statistical « Newton method » of successive approximation is used, that is, the programme executes repeated age approximations with the iterative procedure where an estimate of the age (t) is used to calculate the true age of the sample (t*), and this is repeated until two consecutive age determinations differ by less than 0.1 %.

Errors in the precision and accuracy of a U/Th age can be the result of mainly four factors :

a. analytical error in the chemical procedures
b. statistical counting errors
c. spectrum resolution (fig. 5)
d. possible post depositional migration of U and Th in or out of the speleothem sample
e. an initial contamination of a speleothem with detrital U or Th, *e.g.* from the cave sediments.

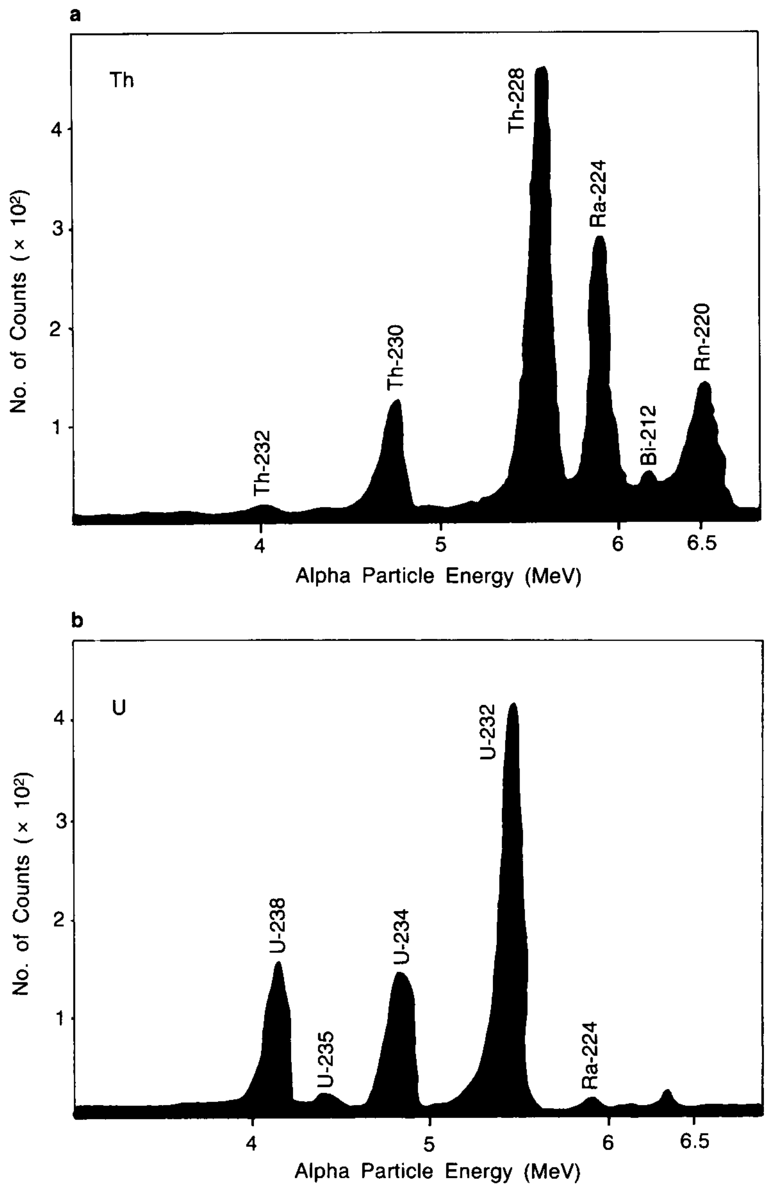


*Fig. 5. Typical alpha spectra from speleothems (Liritzis, 1979) a) for thorium ; b) for uranium.*

For ages greater than 350.000 yrs an approximate age may be readily determined either by using the isochron plot of fig. 3 together with the error of the associate isotope ratios as calculated by the computer programme, or, by the $^{234}U/^{238}U(= r)$ method, provided that the initial (r) ratio is known.

Examples of dating programmes are given in PART C.

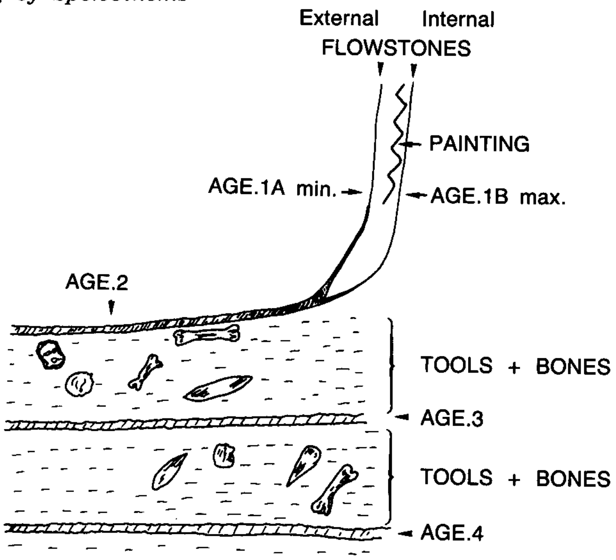


*Fig. 6. Cave paintings and engravings. A possible situation.*
*Ages 1A, 1B are for wall flowstones.*
*Ages 3,4 are for travertines.*
*The ages obey a stratigraphical order, whereas the age (t) of the painting/engraving lies between two time limits, as follows :*
*Age.1A = Age.2*
*Age.2 < Age.3*
*Age.3 < Age.4*
*if Age.1B ⩽ 3, then Age.1A < t ⩽Age.1B*
*if Age.1B > 3, then Age.1A <t < Age.3 (smaller time span).*
*That Age.1A is the minimum age and the maximum depends on the chronological relation of Ages.1B, 3, 4. The mural picture lies between the two time limits. (Age.1B = Age.3, when the same flowstone layer forms these two deposits).*

## 6. Suitability of speleothems of archaeological significance for dating purposes

The suitability of a speleothem for dating purposes depends on many factors :

a. Degree of purity of a calcite. Contaminants in calcites can range from organic material (bone) to clays.
b. « Soil zones » *i.e.* presence of detrital U, Th in calcitic zones that might relate to climatological events. These isotopes are of detritus origin and give incorrect ages for the respective calcitic horizon.
c. Signs of post deposition, submersion or resolution (*i.e.* disturbance of the radioactive series from 238-U to 226-Ra) of stalagmitic materials that cause the input or output of certain radioisotopes.
d. Closed system conditions, where, at the time of formation the ratios $^{230}Th$ and $^{226}Ra$ to $^{234}U$ are negligible, thereafter the daughter products are formed from the decay of the uranium isotopes (eq. 3).

e. How the archaeological material in the context is related to the history of the speleothems *e.g.* bones, tools, engraved or painted walls etc.
f. Sufficient U must be present ($\geqslant$ 1 ppm *i.e.* 1μg U in 1 g stalagmitic material).
g. The isotopic disequilibrium ratios must exhibit a progression towards secular equilibrium with time and be consistent with stratigraphic relationships.
h. The sample should show no evidence of recrystallization which may cause loss or enrichment of either U or Th radionuclides.
i. Avoid porous materials, where possible leach of radioisotopes might have occured.
j. The obtained age result should agree with ages determined by other methods, if possible, e.g. TL, ESR, $^{14}C$, or be crosschecked by intercomparison with other laboratories or at least to follow a stratigraphic order.

Having described the method of dating and the steps taken to obtain an age result, I will now describe examples of characteristic applications.

## C. APPLICATIONS

### 7. Dating applications

Bearing the background outlined in the introduction and the incredible significance of the transition phase with which we are dealing, let us look at some of the applications of U/Th to caves of the Middle/Upper Palaeolithic age range.

As no single cave wall painting or engraving has been dated by U/Th (though these exist, such in Pyrenees and France, Australia) I will simply set the scene for such a future possibility. We will show how to date the artist if not his work. Some cases : for the cultural transition from *Homo erectus* to *Neanderthal* for the Neanderthalian timespan, and of Mousterian art.

1. La Chaise, Charente, France, Artefacts in the detrital sediments between travertine layers correspond to late Lower Palaeolithic and Middle Palaeolithic industries. The lowest travertine yields an age of 185.000 ± 30.000 yrs BP. Pre-neanderthal hominid skeletal remains occur just above this layer. The middle layer is 145.000 ± 16.000 years old. Immediately below was found an early neanderthaloid mandible. Above this occurs a sequence of beds containing a Mousterian industry, with an age of 106.000 ± 10.000 years BP. The U-series age for this cave was 185 to 106.000 years BP, during which time it was almost continuously occupied by hominids (Schwarcz and Debenath 1979).

2. The Western Mousterian industry is little known. Evidence for it stretches from Italy to the USSR right across Siberia. As evidence in the case of the West Mousterian is less clear than for Eastern Mousterian or Levallois Mousterian, any dating for Mousterian industries in this great expanse of era is very important.

   Schwarcz and Skoflek (1982) dated Mousterian remains from the site of *Tata* in Hungary. This site has evidence of Neanderthal man's creativity in art, not the cave wall art of his successor in the Upper Palaeolithic, but in a mobile art form - in the form of a carved piece of mammoth tool and inscribed *amulets.*

   *Amulets* are known from other prehistoric communities as symbols worn to ward-off evil, as for example the holy cross today, so this piece of art, just like the wall paintings of Upper Palaeolithic man had an artistic and magic/spiritual/religious significance.

   From the dating of Tata the age of this site was first determined by C-14 analysis of charcoal from the cultural level. The age of 55.000 ± 2.500 years BP lead some to assign the cultural material to the Middle Mousterian, while palaeontological data indicate that this site was occupied towards the end of the last interglacial. Two single U/Th ages on travertines from this site yielded indeed dates of 116.000 ± 16.000 and 70.000 ± 20.000 years, both of which are more consistent with present estimates of the time interval that corresponds to the last interglacial (125-90.000).

   Further U/Th dates showed that the site was occupied at around 100.000 years BP. This confirms that the amulet from this site is one of the eldest decorative artefacts known and was presumably created by *Homo sapiens neanderthalensis.*

3. Pech de l'Aze is a group of caves and rock shelters near Sarlat in the Dordogne district of south-west France. In Pech I there occurs a remanent of breccia, containing Mousterian (Middle Palaeolithic) artefact, overlying a travertine layer. The $Th^{230}/U^{234}$ method was used to date the travertine. The age obtained was 123.000 ± 15.000 years BP. This result is consistent with geological an palaeontological evidence of sediments filling the cave (Schwarcz *et al.* 1981).

4. Ehringsdorf Quarry, Weimar, G.D.R. The site of Ehringsdorf gives evidence through its animal and plant remains, that it was fully interglacial in character. It thus dates to the last interglacial. It has East Mousterian associated implements. Parts of this quarry are covered by travertine. U/Th dating was applied by Blackwell (Schwarcz, 1980). The ages obtained from a travertine sequence tanged from 205 ± 90 × $10^3$ years BP for the lower layer and 146.000 ± 30.000 years for the upper layers.

5. Nahal Mor, Israel. At Nahal Mor, tools associated with the transitional cultural phase from Middle to Upper Palaeolithic were found, embedded in a block of travertine which had fallen on the wall of the canyon, where a spring had once flowed. Layers of pure travertine just above and below the tool-bearing layer yielded a concordant $Th^{230}/U^{234}$ age of 46.500 ± 2.900 year BP. This is in excellent agreement with minimum estimates of the age based on $^{14}C$ dates on charcoal from a nearby site in the valley of 45.000 ± 2.400 BP (Schwarcz *et al.* 1979).
6. In Umm Quatafa, Judea, a few Levallois-like flakes associated with a stalagmite that was dated, yielded an U/Th age of 175.000 ± 19.000 years BP, Schwarcz *et al.* (1979) ; while in Israel, too, speleothems and spring deposits associated with tools of Acheulean, Levallois to Mousterian types were dated with obtained ages of 45.000 ± 2.400, 80.000 ± 10.000, and 258.000 ± 66.000.
7. Caune de l'Arago, France. Cultural and hominid skeletal remains in the site were dated via their associated travertines by Turekian and Nelson (1976), De Lumley *et al.* (1978). Their dates swayed from 100.000-145.000 years BP.
8. Petralona Cave, Chalkidiki, Greece. An early hominid skull was found in the cave encrusted in travertine. Samples believed to be from the same layer which encrusted this skull were dated by 230Th/234U, Schwarcz *et al.* (1980), Hennig *et al.* (1980, 1981), while other dating methods were applied too, *e.g.* TL, ESR, palaeomagnetic, aminoacid, palaeontological, phylogenetical (Liritzis, 1982).

   The palaeoanthropological significance of this skull regarding its peculiar morphological traits and the lack of controlled excavation enchanced the dispute over the *tempo* and *mode* of hominid evolution and made the Petralona case to be widely discussed.

   From the unearthed findings this « archanthropos Petraloniensis » could have been existing at least 240.000 years and human activity through lithic and bone tools, traces of fire, as well as faunal remains, were present at 300-350.000 years and around 700.000 years ago. These data suggest that the skull belongs to the transition of the human species from *Homo erectus* to *Homo sapiens*, perhaps a very *early Homo sapiens.*
9. Case of dating actual mural paintings and engravings :

   Such cave-art can be dated by the U/Th series described in Parts A and B above (fig. 2). The inner layer of a flowstone being in contact with or partially covering, this art, provides the minimum age for the mural work (fig. 6). By dating other interstratified layers of travertines or flowstones on the cave's floor or deep strata whereas human bones or implements were found related possibly to the cave habitation one can define narrow time limits that date the cave art.

## 8. CONCLUSIONS

It is possible to estimate the age of speleothem deposits, where $CaCO_3$ has been deposited from cold spring or cave seepage waters onto or below archaeologically significant materials. The method of dating is based on the degree to which 230-Th and 231-Pa have grown into equilibrium with their respective parents 234-U and 235-U. In cases that such calcitic deposits contain uranium between 1-2ppm a dating range from recent times to 350.000 yrs can be obtained.

The two principal problems encountered with this method are :

a. the porosity of the samples with the subsequent enrichment or leach of certain U, Th isotopes and
b. the presence of detrital material (clay, bone, limestone) admixed with the carbonates, mainly the travertines.

The monitoring of these problems can be made employing the microscope, thin section, X-rays, fission track mapping analyses and by applying appropriate correction techniques. The application of the U-series methods has provided sufficient enough understanding into the cultural and biological evolution of man over the lost 200.000 years at sites in Europe and Asia.

Recent applications of these U/Th methods are coupled with the newly developed and promising dating techniques of TL, ESR and $^{14}C$ with tandem or Van de Graaff accelerators, for comparison purposes.

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## GLOSSARY

*Isotopes* = chemical elements that are not consisted from one kind of atoms but from atoms with different atomic weights and similar atomic number *e.g.*, carbon has three isotopes : C-12, C-13, C-14, hydrogen has three : H-1, H-2, H-3, uranium has U-234, U-235, U-232, U-238.

*Isotopic Disequilibrium* = when the activity (disintegration per unit time) of an isotope in a radioactive series is the same with the activities of all other isotopes, this state is called secular equilibrium. The opposite is the isotopic disequilibrium and occurs when an isotope is enriched or deficient with respect to the others of the same series.

*TL* = abreviation for the dating method of thermoluminescence *i.e.* the emission of light from heated crystals.

*ESR* = abbreviation for the dating method of electron spin resonance i.e the measurement of the number of unpaired electrons trapped in paramagnetic sites of the crystal lattice.

$^{14}C$ = abbreviation for the dating method of radiocarbon.

*Pleistocene* = geological epoch (10000-1.5 million years).

*Ice Ages* = the periods during which continents were covered with ice sheets. It is a recurrent phenomenon in the earth's history. The alternations in the occurrence of ice are called glacial and interglacial periods. The last glaciation is called Würm that started at around 80.000 yrs and finished at about 10.000 yrs before present. During this period human types are represented by *Neanderthalian* and the *Homo sapiens sapiens* cultures.

*Radioactive decay* = the spontaneous decay of some atoms producing other isotopes.