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NOTES AND COMMENTS

DISCUSSION
COMMENTS ON MULTIPLE DATING OF A LONG FLOWSTONE PROFILE

RAINER GRÜN and HENRY P SCHWARCZ
Department of Geology, McMaster University, Hamilton
Ontario, Canada

We strongly welcome the investigation by Geyh and Hennig (1986) and agree with their conclusion that the boundaries of the interglacial periods cannot be determined exactly using the methods applied so far in the Heggen cave. However, since we have been engaged for several years in the application of these methods (except ^{14}C), and since the paper gives a very different interpretation of the ESR results from that presented by one of us (Grün, 1985), we feel the need to make some comments on this paper.

Samples were collected in the Heggen cave during three campaigns. First, samples were taken for paleomagnetic study (see Fig 1: A1–E31; circles), which were additionally investigated by U-series (Peters, 1981) and ESR. During a second visit to the site, the profiles HA and HB were cut and later studied by ESR only. Subsequently, a third profile was cut near the sample locations A1–B9 and studied by Geyh and Hennig. As can be seen in Figure 1, the numbering of the samples in series A–E does not coincide with the numerical sequence of series HA or HB. Although Geyh and Hennig propose to use the paleomagnetic sequence as an indication of the rate of deposition, the different numbering in the respective sample profiles might have led to some confusion. The Brunhes/Matuyama boundary was, in fact, observed between samples C18 and C19 at a depth of ca 60cm and not between samples HA17 and HA18 at a depth of 70cm, as cited by Geyh and Hennig. Unfortunately, the scale in Figure 1 of their paper does not agree with the depths quoted in Table 1. Therefore, it is rather difficult to determine from where the samples for ^{14}C and U-series dating were taken.

ESR DATING

The naive reader might get the impression from the discussion by Geyh and Hennig that ESR is anything but a dating method. We would like to clarify the presentation of the data and to suggest an alternate explanation.

The whole profile can be subdivided into 13 units. The correlation of the different sample sites is shown in Figure 1 (Fig 1 of Geyh & Hennig shows an area to the right of profile HB). The upper parts of profiles HA and HB were connected to the ceiling with calcite drapes. The ESR results for these samples (HA1–HA3a and HB1–HB4a1) therefore scatter quite randomly and are not included in the following discussion. We shall limit our further discussion to the upper part of the deposit (Units 1–5). The problems of ESR dating in the lower part (recrystallization, U-mobilization, alpha-paleodose, etc) are discussed elsewhere in detail (Grün, 1986).

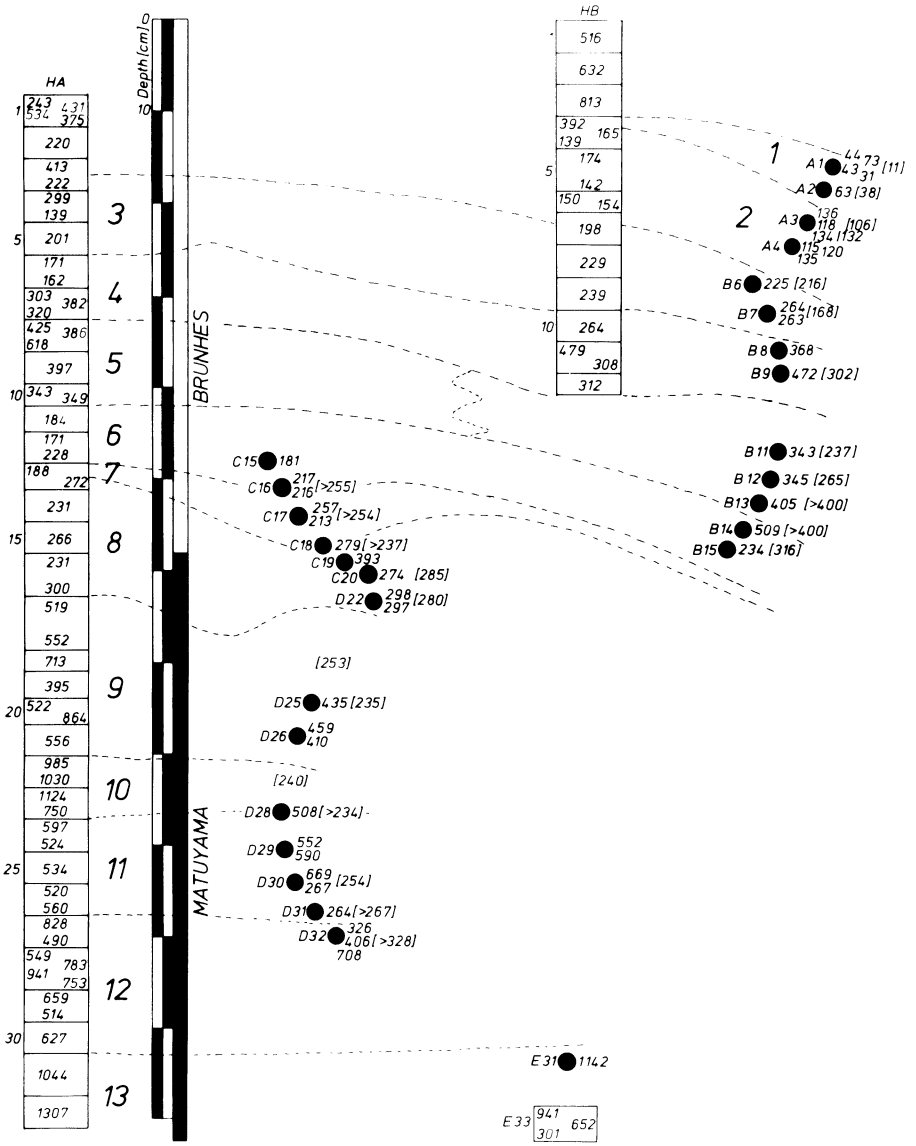

Fig 1. (Fig 76 *in* Grün, 1985). Schematic presentation of the sampling sites with U series (Peters, 1981; in brackets) and ESR age results (Grün, 1985). ● = samples for NRM: – – – = correlation of the samples according to the speleothem layers.

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We can roughly correlate between the sequence of ESR samples and Geyh and Hennig's sequence as follows:

ESR sequence	Geyh and Hennig
Unit 1: A1–A2	Layer 1–2
Unit 2: A3–A4, HB4a2–HB6B	Layer 3–4
Unit 3: B6–B7, HA3B–HA5, HB7–HB9	Layer 5–7
Unit 4: B8–B9, HA8–HA10, HB10–HB12	Layer 8–9
Unit 5: B11–B13, HA8–HA10	Layer 10–12

Geyh and Hennig present, in their Figure 2, the "scattering of AD with depth." It must be noted, however, that the layers given on the x-axis do not correspond to the layers as presented in their Figure 1 and Table 1, but are taken from the HA profile. Also, we cannot reproduce their correlation of the plots, eg, the AD of Sample B9 is plotted together with those for HA4 and HB9, which is obviously wrong (this might be due to the confusion in labeling noted previously). Since the layers of their Figure 2 do not agree with the layers as used for ^{14}C and U series dating, it is not surprising that, as the authors state: "the apparent stepwise increase of the AD . . . does not coincide with the boundaries reflected by the ^{14}C and U/Th data."

More important is the question of the possible significance of the plot of AD *vs* depth presented by the authors. The accumulated dose is only one of many parameters used to calculate an ESR age. Therefore, a plot of AD alone is not very meaningful. For example, the samples with the highest ages (above 1 Ma) have ADs varying between 11.8 to 44 krad and the highest AD (95 krad) yielded an age of only 769 ka. For these reasons, no significant conclusions about the validity of ESR dating can be drawn from their Figure 2.

In our Figure 2 we show the plot of ESR ages *vs* depth for the Units 1–5. The ESR age estimates of ca 40 ka for the upper samples (Holocene

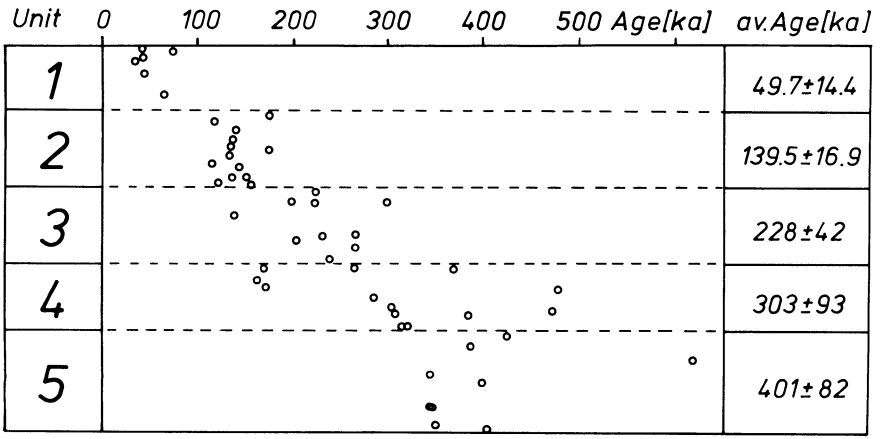

Fig 2. ESR age results for Units 1–5 (see Fig 1).

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according to ^{14}C and U series) are attributed by Geyh and Hennig to the large interlaboratory variation in AD estimates (25 – ≥100%) as shown by the ESR comparison project (Hennig, Geyh & Grün, 1985). If this were an explanation of the four-fold overestimation in age, this systematic error should occur throughout the profile (the laboratory reproducibility for our ESR data was in the range of 10–30%; see Fig 2), but this is obviously not the case. Even though the age data show a scatter of up to 30% (Unit 4), the ESR results of the various units can easily be correlated with the warm stages of the oxygen isotope record. The scatter can be accounted by the failure of one or more of the assumptions made for ESR age calculations: constant alpha-efficiency and $^{234}U/^{238}U$ ratio; closed system behavior (lack of recrystallization or U mobilization). Up to now, we have no reasonable explanation for the high dates of Unit 1 and the slightly high ages for Unit 2 (which should be ca 125 ka). Although we do not insist that Unit 1 is not Holocene, we also do not know whether Geyh and Hennig in fact used the same samples for their measurements. It must be mentioned that the U series results of Peters (1981) on the samples used for NRM yielded 11 ka for A1 and 38 ka for A2; the latter obviously agrees with the ESR results.

Geyh and Hennig further assert: ". . . most of the samples deeper than Layer 2 yielded ESR ages with a range of 200 to 400 ka without an obvious trend towards an increase with depth." It is apparent from Figure 2 that there is indeed a trend of increasing ESR ages with depth (with a correlation coefficient of 0.85). Possible explanations for the scatter are given above. The ESR dates for Units 3 and 4 agree fairly well with the Geyh and Hennig U series results of 216 ± 77 and 300 ± 76 ka, respectively (the age of Unit 5 is beyond the Th/U dating range).

U SERIES DATA

Geyh and Hennig state that the brownish layers might contain clay minerals being pushed from the deeper part into this layer. This should be documented by the presence of a ^{232}Th peak of the alpha spectra. Unfortunately, the authors do not present the isotopic results of the Th/U analyses. For this reason it is also difficult to estimate the reliability of ages for the lower layers, since the $^{230}Th/^{232}Th$ ratio might be so low as to contribute significantly to the error in the age.

STABLE ISOTOPE ANALYSES

As noted by Geyh and Hennig, oxygen isotopic data for calcite deposited in caves can only be used to infer paleoclimatic conditions if the calcite was precipitated in isotopic equilibrium with drip waters. It is, in fact, possible to determine whether this is the case, as pointed out long ago by Hendy (1971). Deposits that satisfy these criteria have been shown to record paleotemperatures in other caves, as shown by several studies in this laboratory (eg, Gascoyne, Ford & Schwarcz, 1981). Essentially, one must test whether the oxygen isotopic composition of a single growth layer is constant over a considerable area of the layer. In cases where this criterion is not satisfied, there is no simple relation between paleoclimate and the isotopic composition of the speleothem. The calcite deposited on such a

speleothem is isotopically out of equilibrium with the cave drip water, and an isotopic profile such as shown by Geyh and Hennig (Fig 3) would depend on such factors as the humidity in the cave, the degree of supersaturation of calcite in the cave, and the position on the speleothem where the profile was taken. Even under conditions of equilibrium deposition, we do not yet know how to interpret profiles of carbon isotopic composition (although pronounced variations such as shown by Geyh and Hennig have been seen in other speleothem records and presumably are somehow related to environmental changes above the cave).

RATE OF SPELEOTHEM GROWTH

The authors also make some claims about the relationship between growth rates of speleothems and climate. We would like to note here that, contrary to these authors, speleothems *can* grow during glacial periods, although normally only in caves located at low latitudes (but may grow even under active glaciers (Gascoyne *et al,* 1983)). Further, the rate of accumulation of calcite on a speleothem is probably not a simple function of climate. It depends principally on the degree of supersaturation of the drip water with calcite, plus the rate of release of CO_2 from the cave atmosphere. These variables can be controlled by such parameters as the depth of soil above the cave, the size (or existence) of an opening connecting the cave atmosphere to the external atmosphere, etc. Temperature alone is not a significant control, except that when the temperature falls below zero, deposition stops. We have studied caves in which deposition continued at an approximately uniform rate until it was apparently abruptly stopped by freezing in the cave (Gascoyne, Ford & Schwarcz, 1981).

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