U-Th direct dating of weathering processes: Preliminary results from the lateritic profile of Yaou (French Guiana)

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Since the development of the thermal ionisation technique (Edwards *et al.*, 1986), U-series have been increasingly used to date corals, marine sediments and hydrothermal carbonates. Attempts to use this approach to date weathering phenomena are much fewer, mainly due to the fact that soils are open systems in which many chemical elements (including U) are readily mobilized. This study focusses on goethite pseudomorphs in the 28 m thick weathering profile of Yaou. The goethite pseudomorphs, which may constitute 'closed' systems for U-series, occur throughout the profile and formed after hydrothermal pyrite disseminated in the bedrock. Detailed description of the Yaou profile can be found in Freyssinet (1994) and oxygen isotopic compositions of goethite pseudomorphs are given in Girard *et al.* (1997).

Analytical procedure

Goethite pseudomorphic cubes were extracted from a single level (−13 m) in the saprolite. They range from *c.* 1 to 10 mg in weight, but all analyses were done on fractions of *c.* 10 mg (Table 1). U and Th were analysed using a MAT 262-RPQ II Finnigan mass spectrometer at BRGM, Orléans. Analytical uncertainty (2σ) is better than 1% for U concentration. Uncertainties on Th isotopic composition and concentration are somewhat higher (typically around 2%) due to the small amounts of Th analysed and the low $^{230}Th/^{232}Th$ activity ratios (Table 1).

U and Th contents and isotopic ratios

U and Th concentrations are comparable from one fraction to another (Table 1). Th contents are 5 to 9 times higher than U contents. $^{234}U/^{238}U$ activity ratios are high and similar for all fractions. This may be related to elevated $^{234}U/^{238}U$ ratios (not measured) of Yaou groundwaters, as documented by Kronfeld (1974) in similar settings. In a first stage, ^{234}U would be preferentially leached from primary minerals, transported by groundwater and trapped in weathering goethites. $^{230}Th/^{232}Th$ activity ratios range from about 1 to 1.5. In spite of this, the goethite pseudomorphs may still be suitable for U-series dating (see below).

U-Th age

Since Th was initially present in goethite, a simple $^{234}U/^{230}Th$ age cannot be calculated, and a $^{230}Th/^{232}Th$ - $^{238}U/^{232}Th$ isochron dating is required (Allègre and Condomines, 1976). $^{230}Th/^{232}Th$ (Y) is related to $^{238}U/^{232}Th$ (X) by:

$$Y = A \times X + Y_0 \times e^{-\lambda 0 * t},$$

TABLE 1. U and Th concentrations and activity ratios of goethite cubes (sample C44-11)

Aliquot	Weight (mg)	Nb. of cubes	U(ppm)	Th (ppm)	$^{234}U/^{238}U$	$^{238}U/^{232}Th$	$^{230}Th/^{232}Th$
1	12.22	3	2.79	20.19	2.947 (16)	0.430 (9)	1.125 (32)
2	12.14	1	2.92	18.88	3.036 (16)	0.481 (11)	1.228 (26)
3	10.35	6	2.15	16.41	2.803 (18)	0.408 (9)	1.083 (28)
4	12.34	3	2.84	15.46	2.976 (16)	0.572 (13)	1.447 (44)
5	11.21	10	2.35	19.17	2.886 (14)	0.381 (8)	0.977 (12)
6	14.72	10	2.24	19.58	2.876 (11)	0.356 (8)	0.975 (26)

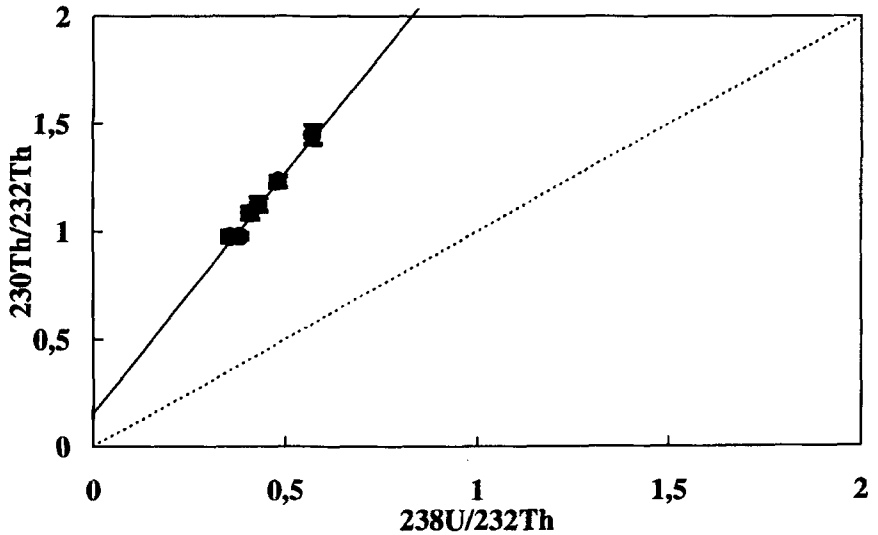

FIG. 1. $^{238}U/^{232}Th$-$^{230}Th/^{232}Th$ isochron diagram for the six goethite fractions. Dotted line = equiline.

where λ_0 is the ^{230}Th decay constant.
In this case however, due to the presence of ^{234}U in excess, A is not only time-dependent but also depends on the $^{234}U/^{238}U$ ratio, and will represent the slope of a straight line only if the $^{234}U/^{238}U$ ratio is the same for all samples. $^{234}U/^{238}U$ ratios of the six goethites from Yaou are very consistent, averaging of 2.92 ± 0.06. Thus A can be considered equal to the slope of the straight line.

The six data points plot on a straight line in the isochron diagram (Fig. 1), suggesting that the U-Th geochemical system may have remained closed since the trapping of U in the secondary goethites. The slope is much steeper than the equiline due to excess ^{234}U. Since the ^{234}U-^{238}U system has not reached secular equilibrium, the straight line can be considered an isochron. Assuming a closed-system evolution, the calculated age is 127 ± 5 kyr, with an acceptable MSWD (3.3 for n = 6) considering the analytical uncertainties on Th isotopic ratios and the ^{234}U-^{238}U average ratio. Calculated $^{230}Th/^{232}Th$ and $^{234}U/^{238}U$ initial ratios are 0.496 ± 24 and 3.741 ± 97, respectively. It is noteworthy that similar informations may be obtained using a $^{230}Th/^{232}Th$ vs. $^{234}U/^{232}Th$ diagram (not represented here).

Conclusion

The 127 kyr age is unlikely to represent the age of goethite precipitation at the weathering front, and proper interpretation must await acquisition of additional data. However, these preliminary results indicate that the U-series constitute a promising tool for direct dating of weathering processes and understanding of profile development. It is foreseen that U-series dating of different horizons or phases within a same profile may lead to direct determinations of weathering rates and their evolution through time.

References

Allègre, C.J. and Condomines, M. (1976) *Earth Planet. Sci. Lett.*, **28**, 395.

Edwards, R.L., Chen, J.H. and Wasserburg, G.J. (1987) *Earth Planet. Sci. Lett.*, **81**, 175.

Freyssinet, P. (1994) *Catena*, **21**, 159.

Girard, J.P., Razanadranorosoa, D. and Freyssinet, P. (1997) *Appl. Geochem.*, **12**, 163.

Kronfeld, J. (1974) *Earth Planet. Sci. Lett.*, **21**, 327.