chromium and nickel, is very difficult to explain on the basis of meteoritic contamination, but could readily result from the presence in the parent material of clay or accessory minerals, containing these elements².

The possibility of two distinctive australite compositions needs further investigation, as well as the relation of the Lake Wilson sample to the nickel and chromium rich tektites in Java, Billiton, Borneo and Cambodia.

S. R. TAYLOR

Department of Geophysics,
Institute of Advanced Studies,
Australian National University,
Canberra.

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Argon Retention in a Granitic Xenolith from a Pleistocene Basalt, Sierra Nevada, California

THIS note reports measurements made in an attempt to determine: (1) the possible effect of xenoliths on whole-rock basalt age determinations; (2) whether or not potassium-argon age determinations on xenoliths in basalt might approximate the age of the basalt flow. The field location is in the canyon of Sawmill Creek, Inyo County, sec. 7 and 18, T. 12 S., R. 34 E., and sec. 12 and 13, T. 12 S., R. 33 E.

Table 1. ANALYTICAL DATA

No.	Sample	Material	Wt. (g)	K (%)	$\frac{Ar^{40}_{40} \times 100}{Ar^{40}_{40} + Ar^{40}_{36}}$	Ar^{40}_{40}/K_{40}	Age (m.y.)
970	Basalt	Whole-rock	19.01	1.37	99.35	0.053×10^{-4}	0.090 ± 0.090
	Basalt, argon re-run	Whole-rock	13.33		99.43	0.033	0.060 ± 0.050
980	Granitic inclusion	Sanidine	14.12	6.16	52	1.16	2.0 ± 0.1

Potassium feldspar from a granitic inclusion in an interglacial Pleistocene basalt flow¹ the probable age of which is less than 100,000 years was analysed for potassium and argon with the results shown in Table 1. Presumably the potassium feldspar was originally orthoclase or microcline, but X-ray data show that it has been converted to a sodic sanidine. The inclusion was roughly spherical, about 10 cm in diameter, and located about 3 m below the top of the flow, which is approximately 25 m thick at the sample locality. The source of the xenolith is the Sierra Nevada batholithic complex, which is composed of plutons which range in age from about 80–180 million years. It is probable, however, that the inclusion came from one of the group of younger plutons and its age before inclusion in the basalt flow most likely is in the range 80–92 million years².

The results show that this potassium feldspar retained about 2.0–2.5 per cent of its radiogenic argon assuming a primary age of 80–92 million years. (Potassium feldspars of plutonic origin and/or intermediate potassium content may have retentivities as low as about 50 per cent³, thus this feldspar could have had an apparent primary age as low as 40–50 million years and may have actually retained up to 5 per cent or more of its radiogenic argon.)

Quantitative conclusions about argon retention in xenoliths from basalt flows must await further data, but the measurements presented here indicate that it is not safe to assume that such xenoliths have been completely degassed of their previously accumulated radiogenic argon. This conclusion leads to the following remarks.

Possible Effects of Xenoliths on Whole-rock Basalt Dates. Heating times are rapid (for example, the centre of a granitic sphere of 10-cm diameter would reach 98 per cent

of the temperature of the basalt in about 40 min) and argon diffusion dimensions are of the order of the mineral grain size or are subgrain size (for example, for potassium feldspar the diffusion dimension may be 10–30 μ) (ref. 4), therefore the size of a xenolith should have very little effect on its argon retention and thus microscopic inclusions could have a significant effect on the potassium-argon age determined for a whole-rock basalt. The magnitude of the effect would depend on: (1) the potassium content and age of the basalt; (2) the percentage of the basalt sample that is xenolithic; (3) the amount of radiogenic argon-40 retained by the inclusions; (4) the potassium content and age of the inclusions at the time of solidification of the lava (or more appropriately the argon-40/potassium-40 value).

The effect of xenoliths on the age of a basalt may be estimated using:

$$T = t_1 - \alpha \beta t_2 \frac{K_2}{K_1}$$

where T = true age of the basalt, t_1 = apparent age of the basalt, α = fraction of basalt sample that is xenolithic, β = fraction of argon retained by the inclusions, t_2 = apparent potassium-argon age of the inclusions at the time of solidification of the lava, K_2 = potassium content of the inclusions, and K_1 = potassium content of the basalt. This formula will give values within a few per cent of the correct values provided the basalt and the inclusions are Mesozoic or younger, and provided the inclusions comprise less than about 10 per cent of the rock. A more rigorous formula can easily be derived, but because most of the variables must be estimated a more complicated expression would serve little useful purpose. t_1 and K_1 are measured directly, K_2 can either be estimated or in some cases can be measured, t_2 and α can usually

be estimated, and β can be estimated from heat flow and diffusion calculations for each individual case. Hopefully, accurate estimates of β under various conditions, for example, depth within a flow, will come from systematic experiments. Note that the age effect of xenoliths on a 10-million-year old basalt would be small, but the effect of similar inclusions on a 1-million-year old basalt would be increased by a factor of 10 and thus could be large enough to be significant. Careful inspection for xenoliths should therefore be a routine part of the petrographic examination of basalt samples for whole-rock potassium-argon dating.

Use of Xenoliths to date Mafic Volcanic Rocks. If future work leads to the discovery of certain conditions whereby $\beta = 0$, it will be possible to use xenoliths, or mineral separates therefrom, to date mafic volcanic rocks that are otherwise undatable. In circumstances where the

factor $\beta t_2 \frac{K_2}{K_1}$ is small compared with T , it should be possible to use xenoliths to closely approximate the age of the flow.

The analytical work was done at the Department of Geology and Geophysics, University of California, Berkeley, and publication is authorized by the Director, U.S. Geological Survey.

G. BRENT DALRYMPLE

U.S. Geological Survey,
Menlo Park, California.

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