^{40}Ar-^{39}Ar age of a lava flow from the Bhimashankar Formation, Giravali Ghat, Deccan Traps

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We report here a ^{40}Ar-^{39}Ar age of 66.0 ± 0.9 Ma (2σ) for a reversely magnetised tholeiitic lava flow from the Bhimashankar Formation (Fm.), Giravali Ghat, western Deccan province, India. This age is consistent with the view that the 1.8–2 km thick bottom part of the exposed basalt flow sequence in the Western Ghats was extruded very close to 67.4 Ma.

1. Introduction

The Deccan flood basalt province (DFBP) of peninsular India presently covers an area of 0.5×10^6 km^2 (figure 1) with thick lava piles well exposed around Igatpuri (∼ 1.6 km thick) and Mahabaleshwar (∼ 1.2 km thick) in the Western Ghats. It has been estimated that the initial area covered by DFBP may have exceeded 1.5×10^6 km^2 with a total eruptive volume of $\sim 2 \times 10^6$ km^3 (Krishnan 1960). A comprehensive stratigraphic framework for the Deccan basalts has been established through extensive geochemical and magnetic studies in the > 2.5 km thick composite lava pile along the NNW-SSE trending Western Ghats escarpment from Nasik to Belgaum (Cox and Hawkesworth 1985; Beane *et al* 1986; Devey and Lightfoot 1986; Beane 1988; Lightfoot *et al* 1990). The composite Western Ghats stratigraphy consists of eleven formations grouped into three subgroups. There is a continuing debate on the timing and duration of Deccan volcanism (Kaneoka 1980; Courtillot *et al* 1986, 1988; Duncan and Pyle 1988; Pande *et al* 1988; Duncan and Pringle 1991; Vandamme *et al* 1991; Baksi 1994; Allègre *et al* 1999; Hofmann *et al* 2000; Sheth *et al* 2001). Pande (2002) reviewed the available isotopic and paleomagnetic data on the DFBP and suggested that:

- the volcanism was episodic and probably had an extended duration from 69 Ma to 63 Ma (between chrons 31R-28N);
- the most intense pulse of volcanism was at 66.9 ± 0.2 Ma (recalculated to an age of 523.2 ± 0.9 Ma for monitor MMhb-1 recommended by Spell and McDougall 2003) and predated the Cretaceous Tertiary Boundary (KTB, 65.2 ± 0.2 Ma, elative to an age of 523.2 ± 0.9 Ma for MMhb-1) events by ∼ 1.7 Myr and
- the available magnetostratigraphic record in the Deccan sequence does not preclude more than one reversed magnetic chrons. The reversed polarity flows of Bhimashankar and Khandala Fms. constitute a ∼ 400 m thick sequence at Giravali Ghat (Navaneethakrishnan *et al* 1994; Subbarao *et al* 1994).

The complete lack of radioisotopic data for these chemically and magnetically well-studied sections prompted the present study.

We report here the first ^{40}Ar-^{39}Ar ages from this sequence. We dated two samples (JEB127.1a, JEB127.4b) of a basalt flow from the Bhimashankar Fm., exposed at Giravali Ghat. The

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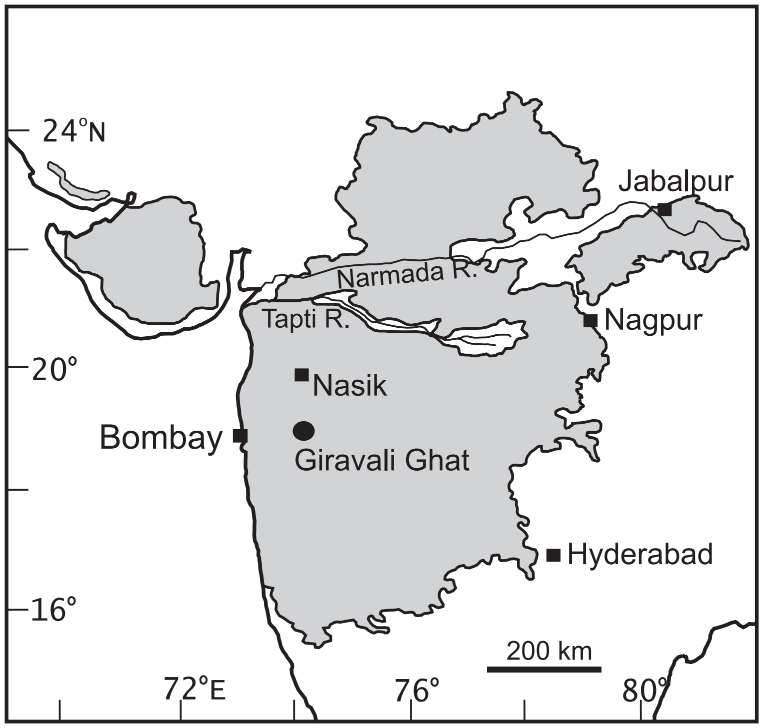

Figure 1. Present outcrop of the Deccan traps (grey) with locations of Giravali Ghat section and some other localities.

samples were fresh whole-rocks and analysed by the ^{40}Ar-^{39}Ar incremental heating technique following methods discussed in Venkatesan *et al* (1993) and Pande *et al* (2001). The standard MMhb-1 hornblende was used, and appropriate correction for ^{37}Ar decay between segmented irradiations was made following McDougall and Harrison (1988). Interference corrections (Dalrymple *et al* 1981) were applied based on measurements on pure CaF_2 and K_2SO_4 salts irradiated with the samples. The mean values for $(^{36}Ar/^{37}Ar)_{Ca}$, $(^{39}Ar/^{37}Ar)_{Ca}$ and $(^{40}Ar/^{39}Ar)_K$ are 0.00031, 0.000786, and 0.0052, respectively. The ages are reported relative to an age of 523.2 ± 0.9 Ma (2σ) for MMhb-1 (Renne *et al* 1998; Spell and McDougall 2003). The values of the irradiation parameter J are as follows: sample JEB127.1a, 0.00191 ± 0.00002, sample JEB127.4b, 0.00184 ± 0.00002.

We define a plateau as comprising four or more contiguous steps in an apparent age spectrum, together constituting 60% or more of total ^{39}Ar release, and with apparent ages that overlap with the mean at 2σ level of error excluding the contribution from the error in J value. The plateau age and the associated error were calculated by weighting each step age by the inverse of its variance which includes the error in J following the scheme outlined by Baksi (1999). The isochron and inverse isochron ages were determined using the regression method of York (1969) through the selected step gas composition using the $^{40}Ar/^{36}Ar$ vs. $^{39}Ar/^{36}Ar$ and $^{36}Ar/^{40}Ar$ vs. $^{39}Ar/^{40}Ar$ isotope correlation diagrams, respectively. ^{40}Ar blanks were about 1–2% of sample ^{40}Ar for temperature steps up to 1000°C, and increased gradually to $< 20\%$ at 1400°C.

Table 1. *Summary of results of* ^{40}Ar-^{39}Ar *dating of basalt samples from Giravali Ghat.*

Sample number	Plateau			Isochron			Inverse isochron		
	Steps	$\%^{39}Ar$	Age(Ma)	Age (Ma)	Trap	MSWD	Age (Ma)	Trap	MSWD
JEB127.1a	8	80.8	66.5 ± 0.9	66.0 ± 1.4	291 ± 56	2.7	66.1 ± 1.4	296 ± 37	1.0
JEB127.4b	7	73.2	66.7 ± 0.7	66.4 ± 1.0	314 ± 12	0.8	66.7 ± 1.2	314 ± 16	0.4
Mean*			66.6 ± 0.6	66.3 ± 0.8	313 ± 12		66.4 ± 0.9	311 ± 15	

Note: Trap – trapped initial $^{40}Ar/^{36}Ar$ composition;
MSWD – mean square weighted deviate.
Errors on ages are 2σ and obtained relative to flux monitor MMhb-1 (523.2 ± 0.9 Ma).
Mean* – weighted mean.

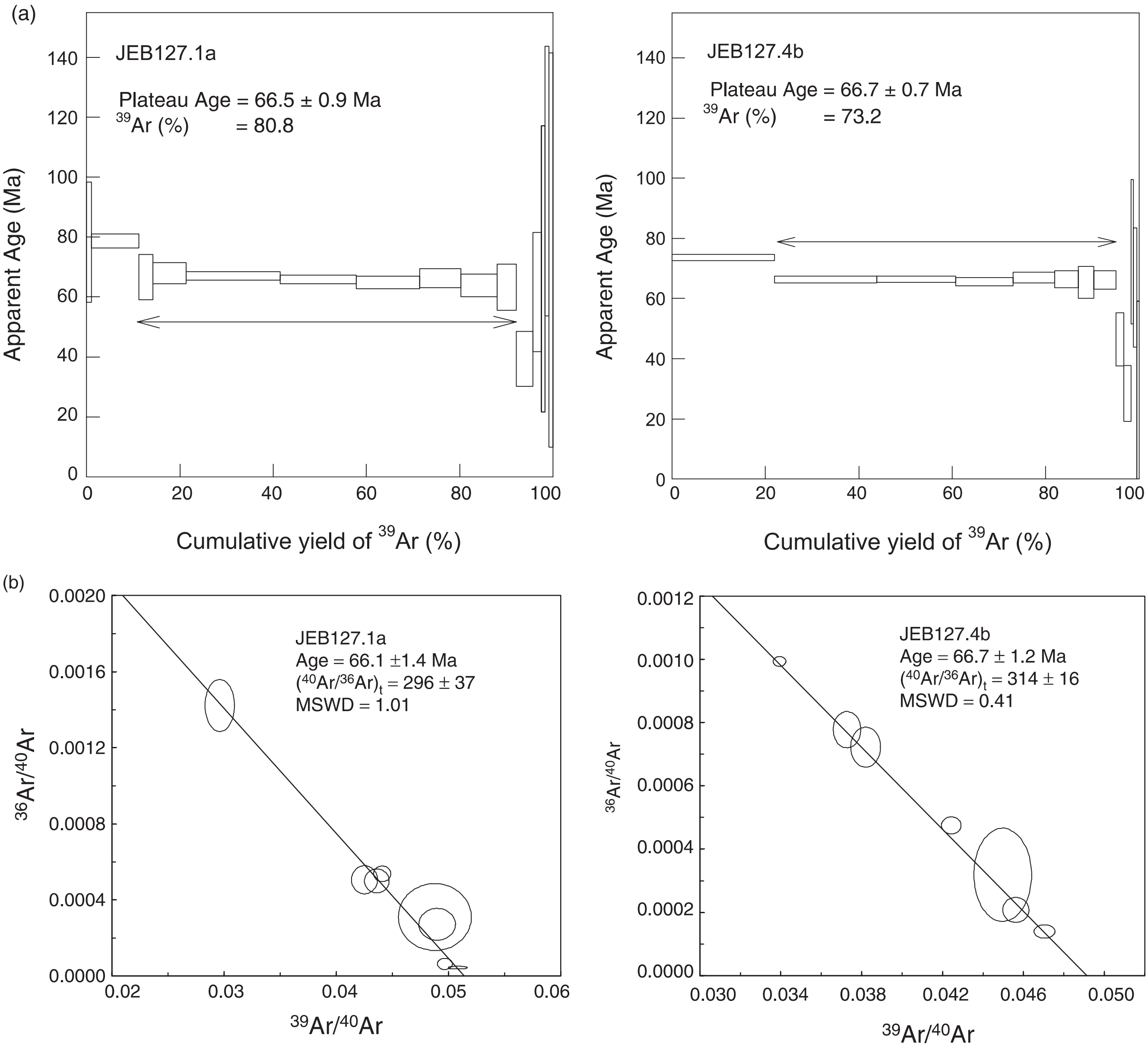

Figure 2. **(a)** Whole-rock step heating age spectra showing the apparent age as a function of cumulative fraction of ^{39}Ar released. The vertical width of the individual steps indicates 2σ error calculated without propagating the error on J. Plateau ages with the corresponding 2σ uncertainty, calculated using the isochron-defined initial $^{40}Ar/^{36}Ar$, are shown. **(b)** Isotope correlation diagrams ($^{36}Ar/^{40}Ar$ versus $^{39}Ar/^{40}Ar$) for the plateau steps showing 2σ error envelopes and the best fit regression line for each. Inverse isochron ages ($\pm 2\sigma$), intercept values (trapped $^{40}Ar/^{36}Ar$, $\pm 2\sigma$) and MSWD (mean square weighted deviate) are given.

2. Results and discussion

The analytical results with the errors ($\pm 2\sigma$) are shown in table 1. Both the samples yield good plateaus and inverse isochrons (figure 2a,b). The sample JEB127.1a gives an 8-step plateau age of 66.5 ± 0.9 Ma with the age spectrum comprising 80.8% of total ^{39}Ar released and the sample JEB127.4b has a 7-step plateau age of 66.7 ± 0.7 Ma with the age spectrum comprising 73.2% of total ^{39}Ar released (figure 2a). Their isochron and inverse isochron ages are statistically indistinguishable from the plateau ages (table 1) within their error limits. The MSWD values for the isochrons are low and the $^{40}Ar/^{36}Ar$ intercepts are close to the atmospheric values of 295.5 (table 1). Good analytical precision is reflected in the similar ages obtained on both samples. The weighted mean of plateau, isochron and inverse isochron ages for the two samples of this flow are 66.6 ± 0.6 Ma, 66.3 ± 0.8 Ma and 66.4 ± 0.9 Ma, respectively.

The concordance of plateau and isochron ages for both samples, the large amounts ($> 73\%$) of total ^{39}Ar for the plateau steps, the atmospheric values of the trapped ^{40}Ar/^{36}Ar component, and the low MSWD values for the isochrons, imply that these ages are true crystallisation ages. The inverse isochron age that has the largest associated uncertainty can be considered as the age of the flow. The 66.4 ± 0.9 Ma age for this Giravali Ghat flow, the only age available as yet from the top of Bhimashankar Fm., is consistent with the earlier available evidence (Venkatesan *et al* 1993) that the 1.8–2 km thick bottom segment of the flow sequence in the Western Ghats was extruded very close to 67.4 Ma (recalculated to an age of 523.2 ± 0.9 Ma for MMhb-1).

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