Table 1a. Data of sample close to granite (marked 1 in Figure 1)

L (mm)	N_A (no./cm^2)	N_V (no./cm^3)	n (no./cm^4)	ln(n)
0.025	13	46.87	937.44	6.84
0.075	245	3834.85	76697.13	11.24
0.125	217	3196.60	63932.19	11.06
0.175	260	4192.37	83847.48	11.33
0.225	242	3764.63	75292.73	11.22
0.275	105	1075.92	21518.59	9.97
0.325	67	548.41	10968.37	9.30
0.375	38	234.24	4684.95	8.45
0.425	19	82.81	1656.38	7.41
0.475	7	18.52	370.40	5.91
0.525	6	14.69	293.93	5.68
0.575	2	2.82	56.56	4.03
0.625	3	5.19	103.92	4.64
0.675	1	1.00	20.00	2.99

Table 1b. Data of sample far from granite (marked 2 in Figure 1)

L (mm)	N_A (no./cm^2)	N_V (no./cm^3)	n (no./cm^4)	ln(n)
0.025	3200	181019.33	3620386.71	15.10
0.075	2515	126126.68	2522533.71	14.74
0.125	195	2723.02	54460.53	10.90
0.175	21	96.23	1924.68	7.56

the rock must have been in a cold-worked state with a high dislocation density. With the intrusion of the granite, the quartz crystals annealed and ripened because of the rise in temperature so as to achieve greater thermodynamic stability. During this process the quartz crystals grew in size and reduced in number. Contrary to this, the sample away from the granite shows a CSD plot for quartz crystals with greater linearity. This connotes that the growth of quartz crystal was continuous. This sample possesses a large number of small crystals of quartz, a low mean crystal size and a large number of total quartz crystals. According to us, all this is directly related to the absence of any significant post-deformational Ostwald-ripening due to the greater distance of this sample from the Godhra granite.

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Trace and REE signatures in the Maastrichtian Lameta Beds for the initiation of Deccan volcanism before KTB

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Assignment of Maastrichtian age[1-3] for the Lameta sediments locally underlying the Deccan basaltic flows in the eastern lobe of the Deccan volcanic province has been integrated with the radiometric and palaeomagnetic data of the Deccan Trap by recent workers[4,5] in evolving an extremely shorter duration model for the Deccan volcanism at KTB. However, the earlier mineralogical studies[6,7] and the current geochemical findings on the detrital clay assemblages of the Lametas are indicative of their derivation from Deccan basalt. The negative Ce anomalies recorded in the smectites of Lametas are supportive of their basaltic lineage, implying early eruptions of Deccan volcanism predate these Maastrichtian sediments. This finding is incongruent with the rapid eruptive duration model of < 1 Ma, at KTB[4,5] proposed for the Deccan volcanic episode.

ARGUMENTS in favour of an *internal cause*[4,8] for the mysterious mass extinction at KTB largely revolved around the coincidence of Deccan volcanism in central

India towards the Cretaceous/Tertiary transition. Reasonings along this line gained momentum with the assignment of an extremely shorter duration of < 1 Ma close to KTB[4,5] for the Deccan volcanism on a combined consideration of palaeomagnetic, geochronological and palaeontological data. Biochronological age estimate of the Deccan Traps is primarily based on the Maastrichtian microvertebrate assemblages in the sediments underlying and fringing the *visibly lowermost* lava flow in the Eastern Deccan Volcanic province. The basal lithounit of the 0.5–70 m thick Lameta Beds rests unconformably over the Upper Gondwana sediments (Table 1) and exhibits conspicuous colour contrast owing to its detrital green clay content. Green detritals of the Lametas are represented as widespread disseminations and disparate pockets in its basal lithounit. Of late, the green sandstone unit has been interpreted as braided stream deposit and a palaeoenvironment model of terrestrial freshwater pedogenic environment has been proposed for the Lameta sediments[9]. This is in contrast to the earlier marine depositional models proposed for Lametas based on the reported presence of authigenic glauconite[10,11] and other marine features in them. The X-ray diffraction studies on clay assemblages, including the green clays of basal Lametas, show smectites as their principal component besides a little chlorite, illite and kaolinite[6]. The compositional and structural formula studies on these smectites indicate that they are rich in Mg and Fe, implying their derivation from Deccan basalt[6].

On the basis of earlier mineralogical studies, representative samples of detrital Lameta sediments of Chuihill (S10), Tendukhera (S2), Amokhoh (S15) were selected for the current trace and REE analyses. One sample each of intertrappean of Lametaghat (S6) and weathered Deccan basalt (W6) were also analysed similarly for their comparative study with Lameta sediments. Trace and REE data were obtained by ICP–MS and are given in Table 2.

The ranges of trace element abundances in the Lameta, intertrappean and weathered Deccan basalt are shown in Figure 1. The varying abundance levels of elements in the Lameta, intertrappean and weathered basalt samples are attributed to differential mobility of these elements in weathering environment. However, Nb, demonstrated as the least mobile element in the leaching experiments on basalts[12], showed almost the same concentration levels in the green detritals (S10) and weathered Deccan basalt

Table 1. Geological setting of the Jabalpur area, Central India where the Lameta beds are exposed (after Matley[20])

D – Deccan Trap

C – Lameta Group

- (e) Upper sands
- (d) Upper limestone
- (c) Mottled nodular beds
- (b) Lower limestone
- (a) Green sand

Unconformity

B – Jabalpur Group

- (b) White clays
- (a) Sand stones

Unconformity

A – Ancient crystalline rocks

Table 2. Abundances of trace elements and REE (in ppm) in the Lametas, intertrappean sediments and weathered Deccan basalt

	Sample number				
Element	S10	S15	W6	S6	S2
Be	100.00	100.00	100.00	100.00	100.00
Sc	19.97	26.75	51,15	53.40	33.13
V	450.45	233.06	429.16	692.70	363.57
Cr	80.67	95.39	127.11	139.74	106.58
Co	44.45	32.13	161.24	106.41	20.03
Ni	18.97	24.87	33.58	58.49	36.37
Cu	124.76	150.48	278.06	300.61	63.86
Ga	24.65	23.49	32.58	30.89	20.72
Rb	57.06	99.03	8.41	21.28	97.98
Sr	65.49	31.23	121.34	238.05	27.77
Y	46.89	36.89	63.02	33.48	39.66
Zr	173.24	256.84	215.34	214.54	204.85
Nb	20.14	45.03	19.69	31.49	42.51
In	100.06	100.06	100.06	100.06	100.07
Ba	200.71	103.25	311.22	240.10	128.26
La	47.81	18.94	40.04	15.84	55.77
Ce	112.49	35.56	140.42	49.85	126.57
Pr	25.00	7.76	18.29	8.48	20.76
Nd	75.06	18.70	55.77	27.30	53.78
Sm	10.56	3.76	9.22	4.82	7.81
Eu	1.95	0.98	3.57	1.75	1.61
Gd	9.23	4.25	11.93	6.82	9.03
Dy	8.81	3.96	12.10	5.08	4.91
Er	3.01	2.80	4.15	2.90	2.84
Yb	3.03	2.81	4.40	2.17	2.56
Lu	0.44	0.33	0.44	0.34	0.48
Hf	4.98	6.32	4.88	4.79	4.41
Ta	0.81	0.97	0.63	0.76	1.03
Bi	99.91	99.91	99.91	99.91	99.91
Th	0.59	0.41	0.55	0.51	0.59
U	0.12	0.15	0.15	0.21	0.19

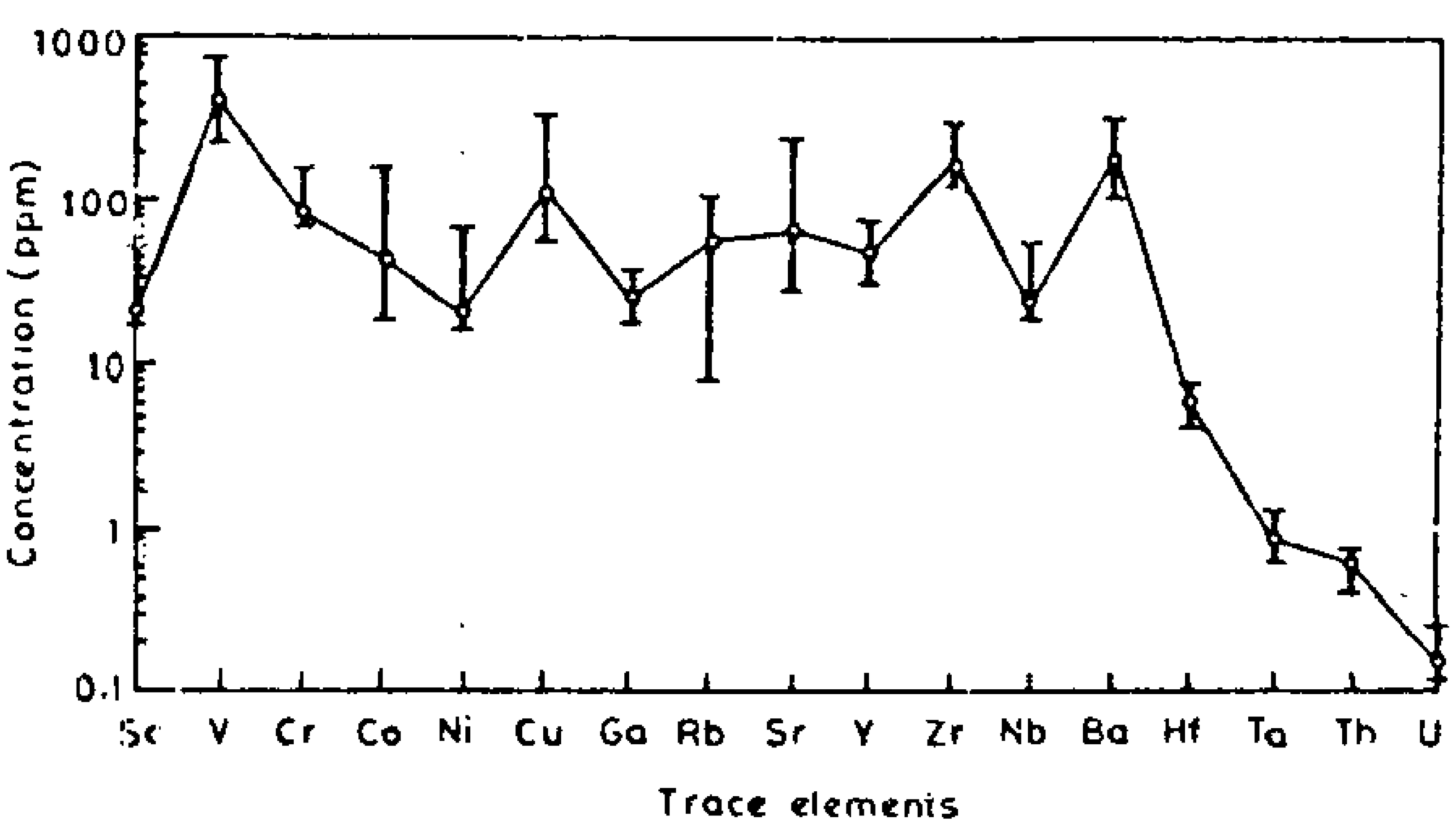

Figure 1. Range of trace element concentrations in the Lametas, intertrappean and weathered Deccan basalt. The line joining open circles represents the trace elements concentrations in the green sandstone.

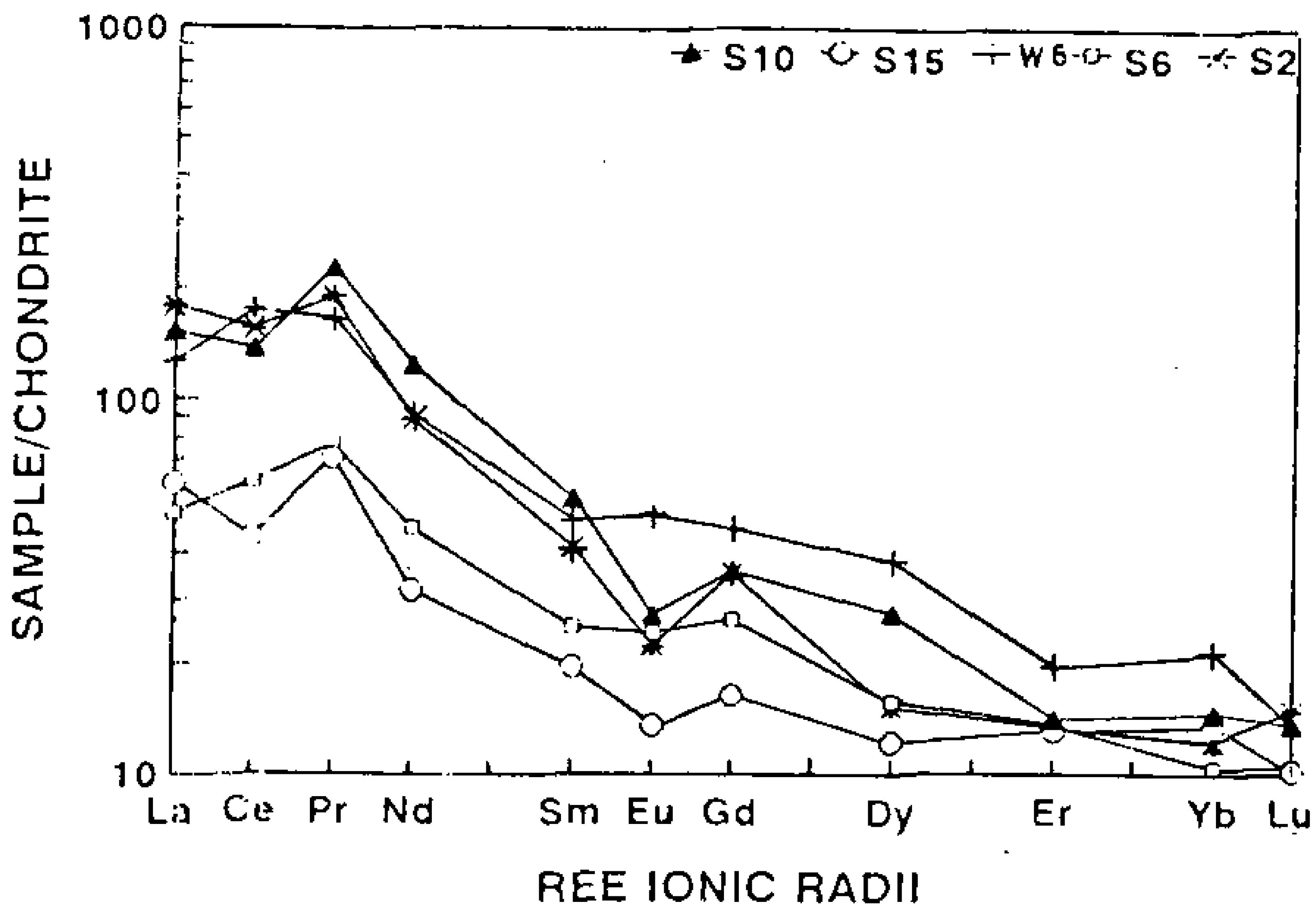

Figure 2. Chondrite normalized REE plots of Lametas, intertrappean and weathered Deccan basalt.

(W6). The chondrite normalized REE plots of Lameta, intertrappean and weathered Deccan basalt are shown in Figure 2. The REE patterns of the Lametas and intertrappeans are subparallel with the weathered basalt and show enrichment of LREE in relation to HREE. However, the REE pattern of the Lameta is conspicuous by the depletion of Ce and Eu. Both Ce and Eu could exist in divalent and tetravalent states and their concentrations are dependent on the redox conditions prevailing in the system at the time of deposition[13]. The negative Ce anomalies observed in Lameta samples are comparable to the Ce depletion documented during basalt weathering in general[14], and that of the Deccan basalt in particular[15]. It has been demonstrated that under oxidizing conditions Ce gets oxidized to + 4 state and gets removed from the reservoir[12]. The Lameta samples S10, S15 and S2 have weathering indices of 21, 7 and 49 respectively and Ce depletion in them could be explained in the light of their basaltic derivation and subsequent intense weathering they have undergone. This observation draws support from the absence of Ce depletion in Deccan basalt, which is only slightly weathered (weathering index-2), while the concentration patterns of other REE, except for Eu in it are subparallel with those of the Lametas. The other depleted element Eu is taken up as a substituent of Ca[15] of the plagioclase feldspars in basalt. Its depletion could be explained by the removal of Ca in solution with the progression of weathering, as major elemental data show very low levels of Ca concentrations in the Lameta sediments[7].

The above findings in conjunction with the earlier mineralogical results[6,7] on the Lametas are indicative of the invariable presence of Deccan basaltic derivatives in them. Contribution from Rajmahal Traps (110–120 Ma)[16] or other preexisting basic rocks towards the Lameta sediments does not seem to be a possibility as the immediately underlying Jabalpur clays of the Upper Gondwanas are completely devoid of green detritals, smectites, and, in contrast, are characterized by predominant kaolin minerals[17]. Absence of green matrix in the higher Lameta level sediments closer to the contact with the overlying flows negates their derivation from the upper flows through the downward percolations. This implies that Deccan basalt had made its presence in the provenance of Lameta sediments during the Maastrichtian times before the KTB. The arguments for the existence of ~ 3 km thick older flows below the exposed Deccan lava pile[18] cannot be altogether overlooked in this background. The recent Ar–Ar data on a western Trap section[19] also indicate an age prior to KTB for the Deccan volcanism. These observations are significant not only for their incongruencies with the models suggesting an extremely shorter duration (< 1 Ma) for the Deccan volcanism but for the assessment of the link between Deccan volcanism and KTB extinction event.

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