Comments on 'Generation of Deccan Trap magmas'

by Gautam Sen

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The eruption age and eruptive duration of the Deccan flood basalt province have been controversial (e.g., Courtillot *et al* 1986, 1988; Duncan and Pyle 1988; Allègre *et al* 1999 vs. Venkatesan *et al* 1993; Sheth *et al* 2001a,b). Age and duration are both very important for understanding the geodynamic origins of flood basalt events and their possible role in biological mass extinctions. New work and ideas that would help in resolving the continuing controversy are therefore welcome.

Sen (2001) has used a novel approach to estimate the eruptive duration of the magnificently developed 1.7-km-thick Deccan flood basalt sequence along the Western Ghats (WG hereinafter). This approach uses the possible formation times for the giant-plagioclase-basalt (GPB) lavas which constitute a small part of the WG sequence. Sen (2001) has derived a probable duration of only ~55,000 years (55 kyr) for the eruption of the WG sequence. To explain this extraordinarily low estimate not consistent with the palaeomagnetic data of Courtillot *et al* (1986), Sen speculates that a lack of resolution in the palaeomagnetic time scale is probably the cause. In fact, the 55 kyr estimate is inconsistent also with ^{40}Ar-^{39}Ar age data (Venkatesan *et al* 1993) for WG basalts, which suggest a duration of 4–5 million years.

Estimation of the eruptive duration of the WG sequence constitutes only a small part of Sen's informative paper, but this issue is of critical importance, especially because of the probable role of Deccan volcanism in the K-T boundary mass extinctions. Since implications of eruption duration would be far-reaching, Sen's estimate deserves critical assessment. I show below that his 55 kyr estimate involves a logical error, and is therefore a huge underestimate by at least 80 times. I then make some calculations using Sen's own approach. The eruptive duration I calculate is consistent with all other available data, which suggests that Sen's approach is potentially useful.

Sen's first premise, which I consider reasonable, is that plagioclase formation times determined from the Makaopuhi lava lake in Hawaii (Cashman and Marsh 1988) can be used to estimate the formation times for plagioclases of the GPBs of the WG. He notes that because of the higher pressures at depth in the magma chamber, and petrographic features suggestive of dissolution and re-precipitation the WG GPB plagioclases should have taken somewhat longer to form, and therefore the Hawaiian lava lake data can be used as a minimum formation time. He estimates that 10-cm-long plagioclase crystals in the WG GPBs would have taken 3,200 yr to form. I think that 5 cm is a more appropriate average size for individual plagioclase crystals of the GPBs, but I shall nevertheless proceed with his calculated figure of 3200 yr for an individual GPB flow. Since there are six GPBs in the WG sequence, Sen calculates that the time represented by the six GPBs taken together is $6 \times 3,200 = 19,200$ yr. No argument here.

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Sen then assumes a thickness of 100 m for each GPB based on the field data of Beane (1988), which I shall use too. Then, dividing the 600 m total thickness of the six GPBs by their estimated formation time (19,200 yr), he derives a "back-of-the-envelope", *one-dimensional eruption rate* of 0.031 m/yr. Finally, he has divided the 1700 m thickness of the WG lava pile by this one-dimensional eruption rate to arrive at his figure of ~ 55 kyr (exactly, 54,839 yr) for its total eruptive duration.

The calculation is incorrect because Sen considers only the thickness of the lava pile to calculate eruption rate. However, the thickness of a *unit volume* of lava will vary depending on factors like its composition (which controls its viscosity or fluidity), and topographic conditions. For example, a topographic barrier near the vent would prevent the lava from covering much area, and the lava would pile up in the vertical direction instead, and then Sen's calculation would involve a much greater thickness value and the final result would be quite different. Clearly, one must use the *volume* of a single lava flow or a lava pile, not its thickness, to calculate its eruption rate, since it is only the volume that forms the absolute measure of size. Eruption rate is volume erupted per unit time, and is usually measured in km^3/yr or m^3/s. A 'one-dimensional' eruption rate based on only the thickness of a lava pile is not meaningful.

I now make some first-order calculations using Sen's GPB-based approach, and my results show its potential usefulness. I assume, besides a 100 m thickness for each of the six GPBs, a length of 50 km and a width of 20 km. Quantitative estimates of the areas and volumes of all these GPBs are not available in the published literature, but the Manchar GPB has been traced for 100 km (Khadri *et al* 1988; width unknown). Some other large Deccan flows have also been traced for over 100 km, though most are apparently much smaller (e.g., Mahoney 1988; Sheth 2000), and therefore it is reasonable to assume a length of 50 km, a width of 20 km, and a thickness of 100 m (0.1 km) for an individual GPB flow. The volume of each GPB is therefore 100 km^3. The combined volume of six GPBs (600 km^3) erupted in 19,200 yr yields a volumetric eruption rate of 0.031 km^3/yr.

This volumetric eruption rate can be easily compared with known rates for modern and historic lavas. The 0.031 km^3/yr volumetric eruption rate for the WG is 3.2 times *less* than that estimated for Hawaii (0.1 km^3/yr, Courtillot *et al* 1986; Sen, *op.cit.*), and thus, contrary to popular beliefs, eruption rates for the Deccan were not higher than for the modern Hawaiian lavas. Physical volcanologists (e.g., Self *et al* 1997) have arrived at precisely this conclusion, and suggested that the much larger volumes erupted in provinces like the Deccan are due to considerably greater lengths of their eruptive fissures, not due to greater eruption rates (volumes emitted per unit time). A rate of 0.031 km^3/yr translates to 0.98 m^3/sec. This is hardly significant in front of the highest-effusion-rate *historic* eruption, Laki in Iceland (1783–84), with an eruption rate of 4000 m^3/s (Self *et al* 1997).

Now I estimate the eruptive duration for the WG lava pile by dividing its volume ($136,000\,km^3$) by the 0.031 km^3/yr eruption rate. For this I have assumed a length of 400 km, width of 200 km, and thickness of 1.7 km for the WG sequence. These are reasonable figures, since the WG stratigraphy is exposed and has been mapped along a 450-km-length (Beane *et al* 1986; Subbarao 1988 and references therein; Lightfoot and Hawkesworth 1988; Lightfoot *et al* 1990), and the thickness of the basalts is close to 1700 m over a ~ 200 km width (measured across the Ghats), while farther east the lava pile progressively thins. Therefore the volume figure is quite conservative. I have not included the substantial volumes to the east of the main axis of the WG. Considerable volumes of the basalts are in the subsurface underneath the WG axis (as much as 500 m thick in places), and I have not included them either (partly because if there are any GPBs in the subsurface, they would have to be taken into account). My *minimum* eruptive duration estimate for the WG is *4.39 million years*.

The 4.39 Myr eruptive duration estimate is 80 times higher than Sen's 55 kyr estimate, and is easily reconciled with the ^{40}Ar-^{39}Ar ages of Venkatesan *et al* (1993), palaeomagnetic data, and field evidence, especially if red boles constitute weathering horizons (which Sen entertains as one possibility). The Deccan red boles resemble in appearance clayey, red soils developed on the Hawaiian basalts (e.g., around central Oahu). Also, GPBs are probably really absent within the Mahabaleshwar and other Wai Subgroup lavas in their *type* areas, but numerous GPBs are certainly found amongst Wai-Subgroup-*like* lava piles in the Satpura-Tapi region (e.g., Mahoney *et al* 2000). The absence of GPBs in sections like the 1,200-m-thick Mahabaleshwar section may not indicate very rapid eruptions as Sen suggests, but the widespread occurrence of red boles in Mahabaleshwar section and the surrounding areas probably indicates declining or periodic eruptive activity.

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References

Allègre C J, Birck J L, Capmas F and Courtillot V 1999 Age of the Deccan Traps using ^{187}Re-^{187}Os systematics; *Earth Planet. Sci. Lett.* **170** 197–204

Beane J E 1988 Flow stratigraphy, chemical variation and petrogenesis of Deccan flood basalts, Western Ghats, India; *Ph.D. Dissertation*, (Washington State University, Pullman) 576 pp.

Beane J E, Turner C A, Hooper P R, Subbarao K V and Walsh J N 1986 Stratigraphy, composition and form of the Deccan basalts, Western Ghats, India; *Bull. Volcanol.* **48** 61–83

Cashman K V and Marsh B D 1988 Crystal size distribution, CSD, in rocks and the kinetics and dynamics of crystallization. III. Makaopuhi lava lake; *Contrib. Mineral. Petrol.* **99** 292–305

Courtillot V, Besse J, Vandamme D, Montigny R, Jaeger J-J and Capetta H 1986 Deccan flood basalts at the Cretaceous/Tertiary boundary; *Earth Planet. Sci. Lett.* **80** 361–374

Courtillot V, Féraud G, Maluski H, Vandamme D, Moreau M G and Besse J 1988 Deccan flood basalts and the Cretaceous/Tertiary boundary; *Nature* **333** 843–846

Duncan R A and Pyle D G 1988 Rapid eruption of the Deccan flood basalts at the Cretaceous/Tertiary boundary; *Nature* **333** 841–843

Khadri S F R, Subbarao K V, Hooper P R and Walsh J N 1988 Stratigraphy of Thakurvadi Formation, western Deccan basalt province, India. In: *Deccan Flood Basalts* (ed) K V Subbarao, *Geol. Soc. Ind. Mem.* **10,** pp. 281–304

Lightfoot P and Hawkesworth C 1988 Origin of Deccan Trap lavas: evidence from combined trace element and Sr-, Nd- and Pb-isotope studies; *Earth Planet. Sci. Lett.* **91** 89–104

Lightfoot P C, Hawkesworth C J, Devey C W, Rogers N W and van Calsteren P W C 1990 Source and differentiation of Deccan Trap lavas: implications of geochemical and mineral chemical variations; *J. Petrol.* **31** 1165–1200

Mahoney J J 1988 Deccan Traps. In: *Continental Flood Basalts* (ed) J D Macdougall (Dordrecht: Kluwer Acad.), pp. 151–194

Mahoney J J, Sheth H C, Chandrasekharan D and Peng Z X 2000 Geochemistry of flood basalts of the Toranmal section, northern Deccan Traps, India: implications for regional Deccan stratigraphy; *J. Petrol.* **41** 1099–1120

Self S, Thordarson Th and Keszthelyi L 1997 Emplacement of continental flood basalt lava flows. In: *Large Igneous Provinces: Continental, Oceanic, and Planetary Flood Volcanism* (eds) J J Mahoney and M F Coffin, *AGU Geophys. Monogr.* **100** pp. 381–410

Sen G 2001 Generation of Deccan Trap magmas; *Proc. Indian Acad. Sci. (Earth Planet. Sci.)* **110** 409–431

Sheth H C 2000 The timing of crustal extension, diking, and eruption of the Deccan flood basalts; *Int. Geol. Rev.* **42** 1007–1016

Sheth H C, Pande K and Bhutani R 2001a ^{40}Ar-^{39}Ar ages of Bombay trachytes: evidence for a Palaeocene phase of Deccan volcanism; *Geophys. Res. Lett.* **28** 3513–3516

Sheth H C, Pande K and Bhutani R 2001b ^{40}Ar-^{39}Ar age of a national geological monument: the Gilbert Hill basalt, Deccan Traps, Bombay; *Curr. Sci.* **80** 1437–1440

Subbarao K V 1988 (ed) Deccan Flood Basalts. *Mem. Geol. Soc. India* **10** 393 pp.

Venkatesan T R, Pande K and Gopalan K 1993 Did Deccan volcanism pre-date the Cretaceous/Tertiary transition?; *Earth Planet. Sci. Lett.* **119** 181–189

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