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Plate tectonic and palaeomagnetic implications for the age of the Deccan Traps and the magnetic anomaly time scale

IF reconstructions of plate tectonic movement based on magnetic anomaly data are found to be inconsistent with reconstructions based on palaeomagnetic data (see refs 1–3) it may indicate that one or more of the basic assumptions of the plate tectonic model is erroneous; the age or identification of a particular anomaly may be incorrect, the pole positions or sample ages may be unreliable, or there may be an error in assessing plate rigidity. We present an example of inconsistency between the two types of data and explore its implications for the chronology of magnetic reversals during the late Cretaceous and early Tertiary and for the age of the Deccan Traps.

We have previously[4] reconstructed the major plates in the Atlantic and north-eastern Indian Ocean at the time of anomaly 24 (approximately 60 Myr ago according to the magnetic anomaly time scale of Heintzler et al.[5]). Anomaly 24 is particularly well defined in these oceans, and we estimated that the uncertainty of the relative positions of the plates is about 200 km. Yet when palaeomagnetic poles for Europe and India, implicitly assumed also to be 60 Myr old, are reconstructed according to the positions of anomaly 24 in the Atlantic and Indian Oceans, the pole positions fall short of one another by more than 2,000 km (Fig. 1). It seems reasonable to assume that the plates are rigid, as the only obvious internal deformation has occurred in the East African Rift System and is clearly negligible compared with the discrepancy obtained. Possibly the best sets of palaeomagnetic data are from the North Atlantic Tertiary Volcanic Province and the Deccan Traps, (Table 1, Fig. 1)[6,7]. Thus, the age of either the North Atlantic Tertiary Volcanic Province or the Deccan Traps, or anomaly 24, must be significantly different from 60 Myr.

The dating of the North Atlantic Tertiary Volcanic Province has been particularly thorough. Nearly all of the measured potassium–argon and rubidium–strontium determinations have given ages of 50–65 Myr (Table 1).

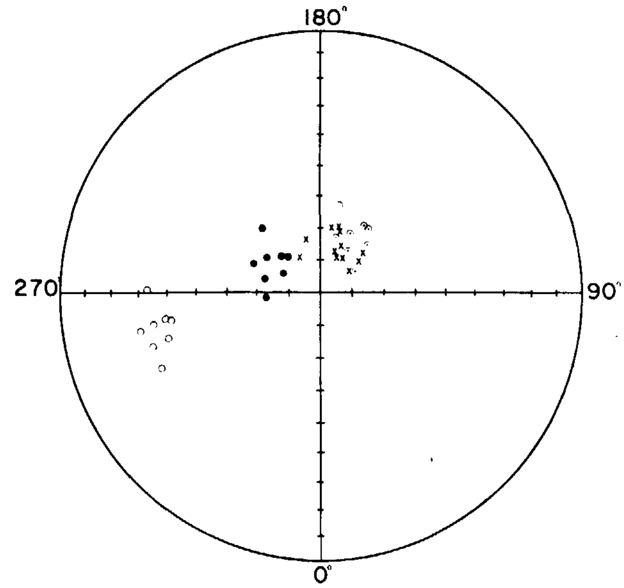

Fig. 1 Equal area projection of present palaeomagnetic pole positions from the North Atlantic Province (crosses); present Deccan Trap pole positions (open circles); reconstructed pole position of Deccan Traps (in their positions relative to Europe at the time of anomalies 24 and 32, respectively), (closed and dotted circles).

The age of the Deccan Traps has been less well determined. Although measured ages range from 40–65 Myr (refs 8–10), argon loss seems to have occurred in some of the samples, and the Deccan Traps could have been extruded entirely between 60 and 65 Myr ago[6,8,10]. Thus, although the few radiometric ages that exist for the Deccan Traps may indicate that both the Traps and the North Atlantic Tertiary Igneous Province were erupted simul-

Table 1 Selected palaeomagnetic poles and ages from the North Atlantic Tertiary Volcanic Province and the Deccan Traps*

Rock unit	Age (Myr)	Ref.	Pole Latitude (°N)	Pole Longitude (°E)	Ref.
North Atlantic Tertiary Volcanic Province					
Faeros Island volcanics	53–59	14	77	161	15
Skye lavas and intrusives	54 ±3	16	74	157	17
Ardnamurchan gabbro	55 ±6	18	69	165	17
	60 ±3	19, 20			
Rhum gabbro			69	171	17
Mull intrusives	60 ±10	18	72	133	21, 22
Arran dykes	55–65	23	78	149	24
Antrim igneous suite	49.9 ±2.2	25	78	145	26
Lundy dykes	52 ±2	27, 28	75	130	29
Ayrshire dykes			79	128	30
Tertiary dykes, Scotland	34–57	31	73	197	31
Tertiary dykes, UK			77	211	32
St Kilda	56–64	33			
Northern Ireland igneous rocks			70	163	34
Deccan Traps					
Deccan Traps (McElhinny's average)			30	281	6,12
Amarkantak lavas			33	294	35
Mount Pavargash lavas	59–63	9	39	286	36
	66	10			
Aurangabad lavas			33	287	37
Deccan Traps, western Ghats			35	280	38
Mount Gima lavas and intrusives	65	10	41	280	39
Mahabeleshwar lavas	≥61.5	10			
Malwa Plateau lavas			33	269	40
Jalna lavas			39	279	41

* McElhinny[4] and Bott[12] were used as guides for selecting and combining these data.

taneously the Deccan Traps may, in fact, be a few million years older. At the same time, recent revisions of the magnetic time scale assign to anomaly 24 an age of 56 Myr (ref. 11) or 53 Myr (R. L. Larson, personal communication). Thus, uncertainties in the ages of both the Deccan Traps and anomaly 24 allow some flexibility in reconciling differences of calculated pole positions at the time of anomaly 24. In fact, because of the especially rapid motion of India with respect to both the pole[12] and the surrounding plates[13] during the late Cretaceous and early Tertiary, the ages of both the Deccan Traps and anomaly 24 are critical: an older age for the Deccan Traps or a younger age of anomaly 24 will reduce the discrepancy in reconstructed pole positions.

Table 2 Assumed and estimated ages (Myr) of anomalies 24 and 32 and of the Deccan Traps

	Deccan Traps	Anomaly 24	Anomaly 32
a	72	60 (5)*	75 (5)
b	68	56 (11)	70.5 (11)
c	67	53†	70.5 (11)
d	65 (9)	53†	68
e	65 (9)	56 (11)	66
f	65 (9)	25	75 (5)
g	65 (9)	45	70.5 (11)

* Number in parentheses gives reference; ages not referenced are estimated.
† R. L. Larson, personal communication.

To explore this further we reconstructed the positions of the lithospheric plates with respect to Europe at the time of anomaly 32, with assigned ages of about 75 Myr (ref. 5) and 70.5 Myr (ref. 11). The average pole positions again disagreed, by about 600 km, but in the opposite sense from the disagreement obtained using anomaly 24. The age of the Deccan Traps is apparently less than that of anomaly 32.

Because Europe moved relatively little with respect to the pole during the Tertiary and Cretaceous[6], the North Atlantic Tertiary Province probably moved very little with respect to the pole during the period when anomalies 24 to 32 formed. Assuming this, we can use a reconstruction that brings the two sets of palaeomagnetic poles into approximate coincidence to constrain the age of the Deccan Traps or the anomalies. Assuming an approximately constant rate of motion between India and Europe between the times of anomalies 24 and 32, the age of the Deccan Traps can be estimated for various proposed ages of anomalies 24 and 32. Similarly, using given ages of the Deccan Traps and one of these anomalies, the age of the other anomaly can be estimated. Table 2 summarises several combinations of assumed and calculated ages.

Using the time scale of Sclater *et al.*[11], the Deccan Traps are calculated to be only 68 Myr old (line *b*, Table 2). If we accept the age found by Sclater *et al.*[11] for anomaly 32 but Larson's age determination for anomaly 24 (personal communication), then the calculated age for the Deccan Traps is 67 Myr (line *c*, Table 2). Given the uncertainties in all of the ages, reconstructions, and palaeomagnetic poles, 67 or 68 Myr is probably indistinguishable from the measured ages of 60–65 Myr[8-10].

Similarly, assuming that the Deccan Traps are 65 Myr old, then anomaly 32 becomes younger than 70 Myr old (lines *d* and *e*, Table 2). A small change in the assumed age of the Deccan Traps produces a large effect on the age of anomaly 24 (compare lines *b* and *c* with line *g* in Table 2). Because of the uncertainties in the dating of rocks, an accurate determination of the age of anomaly 24 by this method will be difficult. Nevertheless, anomaly 24 must be younger than 60 Myr old.

Thus, reconstructions of the Indian and Eurasian plates, using marine magnetic anomalies and differences in the position of palaeomagnetic poles obtained from these plates together place constraints on the ages of both the anomalies and the samples studied palaeomagnetically. These results are consistent both with results of Sclater *et al.*[11] and Larson (personal communication), suggesting that anomaly 24 is younger than suggested by Heirtzler *et al.*[5], and with the idea that the Deccan Traps may be older than measured. The results presented here are also consistent with an age for anomaly 32 younger than that suggested by Heirtzler *et al.*[5]. Plate reconstructions are apparently sufficiently accurate to be used as a laboratory tool for age dating and 'stratigraphic' correlation over large distances.

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PETER MOLNAR

Department of Earth and Planetary Sciences,
Massachusetts Institute of Technology,
Cambridge, Massachusetts

JEAN FRANCHETEAU

Centre Océanologique de Bretagne,
BP 337,
29273 Brest,
Cedex,
France

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