

PALAEOMAGNETIC INVESTIGATION OF THE DECCAN BASALT LAVA FLOWS, AMBA FORMATION, CENTRAL INDIA: INSIGHTS OF TD AND AFD TECHNIQUES**Mayura M. Deshmukh¹, Manish S. Deshmukh^{2*}, S.F.R. Khadri³**¹Assistant Professor, Department of Geology, Shri Shivaji Science College, Amravati, M.S., India.²Associate Professor, P.G. Deptt. of Geology, R.T.M. Nagpur University, Nagpur-440001, MS, India.³ Professor, Deptt. of Civil Engg., V.R. Siddhartha Engineering College, Vijaywada-520007, AP, India.***Corresponding Author's Email:** manishdesh40@gmail.com**ABSTRACT**

This study represents palaeomagnetic investigations of the Amba formations, utilizing magnetic and thermal cleaning techniques to differentiate primary magnetic components from secondary ones. The study area is a part of Deccan Volcanic Province (DVP) and comprises lava sequence of 400 meter thickness. Total 38 representative specimens were analyzed to assess the stability of their natural remanent magnetization (NRM) using alternating field demagnetization (AFD) and thermal demagnetization (TD). The results of alternating field demagnetization reveal different behavior, with some samples retaining stable NRM directions and others indicating significant secondary components. The thermal demagnetization technique demonstrated three distinct patterns of magnetic behavior, from steady intensity decreases to initial increases, followed by gradual decreases, and steep initial falls indicating strong isothermal remanent magnetization. These findings highlight the effectiveness of AFD and TD in identifying primary magnetization and provide a foundation for correlation of the lava flows, exposed all over the globe.

Keywords: Deccan Volcanic Province (DVP), Paleomagnetism, Alternating Field Demagnetization (AFD), Thermal Demagnetization (TD).

INTRODUCTION

Palaeomagnetism study incorporates old record of the earth's magnetic field, preserved in the rocks. Magnetic and thermal cleaning techniques play a pivotal role in paleomagnetic studies, facilitating the removal of soft secondary magnetic components from rock samples to isolate primary magnetization (Koenigsberger, 1938; Thellier, 1938 and Nagata, 1943). Alternate field demagnetization (AFD) involves subjecting samples to varying alternating magnetic fields, effectively demagnetizing secondary components (Tauxe, 2010; Butler, 1992 and Butler, 2004). It aids in the reconstruction of past tectonic plate movements, the history of the geomagnetic field, and the age dating of rocks through magnetostratigraphy. In the context of the Deccan Traps, paleomagnetic investigations can reveal details about the timing, duration, and rate of the volcanic eruptions, as well as any geomagnetic field reversals that occurred during the emplacement of these extensive lava flows. This research provides a comprehensive analysis of the paleomagnetic properties of the Amba Formation, enhancing our understanding of the geological history and evolution of the Asirgarh Region within the Deccan Traps.

STUDY AREA

The study comprises Amba Formation within the Asirgarh Region, which was mapped

meticulously between latitudes 21°11' to 21°52' N and longitudes 75°55' to 76°30' E, covering approximately 4,000 square kilometers within toposheets 55C/1 to 55C/8. The area features a remarkable 460-meter-thick sequence of lava flows, contributing significantly to our understanding of the regional geology and landscape evolution (Fig. 1).

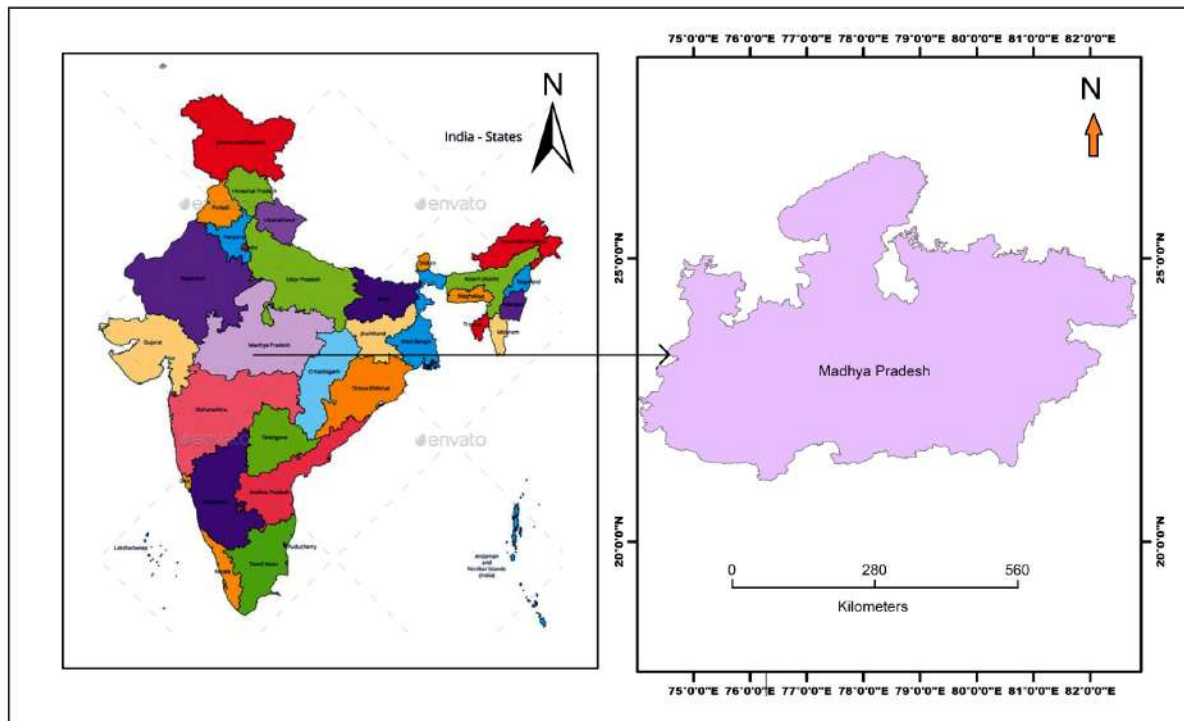


Figure 1: Location map of the study area.

GEOLOGY AND FLOW MAPPING

The study area (Fig. 1) is a geological marvel that plays a pivotal role in understanding the Deccan Traps' vast expanse and complexity. It is largest & well-preserved Volcanic province in India (Shukla, et al.,2026, Krishnamurthy, 2020, Mittal, Sprain, et al.,2021). The Amba Formation, part of this extensive lava sequence, offers unique insights into the geological history of the region through palaeomagnetic studies. According to Roy Thompson (1974), paleomagnetism entails studying the Earth's geomagnetic field over geological time by analyzing the stable magnetization preserved in rocks. By examining the palaeomagnetic properties and remanent magnetization of this formation, this study aims to elucidate the complex geological processes that have shaped the Asirgarh Region within the broader context of the Deccan Traps. Through detailed analysis of the magnetic signatures preserved in the lava flows, we can reconstruct past geomagnetic field behavior and understand the tectonic movements and volcanic activities that influenced the region. The findings will not only enhance our understanding of the local geological history but also contribute to the broader palaeomagnetic knowledge of the Deccan Traps, a crucial area for studying volcanic activity and its impact on the Earth's magnetic field and geological evolution.

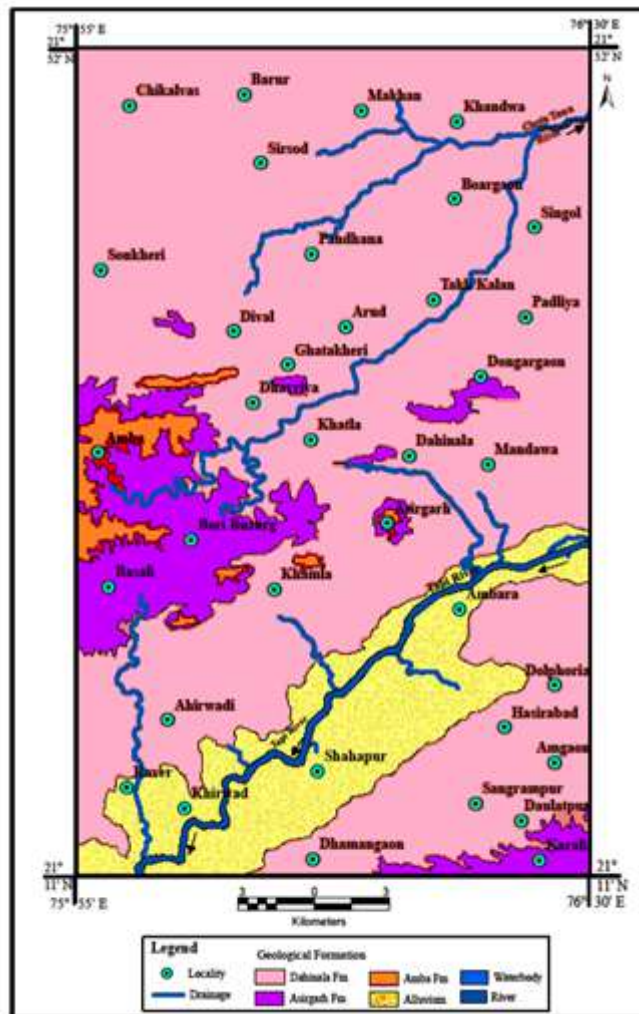


Figure : Geological map of Amba area, Madhya Pradesh, India.

Amba traverse is near about 5 km from Sukta, the way to reach traverse is Burhanpur to Asirgarh to Dulkote to Sukta to Amba to near about 1 km NE direction and is characterized by the presence of undulating topography. The minimum and maximum elevation recorded by the GPS is 610 to 730 meters. In this field traverse, five different flows (XII to XVI) (Fig. 2) belonging to Amba and Asirgarh formations have been recognized in 120m thick lava pile sequences (Fig.2).

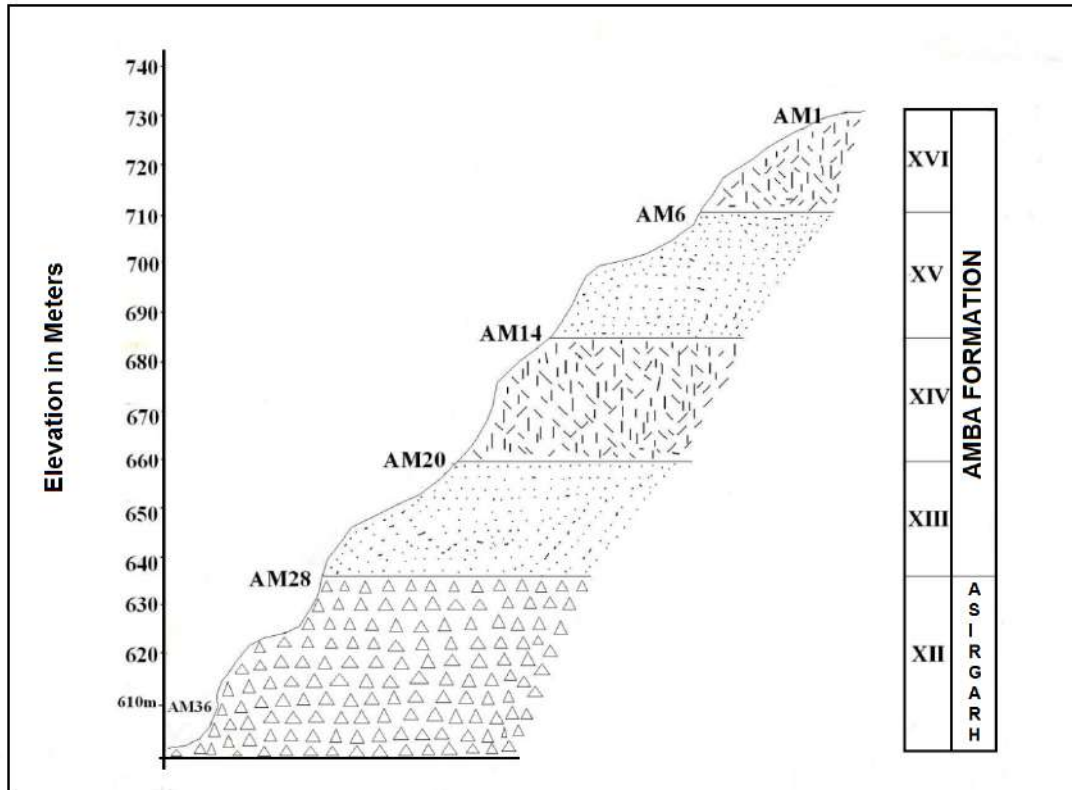


Figure 2 : Amba field traverse, Madhya Pradesh, India with different basalt lava flows.

METHODOLOGY

The methodology employed in this study begins with systematic fieldwork in the Asirgarh Region of Madhya Pradesh, focusing on the Amba Formation within the Deccan Traps. Oriented rock samples were meticulously collected from various exposures to ensure representative sampling of the formation's lithological diversity. In the laboratory, these samples were processed to prepare standard specimens for subsequent analysis. Initial measurements included the determination of Natural Remanent Magnetization (NRM) and susceptibility to characterize the magnetic properties of the specimens.

Following these measurements, the samples underwent palaeomagnetic cleaning techniques, notably Alternating Field Demagnetization (AFD) and Thermal Demagnetization. AFD involved subjecting the samples to progressively increasing alternating magnetic fields to remove secondary magnetic components, while Thermal Demagnetization used incremental heating steps to achieve the same goal. Throughout these processes, careful attention was given to maintaining the integrity of the primary magnetic signals preserved within the rocks.

Data analysis comprised the construction of stereoscopic projections and Zijderveld diagrams to visualize and interpret the remanent magnetization directions and intensities. From these analyses, palaeomagnetic directions were derived, and palaeo pole positions were calculated. These positions were subsequently compared with established polar wander curves for the relevant geological period to infer the movements of the Earth's crust and geomagnetic field over time.

RESULT AND DISCUSSION

PALAEOMAGNETIC COMPONENTS OF THE LAVA FLOWS

The preliminary palaeomagnetic investigations have yielded various magnetic parameters, including Declination (D) (Table 1, fig 3), which is measured in degrees from 360° East of geographic North, and Inclination (I), which is positive when downward and negative when upward. The results also include intensity and other relevant parameters, as shown in Table 1, fig 3

Table 1: Rock Magnetic and Preliminary palaeomagnetic data of the lava flows, exposed in the Amba Formation.

[K-Magnetic Susceptibility $\times 10^{-4}$ emu/gm, Jn-NRM intensity $\times 10^4$ emu/gm, Ji- Induced magnetization in the field of 0.5 Oe computed from susceptibility; Qn-Koenigsberger ratio (Jn/Ji), I-Inclination, Downward inclination (+ve), Upward inclination(-ve).D-Declination (EAST of North), RS (77K/300K) – Relative Susceptibility; P.S. (120K/300K)- Peak Susceptibility; TM: Titanomagnetites].

Flow No.	Sample & Specimen no	Elevation (m)	Wt (gm)	D ^o	I ^o	J _n X 10 ⁴ emu/gm Oe	J _i X10 ⁴ emu/gm Oe	Qn	K ₃₀₀	R.S. (77K/300K)	P.S. (120K/300K)	Domain State	TM Composition
XVI	AM1al	730	24.678	158	40	41.21	1.64	3.26	2.18	0.73	-	SD+CD	TM ₆₅
XVI	AM4al	720	24.028	143	32	39.12	1.82	2.43	2.20	0.75	-	SD+CD	TM ₆₅
XVI	AM6al	715	24.336	132	39	36.12	1.48	4.41	3.04	0.43	-	SD	TM ₆₀
XV	AM7al	710	24.851	137	28	32.54	2.62	1.04	1.42	0.96	-	SD+CD	TM ₇₀
XV	AM10a1	700	25.841	145	32	37.23	1.98	2.86	1.21	0.86	-	SD+CD	TM ₆₈
XV	AM13a3	690	21.807	126	41	38.21	1.63	1.68	1.42	0.94	-	SD+CD	TM ₇₀
XIV	AM15a1	680	25.130	146	39	35.21	1.04	2.45	1.12	1.04	-	CD+MD	TM ₅₄
XIV	AM20a1	660	24.400	133	36	33.43	1.08	1.09	1.31	1.12	-	CD+MD	TM ₅₃

				0									
XI	AM2			1	4	36.7	1.64	1.	1.	1.08	-	CD+	TM ₅₄
II	1a1	658	23.900	2	0	3		48	20			MD	
				6									

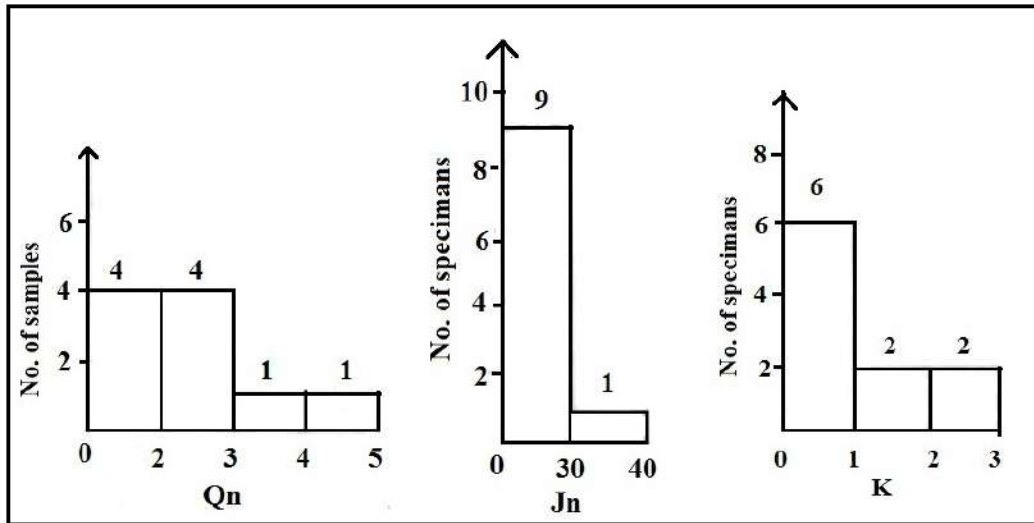


Figure 3: Distribution of number of specimen Vs Koenigsberger ratio (Qn), Natural remanent magnetic intensity (Jn) and Magnetic susceptibility (K) for Amba Formation

MAGNETIC AND THERMAL CLEANING TECHNIQUES

Magnetic and thermal cleaning techniques play a pivotal role in paleomagnetic studies, facilitating the removal of soft secondary magnetic components from rock samples to isolate primary magnetization (Koenigsberger 1938, Thellier 1938 and Nagata 1943). Alternate field demagnetization (AFD) involves subjecting samples to varying alternating magnetic fields, effectively demagnetizing secondary components (Tauxe, 2010; Butler, 1992, Butler, 2004). Conversely, thermal cleaning utilizes controlled heating, either stepwise or continuous, to achieve similar results by progressively altering magnetic properties at increasing temperatures (Dunlop & Özdemir, 1997). These techniques are essential for deciphering the Earth's magnetic history, aiding in the reconstruction of past geomagnetic field behavior and geological processes (Kent & Lowrie, 2013).

Alternate Field Demagnetization (AFD):

Alteration of Field Demagnetization involves applying a decaying alternating magnetic field to a sample, identifying, and eliminating secondary natural remanent magnetization (NRM). The process was applied to 38 representative specimens from the study area using progressively increasing fields (0 Oe, 60 Oe, 120 Oe, 180 Oe, and 240 Oe) to assess NRM direction stability and remove soft secondary components (Table 2). Among the specimens subjected to alternating demagnetization, a subset retained their NRM directions (Tauxe, 2010; Butler, 1992; Dunlop & Özdemir, 1997).

The plotted vector diagrams (Fig. 4) for representative specimens during alternating field (AF) demagnetization reveal significant insights into the nature of magnetization within the samples. The analysis indicates that several samples exhibit enhanced magnetic directions (AM 21a1, Fig.4 a, b, c) as demagnetization progresses. This enhancement likely arises from the presence of substantial secondary magnetization components, which may have been acquired due to geological events or chemical changes occurring after the rocks' initial formation. The AF demagnetization process seems to realign these secondary magnetic domains, making them more prominent and stable. Some samples, such as AM20a1, (Fig. 4 b) demonstrate stable magnetic directions and a slow decrease in intensity even after extensive demagnetization, indicating they likely retain their primary magnetization from the time of rock formation. These samples are ideal for paleomagnetic studies because they accurately reflect the Earth's magnetic field at that time. However, other samples exhibit odd magnetic directions or scattered directions that persist after demagnetization, accompanied by either a slight or steep intensity decrease. This behaviour suggests that the primary magnetization has been altered, possibly due to chemical or thermal events, resulting in dominant secondary magnetization components, as seen in samples like AM1a1 and AM29a1 (Fig. 4 a). Such samples, dominated by secondary signals, are unsuitable for paleomagnetic studies.

Vector diagrams highlight that samples with stable directions and slow intensity fall are valuable, while those with enhanced or odd directions indicate significant secondary magnetization. Secondary magnetization can result from geological processes such as lightning strikes, metamorphism, and tectonic disturbances, introducing new magnetic signals that alter the original magnetization (Irving and Opdyke, 1965). Therefore, careful interpretation of these behaviours is crucial for accurately reconstructing past geomagnetic fields.

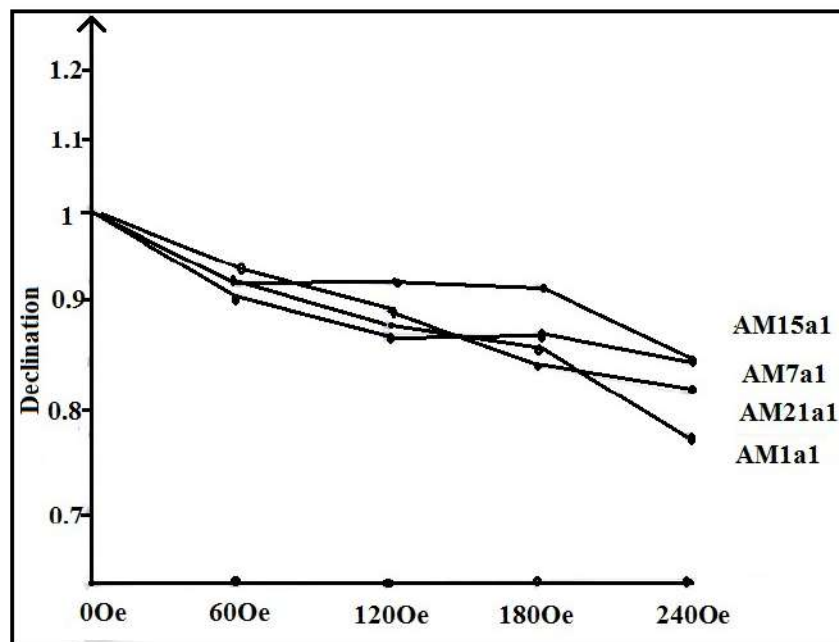


Figure 4 (a): Declination of alternating field demagnetization (AFD) for selected samples.

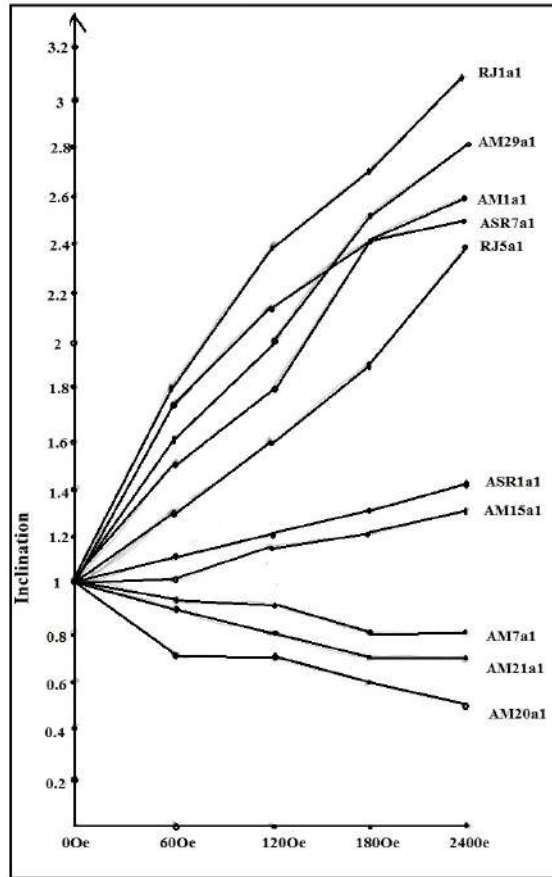


Figure 4 (b): Inclination of basalt samples after applying alternating field demagnetization (AFD) technique.

Table 2: Alternating field demagnetization of rock samples from different lava flows. (D-Declination, I-Inclination, Jn-NRM intensity x 10⁴emu/gm)

S r. N o.	Che mic al Typ e (CT)	Fl o w N o.	Sa mpl e No.	Hei ght (m ete r, ab ove msl)	We igh t (g m)	00 ^e			600 ^e			1200 ^e			1800 ^e			2400 ^e		
						D 0	I 0	J _n	D 0	I 0	J _n	D 0	I 0	J _n	D 0	I 0	J _n	D 0	I 0	J _n
1	CT ₂	X V I	AM 1a1	730	24. 678	1 7 4	1 2	42 .1 4	1 5 5	2 1	39 .1 2	1 4 1	2 6 1	36 .1 1	13 4	2 9	34 .8 7	12 4	3 2	31 .2 3
2	CT ₄	X V	AM 7a1	710	24. 851	1 6 5	4 3	45 .2 2	1 5 8	4 0 1	42 .1 1	1 4 4	3 9 3	41 .0 3	14 0	3 8	39 .1 1	13 6	3 6	38 .2 3
3	CT ₃	X	AM	680	25.	1	2	39	1	2	36	1	2	35	14	2	34	14	2	32

		I V	15a 1		130	5 8	1	.5 4	5 0	3	.2 5	4 8	5	.1 2	4	7	.1 1	2	9	.4 5
4	CT ₃	X I V	AM 20a 1	660	24. 400	1 7 3	5 8	47 .3 2	1 6 5	4 6	42 .3 2	1 5 4	4 1 4	40 .0 2	14 3	3	39 .9 8	13 2	3 2	38 .2 1
5	CT ₁	X III	AM 21a 1	658	23. 900	1 4 8	4 9	44 .1 2	1 3 9	4 5	40 .5 4	1 3 6	4 1 2	38 .4 2	13 1	3	35 .6 5	12 9	3 6	34 .2 5

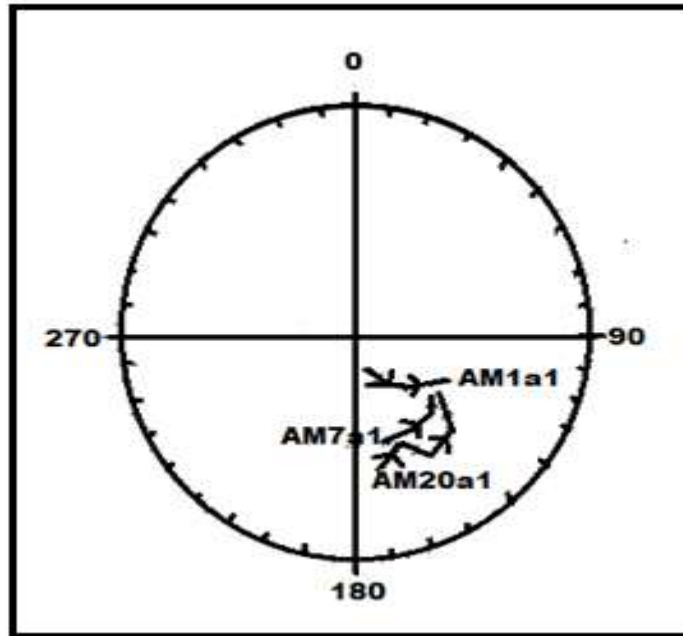


Figure 4 (c): Behavior of vector directions in representative specimens, during alternating field demagnetization (inclination positive: downward, negative: upward; arrow indicating increased demagnetization).

STEPWISE THERMAL DEMAGNETIZATION (TD)

This study evaluated the stability of Natural Remanent Magnetization (NRM) directions in rock specimens using a stepwise thermal demagnetization technique. Samples were heated sequentially at 100°C, 200°C, and 300°C, and then cooled in a field-free environment to assess stability. The results showed (Table 3) varied responses among magnetic grains: some samples had stable NRM directions, indicating strong primary magnetization, while others experienced changes in vector directions and intensity, indicating the removal of secondary magnetization components (Venkateshwarlu et al., 2008; Khadri, 1988a). Vector direction and intensity changes during thermal demagnetization were analysed (Table 3, Fig. 5 a-c) to understand magnetization behaviour with increasing temperature. This method provides valuable insights for interpreting paleomagnetic data and understanding the magnetic properties of geological materials.

Thermal demagnetization revealed three distinct response patterns to increasing temperatures. First, most rock samples showed a gradual decline in magnetic intensity, maintaining

consistent directions (Fig. 5a,b), consistent with the principle that thermal demagnetization progressively removes secondary magnetization, revealing primary remanence (Tauxe, 2010; Dalim et al., 2008). Second, some samples initially showed increased magnetic intensity followed by a gradual decrease (Fig. 5b), suggesting removal of unstable components and enhancement of primary directions, crucial for identifying characteristic remanence directions. Third, a few samples exhibited a rapid decrease in intensity early in demagnetization, indicating strong isothermal remanent magnetization (IRM) (Fig. 5c,d). These samples did not show improved remanent direction, suggesting a complete loss of primary magnetization originally acquired by the rocks (Fig. 5c, d).

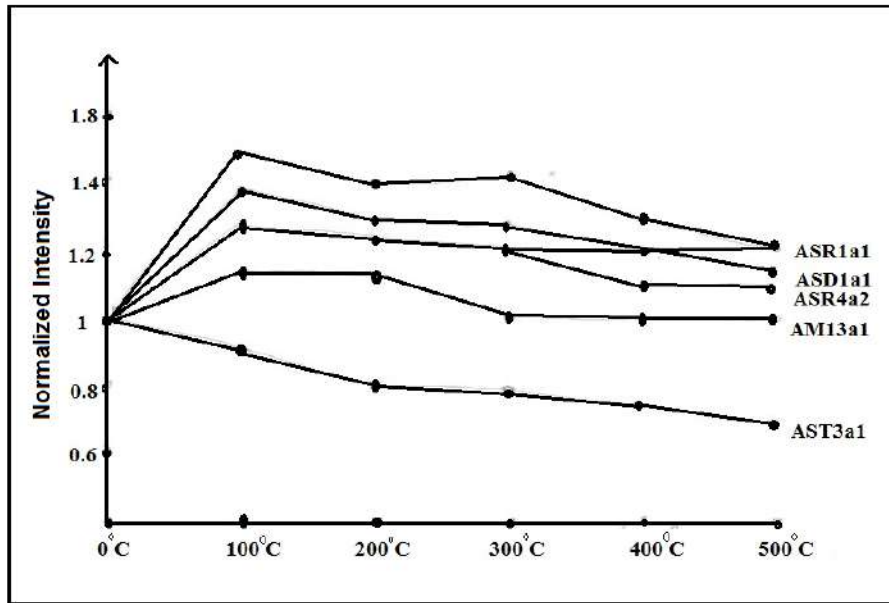


Figure 5 (a): Normalized intensity curves of stepwise thermal demagnetization for representative specimens.

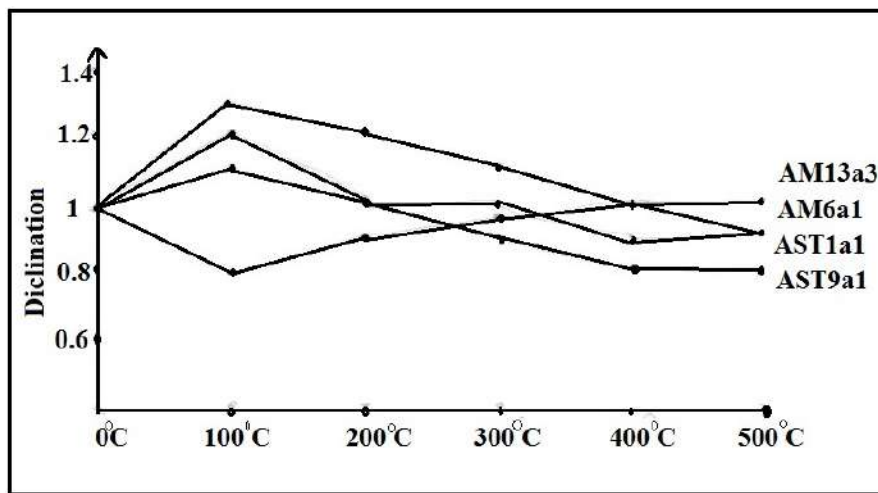


Figure 5 (b): Diclination curves of stepwise thermal demagnetization for

representative specimens.

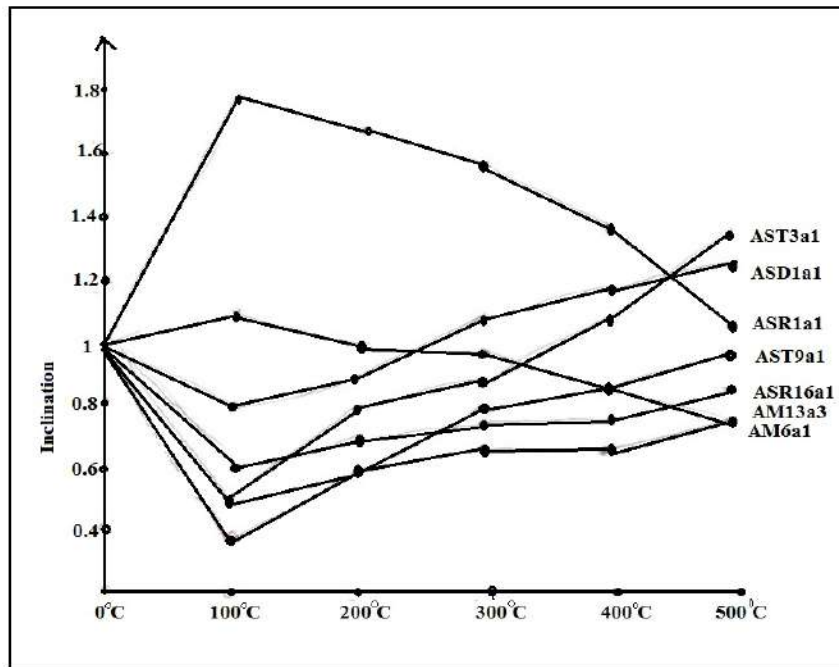


Figure 5 (c): Inclination curves of stepwise thermal demagnetization of representative specimens.

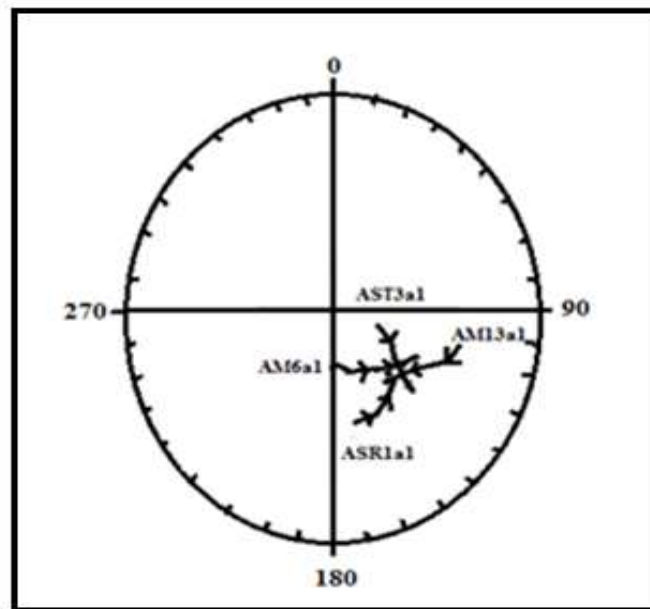


Figure.5(d): Behaviors of vector directions in representative specimens, during Step wise thermal demagnetization (TD) (Inclination positive: downward and, Negative: upward (arrow indicates increased demagnetization)).

Table 3: Results of progressive stepwise thermal demagnetization of rock samples from different lava flows.

S r. N o.	Che mic al Typ e (CT)	Fl o w N o.	Sa mpl e No.	Hei ght (m, ams l)	We igh t (g m)	100°C			200°C			300°C			400°C			500°C		
						D 0	I 0	J _n	D 0	I 0	J _n	D 0	I 0	J _n	D 0	I 0	J _n	D 0	I 0	J _n
1	CT ₂	X VI	AM 6a1	715	24. 336	1 7 9	2 1 4	39 .1 4	1 6 6	2 4 4	37 .8 4	1 5 3	2 8 3	36 .8 2	1 4 1	3 0 4	33 .4 4	1 2 4	3 2 4	31 .2 3
2	CT ₄	X V	AM 13a 3	690	21. 807	1 0 7	4 6 1	44 .1 1	1 1 8	4 4 5	43 .8 5	1 2 2	4 1 0	41 .8 0	1 3 1	3 9 9	40 .8 9	1 3 6	3 6 6	38 .2 3
3	CT ₃	XI V	AS R1a 1	671	24. 378	1 7 2	4 8 3	39 .6 3	1 6 3	4 6 5	38 .9 5	1 5 8	4 3 2	37 .4 2	1 5 0	3 7 2	35 .8 2	1 4 2	2 9 2	32 .4 5
4	CT ₃	XI V	AS R4a 2	465	24. 530	1 6 6	2 2 2	42 .3 2	1 5 8	2 4 6	41 .7 6	1 4 7	2 7 6	40 .8 6	1 4 1	2 9 4	39 .6 4	1 3 2	3 2 2	38 .2 1
5	CT ₁	XI II	AS T1a 1	658	23. 874	1 7 3	4 8 1	40 .2 1	1 4 6	4 6 4	38 .7 4	1 4 2	4 2 1	36 .2 1	1 3 4	3 9 2	35 .1 2	1 2 9	3 6 9	34 .2 5

CONCLUSION

This study investigates the paleomagnetic properties of the Amba Formation in the Asirgarh Region of Madhya Pradesh, India, part of the extensive Deccan Traps. Preliminary paleomagnetic studies employed Alternate Field Demagnetization (AFD) and Stepwise Thermal Demagnetization (TD) on 38 samples from the Amba Formation. AFD results revealed varying behaviours, with some samples showing stable Natural Remanent Magnetization (NRM) directions, while others exhibited significant secondary magnetization, requiring further demagnetization to isolate primary magnetization. Vector diagrams from AFD highlighted enhanced magnetic directions in some samples, likely due to secondary magnetization acquired post-formation. TD results identified three magnetic patterns: a gradual decrease in magnetic intensity indicating stable primary magnetization, an initial increase followed by a gradual decline indicating removal of unstable components, and an abrupt intensity drop indicating strong isothermal remnant magnetization obscuring primary signals. These findings demonstrate the effectiveness of AFD and TD in distinguishing primary from secondary magnetization, crucial for accurate paleomagnetic interpretations. This study contributes significantly to our understanding of the magnetic history of Amba Formation and can be useful for further palaeomagnetic investigations within the Deccan Traps.

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