

also contributed by zircon grains (Figure 2 a–d).

Dariba shear zone hosts copper deposits. In the early 80s radiometric investigations in some underground levels of a copper mine revealed sporadic, high-grade (up to 1.57%) uraniferous patches (G. V. G. Sharma *et al.*, unpublished). The mine dumps and excavations comprising schists, phyllonites and metabasites also show higher level of radioactivity. Petrographically, underground uraniferous samples indicate uraninite as disseminations and veins along with polymetallic association of bornite, chalcocopyrite, pyrite and molybdenite, suggesting epigenetic hydrothermal type of mineralization (M. K. Khandelwal *et al.*, unpublished).

The uranium-mineralized shear zone of Dariba copper mine continues further south and extends over 2 km. The area offers ample scope to look for high-grade uranium mineralization. The shear zone

bears significant importance in hosting uranium mineralization in the Kho-Dariba area. It is pertinent to mention here that lateral and vertical facies variation is well demonstrated along the shear zone. The shear zone cutting through hard quartzite on the surface passes through carbonaceous pelites at depth. The carbonaceous pelites with iron and copper sulphides provide a favourable host for uranium mineralization. Thus a conducive geological environment for precipitation of uranium is evident and a shear-controlled uranium mineralization can be envisaged at depth.

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Pulsed inflation in the hummocky lava flow near Morgaon, western Deccan Volcanic Province and its significance

Inflation is a widespread process of emplacement of magmas from recent shield volcanoes and in parts of ancient Continental Flood Basalt provinces. It is the process by which lava at low effusion rates accumulates endogenously within its own viscoelastic crust to develop bulbous forms. Inflation transforms a lobe that is a few centimetres thick to greater than 10 m. Inflation is a fairly continuous process, but at times is disrupted due to waning of lava supply either from the vent or within the flow field due to temporary stoppage, blockage or diversion. This results in discontinuous inflation, popularly called as 'pulsed inflation'.

A large area of the west-central Deccan Volcanic Province (DVP) is occupied by pahoehoe lavas¹. Pahoehoe flows range from the typical hummocky² and sheet-flow types to the more viscous varieties like slabby pahoehoe (Table 1). The recent studies^{3–6} have conclusively demonstrated that inflation has played a major role in the emplacement of the pahoehoe flows from the DVP. Locally, however, there are several instances where lava morphology indicates emplacement by a less conspicuous mechanism of 'pulsed' inflation. The present account is of one

such occurrence near Morgaon (74°18'20"–18°16'55"), southeast of Pune, where evidence of pulsed inflation in the form of a ridged lobe having a distinct morphology is being reported.

The lobe containing evidence of pulsed inflation is exposed on the bed of Karha River near Morgaon (Figure 1). The area around Morgaon is dominated by an undulating topography. The Karha River and its tributaries drain the area⁷. Quaternary alluvial sediments cover the area. The thickness of the alluvium is variable and ranges from 1.5 to 15.8 m. It is seen that a basal conglomerate consisting of boulders and cobbles of basalt is present in many sections. This is followed by silt and clay, with intercalations of sand and conglomerate. Towards the upper parts of the section, calcrete deposits are present. Calcrete is of nodular, bedded and hard-pan varieties. In some sections, a ~50 cm thick layer of volcanic ash is exposed^{8,9}.

The Morgaon flow containing the lobe is reddish, fine-grained, and exposed as discontinuous outcrops within the bed of the Karha River. The surface of the flow is hummocky. The crust is vesicular and vesicle banding is common. Numerous


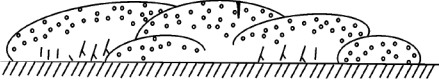
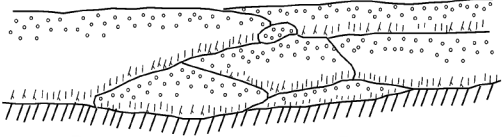
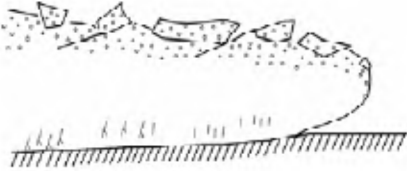


inflation clefts are present in the crust and these are occupied by squeeze-ups. In one of the outcrops near the bridge over the Karha River, a small (~1.5 m), fragile lobe is exposed on the surface. The crust of the lobe is highly vesicular. The vesicles are small (2–4 mm), spherical and their density is high compared to the surrounding lava (Figure 2). The vesicles from the ridged lobe themselves do not define any preferred orientation or lineation.

The lobe is distinguished from the surrounding as it consists of a prominent ridged surface (Figure 3). Individual ridges range from 11 to 30 cm. Closer observations reveal that the ridges constitute several bumps or bulges. There is no distinct symmetry in the bulge geometry and the amplitudes of the bulges vary considerably. The ridges constituting the bulges resemble folds of ropy lava¹⁰, but are distinct in that they are separated by deep grooves. Moreover, the ridges have no flow directional convexity as seen in ropy lavas.

Morphologically, the feature in question could easily be mistaken for lava squeeze-ups. The squeeze-ups preserved elsewhere in the Karha River bed are

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Table 1. Simplified definition of lava types and their morphology. Note that all the sketches are along the longitudinal section

Lava type	Definition	Sketch	Significance
Pahoehoe	Pāhoehoe is a Hawaiian term meaning 'smooth, unbroken basic lava' that has a smooth, billowy, undulating, or ropy surface. Pahoehoe lavas are composed of many units.	Multiple units (compound) constituting pahoehoe 	These surface features are due to the movement of fluid lava under a congealing surface crust. Compound type of lava.
Hummocky pahoehoe	A variety of pahoehoe lava comprising of lava toes, small lobes and tumuli. The surface of this type of lava is smooth, bun-like and hummocky.	Smooth, hummocky surface 	This type of compound flow forms either due to low lava effusion rate or due to undulating paleotopography.
Sheet pahoehoe	A variety of pahoehoe lava that consists of large, tabular lobes and thick sheets of lava units. The units are stacked one above the other to form a flat, tabular geometry.	Flat, gently undulating surface 	Inflation and coalescence of lava lobes give rise to flat-topped sheet lobes, with typical three-tiered internal structure (crust-core-basal pipe zone).
Slabby pahoehoe	Slabby pahoehoe contains a series of closely spaced slabs, a few metres across and a few centimetres thick, broken and tilted by mass movement or draining of the underlying lava.	Surface disrupted with crustal slabs 	It is considered a type of gradational lava between pahoehoe and Aa, and shows predominant pahoehoe characters but with a disrupted crust.
Toothpaste lava	A distinct tongue-shaped lava type with longitudinal grooved, ridged and spinose surface with clinkery lateral margins. Surface of some toothpaste tongues is broken into imbricated crustal plates.	Surface with buckles and ridges 	A transitional type of lava that develops within flow fields when the lava has cooled sufficiently to have a high viscosity and when the flow is advancing slowly.
Aa	Aa is a Hawaiian term meaning 'stony with rough lava'. It is one of three basic types of lava flow, whose surface is composed of broken lava clinker.	Irregular, clinkery surface 	Generally Aa flows are most viscous of all morphological types and advance much less rapidly than pahoehoe flows on the same slope.

mostly singular features that have a typical morphology and internal structure. The squeeze-ups are generally irregular in plan and have lengths >0.7 m. They have typically developed a thin zone of chilled margin along the contacts with the host lava and a coarser central portion that is plagioclase phyric. In contrast, the ridge-like feature is actually a single lobe with surface grooves that mimic being a parallel swarm of squeeze-ups. However, closer examination reveals the absence of chilled margins. Besides, the lava is not plagioclase phyric and is completely vesicular, indicating that the upper surface of the lava has been grooved. Thus, the

absence of bounding inflation cleft, lack of chilled margins and absence of a porphyritic core, common to many squeeze-ups in pahoehoe flows from the Deccan Traps negate the possibility of this feature being a squeeze-up.

One is also tempted to correlate this structure to pasty pahoehoe or toothpaste lava¹¹ – a lava-type transitional between pahoehoe and Aa. In Hawaii, this transitional morphological type is found at greater distance from the vent and has a rough, hackly crust that deforms into broken plates^{12,13} or ropy folds. Although the lobe from the present investigation bears morphological resemblance to

toothpaste lava, the possibility is refuted, as the crust is not sufficiently broken into plates. In case of toothpaste lava, the 'ridges' are formed perpendicular to the flow direction and the surface grooves and striations on the surface are parallel to the flow direction. The ridges in case of the lobe from Morgaon are smooth, without any surface grooves or striations. Moreover, it is not clear as to how an extremely viscous lava type like toothpaste lava (viscosity: 6000–12,000 Pas¹¹) could be generated locally in a predominantly pahoehoe flow.

Inflation or endogenous growth of lava has come to be recognized as the main

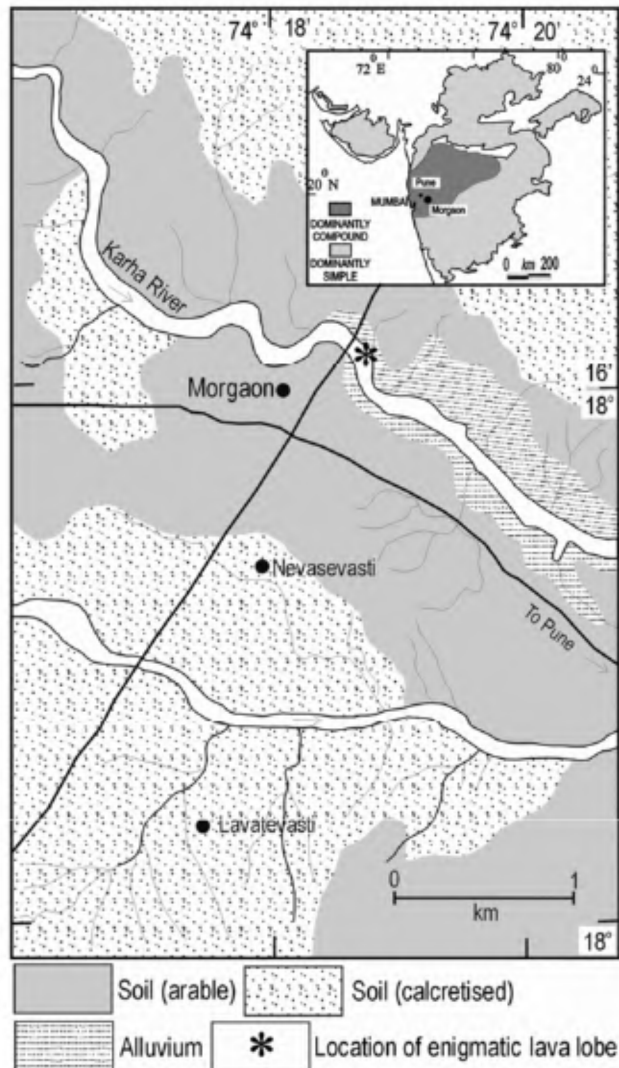


Figure 1. Location map of the Morgaon area.

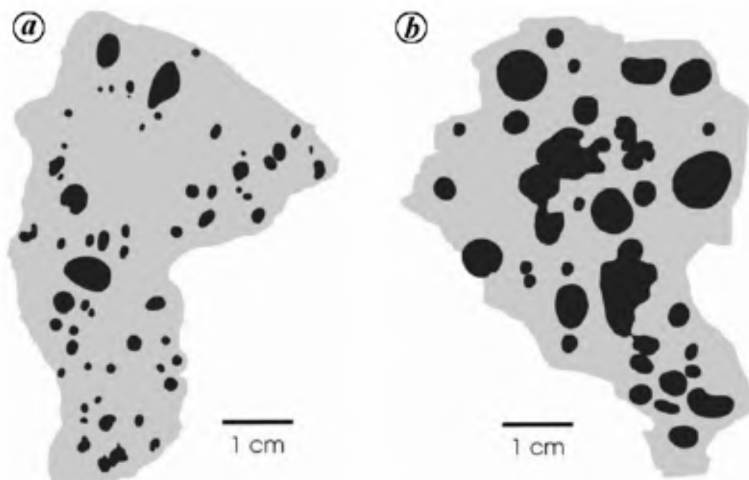


Figure 2. Distribution patterns of lava vesicles from (a) ridged lobe and (b) hummocky flow. Note the difference in size, shape and density of vesicles.

mechanism of lava transfer, especially in pahoehoe lavas¹⁴. Locally however, storing and/or retreating of lava have been recorded from active flows¹⁴ and may cause oscillations in lava supply to the flow front. The concept of 'pulsed' inflation¹⁵ suggests that you can have a constant overall supply rate, yet feed different parts of the inflating flow at different rates or times. Thus, pulsed inflation with steady supply rate could have the same effect as oscillating supply rate and produce lava morphology that is distinct from the regular pahoehoe. The lobe from Morgaon possibly provides evidence for pulsed inflation in flows from the DVP. It is believed that the lobe propagated from an ephemeral vent or surface crack from a large inflating lobe (Figure 4). During this process, the rate of lava supply varied intermittently (pulses), resulting in a ridged surface. Each bulge is therefore a product of a 'pulse' of lava, temperature, viscosity and composition being almost constant. In other words, the bulges were formed when the lava came out in pulses (pulsed inflation) rather than at a constant rate. The deep grooves represent the number of lava surges (pulses), especially towards the terminal parts of the pahoehoe lava flow-field. Each pulse produced enough lava pressure to extrude a limited volume of lava through the inclined inflation cleft (crack) in the propagating sheet lobe.

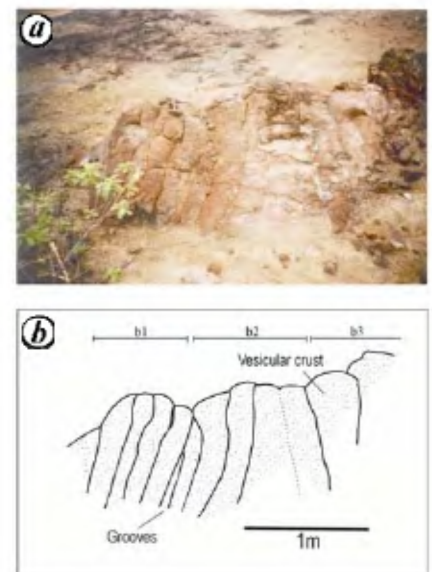


Figure 3. (a) Photograph and (b) field sketch of lava lobe showing evidence of pulsed inflation. Note the number of bulges, b1 to b3, on the surface of the lobe.

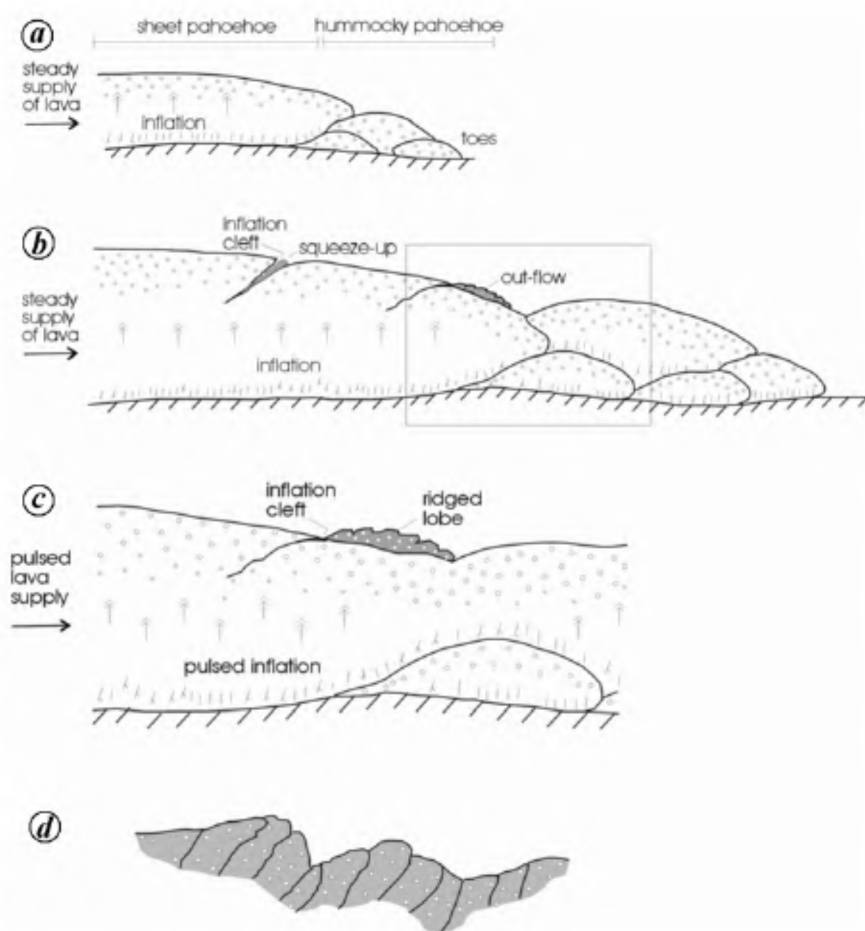


Figure 4. Cartoon depicting the formation of the ridged lobe from Morgaon. **a.** Emplacement of a hummocky flow with few sheet lobes. **b.** Endogenous thickness and development of inflation clefts. **c.** Pulsed inflation resulting in extrusion of lava in pulses and the development of ridged lobe. **d.** Exhumation of the ridged lobe after ~65 Ma.

The extruded lava cooled significantly between pulses and produced the local humps bounded by deep grooves. This produced a distinct morphology quite different from the regular pahoehoe.

The pahoehoe flow exposed in the Morgaon area probably represents the terminal parts of a larger flow field belonging to the Bushe Formation¹⁶. It is envisaged that the lavas belonging to the Bushe Formation could have erupted close to the crest line of the Western Ghats near Lonavala and the lavas could have travelled eastwards to the extent of >140 km through a complex network of interconnected lobes constituting distinct flow-fields. The earlier extent of the Bushe Formation was mapped as ending a short distance east of Pune city¹⁷. However, the present investigation and presence of pahoehoe east of Daund¹⁸ and near Indapur, could indicate that the

Bushe Formation could be more extensive than previously mapped. The presence of evidence of a lava lobe preserving the evidence of pulsed inflation in the terminal parts of the hummocky flow is significant. Based on this evidence it can be concluded that pulsed inflation could be a phenomenon common in the terminal parts of some of the hummocky pahoehoe flows from the Deccan Trap and can account for some of the intriguing geometry in the pahoehoe flows. Understanding the phenomenon of pulsed inflation will help in mapping individual flow-field that can provide better insight into the physical modelling and emplacement mechanism of pahoehoe flows at the time of the Deccan Trap volcanism.

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