Breccia filled inflation clefts on the banks of the Kukadi River near Hanewadi, Ahmednagar District, Maharashtra

The surface features of basaltic lava are classified as pahoehoe, aa, and blocky. Pahoehoe or ropy lava is mostly fluid and spreads as thin sheets with smooth and glistering surfaces, commonly twisted into ropy wrinkles through continued flow of lava below the elastic skin. In the Deccan, several features related to the pahoehoe morphology have been reported and the mechanism of inflation has been invoked for their emplacement. Inflation clefts and squeeze-ups are common features in the pahoehoe flows from the Deccan and are mostly associated with tumuli and sheet lobes. Inflation clefts are cracks or fractures formed within the crust of inflating lobes and sheets through which fluid lava from the interior oozes out in the form of 'squeeze-ups'. In thick sheet lobes, the incandescent tip of the inflation cleft does not reach the lobe interior and fails to tap the liquid core resulting in the lack of formation of squeeze-ups. Such inflation clefts seldom remain empty or are filled by the lava from the overlying lobes to form 'lava-fingers'. Empty inflation clefts have typical striations and groove that have been used to decipher the nature of inflation. Although empty inflation clefts are common in pahoehoe flows in the Deccan, no published report exists of breccia filling these features. Significant therefore is the present report of inflation clefts exposed on the banks of the Kukadi River, near Hanewadi (18°55'40"N; 74°15'45"E), approximately 80 km NE of Pune (Figure 1).

The area near Hanewadi is included in the toposheet no. 473/5 and is drained by the Kukadi River and its tributaries. The source of Kukadi River lies in the Western Ghats, near Nanehat, around 25 km north of Bhimashankar. The river flows eastwards along a 150 km course to meet the Ghod River, which flows along the well-known Ghod lineament near Hanewadi. The Kukadi River has developed a knick point where a deep, incised gorge has developed with a remarkable assemblage of potholes. The gorge occupies only a part of the width of the river and is 6 to 10 m wide, more than 10 m deep and extends about 100 m in length. This deep gorge exhibits a remarkable assemblage of isolated, merged and interconnected potholes of varying dimensions. Some potholes are more than 9 m deep and 2–4 m wide. These giant and deep potholes are correlated to a high-energy profile of the major rivers of the Deccan Volcanic Province during the Quaternary Period and their formation is attributed to lithological and structural control. The walls of the gorge expose excellent features of compound pahoehoe (Figure 2). In general, two large sheet lobes are seen in the section, but locally lava toes, lobes and tumuli are also seen. Each lobe is divisible into a typical three-tiered internal structure consisting of an upper vesicular crust, middle dense, massive core and basalt vesicular zone typical of compound pahoehoe flows. The basal vesicular zone consists of distinct 'pipe vesicles' at the base, many of which have coalesced into the typical inverted, y-shaped form. In one section a tumulus is exposed (Figure 2a). The sheet lobes and tumuli record characters of inflation and show the development of several inflation clefts and squeeze-ups. The crust of some of the lobes shows the development of crude vesicle banding at places. The lower sheet lobe is partially exposed in the gorge section. Towards the south-eastern end of the gorge, the lobes taper and give rise to several smaller lobes. A couple of lava inflation clefts are developed in these lobes. Lava fingers from the overlying lobe fill these clefts.

Several brecciated cleft fillings can be observed within the upper sheet lobe constituting the extensive rocky, pelt-plained bank of the Kukadi River (Figure 3a and b).

Figure 1. Location map of Hanewadi area near Nighoj, Ahmednagar District, Maharashtra.
The cleft fillings vary in length from a few metres to more than 13 m, and a width of 3 to around 7 cm. These generally trend in the N15°E–S15°W, N20°E–S20°W, and E–W but exhibit a good sinuous form. At places, these are found to form small ridges due to differential weathering. Many of the brecciated clefts are exposed in plan, only a few are exposed in vertical sections. However, given the morphological similarities between the present breccia-filled features and those found in the Hanewadi flow and elsewhere in the Deccan, they are invariably inflation clefts. In majority of the cases the cleft fillings are found to be filled by a white to greenish-white, hard material with appreciable amounts of brecciated material. In hand specimens, the brecciated cleft fillings are found to consist of angular fragments of basalt of varying dimensions found cemented in a fine-grained greenish-white material (Figure 3c). The brecciated fragments range in size from less than 1 mm to about 10 cm. The basalt fragments are hard, reddish-brown, massive, rarely exhibiting vesicular and amygdaloidal forms.

In thin sections the host rock is made up of fine-grained aggregate of plagioclase feldspar and pyroxene along with appreciable amounts of opaque. Intergranular and intersertal texture is a common feature. The cleft filling is found to consist of appreciable amounts of angular basalt fragments cemented together by a fine, greyish-white siliceous or zeolitic material (Figure 4). The walls of the cleft and the breccia fragments themselves are lined by a thin rim of zeolite minerals. A great similarity exists between the texture and mineralogy of the host basalt and the breccia fragments, indicating common parentage.

The process leading to the formation of the breccia-filled cleft is depicted in Figure 4. It is postulated that a large surface pahoehoe lava flow emerged and travelled from a distant source near Hanewadi. The flow advanced due to repeated budding of toes and lobes, and individual lobes grew into thick sheet lobes through the process of inflation. During its journey it was slowly inflating and solidifying with the formation of a thick crust, retaining its hot liquid core (Figure 5a). Further inflation of the cooling viscous-elastic crust could not accommodate the differential stresses resulting in the incipient development of inflation

Figure 2. Field sketches of compound pahoehoe flow exposed in the southeast end of the gorge section near Hanewadi. Note the presence of various inflation features such as tumuli, inflation clefts, squeeze ups, vesicle banding, etc.

Figure 3. Field photographs. a. Brecciated cleft filling on the banks of the Kukadi River near Hanewadi. Note the silica along the cracks. b. View of another brecciated cleft. Note the brecciated matter of variable dimensions embedded in a fine greenish-white matrix. c. Hand specimen of a brecciated cleft-filled material exhibiting angular fragmentary material set in a fine, greenish-white matter. Note the variations in the dimensions of the fragmentary material.
clefts (Figure 5b). With continued supply of lava to the core, the flow inflated and developed the inflation cleft (Figure 5c). However, further development of the cleft was arrested at this stage either due to pulsed inflation² or cessation of magma supply¹⁴. This hampered the downward propagation of the inflation cleft whose incandescent tip did not reach the liquid lava stored in the core (Figure 5c). The lack of formation of squeeze-ups within the brecciated clefts confirms this. The resulting cleft therefore remained empty and served as a receptacle for the already brecciated cleft tip.

The genesis of the breccia within the inflation cleft is intriguing. It is speculated that the breccia fragments could have been formed either due to tectonics along the Ghod lineament or due to pulsed inflation. Field evidences such as absence of distinct fault zones, fault breccia, local and limited extent of breccia-filled clefts, etc. indicate the lack of tectonic control on the formation of breccia-filled features. Hence it is not possible that the breccia could be derived by faulting of the host basalt. Syn-emplacement brecciation of pre-existing lobes/sheets due to sudden supply of lava to the flow front, i.e. pulsed inflation could have directly produced the breccia fragments. However, absence of brecciated squeeze-ups suggests that injection of breccia-filled magma into empty inflation clefts could not have been the preferred mechanism in the present case. Pulsed inflation could have had another influence on the growing inflation clefts. It could have been responsible for sudden widening of cleft mouths, especially in deep clefts where the upper crust had sufficiently cooled resulting in the formation of fragments of basalt. The basalt fragments thus formed could have been dislodged and trapped within the inflation clefts. This process could have been localized and restricted to only certain portions of the flow field, and therefore, these breccia-filled clefts are limited in number. The brecciated matter within the cleft was subsequently cemented by emanating silica-rich zeolitic fluids formed due to migration of volatiles and gases towards the inflation clefts due to decompression (Figure 5d). Alternatively, cementation could have also occurred by post-magmatic hydrothermal deposition of zeolitic fluids. Further studies of fluid inclusions within the matrix of the breccia may help decipher the nature and process of deposition of the zeolitic matrix. Subsequent exhumation of the sheet lobes at Kukadi River has exposed the fascinating breccia-filled inflation cleft near Hanewadi, Nghohai.

A rapid method of measuring shoot hydraulic resistance of rice: implications for efficient water use

The capacity for better moisture storage and its retention by the soil is a key factor for avoiding crop failures in drought-prone and water-limited environments. Such properties of soils are mainly dependent upon their texture and structure, which can be improved by adopting moisture-conserving practices like addition of organic matter, deep ploughing, field bunding, mulching, weed control, low crop density, etc. However, in the chain of these events there still exists a factor, namely plant factor and more precisely plant hydraulic resistance, i.e., the ease or difficulty with which water is transported up in the plant, which could be of prime significance in agriculture. This morphophysiological plant factor might be important in minimizing water consumption, hence saving the stored soil moisture by virtue of its slow transport in the plant due to greater shoot hydraulic resistance, thereby increasing the water-use efficiency.

This, in turn, would make the residual moisture available to plants for an extended period of time and may eventually enable the crops to grow and yield satisfactorily under depleted water-supply conditions in water-limited environments. But, in spite of its significance, this aspect of plant characteristics has attracted little attention of plant biologists, agronomists and plant breeders owing mainly to the lack of a reliable laboratory test for easy and quick measurement of hydraulic resistance of crop plants. In the recent past, however, some efforts have been made to measure the hydraulic resistance of tree plants, tomato plants and the roots of wheat, but they are too laborious, costly, cumbersome and time-consuming techniques, rendering them unfit for large-scale testing, as required by plant breeders, of plant hydraulic resistance. Here we present a technique for measuring the hydraulic resistance of rice shoot, which is easy, simple, reliable and quick to perform in the laboratory.

Since the rolling and unrolling of rice leaves are the most visible and quickest physiological response to water deficit and its alleviation respectively, it was decided to use the duration of time-lapse between these two responses as a measure of shoot hydraulic resistance under externally applied pressure, to force entry and transport of water through the cut ends of the excised stems up to the leaves, reversing the phenomenon of natural leaf rolling upon plant excision back to unrolling. Accordingly, plants of hybrid rice cultivar, NDR11-2 were grown in earthen pots of 10 kg capacity, each using soil as growth medium with normal supply of water and fertilizers till booting stage. The main tillers were then excised at 5 cm below the second node from the top with only flag leaf and the panicle wrapped inside the sheath intact and keeping the plant straight upright was inserted about 8 cm of one’s base touching the floor of the tank, into the neck of an ordinary laboratory stove through rubber cork and made it fully air-tight. The tank of the stove was then filled with water through the side opening and subsequently a pressure gauge was fitted for monitoring the external pressure applied by hand power, similar to that of a kerosene oil stove.

After preparing the experimental set-up in this manner, a pressure of 0.2 MPa was applied to unroll the leaves, which were already in the rolled state after plant excision. The unrolled leaves rolled back again in situ once the pressure was released. The process of pressure application and its release was repeated thrice with the observations recorded intermitently on the time taken for complete unrolling reaching a steady state. The duration of time thus taken for leaf unrolling was presumed to be proportional to the hydraulic resistance of the stem. The relative water content (RWC) of the experimental leaves was determined at the beginning (score 5) and end of leaf unrolling (score 1) to find out whether pressure-induced leaf unrolling was due either to increased turgor or simply to applied physical pressure per se. For the logical interpretation and useful conclusion of the findings, the observations were analysed statistically.

The time course of pressure-induced leaf unrolling is presented in Figure 1, wherein it can be seen clearly that the leaves took about 10 min before any signs of unrolling became visible (score slightly <5), but within the next 20 min (total time 30 min) the leaves completely unrolled (score 1) and remained so, thereafter resembling that of a normal, turgid leaf. On the other hand, the leaves remained completely rolled (score 5) with 65% RWC in the absence of applied pressure, suggesting that the pressure-induced leaf unrolling was indeed due to concurrent increase in the contents of water (RWC being 95%) having been forced to enter