Article

Phytolith analysis of intrabasaltic palaeosols (bole beds) from the Deccan volcanic province of western India

M. R. G. Sayyed
Department of Geology, Poona College of Arts Science and Commerce, Camp, Pune 411001, India
E-mail: mrgsayyed@yahoo.com

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Abstract
Phytolith studies were carried out for the intrabasaltic bole beds occurring in the western part of the Deccan Volcanic Province. This preliminary study indicates the presence of multiform phytoliths both in red and green boles. Red bole indicates well preserved elongate phytoliths from Acanthaceae plants while bulky Bulliform phytoliths mainly from Pleioblastus / Andropogonea / reeds plants. Degeneration of few phytoliths from red bole indicate either leaching/etching or some other activity that is responsible for such post preservation conditions. Phytoliths from green bole, however seem to be well preserved as compared to those from the red bole. The phytoliths from green bole are mainly of Festucoid types (especially small square and rectangular types) indicating the presence of Chrysobalanaceae type of vegetation followed by elongate phytoliths from Acanthaceae plant types. The Multiform Trichomes seems to be derived from Panicoid / Andropogonoid / Burseraceae / Fabaceae while Bulliforms from Pleioblastus / Andropogonea/ reeds. Presences of silicified woody elements from both red and green boles indicate the presence of dicotyledonous plants which could have been in the form of small shrubs. The degenerated phytoliths in red bole suggest leaching/etching or higher intensity of weathering suggesting the existence of well-drained conditions during its formation that enhanced the leaching activity while the presence of well-preserved phytoliths in green bole point towards the existence of damp and desiccated conditions during its formation. The prevalence of dry condition during red bole formation could suggest their formation under higher temperature as compared to green bole. Based on the phytolith analysis it is too early to comment on the palaeoclimates which could have been prevailed during the bole bed formations. However a detailed micromorphological as well as phytolith analysis of more samples can throw light on the palaeoenvironmental conditions as well as the biological activity during their formation.

Keywords Deccan volcanic province; intrabasaltic bole beds; palaeoclimate; phytoliths.

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1 Introduction

Understanding of the past climates is necessary in predicting the future climatic changes on the earth as the series of palaeoclimatic records unveiling the changes in the atmospheric chemistry and the response of natural systems to it can be tested to know the climate change (Mude, 2012; Mude et al., 2012; Briggs, 2014; Zhang and Liu, 2012). There were periods when the climates were significantly cooler and warmer than the present as recorded in the earth's history in response to the globally distributed climate change events, which affected the oceanic, atmospheric and terrestrial events.These periods offer unique opportunity in modelling and predicting the global climate response to enhanced greenhouse gases as the variations in the atmospheric carbon dioxide concentrations are now linked, on almost every timescale, to extreme past climate change record (global cooling to global warming). Thus in order to develop a unifying global climate change model it is important to understand the terrestrial events as well (Sayyed and Hundekari, 2006) and hence study of intrabasaltic palaeosols carries great potential as their mineralogy, chemistry and weathering pattern can be used in deducing the palaeoclimatic conditions. Further the interpretative value of basalt-derived palaeosols is increased because of the fairly homogeneous nature of the basaltic parent-material and also the palaeosol characteristics can be related to and compared with those of modern soils formed on similar basalt. Thus flood basalt-hosted palaeosols provide high-resolution palaeoclimatic records of terrestrial environment if the ages of the associated basalt flows can be determined. The intrabasaltic palaeosols (bole beds) have the potential to be excellent tools in the reconstructions of terrestrial palaeoenvironments and palaeoclimate due to the fact that they formed in direct exposure to climatic and related environmental conditions (Sheldon and Tabor, 2009; Sayyed, 2014; Sayyed et al., 2014). Sayyed et al. (2014) after studying a red bole horizon came to very significant conclusion that the post formational weathering processes have least affected the original palaeoweathering characters of the red bole horizon.

The ancient intrabasaltic red and green boles (palaeosols) from the Rajgurunagar area of Pune district (Maharashtra, India) were studied for their phytolith contents to understand the climatic conditions of their formations. The analyses were carried out by calculating Phytolith Index (Iph) and Cold/Warm ratio (C/W) using thephytolith morphotypes present within the soils. High Iph values indicate aridity (reduced precipitation) while high C/W ratio suggests cool and dry milieu during the soil genesis. For this climatic analysis the peculiar shapes of various phytolith remains after variety of grasses of different subfamilies were identified, e.g. *Panicoidea* type of grasses produces dumbbell and cross shaped phytoliths (warm and moist climate); *Festucoidea* grasses produce rondel and trapezoide shaped phytoliths (cold and dry climate) while *Chloridoideae* grasses yield short-saddle shaped phytoliths (warm and dry climate).

2 Phytoliths as Palaeoenvironmental Indicators

Microscopic plant silica bodies as phytoliths, are often preserved in modern and fossil soils (paleosols) and sediments (Stromberg et al., 2018). Many workers consider phytoliths as indicators of environmental conditions (Dinan and Rowlett, 1993; Fredlund, 1986, 1993; Fredlund and Tieszen, 1994, 1997; Piperno, 1988, 2006; Twiss, 1986, 1992) as the use of phytoliths as palaeoclimate indicator becomes significant as they are less susceptible to decaying processes and can withstand oxidation in comparison to pollen (Piperno, 1988). The relative abundance of different types of grasses can be estimated by taking the ratio of the total of each type with respect to the sum of phytoliths associated with the subfamilies Pooideae (F), Panicoideae (P) and Chloridoideae (C) in a given assemblage (total "regular grass phytoliths", indicated throughout as "FPC"). Accordingly, Twiss (1992) argued that high values of the ratio for relative abundance of pooid (C3) grasses indicate cool climatic conditions appropriate to high latitudes or high altitudes in zones where C3 grasses prevail. In contrast, low values suggest warm, humid to arid climatic conditions associated with lower latitudes and elevations. High values of the ratio for relative abundance of chloridoid grasses (C4) suggest the predominance of semi-arid conditions. Phytoliths provide evidence of plant life, proving that the soil must have been exposed for an extended length of time.

Some plants absorb silica in the form of monosilicic acid (H_4SiO_4), which is precipitated within the cells or intercellular regions of living plant tissues and are in turn redeposited in the form of phytoliths (from Greek, phyto- plant, lith-stone i.e. plant stone). Phytoliths usually takes the shapes of cellular bodies of the plant (Stromberg, 2004) and hence occur in various sizes, shape and structure. The occurrence (formation and abundance) of phytolith is influenced by the concentration of monosilicic acid in the soils, temperature, pH, water content, climate etc. (Piperno, 1988; Madella et al., 2005). Unlike other microfossils, being siliceous and inorganic in nature the phytoliths are quite durable and not susceptible to bacteria corrosion and hence are stable across a wide pH range and are well preserved in damp and desiccated as well as alternating wet and dry conditions (Piperno, 2006). Hence they do not depend on exceptional conditions for survival and are therefore widespread in sediments and soils. Phytolithsrecord the environmental conditions at the time of deposition,as they provide geological evidence of the presence of indicator plant species.

In a variety of palaeoclimate studies the vegetation types represented by diagnostic phytolith morphologies are used (Morgan-Edel et al, 2015). Biswas et al (2016) carried out analysis of phytoliths from soil samples to infer the potential and limitations of grass phytolith assemblages and indices to reconstruct vegetation vis-a-vis climate in the Himalayan mountain region. A phytolith study of modern surface soil samples from different vegetation types of south coast of South Africa (Estebana et al, 2017 showed that phytolith concentration relates to mostly vegetation type and dominant vegetation rather than to the type of soil. Stromberg et al. (2018) by reviewing the present state of phytolith analysis discussed the past ecosystem with a focus on pre-Quaternary applications.

3 Study Area

The Deccan volcanic province (DVP) is the region encompassing a series of Maastrichtian to Paleocene (Danian) continental flood basalts estimated to comprise a volume of more than 1.3 million km^3 (Jay and Widdowson, 2008; Schoene et al., 2015). These basalts, or traps, presently cover an area more than 500,000 km^2 (Fig. 1) and are estimated to have originally covered over 1,500,000 km^2 (Krishnan, 1960). They crop out over large areas of western and central peninsular India including Gujarat, Madhya Pradesh, Maharashtra, Karnataka, and Andhra Pradesh, with outliers to the southeast in Rajahmundry in the Krishna-Godavari basin (K-G basin). The oldest flows commenced in the northwestern part in Gujarat, with successively younger flows overlapping these and extending more to the south (Chenet et al., 2007).

Systematic profile sampling of intrabasaltic red and green bole beds (palaeosols) from Rajgurunagar profile (including underlying and overlying rocks) was conducted (Fig. 2). This profile is exposed on Nashik-Pune highway before Rajgurunagar opposite Vidyasagar English medium school near the back side of the Dak Bungalow. The total thickness of bole bed is ~40cm which is mainly red in colour. However laterally there is a small patch of green bole resting above the red bole horizon and a portion of reworked bole (mixture of red and green bole materials). The red bole material is seen to penetrate into the lower zeolitic basalt which is highly weathered while the upper zeolitic basalt is comparatively less weathered. Patches of reworked green and red bole are found randomly scattered in the area.

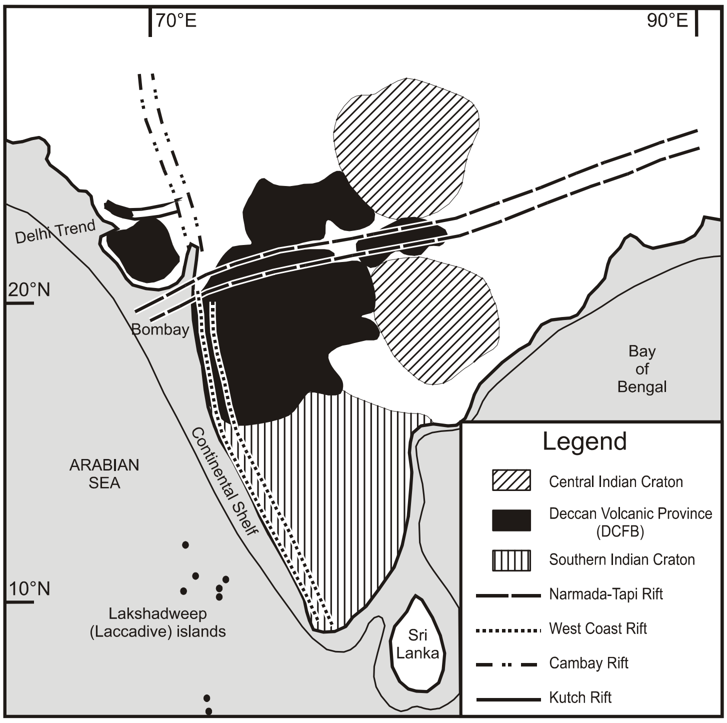


Fig. 1 Geological map showing the location of the Deccan volcanic province and its relationship with the geo-tectonic features of the region (after Sheth, 2005).

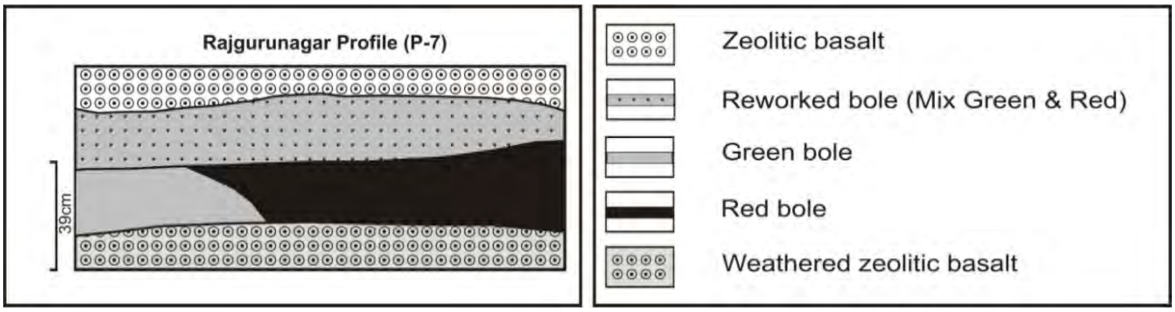


Fig. 2 Lithologic logs of the Rajgurunagar profile.

4 Methods

Phytolith were recovered from two intrabasaltic palaeosol samples (a red bole and a green bole) with a focus to distinguish the climatic conditions of their formation. The extraction of phytoliths was undertaken in the laboratory by using standard nondestructive sonicator technique. As both samples had lighter fraction of phytoliths the heavy density liquid (HDL) used had to be reset several times so as to have maximum recovery. Upto 200 phytoliths from each sample were observed and counted to generate a quantified data. Observations were also made on the physical character of phytoliths so as to get an idea about its general preservation condition. The classification used for phytolith analysis is a combination of – phytolith shape, anatomical origin and classification based on grass families. This is a common practice of classification used by most scholars. The phytoliths were observed under ‘Olympus’ research microscope and photomicrographs were taken under 45X magnifications.

4.1 Background to the phytolith classification used

Grasses are known to be the major accumulators of opal silica / phytolith. The basic classification used here is derived from grass families as suggested by Twiss (2001), with further modifications by including phytoliths of anatomical origin and other non-diagnostic silicified cells such as woody elements and perforated cells ensued from shrubs and trees. Different phytolith morphotypes were noted that included subtypes within each group. Taking into consideration the adapted classification the phytolith morphotypes were grouped as follows

1. Panicoid (e.g. dumbbells)
2. Chloridoid (e.g. saddles)
3. Festucoid (e.g. spherical, square)
4. Elongate (e.g. Rods and tracheids)
5. Trichome (e.g. epidermal hairs)
6. Bulliform (e.g. bulky phytoliths like fan shape)
7. Silicified cells (e.g. woody elements)

4.2 Diagnostic phytolith summary

Phytoliths observed from the red and green bole samples (Table 1) were compared with the in house Phytolith Database of Phytolitharium collection housed at the "Phytolith Research Institute" and the published reference as mentioned. The phytolith morphotypes based on their anatomical origin and structural character suggest the presence of following vegetation in the bole bed samples.

5 Results and Discussion

Each individual sample (red and green bole) was subjected to quantitative phytolith analysis (up to 200 counts); the frequency of each individual phytolith group is represented in Table 2. The phytolith morphotypes have been used to calculate various indices in deducing climatic conditions of their formation. Diester-Hass et al. (1973) proposed a phytolith Index (Iph) which is expressed as a ratio of saddle phytolith versus sum of saddle, dumbbell and cross phytoliths and it is calculated as follows

Phytolith Index (Iph) = [Saddle/ (Saddle + dumbbells+cross)] × 100

Table 1 Classification of phytoliths from red and green bole samples.

Phytolith Type	Family/genus	Diagnostic level	Classification /Remarks
Rods straight	Acanthaceae	Family	Elongate
Spherical/circular plain	Amaranthaceae	Family	
Solid bulky spherical	Cannaceae	Family	Festucoid
Pointed bulky	Panicoid/ Andropogonoid	Family	Trichome
Long pointed hair	Burseraceae/Fabaceae	Non diagnostic	Trichome
Square facetted	Paleoblast/ Gramineae	Family	Bulliform
Small square and rectangular	Chrysobalanaceae	Family	Festucoid
Rectangular facetted	Euphorbiaceae	Family	Bulliform
short shaft dumbbell	Gramineae/ Panicum	Family	Panicoid
Saddle	Gramineae	Family	Chloridoid
Fan shaped/ square / rectangular	Paleoblast (Bamboo)/Reeds spp.	Non diagnostic	Bulliform

A high Iph value indicates aridity or a reduced monsoon precipitation. As the various types of phytoliths are produced under different climatic condition, the ratio of cold - dry (trapezoid and roundel) to warm - moist (bilobate, cross, and saddle) phytoliths indicates terrestrial climatic conditions and vegetation of the source area (Wang and Lu, 1993; Lu et al., 2002). Warm and humid conditions can be inferred from the lower values while cold and dry conditions are indicated by higher values. The cold/warm ratio can be calculated using the formula given below

Cold/Warm (C/W) = elongate/ (panicoid + chloridoid)

Table 2 Phytolith counts in red and green boles.

Phytolith Type	Panicoid	Chloridoid	Festucoid	Elongate	Trichome	Bulliform	Woody Elements	Total
Red Bole	11.43	18.58	24.29	64.29	34.29	15.72	34.29	200
Green Bole	14.26	15	37.13	39.26	40.71	33.55	20.71	200
Phytolith Type %	Panicoid	Chloridoid	Festucoid	Elongate	Trichome	Bulliform	Woody Elements	Total
Red Bole	5.63	9.16	11.97	31.69	16.90	7.75	16.90	100
Green Bole	7.11	7.48	18.51	19.57	20.29	16.72	10.32	100

With reference to the variations in the phytolith counts IpH and C/W ratios were calculated (Table 3) for red and green bole samples to evaluate the paleoclimates. The relative dominance of different types of phytoliths is shown in Figures 3 and 5.

Table 3 Calculated values of Cold/Warm Ratio (C/W) and Phytolith Index (Iph).

Name of the Index	**Red Bole**	**Green Bole**
Cold/Warm Ratio (C/W)	**2.14**	1.34
Phytolith Index (Iph)	**61.91**	51.26

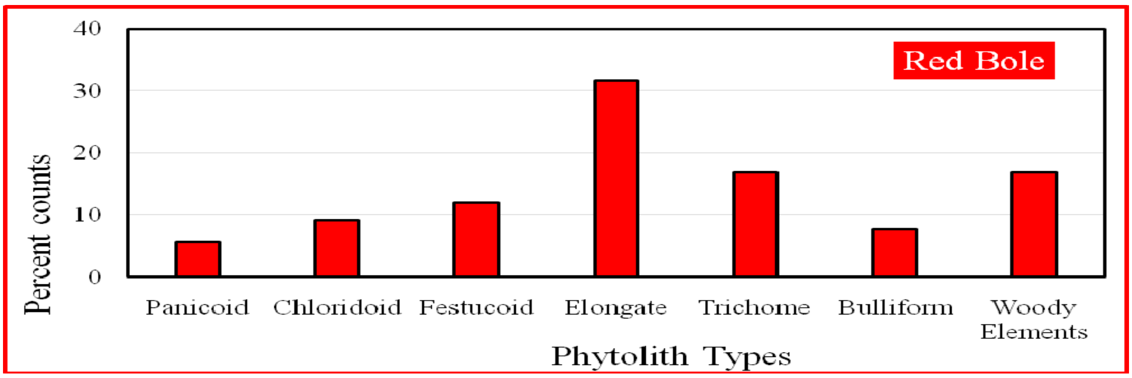
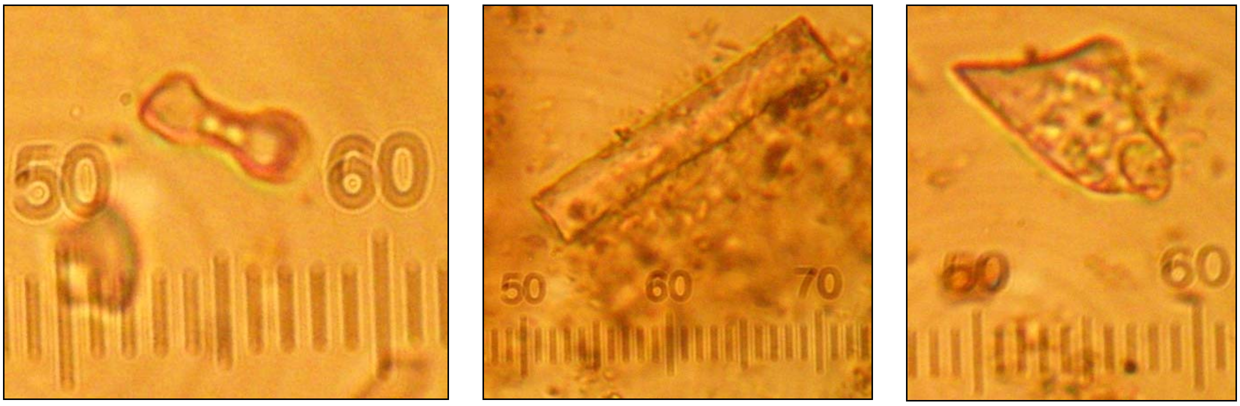


Fig. 3 Phytolith types from the red bole sample.

The red bole sample indicates high frequency of multiform elongate phytoliths with occlusion in most phytoliths. Short cell phytoliths of chloridoid and festucoid were noted along with silicified woody elements. The frequency of panicoid phytoliths was low as compared to other morphotypes. In total 6 slides were scanned to get a quantification of 200 counts which indicates that the sample has overall less frequent phytolith deposition. Typical phytoliths occurring in red bole sample are shown in Fig. 4.



Short shaft panicoiddumbbell | Elongate rod type | Bulky Trichome variant

Fig. 4 Phytoliths from red bole sample.

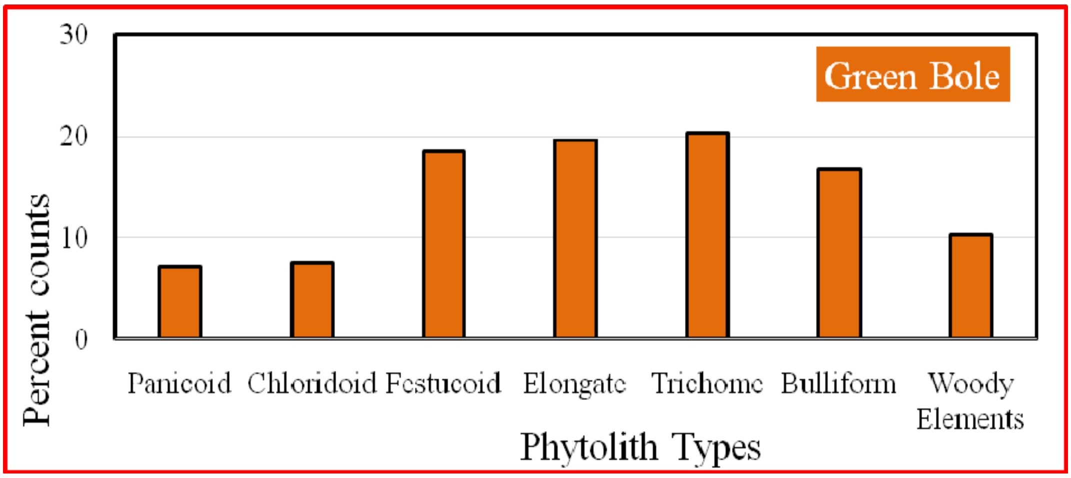
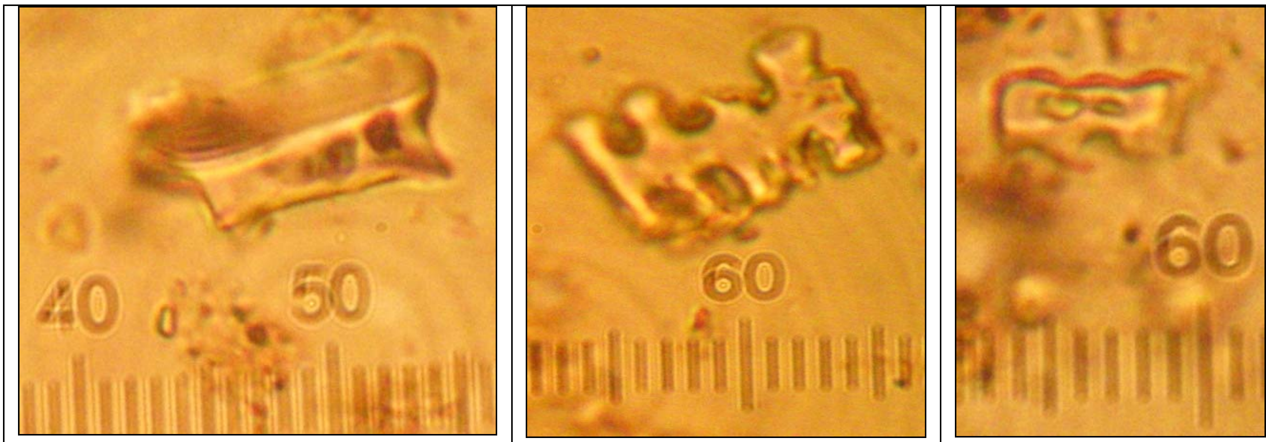


Fig. 5 Phytolith types from the green bole sample.

The Green bole sample shows well preserved phytoliths with high frequency of festucoid, elongate and trichome morphotypes as compared to red bole. This could be attributed to their preservation in damp and desiccated as well as alternating wet and dry conditions (Piperno, 2006). The abundance of festucoid phytolith in green bole as compared to the red bole suggests the climatic conditions were cooler during green bole formation. Similarly the greater abundance of panicoid and chloridoid in green bole than in red bole indicates presence of humid conditions during the green bole formation. In this multiform trichomes phytoliths as well as stony, square and rectangular bulliform phytoliths were noted. Most phytoliths were occluded and few woody elements were also noted. In total 3 slides were scanned to get a quantification of 200 counts which indicates that the sample have over all fairly more frequent phytolith deposition as compared to the phytolith preserved in Red bole sample. Typical phytoliths occurring in green bole sample are shown in Fig. 6.



Chloridoid type (rondel) rotated	Elongate- two side wavy	Trilobite variant

Fig. 6 Phytoliths from green bole sample.

The co-existence of red and green bole in the same profile as in the current study suggests the changing climatic condition during their formation. The values obtained for Cold/Warm (C/W) ratio and phytolith index (Iph) (Table 3) suggest cooler and drier (arid) conditions during the formation of red bole (C/W = 2.14 and Iph = 61.91) under lower rainfall than green bole(C/W = 1.34 and Iph = 51.26). The presence of degenerated phytoliths in red bole suggests leaching / etching or higher intensity of weathering. The degenerated phytoliths in red bole could also point towards the existence of well-drained conditions during its formation that enhanced the leaching activity. On the contrary the green bole shows presence of well-preserved phytoliths suggesting the existence of damp (moist / wet) and desiccated conditions (waterlogging or gleying conditions) during its formation. The prevalence of dry condition during red bole formation could suggest their formation under higher temperature as compared to green bole. Thus the conditions that prevailed during red bole formation could have changed during the green bole formation.

6 Conclusions

Overall both the red and green boles indicate presence of multiform phytoliths. Although the phytolith studies indicate that the red bole were formed under cooler and drier (arid) conditions with lower rainfall as compared to the green bole, a detailed micromorphological as well as phytolith study on more samples can give better understanding on the palaeoenvironmental conditions during their formation.

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