



SPATIAL AND MORPHOMETRIC DIFFERENTIATION IN A MULTI-NODAL CUPULE LANDSCAPE WITH A STRUCTURALLY ORGANISED SHELTER CONTEXT IN HAWĀLBĀGH, ALMORĀ

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Abstract: In this study, 74 cupules spread across six spatial Areas (A-F) in a compact hill-valley micro-landscape in Hawālbāgh, Uttarakhand, are documented and quantitatively analysed. Each feature's maximum diameter and depth were noted, and morphometric differentiation between Areas was assessed statistically. Both diameter ($F(5,68) = 13.65, p < 0.001$) and depth ($F(5,68) = 8.18, p < 0.001$) show significant inter-zonal variation according to descriptive statistics and one-way ANOVA. Three morphometric classes are identified from the dataset: an intermediate class (Area F), a micro class (Areas B, D, and E), and a large class (Areas A and C). In the context of a shelter, Area B displays strong internal standardisation and geometric structuring, such as a recessed panel with cupules and a grid of micro-cupules. Within a limited micro-watershed, the statistical and geographical evidence shows patterns of anthropogenic modification across distinct topographic contexts. Chronological attribution remains undetermined; however, the assemblage demonstrates structured morphometric and spatial organisation rather than random distribution.

Keywords: Himalayan archaeology, cupules, petroglyphs, landscape archaeology, archaeology

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Introduction

Within the larger field of rock art research, the study of cupules, hemispherical or cup-shaped depressions purposefully crushed or pecked into rock surfaces, represents one of the most persistent and intricate archaeological investigations.

Cupule creation is one of the most temporally durable of all known human marking behaviours, as Bednarik (2008) has shown, spanning from the Lower Palaeolithic to the twentieth century. Cupule studies are situated at a fruitful nexus of cognitive archaeology, landscape theory, and archaeometric analysis due to their widespread presence on almost every inhabited continent and the ongoing ambiguities regarding their purpose, authorship, and symbolic content.

A significant program of comparative and experimental research was sparked by early studies of assemblages, most notably the nine cupules on Chief's Rock, Auditorium Cave, at Bhimbetka in central India, which established the extraordinary antiquity potentially attached to this practice (Bednarik, 1996; Chakravarty & Bednarik, 1997). By conducting a systematic spatial and morphometric analysis of a multi-nodal cupule assemblage within a structurally organised rock shelter context at Hawālbāgh, district Almorā, in the central Himalayan region of Uttarakhand, India, the current study adds to this expanding body of research. It has been known that there was a great amount of prehistoric activity in the Kumaon Himalaya, of which the Almorā district is a central and culturally significant portion. Its hills, riverine terraces, and sheltering outcrops are home to rock art sites that demonstrate continuous human interaction with the terrain from at least the Mesolithic era onward (Mathpal, 1995; Pandey, 1993). In contrast to other significant rock art provinces of the Indian subcontinent, such the Vindhyan belt or the Deccan plateau, the area is still relatively unexplored (Pandey, 1993).

Hawālbāgh, located in the district's lower hill Area about seven kilometres from the town of Almorā, offers an especially instructive case study because its cupule-bearing panels are embedded within, and seem to respond architecturally to a distinct rock shelter environment. This arrangement raises significant issues regarding intentionality, site selection, and the organisation of symbolic space (Mathpal, 1984; Chakravarty & Bednarik, 1997). Any evaluation of prehistoric site selectivity must consider the structurally stable and appropriately resistant surfaces for percussive engraving provided by the region's geological substrate, which consists of Proterozoic to Cambrian metasedimentary rocks of the Almora Crystalline Area, primarily phyllites, schists, and quartzites metamorphosed under greenschist to amphibolite facies conditions.

In recent decades, morphometric analysis of cupules which includes systematic measurements of diameter, depth, rim profile, volumetric

displacement, and surface micro-topography has become an essential methodological supplement to typological or purely descriptive approaches. Based on the experimental replication program at Daraki-Chattan (Bednarik et al., 2005) and the foundational work by Bednarik (2008), morphometric characterisation allows researchers to identify differential tool use, differentiate manufacturing sequences, and possibly correlate formal variation with temporal or functional patterning. Such analysis takes on an additional interpretive dimension when used within a spatially bounded, multi-nodal assemblage that is, a site where cupules are dispersed across multiple distinct rock panels or nodal clusters within a circumscribed area. The differentiation of nodes may reflect intentional organisational logic rooted in social memory, ceremonial practice, or territorial demarcation, in addition to taphonomic or lithological contingency (David & Thomas, 2008; Tañ & Chippindale, 1998).

The present study's use of the term "cupule landscape" is based on a landscape archaeological framework that views individual marks as constitutive components of a relational, experientially constructed space rather than as isolated phenomena (Tilley, 1994; David & Thomas, 2008). This framework treats cupule cluster spatial arrangement, orientation with respect to natural features like driplines, light apertures, and rock overhangs, as well as their proximity to habitation or transit Areas, as analytically significant data. This method places cupules within a phenomenologically and socially informed reading of the engraved landscape, departing from site-level inventories that treat them as distinct artifacts. A particularly well-defined test case for this theoretical orientation is provided by Hawālbāgh's multi-nodal configuration, which consists of several discrete panels with different cupule densities within a single shelter complex.

The rock shelter at Hawālbāgh demonstrates what can be described as a structurally organised context, a term used to describe a shelter environment where the distribution of cultural residues, architectural affordances, and spatial patterning all suggest intentional human organisation of interior and peri-shelter space (Conkey, 1991; Gamble, 1991). This suggests a level of consistent, socially controlled occupation and contrasts with opportunistic or incidental shelter use. In such a setting, the presence of cupules on several panels encourages examination of the connection between the morphometric characteristics of individual marks and their placement within the spatial

grammar of the shelter. Are cupules with larger diameters and depths more likely to be found in visually striking or acoustically resonant locations?

Do distinct nodal clusters show morphometric profiles that are statistically separable and suggest distinct authorial communities or manufacturing episodes? The current study's analytical program is organised by these questions. From an archaeological standpoint, the Hawālbāgh assemblage is part of a larger pattern of rock art found in the foothills of the Himalayas, which has drawn more scholarly attention recently (Mathpal, 1995; Pandey, 1993). Although definitive cultural attribution is still tentative in the absence of stratified contextual data, rock art in the Kumaon region has been carefully linked to successive occupation phases spanning the Mesolithic through protohistoric periods (Mathpal, 1984, 1995). Therefore, the morphometric differentiation seen at Hawālbāgh may encode both functional variation and diachronic stratification within a single locus of enduring cultural significance. This interpretive possibility highlights the significance of thorough chronometric research as an adjunct to the current formal and spatial analysis.

The aim of the present report is:

- To document measurable morphological characteristics (diameter, depth, shape)
- To compare morphometric variation between Areas
- To analyse spatial distribution across topographic contexts
- To identify patterning within and between loci.

Literature Review

Cupules are small, round depressions that were made by striking the rock with a hard object. These cupules are some of the earliest forms of human markings and are found all over the world (Bednarik, 1996; Kumar, 1996). Originally, cupules were seen as separate from other features that were used for grinding or processing food; however, this assumption has been increasingly challenged by researchers who have been finding that these features could be one in the same (Ouzman, 2001). Standard morphometric measurements of cupules have been developed over time (Kumar, 1996; Bednarik et al., 2008) but have been improved upon using modern technologies like photogrammetry and statistical modelling. Geographically, researchers studying cupules have shifted their focus to analysing rock art sites and surrounding landscapes in terms of their spatial and cultural relations (Tilley, 1994; Bradley, 2000). However, there

have been very few studies conducted in the region of Uttarakhand in terms of a landscape-based approach. Currently available research in the region documents the presence of both rock art and shelter use, but does not include any form of integrated morphometric or spatial analysis; thus, knowledge regarding the morphology of cupules, spatial distribution of cupules in relation to one another, and their relationship to the architecture of rock shelters is still not adequately understood.

Study Area

Hawālbāgh village sits between the North Almorā Thrust and South Almorā Thrust which consists of three formations, i.e., Saryū Formation, Almorā Genesis and Gumālikhet Formation, and the Damtha Group in the northern part that have Rauthgarh Formation (Valdiya, 1980). It extends between 29°32'30" N to 29°44'23" N latitudes and 79°31'11" E to 79°43'50" E longitudes and encompasses an area of 267.53 km². Hawālbāgh village is flanked by Kasār Devi hill in the east and Katārmal hill. One can also take a glimpse of Syāhi Devi hilltop towards the South-west of Hawālbāgh village. It is located at ~1100m asl. The village has a dry climate with rain triggered mostly by western disturbances and monsoon. It also experiences cold dry winters with temperatures dropping to -3°C and 34°C in summers. Metamorphic rocks are exposed in the riverbed of Dandēśwar nālā. Common cropping patterns include rice, ragi, pulses, and wheat cultivation. The village experiences winters for longer months than summers, with the month of May being the hottest while January remains the coldest month. It receives an annual rainfall of 1065.01mm. Hawālbāgh block consists of 10 nayāy-panchāyats, 124 gram-panchāyats and 234 villages.

The study Area Forms a micro-watershed characterised by two elevated ridge systems (Areas A and E) separated by a shallow valley floor. A seasonal drainage channel flows east-west, with two nalas converging between the ridge systems. Area B (rock shelter) is situated near the valley and drainage Area. Area C occupies a central exposed bedrock surface. Area D lies on an eastern slope above the nala. Area E occupies a northern ridge position higher than Area A. Intervisibility is a notable feature of this landscape. From Area B (shelter), Areas C, D, and E are directly visible, while Area A lies beyond the immediate line of sight. From Area E, the valley and lower micro-Areas are visually accessible. The crest-edge placement of cupules in Areas A and

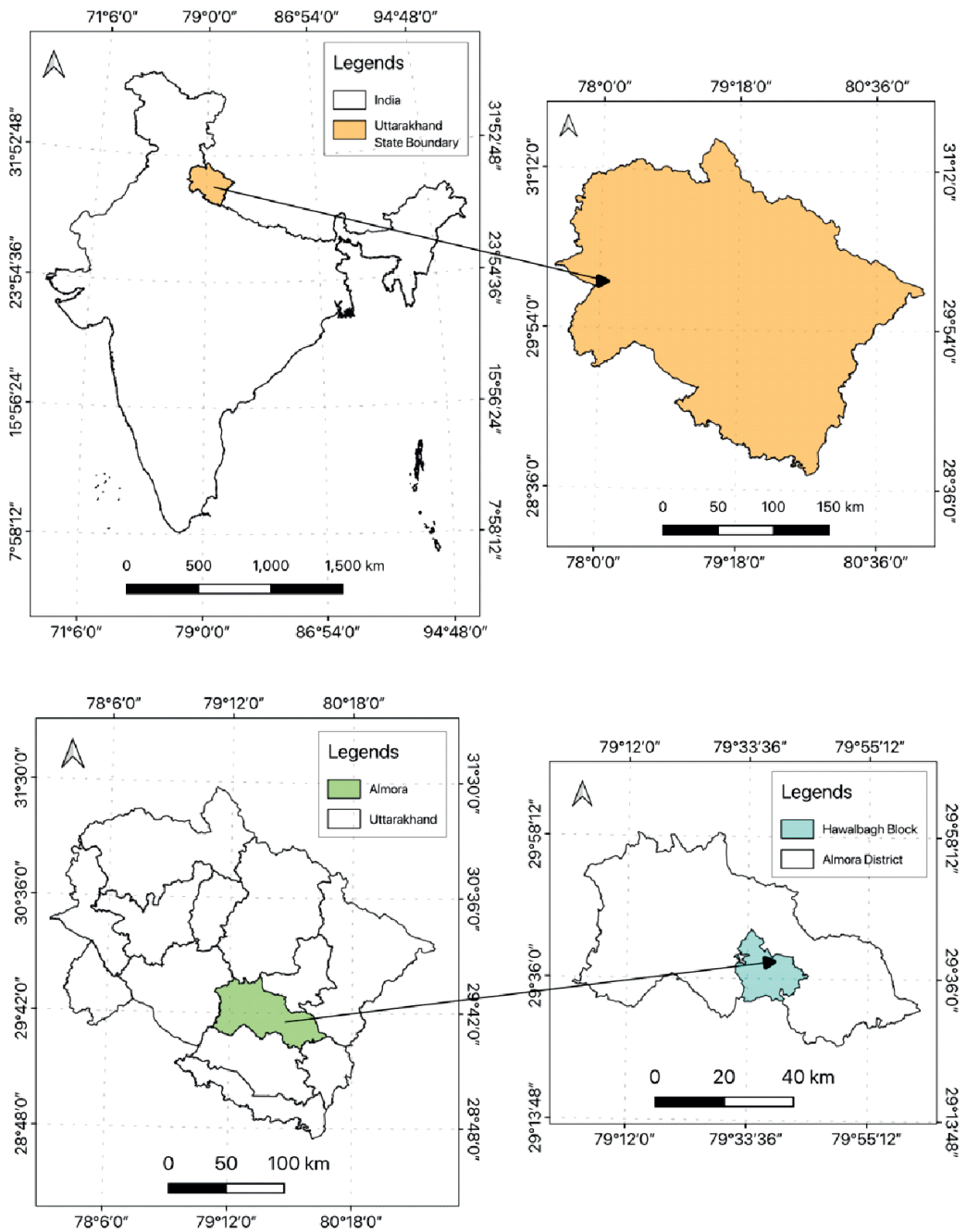


Figure 1

Source: Aman Pathak, Study area.

E suggests deliberate positioning near visually prominent bedrock exposures rather than deep slope interiors. This topographic integration indicates patterned use of crest, slope, shelter, and valley-floor surfaces within a single compact terrain unit.

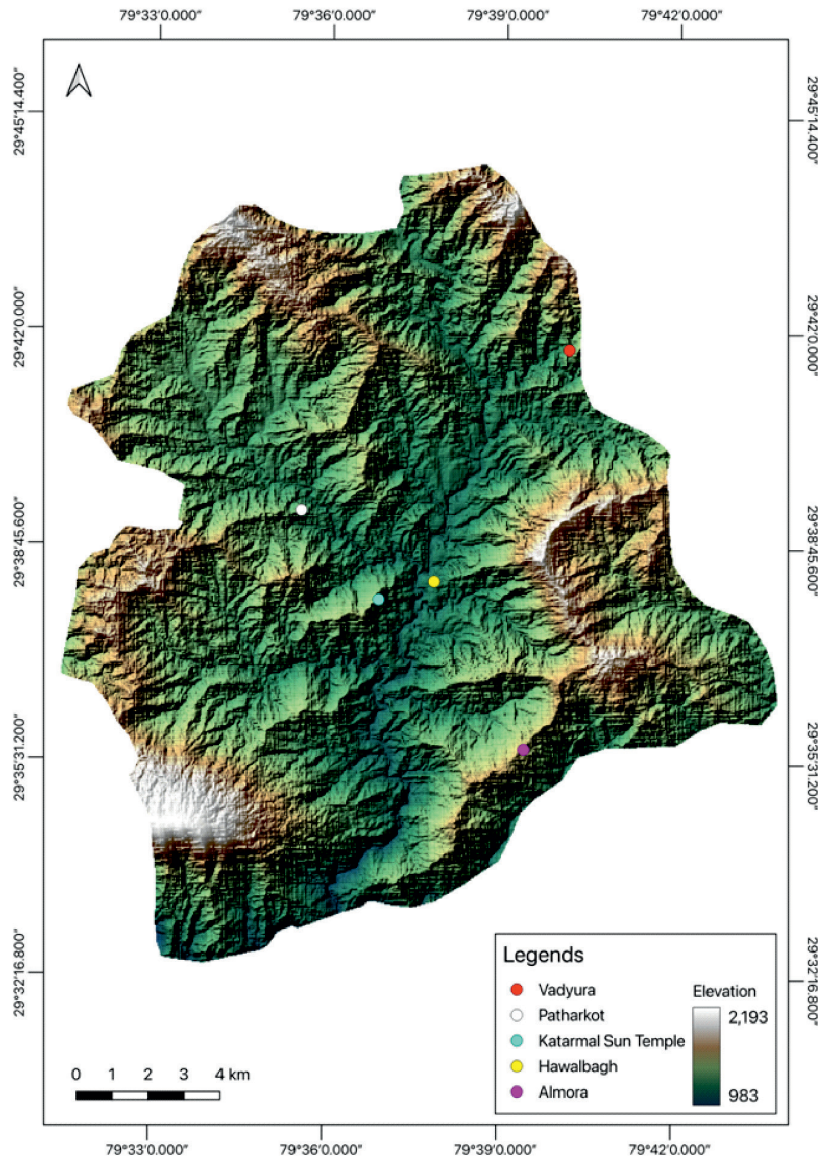


Figure 2

Source: Aman Pathak, Elevation map of Hawālbāgh block.

Methodology

Authors conducted a field survey based on digital maps. The main objective of the survey was to explore the possibility of rock art in Hawālbāgh village and surrounding. GPSMap Camera Mobile application was used to verify and document sites. QGIS was used to create a cartographic presentation of the sites in their spatial context. The outcome of the exploration was then analysed. Adobe Illustrator was used to illustrate the cupules and rock art. Open-source DEM Data 12.5m x 12.5 m was obtained from Alaska Satellite Facility provided by University of Alaska using ALOS PALSAR, Hi Res Terrain Corrected dataset. The research utilised scientific methods of investigation for the field survey. Previous research including Henwood & Kharakwal were used to corroborate with previous understanding of the sites and related findings. Nikon D7200 was used for photography. Descriptive statistics (mean, standard deviation, coefficient of variation) were calculated for diameter and depth. One-way ANOVA was performed to test for statistically significant differences between Areas. One-way ANOVA was selected because the study examines morphometric variation across multiple independent spatial groups (Areas A–F). Diameter was measured along the maximum rim-to-rim axis



Figure 3

Source: Google Earth image of Study Area and Areas (A-F).

using callipers. Depth was measured from rim plane to deepest point using a depth probe. Measurements were recorded to the nearest 0.1 cm.

Udiyāri

The site of Udiyāri was first mentioned by Henwood in 1856, followed by Kharakwal (1993) who mentioned the presence of only 10 cupules. No work since then cites Udiyāri. The site is an open landscape with 2 separate streams flowing east to west meets at Dandēśwar temple in between the site.

As part of our exploration, a total of 74 cupules (Udi0001-Udi0074) were systematically recorded in the current morphometric dataset. For each feature, the following variables were documented:

- Area Designation (A, B, C, D, E, F)
- Diameter (cm)
- Depth (cm)
- Shape classification (Circular, Oval, Irregular)

Diameter values range from 2.1 cm to 20.8 cm. Depth values range from 1.8 cm to 11.6 cm. Most cupules are circular in plan, with a smaller number classified as irregular or oval. Shape distribution shows a clear dominance of circular morphology, indicating non-random surface formation. Across the entire dataset, diameter clusters primarily within the 5-12 cm range, with two significantly larger features exceeding 20 cm. Depth-to-diameter ratios vary between approximately 0.25 and 0.80, indicating variability in labour investment and possibly functional differentiation. Certain features (e.g., Ud003; Ud014; Ud019) demonstrate unusually high depth-to-diameter ratios and require re-measurement confirmation to rule out recording error. The dataset does not demonstrate random continuous size distribution; rather, clustering is evident in specific ranges depending on Area.

Area-wise analysis

Area A (Western Ridge Crest)

Area A contains 11 recorded cupules with diameters between 5.1 cm and 14.1 cm and depths between 1.8 cm and 11.1 cm. These are positioned near crest-edge exposures, requiring 5-10 steps downslope from the ridge top to become visible when facing north. Morphologically, Area A shows moderate internal consistency, with most cupules falling within a mid-sized range. No strict geometric arrangement is observed; instead, clustering appears organic

but non-random. The crest-edge positioning suggests deliberate selection of elevated, visually prominent rock surfaces.



Figure 4

Source: Aman Pathak, A cluster of 6 Cupules in Area A.

Table 1: Measurement of Cupules in Area A

Cupule ID	Area	Elevation (m)	Diameter (cm)	Depth (cm)	Shape
Udi001	A	1254	6.1	1.8	Oval
Udi002	A	1204	10.2	2.6	Circular
Udi003	A	1219	8.7	6.8	Circular
Udi004	A	1219	11.4	8.5	Irregular
Udi005	A	1219	5.4	4.8	Circular
Udi006	A	1219	5.1	3.9	Circular
Udi007	A	1219	14.1	5.5	Irregular
Udi008	A	1219	8.6	4.7	Irregular
Udi009	A	1219	7.8	5.2	Circular
Udi010	A	1219	11.3	8.7	Circular
Udi011	A	1219	12.9	11.1	Circular

Area B (Shelter Area)

Area B is the most structurally complex locus in the study Area And contains three distinct morphological components within a single shelter space:

1. A large deep basin (deepest recorded cupule in the entire dataset).
2. A recessed rectangular prepared panel containing internal cupules.
3. A structured 7×3 grid of small cupules.

The small grid cupules exhibit extremely tight dimensional standardisation (2.3-2.6 cm diameter; ~2 cm depth). Such narrow variation suggests controlled production rather than casual pecking. The grid is spatially organised, rectilinear, and clearly patterned. The rectangular panel appears deliberately recessed relative to the surrounding rock surface. Its boundaries are defined by straighter edges, and the surface within the panel is smoother compared to the adjacent rock. Cupules placed inside the panel do not cut or overlap the boundary edges, indicating compositional planning. Spatially within the shelter, the sequence from entrance inward is structured: stair-like rock projections create an entry articulation; immediately visible is the large deep basin; slightly higher on a connected surface lies the recessed rectangular panel; further right appears the 7×3 grid. This internal zoning indicates differentiated use of the shelter surface.



Figure 5

Source: Aman Pathak, Prepared panel with cupules pecked inside it.



Figure 6

Source: Aman Pathak, Cupule is Area B.



Figure 7

Source: Aman Pathak, Cupules in 7X3 arrangement.

Table 2: Source: Aman Pathak, Measurement of Cupule in Area B.

<i>Cupule ID</i>	<i>Area</i>	<i>Elevation (m)</i>	<i>Diameter (cm)</i>	<i>Depth (cm)</i>	<i>Shape</i>
<i>Udi012</i>	B	1213	6.5	3	Circular
<i>Udi013</i>	B	1221	2.3	1.9	Circular
<i>Udi014</i>	B	1221	2.3	1.8	Circular
<i>Udi015</i>	B	1221	2.4	2	Circular
<i>Udi016</i>	B	1221	2.5	2.1	Circular
<i>Udi017</i>	B	1221	2.4	1.7	Circular
<i>Udi018</i>	B	1221	2.1	1.8	Circular
<i>Udi019</i>	B	1221	2.2	1.8	Circular
<i>Udi020</i>	B	1221	2.3	1.9	Circular
<i>Udi021</i>	B	1221	2.3	1.7	Circular
<i>Udi022</i>	B	1221	2.2	1.5	Circular
<i>Udi023</i>	B	1221	2.2	2.3	Circular
<i>Udi024</i>	B	1221	2.1	2.2	Circular
<i>Udi025</i>	B	1221	2.5	2.1	Circular
<i>Udi026</i>	B	1221	2.6	2.3	Circular
<i>Udi027</i>	B	1221	2.8	2.4	Circular
<i>Udi028</i>	B	1221	2.3	2.2	Circular
<i>Udi029</i>	B	1221	2.0	2.2	Circular
<i>Udi030</i>	B	1221	2.4	2.3	Circular
<i>Udi031</i>	B	1221	1.9	2.1	Circular
<i>Udi032</i>	B	1221	2.3	1.8	Circular
<i>Udi033</i>	B	1221	2.4	1.8	Circular
<i>Udi034</i>	B	1221	4.2	3.1	Irregular
<i>Udi035</i>	B	1221	3.3	2.7	Circular
<i>Udi036</i>	B	1221	3.11	2.1	Irregular

Area C (Central Exposed Bedrock)

Area C exhibits the highest morphometric variability. Diameters range from 2.1 cm to 20.8 cm, and depths range from 1.9 cm to 11.6 cm. Both exceedingly small and exceptionally large cupules occur within this Area.



Figure 8

Source: Aman Pathak, Cluster of Cupules in Area C.

Unlike Area B, no strict geometric arrangement is evident. However, clustering is present, and the evidence of two exceptionally large cupules suggests either functional differentiation or multiple episodes of production. Area C occupies a slightly elevated bedrock surface visible from Area B and other Areas, reinforcing its integration within the broader landscape system.

Table 3: Measurement of Cupules in Area C

<i>Cupule ID</i>	<i>Area</i>	<i>Elevation (m)</i>	<i>Diameter (cm)</i>	<i>Depth (cm)</i>	<i>Shape</i>
<i>Udi037</i>	C	1206	9.6	4.2	Oval
<i>Udi038</i>	C	1206	20.8	11.6	Circular
<i>Udi039</i>	C	1206	7.9	2.2	Irregular
<i>Udi040</i>	C	1206	2.1	1.9	Irregular
<i>Udi041</i>	C	1206	8.7	2.4	Irregular
<i>Udi042</i>	C	1206	9.8	3.9	Circular
<i>Udi043</i>	C	1206	20.1	7.4	Circular
<i>Udi044</i>	C	1206	7.5	3.9	Circular
<i>Udi045</i>	C	1206	7.9	4.2	Circular
<i>Udi046</i>	C	1206	7.3	4.5	Circular
<i>Udi047</i>	C	1206	9.7	4.5	Circular
<i>Udi048</i>	C	1206	5.9	2.5	Circular
<i>Udi049</i>	C	1221	3.56	2.8	Circular
<i>Udi050</i>	C	1221	3.78	2.45	Circular
<i>Udi051</i>	C	1221	4.22	3.1	Circular
<i>Udi052</i>	C	1214	8.22	7.4	Circular
<i>Udi053</i>	C	1214	12.89	8.2	Oval

Area D (Eastern Slope near the banks of Nala)

Area D lies approximately 300-400 m from the shelter and is positioned above a small seasonal drainage channel flowing east-west. Cupules in this area measure approximately 4-5 cm in diameter and 3-4 cm in depth, yielding relatively high depth-to-diameter ratios. Distribution in Area D appears irregular and lacks geometric patterning. However, the depressions are elevated above the active water flow and are not confined to water-polished surfaces. Their presence on sloping bedrock suggests deliberate placement rather than fluvial formation.

Table 4: Measurement of Cupules in Area D

<i>Cupule ID</i>	<i>Area</i>	<i>Elevation (m)</i>	<i>Diameter (cm)</i>	<i>Depth (cm)</i>	<i>Shape</i>
<i>Udi054</i>	D	1214	4.9	3.1	Irregular
<i>Udi055</i>	D	1214	3.4	2.4	Irregular
<i>Udi056</i>	D	1214	3.5	2.6	Irregular
<i>Udi057</i>	D	1214	2.3	1.9	Irregular
<i>Udi058</i>	D	1213	2.1	1.7	Irregular

Area E (Eastern Ridge)

Area E is located on the ridge-facing slope opposite the shelter Area (Area B). Seven cupules were recorded here. Six are small circular depressions with diameters between 2.2-2.4 cm and depths of 1.5-1.8 cm, showing strong dimensional consistency. One feature (Udi064) is markedly larger (8.9 cm diameter; 7.23 cm depth), creating higher variability in the Area's measurements. Unlike the structured grid in Area B, the cupules here are loosely distributed, though their morphometric similarity suggests inclusion within the same micro-cupule class.

Table 5: Measurement of Cupules in Area E

<i>Cupule ID</i>	<i>Area</i>	<i>Elevation (m)</i>	<i>Diameter (cm)</i>	<i>Depth (cm)</i>	<i>Shape</i>
<i>Udi059</i>	E	1224	2.4	1.7	Circular
<i>Udi060</i>	E	1224	2.1	1.8	Circular
<i>Udi061</i>	E	1224	2.2	1.8	Circular
<i>Udi062</i>	E	1224	2.3	1.9	Circular
<i>Udi063</i>	E	1224	2.3	1.7	Circular
<i>Udi064</i>	E	1224	2.2	1.5	Circular
<i>Udi065</i>	E	1214	8.9	7.23	Circular

Area F (Northern ridge)

Area F occupies a northern ridge slightly higher than Area A. Approximately 10-12 cupules occur here, morphologically like those in Area C. From the ridge crest, the southern micro-Areas (A-D) are visible. The cupules are positioned slightly downslope from the ridge top, like Area A, indicating crest-edge placement rather than interior slope distribution.

Table 6: Measurement of Cupules in Area F.

<i>Cupule ID</i>	<i>Area</i>	<i>Elevation (m)</i>	<i>Diameter (cm)</i>	<i>Depth (cm)</i>	<i>Shape</i>
<i>Udi066</i>	F	1231	8.9	7.23	Circular
<i>Udi067</i>	F	1231	3.9	2.1	Circular
<i>Udi068</i>	F	1231	4.9	3.8	Circular
<i>Udi069</i>	F	1231	5.3	4.2	Circular
<i>Udi070</i>	F	1231	9.4	7.6	Circular
<i>Udi071</i>	F	1231	4.3	2.9	Circular
<i>Udi072</i>	F	1231	8.4	7.1	Circular
<i>Udi073</i>	F	1231	6.1	5.4	Circular
<i>Udi074</i>	F	1231	5.6	3.2	Circular

Across the micro-landscape, at least four distinct morphological-pattern types are identifiable:

- Isolated or clustered mid-sized cupules (Areas A, C, E)
- Structured grid formation (Area B shelter)
- Linear row arrangement (documented on exposed surface)
- Recessed prepared panel with internal cupules (Area B)

The coexistence of these types within a confined 3.7-hectare watershed indicates behavioural diversity rather than single-event marking.

Discussion

Table 7: Area wise mean diameter, depth, and standard deviation (in cm)

Area	<i>n</i>	Mean Dia.	SD Dia.	Coeff of Variance (Diameter)	Mean Depth	SD Depth	Coeff of Variance (Depth)
A	11	9.24	3.02	0.327	5.78	2.780	0.481
B	25	2.62	0.94	0.357	2.11	0.389	0.184
C	17	8.82	5.15	0.583	4.54	2.638	0.581
D	5	3.24	1.12	0.346	2.34	0.559	0.239
E	7	3.20	2.52	0.786	2.52	2.081	0.826
F	9	6.31	2.06	0.327	4.84	2.068	0.428

A total of 74 cupules were documented across six spatially discrete Areas (A-F) within a compact hill-valley micro-landscape. Maximum diameter and maximum depth were measured for each feature in centimetres. Descriptive statistics were calculated for each Area, and one-way ANOVA was employed to evaluate whether morphometric differences between Areas were statistically significant. Area B contains the highest number of cupules ($n = 25$), followed by Area C ($n = 17$). Areas D and E contain comparatively smaller samples. While unequal sample sizes influence dispersion metrics, the dataset remains sufficiently large ($n = 74$) for statistical comparison. Mean diameter varies markedly between Areas. Areas A and C exhibit substantially larger mean diameters (9-10 cm range), whereas Areas B, D, and E cluster within the 2-4 cm range. Area F occupies an intermediate position at 6.31 cm. This distribution immediately suggests the presence of multiple morphometric classes rather than a single continuous size spectrum. Coefficient of Variation values further indicate differing levels of internal consistency. Areas A and F display moderate dispersion ($CV \approx 0.33$), whereas Area C ($CV = 0.55$) and Area E ($CV = 0.73$) show

elevated variability. The high variability in Area C reflects its broad diameter range (2.1-20.8 cm), indicating the coexistence of small and exceptionally large forms within the same spatial context.

A one-way ANOVA confirms that these differences are statistically significant: $F(5,68) = 13.65$, $p < 0.001$. The F-value substantially exceeds the critical value, and the extremely small p-value indicates that the probability of observing such variation by chance is negligible. Thus, diameter differences between Areas are statistically robust. Depth values demonstrate a pattern parallel to diameter. Areas A and C show greater mean depths (4.5-5.8 cm), Areas B, D, and E cluster around 2-2.5 cm, and Area F again occupies an intermediate position. Notably, Area B exhibits the lowest depth variability (CV = 0.20), indicating strong internal consistency. Area C shows high variability (CV = 0.60), and Area E shows remarkably high dispersion (CV = 0.83), though the latter may partly reflect small sample size. ANOVA confirms statistically significant depth variation between Areas: $F(5,68) = 8.18$, $p < 0.001$. Thus, both diameter and depth demonstrate significant inter-zonal differentiation.

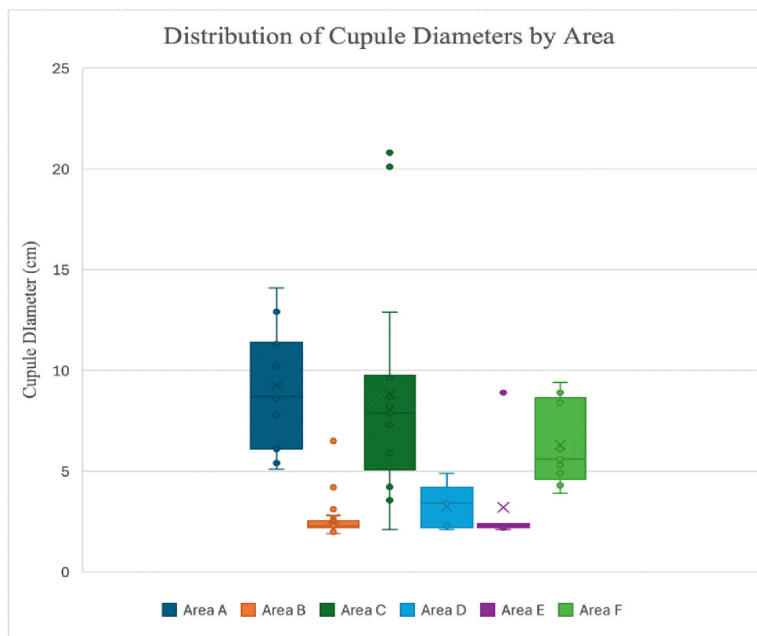


Figure 9: Boxplot showing the distribution of cupule diameters across six spatial Areas in the Hawālbāgh micro-landscape. Areas A and C contain larger cupules, whereas Areas B, D, and E show consistently smaller forms. Area F occupies an intermediate morphometric.

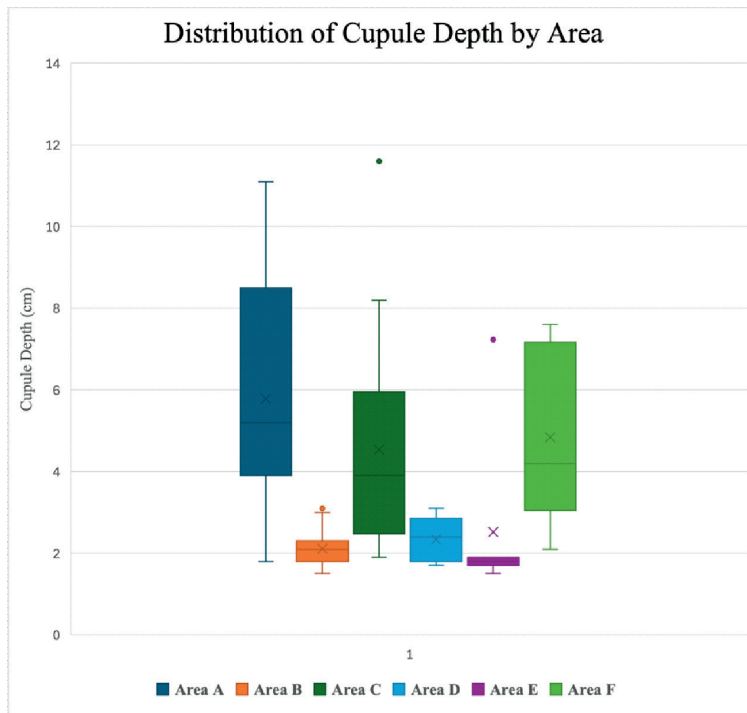


Figure 10: Boxplot showing the distribution of cupule depth across spatial Areas. Depth values broadly mirror the diameter pattern, with Areas A and C exhibiting deeper cupules and Areas B, D, and E forming a micro-cupule cluster.

The recurrence of consistent clustering across both diameter and depth allows the identification of three morphometric classes:

<i>Class</i>	<i>Areas</i>	<i>Mean Diameter</i>	<i>Mean Depth</i>
<i>Large Class (group a)</i>	A & C	~9-10 cm	~4.5- 5.8 cm
<i>Micro Class (group b)</i>	B, D, & E	~2.7- 3.7 cm	~2.1- 2.5 cm
<i>Intermediate Class (group ab)</i>	F	~6.3 cm	~4.8 cm

The alignment of these classes across two independent variables strengthens their validity and reduces the likelihood that they are artifacts of sampling. Tukey HSD post-hoc comparisons indicate that Areas A and C do not differ significantly from each other but differ significantly from Areas B, D, and E. Area F occupies an intermediate position and differs significantly from the micro-cupule Areas but not consistently from the large-cupule Areas.

Table 8: Results of Tukey HSD post-hoc comparisons for cupule diameter across spatial Areas. Areas sharing the same letter are not significantly different at $\alpha = 0.05$

<i>Area</i>	<i>n</i>	<i>Mean Diameter (cm)</i>	<i>Tukey Group</i>
A	11	9.24	a
C	17	8.82	a
F	9	6.31	ab
D	5	3.24	b
E	7	3.20	b
B	25	2.62	b

The statistical results show that the shape of the cupules at the site is structured in space and varies a lot between Areas. The existence of three recurring morphometric classes large, micro, and intermediate suggests patterned variability instead of a singular homogeneous production tradition. However, morphometric differentiation alone does not completely reflect the behavioural intricacy of the site. When viewed together with the spatial arrangement and surface preparation features seen in the shelter context (Area B), the interpretation becomes stronger. Area B is not only statistically different, but it is also structurally different from the rest of the landscape. There is a structured grid of micro-cupules in this Area, and a recessed rectangular panel with internal cupules. The grid shows tight dimensional clustering, and the low depth coefficient of variation ($CV = 0.20$) shows that production is very standardised. This level of consistency suggests that the pecking was planned, not random. The spatial regularity of the grid, along with morphometric homogeneity, sets Area B apart from all other Areas in the assemblage. The recessed rectangular panel makes it even more clear that the surface was changed on purpose.

The cupules inside this panel respect the boundaries rather than cutting through them, and the panel appears to have been prepared by lowering or smoothing the rock surface within predetermined boundaries. This compositional integration implies deliberate surface space planning. In contrast to haphazard or opportunistic marking, the combination of geometric preparation and standardised cupule production in the same spatial context suggests structured engagement with the rock surface. Area C, on the other hand, shows significant morphometric variability in both depth ($CV = 0.60$) and diameter ($CV = 0.55$). Either several production episodes or distinct

forms within a single production tradition are suggested by the presence of both large and smaller cupules within the same Area. Area C lacks distinct geometric structuring, in contrast to Area B, and its statistical heterogeneity lends credence to the idea that it is a morphometrically mixed Area. In comparison to the micro class, ridge-associated Areas (A and F) exhibit greater mean diameters and moderate variability. A patterned use of elevated bedrock exposures is suggested by their morphometric clustering. Area F, which occupies an intermediate morphometric position, could be a clear localised activity Area or a transitional production scale. Morphometrically, Areas D and E belong to the micro class, but they lack the clear geometric organisation seen in Area B, suggesting that small size by itself does not imply structured arrangement.

When morphometric statistics and spatial arrangement are combined, distinct behavioural signatures are revealed throughout the micro-landscape. Area B suggests a different production context by combining geometric structuring, surface preparation, and statistical standardization. While Areas D and E show smaller but less spatially formalised forms, Areas A and C show larger-scale modification. The interpretation of the assemblage as systematically organised rather than randomly accumulated is supported by the recurrence of morphometric clustering across two independent variables (diameter and depth) in conjunction with spatial patterning. Although these results do not establish chronological sequencing or a specific functional interpretation, they do show clear internal structuring of rock modification practices within the landscape. Together, the statistical and geographical data show a pattern of anthropogenic interaction with several topographic nodes.

Conclusion

The Udiyari-Kutgoli micro-landscape contains a structured cupule complex distributed across ridge crests, slopes, exposed bedrock platforms, and a shelter context. Morphometric clustering, geometric grid arrangement, recessed panel preparation, and crest-edge positioning collectively support interpretation as deliberate anthropogenic rock modification.

While chronology remains undetermined, the internal spatial logic and morphological differentiation across Areas indicate patterned landscape use within a compact watershed system.

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