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Physical and mineralogical evaluation of a brick sample from an ancient altar structure in Garhwal Himalayan region

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A brick sample from an ancient site at Purola situated in Garhwal Himalayan region was evaluated for its physical and mineralogical properties. The present investigations were aimed to assess the impact of environmental weathering on the building elements of the brick altar structure, which is said to be nearly 2000 years old. The finding reveals some interesting attributes of the burnt bricks used in the construction of the altar structure for performing certain rituals according to the vedic culture. Investigations based on X-ray diffraction and scanning electron microscope studies reveal that the deterioration of the brick body used in the construction was mainly due to physical and chemical factors. Results of laboratory findings are presented here.

AN ancient massive brick altar at Purola in Uttarkashi District in the Central Himalayan region was identified by a team of archaeologists in 1986–88 (ref. 1). The remains of the brick altar structure are situated on the left bank of river Kamal, a tributary of the major river Yamuna in the vicinity of the Indus Valley at Purola town (Figure 1). Earlier findings by geologists and archaeologists in the region, including remains of a temple structure at Lakhamandal, *syenachiti* at Jagatgram and Challis rock edict of the Ashoka regime are well documented[1–4]. Leaving aside the historical aspect of these ancient remains, the findings are vital to work out missing links in technological development in the field of building materials and technology, which took place during the past few thousand years in the Indus Valley. The first reference of brick–*istaka* appears in *Yajurveda*[5] for construction of altars of different geometrical shapes and sizes to perform specific rituals[4–7]. The excavated altar structure at Purola is in fact a *syenachiti* measuring 24 m × 18 m east-west direction and bears the shape of an eagle or hawk (the *Garuda* according to Hindu mythology). Various sizes of burnt bricks are reported for the construction of the *syenachiti*, ranging from 80 cm × 50 cm × 11 cm to 50 cm × 50 cm × 11cm or even smaller. In the present study a small, burnt brick sample measuring 28 cm × 19 cm × 12.5 cm and approximating to half the size of the burnt clay brick (or block in present-day terminology) as used in the construction, was subjected to physical and

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mineralogical examination. The brick sample was drawn so as to cause minimal distress to the altar structure. The experimental details and methodology of sample pretreatment are dealt within the subsequent paragraphs.

After conducting visual and physical examinations of the brick sample as obtained from the site, it was cut into smaller briquettes (size 7.2 cm × 5.6 cm × 3.5 cm) by a hacksaw blade, manually, so as to present the exposed outer face, core and unexposed side of the brick body sample. The briquette samples were subjected to physical and visual examinations for appearance, colour etc. They were kept for air-drying for two weeks, to attain equilibrium conditions prior to testing for strength and water-absorption characteristics followed by oven-drying at 105 ± 2°C for 16 h, as specified in the standard testing procedures for burnt bricks. The powdered samples of the brick body as obtained while cutting the brick sample representing near surface and core materials, were finely ground to pass 300 mesh screen (53 micron-size opening) for X-ray diffraction (XRD) analysis to identify microcrystalline phases present in the body. A few pieces of the brick sample were also kept aside for microscopic examination using a scanning electron microscope (SEM). XRD analysis was carried out using copper target (K_α radiation of wavelength 0.154 nm and filtered through nickel foil) set at operating voltage of 30 kV and current 20 mA. The observed XRD profile was used to identify microcrystalline mineral phases in the samples. Test results on briquette samples are summarized in Table 1 and Figure 2, while photomicrographs are shown in Figure 3.

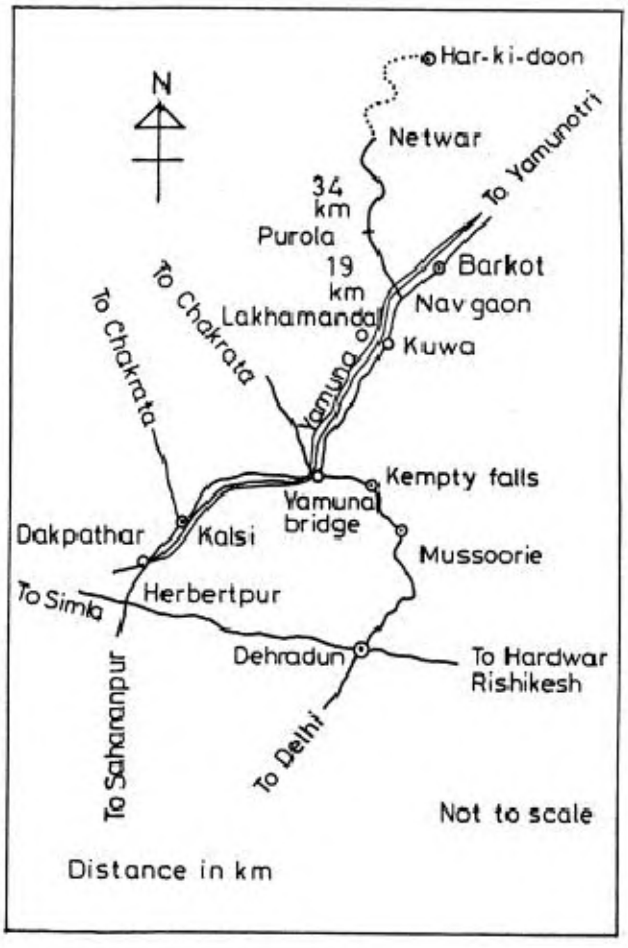

Figure 1. Site location map.

Visual examination reveals a yellowish brick-red colouration of the brick body, with fairly intact edges and corners. The brick body is apparently subjected to firing at a temperature range of 900–950°C. The brick sample did not bear any inscription or marking as prevalent in present-day hand-made bricks. The brick sample, on striking with a metal rod, yielded a dull ringing sound indicating moderate-to-high level of porosity or voids. The brick body, on cutting by a hacksaw blade, reveals honeycomb structure with moderately large voids. This specific void pattern in the brick body could possibly be due to the use of some plant residues like straw or paddy husk with the clay mass prior to shaping, as the geometrically large brick bodies are prone to severe cracking during drying stage as a result of excessive drying stresses, particularly when plastic clays are used for shaping[8]. It is interesting to note that no bio-degradation of brick body had occurred as a result of perceptible penetration of plant roots within the brick matrix.

The results of physical tests, i.e. strength and porosity measured in terms of water-absorption characteristics of the briquette samples as detailed above, range from 84 to 124 kg/cm^2, and 19.1 to 22.8%, respectively. Bulk density of the briquette samples was found to vary in the range of 1.45 to 1.49 g/cc, which is lower compared to manually-made traditional bricks (1.6 to 1.8 g/cc). It is interesting to note that the briquette cut-sample from the outer surface of the burnt clay block shows lower compressive strength (84 to 86 kg/cm^2) compared to a sample obtained from the inner core which showed significantly high compressive strength (124 kg/cm^2). This observation were found to be conformity with the water-absorption characteristics, which were found higher for samples cut from outer faces of the burnt brick sample (22.5 to 22.8%) compared to inner core briquette samples (19.1%).

Table 1. Physical properties of briquette samples cut from fired brick at the altar structure

Attribute	Briquette sample representing		
	Exposed face	Unexposed face	Core material
Compressive strength (kg/cm^2)	82	86	124
Water absorption (%)	22.5	22.5	19.1
Bulk density (g/cc)	1.45	1.45	1.49

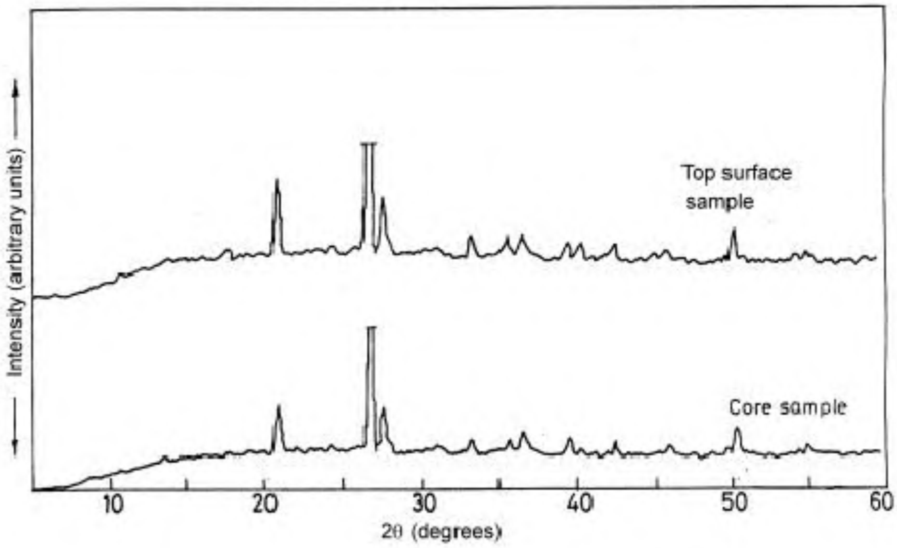

Figure 2. XRD profile of fired brick sample (CuK_{α} radiation).

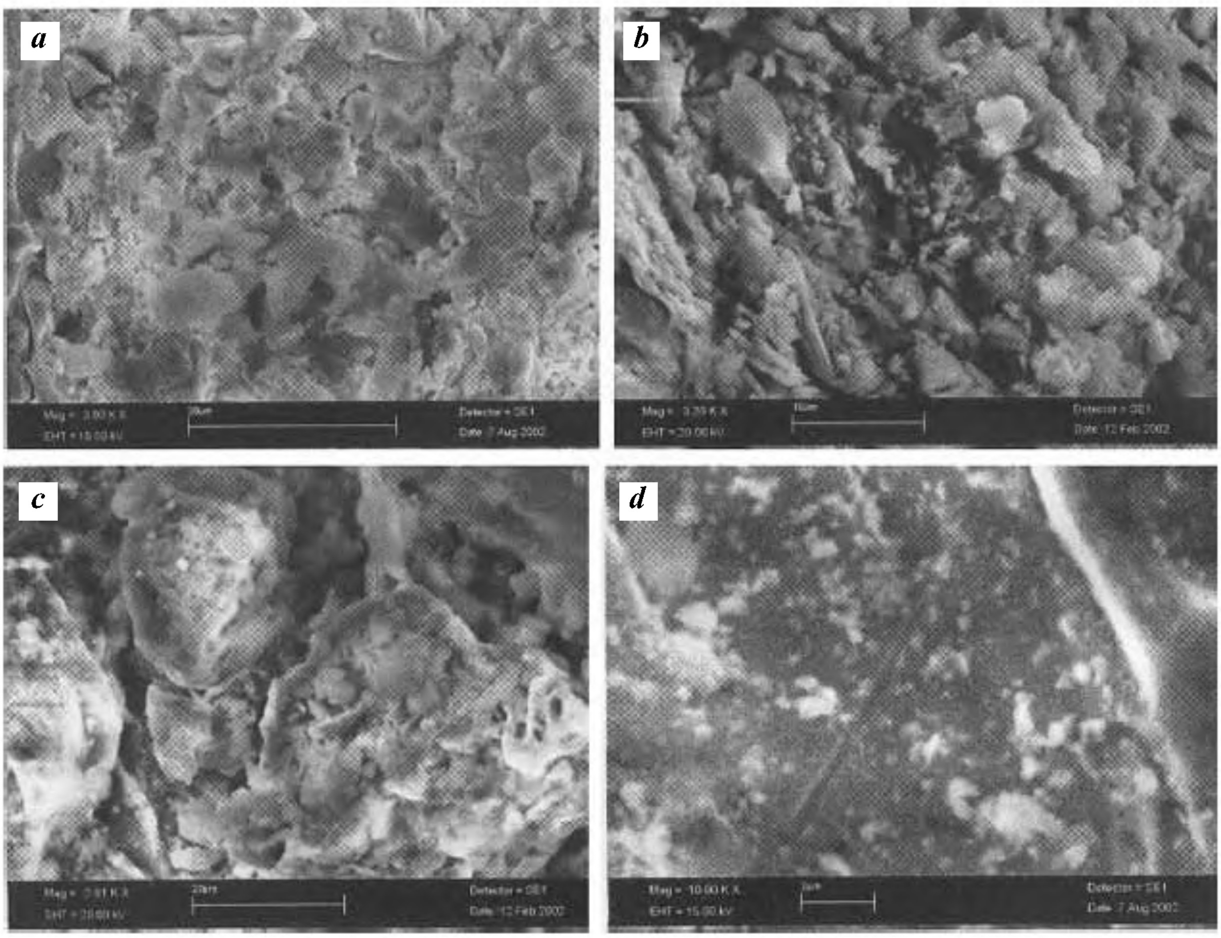

Figure 3 *a–d*. Photomicrograph of fired brick sample.

Major seismic activities which occurred in the region, according to available published information[9,10], might have also caused failure of mortar joints besides propagation of macro-cracks in at least a few of the brick members of the altar structure. In this context, it is worthwhile to mention the recent findings on the tectonic appraisal of the Shiwalik range, wherein it is reported that the high magnitude of the geodynamic process constitutes the major cause for seismic and tectonic activity in the region[11,12]. These visualizations could be taken for failure of mortar joints of the altar structure, so as to create enough gap for the ingress of natural, deteriorating agents like rainwater, plant roots, etc.

The water-absorption value of burnt ceramic ware largely depends on the pore size and its distribution in the body. Macro-pores and voids get filled up with water when porous, burnt clay-bodies are soaked in water. However it has been reported that such a pore structure does not hold water due to inherent surface characteristics of pores/voids, besides electrical and other constitutional properties of water. Therefore, it implies that water absorption of burnt clay products with large pore size is not a measure of porosity in real terms.

Results of mineralogical examination based on XRD analysis of two samples representing near surface and core material of the burnt clay brick-body are shown in Figure 2. XRD profile of both the samples shows high level of resemblance, except in terms of certain low to very low-intensity peaks which appear only in the near-surface sample from the brick body (i.e. $d = 8.40$, 5.03, 3.67, 1.68 and 1.60 Å); three additional peaks of very low intensity ($d = 6.56$, 4.02 and 2.88 Å) were noticed in the core sample. The d values quoted are given by the Bragg expression $d = \lambda/2\sin\theta$ where $\lambda = 1.54$ Å the Cu-K_α wavelength. All these peaks correspond to feldspathic minerals (albite–anorthite series), which are normally associated with the clay mass[13]. However, when clay products with such feldspathic materials are subjected to elevated temperatures during the firing stage, a series of changes in their inherent micro-crystalline structure takes place depending on the temperature, duration of heat treatment, firing environment, etc.[14,15]. Further, formation of additional feldspathic constituents from clay materials takes place at elevated temperatures, particularly in the presence of certain cationic species like Na^+, K^+, Ca^{++}, etc. (refs 13–15). Since the firing temperature of the fired brick sample under reference is expected to be below 950°C, the chances of their *in situ* formation during the firing stage appears low and feldspathic material found to be associated with the fired body could be considered as the integral constituent of the clay material. Other micro-crystalline phases in the fired mass and as identified through XRD analysis are mixtures of iron and aluminium oxides, which have undergone repeated cycles of wetting and drying during the course of their existence. Alteration of dehydrated silicates to crystalline hydrous phases is generally sluggish in nature. However, absorbed water could facilitate transformation of amorphous oxides/silicates to hydrated form[16,17]. Such alterations in low-temperature burnt clay-bodies led to loss in mechanical strength, in the course of time. Presence of hydrated oxides of iron (possibly as $\gamma Fe_2O_3.H_2O$) in the near-surface samples ($d = 6.43$, 3.24, 2.69 Å) might have resulted due to prolonged exposure involving the wetting and drying cycles of the fired body. Further, in addition to the normally present micro-crystalline phases in low-temperature burnt clay-bodies, i.e. quartz, cristoballite, etc. various spinels or spinel-like phases, large quantities of amorphous/noncrystalline mass have also been identified in both the powdered samples through XRD analysis, indicating low-temperature burning of these bricks (below 900°C). Further, the presence of mullite phase in both the samples could not be established through XRD analysis. This further confirms that the bricks as used in the altar structure construction were not high-temperature burnt, as the formation of mullite phase in burnt clay-bodies is usually indicative of elevated temperature of firing (above 1000°C)[17].

It is also observed from the XRD results (Figure 2) that formation of hydrated oxides of iron mass is more pronounced in the outer layers of the brick body compared to the core material. These results further show that the magnitude of degradation, close to the outer surface of the burnt brick-body, is more dominating compared to degradation within the inner core. Degradation as a result of profuse leaching of the brick body due to rains and/or flowing water during the entire period of its existence could be the main reason for this behaviour.

Micro-structural examination of randomly broken pieces from the brick sample was undertaken using Leo Scanning Electron microscope (Model 438 VP) under varying pressure mode. The scan results, obtained at magnifications of × 3 K to × 10 K are shown in Figure 3 *a–d*. These photomicrographs show wide distribution of quartz grains with large voids and macro-pores in the brick body (Figure 3 *a* and *b*). Spreading of the burnt organic residues/vesicular remains can also be noticed in Figure 3 *c* and *d*. Addition of combustible organic materials in finely distributed form, to overcome the drying problem in bricks, is known since ages and is still practised in the country[18]. The presence of elongated/rod-shaped burnt remains of carbonaceous matter (Figure 3 *d*) further strengthens the observation of biomass addition to the clay material prior to shaping of the bricks. Addition of dried plant residues or vegetable matter is all the more essential in large-sized clay-bodies, as susceptibility to excessive drying and firing losses increases with overall volume of the brick body[16]. Large-sized voids, as visible within the fired body, have been ascribed to addition of granular combustible mass, e.g. powdered and sieved charcoal, wood chips, dried barks, etc. which impart heat within the body during the brick-firing stage. Although the addition of such combustible materials in the brick body increases porosity, it also helps in developing adequate heat built up to bring in pyrolytic transformations which are essential for development of mechanical strength and water-resistant properties. However, SEM photomicrographs of the brick sample could not reveal any perceptible bio-deterioration of fired clay brick during the course of its existence in the altar structure.

Investigations on a fired brick sample from an ancient altar structure reveal that technology of making fired clay building-material was adequately known during the period. Further, physical and mineralogical examination of briquette samples revealed that partial deterioration of fired body resulted due to physical factors like river flow, seismic activity, temperature fluctuations, etc. and partly due to chemical factors involving rain-water leaching, wetting and drying cycles during its existence in the altar structure.

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^{207}Pb–^{206}Pb ages of zircons from the Nuggihalli schist belt, Dharwar craton, southern India

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^{207}Pb/^{206}Pb ages of individual zircon grains from metasediments and tonalite trondhjemitic and granitic gneisses in the Nuggihalli schist belt, Dharwar craton are determined by an ion microprobe. Zircons identified in a metasedimentary rock have ages up to ~3.2 Ga, suggesting an upper limit age of 3.3 Ga for the onset of sedimentation in this region. The ages of the gneissic protoliths are ~3.1 Ga and they appear to be nearly contemporaneous with the metasedimentary protoliths. Our data and those reported previously are indicative of multiple emplacement of the gneissic precursors, and suggest an episodic evolution of the Dharwar craton over an extended period during the early Archean.

THE Dharwar craton forms a major part of the southern Indian shield. The supracrustal association of this craton is divided into two groups, the older Sargur group and the younger Dharwar Supergroup on the basis of lithological, metamorphic and structural characteristics[1]. The craton is comprised of two blocks, the western and the eastern, with the eastern margin of Chitradurga schist belt acting as a notional boundary between them[2]. The western block is made up of orthogneisses and granodiorites, interspersed with older tracts of metasedimentary and metamorphosed igneous suites. A variety of mafic and ultramafic rocks, many having affinities with komatiites, high-magnesian basalts and tholeiites that are regarded as some of the early recognized greenstone rocks, are exposed in the western block. Nuggihalli schist belt in the southern part of the craton is one such unit. It is surrounded by older granitoid suites that include dioritic, tonalitic and trondhjemitic gneisses and migmatites. Some of the granitoid units in the western block are reported to be intrusive into the supracrustal mafic and ultramafic rocks[3]. However, in the absence of clearly-defined field evidence it is difficult to infer the exact relationship between the supracrustals and the surrounding gneisses. We have determined ^{207}Pb–^{206}Pb ages of zircons from four samples, a metasediment, two closely spaced tonalite trondhjemitic gneisses (TTG) and one granitic gneiss, surrounding the Nuggihalli schist belt to further our understanding of the early Archean evolution of the Dharwar craton.

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