Archaeological and Anthropological Sciences (2021) 13: 221
https://doi.org/10.1007/s12520-021-01454-6

ORIGINAL PAPER

Examination of Mughal stone inlay work on the mausoleum of I'timad-ud-Daulah, Agra, India

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Received: 23 May 2021 / Accepted: 25 September 2021 / Published online: 25 November 2021

Abstract

The stone inlay work on a Mughal mausoleum at Agra in India, dating to the early seventeenth century, was investigated to shed light on its character and composition. Fragments of the different coloured stones used for the inlay were examined by binocular stereoscope and optical polarized light microscopy, and microchemical analysis conducted by scanning electron microscopy with energy dispersive X-ray spectrometry. Two of the five coloured stone varieties present are characterized as bioclastic limestones, while one each is a dolomitic limestone and marble. The last variety is a black coloured stone for which a phyllite and a carbonaceous limestone are shown to have been interchangeably employed. The provenance and decay processes that affect the individual stone types are discussed, and new information on their textural and material composition is brought to notice.

Keywords I'timad-ud-Daulah · Mughal · Stone inlay · Parchin kari · Analysis · Characterization · Provenance

Introduction

The tomb of I'timad-ud-Daulah is a Mughal-era mausoleum located on the eastern bank of the river Yamuna at Agra, in the state or province of Uttar Pradesh, India (Fig. 1). It was built between 1622 and 1628 CE by Nur Jahan, wife of the fourth Mughal emperor Jahangir, in memory of her parents and to house their mortal remains. The tomb is named for her father, Mirza Ghiyas Beg, who was a high noble in the court of Jahangir, and was conferred the title I'timad-ud-Daulah, meaning 'Pillar of the State'. The tomb structure is considered to herald a new phase in the development of Mughal architecture, notably on the use of inlaid white marble as a veneer for eminent buildings in place of red sandstone. While the tomb has much art and ornamentation to speak of, its chief attraction is the intricate stone inlay work applied on its marble surfaces. The inlay work consists of cut-pieces of different coloured stones that have been laid in specially carved grooves in the marble, in a pre-designated scheme, to attain a remarkable variety of geometric and arabesque patterns. Stone inlay itself is a well-known Mughal art form used widely on their buildings over the sixteenth and seventeenth centuries, although some debate exists on the circumstances of its origin and first appearance (Fergusson 1876, p. 588; Havell 1904, pp. 88–89; Marshall 1904, p. 27; Crosthwaite 1906, pp. 25–27; Nath 1989, pp. 65–68; Koch 2012, pp. 91–92). The art has survived as a tradition down to current times, and a craft industry engaged in the production of inlay work objects is known to still flourish in Agra.

I'timad-ud-Daulah's tomb and its stonework ornamentation have been subject to scholarly attention for long, the geometry of the inlaid patterns and sophistication of the work being commented upon in considerable detail (Carlleyle 1874, pp. 137–141; Smith 1901, pp. 18–20, Plates LXIV–LXXVII; Brown 1964, pp. 100–101; Asher 1992, pp. 130–133; Nath 1994, pp. 406–421; Okada 2003; Koch 2012, pp. 48–53). Efforts have also been spent on making comparisons between Mughal *parchin kari*, as the craft of inlaying is known, and Italian *pietra dura* work (Crosthwaite 1906, pp. 25–27; Nath 1989, pp. 65–68; Koch 2012, pp. 91–92). Comparatively less attention has been paid to the stones themselves, particularly on their material character. The few observations that have been made in this regard are also fraught with inconsistencies; the stones have been invariably

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Fig. 1 The tomb of I'timad-ud-Daulah

identified or described differently in the published works (Smith 1901, pp. 19–20; Crosthwaite 1906, pp. 28–29; Nath 1994, p. 416; Okada 2003, p. 18).

Available records further indicate that the stone inlay on the tomb has been subject to several conservation-restoration interventions over the last century and a half to address the decay that has set in commensurate with its long period of existence (Cole 1882, Appendix p. xxxi, p. ccx; Fábri 1936, p. 2; Blakiston 1938, p. 5; Ghosh 1961, p. 86; Ghosh 1964, p. 123; Misra 2004, p. 259; Babu Rajeev 2005, pp. 261–62). While the inlay work is largely stable in the current date, not enough is yet known on some particular kinds of deterioration that affect the appearance and texture of some of the stones. Conservation measures for these, to an extent, remain hampered by the scarcity of information on the intrinsic nature of the stones.

A detailed study of the inlay work was recently carried out as part of the larger Mughal Riverfront Gardens of Agra Project, a partnership project planned by the Archaeological Survey of India (ASI) and World Monuments Fund (WMF) for the revitalization of the site and its components. The stonework on the entire tomb was documented in detail, and representative samples of the stones subject to microstructural and chemical analysis. This paper focuses on the scientific investigations conducted and uses the results to present an enhanced understanding on the material character and composition of the stones employed on the tomb.

The building and its inlay work

The tomb structure is the centrepiece of a large funerary garden complex. It is situated on a high plinth in the middle of a classic Mughal *chahar bagh* or four-quartered garden and approached through walkways leading in from gates that lie on the garden perimeter. The tomb is the only structure in the complex that is clad with white marble, the gates and other minor constructions within being either faced with red sandstone or plastered. The elegant architectural form of the tomb is enriched by a rich decorative programme, notably by its inlay work ornamentation featuring a choice of stylized floral and vegetal patterns and geometrical motifs and designs (Fig. 2).

The traditional process of inlaying, as on the tomb, involves several stages. The pattern from a drawing is transferred onto the marble surface to be inlaid, and grooves or recesses to receive the stones shaped in the marble with the help of small chisels. Individual pieces of the different stones to be inlaid, of sizes and shapes corresponding to the pattern, are separately fashioned from stone slabs of specific

Fig. 2 Details of the inlay work on the exterior of the tomb showing intricate motifs and patterns attained by embedding different coloured stones in a white marble base

thicknesses. Final trimming and shaping of the stones are then done, and the edges or sides of the stones bevelled to facilitate their fitment. The stones are finally embedded in the recesses with a cementing material made of 'white lime and gum' (Crosthwaite 1906, pp. 27–28; Khan 1914, p. 29), nowadays a 'special lime mortar' (Vikrama 2011), and polished to the required degree of smoothness and colour saturation.

The stonework is most profuse on the exteriors of the tomb but is also present in the interiors. The wall surfaces on the outside are inlaid almost all over, the decoration being emphasized upon in the lower portions of the walls where little of the basal marble veneering is visible as compared to the inlaid stones. The work in the interiors is largely limited to the dadoes and flooring, the ceiling and rest of the wall surfaces here being mostly filled with wall paintings. The intricacy of the inlay executed on the tomb is said to mark a turning point in the development of the craft in Mughal times, the full realization of which was achieved in the even more refined work done on the Taj Mahal about a decade later (Koch 2012, p. 52). The marble-and-inlay combination used on the tomb in fact is believed to have been a source of inspiration for the decoration of the Taj, for which it is often referred to as 'Baby Taj' locally.

Although the inlay stones on I'timad-ud-Daulah's tomb are limited in variety, there is considerable ambiguity associated with their identification in various reports and publications. Nath (1989, p. 63; 1994, p. 416) and Okada (2003, p. 18) for instance maintain that a wide range of stones including semi-precious varieties like onyx, jasper, lapis-lazuli, topaz and agate were used here, while others like Smith (1901, pp. 19–20) make no mention of these particular stones and suggest the employment of a more limited repertory. In all cases, there is generally little consensus on their correct nomenclature and provenance. Perhaps the most specific of available accounts is provided by Smith (1901). The stones on the tomb according to him include *khattu*, described as a yellow or red marble, and two other stones as 'mottled marbles' with the names *abri* and *dal-chana*. A black stone also used is reported to be a slate from Ulwar [Alwar] (Fig. 3). *Abri* is remarked as being sourced from Jesalmir [Jaisalmer] in Rajputana [Rajasthan] but is also mentioned again in the text as being jasper. Crosthwaite's (1906, pp. 28–29) monograph is not exclusive to the inlay work on the tomb, remarking instead on the materials and practices employed in the stone inlay industry in Agra at that time and correlating the findings with Mughal buildings there. The stones described by him include a yellow marble from Jaisalmer, identified here as *Abri*, a black marble being sourced from Rajputana, and *ujuba* (*ajooba*) as a kind of porphyry. White marble was apparently then being sourced from Makrana, which also lies in Rajputana.

Two other early studies that provide some more details include that of Ahmad (1924, pp. 119–20), and a pioneering work by Voysey (1825) who looked into the stone inlay on Mughal buildings in Agra in some depth. While Voysey has a particular focus on the more elaborate work on the Taj Mahal, the stones that are common to I'timad-ud-Daulah's tomb are also enumerated in the full list provided by him. These include a yellow marble said to be Guzerat [Gujarat], a clay slate, and two varieties of shelly limestones — yellow and variegated — called *sengmiriam*. More recent studies, including authoritative writings by art historians (Nath 1989, 1994; Okada 2003; Koch 2012), usually rely on one or more of these early reports for identifying the stones or extrapolate from these to draw their own conclusions. The stones, for the most part, are still referred to by their vernacular or local names.

In situ examination

A visual examination of the inlay work on the tomb, conducted for this study, reveals the presence of five different coloured stone varieties (Fig. 4). Two of these stone types have distinctive natural surface patterns, one of which is dark brown-and-yellowish in colour and the other of a pale brown-and-green appearance. Two other types include a plain yellow coloured stone and a plain black coloured stone that appears grey at places ostensibly on account of some kind of induced alteration. The last type is white marble, which besides being the base for the whole work has been used in small cut-pieces for the purpose of inlaying as well. Three of these stone types are known by their locally assigned names, the yellow–brown patterned stone identified as *abri* (Fig. 4a), the greenish-brown patterned stone being called *ajooba* (Fig. 4b), and the plain yellow stone known as *khattu* (Fig. 4c). The word 'marble' by itself is generally used over the traditional *sang-i marmar* for white marble (Fig. 4d), while the black coloured stone is typically referred to as 'Black Marble' (Fig. 4e).

The stones on the exteriors are further noticed to have a dull or faded look, especially when compared to the interiors where the same stones are seen to exhibit bright and vibrant colours. This variation can be partly attributed to the actual physical locations of the stones on the building, those on the exteriors understandably having weathered more on account of their direct exposure to sunlight and a polluted environment. However, this does not fully explain the enhanced textural deterioration that is observed in the case of the *abri* and *ajooba* specimens on the outside. The matrix in many of these stones has receded considerably on account of some kind of dissolution, leaving the inclusions uplifted and giving their surfaces an uneven feel and appearance. The *khattu* stones on the exteriors are also much duller than their counterparts in the interiors, the latter being a rich

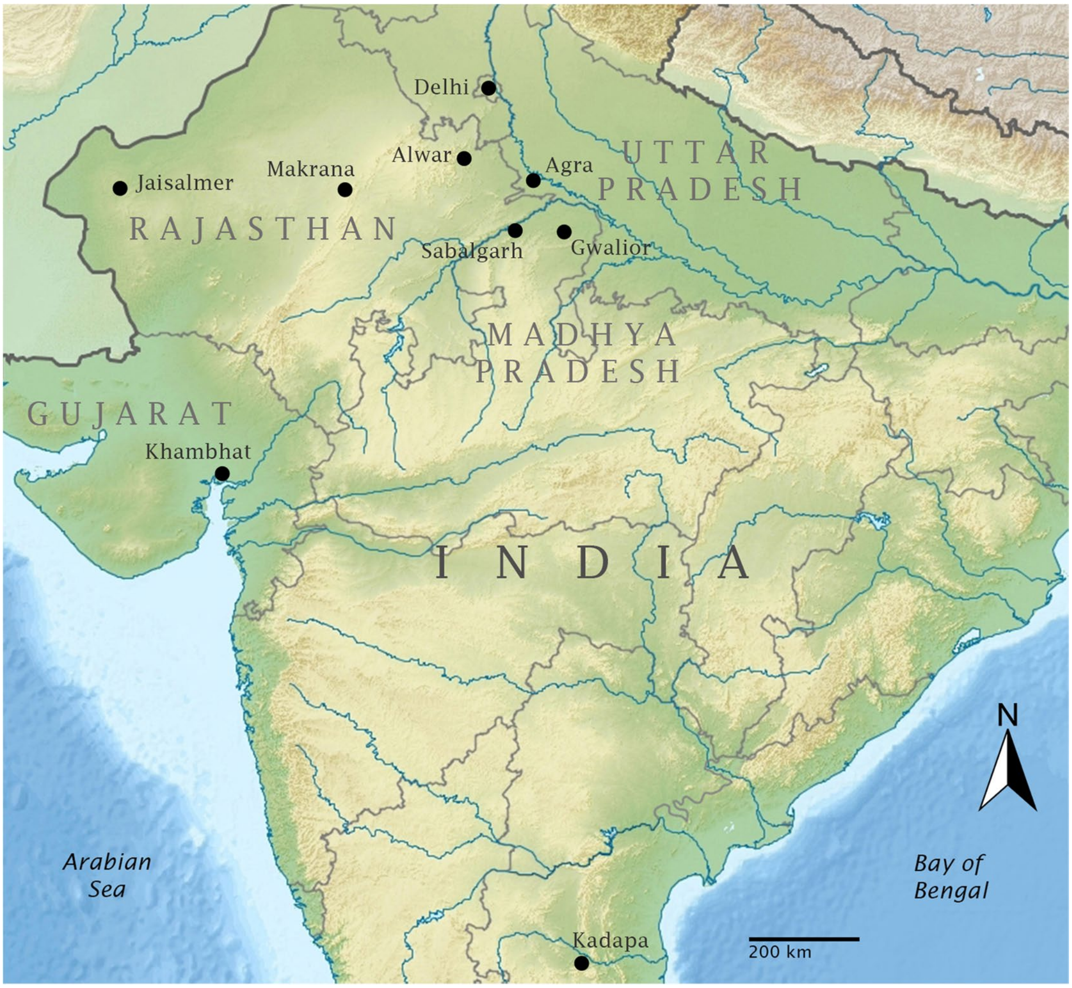

Fig. 3 Map showing the location Agra, relative to Delhi, and various other towns or sources associated with the stones employed for inlay work on the tomb (adapted from Uwe Dedering: File:India relief location map.jpg derivative work: User:Milei.vencel, CC BY)

yellow, but their textural quality is not as compromised as in the case of *abri* and *ajooba*. The surface texture is of less concern in the case of the black stones with which a peculiar phenomenon is found associated. A significant number of these stones on the exteriors are observed to have grey or steel-grey coloured surfaces instead of being black (Fig. 5). The individual black and grey stones, while being distinct from each other, were clearly meant to be of the same colour when originally laid in place as evident from the schematic layout of the whole work. No such greying is visible in the interiors though, the black stones here consistently being of a black colour tone only.

Records of conservation-restoration specific to the inlay work suggest that the repairs undertaken have mainly focused on the replacement of missing stones (Cole 1882, Appendix p. xxxi, p. ccx; Fábri 1936, p. 2; Blakiston 1938, p. 5; Ghosh 1961, p. 86; Ghosh 1964, p. 123; Misra 2004, p. 259; Babu Rajeev 2005, pp. 261–62). The loss of individual inlay stones is apparently a recurring feature which cannot be fully dispensed with (Vikrama 2011). The gradual decay of the cementing material in which the stones are embedded causes them to loosen in position over a period of time and ultimately fall off in some cases. This occurrence is not uniform all over but restricted to stones that are comparatively less well-fitted in their respective recesses, and mainly on the exteriors. The detached stones are collected and used again for restoration, together with new stones to make up for pieces that are completely missing or weathered beyond the point of reuse. The replacement stones are readily available in Agra and are typically procured from vendors who cater to the requirements of the local traditional craft industry. The recorded details on past repairs, together with site observations, indicate that while all the stones on the tomb may not be considered 'original' in the current date, efforts were made to ensure that only similar stone types (the black stone is a possible exception) be used for the substitution of lost or decayed pieces during the restoration processes.

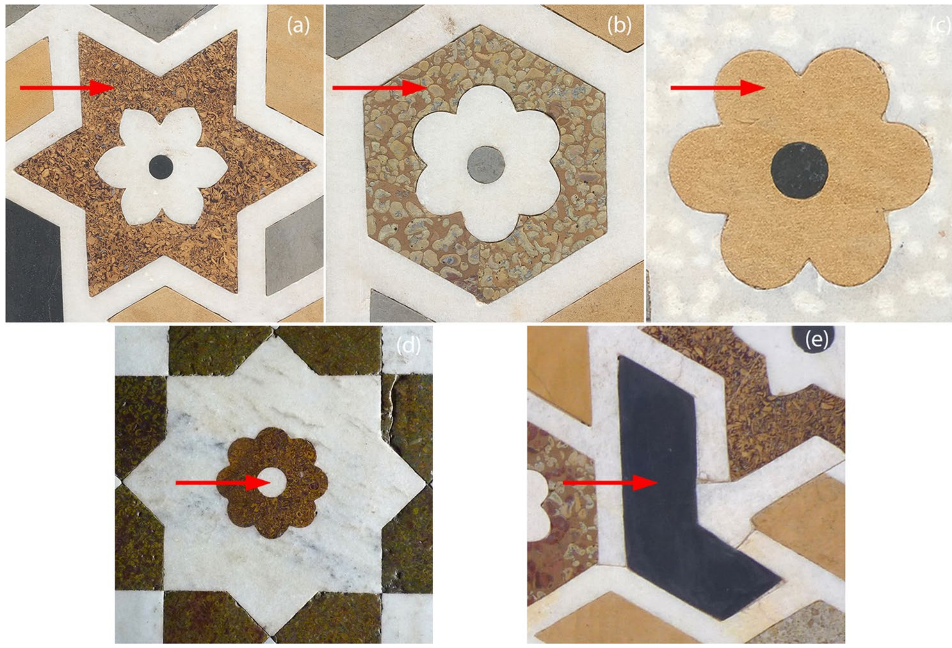

Fig. 4 Close-up of the different stone types observed in the inlay work. On the top row from left to right and indicated with an arrow are **a** Abri, **b** Ajooba and **c** Khattu. The bottom row has **d** White Marble and **e** the so-called Black Marble on the left and right respectively

Fig. 5 Close-up of a panel on the exteriors. The pattern indicates that the grey and black coloured stones were ostensibly of the same (black) colour when originally fitted in place

Experimental procedures

Petrographic and chemical analyses were performed to characterize the inlay stones and assist determine reasons for their observed deterioration. A total of 12 stone pieces or fragments, provided through the office of the monument-in-charge, were taken up for analysis. The samples included 2 specimens each of *abri*, *ajooba*, *khattu* and white marble, and 4 of the black stone — two of which had an altered or discoloured grey surface. All the stone types visible on the building were therefore represented in the sampling.

The fragments were first observed macroscopically and then by optical microscopy (OM) using a Leica M205A stereomicroscope to study distinguishing features. The 2 discoloured black stone samples were separately subject to a preliminary examination by X-ray fluorescence (XRF) spectroscopy. The aim was to determine if there was any significant variation in the chemical composition at the black and grey coloured areas on these fragments. The XRF analysis was carried out using a Fischerscope X-Ray XUV 773 bench-top instrument with Rh excitation source set at 20 kV potential and current 800 μA.

Petrological characterization of the different stone types was then carried out through polarized light microscopy (PLM). For this, thin sections of each of the samples were prepared and examined using Leica DM2500P and DM750P polarizing microscopes. The texture and distribution of the main components were identified under transmitted plane-polarized light (PPL) and crossed polars (XP).

For microchemical analysis, cross-sections of the samples were mounted in resin blocks and subject to standard grinding and polishing procedures. The polished samples were carbon coated and examined in a JEOL JSM-6610LV scanning electron microscope (SEM) equipped with an Oxford Instrument X-MaxN50 energy dispersive spectrometer (EDS). Chemical compositions were determined through bulk area analysis of the stone fabric, with the SEM–EDS system being run in high vacuum conditions at an accelerating potential of 20 kV and acquisition time 60 s. The beam current and spot size were monitored using a cobalt standard and adjusted periodically to achieve an optimum deadtime of 40%. Spot and localized analysis of various phases and areas of interest that could be distinguished in the fabric

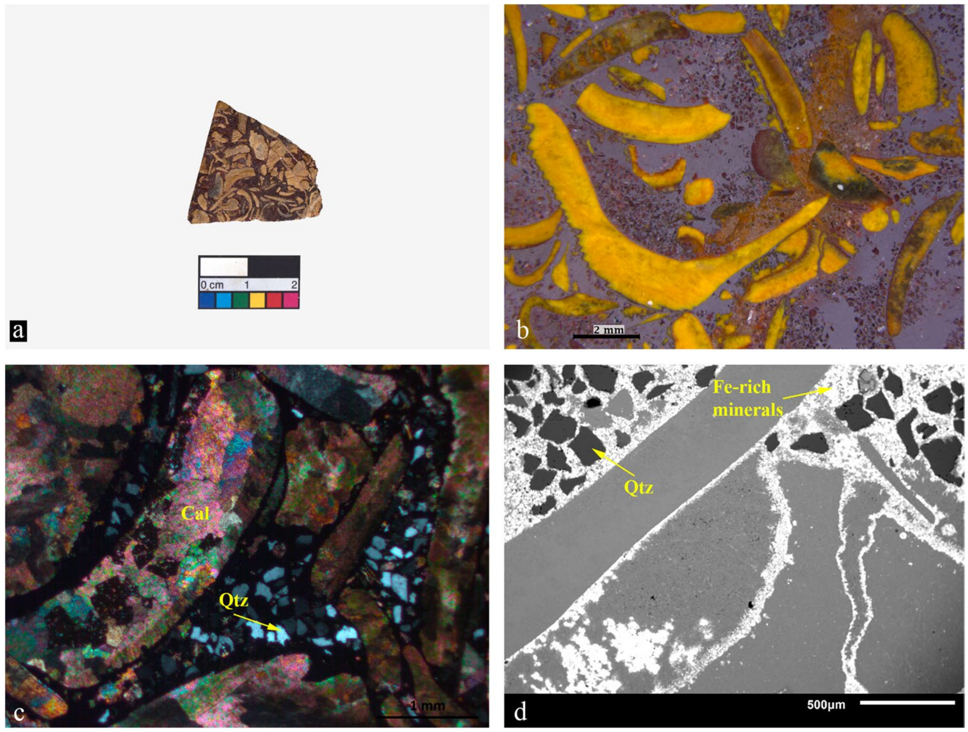

Fig. 6 Abri stone: **a** Fragment illustrating the general appearance of the stone. **b** Optical microscopy detail from a polished section showing fossil fragments in its fabric. **c** Thin-section photomicrograph, taken under XP, showing the presence of sparry calcite (Cal) in the fossil shells and a dark groundmass containing quartz (Qtz) grains. **d** SEM photomicrograph of the stone. The plain grey coloured areas correspond to the fossil clasts, while the fine bright Fe-rich particles mark the areas filled with the groundmass. The larger dark grains with the iron minerals are the quartz particles

were carried out in the same settings. Backscattered electron (BSE) images of the analysed areas were taken as required.

Results

Abri

Macroscopically, the stone is characterized by a fine-grained dark-brown coloured matrix in which numerous yellowish coloured inclusions are seen dispersed (Fig. 6a). Under the microscope, the inclusions are better identified as skeletal fossil remains of different marine invertebrates (Fig. 6b). The bioclasts vary in size and shape but are mostly thin, curved and elongated and of a length that typically varies over 0.5–1.5 cm. They are fairly tightly packed in the groundmass with no specific orientation and are well-preserved with their shell structures mostly intact. The groundmass is dark brown, appears ferruginous and micritic, and has sand-sized grains of quartz consistently distributed within (Fig. 6c). The sand grains are well-sorted and mostly range from 125 to 175 microns across. The shell cavities of the fossils are invariably found filled with sparry calcite. Some patches of the groundmass are also observed in few instances within the shell structures where they are fragmented.

The groundmass is also distinguishable in the SEM, its extent defined by an agglomeration of small bright crystals as opposed to the fossil fragments that are virtually featureless here (Fig. 6d). The bright crystals are identified as Fe-rich minerals. The ferruginous character of the groundmass as a whole is reflected in the unusually high FeO values (c. 70%; Table 1) obtained on its localized analysis. Iron oxide otherwise is measured at c. 20% on the bulk analysis of the stone fabric, while CaO and SiO_2 stand at c. 65% and 10% respectively here. The fossils are enriched in CaO (c. 95%) and have small amounts of FeO (3–3.5%) and MgO (1–1.5%) present as well.

Ajooba

This stone is marked by distinctive rounded grains preserved in a fine and homogeneous buff to brown coloured matrix (Fig. 7a). The grains are generally greenish in colour but also exhibit shades of yellow, and at times dark-brown, in concentric bands (Fig. 7b). They are typically 0.5–1 cm in length/dia, with a tendency to be rounded and spherical, but are mostly irregular in shape with protuberances on their peripheries. Petrographic analysis revealed that the matrix is essentially composed of a mosaic of rhombic crystals with a honeycomb texture (Fig. 7c), characteristic of secondary dolomite. Some rare small grains of green glauconite are also detected at a few places in the dolomitic groundmass. The prominent allochems in the fabric appear to be concretionary grains, and not fossils, being entirely made up of microcrystalline carbonate and do not exhibit any evidence

Table 1 Chemical compositions of the different stone types determined through SEM–EDS analyses. All results are in wt% and normalized to 100%. '–' indicates not detected

Sample (stone)	Analysis	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	FeO	TiO_2	P_2O_5	SO_3	Total
Abri	Fabric bulk	–	1.2	1.8	10.8	–	64.2	22.0	–	–	–	100.0
	Groundmass	–	0.5	4.7	4.4	–	20.5	69.3	–	0.6	–	100.0
	Fossil clasts	–	1.3	0.4	–	–	94.3	3.6	–	–	0.3	100.0
Ajooba	Fabric bulk	–	2.2	1.7	5.7	0.5	86.7	3.2	–	–	–	100.0
	Groundmass	–	5.3	3.6	12.3	0.6	70.7	7.6	–	–	–	100.0
	Grains	–	1.0	2.4	6.5	1.0	86.9	2.2	–	–	–	100.0
Khattu	Fabric bulk	–	0.5	1.4	0.8	–	95.3	2.0	–	–	–	100.0
(White) Marble	Fabric bulk	–	2.2	–	–	–	97.8	–	–	–	–	100.0
Black stone	Fabric bulk	0.3	2.8	15.5	65.7	6.0	1.4	7.2	1.1	–	–	100.0
Black stone (discoloured)	Fabric bulk	0.4	0.9	4.1	30.3	0.3	62.8	1.2	–	–	–	100.0

of faunal remains. Although no internal structure can be distinguished, a reddish-brown band of varying thickness that follows the contours of the outer boundaries is observed in most of these grains.

SEM–EDS analysis corroborates the presence of euhedral rhombic crystals of dolomite in the groundmass, the faces or sides of which are typically 150 microns or so across (Fig. 7d). Fine Si- and Fe-rich minerals are detected in spaces that exist between the crystals, while the allochems are generally indistinguishable and appear as a uniform grey coloured mass. Calcium oxide and MgO contents are measured at c. 70% and c. 5% respectively on localized analysis of the groundmass (Table 1), but higher values of MgO (c. 30%) are attained when relatively darker phases on individual crystals are subject to spot analysis. Calcium oxide (c. 85%) is comparatively higher in the grains, as is K_2O (1%). The other components in appreciable quantities are SiO_2, Al_2O_3 and FeO, the concentrations of which are approximately double in the groundmass as compared to the fabric as a whole.

Khattu

The plain yellow coloured stone, which is dull and weathered on the building exteriors, has a noticeably saturated golden-yellow appearance when polished (Fig. 8a). Petrographic analysis indicates that the stone is a peloidal limestone having abundant well-sorted spherical to ovoidal peloids dispersed in a matrix of sparry calcite (Fig. 8b). Some occasional fossil fragments and very few fine grains of quartz are also detected in the cement. The peloids are filled with micrite and do not exhibit any internal structure. They are typically 75–100 microns in length along their longer axis.

Chemical analysis confirms that the stone is a limestone, with CaO comprising c. 95% of the fabric bulk (Table 1). Iron oxide content is low at c. 2%, while MgO, SiO_2 and Al_2O_3 are in even lower concentrations, from 0.5 to 1.5%. The peloids are indistinguishable in the SEM, although some evidence of their outlines can be determined from small bright Fe-rich particles in the fabric that seem to lie along their peripheries.

(White) Marble

The marble, while being closer to an off-white shade superficially, appears bright white in section with some flecks of minor impurities. Thin sections studied by PLM show that the matrix is almost wholly made up of large interlocking crystals of calcite (Fig. 9), characteristic of marble. A significant proportion of the calcite grains in the fabric exhibit twinning. The grains do not show any preferred orientation and invariably have well-sutured boundaries.

The bulk chemical composition of the stone concurs with that for marble derived from fairly pure limestone, CaO being predominant at c. 98% (Table 1). Magnesium oxide is in minor quantities, c. 2%, and only traces of SiO_2 are detected.

Black stone

The dull-black coloured stone has a surface texture that appears a little rough and less inclined to take polish. Petrographic analysis shows that it has a fine-grained matrix with abundant feldspars, quartz, and biotite (Fig. 10a), some polycrystalline quartz, and possibly some epidote as well. The fabric exhibits a weak schistose texture and an average grain size suggestive of a phyllite, and therefore could be considered a biotite-phyllite.

BSE images further assist in establishing the partial alignment of the minerals and their grain sizes (Fig. 10b), which typically range over 50–80 microns, but extend up to 150 microns for some of the larger grains. The SiO_2 values for the stone fabric stand at c. 66%, while Al_2O_3 is c. 16% (Table 1). Potassium oxide and MgO are measured in concentrations of c. 6% and c. 3% respectively, while CaO is c.

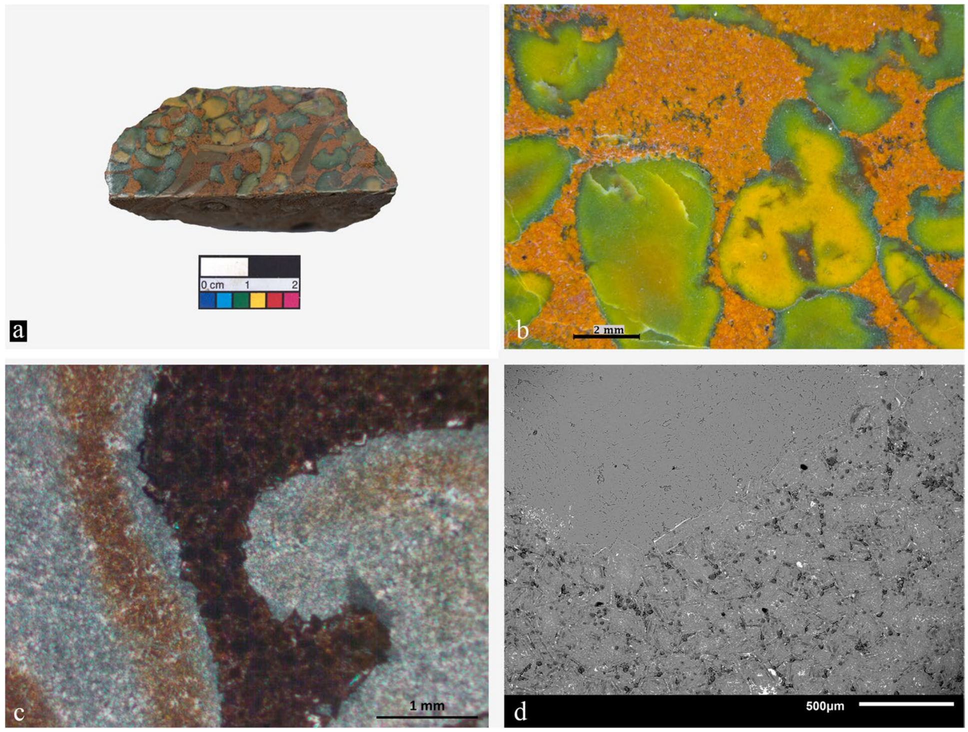

Fig. 7 Ajooba stone: **a** Freshly-cut section illustrating the general appearance of the stone. **b** Optical microscopy detail from a polished section showing the shapes and colour banding associated with the grains in the fabric. **c** Thin-section photomicrograph, taken under XP, showing the groundmass to be composed of dark brown rhombic crystals, which are tightly wedged into micrite-containing grains. Note the occurrence of a brownish concentric band within the grain boundaries. **d** SEM photomicrograph of the stone. The crystalline shapes mark the groundmass while the plain grey areas correspond to the allochems

1.5% or so. Iron oxide stands at around 7%; the black colour of the stone is suggestive of iron in its + 3 oxidation state.

Black stone (discoloured)

This stone is differentiated from the other black variety by its outward steel-grey appearance where extant in place on the building (Fig. 11a; see also Fig. 5). In section, the grey colour is found to be limited to the exposed surface of the stone only, like a thin superficial film, the fabric otherwise being black throughout (Fig. 11b). Investigations on hand specimen with the bXRF were inconclusive, similar compositional results being attained on analysis of the obverse (steel-grey coloured) and reverse (black coloured) sides of the individual samples. Petrographic studies are also less informative in this case, the petrofabric appearing little more than a closely packed mass of micrite or microsparite (Fig. 11c), indicating that the stone is a kind of limestone, ostensibly a carbonaceous limestone for its black colour.

SEM–EDS analysis corroborates that the matrix is essentially composed of very fine grains of a Ca-rich mineral but also has some fine Si-rich grains that occur both randomly and in veins within (Fig. 11d). Calcium oxide and SiO_2 are in concentrations of c. 63% and c. 30% respectively in the fabric bulk (Table 1), indicating that the stone is a siliceous limestone. Iron oxide is comparatively low, at c. 1.2%, as is Al_2O_3, which is c. 4% here. Magnesium oxide is around 1%, while K_2O is just about detectable at c. 0.3%. The black colour can be attributed to bonded organic (carbonaceous) matter, which cannot be detected through SEM–EDS.

Discussions

The characteristics of the *abri* stone correspond fully with that of Habur Limestone, a fossiliferous stone sourced from limestone deposits that are exposed around Jaisalmer town in the province of Rajasthan in Western India. Habur itself

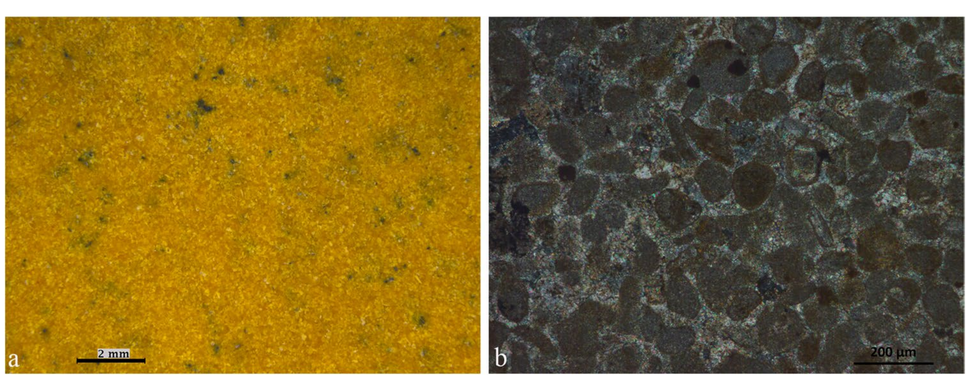

Fig. 8 Khattu stone: **a** Optical microscopy detail showing the rich yellow colour achieved on the polishing of a sample. **b** Thin-section photomicrograph, taken under XP, showing an abundance of peloids in the stone fabric

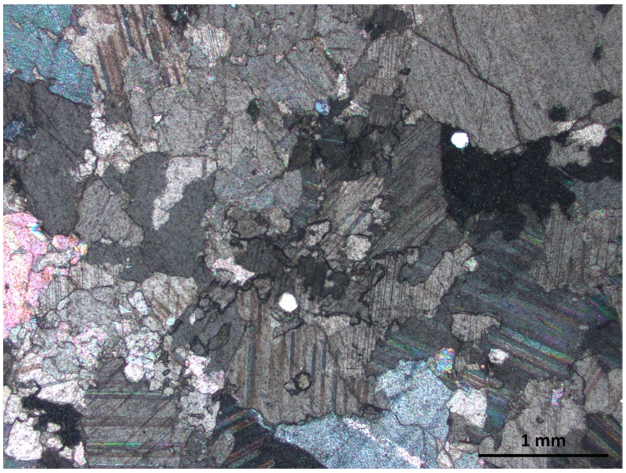

Fig. 9 Marble: thin-section photomicrograph showing crystals of calcite in the fabric, and the characteristic pale, high-order interference colours that they exhibit under XP

is a village located about 40 km from Jaisalmer. The stone is marketed as a décor item in Jaisalmer and often gifted for its 'magical' properties that include its purported ability to curdle milk without the use of any other additive/starter (Ranawat 2005). Reports on the microfacies of various carbonate rocks in the Jaisalmer Basin describe the parent rock of *abri* as a molluscan packstone, and the fossil inclusions as belemnites, brachiopods and echinoderms among others (Mahender and Banerji 1990; Ahmad and Aquil 2000). Habur stone also finds much use in the traditional stone beadmaking industry at Khambat in neighbouring Gujarat province where it is known as *sang-i mariam* and *arabi* (literally Arabic), the latter name apparently given for the resemblance of the shapes of the fossil inclusions to characters in the Arabic script. Its local name in Agra, *abri*, seems to be a corrupted version of *arabi*.

The allochems in the *ajooba* stone remain to be conclusively identified but can certainly be described as calcitic concretionary grains, rather like pisoids but lacking their characteristic concentric laminae. The possibility that they are fossilized remains of some marine invertebrates or higher plant species is highly unlikely. The enriched levels of potassium oxide in the grains over that in the groundmass and the noted presence of some sand-size glauconite grains in the fabric suggest that the pervasive greenish colour of the allochems is likely attributable to glauconitic minerals. At a macroscopic level, it is easy to see why the stone is often mistaken for a porphyry as the coarse grains can seem to appear like phenocrysts dispersed in fine-grained matrix — as in porphyritic igneous rocks. However, this is evidently not the case here, the stone apparently being a kind of dolomitic limestone. The stone is locally known to be procured from Gwalior in Madhya Pradesh province, south of Agra, and correlates with the so-called Sabalgarh Marble that is reported to occur in the Vindhyan formation near Sabalgarh town located 80 km or so to its east (Watson 1916, pp. 255–256; Krishnan 1956, p. 207; Price 2007, p. 146). Sources at Agra inform that the mining of this stone is currently restricted, since the area where its deposits are located now falls within a notified protected zone. The name, *ajooba*, given to the stone, can be translated as 'wondrous' or 'wonderful thing' and has apparently been bestowed for its unusual visual appearance.

A rock with some similar features to *ajooba*, identified as a peloidal or pisolitic dolomite, has also been reported from isolated hillocks in the Chitrakut (Chitrakoot) subbasin of the Vindhyan system (Singh and Pal 1970; Bhattacharayya et al. 1986; Anbarasu 2001; Jaiswal 2013, pp. 37–39, Figs. 33–36). Bhattacharayya et al. (1986) use the word peloid in a nongenetic sense, to include granule- to pebble-sized subrounded to rounded grains of structureless microcrystalline carbonate. They suggest that the peloids in this rock, which exhibit colour zonation like the *ajooba* calcitic grains, are products of in situ pseudomorphic replacement of glauconite grains by dolomicrite. A similar line of reasoning may be considered for the grains in the *ajooba* stone fabric, but any further inferences on their origin are beyond the scope of this paper and can only be drawn through a dedicated separate study that looks into the rock and geology of the concerned area in more detail. As a matter of interest, it is a remarkable coincidence that 'Chitrakoot' is also considered to mean 'hill of many wonders' in the vernacular, although the 'wonders' here are believed to allude to the sacred landscape and spots associated with the spiritual and mythological legacy of the Chitrakoot region, and not to unusual rocks or stones found locally.

Khattu is clearly a limestone from its texture and composition, and not a true marble or Yellow Marble as it is ordinarily known at Agra. The main occurrence of yellow limestone in India is again the Jaisalmer Basin in Rajasthan, where it is quarried in significant quantities and supplied as Jaisalmer Yellow to the stone industry all over the country (Srivastave and Ranawat 2015; Kaur et al. 2020). Its parent rock has been classified as a peloidal/bioclastic packstone to grainstone (Mahender and Banerji 1990; Ahmad and Aquil 2000; Kaur et al. 2020). The stone has been extensively used for architecture and its ornamentation in western India for centuries and continues to find considerable contemporary use for decorative finishes. Two principal varieties of this stone, called Ita Gold Marble and Tariwala Marble, are commercially marketed nowadays (Kaur et al. 2020). The texture and chemical composition of the *khattu* samples from the tomb are comparable to those given for Tariwala Marble (Kaur et al 2020, Table 4, Fig. 6a), indicating the preference of this softer variety of Jaisalmer Yellow limestone for inlay work purposes. Its local name of *khattu* at Agra is much on the same lines as the vernacular *khatta*, meaning 'sour', which is used at times in the context of colour to indicate a lemon- or mustard-yellow colour tone.

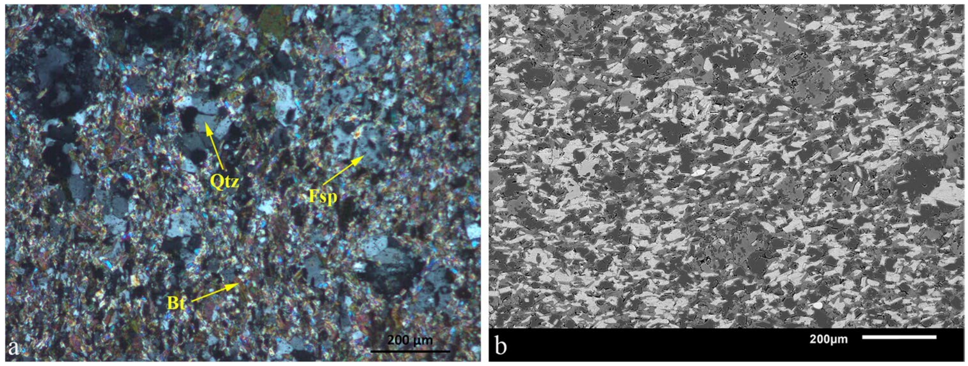

Fig. 10 Black stone: **a** Thin-section photomicrograph taken under XP, and **b** SEM photomicrograph of the stone, showing a fabric composed essentially of quartz (Qtz), feldspars (Fsp) and biotite (Bt)

White marble, as a decorative stone, is commonly available in Agra and typically comes from various quarries in Rajasthan. Among these, the marble sourced from Makrana in Nagaur district is considered the finest for its colour and translucency, but other local varieties like Agaria White from the Rajsamand district, or an imported Vietnam White, are equally in demand and find frequent employment locally. Little information on the petrographic character of these different white marble stones is available in the public domain making it difficult to draw comparisons with the examined samples from the tomb. Makrana marble as such is known to have been extensively used on the Taj Mahal (Koch 2012, pp. 94–95). Given the similarities between the Taj and I'timad-ud-Daulah's tomb in general finish and style of ornamentation, and their near contemporary dates of construction, it is highly probable that the marble used in I'timad-ud-Daulah's tomb was also sourced from Makrana at that time.

In the case of the black coloured stone, at least two distinct varieties have been employed on the tomb. The black stone that exhibits a discoloured grey-white surface is a limestone, whereas the second type that does not show any colour alteration is a biotite-phyllite. No natural black phyllite stone is currently available in the local market at Agra. Official reports on the inlay work and its industry in the early twentieth century describe the black stone as a bluish-black slate (traditionally called *sang-i moosa*) or Black Marble being procured from Rajasthan (Smith 1901; Crosthwaithe 1906), the word 'marble' here likely being a misnomer as in the case of the yellow limestone. Deposits of carbonaceous slate and phyllite as such are known to coexist in the Aravalli belt in Rajasthan (Heron 1953; Paliwal and Okada 1993) and are still exploited for use in the construction industry there. A black coloured actual marble from Bhainslana in Rajasthan is also traded, but this typically has prominent

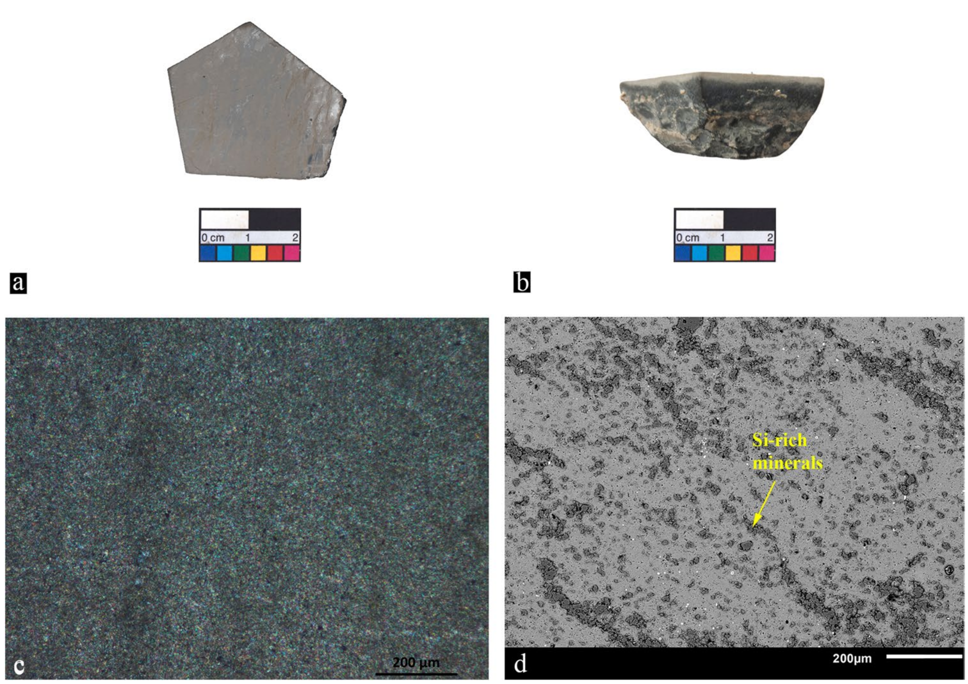

Fig. 11 Black stone variant: **a** Top and **b** side view showing the grey discolouration on the stone surface. **c** Thin-section photomicrograph under XP showing an essentially micritic matrix. **d** SEM photomicrograph showing dark fine grains of Si-rich minerals in a lighter calcareous fabric

grey and white streaks or veins and is not really a true black as in the inlay work. The plain black coloured stone that is now used in the craft industry at Agra is a fine-grained natural black siliceous limestone called Kadapa (Cudappah) or Madras Black, a variety of Narji Limestone (Roy et al. 2018), sourced from southern India. Taken together, it seems that different varieties of black coloured stones were used at different times in the history of the building, one of which must have been originally employed and the other or others fitted during the course of some subsequent restoration effort. Given the widespread usage of black slate and the known occurrence of slate-phyllite deposits in parts of Rajasthan that lie close to Agra, it would seem that the black limestone is a later addition, attributable to one of the more recent restorations carried out in the twentieth century. However, more research on the history of past repairs is required for this to be stated with certainty. The possibility of the converse occurring, meaning that a limestone-black like Kadapa was used originally, and the phyllite-black is from some later repairs, cannot be completely ruled out. It is worth mentioning here that the owners of some craft emporiums and artisans who were consulted in Agra for this study are of the view that some of the black inlay stones on the tomb could be Belgian Black (Noir Belge), a dark-black limestone that was apparently imported for use in the flooring of buildings in colonial times. Some quantities of this stone are available in the market — said to be sourced from colonial-era mansions in Kolkata that are nowadays being refurbished or demolished. There is a possibility that some Belgian Black could also have been used in restoration works on the inlay carried out in the early twentieth century.

From the conservation point of view, the observed surface alteration of the black limestone warrants more study. Although the discolouration of black limestones in the outdoors is a reported phenomenon (Pereira et al. 2015, McCormack n.d) and believed to be related to a polluted environment, reasons for this are not yet fully understood. One possibility is that pollution-related weakly acidic and damp conditions could be causing the dissolution of some of the calcite in the stone matrix, which then recrystallizes on the surface to form a kind of stable grey-white film that acts as a protective layer and arrests any further conversion. Another possibility is that the combined organic carbon nearer to the surface, and which is mainly responsible for the black colour of the stone, could have leached out or oxidized through some chemical process to reveal a calcite-rich matrix with a reduced degree of blackness. More research on a larger corpus of samples is however required for a sounder understanding of this phenomenon. For the time being, it would suffice to state that the use of a black limestone, and the chemical processes that it undergoes when exposed to unfavourable environmental conditions is responsible for the superficial steel-grey look that is exhibited in place of an original black.

The textural deterioration that is observed for the other stones on the exteriors, notably their dull weathered appearance with a hint of whiteness in the case of *khattu*, and the recession of the matrix around the allochems in the case of *ajooba* and *abri*, can again be correlated with the dissolution and leaching out of the cementing material in these stones. As in the case of the black stones, a fuller understanding of the decay mechanisms would require a dedicated study that looks into the behaviour of the stones in their specific macroenvironment, as well as an evaluation of cleaning and maintenance procedures being employed for their care and conservation.

In the larger context, the study confirms that only five different coloured stones were originally used for the inlay work on I'timad-ud-Daulah's tomb. A list of the concerned stone types and other names by which they are known is given in Table 2. Stones other than these that are mentioned in various publications are ostensibly from a later phase of development of the craft or have been erroneously identified/named. No porphyry, jade or jasper, for instance, as mentioned in some publications are found to exist, while the so-called 'marbles' are often just limestones. The findings, therefore, besides allowing an enhanced understanding of the inlay work on the tomb, assist in bringing in greater clarity in matters of accurate reporting. On a final note, given that the tomb is considered the earliest specimen of a new phase of Mughal architecture that emphasized on inlaid marble finishes, the stone varieties used

Table 2 List of the different coloured stones employed for the stone inlay work on I'timad-ud-Daulah

No	Local name	Other name(s)	Type	Appearance
1	Abri	Sang-i Mariam, Arabi, Habur Limestone	Bioclastic limestone	Fine-grained reddish coloured matrix, with yellow coloured skeletal fossil fragments dispersed within
2	Ajooba (Ajuba)	Sabalgarh Marble, Dal-chana	Dolomitic limestone	Fine-grained brownish coloured matrix with greenish coloured rounded grains dispersed within
3	Khattu	Yellow Marble, Jaisalmer Yellow	Bioclastic limestone	Plain yellow coloured stone that takes on a rich golden-yellow appearance when polished
4	Marble	Sang-i Marmar	Marble	Plain white coloured stone with some grey streaks or veins at places
5	Black Marble	Sang-i Moosa	Phyllite/slate or carbonaceous limestone	Plain black coloured stone with dull surface texture

here can be deemed to represent the first step in the chronological development of the craft on the transition to the new style.

Conclusion

Five stones of different colours were originally used for the inlay work on the tomb of I'timad-ud-Daulah of which three are known by their local names of *abri*, *ajooba* and *khattu*. *Abri* and *khattu* are essentially bioclastic limestones sourced from fossiliferous deposits in the Jaisalmer Basin in Rajasthan and correspond to stones that are nowadays traded under the names of Habur Limestone and Jaisalmer Yellow respectively. *Ajooba*, also known as Sabalgarh Marble, is a dolomitic limestone with discrete structureless calcareous grains in its fabric that lend it a pseudo-porphyritic appearance. The two other coloured stones employed on the tomb include a white coloured marble, and a plain black coloured stone for which a phyllite and a carbonaceous limestone have been alternately employed. The steel-grey discolouration observed on the black coloured stones on the exteriors is restricted to the carbonaceous limestones and ascribed to decay processes related to their material character. A high degree of weathering associated with the *ajooba* and *abri* stones on the tomb exteriors is attributed to the partial dissolution of their cementing material under adverse environmental conditions. The stone varieties originally used for the inlay work on I'timad-ud-Daulah's tomb are significant for they exemplify the range that was first put to use on Mughal buildings finished with inlaid marble.

Acknowledgements The authors are grateful to the Archaeological Survey of India (ASI) for according the necessary permissions for this study, and to the Science Branch of the ASI at Agra for assisting in the analyses. Ruth Siddall is much thanked for providing kind comments on examining the mounted samples. The World Monuments Fund (WMF) is gratefully acknowledged for providing financial support to make this work possible.

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