https://doi.org/10.1038/s40494-025-02286-6

Study of Go stones unearthed from the tomb of Fan Xiaocun of the Northern Song Dynasty

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While Go embodies the profound cultural heritage of the Chinese nation, archaeological research on it remains limited, particularly concerning Go-related cultural artifacts. We employed a suite of analytical techniques—including high-depth-of-field 3D optical microscopy (OM), X-ray fluorescence spectrometry (XRF), X-ray diffraction (XRD), and confocal Raman microscopy—to examine three Go stones unearthed from the tomb of Fan Xiaocun (Northern Song Dynasty, 960–1127 CE). The analysis revealed distinct material and manufacturing characteristics: The white stone was crafted from shell material; The black stone, a carburized ceramic piece, was fired below 950 °C; The patterned stone, also ceramic, featured sunken relief carving and required firing temperatures exceeding 1200 °C. This study provides valuable references for research on Go history, Chinese sports/entertainment artifacts, and board game culture, while offering methodological insights for future investigations.

Weiqi (Go), with origins tracing back to the Eastern Zhou Dynasty (770–256 BCE), stands as the quintessence of traditional Chinese intellectual recreation, holding unparalleled cultural significance by embodying the philosophical tenets of Daoism and Confucianism. Historically referred to as "Yi" (弈), as recorded in the Zuo Zhuan (722–468 BCE)[1], the game acquired its modern name "Weiqi" due to the tactical maneuver of surrounding and capturing opponent's stones through territorial control—the essence of its strategic paradigm.

Archaeological findings to date reveal a continuous presence of Go-related artifacts spanning from the Western Han Dynasty (206 BCE–9 CE) to the Qing Dynasty (1644–1912 CE), including game boards, stones, storage boxes, as well as treatises, paintings, and carvings on Go strategy[2]. These artifacts serve as crucial material evidence for studying Chinese Go history and culture. Among them, Go stones constitute the most abundant and diverse category, representing the core of the archaeological corpus. As direct carriers of Go activities, the evolution of stone materials reflects societal productivity, craftsmanship, and aesthetic preferences across eras, offering vivid insights into technological and cultural characteristics of different historical periods. From the Pre-Qin (c. 21st–3rd c. BCE) to Tang (618–907 CE) dynasties, pieces were predominantly made of natural stone, typically featuring oblate or biconvex shapes[3]. This historical reliance on natural stone is subtly echoed in the very term "Go stone". During the Northern Song Dynasty (960–1127 CE), advancements in ceramic production shifted the primary material to pottery and porcelain, with flat-faced oblate forms becoming standard. Pottery stones, constrained by raw materials, commonly exhibited brick-red or grey-tile hues, while porcelain stones were divided into glazed and unglazed varieties, with some aristocratic sets featuring patterned designs. By the Ming Dynasty (1368–1644 CE), mature glassworking techniques enabled glass stones to emerge as the mainstream choice. These stones, typically flat-bottomed and convex-topped, gained popularity for their polished aesthetics and ergonomic feel[4]. Additionally, artifacts made of turquoise, jade, agate, wood, and shell have been unearthed across periods, underscoring ancient enthusiasts' enduring passion for Go.

Currently, research on Go culture predominantly focuses on historical, literary, and ancient textual studies[5], with limited archaeological studies and even scarcer technological analyses of Go-related cultural artifacts[6]. In most cases, the materials of these artifacts are determined merely through empirical judgment, which lacks accuracy. The recent excavation of a batch of Song Dynasty Go artifacts from the Northern Song tomb of Fan Xiaocun at the infrastructure archaeological site of Shaanxi Normal University provides a rare window into the cultural context of Go during that era. This study selected three representative Go stones as research objects, using a super depth of field 3D microscope system(OM) for micromorphological observation, an X-ray fluorescence spectrometer (XRF) for elemental composition analysis, an X-ray diffractometer (XRD) and a confocal Raman microscope for phase identification analysis. The objectives are to determine the material composition of these stones, explore Song Dynasty craftsmanship in Go production, and investigate broader cultural implications, thereby contributing to the academic discourse on Chinese sports and recreational artifacts as well as board game cultural heritage.

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Methods

Materials

In 2022, the Shaanxi Academy of Archaeology conducted archaeological excavations on the Chang'an Campus of Shaanxi Normal University, uncovering a total of 10 Han Dynasty (206 BCE–220 CE) tombs, 6 Tang Dynasty (618–907 CE) tombs, 5 Song Dynasty (960–1279 CE) tombs, 1 Ming-Qing Dynasty (1368–1912 CE, covering both the Ming and Qing dynasties) tomb, and 2 trenches. A variety of funerary objects, including pottery and bronze artifacts, were unearthed. Notably, based on the epitaphs discovered in five of the Song Dynasty tombs, it was determined that these tombs belonged to three successive generations of the Fan clan from Gaoping during the Northern Song period (960–1127 CE). The site selection and arrangement of these tombs adhered to the prevalent " Five Tones Corresponding to Surnames (五音姓利) " theory of the Northern Song era, representing a typical family cemetery laid out in accordance with this principle. The well-preserved cemetery, with its complete array of artifacts, offers valuable insights for studying burial practices and funerary artifact assemblages of the time.

A total of 72 Go stones were unearthed from Tomb M22, the grave of Fan Xiaocun, all positioned to the left of the tomb occupant's skull, as illustrated in Fig. 1a. All the stones can be divided into three categories. Among them, there were 37 white stones, measuring 1.5–2 cm in diameter and 0.4 to 0.5 cm in thickness; 33 black stones, with diameters ranging from 1.7 to 2 centimeters and thicknesses from 0.5 to 0.7 cm; and 2 patterned stones, each 1.85 cm in diameter and 0.46 cm thick, as shown in Fig. 1b.

To maximize the capture and reflection of potential material diversity within this collection, our research deliberately selected one representative specimen from each visual category. These specimens were chosen for their most characteristic morphology, coloration, and state of preservation, as depicted in Fig. 1c. All three stones share similar characteristics, featuring a rounded shape, circular edges, and flat surfaces on both sides, with comparable dimensions. They exhibit minor indentations and chipping along the edges. The white stone displays uneven coloring with visible streaks that possess a pearlescent luster; the black stone is plain, uniformly black throughout; and the patterned stone has a white base with a slightly rough texture, adorned with identical carved floral motifs on both sides—specifically, two chrysanthemum flowers enclosed within a circular border.

Optical microscopy

The super depth of field 3D microscope system (HIROX KH-7700, Japan) employs a metal halide cold light source, providing magnification ranging from 0 to 7000×, and features multiple measurement modes (2D, 3D imaging). The system allows for the observation of surface details of samples at a magnification of 50 and 150 ×.

X-ray fluorescence spectrometry

The handheld XRF spectrometer (BRUKER TRACER 5 g, German) is equipped with a 1μm graphene window. During testing, the mineral mode is used with an 8 mm spot size, a test duration of 90 s, an air testing environment, and an operating voltage of 30 kV.

X-ray diffractometry

The X-ray diffractometer (RIGAKU Smart Lab, Japan), with a maximum power of 9 kW, a copper rotating target, and a standard Z sample stage, used for phase analysis of samples. The sample is directly fixed to the sample stage for testing, with the following test conditions: scanning range 5° to 90°, step size 0.01°, scanning speed 10°/min, voltage 40 kV, and current 150 mA.

Raman spectroscopy

The confocal Raman microscope (RENISHAW InVia, UK) is equipped with lasers at wavelengths of 532 nm, 633 nm, and 785 nm, using 50× and 100× objectives. Test conditions: laser source wavelength 633 nm, exposure time 10 s, resolution 1 cm^{-1}, scanning range 100–4000 cm^{-1}.

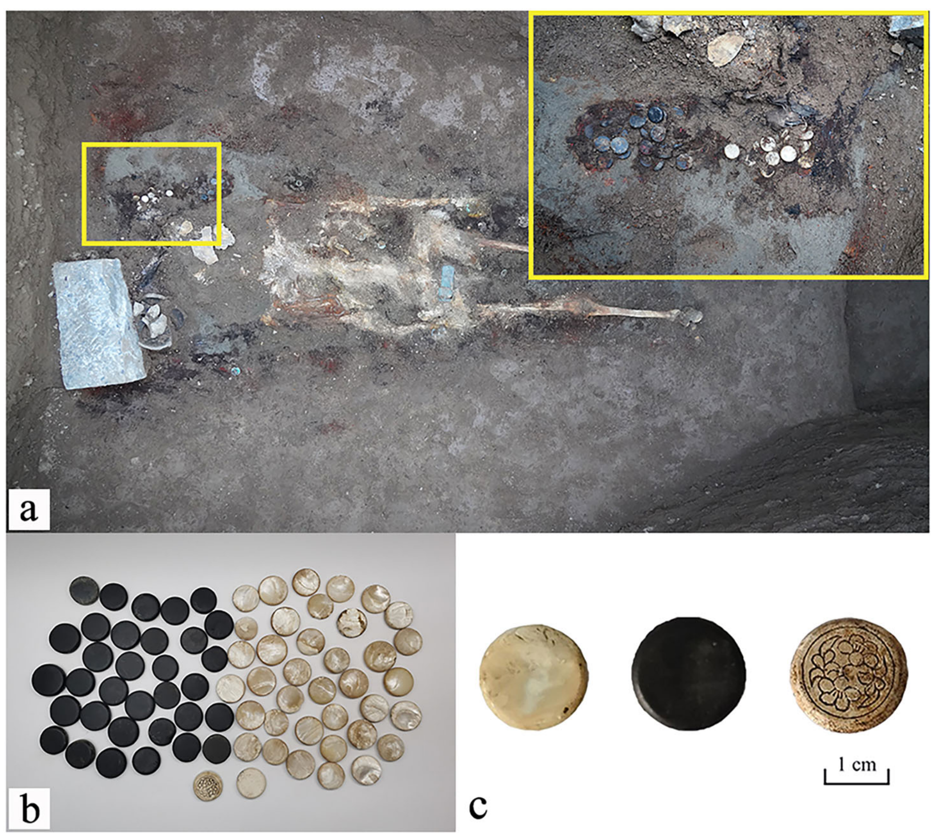

Fig. 1 | Photographs of the sample. **a** Panoramic view of the burial, **b** Photograph of Go stones unearthed, **c** Photographs of samples.

Results

Micromorphology

The super-depth-of-field micrographs of the three stones are shown in Fig. 2. The white stone has uniform lamellar patterns and a pearlescent luster on its surface; the black stone has a relatively uniform and fine texture; and the patterned stone has a slightly rough surface with soil stains and engraved marks on the edges of the patterns.

Elemental composition

Due to its non-destructive nature, rapid analysis, portability, and multi-element detection capability, XRF has become a widely used method in archaeology and cultural heritage conservation for analyzing raw materials, craftsmanship, provenance, and authenticity of ceramic[7–10], though it requires complementary techniques to address limitations in light element detection and matrix effects. The elemental analysis results of the three stones are shown in Table 1. The primary element in the white stone is Ca, making up over 90% of its composition, which is consistent with the characteristics of a shell[11]. The average SiO_2 contents of the two ceramic pieces are 59.28% and 54.42% respectively, while the average Al_2O_3 contents are 30.28% and 36.15% respectively. Due to geographical factors, there is a significant difference in Al_2O_3 content between porcelain bodies from northern and southern China, with a dividing line of 25–27%. If the Al_2O_3 content of the body is below 25%, it is highly likely to have been produced in the south, while an Al_2O_3 content above 27% suggests it may have been produced in the north[12]. Based on the average content of major elements in black and patterned stones, with Al_2O_3 content exceeding 30% and SiO_2 content below 60%, it can be inferred that both were produced using high-alumina, low-silica clay from northern China. The average Fe_2O_3 contents of the two Go stones are 2.85% and 2.50% respectively, which are essentially the same. This indicates that although Fe_2O_3 was previously considered to be highly correlated with the black color manifestation[13], here the black stone's Fe_2O_3 proportion shows little relevance to its black appearance. Therefore, further analytical tests would be conducted to explore other possible factors. In addition, while Fe_2O_3 can be present in the clay used as a raw material, these minerals can appear as by-products created during the firing process as the iron-bearing minerals in the raw material are destroyed and recrystallized[14]. The contents of the two ceramic pieces have 1.20–2.26% of MgO, 1.02–2.15% of TiO_2, 1.52–3.15% of CaO, and 1.06–1.64% of K_2O. Phyllosilicates are a group of silicate minerals named for their layered atomic arrangements. K and Ca are related to illite, whereas Mg and Al reflect the presence of phyllosilicates[15].

Phase identification

The results of X-ray diffraction analysis of the three stones are shown in Fig. 3. The main component of the white stone is aragonite [$CaCO_3$], the main components of the black stone are kaolinite [$Al_2(Si_2O_5)(OH)_4$] and quartz [SiO_2], and the main components of the patterned stone are quartz [SiO_2], cristobalite [SiO_2], and mullite [$Al_6Si_2O_{13}$].

Given the unique characteristics of Go stones and their significance in heritage conservation, damaging methods like thermal expansion analysis

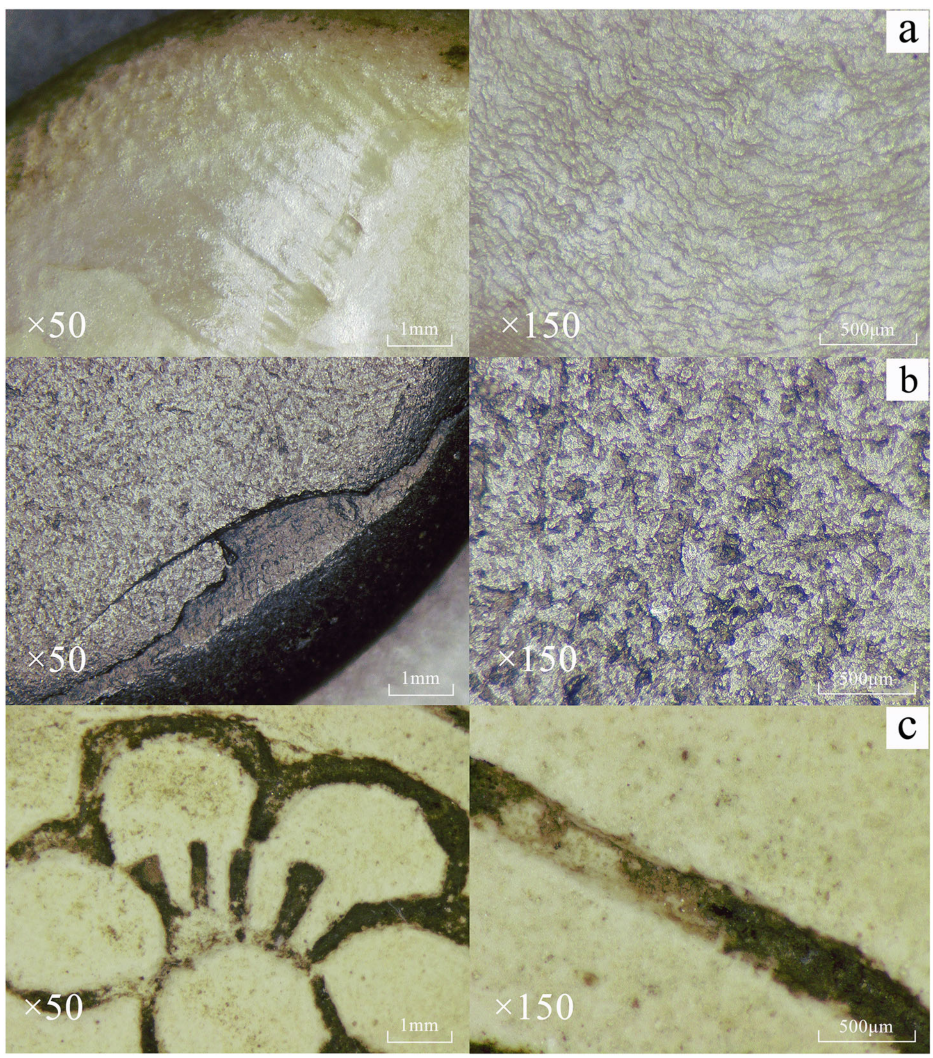

Fig. 2 | Super-depth-of-field micrographs. **a** white stone, **b** black stone, **c** patterned stone.

Table 1 | XRF analysis results of three Go stones (Values are presented as mean ± standard deviation.)

		MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
White stone	**1**	4.75	1.76	0.31	2.69	0.10	90.16	\	0.17	0.05
	2	2.16	2.32	1.19	3.04	0.21	90.86	\	0.08	0.14
	3	4.15	1.82	0.23	2.57	0.11	90.90	\	0.18	0.04
	4	2.59	2.44	1.27	3.02	0.20	90.25	\	0.08	0.14
	Mean ± SD	3.41 ± 1.24	2.09 ± 0.34	0.75 ± 0.58	2.83 ± 0.23	0.16 ± 0.06	90.54 ± 0.35	\	0.13 ± 0.06	0.09 ± 0.05
Black stone	**1**	2.26	29.65	59.73	\	1.64	1.78	2.15	\	2.80
	2	1.91	30.68	59.36	\	1.58	1.68	2.10	\	2.67
	3	2.08	30.65	58.70	\	1.44	3.14	1.03	\	2.97
	4	1.99	30.15	59.34	\	1.40	3.15	1.02	\	2.94
	Mean ± SD	2.06 ± 0.14	30.28 ± 0.43	59.28 ± 0.39	\	1.52 ± 0.11	2.44 ± 0.82	1.58 ± 0.64	\	2.85 ± 0.14
Patterned stone	**1**	1.57	35.73	54.77	1.10	1.10	1.80	1.38	\	2.54
	2	1.20	36.55	54.10	1.36	1.06	1.92	1.33	\	2.47
	3	1.53	36.64	54.68	0.85	1.06	1.52	1.31	\	2.40
	4	1.40	35.68	54.13	1.63	1.09	2.03	1.41	\	2.60
	Mean ± SD	1.43 ± 0.16	36.15 ± 0.45	54.42 ± 0.33	1.24 ± 0.32	1.08 ± 0.02	1.82 ± 0.22	1.36 ± 0.04	\	2.50 ± 0.08

are not suitable. Thus, we indirectly infer their firing temperatures from XRD results[16]. Kaolinite dehydrates to form metakaolin at temperatures between 550 °C and 650 °C, with no structural changes[17]. When the temperature is raised to 950 °C to 1000 °C, metakaolin gradually transforms into aluminosilicate spinel. At temperatures approaching 1050 °C, aluminosilicate spinel converts into mullite. After 1200 °C, mullite gradually develops fully[18]. Quartz converts from β-quartz to α-quartz at 573 °C. After maintaining this state for a considerable time above 1200 °C, α-quartz may convert to cristobalite[19,20]. From this, it can be inferred that the firing temperature for black stone was below 950 °C, while that for patterned stone was above 1200 °C.

To determine the phase of the black substance on the surface of the black stone, a Raman microscope was employed for surface analysis, revealing that the substance was carbon[21], as illustrated in Fig. 4. The vibrational modes observed at 1382 cm^{-1} and 1603 cm^{-1} correspond to the D and G normal modes characteristic of carbon, respectively[22].

The production of black ceramic involves various fields such as ceramic materials science, the history of science and technology, and art history, making it an important research topic in both the ceramic and archaeological communities in China. Experts and scholars have proposed various interpretations of its craftsmanship characteristics and technical features, primarily including "carbonized plant admixture", "black slip or clay coating", and "carburization"[23]. The "carbonized plant admixture" refers to intentionally incorporating carbonized plant branches, stems, leaves, and rice husks into the clay[24]. Black ceramic produced using this technique exhibits visible carbon particles from burnt plant stems, leaves, and rice husk fragments under both naked eye observation and microscopic examination. Microscopic examination of the black stone revealed a smooth surface without charred plant stems, leaves, or rice husk fragments, indicating that the stone was not produced using the "carbonized plant admixture" technique. The "black slip or clay coating" refers to a surface colored black by clay glaze, where the coloring element is iron[25,26], or a black ceramic coating applied, primarily made from clay rich in aluminum, potassium, and iron[27]; Upon observation, the black stone's surface shows no traces of black slip, and XRF analysis results indicate that its iron content does not meet the required level for iron to serve as the coloring element in this technique. This confirms that the stone was not produced using either of these techniques.

Based on the analysis results, it is speculated that the black stone was made using the "carburization" technique[28,29]—at temperatures between 400–600 °C, the ceramic body undergoes moisture evaporation and organic decomposition, creating a near-vacuum state internally with strong adsorption properties. At this point, within the sealed kiln, plants burn in an oxygen-deprived environment, producing black smoke rich in carbon. The microscopic carbon particles in the smoke gradually penetrate the surface of the ceramic, causing it to turn black and become more dense. The depth of the carbonization layer primarily depends on the duration of the carbonization and insulation process; longer carbonization times result in the core turning black, while shorter times only blacken the surface, leaving the core its original color. Observation shows that the core of the black stone has turned black, indicating a longer carbonization and insulation time.

Discussion

The analysis results indicate that the primary component of the white stone is aragonite ($CaCO_3$). Aragonite is a low-temperature mineral that primarily forms through exogenous processes, occurring in modern seabed sediments, clays, and limestone caves. It can also develop via endogenous processes, such as in hot spring deposits and fractures or vesicles within volcanic rocks. Additionally, aragonite can be biologically formed in the shell layers of cephalopods and the nacreous layers of mollusk shells, among other biological settings[30]. The micrograph of the white stone reveals patterns and luster resembling those of a mollusk shell's nacreous layer, leading to the conclusion that this piece is a shell-derived artifact.

Modern shell Go stones are considered top-tier when produced in Kokura Hama, Hyuga City, Miyazaki Prefecture, Japan, which is currently the only region in the world where shell Go stones are manufactured. However, shell Go stones trace their origins back to the Tang Dynasty (618–907 CE) in China. In the poem "Thanking Someone for Ten Colored Flowered Paper and Go Stones(谢人惠十色花笺并棋子)" by Tang Dynasty poet Qi Ji, the line "Shells carved into stars(海蚌琢成星落落)" indicates that the Go stones were made from shells. A batch of shell pieces with drilled holes, remnants from the production of Go stones during the Tang (618–907 CE) and Song (960–1279 CE) Dynasties, was unearthed in the Old City of Luoyang, Henan Province. One of these shell stones and the original shell mold with drilled holes are housed in the Luoyang Go Museum, as shown in Fig. 5a. Information on well-documented official archaeological finds of shell-made Go stones is presented in Table 2. The discovery of these Go stones and their original shell molds sufficiently demonstrates that Chinese had already mastered the technique of making Go stones from shells as early as the Tang and Song Dynasties.

The analysis results show that the black Go stone is ceramic fired using a carburization process, with no glaze or patterns on the surface. During the Northern Song Dynasty, the ceramic manufacturing industry was highly developed. The black porcelain production techniques of well - known kilns

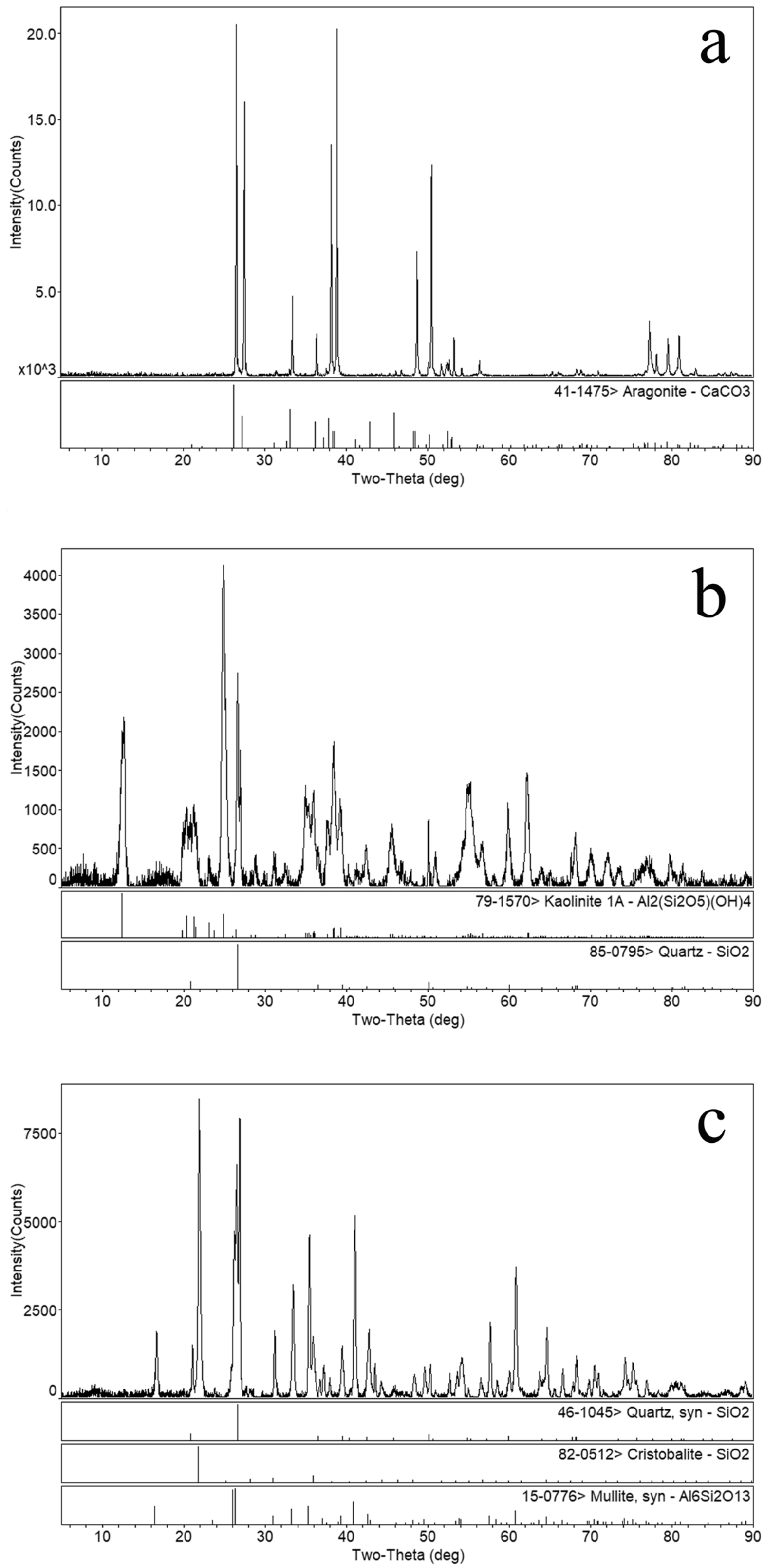

Fig. 3 | X-ray diffraction patterns. **a** white stone, **b** black stone, **c** patterned stone.

such as the Ding Kiln, Cizhou Kiln, and Yaozhou Kiln mainly achieved a black appearance by applying high - temperature glaze containing iron as a color - presenting element. However, most related research has focused on the field of porcelain, with relatively little analysis of ceramics, and there is even less scientific and technological research specifically targeting Go stones. Against this backdrop, the carburizing process used to make this black Go stone appears particularly unique. Compared with the black porcelain techniques of the aforementioned kilns that rely on glaze for coloration, the carburizing process directly acts on the ceramic body. It makes the Go stone turn black through the infiltration of carbon elements, showing significant differences in both technological principles and presentation effects. From the perspective of the development trend of ceramic craftsmanship in the Song Dynasty, the special process of this black Go stone is a vivid manifestation of diversified development.

The patterned stone is high-temperature ceramic pieces made from clay containing kaolinite, with patterns created using engraving techniques. The production techniques for patterns primarily fall into two categories: molding and engraving. Engraving involves using a chisel to directly carve intricate lines on the surface of the clay body, while molding uses pre-made clay molds to imprint patterns onto the surface of the clay body, resulting in patterns that resemble relief sculptures. It is worth noting that the origin and evolution of clay molds have a unique cultural context: they were formed through the long-term fusion of foreign religious culture and Chinese folk culture, and were initially used in sacrificial or blessing ceremonies, embodying beliefs in fertility, prosperity, and protection from evil. With the prosperity of the commodity economy and the growth of the urban middle class during the Song Dynasty, the functions of ceramic molds gradually

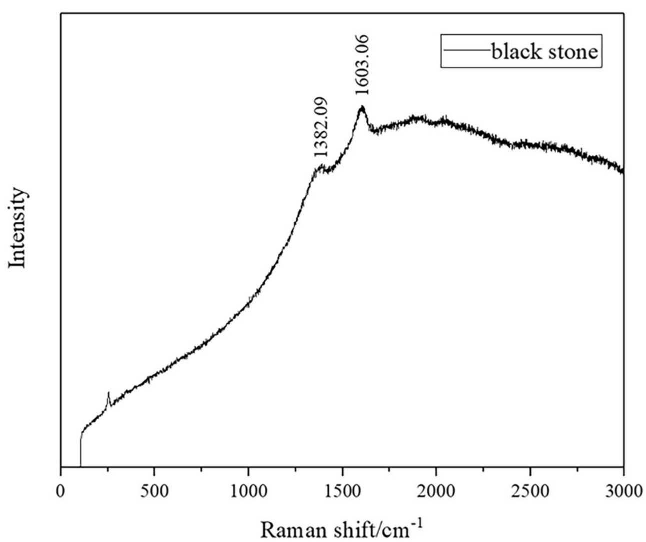

Fig. 4 | Raman spectrum of black stone.

expanded beyond religious contexts, extending into everyday life, commerce, and even entertainment, forming a culturally diverse ecosystem with multiple functions[34]. This transformation promoted the widespread adoption of mold-printing techniques in the production of Go stones. Compared to the high reliance on craftsmen's skills in engraved Go stones, mold-printing techniques enabled mass production through standardized molds, reducing costs while ensuring the uniformity of patterns. As a result, it became the mainstream choice for producing patterned Go stones at major kiln sites during the Song Dynasty. This chrysanthemum-patterned Go stone has numerous identical or similar counterparts in publicly available materials, as shown in Fig. 6, indicating it was a popular pattern at the time. A batch of Go stones from the Song Dynasty (960–1279 CE) was unearthed at the Hutian Kiln site in Jingdezhen, divided into plain and patterned types, with diameters ranging from 1.3 to 2.1 cm and thicknesses from 0.4 to 0.8 cm. Additionally, 11 Go stone molds were unearthed, featuring a circular plan view, concave top surface, straight side walls, and flat bottom. These molds also come in plain and patterned varieties, with patterns including gardenia, chrysanthemum, and coin motifs. Some patterned stones correspond with their respective molds, as shown in Fig. 6a, b[35]. Over 220 Go stones were unearthed from the site of Dongjing City of the Northern Song Dynasty (960–1127 CE). All of them are made of porcelain and come in two shapes: flat and round. They are black and white in color, and some of the flat stones are engraved with floral patterns, coin patterns, and dot patterns. They have a diameter of 1–2 cm, and one of the chrysanthemum pattern stones is shown in Fig. 6c[36]. The Luoyang Go Museum houses 38 types of clay Go stones and 1 type of porcelain Go stone, with a diameter of 1.5 to 2 cm and a thickness of 0.5 to 0.9 cm, all circular and uniformly shaped. The Go stones feature a variety of patterns, including plants and flowers, birds, inscriptions, and coins. 2 Go stones with chrysanthemum patterns are shown in Fig. 6d, e[37].

Based on research into ancient texts, the author makes two speculations about the function of patterned Go stones. One speculation is that they served as gifts or betting chips. Go has been closely linked to daily life since its origin, and betting in Go games has long been prevalent. From imperial court matches between emperors and generals, scholarly gatherings, to commoners' gambling on street corners, Go gambling was common, with stakes ranging from gold and silver symbolizing wealth[38], calligraphy and art

Fig. 5 | Publicly published photographs of shell Go stones. a shell stone and the original shell mold with drilled hole housed in the Luoyang Go Museum, **b** shell Go stones unearthed from the tomb of the Lyu family.

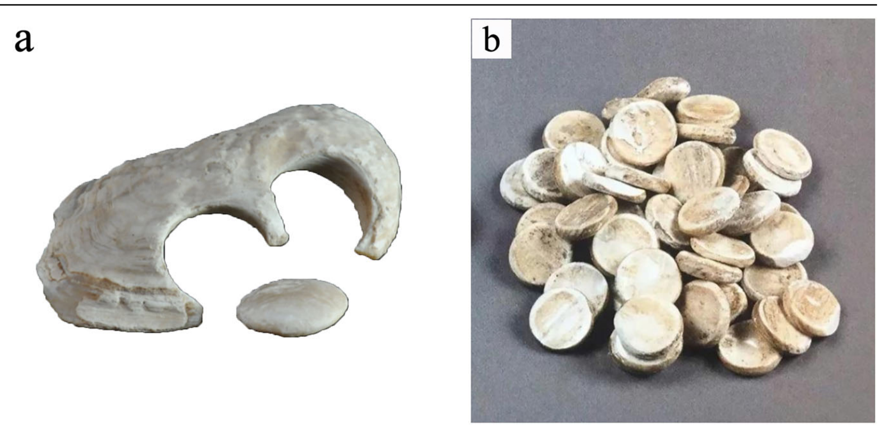

Table 2 | Recorded data for archeological shell-made Go stones

Location	Period	Shape	Quantity	Diameter	Thickness
Lyu family tomb, Lantian, Shaanxi[31]	Northern Song Dynasty	Flat Circle	175	2.1	0.5
Zheng Shaofang Tomb, Yanshi, Henan[32]	Tang Dynasty	Two-Sided Convex Circle	30	1.5	0.5
Baoshan mural tomb No. 1, Chifeng, Inner Mongolia[33]	Liao Dynasty	one-Sided Convex Circle	1	1.3	0.45

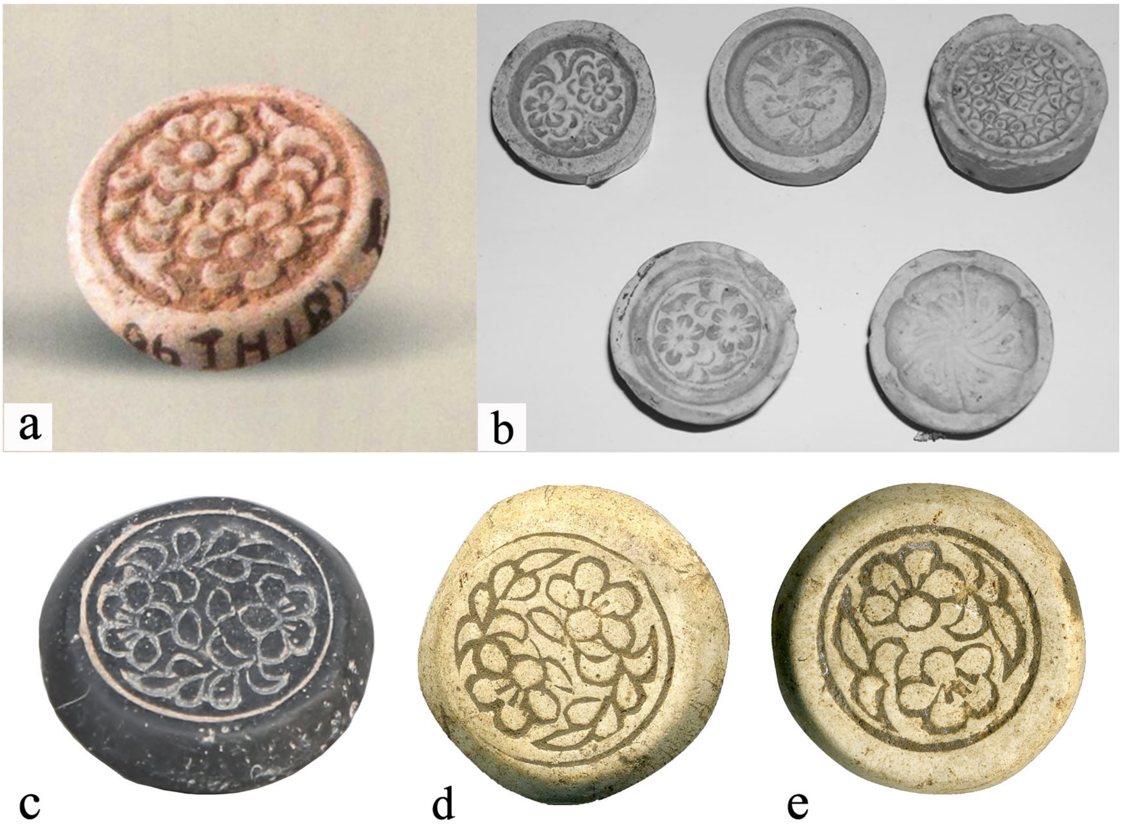

Fig. 6 | Publicly published photographs of patterned Go stones. a Go stone unearthed at the Hutian Kiln site, (**b**) Go stone molds unearthed at the Hutian Kiln site, (**c**) Go stone unearthed from the site of Dongjing City, (**d, e**) Go stones housed in the Luoyang Go Museum.

showing refined tastes, to intangible items like official positions or poems hinting at hidden strategies[39]. These stakes reflect both the competition between winners and losers and different social classes' love and cultural pursuits of Go. So, it's reasonable to think patterned Go stones were also used as stakes. They are not only carriers of material wealth but also symbols of cultural taste and social status, ideal for showing identity and expressing refined tastes in gambling. The other speculation is that they were used as tactical markers in the game. The tradition of marking "critical moves" in Go has a long history. The Dunhuang Go Classic uses rules as metaphors for strategic key points[40]. The Song Dynasty treatise "Thirteen Chapters on the Art of Weiqi" identifies strategic cores through concepts like "winning through unconventional yet appropriate moves(奇胜正合)", and its discussions on "sacrificing stones to gain positional advantage(弃子取势)" and "prioritizing initiative over immediate gains(先机后势)" highlight the impact of "critical moves"[41]. Japanese classics like the Xuanxuan Classic of Weiqi use symbols alongside game records to mark key attack and defense points[42]. These show that Go players have long isolated and reinforced memory of decisive moves using symbols, text, or naming. Extending this to patterned Go stones, their decorative motifs, contrasting colors, or engraved symbols could mark key moves. Specific patterns might denote a "divine move", and differently colored stones could flag "game-deciding moves", ensuring "critical moves" are preserved in the stones. This "embodying strategy in objects" aligns with the Go philosophy that "a single stone can determine the fate of the game(一子定乾坤)", and provides historical justification for the evolution of patterned stones from decorative items to strategic symbols.

Through multi - dimensional analysis of white, black, and patterned Go stones from Fan Xiaocun's Northern Song tomb, we've clarified production and firing features of different - material Go stones. This shows diversified Song ceramic tech and rich Go culture. Against the Song porcelain boom, research confirms Go's form evolution ties to craftsmanship and aesthetics. Examining its form, material, and techniques reveals living habits, aesthetic tastes, and aids in discussing board - game cultural exchange.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Received: 2 September 2025; Accepted: 24 December 2025;
Published online: 08 January 2026

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Acknowledgements
Thanks to Shaanxi Academy of Archaeology for providing the sample. This work has been supported by the National Natural Science Foundation of China (NO. 22101226), 111 project (D18004).

Author contributions
Shu Wang and Ruosu Wang performed all experimental tests, interpreted the data, and wrote the manuscript. Feng Sun provided support and guidance for this study. Xuwei Chen provided the sample used in the study. All authors read and approved the final version.

Competing interests
The authors declare no competing interests.

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