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Artículo

Iksan Granite and Stone Monuments in Sabi Period of Baekje Kingdom, Korea

Granito de Iksan y Monumentos Construidos en Piedra durante el Período Sabi del reino Baekje, Corea

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Abstract: The Iksan granite was included in the mid-western part of the Korean peninsula during the Jurassic Daebo orogeny. This granitic batholith has many historical quarries dating back to the 6th century until today. It is called one of the top 3 quarry sites in South Korea because this area is accessible to stone with a huge reserve in the hill region. Many stone monuments are well-known in the Sabi period (538–660 CE), belonging to the late Baekje Dynasty, which ruled in the Iksan area, in the heyday and was the essence of Baekje culture. Many researchers have reported continuously that Iksan granite is medium- to coarse-grained and K-feldspar porphyritic granite with a very homogeneous texture and geochemical composition over the twenty years. Paradoxically, this 'homogeneity' of Iksan granite has limited previous studies in finding specific historical quarries. The whole-rock geochemical analysis results do not explain the discrimination for each quarry site. This review compares the geochemical composition of the granites from quarry sites and stone monuments. It summarizes interpretation results concerning historical quarries of the late Sabi period of Baekje from the literature. Additionally, new geochemical analysis methods are suggested for tracing historical quarries on the condition that the whole-rock geochemical compositions of stone are homogeneous in the study area. The results on the geological characteristics and tracing historical quarries in the Iksan area show the long-term value of the Iksan granite as a natural resource for more than 1,500 years.

Keywords: Iksan granitic batholith; Geoheritage; Sabi period of Baekje

Key points:

Iksan granite was used to build major structures for the Sabi period of Baekje in the late 5th-6th centuries CE and the modern period in Korea.

The Iksan granitic batholith has homogenous textures consisting of medium- to coarse-grained porphyritic granitoid with similar geochemical composition.

Many results using whole-rock chemical composition analysis showed limited discrimination for the source of the stone monuments in Iksan, and recently, the new method of using REE compositions of accessory mineral was proposed.

Resumen: El granito de Iksan se incluyó en la parte centro-occidental de la península de Corea durante la orogenia Daebo del Jurásico. Este batolito granítico tiene muchas canteras históricas que se remontan al siglo VI hasta hoy. Es uno de los tres principales sitios de canteras en Corea del Sur porque esta zona se accede a una enorme reserva de piedra en la región de las colinas. Muchos monumentos de piedra son bien conocidos en el periodo Sabi (538–660 CE), perteneciente a la *última* etapa de la Dinastía Baekje, que gobernó en el *área* de Iksan en su apogeo y fue la esencia de la cultura Baekje. Muchos investigadores han informado continuamente durante

veinte años que el granito de Iksan es un granito de grano medio a grueso y de feldespato potásico porfídico, y tiene una textura y composición geoquímica muy homogéneas. Paradójicamente, esta "homogeneidad" del granito de Iksan ha limitado los estudios previos para encontrar canteras históricas específicas. Los resultados del análisis geoquímico de roca total no explican la discriminación para cada sitio de cantera. Esta revisión compara la composición geoquímica de los granitos de los sitios de canteras y los monumentos de piedra. Resume los resultados de la interpretación relativa a las canteras históricas del periodo Sabi tardío de Baekje a partir de la literatura. Adicionalmente, se sugieren nuevos métodos de análisis geoquímico para el rastreo de canteras históricas en caso de que las composiciones geoquímicas de roca total de la piedra fueran homogéneas en el *área* de estudio. Los resultados sobre las características geológicas y el rastreo de canteras históricas en el *área* de Iksan muestran el valor a largo plazo del granito de Iksan como recurso natural durante más de 1500 años.

Palabras clave: Batolito granítico de Iksan; Geopatrimonio; Periodo Sabi de Baekje

Puntos clave:

El granito de Iksan se utilizó para construir estructuras importantes para el periodo Sabi de Baekje a finales del siglo V al VI y el periodo moderno en Corea.

El batolito granítico de Iksan tiene características homogéneas que consisten en un granitoide porfídico de grano medio a grueso con una composición geoquímica similar.

Muchos resultados que utilizan el análisis de la composición química de roca total mostraron una discriminación limitada para la fuente de los monumentos de piedra en Iksan y, recientemente, se propuso el nuevo método de utilizar composiciones de REE (elementos de tierras raras) de minerales accesorios.

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Supplementary information ↓

1. INTRODUCTION

1.1. Stone monuments in the Korean Peninsula

Stone is a durable natural resource that preserves historical human information and serves as storage for relics made of other materials in the Korean peninsula. A total of 624 stone cultural heritage were registered in the Republic of Korea's State-Designated Heritage, accounting for approximately 22.4%, and the monuments made with granitoids account for 78% of all stone cultural heritage.

For example, the Komun Moru ruin was located in the limestone cave of the Neoproterozoic Sangwon system in the Nangnim massif, North Korea. This limestone cave was discovered with stone tools made in quartzite and siliceous limestone, and the fossils of 22 species of animals lived before the Upper Pleistocene (Archaeological Laboratory, 1969). The stone tools and fossils in this cave are the oldest evidence that human beings on the Korean Peninsula were 700,000 to 1,000,000 years ago (Academy of Korean Studies, 2024).

A total of 30,000 dolmens are in the Gochang, Hwasun and Ganghwa Dolmen Sites which have the highest density of dolmens in the world. Sehyeong Donggeom, the Korean-style bronze swords, were found as a burial object from some dolmen. They represent the megalithic culture and funerary culture of the Bronze Age, 2,000 to 1,000 BCE, on the Korean Peninsula. In addition, the oldest quarries in the Korean peninsula were discovered near the dolmens.

The Great Dharani Sutra or the Pure Light Dharani Sutra (no later than 751 CE), the world's oldest woodblock print, was found in the central part of the Three-story Stone Pagoda of Bulguksa Temple as the one of reliquaries. Meanwhile, the extensive collections of ancient Korean Buddhist art built from granite, like Buddhist statues, stupas, and temples, are distributed overall in the Republic of Korea. For example, the Buddhist stone monuments series has been designated as United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage sites, Seokguram Grotto and Bulguksa Temple built in 774 CE, Gyeongju Historic Areas from 57 BCE to 935 CE, and Baekje Historic Areas from 475 to 660 CE. Those masterpieces show the diversity of ancient Buddhist art and the preference for granite as the material of sculpture in the Korean peninsula.

1.2. History and stone in Iksan

Among this collection, the Baekje Historic Areas represent the later period of the Baekje Kingdom, which was the crossroads of culture and art of Buddhism between ancient East Asian kingdoms (Fig. 1A). The Iksan region, one of the Baekje Historic Areas, is the secondary capital where King Mu (r. 600–641 CE), who created stability for royal authority, made during the Sabi period (583–660 CE). The royal palace site and the cultural heritage of the Iksan area are representative historical sites that show the heyday of Baekje's Buddhist culture. Today, a total of 23 stone cultural heritage, including the sites of Baekje Historic Areas, are still being preserved in the Iksan area (Fig. 1B).

The Iksan granitic batholith, known as 'Iksan stone', has been continuously quarried since the Baekje Sabi period (Iksan Stone Product Exhibition Promotion Hall, 2025). There is a record that Qing Dynasty merchants began commercial development in earnest during the Joseon Dynasty in 1858. In the Japanese colonial period, they plundered and used granite by train for construction of buildings, such as the Former Seoul Station Building (1925) and the Main Building of the Bank of Korea, Seoul (1907–1912). Modern quarrying in the Republic of Korea started to build the National Assembly Building (1969–1976) with the Hwangdeung stone of the Iksan. This stone was used as a material for South Korean government buildings such as the Guest House of Cheong Wa Dae (the Blue House) (1978), the Independence Hall of Korea (1987), and the Supreme Court of Korea (1991–1995).

2. IKSAN GRANITIC BATHOLITH

The Korean preference for granitoids as a material for stone cultural heritage began to stand out in antiquity. The geological distribution, the granitoid intrusion into about 30% of the Korean Peninsula during the Mesozoic Era, affected this trend. The Iksan region where Baekje people settled during the Sabi period is a hilly area with exposed granite, and their choice of location led to the peak of stone art in the ancient period. The granitoids intruded between metamorphic rocks and the eastern Okcheon metamorphic belt of the Proterozoic eon during the Jurassic Daebo Orogeny movement of the Mesozoic period, forming a wide hilly area in the Iksan (Fig. 1C).

The geological survey of the Iksan area was conducted for two purposes. Many geologists investigated this area to publish geological maps. They described this granitic batholith with similar lithofacies: the light gray medium-grained massive biotite to porphyritic granite to the north area (Chung & Ko, 1963), with the gradational change from biotite normal granite to weak schistose granite to the east area (Hong *et al*., 1969), medium-grained the biotite granodiorite and shown partially porphyritic texture to the north-western area (Lee *et al*., 1980), the medium- to coarse-grained porphyritic two-mica granite to the central area (Kim *et al*., 2012). In the geological survey by Kim *et al*. (2012), they performed Sensitive High Resolution Ion Microprobe zircon U-Pb age analysis to establish the chronostratigraphy of this area. The weighted means of $^{206}Pb/^{238}U$ age for zircon rims were 172.0 ± 2.1 Ma (n = 10, MSWD = 1.7) and 172.4 ± 3.9 Ma (n = 12, MSWD = 7.7), indicating that they emplaced at the same time considering the error range.

The four representative quarry sites related to the stone monuments in the Sabi period or available with large reserves show almost similar lithofacies (Fig. 2). All areas presented in this study are those investigated by Chung & Ko (1963) and Kim *et al*. (2012). The rock-forming minerals of granites in the study area are quartz, orthoclase, plagioclase, and biotite. This batholith contains some minor minerals, muscovite in the centeral part and sphene in the western part. Zircon was an essential

mineral to determine the age of Iksan granite. Those granites is typical porphyritic granites K-feldspars phenocrysts with poikilitic structures. In particular, the Hwangdeung (figs. 2A, 2B) and Hamyeol (figs. 2C, 2D) quarry sites located southwest of Mireuksan Mt. are very homogeneous in terms of the rock-forming minerals, texture, structure, and color of the K-feldspar phenocrysts.

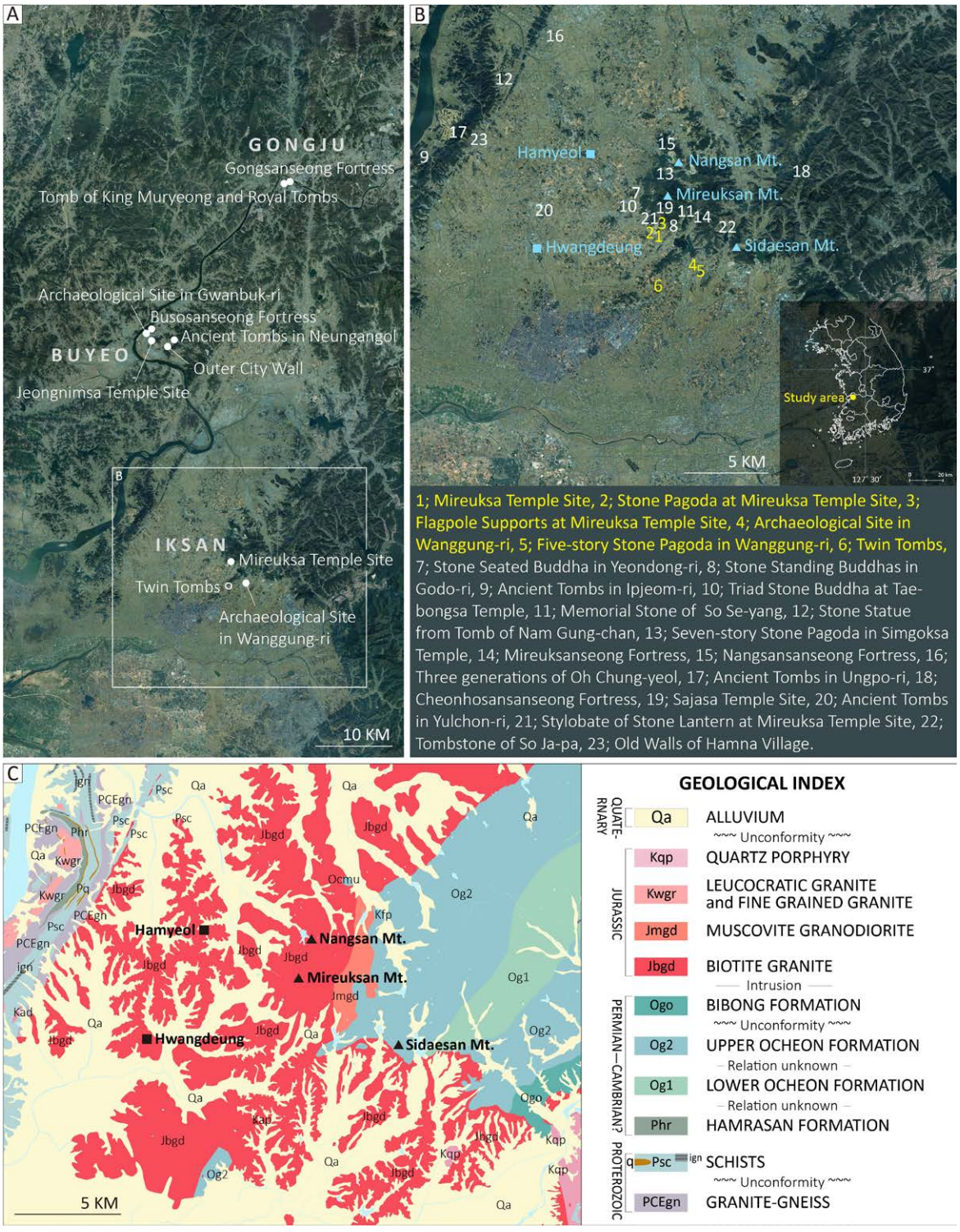

Figure 1. The Iksan area, showing the locations of stone monuments and geological setting. (A) The Baekje Historic Areas in the middle western of Korean Peninsula. (B) Stone monuments designated Korean Heritage in Iksan area. Yellow bold means stone monuments related to this study, and sky-blue means quarry sites. (C) Geological setting and historical quarry sites in Iksan (modified after Chung & Ko, 1963; Hong *et al*., 1969; Lee *et al*., 1980; Kim *et al*., 2012).

*Figura 1. El área de Iksan, mostrando las ubicaciones de monumentos de piedra y entornos geológico. (A) Las Áreas Históricas de Baekje en el medio oeste de la Península Coreana. (B) Monumentos de piedra designados Patrimonio Coreano en el área de Iksan. Amarillo en negrita significa monumentos de piedra relacionados con este estudio, y azul-cielo significa sitios de canteras. (C) Entorno geológico y sitios de canteras históricas en Iksan (*modificado después de Chung & Ko, 1963*; Hong et al., 1969*; Lee et al., 1980*; Kim et al., 2012*).*

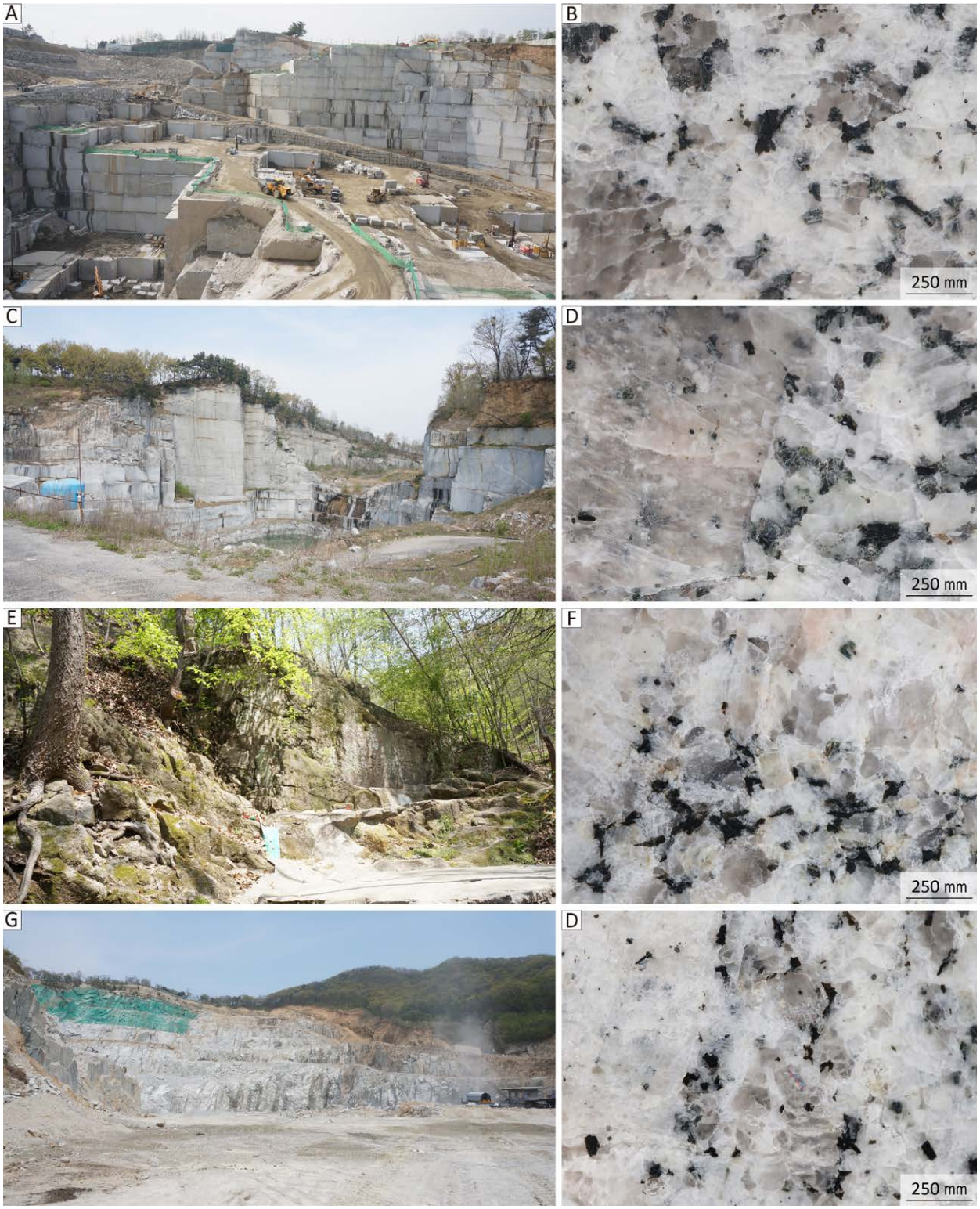

Figure 2. Quarry sites in the Iksan granitic batholith. (A) Hwangdeung quarry site. (B) Granite of Hwangdeung. (C) Hamyeol quarry site. (D) Granite of Hamyeol. (E) Mireuksan Mt. (F) Granite of Mireuksan Mt. (G) Nangsan Mt. (H) Granite of Nangsan Mt.

Figura 2. Sitios de canteras en el batolito granítico de Iksan. (A) Sitio de cantera de Hwangdeung. (B) Granito de Hwangdeung. (C) Sitio de cantera de Hamyeol. (D) Granito de Hamyeol. (E) Monte Mireuksan. (F) Granito del Monte Mireuksan. (G) Monte Nangsan. (H) Granito del Monte Nangsan.

On the other hand, many researchers surveyed this area using whole-rock geochemical analysis methods to trace historical quarries in the Sabi period. The primary purpose was to interpret the ancient quarry techniques and to get the replacement stones from the same source as the stone monument during restoration. They reported that the granitoids from stone monuments composed with an almost similar

chemical composition within the Iksan granitic batholith (Yang *et al*., 2006; Song, 2006; Kim *et al*., 2011; Choie *et al*., 2019; KNU-IACG, 2021). Because of the geochemical characteristics of the Iksan granitic batholith, they chose another method to find specific historical quarry sites related to each study object.

Currently, the total area of the Iksan granitic batholith is 1,702 ha, with an estimated reserve of about 1,062,000,000 m^3 (Kim & Lee, 2013). The authorized areas of underground quarry are total 7 sites, 756,002 m^2 by 2025 (Lee, 2023). The Iksan granite is widely known as one of the largest quarries in South Korea.

This review summarizes the history of the granitic batholith and stone monuments in Iksan, which has been utilized in major buildings throughout long periods, from the rise of Buddhist culture on the Korean Peninsula to the expansion of major government facilities in modern Republic of Korea. It also summarizes the geological survey results for the understanding geological distribution and tracing on the granite quarries and stone cultural heritage of Iksan. This article discusses the geological characteristics and the development of stone cultural heritage, the geochemical methods to trace ancient quarries, identify the limitations and challenges of existing analytical methods, and proposal for future directions focused on the Iksan area.

3. STONE MONUMENTS AND SOURCE

The Iksan is one of the Baekje Historic Areas designated as UNESCO World Heritage in 2015. This group of relics shows the history of Buddhist cultural exchanges in ancient East Asia (present-day Korea, China, and Japan) and the unique culture of the Baekje Kingdom (UNESCO, 2025). The Buddhist culture of Baekje during the late Sabi period enjoyed a prosperous through the rich granite resources of the Iksan. The stone cultural heritage in Iksan allows us to guess at the culture they enjoyed during the cultural heyday of the Baekje period. They are preserved under the Cultural Heritage Protection Act of the Republic of Korea, and basic research including geological survey for restoration and preservation is continuously being conducted.

3.1. Archeological Site in Wanggung-ri and Five-story Stone Pagoda

This remains a rectangular palace with a ratio of 2 to 1 (approximately 490 m in north-south and about 240 m in east-west), and the area was divided, stacking four-fold stone embankments in the central part. The excavation of the Wanggung-ri site began with the dismantling and repair of the five-story stone pagoda in 1965. After that, this site was surveyed and maintained by the Buyeo National Research Institute of Cultural Heritage (BNRICH) for 37 years (1989–present) as part of the Baekje Cultural Zone Heritage Maintenance Project. In the center of the first half of the building site, there are relics of the palace, such as the base stones, which suggest that this palace was used as an ancient temple in the later period. This temple's remains show the typical Baekje temple with the layout of one pagoda and one main hall (BNRICH, 2021) (Fig. 3A).

The Five-story Stone Pagoda is a five-story pagoda body built on a single-tiered platform, and reliquaries were discovered on the platform and the roof stone of the first tier of the pagoda body in 1965 (figs. 3B, 3C). Based on the style of the reliquaries from the Five-story Stone Pagoda, the date of construction is estimated to be a wide range of period, i.e., from Baekje (18 BCE–660 CE) to Tongil Silla (676–935).

This pagoda was surveyed by Yang *et al*. (2004) to build the conservation plan. The stone of this pagoda reported the medium- to coarse-grained feldspar porphyritic biotite granite consisting of plagioclase, orthoclase, quartz, biotite, and magnetite. Yang *et al*. (2004) suggested that the estimated quarry site is the northern area, including Mireuksan Mt., Namgsan Mt., Samgi, and Hamyeol, based on the lithofacies and magnetic susceptibility.

Song (2006) analyzed the geochemical composition of the samples from the pagoda and nearby mountains within 6 km to interpret the historical quarry of the altitude of under 200 m in Sidae Mt. The historical quarry sites in Iksan North Mountains showed similar geochemical behavior to the stone from the Five-story Stone Pagoda and remains. The ancient cutting trace is distributed in the Mireuksan Mt. and Yongwha Mt., but Song (2006) focused on the lithofacies comparison of the granites between the pagoda and mountains and the carry distance.

Figure 3. Archeological Site and Five-story Stone Pagoda in Wanggung-ri, Iksan. (A) Panoramic view of the Archaeological Site in Wanggung-ri, Iksan (BNRICH, 2021). (B) The Five-story Stone Pagoda in Wanggung-ri, Iksan (KHS, 2025). (C) The discovery of the eliquaries in the interior of the sarira box on the first floor of the tower body when the process stone pagoda dismantling and repair in 1965 (KHS, 2025).

*Figura 3. Sitio Arqueológico y Pagoda de Piedra de Cinco Pisos en Wanggung-ri, Iksan. (A) Vista panorámica del Sitio Arqueológico en Wanggung-ri, Iksan (*BNRICH, 2021*). (*B*) La Pagoda de Piedra de Cinco Pisos en Wanggung-ri, Iksan (*KHS, 2025*). (C) El descubrimiento de los relicarios en el interior de la caja de sarira en el primer piso del cuerpo de la torre cuando el proceso de desmantelamiento y reparación de la pagoda de piedra en 1965 (*KHS, 2025*).*

3.2. Mireuksa Temple Site and Stone Pagoda

The Mireuksa Temple is the largest temple in the Baekje Kingdom, with an area of 12,958,688 m^2, and was built to protect the country with the spirit of Buddha. The temple had two stone pagodas —the East Pagoda and the West Pagoda— and a wooden pagoda in the center when they were built. However, now only the west stone pagoda has remained. This is a unique layout of three pagodas and three main halls enshrining Buddhist statues in a total of nine buildings. Starting with the fundamental investigation of the East Pagoda and the West Pagoda by the Mahan-Baekje Cultural Research Institute (MBCRI) in 1975, the BNRICH conducted a total of 18 excavations from 1980 to 2022 (Fig. 4A) (Lim *et al.*, 2023).

Mireuksa West Stone Pagoda is the largest and earliest stone pagoda in Korea. According to the ancient documents, Samguk Sagi (1145, history book) and Geummaji (1756, local history book), it collapsed up to the upper part of the 6th floor due to a lightning strike around the 8th century. Japanese reinforced the collapsed part with concrete through the Mireuk Pagoda Preservation Project (1915) during the Japanese colonial period. The partially lost West Stone Pagoda is about 14.2 m high, about 12.5 m wide, and square. The cross-shaped interior space of this stone pagoda is a Siwon style that succeeds the interior space of a wooden pagoda, and it is the only one among the existing stone pagodas (BNRICH, 2019) (Fig. 4B).

Afterward, due to structural stability issues with the West Stone Pagoda of Mireuksaji, dismantling and repair investigations were conducted from 2001 to 2017. In 2009, during the process of dismantling and restoring the West Stone Pagoda, the sarira reliquaries were discovered in a square sarira hole in the center of the first-floor stone. Among the sarira reliquaries, the golden inscription indicates that the queen of Baekje founded the temple to honor the well-being of the royal family and all living beings and enshrined the sarira in 639 CE (Fig. 4C).

Figure 4. Mireuksa Temple Site and Stone Pagoda, Iksan. (A) Panoramic view of the Mireuksa Temple Site, Iksan (Lim *et al*., 2023). (B) The discovery of the Sarira Reliquaries from the sarira hole of central pillar stone of the West Stone Pagoda at Mireuksa Temple Site, Iksan, in 2009 (KHS, 2025). (C) The Sarira Reliquaries of the West Stone Pagoda at the Mireuksa Temple Site, Iksan in 2009. The collection of artifacts is the gold plaque inscribed with a prayer (639 CE), outer gilt-bronze sarira jar and gold inner sarira jar, precious beads, and offering (KHS, 2025).

Figura 4. Sitio del Templo Mireuksa y Pagoda de Piedra, Iksan. (A) Vista panorámica del Sitio del Templo Mireuksa, Iksan (Lim *et al*., 2023). (B) El descubrimiento de los Relicarios de Sarira del agujero de sarira de la piedra del pilar central de la Pagoda de Piedra Oeste en el Sitio del Templo Mireuksa, Iksan, en 2009 (KHS, 2025). (C) Los Relicarios de Sarira de la Pagoda de Piedra Oeste en el Sitio del Templo Mireuksa, Iksan en 2009. La colección de artefactos es la placa de oro inscrita con una oración (639 CE), el frasco de sarira exterior de bronce dorado y el frasco de sarira interior de oro, cuentas preciosas y ofrenda (KHS, 2025).

Yang *et al*. (2006) reported that more than 3,000 stones were used in the construction of the West Stone Pagoda, and approximately 450 stones were related to the exterior. The stones from the pagoda were light grayish medium-grained granite, and their rock-forming minerals were quartz, plagioclase, orthoclase, biotite, and hornblende. The results of the magnetic susceptibility showed a distribution of 3.0 to 6.0 ($\times 10^{-3}$ SI unit) in 75% of the stone pagoda, which was similar to the results of the middle outcrop of Mireuksan Mt. where four types of quarrying traces remained. The results of analyzing the stone materials of the pagoda, Mireuksan Mt., Nangsan Mt., Hamyeol, and Samgi granites have very similar behavioral characteristics of the whole-rock chemical composition. Therefore, based on the above comparative analysis, the stones were quarried from outcrop in the middle of Mireuksan Mt.

However, because of the physical property evaluation of the parts of the West Stone Pagoda of Mireuksa Temple, only 65% was judged to be reusable, and securing replacement stones emerged as a new topic of discussion. Since Mireuksan Mt. was designated as a cultural heritage protection area (1967), quarrying the original stone was difficult. Accordingly, a study was conducted to reselect the stone supply site for the restoration of the pagoda. The results of the whole-rock chemical analysis showed that the granites from the quarries of Nangsan Mt., Hamyeol, Hwangdeung, and Samgi have the same element behaviors as the stone from the West Stone Pagoda. The Hwangdeung granite was selected as the stone supply site for restoration because of its similar and stable physical properties to those of the Mireuksan Mt. quarry (Kim *et al*., 2011).

3.3. Twin Tombs

The Twin Tombs are royal tombs built in the late Baekje period (Fig. 5A). They are two horizontal digging stone chamber tombs that are almost identical in form except for their size. In the first record, the Goryeosa (1451, history book), it is referred to as the tomb of King Mu of the late Baekje period, and a grave robbery incident was recorded in around 1327. After the first survey by the Japanese Government-General of Korea in 1917, BNRICH, MBCRI, and Iksan City conducted a joint research survey (2017-2019). In 2018, 102 bone fragments from the remains of the Large Royal Tomb were discovered and radiocarbon dated to 620–670 CE (confidence level 68%), making it more likely that the remains belonged to King Mu (Shin and Choi, 2019).

The size of the Large Royal Tomb is 24 m long and 4 m high, and the stone chamber is 469 × 175 × 225 cm (figs. 5B, 5C). The size of the Small Royal Tomb is 13.6 m long and 2.9 m high, and the stone chamber is 396 × 128 × 175 cm (figs. 5D, 5E) (Choi *et al*., 2021). The stone chamber of the Large Royal Tomb is known to be the largest among the royal tombs of the Baekje period, and the stone is medium-grained biotite granite with microcline feldspar observed as phenocryst. The rock-forming minerals of the stone are plagioclase, orthoclase, quartz, and biotite. Choie *et al*. (2019) found sphene, an accessory mineral, in the Large Royal Tomb's stone and in granite from west of the Iksan granitic batholith, Hwangdeung and Hamyeol. By conducting a geochemical comparative analysis of the minor and rare earth elements (REE) of sphene, the granites from Hamyeol and the Large Royal Tomb have very similar behavior.

Kongju National University Industry Academic Cooperation Group (KNU-IACG) (2021) reported that the rock composing the Small Loyal Tomb is light gray to grayish white medium-grained biotite granite with quartz, alkali feldspar, plagioclase, and biotite as rock-forming minerals. The whole-rock chemical analysis of granites in the Iksan area showed that the overall behavior of Iksan granites was almost similar, they were nearly identical, which they interpreted as changes in lithology from the same source magma via slightly different differentiation pathways. In addition, as a result of judging the origin of the Small Loyal Tomb by lithology, magnetic susceptibility range, and whole-rock chemical composition, the stone chamber was from Hwangdeung and the surrounding stones were from Mireuksan Mt.

Figure 5. Twin Tombs, Iksan. (A) Panoramic view of the Twin Tombs, Iksan (KHS, 2025). (B) Excavation of the Large Royal Tomb (Choi *et al*., 2021). (C) The horizontal digging stone chamber of the Large Tomb (Choi *et al*., 2021). (D) Excavation of the Small Royal Tomb (Choi *et al*., 2021). (E) The horizontal digging stone chamber of the Small Tomb (Choi *et al*., 2021).

*Figura 5. Tumbas Gemelas, Iksan. (*A*) Vista panorámica de las Tumbas Gemelas, Iksan (*KHS, 2025*). (*B*) Excavación de la Gran Tumba Real (*Choi *et al*., 2021*). (*C*) La cámara de piedra de excavación horizontal de la Gran Tumba (*Choi *et al*., 2021*). (*D*) Excavación de la Pequeña Tumba Real (*Choi *et al*., 2021*). (*E*) La cámara de piedra de excavación horizontal de la Pequeña Tumba (*Choi *et al*., 2021*).*

4. FUTURE DIRECTIONS

The normalized value of the whole-rock chemical composition is an analytical method generally used to determine the origin of Korean stone monuments, especially igneous rocks. Based on the experimental data from the references on the provenance of the Iksan area, the commonly presented whole-rock chemical analysis results for granites collected from five Iksan quarries and five stone monuments were plotted (Fig. 6). The major and trace elements of Nangsan Mt. granite show diverse behaviors. Some of the REE analysis results of Hwangdeung and Hamyeol observed positive to slightly negative Europium anomalies associated with the plagioclase fractionation. Those values are acceptable considering that various differentiation patterns of magmas could be reflected because the analyses were performed five times in the Iksan area, and the sampling locations of the granites were not completely identical.

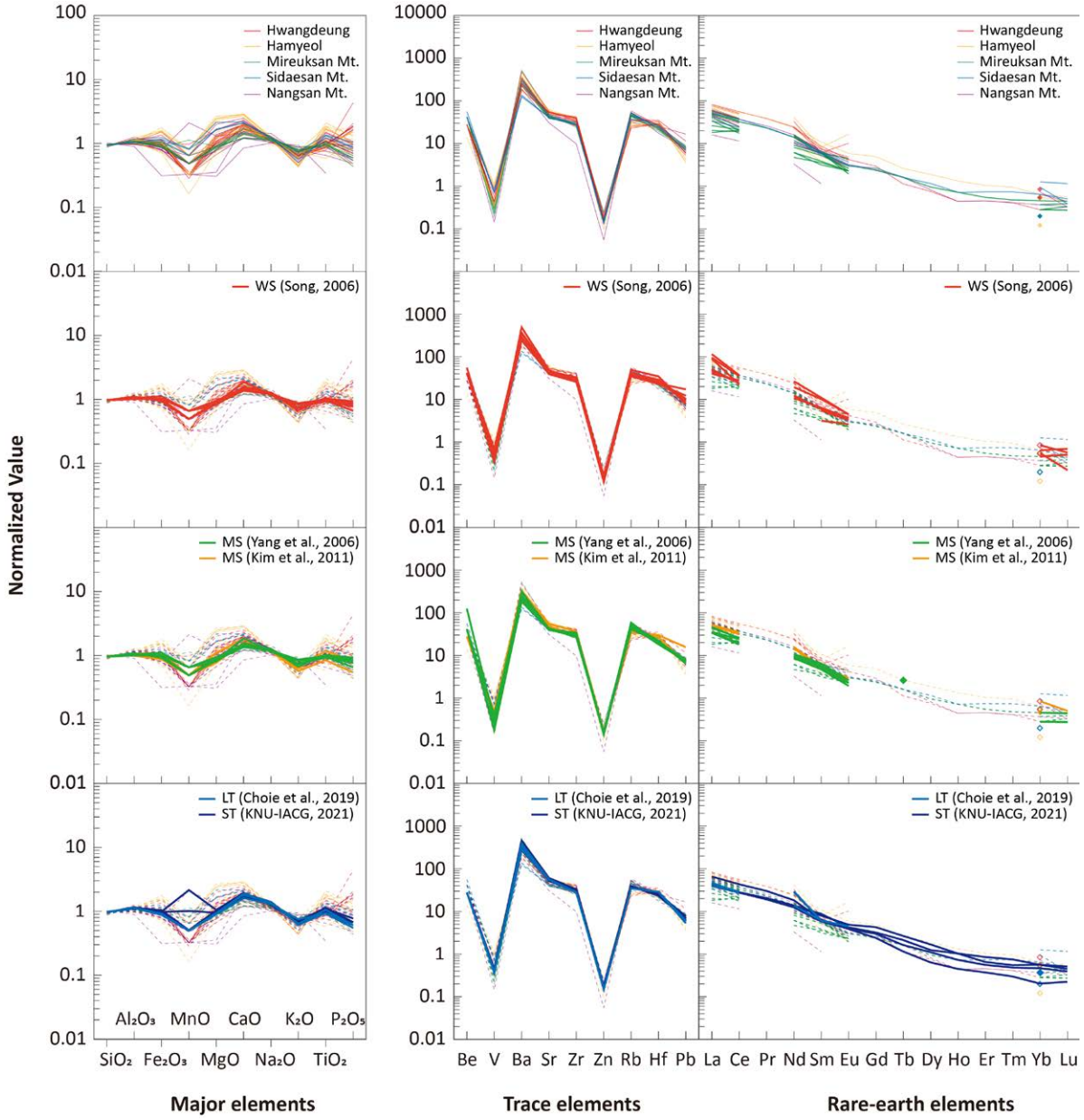

Figure 6. Major, trace, and rare-earth elements normalized for tracking historical quarry sites of Sabi period of Baekje in Iksan, Korea. Normalization values are from Nockolds (1954), Taylor & McLennan (1981). WS; Granite from Five-story Stone Pagoda in Wanggung-ri, MS; Granite from Mireuksa Temple Site, LT; Granite from Large Royal Tomb in Twin tombs, ST; Granite from Small Royal Tomb in Twin tombs.

Figura 6. Elementos mayores, traza y tierras raras normalizados para el rastreo de sitios de canteras históricas del periodo Sabi de Baekje en Iksan, Corea. Los valores de normalización son de Nockolds (1954), Taylor & McLennan (1981). WS; Granito de la Pagoda de Piedra de Cinco Pisos en Wanggung-ri, MS; Granito del Sitio del Templo Mireuksa, LT; Granito de la Gran Tumba Real en las tumbas Gemelas, ST; Granito de la Pequeña Tumba Real en las tumbas Gemelas.

Whole-rock chemical analysis is an excellent method for understanding the overall geochemical characteristics of rocks by quantitatively analyzing the chemical composition of the entire rock sample using X-ray fluorescence (XRF), inductively coupled argon plasma mass spectrometry (ICP-MS), and neutron activation analysis (INAA). However, it does not provide discrimination between rocks of the same origin and similar chemical composition. Therefore, in the case of the Iksan granitic batholith, the existing analytical methods alone have limitations in providing a geochemical basis for estimating the provenance.

Recently, new methods have been attempted to complement the limitations of these previous research methods. Some accessory minerals, zircon and sphene, found in igneous rocks suggest emplaced timing of magma using radioisotopes. The REE contained in accessory minerals sequentially changes geochemical characteristics according to atomic number, so it is helpful to trace the differentiation and origin of igneous rocks. Choie & Lee (2024) proposed a classification and origin interpretation method for stone monuments through U/Pb dating and REE patterns of accessory minerals of granitic gneiss and granite. This approach can provide specific information on the source of stone monuments from geological settings with simple geochemical characteristics, such as the Iksan granitic batholith, or with complex geochemical events with metamorphism and igneous activities.

5. CONCLUSIONS

The stone cultural heritage of Iksan not only has historical value, but also plays a role in preserving various relics, providing direct evidence of the Sabi period of Baekje in the late 5th–6th century CE. The confirmation of stone cultural heritage and relics such as the palace site of Iksan, two national temples, and royal tombs presented that this region was used as a secondary capital in the latter part of the Sabi period.

The Iksan granitic batholith was formed in the Mesozoic Era and was used as a natural resource for the construction of the Iksan area of the Baekje Sabi period. It is the largest quarry in Korea that has been continuously used up to the modern. As a result of reviewing the literature related to the study of the origin of the stone cultural heritage of the Iksan area in the Baekje Sabi period, the medium- to coarse-grained biotite granite of the Iksan batholith. The Iksan granitoid is characterized by feldspar phenocrysts and chemical composition.

Whole-rock chemical analysis has been used to provide information for the sources of comagmatic rocks on Korean stone monuments. This review summarizes the methods to find more 'source indicators' in addition to whole-rock chemical analysis from the literature in the Iksan granitic batholith. Furthermore, this paper also addresses the analytical method that complements the use of accessory minerals as a new approach that may have discrimination within geochemically homogeneous areas. As such, to this day, the Iksan batholith is not only active quarries but also interesting research areas to interpret ancient stone use for huge archaeological complexes during specific historical periods with granites having similar geochemical compositions.

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Authorship contribution statement

Myoungju Choice: Conceptualization, Formal analysis, Investigation, Methodology, Writing / original draft, Photographs / Image editing, Writing review & editing.

Myeong Seong Lee: Funding acquisition, Investigation, Project administration, Writing review & editing.

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Statement on the use of Artificial Intelligence

Not applicable.

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