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Interpretation of Archaeogeological and Lithological Characters for Stones Used in Korean Ancient Tombs around the Songpa of Seoul

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Abstract: This study concerns the lithologic characteristics of the stone used as the main construction materials of ancient Korean tombs, and aims to understand how they were supplied. Specifically, we investigated the main ancient tombs in the Songpa district, south of the Hangang River in Seoul, composing the connected stone-mound tombs in the Seokchon-dong tomb complex, Bangi-dong tomb No. 3, and 13 horizontal stone-chamber tombs in the Gamil-dong tomb complex. There are major differences among the tombs reflected in the types of rock used as construction materials in these sites. Tombs at Seokchon-dong and Bangi-dong were built mainly using biotite gneiss, whereas those at Gamil-dong are composed of amphibole schist. By comparing the characteristics of the rocks collected from the provenance sites, we concluded that the quartzite used at the Gamil-dong tombs was from Cheonma Mountain, the gneiss at the Bangi-dong sites was from Daemo Mountain, and the amphibole schist and diabase at the Gamil-dong sites were from Cheonma Mountain. On the other hand, gravel-shaped stone materials are found in the tombs of Seokchon-dong and Bangi-dong, but not in Gamil-dong tombs. Therefore, it can be seen that between Seokchon-dong, Bangi-dong, and Gamil-dong tombs, there is a difference not only in the main constituent rock types, but also in the shape of the stone materials. These gravel-shaped stones are assumed to have been transported via the Hangang River drainage system and supplied to Seokchon-dong and Bangi-dong tombs. Therefore, we consider that the constructors of the tombs in the ancient Songpa district locally sourced materials of different rock types.

Keywords: *Hanseong Baekje*; Three Kingdoms Period of Korea; construction material supply; stone uses; ancient tomb construction

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1. Introduction

Seoul, the capital of the Republic of Korea, is penetrated by the Hangang River, which flows out of the mountains that belong to the surrounding Gwangju Range. Because of this geography, the city has an extensive history as a center of water-based transportation and as the capital city of the *Baekje* Kingdom (18 BC to 660 AD) and the *Joseon* Dynasty (1392–1910 AD). Notably, in the present-day Songpa district that is south of the Hangang River, several ancient remains can be found, including the *Pungnap* Fortress, and the Seokchon-dong, Bangi-dong, and Gamil-dong tomb complexes.

According to the history of the ancient Kingdom of *Baekje*, which was in the southwestern part of the Korean Peninsula from 18 BC to 660 AD, the above-mentioned remains date mostly from the time before the fall of the city *Goguryeo* in 475 AD. This period is called the *Hanseong Baekje* period after the old name for Seoul, *Hangseong*. Occupying a major portion (70%) of the Kingdom's entire history, this period had its own double-fortress systems and a variety of tomb systems unique in their structures and function.

In comparison to other tombs, the three ancient tomb complexes of Seokchon-dong, Bangi-dong, and Gamil-dong, are considered to have been for those with centralized power, such as royalty and aristocrats. As such, they serve as particularly crucial archaeological data that can help us work out the construction technology and interpret the national system of the ancient Korean Peninsula. Tomb systems also offer invaluable physical means to investigate afterlife ideas held at the time, while helping us understand the technological advances achieved by such an ancient society, of which few historical records remain. It is for this reason that various studies have been conducted on the form of burial and excavated remains.

However, scientific research on ancient tombs focuses on excavated artifacts, not construction materials. Regarding the period of *Hanseong Baekje* in particular, various studies on pottery excavated from tombs have been conducted, and the pottery manufacturing techniques have been analyzed in the buried period [1,2]. Among the construction materials, soil, which is the main material along with stone, has been scientifically reviewed [2–4]. These studies are cases in which the overall soil layer construction techniques were researched by identifying the characteristics of each layer of soil that constitutes the framework of the remains. Most of the soil layers examined are those of Pungnap Fortress, which was built during the *Hanseong Baekje* period, and there are no studies on ancient tombs from the same period.

How a constructor society secures materials is closely related to their technological advances. Additionally, although it is not related directly to everyday life, the burial system is related to religious concepts about the afterlife. The size and advancement level of the tombs and burial system commonly reflect the authority of the central power in the ancient societies. In particular, interpreting the supply site of the stone materials, which are more difficult than soil to secure and transport, should play a major role in understanding the area of activity of the constructor society. Nevertheless, there are not many scientific studies on the stone materials used in tomb construction.

A representative study examining the petrological characteristics of tomb stones and discussing the supply route was related to the Egyptian pyramids [5,6]. Thanks to these studies, the source and transport route of stone, mainly limestone, for the construction of the pyramids were identified, which helped in the analysis of construction techniques. In addition, the results of research on the stones of Stonehenge in England also provide us with information about the quarrying patterns at that time [7,8].

In case of Korea, various types of tombs from the prehistoric era to the *Joseon* Dynasty (1392 to 1910 AD) are distributed in the Korean peninsula, and the provenance of some stone materials were reviewed, focusing on pre-ancient tomb stones, for which we have no historical records related to the quarrying site. It was confirmed that the stone used in the building stone of dolmens, a typical prehistoric tomb, moved about 4 km [9], and in the *Baekje* period after *Hanseong Baekje*, the identified rock type in Donghachong royal tomb was actively used for other cultural heritages in the area [10].

In this study, we investigated the distribution of types of stone materials composing the ancient tombs of the Korean Peninsula. Additionally, we have interpreted their petrologic characteristics and securing method. The 15 tombs investigated include the connected stone-mound tombs in the Seokchon-dong tomb complex, tomb No.3 in the Bangi-dong tomb complex, and 13 horizontal-style stone-chamber tombs at the Gamil-dong site. The academic excavations were performed in these areas over the course of five years between 2017 and 2021. The results of this research may function as an objective pointer to reconstruct the technology and culture related to the acquisition of the stone materials, which are the major ingredient in building the ancient remains on the Korean Peninsula.

2. Background and Methodology

2.1. Historical Significance

The Hangang River area in Seoul was variously affected by many ancient countries owing to its geopolitical location, that has been favorable to extensive settlement. The burial system in this area is important as it makes it possible to review not only past construction technology, but also the overall political, economic, and sociocultural context. Beyond considering the excavated remains and their scale and lateral extent, in this study we investigated them in relation to the social power dynamics and ideas on the afterlife held by the ruling class of aristocrats and above. Additionally, various tomb types, including the stone-mound tombs of the Seokchon-dong tomb complex and the horizontal-style stone-chamber tombs of the Bangi-dong and Gamil-dong tomb complexes, reveal the development of the burial system in ancient Korea, which evolved toward building stone chambers from simple stone pilings.

The stone-mound tombs found in the Seokchon-dong tomb complex are not large in scale and were constructed by piling up *Halseok*s (irregular stone shapes split off from the same source rock). Similar tombs are commonly found in the *Goguryeo* Kingdom area, which was in the northern part of the Korean peninsula. These discoveries correspond to data in the written record indicating that the founding *Baekje* group came from *Goguryeo* in the north [11]. The investigated connected stone-mound tombs are known to have been built in the early 4th century [12], which is the time period when *Baekje* was becoming an ancient state.

In contrast, horizontal-style stone-chamber tombs, such as Bangi-dong tomb No.3 and Gamil-dong tombs, represent a different burial idea than the earlier closed-tomb style in that they have entrances open to the outside on one side and soil mounds on top of the body's main burial chamber [13,14]. The Gamil-dong tomb complex, which was built during the mid 4th through early 5th centuries [15], further confirmed *Beakje* as an ancient state, reflected in the far more frequent use of this distinctive tomb style.

The Bangi-dong tomb No.3 is considered to have been built in the mid- to late 6th century, which was when the *Silla* Kingdom, an ancient state with Gyeongju city in the southeastern part of the Korean Peninsula being its capital, was expanding its territory into the Hangang River drainage area. This interpretation supports the idea that the ancient tomb system appeared within the Hangang River drainage area after the *Hanseong Baekje* period.

2.2. Location and Geology

The investigated remains are all between the Hangang River, which flows into the Yellow Sea, and Namhansan Mountain to the east, and are within 3 km of the center of downtown Seoul. The surrounding area, including Namhansan Mountain, is composed mainly of the Precambrian Gyeonggi Gneiss Complex with Mesozoic granite, and adjacent Cenozoic colluvium and alluvium. The Gyeonggi Gneiss is composed of banded gneiss (the most abundant type) as well as magmatic gneiss, granitic gneiss, porphyroblastic gneiss, and other variants. Additionally, richly diverse metamorphic rocks, including mica schist, quartzose schist, and hornblende schist, are distributed across the area (Figure 1).

Although Mesozoic Seoul granite is distributed north of the Hangang River, such rocks are found around Acha Mountain and thus are of different provenance compared to source materials investigated in the current research. Mesozoic colluvium, a fluvial deposit, is distributed widely in the Hangang River drainage area.

Most of the remains related to the *Hanseong Baekje* period are located south of the Hangang River, where the Gyeonggi Gneiss Complex spreads. Among the ancient tombs from which the stone materials under study were excavated, Seokchon-dong tomb is found on the alluvial, but Bangi-dong and Gamil-dong tombs belong to the biotite gneiss formation, showing differences. However, since alluvial deposits are distributed in close proximity to Bangi-dong and Gamil-dong tombs, and the Seokchon-dong tomb is also located near the biotite gneiss formation, the geological environment of all tombs is confirmed to be similar (Figure 1).

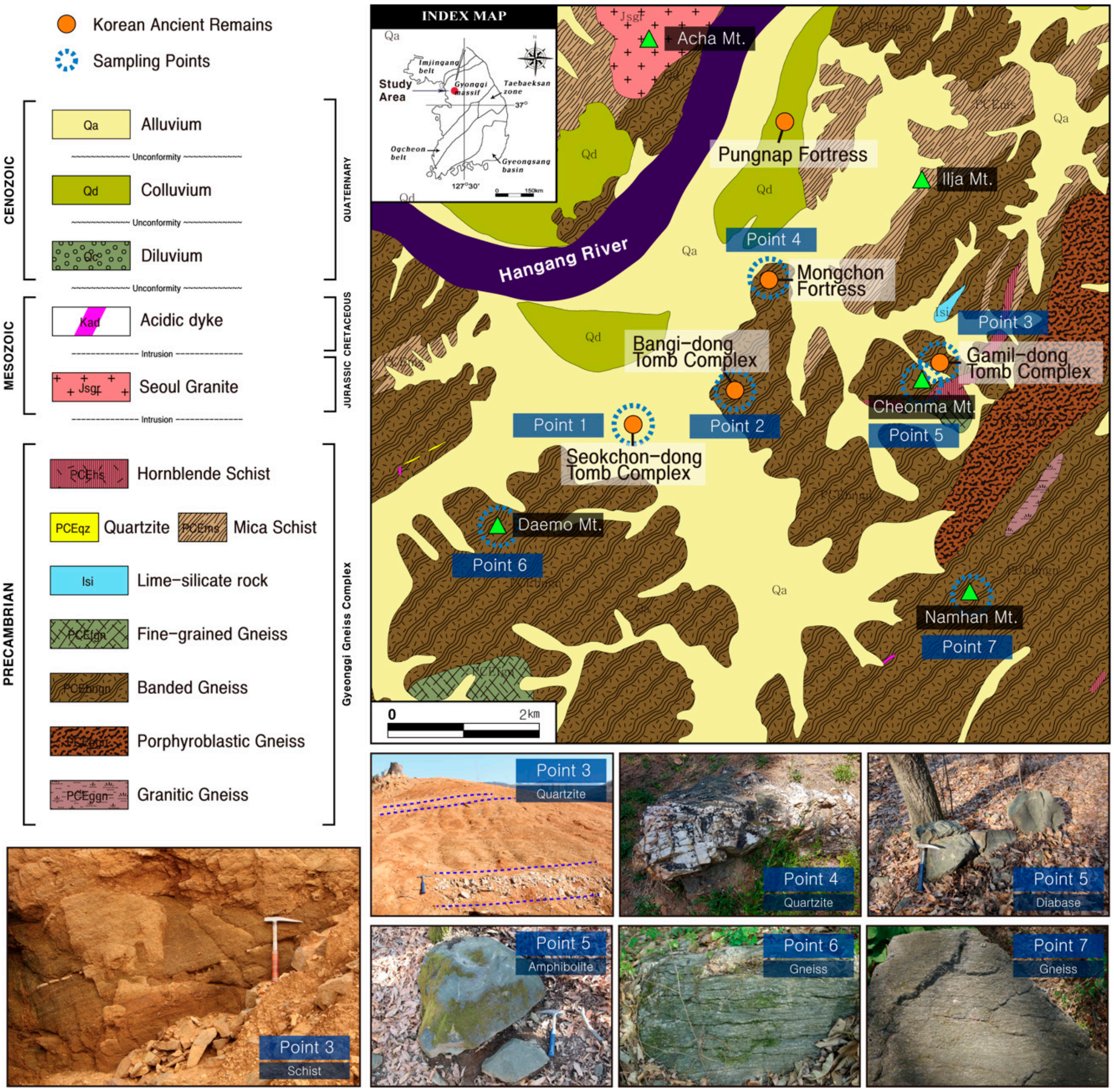

Figure 1. Geologic map and state of outcrop in each sampling points (point 1 to 7) around ancient Korean tombs and other remains in Seoul.

2.3. Methodology

In this research, the stone materials composing 15 tombs were categorized through detailed direct onsite observation. These investigations were performed without damaging the remains with the help of the excavation teams, small amounts of the test samples of the stone materials were collected for petrological study, and micromagnetic characteristics were investigated by measuring magnetic susceptibility (using an SM-30, ZH instrument). Additionally, based on the geologic map, a point expected to be a supply site was set around remains, and rock samples were obtained through comparison of the magnetic susceptibility values of stones excavated from remains and visual observation.

The location and rock distribution pattern of each sampling points are shown in Figure 1. Point 1 and 2 correspond to the area of Seokchon-dong and Bangi-dong tomb complex, and we sampled stones which were not used to construct the tombs with assistance of excavation team. Since point 3 is a residential facility construction site near the Gamil-dong tomb complex, quartzite and schist were easily found. Of these, quartzite was identified, as shown in Figure 1 (point 3-Quartzite), it showed a pattern marked with the blue line. The other points (4 to 7) cover a mountain located in downtown Seoul, where small-scale rock outcrops were found and each rock type was obtained (Figure 1).

All of the stone samples were examined in the laboratory through a variety of scientific analysis. The microstructure and mineralogy were determined by polarizing microscope and X-ray diffraction (using a Rigaku DMAX2000 at 40 kV, 100 mA, 3–50°, 2°/min). Methods such as ICP-MS, ICP-AES, and INAA (analyzed by ACTLABS, Canada) were used to perform the quantitative geochemical analysis on the elements. Samples were also collected from nearby presumed-provenance sites (based on geology and present-day distribution in the vicinity). The same analyses were conducted on the samples collected from the remains, the results of which were comparatively analyzed. Table 1 presents the rock type, sample name, and the point location of collected samples that were analyzed.

Table 1. Sample list by rock type.

No.	Rock Type	Sample Name	Sample Type	Sample Location (Figure 1)
1	**Gneiss**	SGN	Excavated in tombs	Seokchon-dong tomb (point 1)
2		BGN		Bangi-dong tomb (point 2)
3		PGN-1	Collected at presumed-provenance site	Seokchon-dong tomb area (point 1)
4		PGN-2		Bangi-dong tomb area (point 2)
5		PGN-3		Daemo Mountain (point 6)
6		PGN-4		Namhan Mountain (point 7)
7	**Schist**	BSC	Excavated in tombs	Bangi-dong tomb (point 2)
8		GSC		Gamil-dong tomb (point 3)
9		PSC	Collected at presumed-provenance site	Near Gamil-dong tomb (point 3)
10	**Quartzite**	SQU	Excavated in tombs	Seokchon-dong tomb (point 1)
11		GQU		Gamil-dong tomb (point 3)
12		PQU-1	Collected at presumed-provenance site	Near Gamil-dong tomb (point 3)
13		PQU-2		Near Mongchon Fortress (point 4)
14	**Amphibolite**	SAM	Excavated in tombs	Seokchon-dong tomb (point 1)
15		GAM		Gamil-dong tomb (point 3)
16		PAM-1	Collected at presumed-provenance site	Cheonma Mountain (point 5)
17		PAM-2		Namhan Mountain (point 7)
18	**Diabase**	GDI	Excavated in tombs	Gamil-dong tomb (point 3)
19		PDI	Collected at presumed-provenance site	Cheonma Mountain (point 5)

3. Distribution and Proportion of Stone Materials

3.1. Distribution of Stone Materials

The investigation of the distribution of the stone materials composing the studied remains of the Seokchon-dong connected stone-mound tombs, Bangi-dong tomb No.3, and the Gamil-dong tomb complex that a wide variety of materials were used to construct these stone-mound tombs. Although many stone materials were *Halseok*s, irregularly shaped, we found rounded weather-worn gravel at the floor (Figure 2A–C).

Unlike the tombs in Seokchon-dong that were constructed only by piling up the stones with no particular facilities, we classified the materials composing Bangi-dong tomb No.3 into major categories: those composing simple stone circles versus those composing stone chambers, including the surrounding walls, ceilings, and floors. These categories disregard composing materials, which exhibit a variety of different shapes and sizes.

We found that square-shaped materials of at least 1m across were used for the ceiling stone of the chambers (Figure 2D–F). All 13 stone-chamber tombs of Gamil-dong tomb complex are horizontal and are made of irregularly shaped stones (*Halseok*s). Unlike the Seokchon-dong and Bangi-dong tombs, gravels were not used in constructing the Gamil-dong tomb complex (Figure 2G,H).

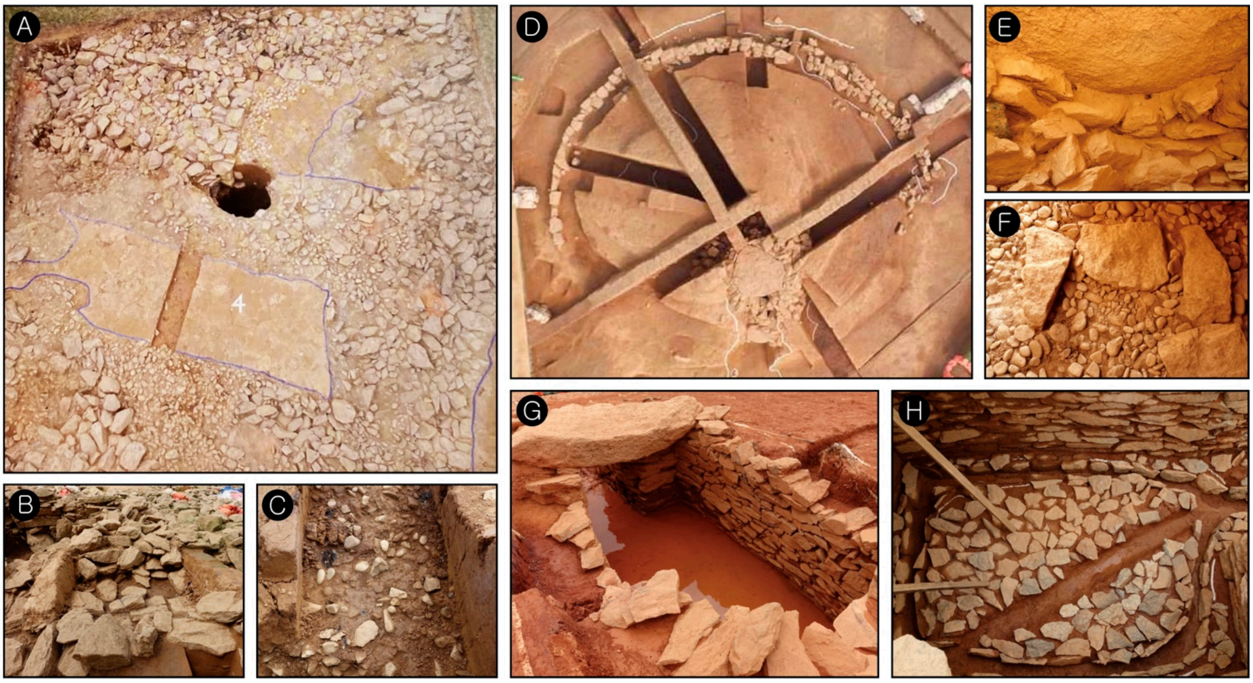

Figure 2. Research-target tombs: (**A**–**C**) show distribution of stone materials composing Seokchon-dong connected stone-mound tombs; (**D**–**F**) are in Bangi-dong No.3 tomb; (**G**,**H**) show representative distribution in Gamil-dong tomb complex.

3.2. Rock Types and Proportions

Rock types were identified by direct observation of the stone materials onsite after minimal washing. The investigation was performed with the help of the excavators of the remains to ensure that the artifacts were not damaged in the process. We identified 25 rock types composing the remains at the three main sites: 10 metamorphic, 13 igneous, and two sedimentary rock types.

Although the igneous rocks showed the most variety, they amount to the lowest proportion across all of the remains. They tend to be found among the gravels in Seokchon-dong and Bangi-dong. Among the remains, Seokchon-dong showed 11 rock types, Bangi-dong 14, and Gamil-dong 7, making the Bangi-dong remains those with the greatest variety of rock type (Table 2).

Out of the 11 rock types composing the Seokchon-dong tombs, seven were metamorphic (biotite gneiss, banded gneiss, garnet gneiss, augen gneiss, biotite schist, felsic schist, and quartzite); three were igneous (porphyry granite, amphibolite, and syenite); and one was sedimentary (sandstone) (Figure 3). Biotite gneiss was found across all the remains, and other types were also not confined to particular locations. Apparently, the rocks were used in building the tombs regardless of their types.

The 14 rock types composing Bangi-dong tomb No.3 include seven types of metamorphic rock (biotite gneiss, leucocratic gneiss, porphyroblastic gneiss, augen gneiss, banded gneiss, mica schist, felsic schist), six types of igneous rock (feldspar porphyry, quartz porphyry, granite, pinkish granite, biotite granite, pegmatite), and one type of sedimentary rock (limestone) (Figure 3).

Considering that similar rock types were found in both the stone chamber and among the stones in use surrounding the tomb, apparently the rocks were not selected by type in building the structures. The Gamil-dong tomb complex contains three types of metamorphic rock (amphibole schist, amphibolite, augen gneiss) and four types of igneous rock (gabbro, diabase, rhyolite, vein quartz) with no hint of selecting the stone materials by their types.

Table 2. Proportions of rock types in each tomb (%).

No.	Rock Type		Seokchon-Dong		Bangi-Dong	Gamil-Dong
1	Metamorphic Rock	Biotite Gneiss	99.00		63.57	0.00
2		Leucocratic Gneiss	Proportions Exception Biotite Gneiss (99.00%)	0.00	1.81	0.00
3		Augen Gneiss		19.78	2.49	0.02
4		Porphyroblastic Gneiss		0.00	0.90	0.00
5		Banded Gneiss		29.12	10.18	0.00
6		Garnet Gneiss		8.24	0.00	0.00
7		Mica Schist		4.95	16.06	0.00
8		Felsic Schist		6.04	0.23	0.00
9		Amphibole Schist		0.00	0.00	91.79
10		Quartzite		14.84	0.00	0.00
11	Igneous Rock	Quartz Porphyry		0.00	1.58	0.00
12		Feldspar Porphyry		0.00	0.45	0.00
13		Pegmatite		0.00	0.45	0.00
14		Granite		0.00	0.90	0.00
15		Pinkish Granite		0.00	0.23	0.00
16		Biotite Granite		0.00	0.90	0.00
17		Porphyry Granite		9.89	0.00	0.00
18		Syenite		1.10	0.00	0.00
19		Amphibolite		4.95	0.00	0.16
20		Gabbro		0.00	0.00	6.18
21		Diabase		0.00	0.00	1.79
22		Rhyolite		0.00	0.00	0.02
23		Vein Quartz		0.00	0.00	0.04
24	Sedimentary Rock	Limestone		0.00	0.23	0.00
25		Sandstone		1.10	0.00	0.00

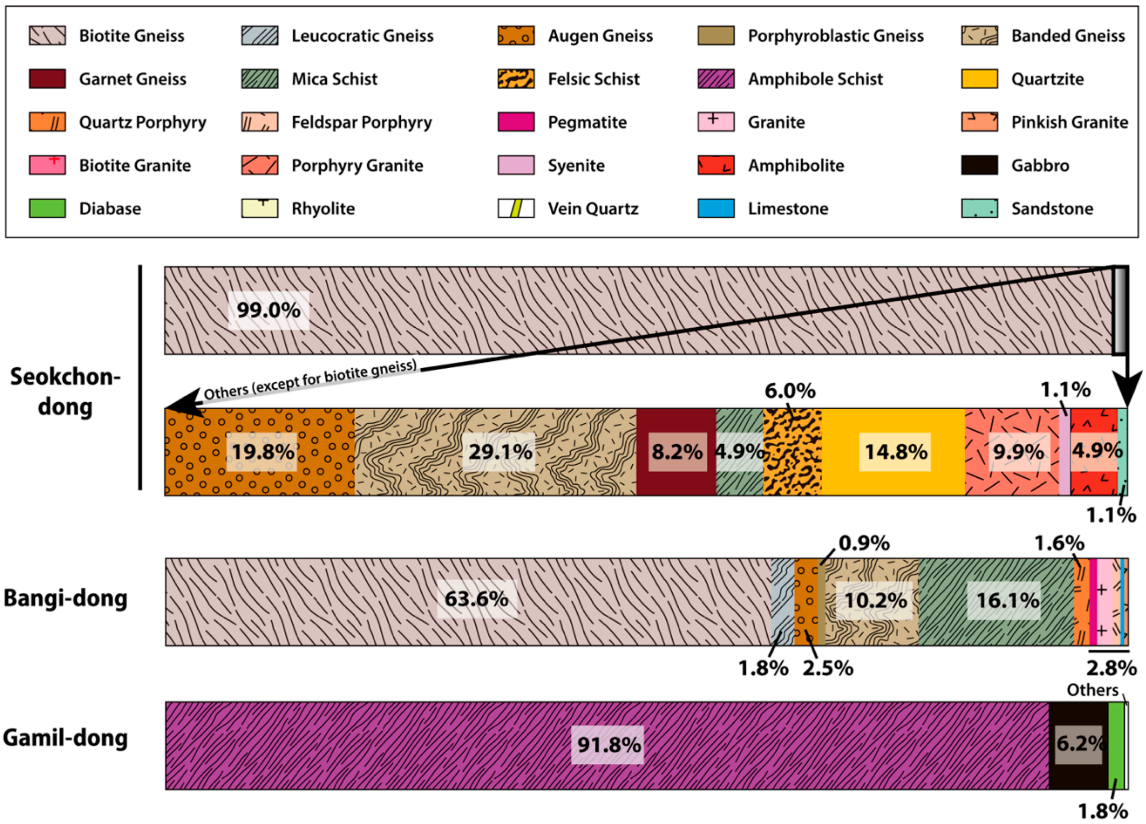

Figure 3. Proportions of rock types composing research target tombs.

Thus, although various stone types were used to build the tombs that we studied, we found that biotite gneiss was the main type used for Seokchon-dong and Bangi-dong tombs, and amphibole schist was the main type used for Gamil-dong tombs (Figure 3). Additionally, minor rock types were similar for Seokchon-dong and Bangi-dong, thereby adding more similarity to the use of the stone materials and the use of gravels in particular. Gamil-dong tombs did not show similar proportions.

4. Petrography and Geochemistry

4.1. Micromagnetic Characteristics

To investigate the mineralogical characteristics of the stone materials composing the remains under study, and to compare them with the rocks in the presumed-provenance sites, we collected 19 stone specimens spanning five rock types (Table 1). To investigate the micromagnetic characteristics, we measured magnetic susceptibility. A nondestructive method was used to investigate the distribution of magnetic minerals in rocks, serving as a simple homogeneity check that shows different values according to chemical composition and minerogenic environment [16–18].

The results for schist and amphibolite were each within a similar range of micromagnetic values regardless of the remains and presumed-provenance sites (Figure 4). Regarding gneiss, Seokchon-dong (SGN) showed a relatively wider range of values 0.186 to 0.774 $\times$ 10^{-3} (averaging 0.434 $\times$ 10^{-3}) SI unit, than Bangi-dong (BGN), which showed a low and narrow range of susceptibility values 0.095 to 0.112 $\times$ 10^{-3} (averaging 0.108 $\times$ 10^{-3}) SI unit.

Although most of the gneiss in the presumed-provenance sites (PGN-1, 3, 4) showed susceptibility 0.5 $\times$ 10^{-3} SI unit, gneiss collected near Bangi-dong (PGN-2) notably produced values of 0.8 $\times$ 10^{-3} SI unit, the highest of any gneiss under study. This diverse value distribution of magnetic susceptibility is also different from the pattern found in gneiss excavated from the remains (SGN and BGN). Whether this result is due to the different origins of each gneiss or the characteristics of the rock type itself, gneiss, requires additional consideration.

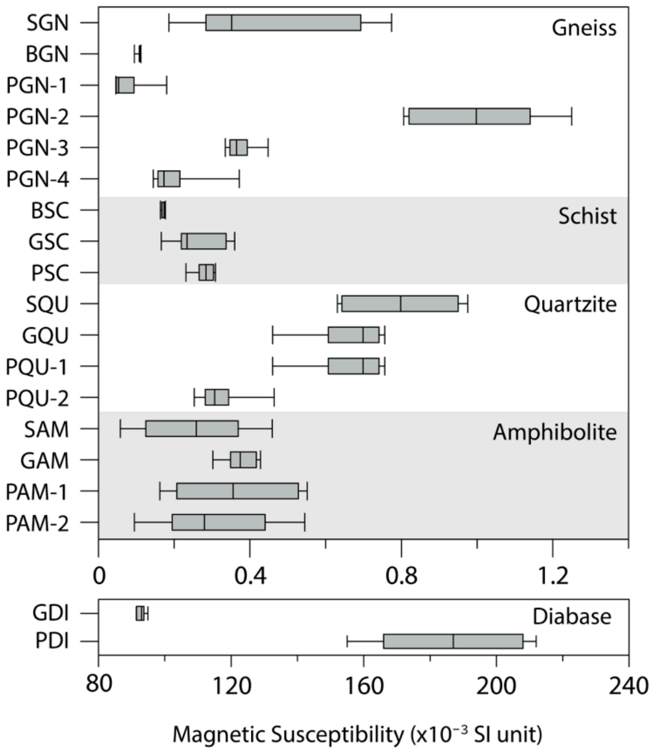

Figure 4. Diagram showing magnetic susceptibility distributions by rock type. Sample names are the same as those in Table 1.

Regarding quartzite, that from the Seokchon-dong (SQU) and from Gamil-dong (GQU) or collected nearby (PQU-1) showed relatively similar micromagnetic values, but the quartzite near the Mongchon Fortress (PQU-2) showed different susceptibility distributions. Although the diabase showed the highest susceptibility values among all of the rock types under study, it showed susceptibility of 91 to 95 $\times$ 10^{-3} (averaging 93 $\times$ 10^{-3}) SI unit for the excavated site (GDI) and 155 to 212 $\times$ 10^{-3} (averaging 186 $\times$ 10^{-3}) SI unit for the presumed-provenance site (PDI). This vastly different range of measurements for diabase suggests that it has very different micromagnetic characteristics.

4.2. Mineral Composition and Texture

To identify the minerals composing the rocks under study and analyze their structures, we performed X-ray diffraction (XRD) analysis and created thin sections for observation using polarizing microscopes. The XRD analysis revealed characteristics of the rocks that show discernible associations of the composing minerals (Figure 5). Although quartz, mica, plagioclase, and garnet were found in all gneiss specimens regardless of the remains excavated and the presumed-provenance sites, the gneiss excavated from Seokchon-dong (SGN) differs by its notably different mica diffraction peak and by the absence of alkali feldspar (Figure 5).

The mineral composition for the schist, excavated from Gamil-dong (GSC) and that for schist from the presumed-provenance sites (PSC) both include hornblende, quartz, garnet, and plagioclase. However, schist excavated from Bangi-dong (BSC) had no hornblende, and the quartz and mica each had notably different diffraction peaks from GSC and PSC. That is, the schists differed, with the BSC schist showing the same pattern as the gneiss instead of matching the other schists' peaks (Figure 5). Within each rock type, the mineral compositions of the quartzites (only quartz), amphibolites, and diabases did not differ regardless of the excavation and collection sites.

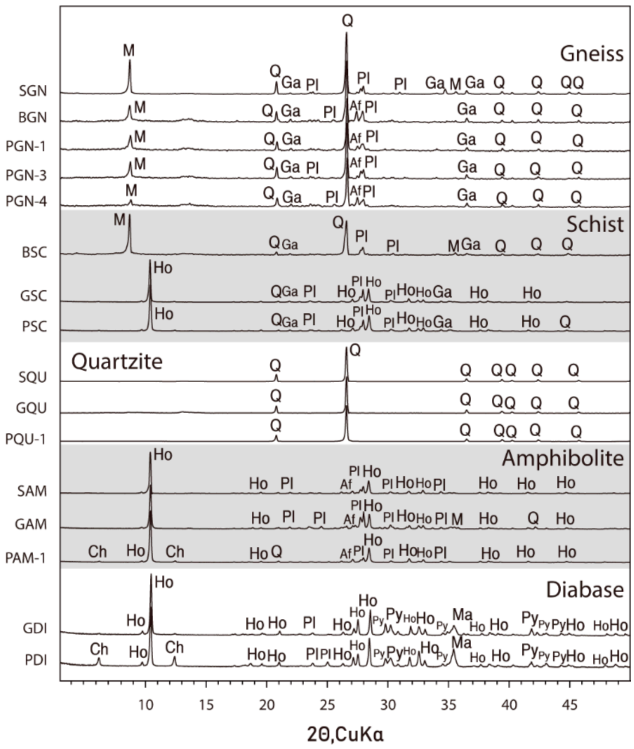

Figure 5. Result of X-ray powder diffraction analysis. Sample names are the same as in Table 1. Ch; chlorite, M; mica, Ho; hornblende, Q; quartz, Pl; plagioclase, Af; alkali-feldspar, Py; pyroxene, Ga; garnet, Ma; magnetite.

The mineral composition determined in thin sections matched that found by XRD, but observation by polarizing microscope also revealed the different textures across rock types (Figure 6). The gneiss typically showed leucocratic zones composed of granoblastic quartz and melanocratic zones composed mainly of biotite. In the gneiss from Bangi-dong (BGN) and Deamo Mountain (PGN-3), alkali feldspar was observed along with quartz composing the leucocratic zones. The gneiss excavated from Seokchon-dong (SGN) was observed to have narrower leucocratic and melanocratic mineral zones. The difference among the gneisses was more obvious where we found large garnets (Figure 6).

By its 1 mm grain size and greater granularity, schist was found to differ from gneiss, most notably with the Bangi-dong schist (BSC), whose major component minerals are quartz and mica. Additionally, although both the Gamil-dong schist (GSC) and schist from the presumed-provenance sites (PSC) contain hornblende, plagioclase, and quartz, GSC samples contain somewhat-larger hornblende and PSC has more plagioclase.

Quartzite excavated from the Gamil-dong remains (GQU) and collected from the presumed-provenance site (PQU-1) both exhibit granoblastic texture, and similar granularity of the quartz crystals, whereas quartzite from Seokchon-dong (SQU) has a somewhat different quartz granularity and texture. It is considered that quartzite from Seokchon-dong (SQU), which has a general sedimentary phase, and Gamil-dong (GQU) and provenance site (PQU-1), where distinct metamorphic structures are observed, are of different origins.

Although the amphibolite excavated from Seokchon-dong (SAM) has granular felsic mineral across the fine-grained hornblende, the amphibolite excavated from Gamil-dong (GAM) shows characteristics similar to the amphibole schist in other areas that was found to show directionality. The GAM sample, the amphibolite collected from Cheonma Mountain (PAM-1), showed an amphibole schist structure, with aligned hornblende crystals 1 mm and larger separating the felsic minerals. Thus, the studied amphiboles have similar composition but only Seokchon-dong amphibolite (SAM) has different structure.

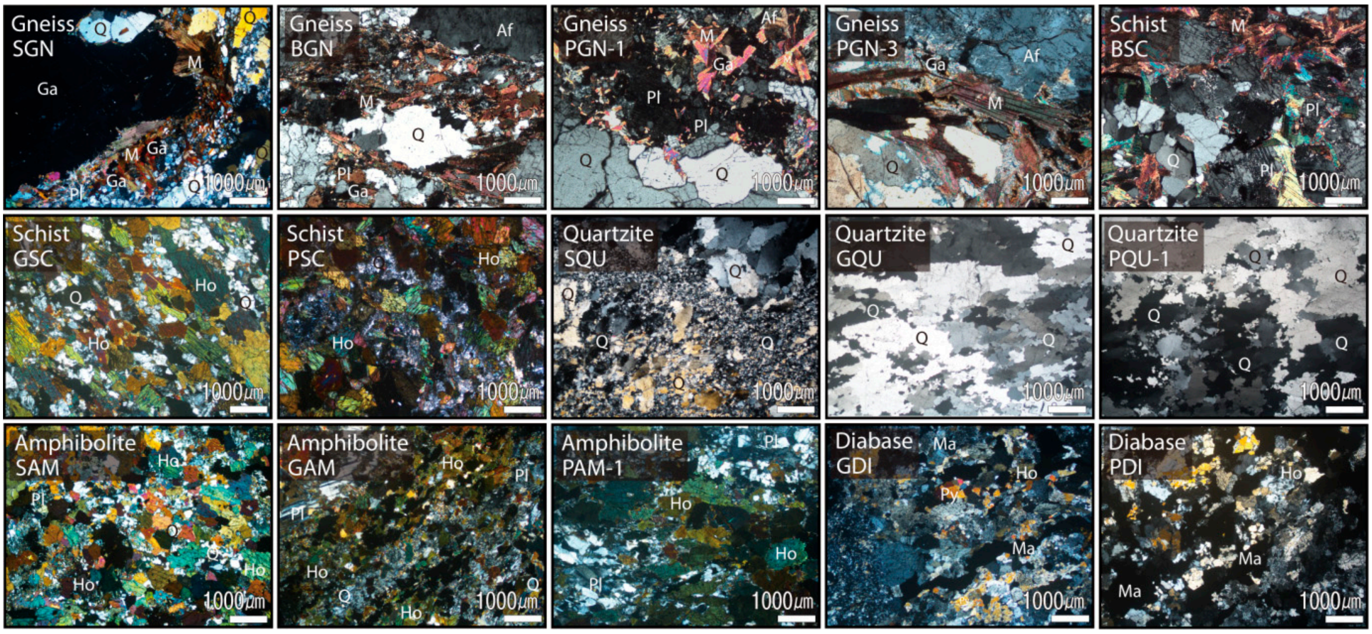

Figure 6. Photomicrographs showing rock textures and component minerals. Samples are as presented in Table 1. Af; alkali feldspar, Ch; chlorite, Ga; garnet, Ho; hornblende, M; mica, Ma; magnetite, Pl; plagioclase, Py; pyroxene, Q; quartz.

The diabase, found only in Gamil-dong, contains hornblende, pyroxene, and magnetite, as XRD results suggest for diabase both excavated from the remains (GDI) and collected from the presumed-provenance sites (PDI). There is a difference in the mineral size of the two diabase samples, and it is observed that the felsic minerals of provenance sample (PDI), in which chlorite is partially detected in XRD, is relatively large. In addition, the magnetite content is also prominent in PDI, which is why the magnetic susceptibility value is estimated to be high (Figures 4–6).

4.3. Geochemical Characteristics

ICP-MS, ICP-AES, and INAA analyses were performed to quantify the major, minor, and rare-earth elements (REEs) to gain an understanding of the lithologic characteristics of the rocks under study. Tables 3 and 4 summarize the results of these analyses. SiO_2 is the most abundant content in all of the rocks, followed by Al_2O_3 and Fe_2O_3 as major components. MgO and CaO were found to be the main minor components, and are more abundant in the amphibolite and diabase compared to other rocks.

Table 3. Geochemical compositions of major oxides(wt.%) and selected minor and rare-earth elements(ppm) for gneiss and schist. Sample names are as used in Table 1. LOI; loss on ignition.

Rock Type	Gneiss						Schist		
Sample	**SGN**	**BGN**	**PGN-1**	**PGN-2**	**PGN-3**	**PGN-4**	**BSC**	**GSC**	**PSC**
SiO_2	64.92	72.16	55.96	64.02	68.29	71.60	60.07	42.76	45.69
Al_2O_3	15.60	13.30	19.18	14.13	15.51	12.97	15.77	17.94	13.61
Fe_2O_3	8.90	4.25	8.31	7.03	4.31	4.25	8.12	14.02	17.33
MnO	0.12	0.04	0.07	0.05	0.05	0.04	0.07	0.15	0.22
MgO	2.75	0.58	3.44	1.81	1.47	0.50	4.69	5.74	6.97
CaO	1.23	1.54	1.49	2.10	2.10	1.72	1.69	10.90	10.37
Na_2O	1.41	2.51	2.18	2.04	2.73	2.28	2.05	2.29	1.88
K_2O	3.36	4.43	4.15	4.12	2.96	4.68	3.78	0.25	0.61
TiO_2	0.66	0.59	0.77	1.06	0.44	0.69	0.97	4.65	2.01
P_2O_5	0.05	0.25	0.09	0.31	0.15	0.21	0.18	0.02	0.21
LOI	1.69	0.59	3.60	2.22	1.85	0.74	3.03	1.15	1.57
Total	100.70	100.20	99.23	98.88	100.70	99.69	100.40	99.86	100.50
Ba	1450	905	2000	1740	647	2060	1130	134	207
Cr	111	16	214	43	88	1	357	1	161
Hf	4.8	8.5	4.8	10.1	4.5	13.8	4.0	1.3	3.9
Rb	160	280	170	160	220	150	210	20	20
Sc	23.1	7.0	12.0	12.5	8.2	7.0	15.5	26.3	41.8
Sr	212	157	310	248	223	276	373	1541	135
Zr	166	328	157	329	146	485	192	37	130
Th	19.8	28.5	53.0	5.0	17.4	23.0	17.1	0.5	0.5
Ta	1	1	1	2	1	1	1	1	1
Y	61	13	23	15	12	21	21	4	28
La	65.4	75.8	109.0	62.0	37.7	84.3	48.8	7.1	12.9
Ce	120	152	205	118	71	173	96	13	29
Nd	52	66	93	59	37	58	45	7	25
Sm	7.1	9.9	14.5	10.6	5.8	9.3	7.3	1.8	5.1
Eu	0.8	0.7	2.8	1.4	1.3	2.8	2.1	1.0	1.4
Tb	1.2	0.5	0.5	0.5	0.5	0.5	0.8	0.5	0.5
Yb	6.9	0.5	2.9	0.7	0.8	1.5	1.5	0.5	3.0
Lu	1.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
$(La/Yb)_N$	6.4	102.4	25.4	59.9	31.8	38.0	22.0	9.6	2.9

Across all rock types analyzed, SiO_2 content was lowest in the diabases (averaging 35.09 wt.%) and Fe_2O_3 was highest in the diabases (averaging 27.52 wt.%). These amounts correspond to the high magnetic susceptibility and the magnetite. It was also confirmed that geochemical proportions in the other rock types correspond to their expected or known characteristics, especially in quartzite (Table 4).

On the other hand, in the case of gneiss and schist, the schist excavated from Bangi-dong (BSC) shows a similar chemical composition to other gneiss, but the schist from

Gamil-dong (GSC) and provenance site (PSC) have a relatively higher CaO content and lower K_2O content than other gneiss (Table 3). It is considered to be the result of the difference in mineral composition as confirmed Figures 5 and 6.

To review the additional geochemical characteristics of the rocks under study, the behavior of the elements was analyzed by standardizing the characteristics in accordance with certain criteria by element types. Specifically, the mean composition of granite was used for the major elements, the chondrite meteorite ratio was used for the REEs, and primitive-mantle composition was used for compatible and incompatible elements (Figure 7) [19–21].

Table 4. Geochemical compositions of major oxides(wt.%) and selected minor and rare-earth elements(ppm) for quartzite, amphibolite, and diabase. Sample names are as used in Table 1. LOI; loss on ignition.

Rock Type	**Quartzite**				**Amphibolite**				**Diabase**	
Sample	**SQU**	**GQU**	**PQU-1**	**PQU-2**	**SAM**	**GAM**	**PAM-1**	**PAM-2**	**GDI**	**PDI**
SiO_2	98.39	97.45	99.36	96.08	47.63	43.55	44.18	48.70	37.42	32.76
Al_2O_3	0.99	0.75	0.96	1.52	14.56	19.90	14.83	15.14	6.12	4.52
Fe_2O_3	0.07	0.06	0.06	1.46	15.12	13.20	16.25	11.21	24.35	30.68
MnO	0.01	0.01	0.01	0.01	0.25	0.17	0.19	0.16	0.23	0.20
MgO	0.02	0.02	0.03	0.02	5.99	4.33	5.91	7.66	13.42	11.80
CaO	0.02	0.02	0.03	0.03	11.76	13.77	10.49	10.74	12.46	10.18
Na_2O	0.04	0.05	0.04	0.07	1.72	0.80	2.38	2.30	0.46	0.47
K_2O	0.17	0.09	0.13	0.42	0.31	0.14	0.35	0.93	0.06	0.10
TiO_2	0.01	0.01	0.04	0.02	1.32	4.17	4.81	0.79	5.90	8.78
P_2O_5	0.01	0.01	0.02	0.01	0.15	0.03	0.05	0.07	0.01	0.02
LOI	0.52	0.29	0.24	0.45	1.88	0.32	0.71	1.45	0.40	0.95
Total	100.20	98.73	100.90	100.10	100.70	100.40	100.20	99.15	100.80	100.40
Ba	17	9	23	225	143	55	178	246	59	32
Cr	1	3	2	4	116	1	1	783	465	443
Hf	0.5	0.5	0.5	0.5	1.8	1.5	1.5	2.7	0.5	1.2
Rb	20	20	20	20	20	20	20	20	20	20
Sc	0.2	0.2	0.2	0.1	44.2	18.4	24.7	29.5	59.2	49.5
Sr	3	2	6	7	221	3187	1331	183	214	145
Zr	6	3	8	8	83	41	55	83	47	46
Th	0.5	0.6	1.7	1.5	1.2	0.5	0.9	3.0	0.5	0.5
Ta	1	1	1	1	1	1	1	1	2	1
Y	1	2	3	2	32	4	6	17	8	3
La	1.2	0.9	4.0	3.0	11.3	7.6	12.2	11.2	12.0	1.2
Ce	3	5	12	6	28	20	29	26	23	3
Nd	5	5	5	5	16	5	16	11	5	5
Sm	0.2	0.1	0.5	0.1	4.1	2.0	2.9	2.6	3.3	1.6
Eu	0.1	0.1	0.1	0.1	1.3	1.5	1.2	0.1	0.7	0.1
Tb	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Yb	0.1	0.1	0.1	0.1	3.3	0.6	0.8	2.2	1.4	0.4
Lu	0.1	0.1	0.1	0.1	0.5	0.1	0.1	0.1	0.1	0.1
$(La/Yb)_N$	8.1	6.1	27.0	20.3	2.3	8.6	10.3	3.4	5.8	2.0

As lanthanoid REEs have fairly similar characteristics, they reflect the differentiation process of the materials of origin of rocks, as they behave predictably in several different environments on Earth. Compatible and incompatible elements underlie the geochemical characteristics of the original rocks formed from magma [22,23]. Examining the homogeneity between stones by comparing the compositional contents of REE, as well as compatible and incompatible elements with previously studied standard values, is a well-known method that has already been applied to various stone cultural heritage including tomb remains [8,9,24–28].

As a result of reviewing elemental behaviors, most of the gneiss, excavated from Bangi-dong (BGN) and gneiss collected near Bangi-dong tomb area (PGN-2) and from Daemo Mountain (PGN-3), showed the most similar behavior for all elements. In such cases, the REEs show a decreased the level of enrichment compared to the standard value as the elements get lighter. In contrast, gneiss excavated from Seokchon-dong (SGN) showed an overall consistent level of enrichment except for a slight drop in Eu (Figure 7).

From spider diagrams of compatible and incompatible elements, different levels of enrichment were found for elements such as Y, Yb, Sc, and Cr (Figure 7). Three schists under study showed slightly different elemental behavior among the REEs. In particular, the only schist excavated from Bangi-dong (BSC) showed a trend similar to the elemental behavior of the other gneiss under study (Figure 7). As this corresponds to the other characteristics, BSC is considered to have undergone metamorphism similar to that of the gneiss although visual observation suggests schist.

Other than SiO_2, major oxides are absent or at very low in the quartzite. All the REEs except Tb showed levels of enrichment within the range 1–10, but no particular trend. Only Rb, Th, and Ta among the elements were seen in the spider diagram. The quartzite excavated from Seokchon-dong (SQU) and Gamil-dong (GQU) or collected nearby Gamil-dong remains (PQU-1) commonly showed such patterns. However, the quartzite collected near Mongchon Fortress (PQU-2) showed more Fe_2O_3 and slightly enriched Ba (Figure 7).

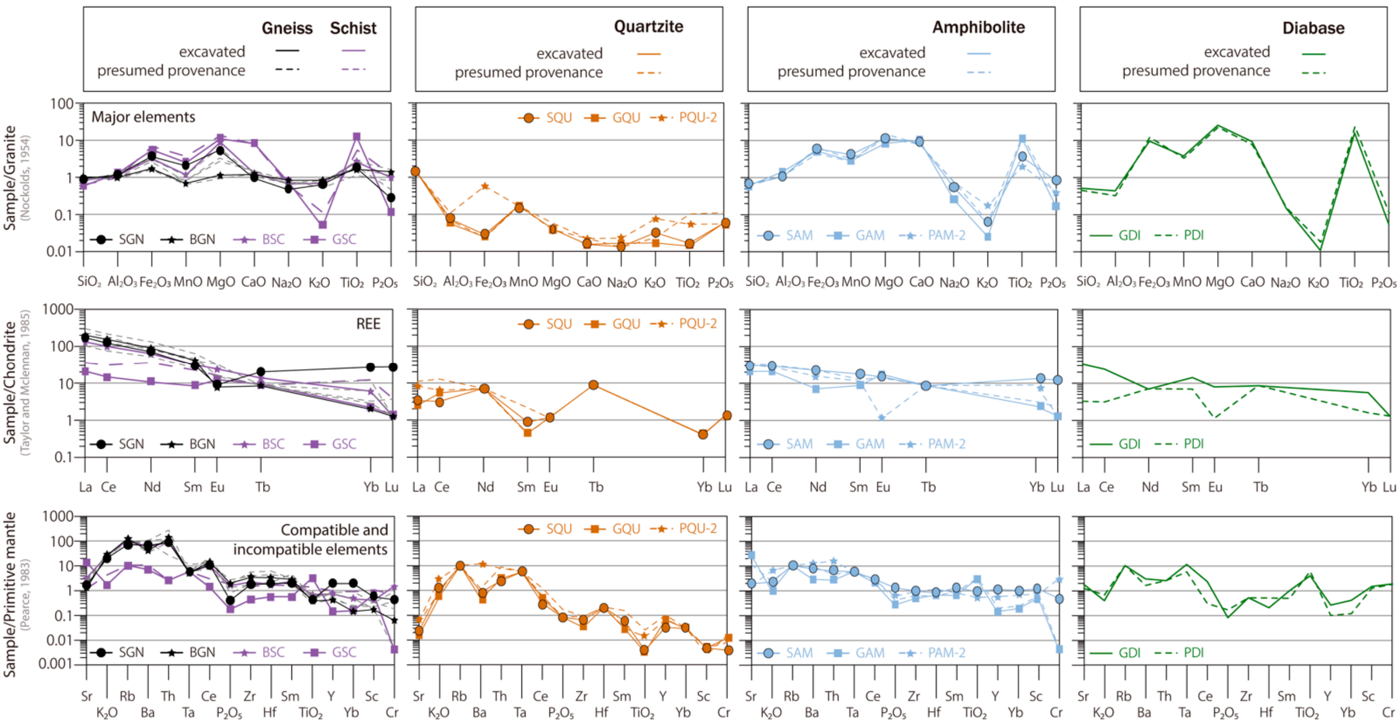

Figure 7. Normalized diagram showing the behavior patterns for composing elements of rock samples presented as in those of Table 1.

The amphibolite from Seokchon-dong (SAM) showed even REE behavior, whereas the amphibolite from Gamil-dong (GAM) differed in that it showed a lower degree of enrichment of Yb and Lu. Even in spider maps showing compatible and incompatible elements, the degree of deficiency in Y, Yb, Sc, and Cr is different as excavation and provenance sites (Figure 7). Judging from these elemental behavior characteristics, it is confirmed that Seokchon-dong amphibolite (SAM) has a similar origin to Namhan Mountain (PAM-2) area and Gamil-dong amphibolite (GAM) to Cheonma mountatin (PAM-1).

However, the diabase from Gamil-dong (GDI) showed a temporarily low level of enrichment of Nd, whereas the diabase collected from Cheonma Mountain (PDI) showed a low level of Eu enrichment. Nevertheless, since the overall elemental behavior has similar pattern in Spider diagram, except for some differences in the deficiency of some elements (at Ce, Hf, Y, and Yb), additional interpretation of the origin of the two rocks is required.

5. Archaeogeological Discussion

5.1. Homogeneity of the Historic Sites

As a result of investigating the rock types of the stone materials composing the ancient Korean tombs (Seokchon-dong connected stone-mound, Bangi-dong tomb No.3, and the Gamil-dong tomb complex), it can be concluded that the dominant rock type, either biotite gneiss or amphibole schist, differs across these three burial sites. Augen gneiss is the only rock type found across all tombs, but owing to its low abundance, we did not consider it a major construction material. Most of the other rock types are found together only in Seokchon-dong and Bangi-dong. Gabbro and diabase are miner components of the Gamil-dong tomb complex and were not found in Seokchon-dong and Bangi-dong. Overall, we concluded that there is a major difference in the stone construction materials used across the three sites.

Lithological and mineralogical characteristics of the gneiss, schist, quartzite, and amphibolite collected from two or more of the remains sites were also investigated. Gneiss samples excavated from Seokchon-dong and Bangi-dong showed the same mineralogical composition but different susceptibility distributions and major element proportions. At a microscopic scale, we found weak augen structures exhibiting different mineralogy: The Seokchon-dong augen structures are composed of garnet, and those of Bangi-dong are composed of quartz. The schist excavated from Bangi-dong and from Gamil-dong also shows different mineralogical composition (Figure 6).

Metamorphic rocks such as gneiss can be affected not only by original materials but also by the movement and the loss of trace elements followed by mineralogical reconstitution, according to the genetic mechanism. However, because REEs (except for Eu) are not affected by the weathering or transformation of the gneiss [22], the homogeneity was reviewed using the REE share of the transformed rock.

In the results, the gneiss used in building the Seokchon-dong tombs showed negative abnormal behavior for Eu, whereas the gneiss from Bangi-dong showed lessening enrichment of the light REEs (Figure 7). Differences in $(La/Yb)_N$ values were also significant, ranging from 6.4 for Seokchon-dong and 102.4 for Bangi-dong(Table 2). For the level of correlation between $(La/Yb)_N$ and $(Yb)_N$ (Figure 8a), the gneiss from Bangi-dong plots within the Archaeozoic tonalite-trondhjemite-granodiorite(TTG) zone [29]. However, $(Yb)_N$ is 27.8 for the Seokchon-dong gneiss, showing significant difference from the Bangi-dong gneiss. We also found that the schist and the gneiss from the Bangi-dong remains exhibited similar REE patterns, whereas the schist from the Gamil-dong showed a consistent REEs-enrichment trend (Figure 7).

Such a trend was also found for the correlation between $(La/Yb)_N$ and $(Yb)_N$ (Figure 8a). Additionally, the schist from Bangi-dong showed values similar to the gneiss type for the distribution of Rb and K, which are relatively highly mobile during the process of transformation. Therefore, we assumed that the studied gneiss and schist were derived from different original materials. In particular, the schist and the gneiss excavated from Bangi-dong appeared to have been derived from the same source material but achieved different facies based on the degree of differentiation and transformation.

Because amphibole, the major mineral in the schist excavated from Gamil-dong showed similar elemental behavior to the amphibolite excavated from the same remains, we considered the rock type to be amphibole schist. In contrast, although the chemical elemental behavior of the quartzites is similar regardless of the excavation site, they showed significant differences in microscopic texture (Figure 6), and thus it is possible that the two quartzite from the Seokchon-dong and Gamil-dong remains had different sources.

The amphibolites excavated from Seokchon-dong and Gamil-dong showed a relatively low degree of enrichment in the light REEs (Figure 7). As plotted, the amphibolite from

Seokchon-dong belongs to the continental flood basalts zone [30], but the Gamil-dong amphibolite is close to the TTG zone (Figure 8a). Although they have the same proportion of Rb, the differences in the distribution of K and Sr (Figure 8b,c) suggest that the two amphibolite have different origins.

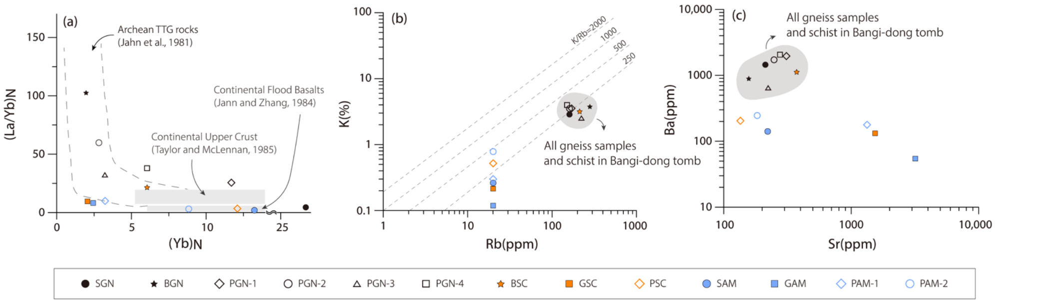

Figure 8. Geochemical plots of gneiss, schist, and amphibolite samples. Graphs (**a**) [20,29,30] and (**b**) are after Lee et al. (2004) and (**c**) shows the relation of Sr(ppm) and Ba(ppm). Sample names are as in Table 1.

5.2. Provenance Sites

According to the review of the homogeneity of the same type of rocks excavated from the three studied remains sites, regardless of the excavation site whereas gneiss, schist, quartzite, and amphibolite appeared to have origins that differ by excavation. We categorized the studied rock samples into seven categories based on their detailed petrology: (1) Seokchon-dong gneiss; (2) Bangi-dong gneiss; and schist; (3) Seokchon-dong quartzite; (4) Gamil-dong quartzite; (5) Seokchon-dong amphibolite; (6) Gamil-dong amphibolite and schist; and (7) Gamil-dong diabase.

We interpreted the source of the stone materials at excavation sites by comparing rocks representing these seven categories to rocks from the respective presumed-provenance sites. The results of comparing the excavated Bangi-dong gneiss (and the related schist) to rocks collected from four points in the vicinity (near Seokchon-dong and Bangi-dong sites, and from the Daemosan, and Namahansan Mountains) showed that all of the gneiss has the same mineralogical composition, except for that from Seokchon-dong, which has macrocrystalline garnet (Figure 6). Additionally, according to the homogeneity review across the remains, only the Seokchon-dong gneiss showed negative abnormal behavior of Eu, whereas the four gneisses from the presumed-provenance site and gneiss and schist from Bangi-dong exhibited similar behavioral trends (Figure 7).

However, we found that although the gneiss collected near the Bangi-dong remains and Daemo Mountain is plotted in the Archaeozoic TTG area (as does the Bangi-dong gneiss), the gneiss from Namhan Mountain is plotted as outside the area (Figure 8a). Therefore, given that the Seokchon-dong gneiss exhibited low homogeneity with the studied rocks from the presumed-provenance site, the Bangi-dong gneiss (and schist) was likely acquired close by the excavated remains or from Daemo Mountain, which is ~4km to the southwest.

The presumed-provenance site for quartzite is near the Gamil-dong remains and the Mongchon Fortress. The quartzite collected near the Gamil-dong remains showed the similar elemental behavior to the two quartzites excavated from the remains (Figure 7). However, according to our petrographic analysis, quartzite from Seokchon-dong is different although identical to the quartzite from the Gamil-dong. Therefore, it is confirmed that the quartzite excavated from the Gamil-dong tomb was supplied from nearby area, but the place where the quartzite excavated from Seokchon-dong was obtained is indistinctness.

For the amphibole used in constructing the remains, there are presumed-provenance sites near Cheonma and the Namhan Mountains. According to the above-mentioned petrographic and geochemical analysis, the amphibolite from Cheonma Mountain is texturally similar to that of Gamil-dong, and amphibolite from Namhan Mountain resembles that of Seokchon-dong (Figures 6 and 7). The correlation diagrams also show that the amphibolite and schist are categorized as Archaeozoic TTG, whereas the amphibolite from Namhan Mountain and Seokchon-dong are categorized as the continental flood basalts. Additionally, the schist collected near the Gamil-dong remains showed the same geochemical characteristics as the amphibolite from Namhan Mountain and Seokchon-dong (Figure 8).

However, as the schist near the Gamil-dong was found to have a higher proportion of plagioclase and higher granularity, we considered the homogeneity to be low. Therefore, we assumed that the Seokchon-dong amphibolite was sourced from Namhan Mountain and Gamil-dong amphibolite (and schist) from near Cheonma Mountain. Since the Gamil-dong diabase exhibited a slightly different microstructure and REE behavior but a similar trend in compatible and incompatible elements, we considered that it was sourced from Cheonma Mountain.

5.3. Assessing Stone Supply

In summary, we reviewed the presumed original sources of stone materials used in building the ancient tombs near Hangang River according to construction period. The connected stone-mound tombs in the Seokchon-dong tomb complex, which were constructed at an earlier time during the early 4th century, were mainly built using gneiss (particularly biotite gneiss), schists, and amphibolite.

From our review of supply sites based on excavated materials, in Seokchon-dong connected stone-mound tomb, we consider the gneiss and schist to have been acquired from areas other than the known supply sites, South of the Hangang River and West of Namhan Mountain, but we concluded that the amphibolite was sourced from Namhan Mountain, which is > 4 km from the remains. We further assumed that stone materials were sourced from a relatively wider area to build the Seokchon-dong tombs.

The Gamil-dong tomb complex, which was built during the late 4th century through the early 5th century, is composed mostly of amphibole schist with minor gabbro (as directly observed in the field). Amphibolite, schists, and diabase were collected for further study of the remains and of the current preservation status. Our results indicate that all component materials were sourced from Cheonma Mountain, which is within 1 km of these remains.

However, although the origins of diabase from Gamil-dong tomb and Cheonma Mountain is similar, there are some differences in the microstructure. Additionally, since the provenance site of gabbro was not suggested in this study, it is necessary to examine the possibility that stones were supplied from Namhan Mountain, the largest mountain area around the remains.

Bangi-dong tomb No.3, which was built in the mid to late 6th century, consists mainly of gneiss, as was used in the Seokchon-dong tombs. It consists mainly of schist, but quartzite, and various igneous rocks are observed as well. Gneiss and schist are assumed to have come from Daemo Mountain, which is 4 km away from the remains. Although the Bangi-dong tomb was constructed at the latest among the tombs under study, it is confirmed that stone materials were supplied in a narrower area in Seokchon-dong tomb, which was built in the 4th century. Whereas the distance between the two remains is close, the range of stone supply differs depending on the era, which may be due to the difference in the construction style of the tombs, but it may also be caused in different culture group as changing the hierarchy.

However, as the Gamil-dong tomb complex is large in scale with many stone-chamber tombs and with a massive material source at Namhan Mountain to the east, the possibility of the stone materials being provided from Namhan Mountain needs further review. Additionally, as the current study compared rock samples collected in mountainous areas and remaining after the development of downtown Seoul, another possible source of supply to Seokchon-dong is Daemo Mountain, which needs further investigation along with a review of the ancient geography (Figure 9).

A distinctive feature is that the gravel-shaped stones was found only in Seokchon-dong and Bangi-dong remains. When examining the proportions of rock types in each tomb and looking at the geologic distribution map around remains, igneous rocks were confirmed, it is assumed that these gravel-shaped stones were supplied from the Acha Mountain area in the northern part of the Hangang River by water system. Additionally, it is assumed that the Gamil-dong remains have no gravel-shaped stones due to their location.

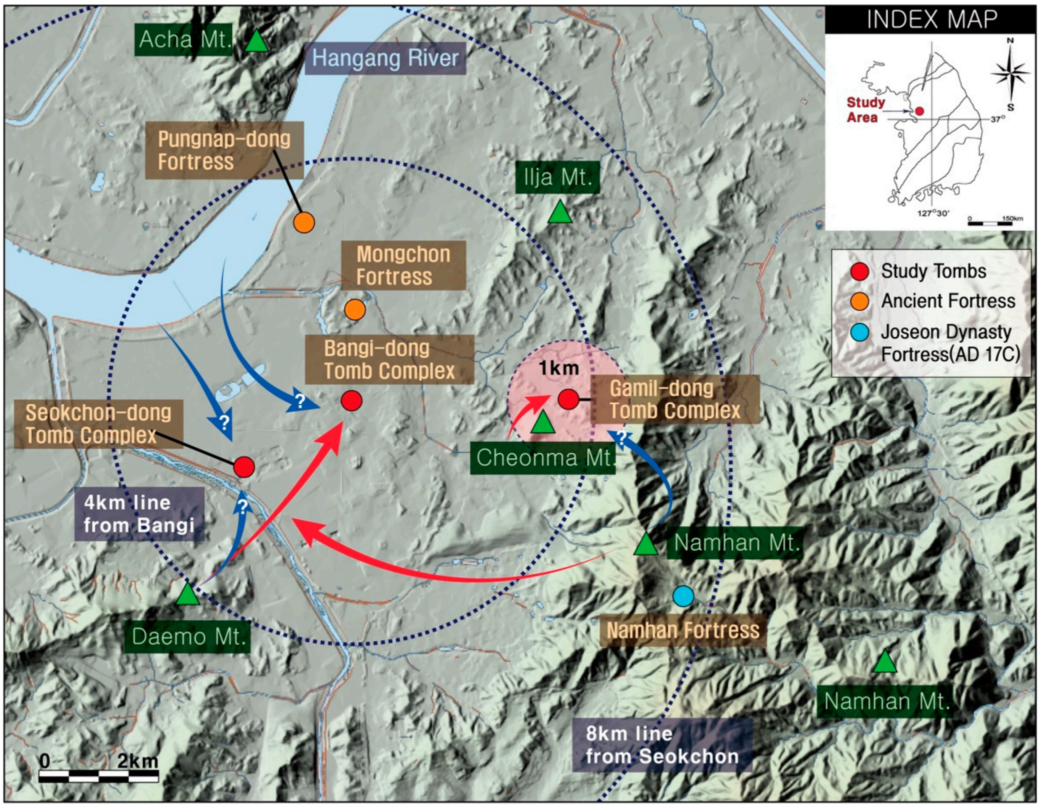

Figure 9. Schematic figure showing the presumption supply route from rock provenance for Korean ancient tombs from the *Songpa* district in Seoul.

Thus, it appears that the stone materials used in building the ancient tombs in the Songpa district near the Hangang River were collected across a relatively wider area in the early 4th century but also collected more locally (within 1 km) during the late 4th and early 5th centuries. In the 6th century, stones were supplied from a point 4 km away from the remains, so it is confirmed that quarrying took place in a narrower range than in the 4th century. On the other hand, regardless of the period and the change in the construction culture group, the gravel-shaped stone supplied through the Hangang River was used in the tombs close to the river, indicating that the ancient human obtained the material near the construction point.

6. Conclusions

Historically, the Hangang area in Seoul has been affected by several ancient states. Today, the tombs of *Baekje* that used the city as a capital until the mid 5th century and those who ruled the city in the 6th century remains. The Seokchon-dong, Bangi-dong, and Gamil-dong tomb complexes are a few such notable tombs. In the current study, the rock types of the stone materials composing the connected stone-mound tombs in the Seokchon-dong, Bangi-dong tomb No.3, and Gamil-dong tomb complexes were analyzed while a thorough academic excavation was performed within the five-year period of 2017–2021.

The Seokchon-dong and Bangi-dong tombs, which are relatively close to the Hangang River, are composed mostly of gneiss and schists, and the Gamil-dong tomb complex near Namhan Mountain is composed mostly of amphibole schist. As a result of reviewing the presumed supply sites for the stone materials with the preservation of each of the remains under consideration, the Seokchon-dong connected stone-mound tombs built in the early 4th century, which belong to the *Hanseong Baekje* period, apparently used source materials from the widest area. In contrast, the Gamil-dong tomb complex from the late 4th and early 5th century used locally sourced stone materials. In the mid to late 6th century, after the *Baekje*'s retreat from the river as invasion of *Silla* kingdom, Bangi-dong tomb No.3 was also built using locally stone materials.

Thus, regardless of their time period, ancient groups of people in or near the area that is now the Songpa district apparently did not consider it important to have different stone materials. Additionally, it seems likely that the stone materials were collected from a wider area when the form of the tomb required materials in greater quantity. Future investigation should examine the constructional data by tomb type in further detail, and study data should be expanded and undergo additional review.

In particular, the gravel-shaped stones supplied from the Hangang River were found only in Seokchon-dong and Bangi-dong tombs. Therefore, additional research on rock data in the northern part of the Hangang River is required to discuss additional rock supply sites for Seokchon-dong and Bangi-dong remains. It is necessary to additionally study the eastern region, including Namhan Mountain, for the detailed interpretation of the supply site for the Gamil-dong tombs.

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