Rocks and Minerals

On the Korean Peninsula, the oldest rocks are Neoarchean meta-igneous rocks ca. 2.5 Ga. Older rocks were recycled through the rock cycle into Paleoproterozoic metasedimentary and igneous rocks ca. 2.0–1.8 Ga. The Paleoproterozoic rocks make up the foundation of the Korean Peninsula and are classified, from north to south, into the Gwanmo, Nangrim, Gyeonggi, and Yeongnam Massifs.

The Paleozoic Imjingang belt, which developed in the east-west direction along the Imjingang to the Chugaryeong Graben, divides the Gwanmo-Nangrim and Gyeonggi Massifs. The Gwanmo-Nangrim Massif runs through Hamgyeong-do, Pyeongan-do, northern Gangwon-do, and Hwanghae-do. The Gyeonggi Massif runs through Gyeonggi-do, Chungcheong-do, and southern Gangwon-do. The Gyeonggi and Yeongnam Massifs are divided by the Neoproterozoic-Paleozoic Ogcheon belt, which extends northeastward from Jeollanam-do to Gangwon-do. The Yeongnam Massif runs through Jeolla-do and Gyeongsang-do. Okcheon belt consists of the Taebaeksan Basin, which is distributed from Gangwon-do to Haenam, Jeollanam-do, and the Okcheon metamorphic belt, which is mainly distributed in Chungcheongnam-do and Chungcheongbuk-do.

Paleoproterozoic metamorphic and igneous rocks in the Korean Peninsula formed at a depth of about 35 km are now exposed at the surface due to tectonic uplift and erosion. Paleoproterozoic metamorphic and igneous rocks were covered in unconformity by metamorphic sedimentary rocks (Seosan Group) formed in the Late Paleozoic era (1.80–1.76 Ga) and were subsequently intruded by granite formed in the Paleoproterozoic era (1.76–1.70 Ga). These rocks were intruded by the Mesozoic igneous rocks (1.25–1.19 Ga), and these rocks are mainly distributed along the west coast, in Hongseong, Chungcheongnam-do, and Hwanghae-do.

Neoproterozoic rocks are widely distributed in the southern part of the Nangrim Massif between Haeju and Wonsan and consist mostly of sedimentary rocks, which was intruded by igneous rocks in some areas. Neoproterozoic rocks were recently discovered in the area adjacent to the Imjingang belt, Hongseong in Chungcheongnam-do, and the northeastern Ogcheon metamorphic belt.

Paleozoic sediments are widely found in the Pyeongnam Basin in Pyeongannam-do and Pyeonganbuk-do, the Taebaeksan Basin distributed from Gangwon-do to Jeollanam-do, and the Ogcheon metamorphic belt. They are also found in the Imjingang belt, the northeastern Hamgyeong-do, and the western part of the Gyeonggi Massif. The Pyeongan and Taebaeksan Basins consist of the Chosun and Pyeongan Supergroups; the Chosun Supergroup was deposited between the Cambrian and Early Silurian, and the Pyeongan Supergroup was deposited unconformably on the Chosun Supergroup between the Middle Carboniferous and Permian. The Chosun Supergroup consists of marine sediments, primarily limestone. The Pyeongan Supergroup mainly consists of continental sediments and contains a lot of coal. Devonian sediments are found in the Imjingang belt. The Okcheon metamorphic belt and the Paleozoic sedimentary rocks in the western Gyeonggi Massif appear to have been deposited after the Ordovician period. Recent studies, however, suggest that some of them deposited during the Permian period.

The Duman Supergroup in northeastern Hamgyeong-do consists of Carboniferous-Permian sediments. Late Paleozoic igneous rocks are found in northeastern Hamgyeong-do and are also reported in the Hongseong and Mungyeong areas.

On the Korean Peninsula, Triassic and Jurassic sedimentary rocks occur only locally in limited areas. However, cretaceous sediments of the Gyeongsang Supergroup are widely distributed in Jeolla-do and Gyeongsang-do. The Gyeongsang Supergroup consists of non-marine sediments deposited in the lake, which provided a good habitat for dinosaurs. Consequently, many dinosaurs lived on the Korean Peninsula, leaving abundant fossils in the Cretaceous sedimentary layers, including footprints and eggs and bone fossils. From the Late Permian to the Cretaceous, there was a subduction zone around the Korean Peninsula, and subduction-related igneous rocks regionally intruded the Korean Peninsula. There was an extensive igneous intrusion during the Jurassic, forming the Daebo Granite, which comprises the main foundation of the Korean Peninsula along with Paleoproterozoic rocks.

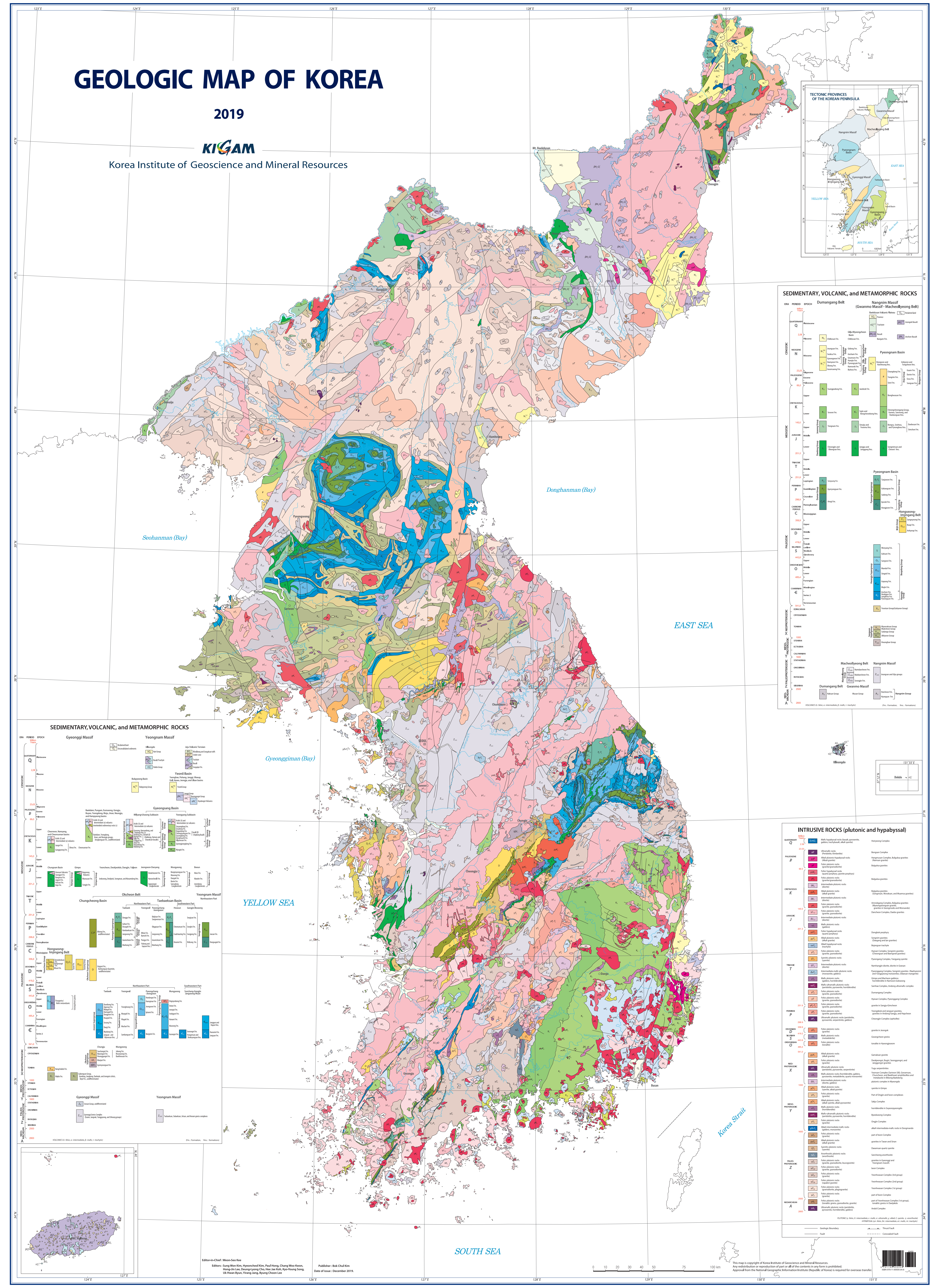
A recent study shows that Triassic granites formed due to a continental collision within the Korean Peninsula are mixed in with Jurassic granites in the northern Gyeonggi Massif. Further evidence of Triassic continental collision is provided by the Triassic eclogite found in the area of Hongseong. The Jurassic granites, which formed at a depth of around 15 km, are directly covered with Cretaceous volcanic and sedimentary rocks. These facts indicate the uplift of the Korean Peninsula before the Cretaceous.

During the Cenozoic, the East Sea was formed, separating Japan from Korea and uplifting the eastern part of the Korean Peninsula higher than the western part, resulting in westward tilting. The Baekdusan, Ulleungdo, Dokdo, Jejudo volcanoes, and the Chugaryeong Graben also formed during the Cenozoic with the Cenozoic sedimentary rocks in Hamgyeong-do and Pohang.

Recently Korean researchers have expanded the scope of research to overseas geology. As a result, mining rights for manganese nodules in the Pacific Ocean (1994), exploration rights for hydrothermal deposits in Tonga and Fiji (2008, 2011), and mining rights for hydrothermal deposits in the Indian Ocean (2012) were acquired, and the geologic map of Suai in East Timor was made. In 1987, Korea began research on the polar regions.

General Geology

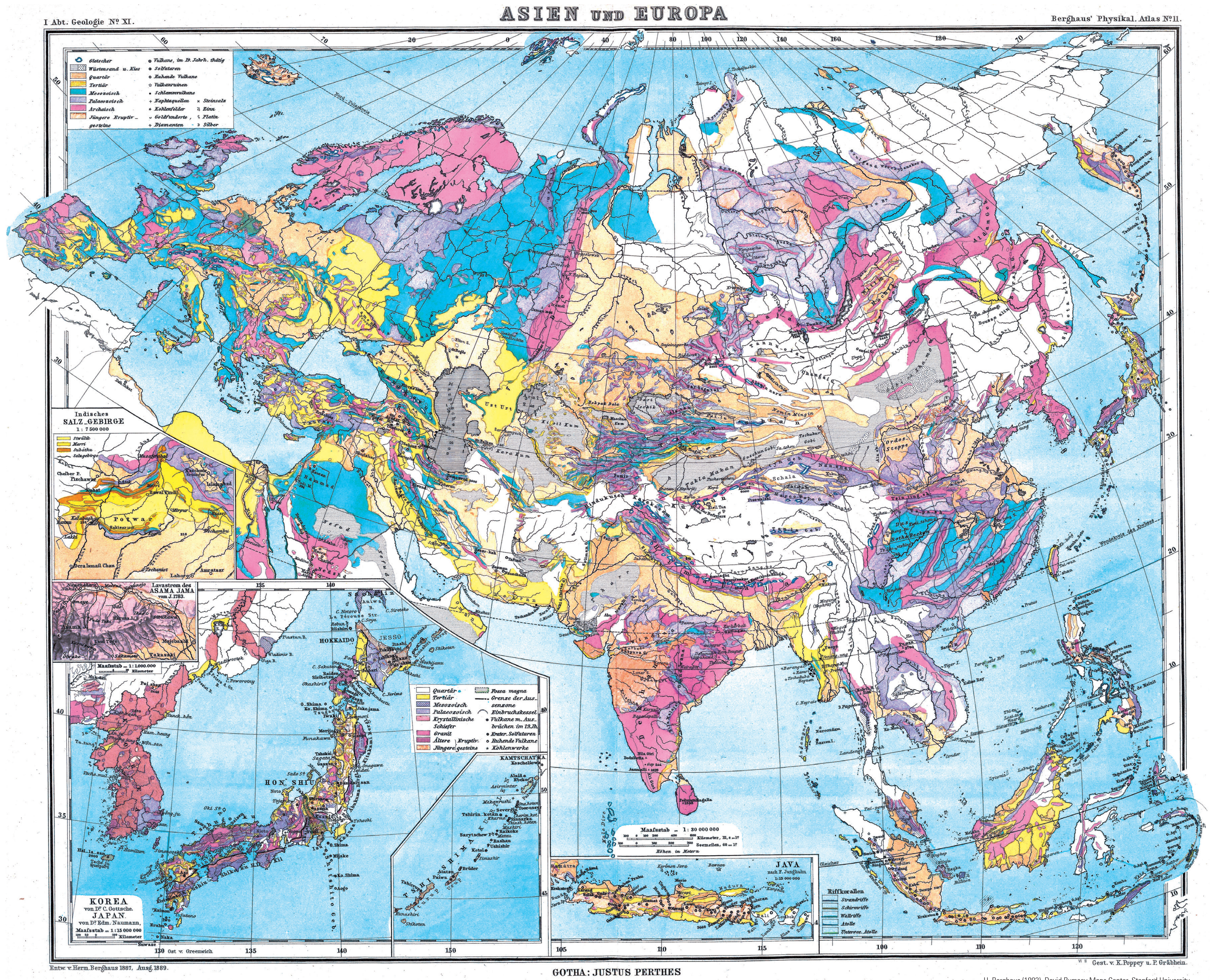
Geologic Map of the Korean Peninsula



Korean Institute of Geoscience and Mineral Resources (2019)

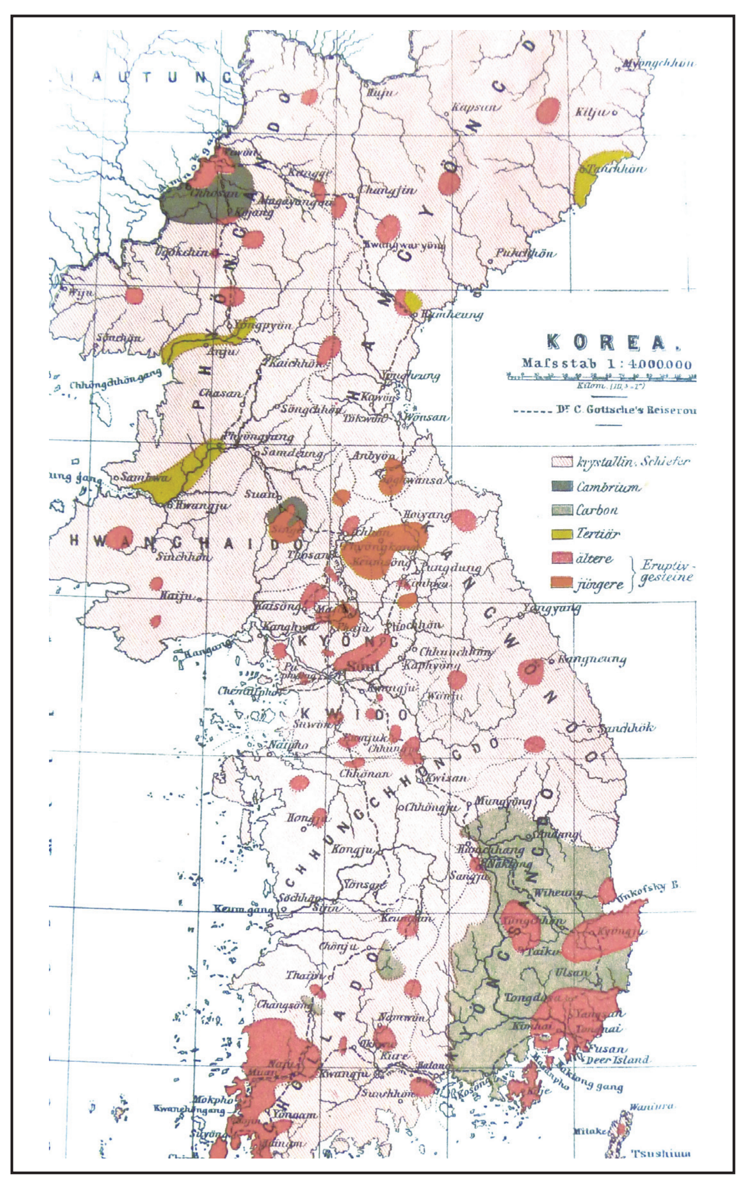
History of Geological Survey in Korea

Geological Map of Asia and Korea (1892)



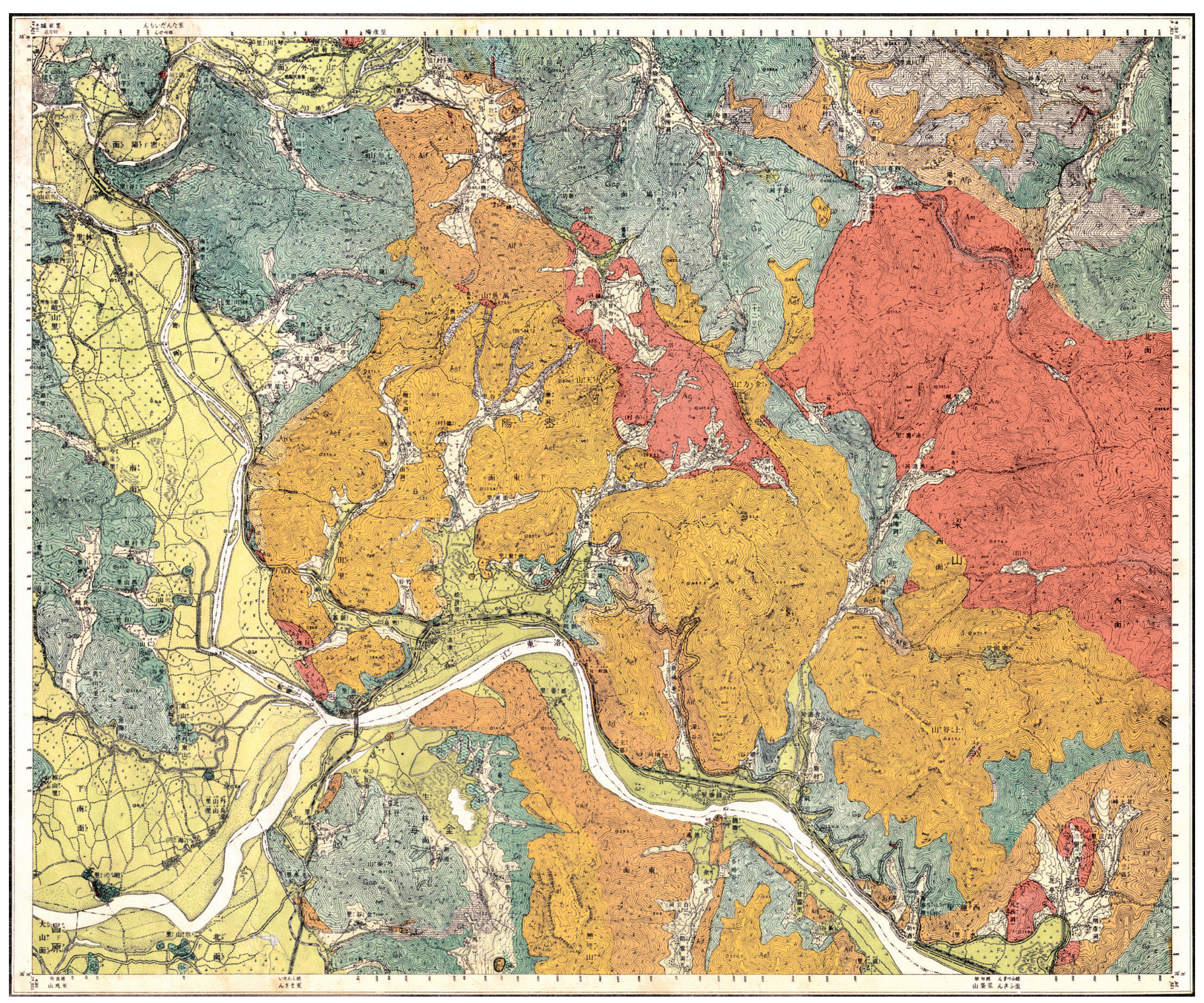
H. Berghaus (1892), David Rumsey Maps Center, Stanford University

First Geological Map of Korea (1883)



C. Gottsch (1883)

Geological Map of Joseon (Miryang, 1924)

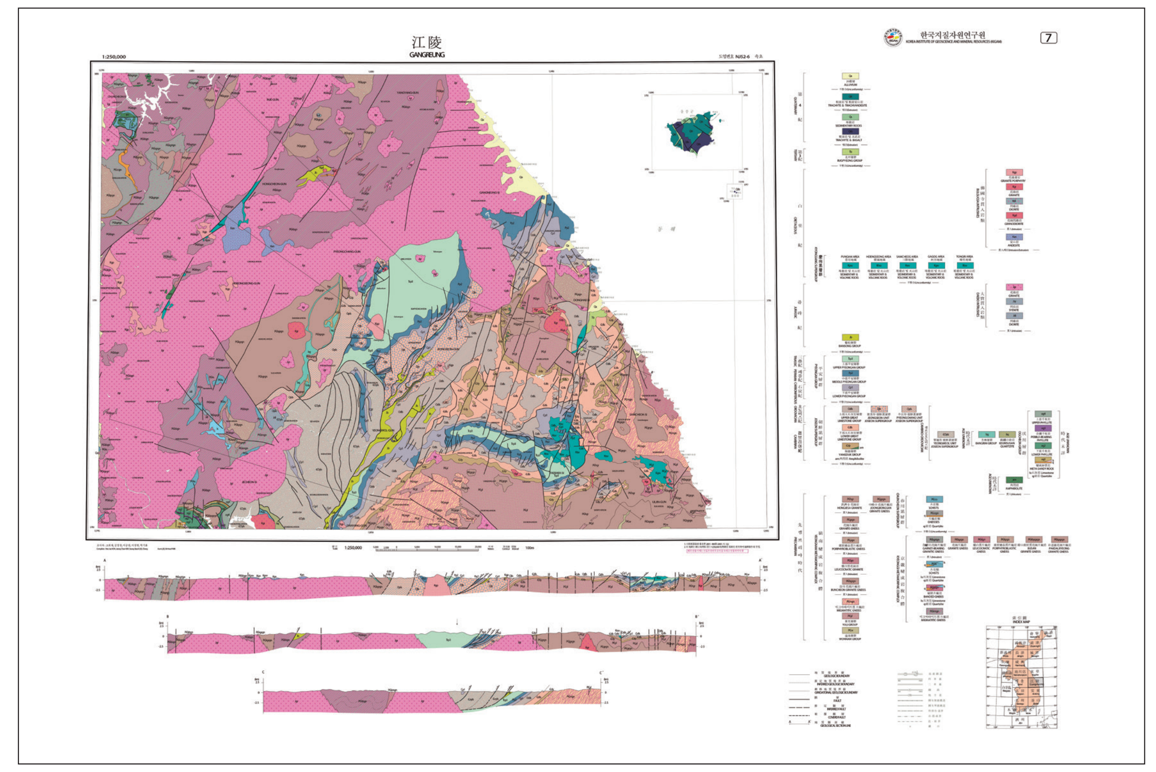


The Geological Survey of the Japanese Government-General of Korea

Information on the variety of ore mineral resources used during and before the Joseon Dynasty and their production districts on the Korean Peninsula is summarized in the *Chosun Ore Deposits in Ancient Literature* published by the Japanese geologist Kawasaki. The literature indicates that the geological prospecting and mining of mineral resources precedes the Joseon Dynasty. The number of ore minerals noted in the ancient literature is substantial—twenty times the number we know of today.

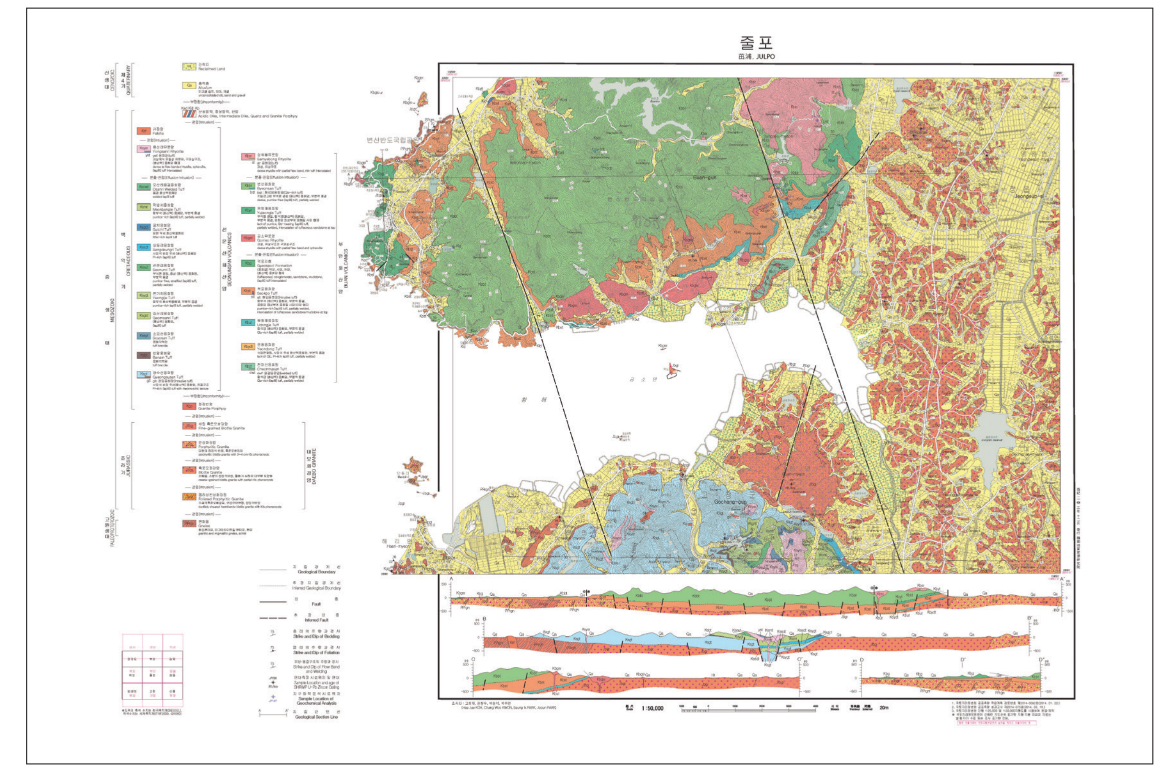
Carl Gottsche, a German geologist, visited Korea on a German diplomatic mission in 1883 and carried out geological research of the Peninsula to publish the first geologic map of Korea in the paper *Geologische Skizze von Korea* (1886). The geological study of Korea by foreign geologists was intensified with increasing pressure from European powers to acquire mining rights after the First Sino-Japanese War in 1894. In 1903, Goto Bunjiro published *An Orographic Sketch of Korea*, explaining the structure and origin of mountain ranges on the Korean Peninsula and producing a *Geotectonic Map of Korea* at a scale of 1:2,000,000.

Example of Geologic Map at a Scale of 1:250,000



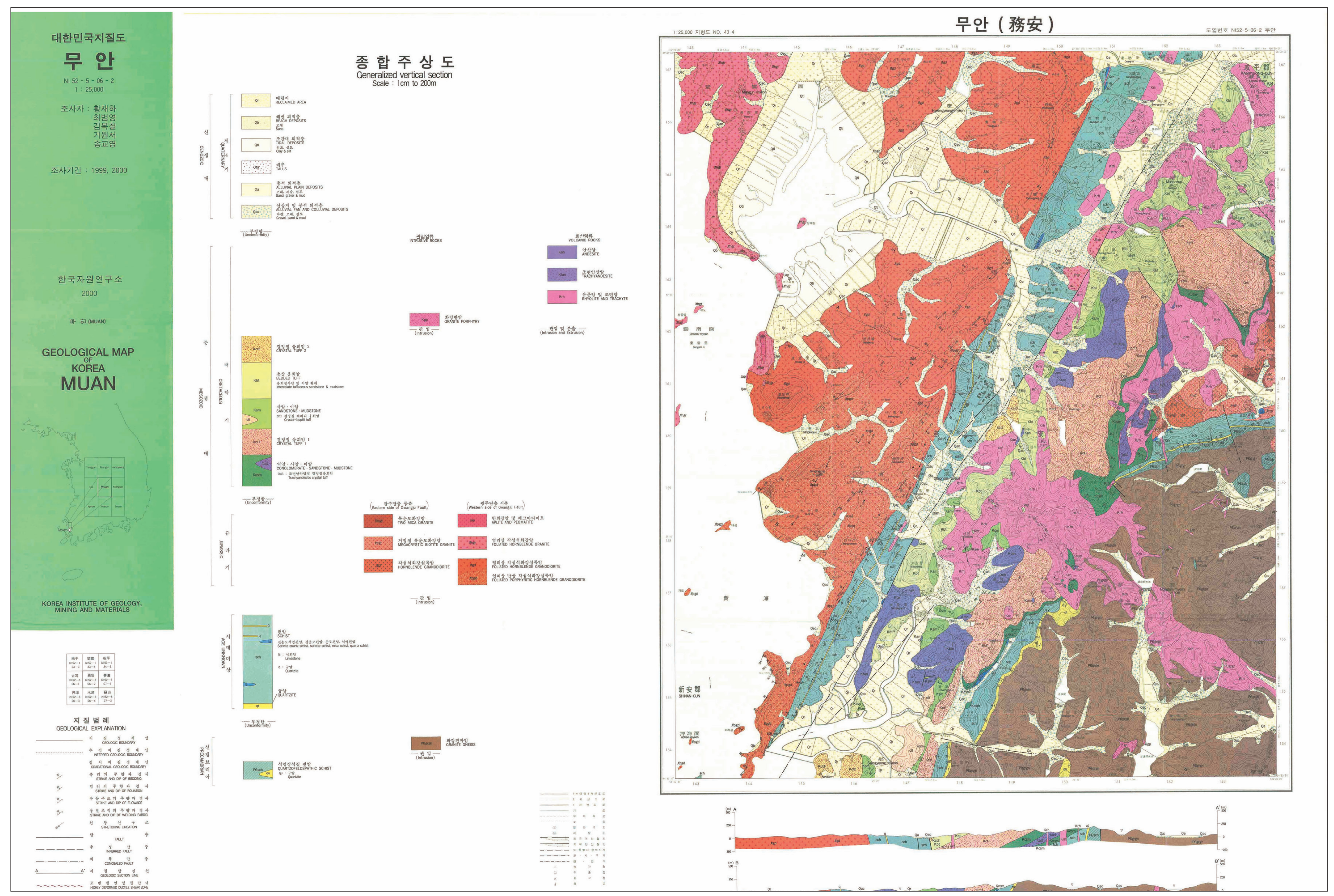
Korea Institute of Geoscience and Mineral Resources

Example of Geologic Map at a Scale of 1:50,000



Korea Institute of Geoscience and Mineral Resources

Example of Geologic Map at a Scale of 1:25,000



Korea Institute of Geoscience and Mineral Resources

The Chosun General Geologic Map at a scale of 1:1,500,000 and *the Chosun Geology and Ore Deposits Map* at a scale of 1:1,000,000 were published in 1907 and 1919, respectively. In 1928, *the Chosun General Geologic Map* was revised. During 1924–1938, geologic maps at a scale of 1:50,000 were made for several areas, including Miryang in Gyeongsangnam-do and Gilju in Hamgyeongbuk-do. Since then, geologic maps at a scale of 1:50,000 have been made to cover the entire Korean Peninsula.

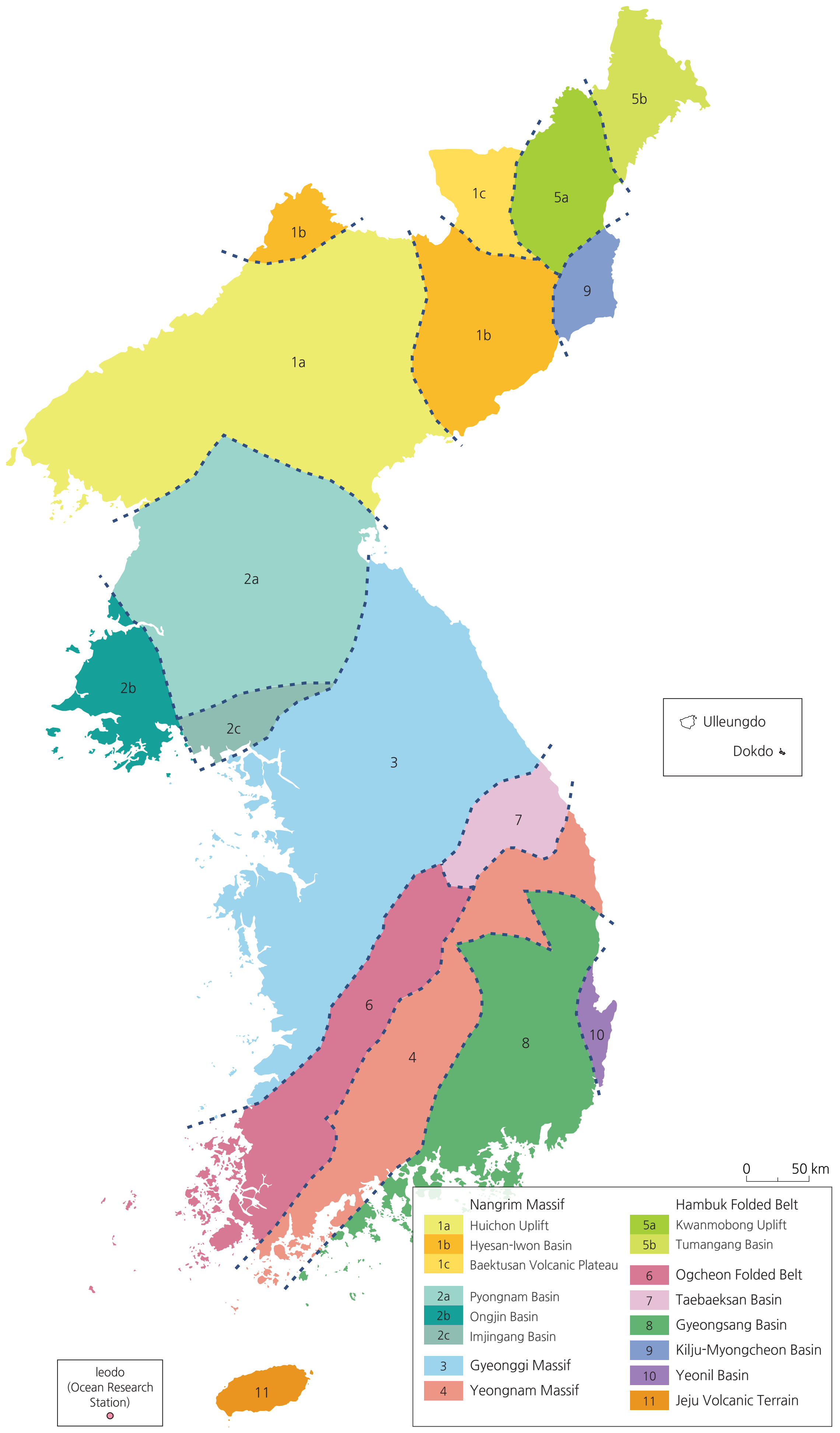
Since the restoration of independence, 1:50,000 geologic maps for South Korea have been made by the Korea Institute of Geoscience and Mineral Resources (Previously, the Central Research Institute of Geoscience and Minerals and the Korea Institute of Energy and Resources). *The Geologic Map of Korea* (1:1,000,000), made in 1956, was the first outcome of a geological study by Korean geologists, and it has been revised several times, with the final version published in 2019. Geologic maps of 1:250,000 and 1:25,000 scales have also been published, along with other geologic maps for special purposes, such as *the Submarine Geologic Map of the Continental Shelf of Korea, Applied Geologic Map, Isotopic Age Dating Map of Korea, Bouguer Gravity Anomaly Map of Southern Korea, Magnetic Anomaly Map of Korea, Geochemical Atlas of Korea, The Metallogenic Map of Korea, The Geologic Map of Coal Fields, and The Hydrologic Map of Korea.*

Characteristics of Geological Time

Geologic History of the Korean Peninsula

Geological Time			Age (Ma)	Stratigraphy	Magmatism	Tectonic Environment and Geologic Activities
Cenozoic	Quater-nary	Holocene	0.0117	Sand Gravel Layer	• Igneous activity related to the formation of Baekdusan, Ulleungdo, Dokdo, and Jejudo volcanic islands	• The formation of Baekdusan, Ulleungdo, Dokdo, and Jejudo volcanic islands
		Pleistocene	2.58	Shinyangri Formation Seogwipo Formation		
	Neo-gene	Pliocene	5.333			
		Miocene	23.03	Yeonil Group Beomgokri Group Janggi Group	• Igneous activity related to the opening of the East Sea and the formation of a lava plateau under Baekdusan	• Opening of the East Sea • The formation of Taebaeksan • A lava plateau under Baekdusan
	Paleo-gene	Oligocene	33.9	Yongdong Group		
		Eocene	56.0	Bongsan Group		
		Paleocene	66.0		• Igneous activity related to mantle upwelling • Strike-slip fault movement	• Bulguksa orogeny related to mantle upwelling • Subduction existing near the Korean Peninsula • Formation of the Gyeongsang basin and small pull-apart basins
Mesozoic	Cretaceous		145.0	Gyeongsang Supergroup (Era of dinosaurs in the Korean Peninsula) Myogog Formation		
	Jurassic		201.3	Bansong Group Nampo Group	• Igneous activity related to the continental arc • Strike-slip fault movement	• Daebo Orogeny related to subduction existing near the Korean Peninsula • Formation of the Honam Shear Zone
	Triassic		251.9		• Igneous and metamorphic activities related to continental collision and subduction	• Songrim orogeny related to continental collision during the formation of the Pangea Supercontinent • Subduction at the southern and eastern margins of the Korean Peninsula
Paleozoic	Permian		298.9	Pyeongan Supergroup including coal-bed	• Igneous activity related to subduction	• Subduction zone in the Hamgyeong-do area
	Carboniferous		358.9			
	Devonian		419.2	Imjin System	• Metamorphism and ilgneous activity related to Paleozoic continental collision • Back arc basin formation	• Paleozoic continental collision (Hongseong) • Back arc basin (Imjingang Belt)
	Silurian		443.8		• Igneous activity related to subduction	• Possibility of subduction at the southwestern Gyeonggi massif
	Ordovician		485.4	Oknyeobong Formation	• Igneous activity related to rifting	• Separation of southern Korean Peninsula from the Gondwana Supercontinent
	Cambrian		541.0	Choseon Supergroup with Limestone and Trilobite		
Precambrian	Neoproterozoic		1000	Sangwon System Wolhyeonri Formation Munjuri Formation Deokjeongri Granitic Gneiss	• Igneous activity related to rifting • Igneous activity related to subduction	• Break up of the Rodinia Supercontinent • Subduction before the formation of the Rodinia Supercontinent
	Mesoproterozoic		1600	Dongmando Monzonite and Gabbro	• Igneous activity related to rifting	• Break up of the Columbia Supercontinent
	Paleoproterozoic		2500	Metasedimentary rocks and meta-igneous rocks in the Nangrim, Gyeonggi, Yeongnam Massifs	• Igneous and metamorphic activities related to subduction and formation and break up of supercontinent	• Subduction before the formation of the Columbia Supercontinent • Formation and break up of the Columbia Supercontinent
	Archean			Panmunjeom, Ganseoung, Daeijakdo metaigneous rocks	• Igneous activity related to subduction and continental collision	

Tectonic Regions of the Korean Peninsula



Korea Institute of Geoscience and Mineral Resources (2016)

The base of the Korean Peninsula consists of Paleoproterozoic rocks formed around 1.9–1.8 Ga; it is divided into the Nangrim, Gyeonggi, and Yeongnam Massifs by the Ogcheon belt and Imjingang belt. It has long been believed that the Korean Peninsula was created during the Paleoproterozoic era. However, in the early 2000s, it was confirmed that the present shape of the Korean Peninsula is the result of a continental collision during the Permian-Triassic (250–230 Ma). In Hongseong-gun Chungcheongnam-do, evidence of Triassic eclogite was found that supports the continental collision theory. Additional evidence for the continental collision is the Triassic post-collision granitoid found in Odaesan area in Gangwon-do. These data indicate the possibility that the present Korean Peninsula was formed in the Triassic period by the collision between the southern and northern Korean Peninsula along the line connecting the Hongseong and Odaesan areas. Although the location of the collision boundary is still uncertain, some parts of the Korean Peninsula are expected to be connected to the North China Craton while other parts are expected to be connected to the South China Craton. Therefore, in this Atlas, the North China Craton and some parts of the Korean Peninsula connected to it will be called the North Korea-China Craton, and the South China Craton and some parts of the Korean Peninsula connected to it will be called the South Korea-China Craton.

Precambrian Geologic History of the Korean Peninsula

(Ga, Billion Years Ago)

Division	Nangrim Massif	Northern Gyeonggi Massif	Southern Gyeonggi Massif	Ogcheon Metamorphic Belt	Yeongnam Massif	
					Sobaeksan Block	Jirisan Block
Archean	2.64−2.54 Ga Arc Related Igneous Activity 2.46−2.44 Ga Metamorphism	2.58 Ga Arc Related Igneous Activity 2.51 Ga Metamorphism	2.51−2.44Ga Post Collisional Igneous Activity			
Paleo-protero-zoic	1.91−1.90Ga Collision Related Metamorphic Activity	1.93−1.91Ga Collision Related Metamorphic Activity	1.95−1.91Ga Arc Related Igneous and Metamorphic Activities		2.02−1.96Ga Arc Related Igneous Activity	
	1.87−1.84Ga Post Collisional Igneous and Metamorphic Activity	1.88−1.85Ga Post Collisional Igneous and Metamorphic Activity			1.87−1.85Ga Arc Related Igneous and Metamorphic Activity	1.87−1.86Ga Post Collisional Igneous and Metamorphic Activity
		1.85−1.69Ga Sedimentation, Igneous Activity	1.80−1.78Ga Post Collisional Igneous Activity		1.69Ga Arc related Igneous Activity	
Neo-protero-zoic	−0.9Ga Rifting Related Igneous Activity and sedimentation	0.9−0.74Ga Rifting Related Igneous Activity and sedimentation	0.9−0.82Ga Arc related Igneous Activity 0.79−0.70Ga Rifting Related Igneous Activity	0.87−0.76Ga Rifting Related Igneous Activity and sedimantation		

Geologic History of the Paleozoic

(Ga, Billion Years Ago)

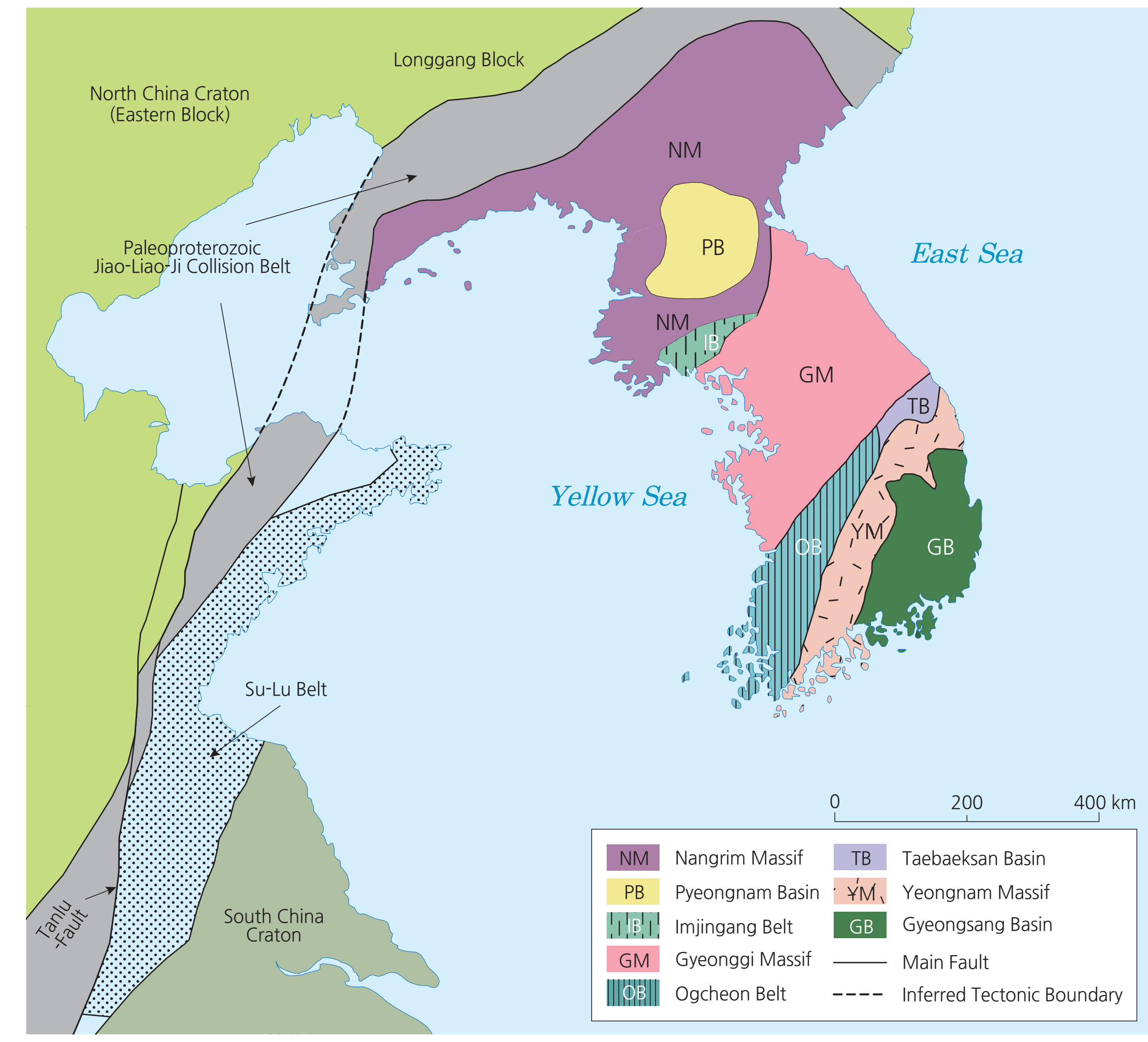
Division	Pyeongnam Basin	Taebaeksan Basin	Imjingang Belt Gyeonggi Massif	Magmatism
Permian	Pyeongan System (Most beds are Terrestrial, including Coal)	Pyeongan Supergroup (Most beds are Terrestrial, including Coal)	Unconfirmed	Igneous Activity Related to Subduction (Hamgyeong-do)
Carboni-ferous	Great Hiatus	Great Hiatus		
Devonian			Imjin System Guryong Formation	Metamorphic Activity Related to Continental Collision (Hongseong) Igneous Activity in Back Arc Basin (Imjingang Belt)
Silurian			Unconfirmed	Igneous Activity Related to Subduction (Hongseong, Islands near Buan) Igneous Activity Related to Continental Rifting (Mungyeong)
Ordovician		Oknyeobong Formation		
Cambrian	Hwangju System (Marine beds, Abundant Limestone)	Choseon Supergroup (Marine beds, Abundant Limestone)		

The Paleoproterozoic igneous and metamorphic rocks of the Korean Peninsula formed due to the continental collision related to the formation of the supercontinent Columbia (which existed from 2.1–1.8 Ga) and the subduction before that collision. Neoproterozoic sedimentary and igneous rocks formed in several areas from 900–750 Ma. The Paleoproterozoic supercontinent Columbia began to break into separate continental cratons from 1.8 Ga and then the separated cratons assembled again to form the supercontinent Rodinia at around 1,000–850 Ma. Rodinia broke up again into separate cratons from 850–700 Ma. Neoproterozoic rocks on the Korean Peninsula formed during subduction before the formation of Rodinia and during the breakup of Rodinia.

After the disintegration of Rodinia, most continents reassembled, forming the supercontinent Gondwana. At that time, the North Korea-China Craton and the South Korea-China Craton were located on the western side of Gondwana. During the early Paleozoic, these Cratons were separated from Gondwana and moved northward. During this geologic process, the Chosun Supergroup, consisting of Paleozoic marine sediment dated between the Cambrian and early Silurian, was deposited in the Pyeongnam and Taebaeksan Basins. The Pyeongan Supergroup, consisting of non-marine sediments, was deposited on the Chosun Supergroup unconformably. Devonian sediments occur in the Imjingang belt. Between the Carboniferous and Permian, a subduction zone developed, causing subduction-related igneous activity in the northeastern fold belt in Hamgyeong-do. Recently, subduction-related Ordovician igneous activity was reported in Hongseong and Mungyeong areas.

After the separation of the North Korea-China and South Korea-China Cratons from Gondwana during the early Paleozoic, they moved northward and finally collided with each other during the Permian-Triassic, forming the present shape of the Korean Peninsula. At the time of that collision, a subduction zone was initiated along the southern margin of the Korean Peninsula and continued until the Cretaceous. As a result, subduction-related igneous rocks regionally intruded the Korean Peninsula, making up the basement of the Korean Peninsula along with Paleoproterozoic metamorphic rocks. During the Cretaceous, many basins were formed on the Korean Peninsula and in the Yellow Sea. Lakes that formed in the basins provided good habitat for dinosaurs. During the Cenozoic, the East Sea was opened, separating Japan from the Korean Peninsula and forming the Taebaeksanmaek. Also, during this time, volcanic activity resulted in the formation of Baekdusan, Ulleungdo, Dokdo, and Jejudo, and sedimentation occurred in the areas of Gilju-Myeongcheon and Yeonil.

Precambrian Massifs and Continental Collision Belts in and around the Korean Peninsula



Precambrian Research (2014)

Korean Peninsula in the Gondwana Supercontinent

Modified from Paleontological Society of Korea (2011)

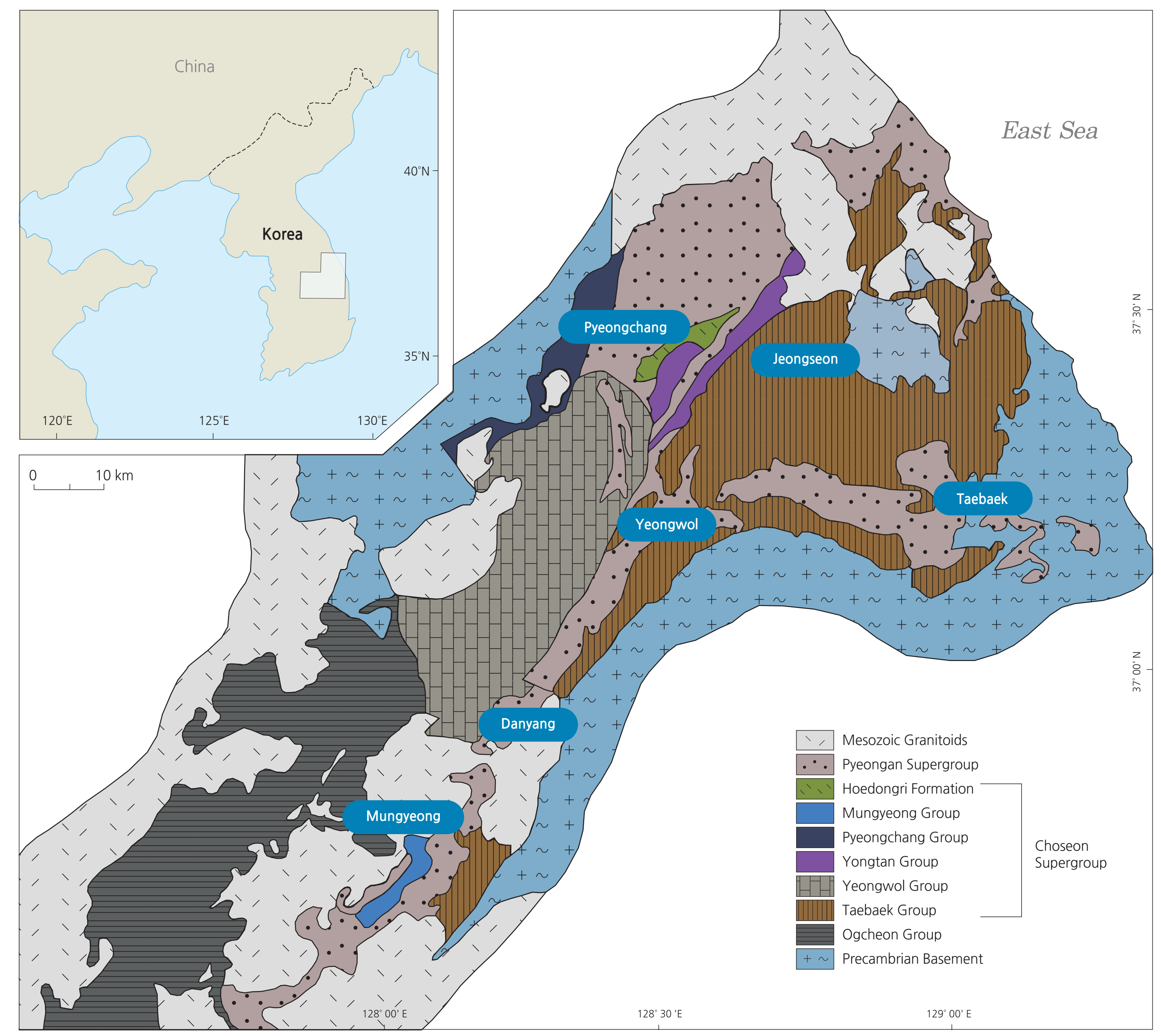
The oldest rocks on the Korean Peninsula are igneous rocks formed during the Neoarchean, 2.6 Ga. Most Precambrian rocks on the Korean Peninsula are Paleoproterozoic rocks. The Nangrim Massif includes igneous rocks formed at 1.93–1.90 Ga and 1.88–1.84 Ga. The former may be related to the continental collision and the latter to the post-collision stage accompanied by the transition from a compressional to extensional stress regime after the continental collision. Similarly, in the northern Gyeonggi Massif, sedimentary and igneous rocks formed during the continental collision (1.85–1.69 Ga).

Subduction-related igneous rocks intruded at 1.95–1.91 Ga and igneous rocks formed during the post-collision stage (1.80-1.78 Ga) were found in the southeastern part of the Gyeonggi Massif. Subduction-related igneous rocks and metamorphic rocks formed 2.02–1.69 Ga were found in the northern margin of the Yeongnam Massif. The meta-igneous rocks formed in the post collision tectonic setting at 1.87–1.86 Ga were found in the southwestern Yeongnam Massif. This distribution of the meta-igneous rocks indicates a continental collision along the line connecting Sancheong and Hadong areas.

The Sangwon System, consisting of Neoproterozoic sediments, runs through the area connecting northern Gangwon-do and Hwanghae-do and extends out to Baengnyeongdo. The Sangwon System was intruded by basic dykes formed at 900 Ma in the continental rift tectonic setting.

Recently, Neoproterozoic igneous rocks of 900–740 Ma formed in the continental rift zone were found in the northern Gyeonggi Massif. Igneous rocks formed during subduction at 900–820 Ma and during continental rifting at 790–700 Ga were reported from the Dangjin-Hongseong area located in the southwestern Gyeonggi Massif. Igneous rocks formed during continental rifting at 870–760 Ma were also found in the northeastern Ogcheon metamorphic belt.

Paleozoic Sedimentary Rocks in the Taebaeksan Basin



Association of Korean Geoscience Societies (1998)

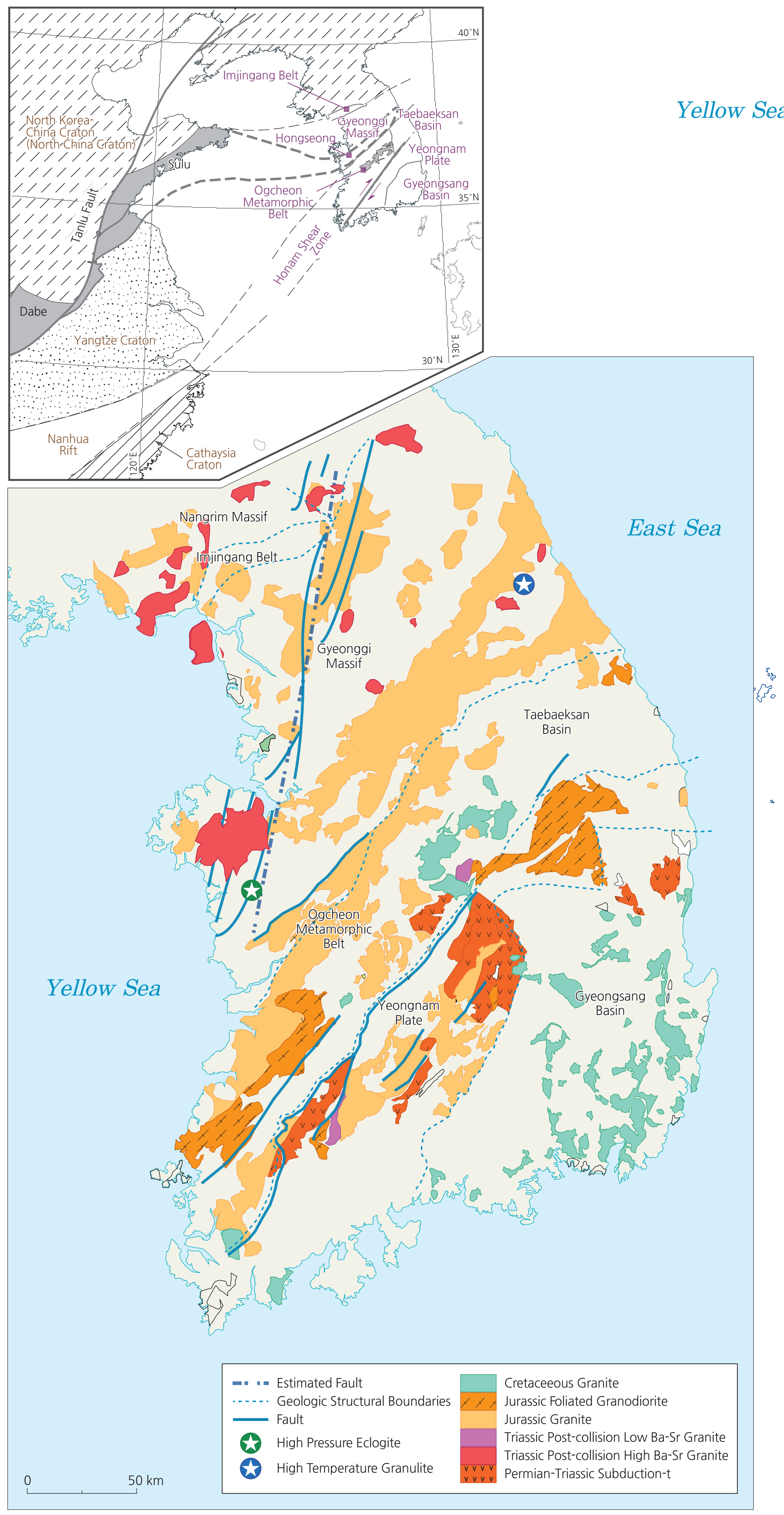
Paleozoic sedimentary rocks are mainly distributed in the Pyeongnam and Taebaeksan Basins and are divided into the Lower and Upper Paleozoic sequences. The Lower Paleozoic sequence is characterized by alternating siliciclastic and carbonate successions deposited from the Cambrian to Ordovician. In the Lower Paleozoic sequence, macrofossils, including trilobites, the index fossil of the Cambrian, occur abundantly with microfossils such as conodonts.

The Upper Paleozoic sequence that unconformably overlays the Lower Paleozoic sequence was deposited from the Late Carboniferous through the Permian up to the Early Triassic and mainly consists of siliciclastic sedimentary rocks with carbonates and coals in the lowermost part of the sequence. The Ogcheon metamorphic belt is comprised mainly of Paleozoic sedimentary rocks. The Imjin series of the Devonian strata, which is absent in the Pyeongnam and Taebaeksan Basins, occurs in the Imjingang belt locating between the Nangrim and Gyeonggi Massifs.

Recently it was reported that the Ordovician bi-modal volcanism occurred at 452–445 Ma in the Ognyebong Formation near Mungyeong. The Ordovician bi-modal volcanism is thought to have occurred when the southern part of the Korean Peninsula drifted apart from the supercontinent Gondwana during the early Paleozoic. The igneous rocks that intruded in the subduction zone at 470–452 Ma and the intermediate- and high-pressure metamorphism that occurred at 442–381 Ma were recognized in the Hongseong area within the Gyeonggi Massif. In the Imjin series of Devonian strata, igneous rocks intruded into the back-arc basin at 373–361Ma. Intensive igneous rocks formed during subduction in the Late Paleozoic were found in the Hamgyeong-do.

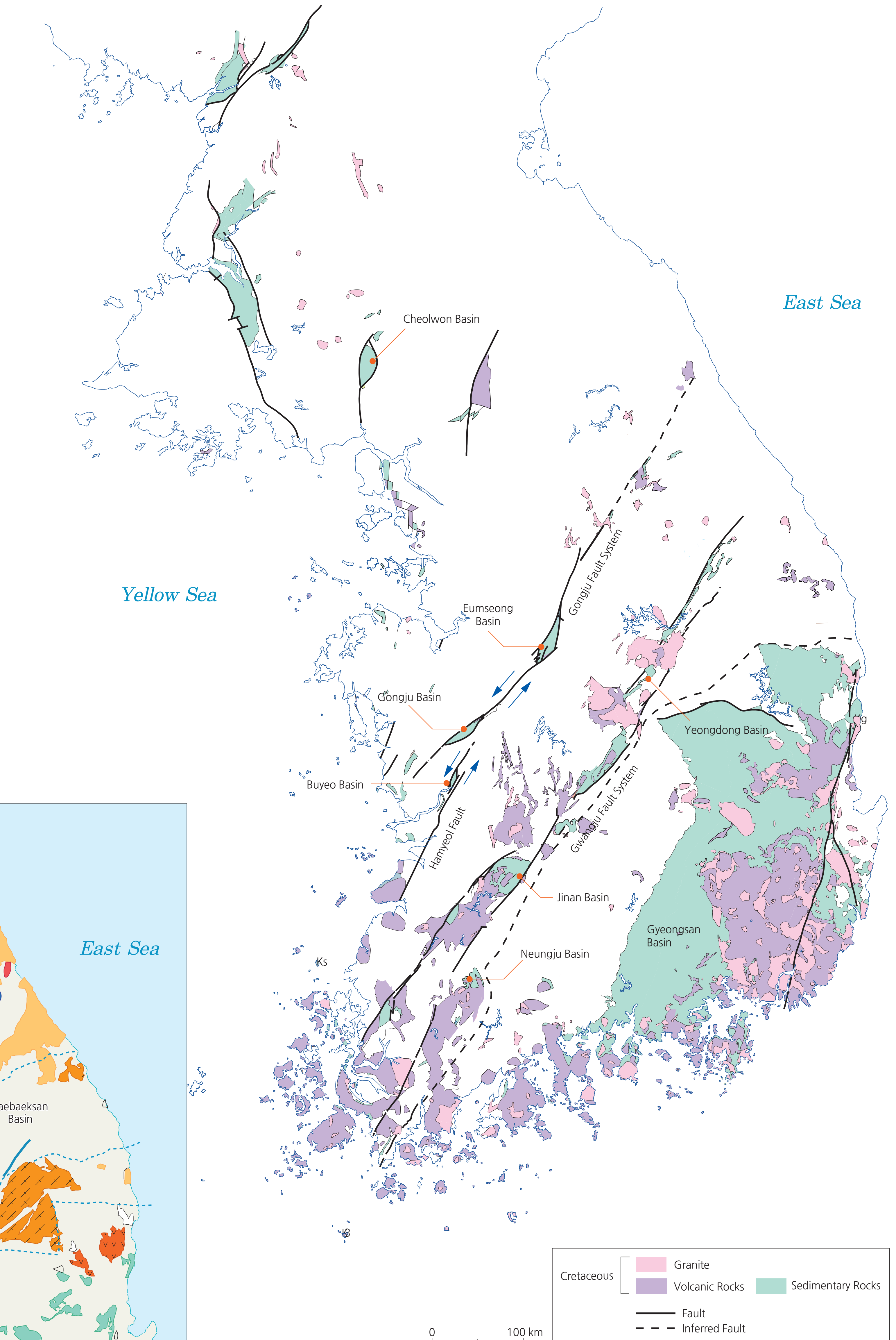
One of the most important recent findings is the 230 Ma eclogite from the Hongseong area in Chungcheongnam-do within the Gyeonggi Massif. As the eclogite formed in the subduction zone, the occurrence of this rock indicates that there were a subduction zone and ocean in the Hongseong area, which disappeared due to continental collision. Another important finding is the 230 Ma post-collision igneous rocks in the northern Gyeonggi and southern Nangrim Massifs, which are located on the north side of the line connecting the Hongseong, Yangpyeong, and Odaesan areas. Thus, the 230 Ma eclogite and post-collision igneous rocks potentially indicate that the continental collision boundary may be the line connecting the Hongseong, Yangpyeong, and Odaesan areas. The Imjingang belt and the line connecting the Imjingang belt and Hongseong have also been suggested as the continental collision boundary, but no clear pieces of evidence for the collision were found in those areas. Due to the Permian-Triassic continental collision on the Korean Peninsula, Permian-Triassic regional metamorphism occurred in the Gyeonggi Massif, Imjingang belt, and Ocheon metamorphic belt.

Igneous Rock in the Late Paleozoic-Mesozoic Era



Petrological Society of Korea (2020)

Distribution of Major Strike-Slip Faults and Cretaceous Sedimentary Basins



Geological Society of Korea (2015)

Along the southern margin of the Korean Peninsula, subduction-related igneous activity started to occur between the Late Permian and Triassic. Therefore, during the Songrim Orogeny, the post-collision igneous activity and subduction-related igneous activity occurred in the middle and the southern parts of the Korean Peninsula, respectively.

During the Jurassic, Japan was attached to the Korean Peninsula. A subduction zone existed at the eastern and southern margins of the Korean Peninsula, resulting in the extensive regional intrusion of Jurassic granite in the Korean Peninsula. This event is called the Daebo Orogeny.

During the Cretaceous, a subduction zone was also developed along the margin of the Korean Peninsula, and Cretaceous igneous rocks intruded the Korean Peninsula regionally due to the mantle upwelling which was caused by rollback of subduction slab towards Pacific Ocean side. The Cretaceous igneous activity mainly occurred in Gyeongsang-do, Jeolla-do, and southern Chungcheongbuk-do.

The Cretaceous Gyeongsang Supergroup consists of continental sedimentary rocks deposited in lacustrine environments and is widely distributed in the Gyeongsang Basin and the Namhwanghae Basin. Cretaceous sedimentary rocks are also deposited in the small basins formed during the Cretaceous across the Korean Peninsula. The small-scale Cretaceous basins were pull-apart basins formed by the extension between or along the strike-slip faults, which underwent left lateral movement (the opposite part of the fault moves left) with a northeast strike.

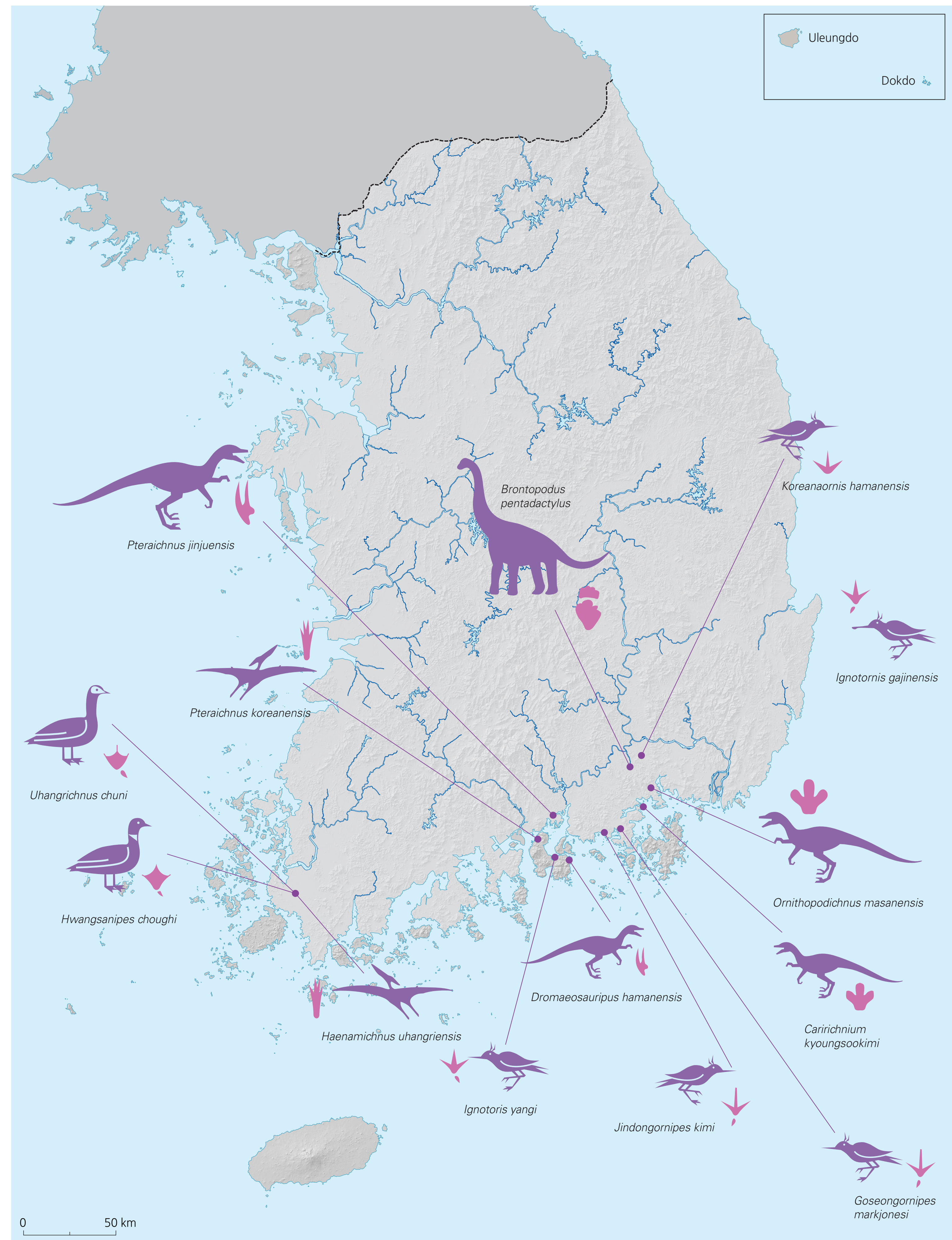
The Cretaceous terrestrial (non-marine) sedimentary layers on the Korean Peninsula contain abundant dinosaur fossils, including footprints and egg and bone fossils. In 1972, the first dinosaur fossil found on the Korean Peninsula was an egg fossil from the Hadong-gun in Gyeongsangnam-do.

Dinosaur footprint fossil sites are found in the 27 Cretaceous terrestrial sedimentary layers in the southern region of the Korean Peninsula; the Cretaceous terrestrial sedimentary layers in Hanam-gun, Hwasungun, and Yeosu-si within Jeollanam-do, and Goseong-gun within Gyeongsangnam-do, are representative sites. Ornithopod footprints are very abundant on the Korean Peninsula, and representative theropod footprints have been found in Hwasun-gun within the Neungju Basin. Abundant sauropod footprints are reported from the Jindong sedimentary layer in the southeastern region of the Korean Peninsula, and the diverse size, shape, and trackway of sauropod footprints indicate that diverse sauropods lived on the Korean Peninsula. The pterosaur found in Uhangri, Haenam-gun, was internationally approved as a new species named *Haenamichnus uhangriensis*.

The largest number and the widest trackway of pterosaur footprints (443 and 7.3 m, respectively), are found in the Uhangri area. In this area the footprints of pterosaurs, dinosaurs, and birds occur together in the same sedimentary layer, which is very rare in the world. For the first time in Korea dinosaur bone fossils that are sufficiently preserved to identify the species of dinosaurs were found in the sedimentary layer in Hadong-gun, Gyeongsangnam-do; the bone fossils were identified as a new species, *Pukungosaurus millenniumi*. It was registered as the 931st dinosaur genus in the world inventory of dinosaurs.

During the Cretaceous, many lakes existed in the southern region of the Korean Peninsula. Gymnosperms, including conifers and ferns, and various vertebrates and invertebrates were also abundant in and around lakes. These lake environments made the Korean Peninsula a habitat favorable for dinosaurs during the Cretaceous.

Distribution and Types of Fossil Footprints of Major Vertebrates in the Cretaceous Period



Department of Earth and Environmental Sciences, Chonnam National University

Dinosaur Fossils in the Korean Peninsula


Dinosaur Fossils: Dinosaur Egg Nest Fossil in Boseong


Dinosaur Fossils: Theropod Footprints in Hwasun

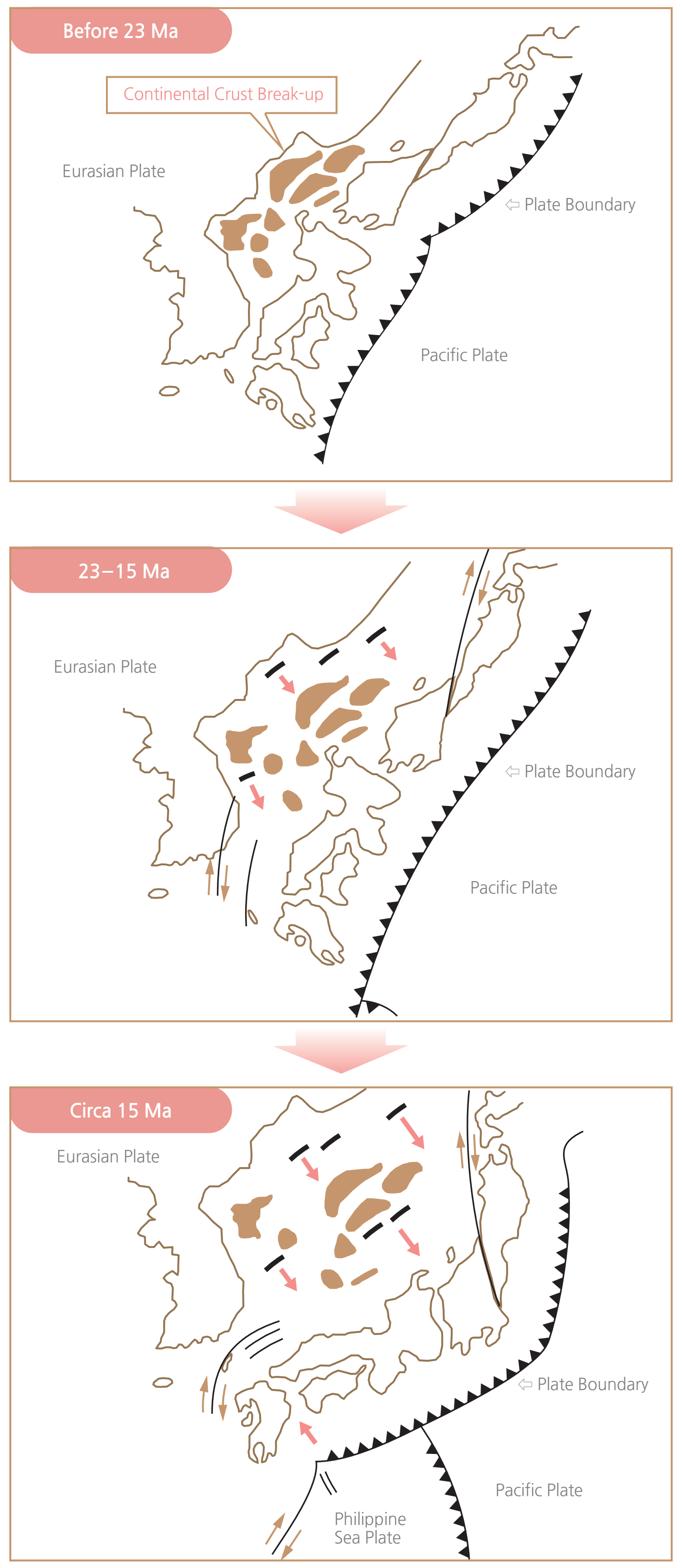

Dinosaur Fossils: Ornithopod Footprints in Yeosu


Dinosaur Fossils: Ornithopod Footprints in Haenam


Pterosaur Fossils: Pterosaur Footprints in Haenam

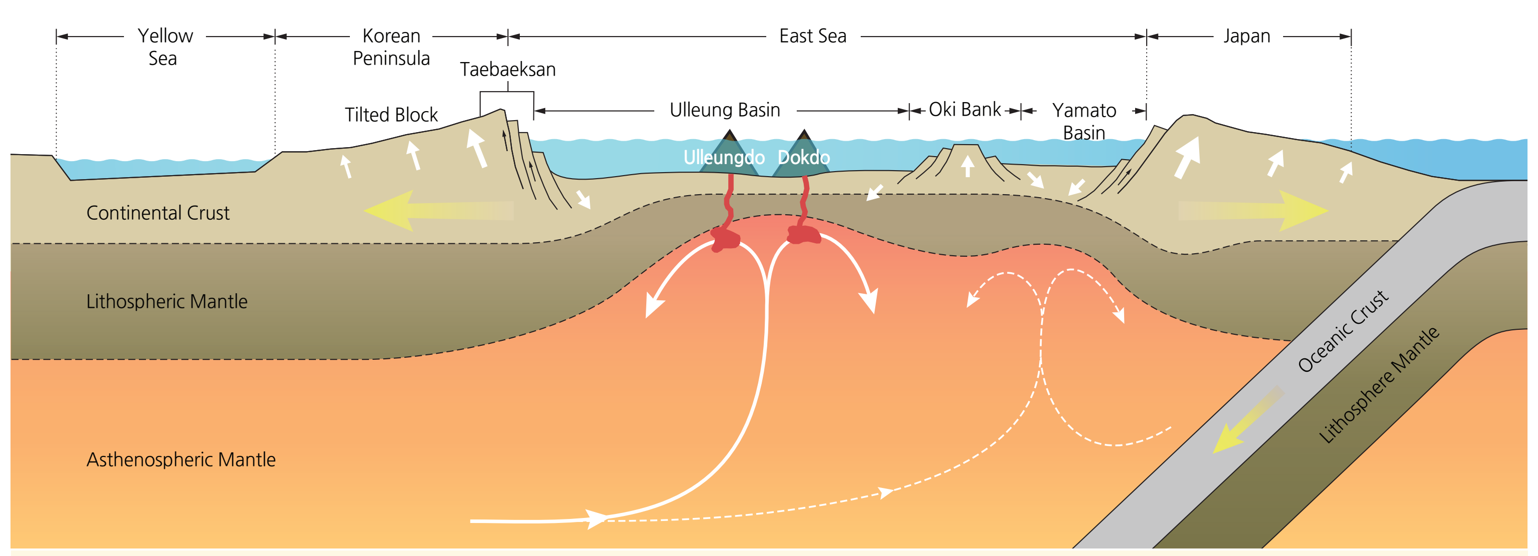

Dinosaur Fossils: *Koreanosaurus* Bones in Boseong

East Sea Opening Tectonic Model



Korean Society of Economic and Environmental Geology (2006)

Topographic and Geotectonic Cross-Sectional View



The Formation of the East Sea, Taebaeksanmaek, and Tilted Block

During the Cenozoic, the subduction zone retreated towards the ocean resulting in the separation of Japan from the Korean Peninsula in the southeast direction, forming the Japan Basin in the northern East Sea at the beginning phase. Later the Ulleung and Yamato Basins formed in the southern East Sea with the rotation of southwestern Japan. The opening of the East Sea was thought to be caused by extensional force due to the eastwards retreat of the subduction zone and/or eastward mantle flow due to the collision between the Indian and Asian continents. During the opening of the East Sea, Dokdo and Ulleungdo volcanic islands formed from the magma caused by the uplifted mantle. The normal fault caused by the extension caused a sinking of the East Sea area.

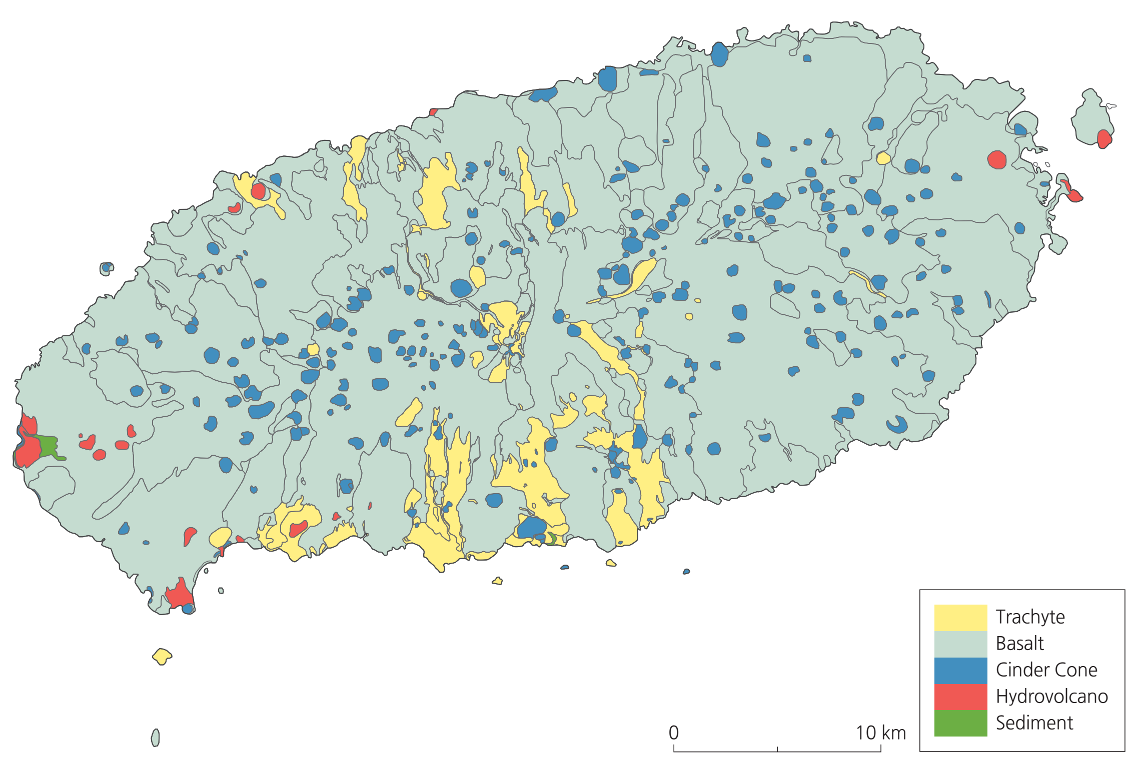
The Cenozoic can be defined by the appearance of the East Sea, Baekdusan, Hallasan, Ulleungdo, and Dokdo. The timing of the formation of the East Sea (23–15 Ma) is similar to the timing of the regional formation of lava plateaus (28–13 Ma) in northeastern Asia, including the Baekdusan area. It indicates that there was a regional extension in Northeast Asia, which formed enormously long fissures in the East Sea and Baekdusan area.

From 15 Ma, compressional stress replaced extensional stress. As a result, shield volcanos formed on the lava plateau in the Baekdusan area by the central extrusion of basaltic lava during 5–1.5 Ma, and the submarine volcanic part of Ulleungdo and Dokdo may also have formed in the East Sea during 8.1–3.7 Ma by submarine volcanic activity. Finally, a stratovolcano consisting of trachytic and rhyolitic volcanic and pyroclastic rocks formed in the Baekdusan area during 0.61 Ma–1903, and in Ulleungdo and Dokdo during 2.9 Ma–6300 BP. At around 969 CE, Baekdusan experienced its strongest eruption, forming the Cheonji Caldera. During this eruption, volcanic ash was transported to the East Sea and Japan and sedimented there. This suggests that similar tectonic activities formed the East Sea, including Ulleungdo and Dokdo, and Baekdusan.

Cenozoic Geologic Outline

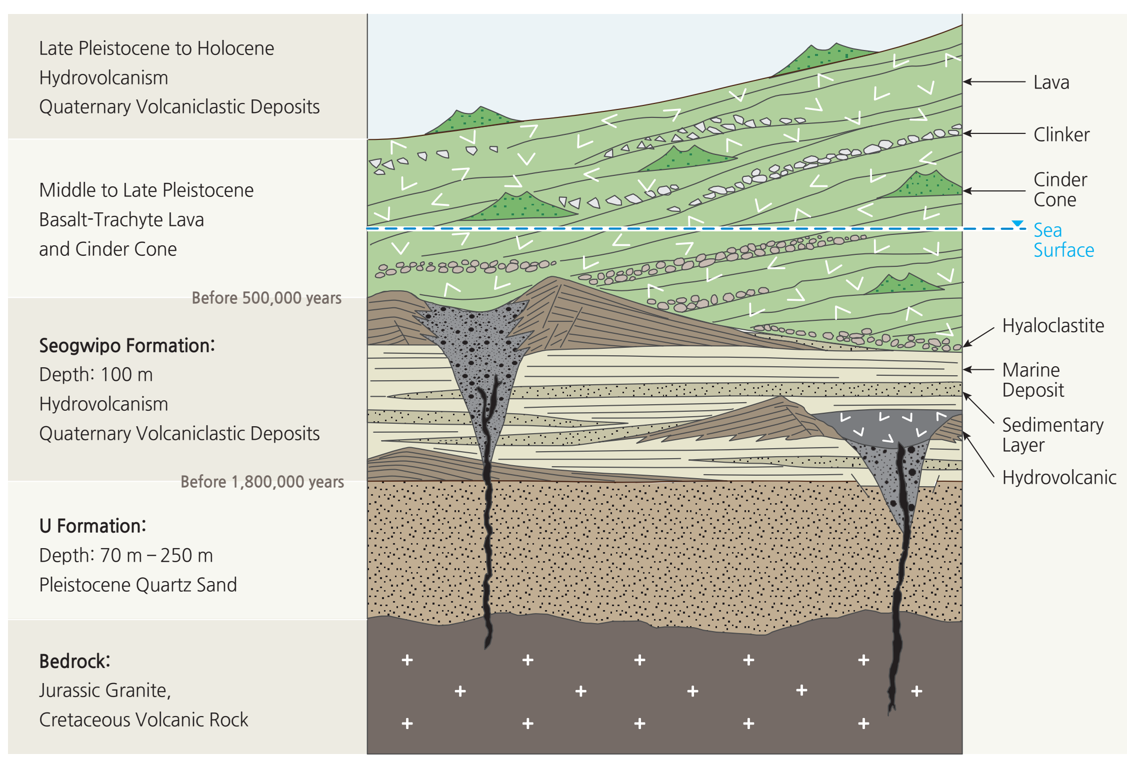
Division	Baekdusan	East Sea	Hallasan
AD 969-AD 1,903	Baekdusan Explosive Eruption and Cheonji Formation		
BP 9,300-BP 6,300		Ulleungdo Explosive Eruption	
500-25 Ka			Formation of Present Shape of Hallasan
610-20 Ka	Formation of Strato-volcanic Upper Part of the Baekdusan Area		
1,880-500 Ka			Sedimentation Volcanic Movement
2,900-500 Ka		Formation of Strato-volcanic Upper Part of Dokdo, Ulleungdo	
5.0-1.5 Ma	Formation of Shield Volcanic Lower Part of the Baekdusan Area		
8.1-3.7 Ma		Formation of Subma-rine Volcanic Part of Dokdo, Ulleungdo	
23-15 Ma		Opening of the East Sea	
28-13 Ma	Formation of Lava Plateau under the Baekdusan		

Geologic Map of Jejudo at a Scale of 1:250,000



Korea Institute of Geoscience and Mineral Resources

Schematic Cross-Sectional Diagram of the Strata in Jejudo



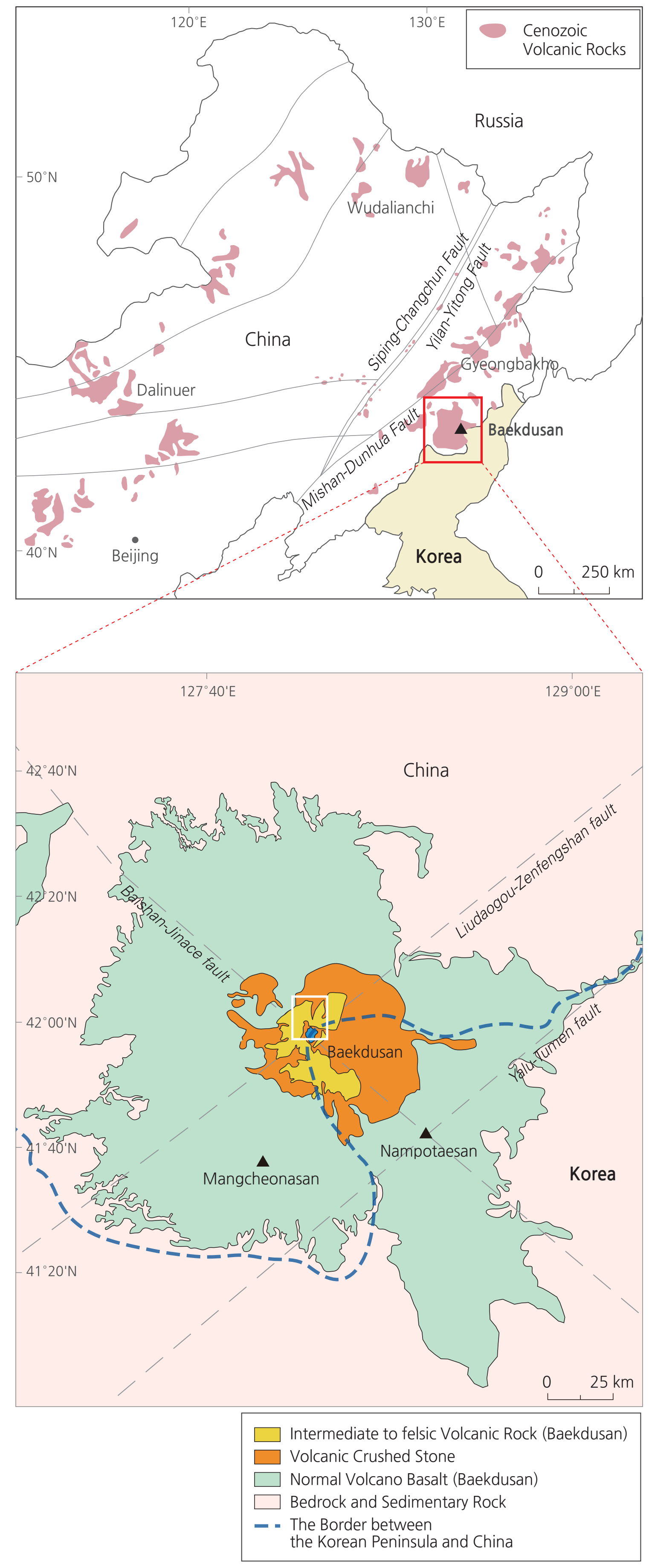
American Mineralogist (2011)

In the eastern coastal area, normal fault movement occurred due to the regional extension during the opening of the East Sea, resulting in the deepening of the East Sea. Together with the sinking of the East Sea, the Taebakesanmaek was formed by the uplift of the eastern coast tilting the Korean Peninsula westward. Unlike the East Sea, the Yellow Sea formed on submerged land due to sea-level rise during the interglacial period.

Jejudo shows different geological characteristics compared to Ulleungdo and Dokdo. It took about 1.8 million years for Jejudo to take its present shape. The volcanic activity of Jejudo can be divided into two stages: hydrovolcanic activity (1.88–0.5 Ma) and lava effusion on land (0.5 Ma–25 Ka). The hydrovolcanic activity occurred locally and sporadically in the first stage, and the lava effusion occurred actively and regionally on land, forming the present shape of Jejudo, in the second stage.

Jejudo was created from volcanic activity within the Yellow Sea continental shelf about 1.8 Ma. The initial volcanic activity of Jejudo was hydrovolcanism. During the Quaternary, sea level has fluctuated dramatically, varying between glacial periods and interglacial periods. Volcanic activity has alternately occurred on the seafloor and on land. Hundreds of tuff rings and tuff cones have been created by sporadic hydrovolcanic eruptions over a million years. During the Quaternary, as the Seogwipo Formation, a mixture of tuff and terrestrial and marine sedimentary rocks, accumulated over 100 m, Jejudo grew above the sea level and became an island. Since about 500 Ka, lava effusion has taken place predominantly on land. The Hawaiian eruptions created the lava plateau and shield volcano, and the Strombolian eruptions that occurred everywhere on the island created numerous cinder cones called "oreum." The current shape of Hallasan was formed approximately about 20 Ka. About 4–5 Ka, hydrovolcanic activity took place on the seashore again, forming oreums including Seongsan Ilchulbong and Songaksan; volcaniclastic sedimentary strata, such as the Sinyangri Formation and Hamori Formation, were formed in the surrounding areas. According to ancient documents, a lava eruption occurred on the hillside of Hallasan in 1002 CE. In 1007 CE, a hydrovolcanic eruption occurred on the seashore, but its location is not confirmed yet.

Regional Geologic Map around Baekdusan

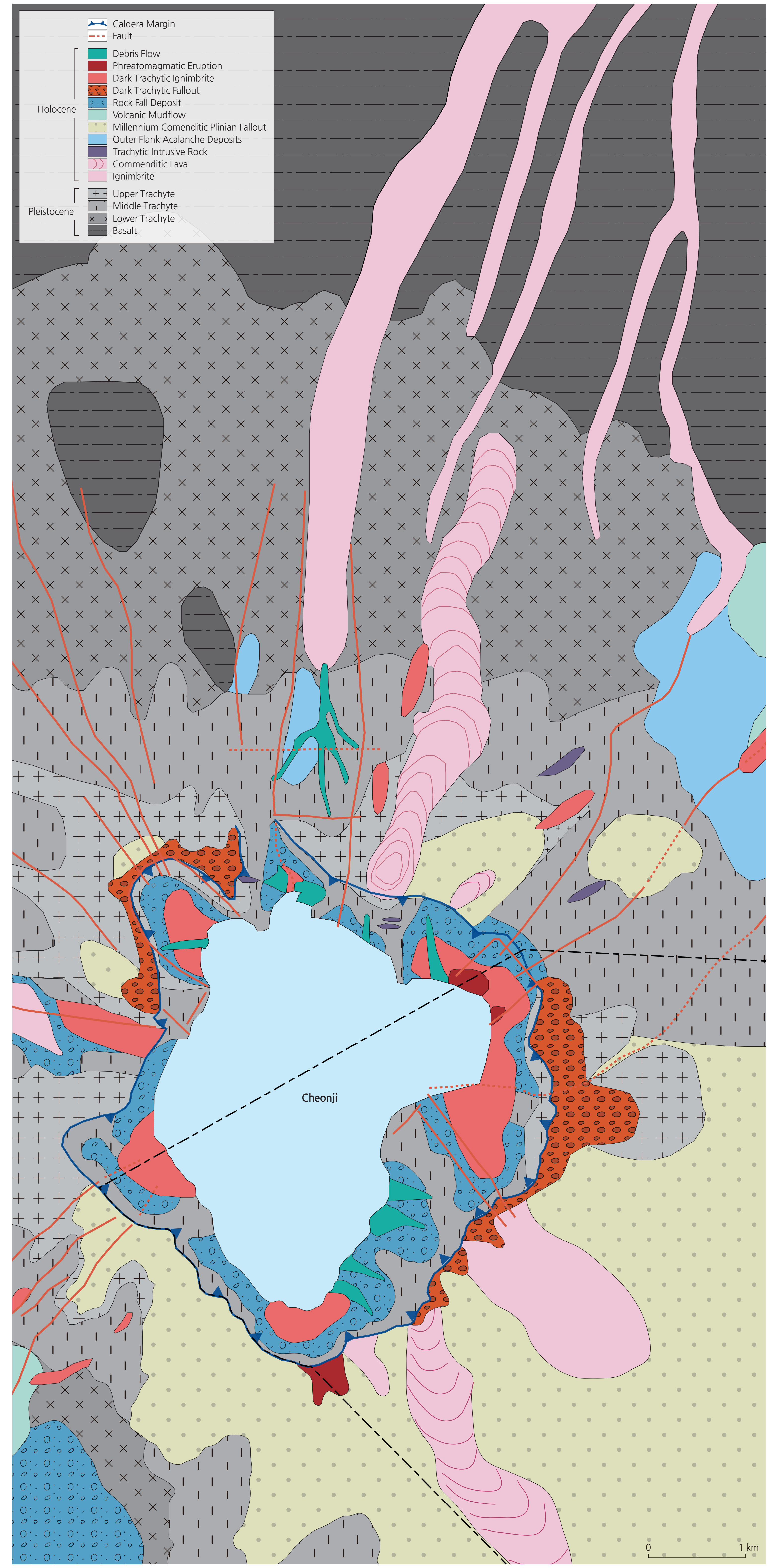


Lithos (2020)

The history of the volcanic eruption of Baekdusan is divided into four periods. In the first period, a basaltic lava plateau was formed by the fissure eruptions. In the second period, central eruptions occurred to form a shield volcano like Jejudo on the lava plateau. In the third period, explosive volcanic activity occurred as composition of magma was changed to felsic or intermediate, and as a result, a younger bell-shaped stratovolcano was built on the top of the shield volcano. During the Holocene (1690 BCE–1702 CE), explosive eruptions occurred. The eruption in 969 CE was a large-scale volcanic eruption estimated to be tens of times stronger than the Vesuvius eruption that destroyed Pompeii. Baekdusan is a very peculiar volcano developed inside the continent and its origin is not clearly identified.

The frequency of volcanic earthquakes increased sharply in the vicinity of Cheonji, the caldera of Baekdusan, from 2002 to 2006, then decreased. Currently, the frequency of volcanic earthquakes is similar to that of 1999–2001. All earthquakes that occurred during this period were caused by the activity of a magma chamber located 2–4 km underground. Recent studies have identified a magma chamber located 5–10 km underground. From 2002 to 2007, the volcanic body of Baekdusan expanded and rose about 10 cm. In 2004, the groundwater temperature around Cheonji rose from 69°C to 83°C. These pieces of evidence indicate that it is necessary to investigate the conditions and potential for eruption of Baekdusan.

Geologic Map of Baekdusan

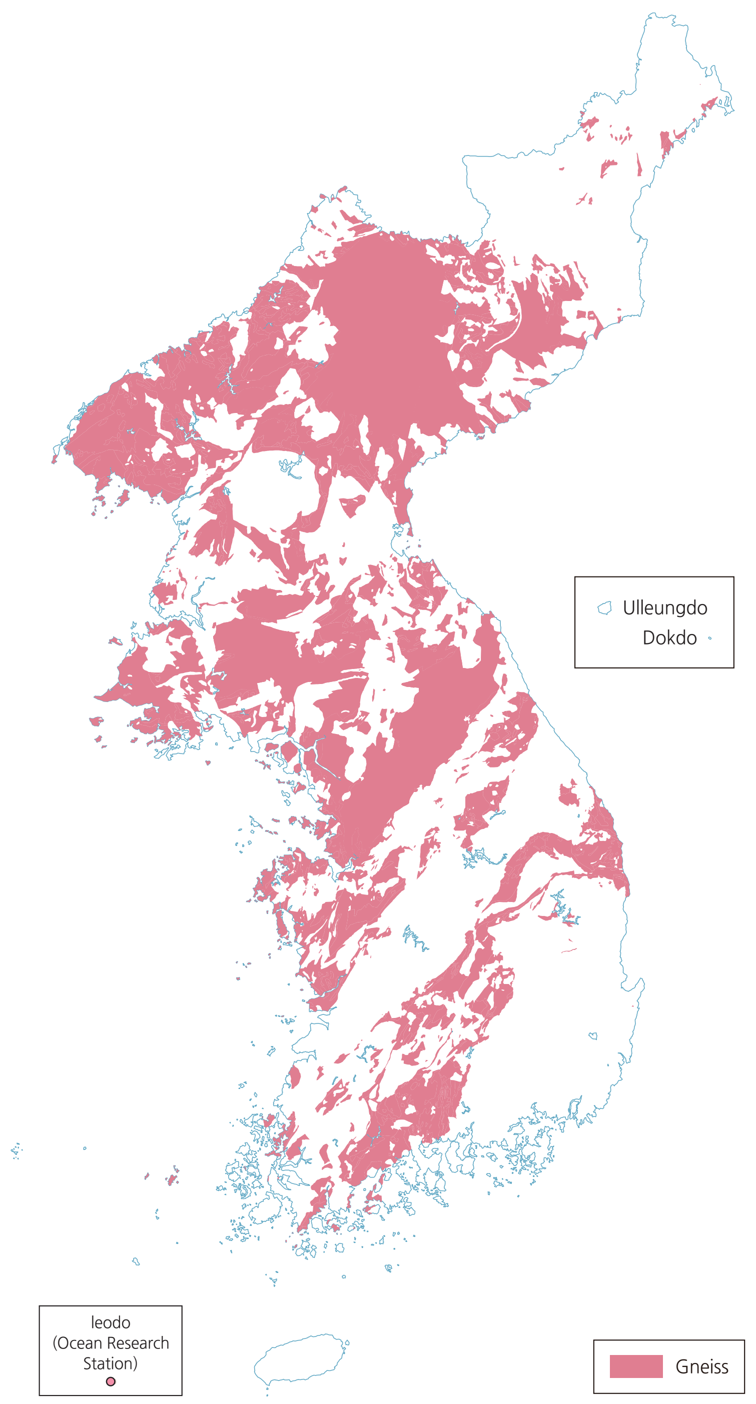


KIGAM (2020)

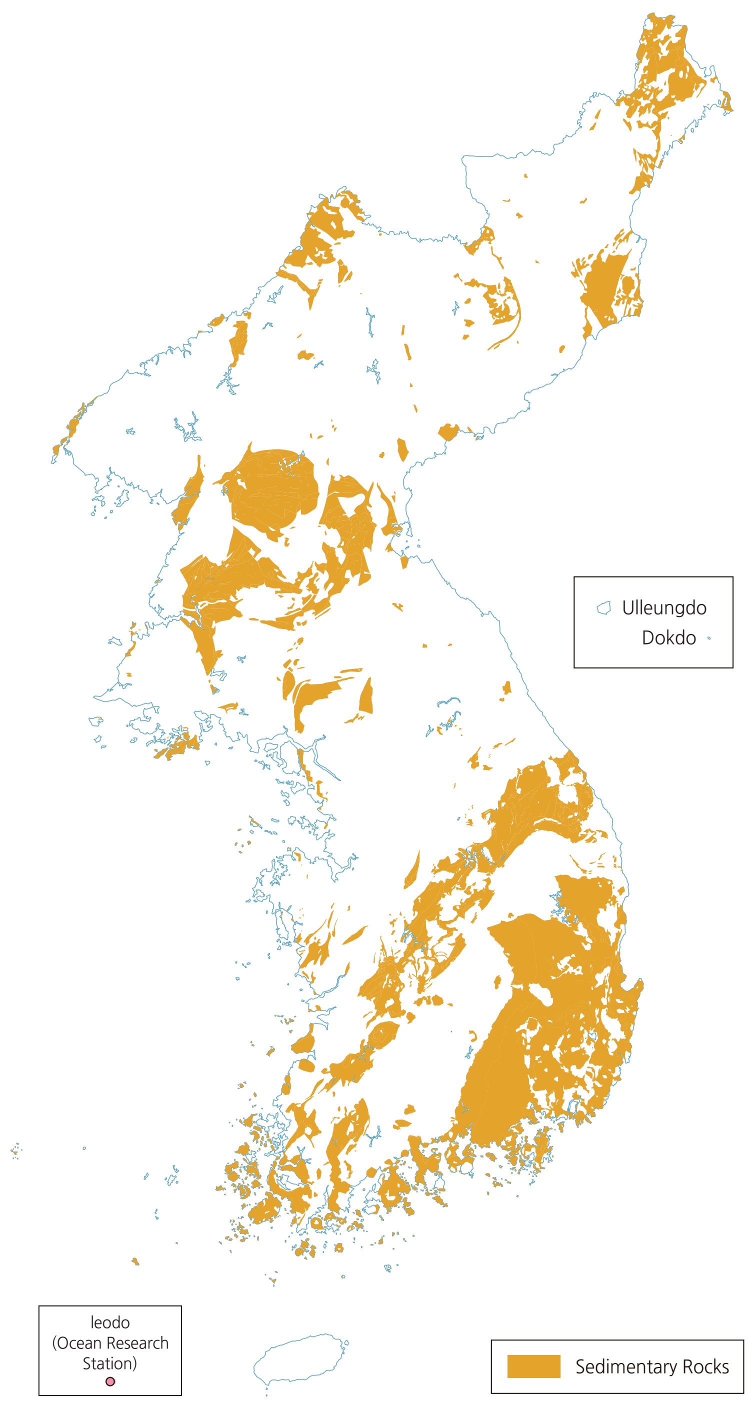
Representative Rocks on the Korean Peninsula

Distribution of Granite

Distribution of Gneiss



Distribution of Sedimentary Rocks



Selected from the Geological Map of Korea (1995)

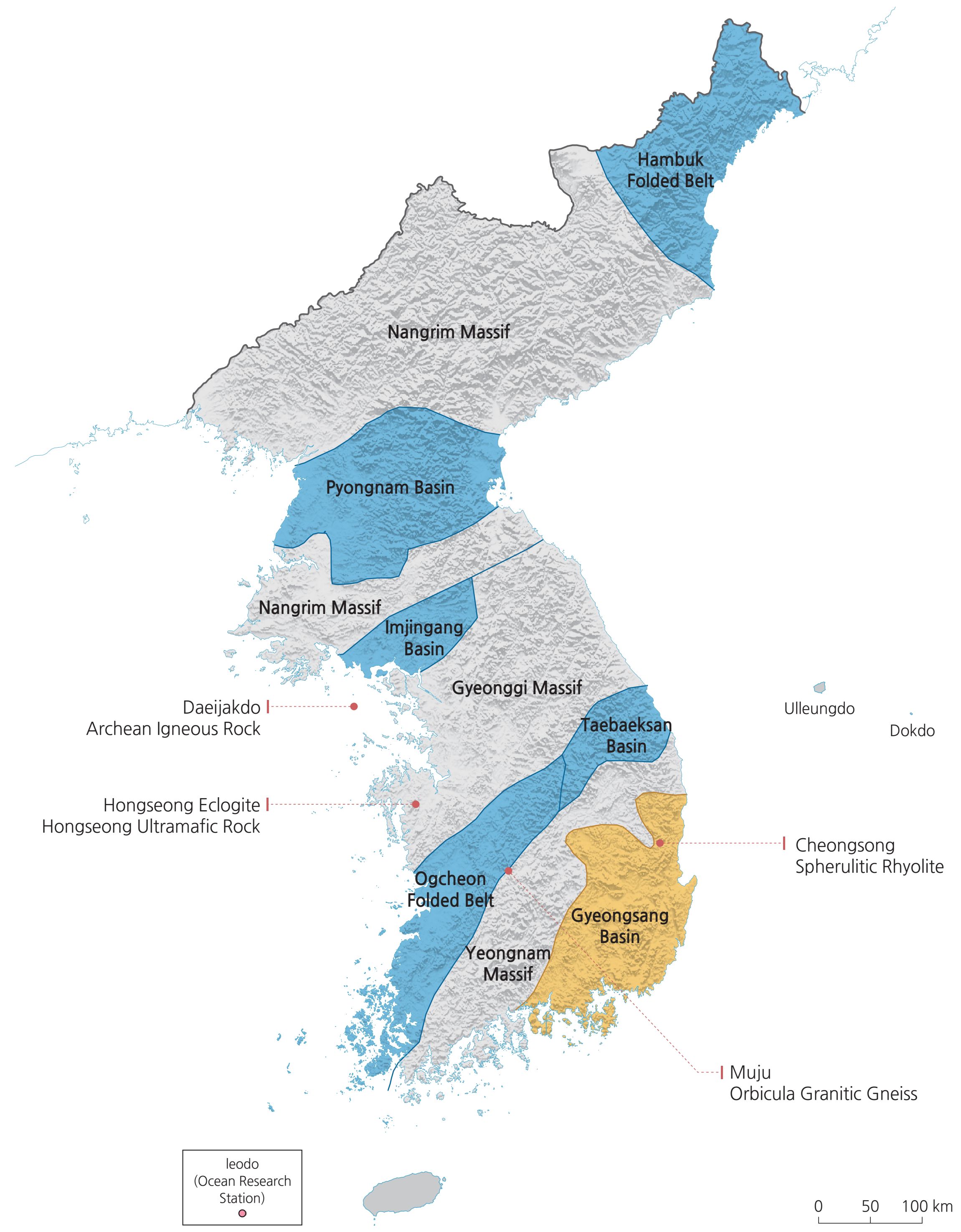
More than two-thirds of the Korean Peninsula consists of granite and metamorphic rocks. Jurassic Daebo granite and Cretaceous Bulguksa granite are the main types of granite on the Korean Peninsula. As the Jurassic granite formed at a deeper depth than the Cretaceous granite, the Jurassic granite is more coarse-grained than the Cretaceous granite. Most granites are milk-white in color, but alkali granites show a pinkish-red color.

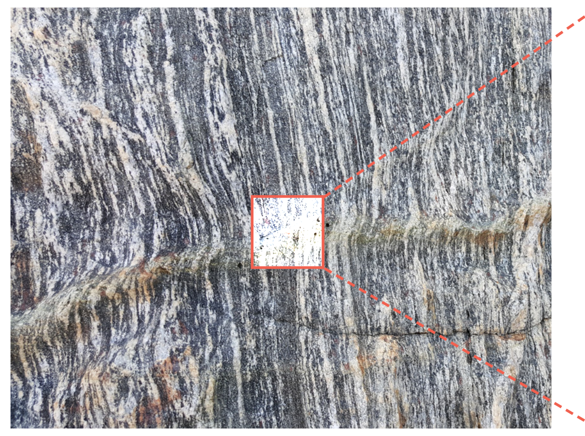
Metamorphic rocks consist mainly of gneiss and include schist, phyllite, quartzite, marble, and amphibolite, which formed by the metamorphism of shale, sandstone, limestone, and basic igneous rocks. The gneiss can be classified into sedimentary origin gneiss (paragneiss) and igneous origin gneiss (orthogneiss). The paragneiss commonly occurs as banded gneiss, whereas the orthogneiss occurs as porphyroblastic gneiss. These gneisses were transformed into migmatitic gneiss if they had been partially melted due to very high-grade metamorphism. Some porphyroblastic and banded gneisses were changed into augen gneiss due to strong shearing at a deep depth.

The main sedimentary rocks are shale, sandstone, conglomerate, and limestone. The Cretaceous basins, including the Gyeongsang Basin, consist of sedimentary rocks together with volcanic rocks made by cooling lava, and tuff (pyroclasitc rocks made by volcanic eruptions). These volcanic rocks and tuffs are mostly rhyolitic and andesitic rocks having acidic and intermdiate composition. The rhyolitic and andesitic volcanic and pyroclastic rocks constitute the stratovolcanic part of Baekdusan, Ulleungdo, and Dokdo. By contrast, the lava plateaus under Baekdusan and the shield volcanic part of Jejudo are composed of basic igneous rocks such as basalt and trachytic-basalt. Obsidian (volcanic glass)was formed by quick cooling of lava in Baekdusan, while scoria and pumice, which are pyroclastic rocks with many vesicles, are found in Baekdusan and Jejudo. Red scoria commonly occurs in and around cinder cones on Jejudo. The Korean side of Baekdusan is covered by white pumice, creating the illusion of a snowy white peak year-round. As such, Baekdusan translates to the mountain with a white head in Korean.

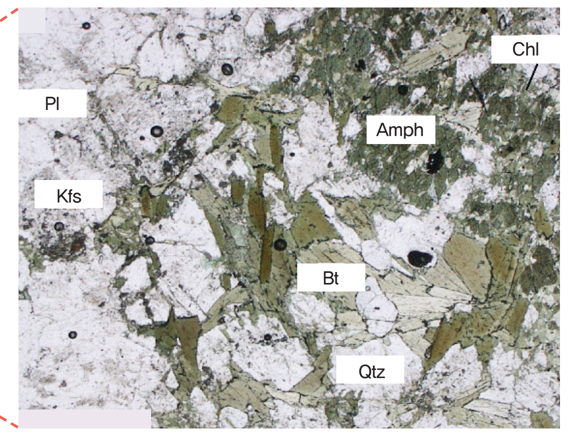
Representative Rocks of the Korean Peninsula

Distribution of Special Rocks

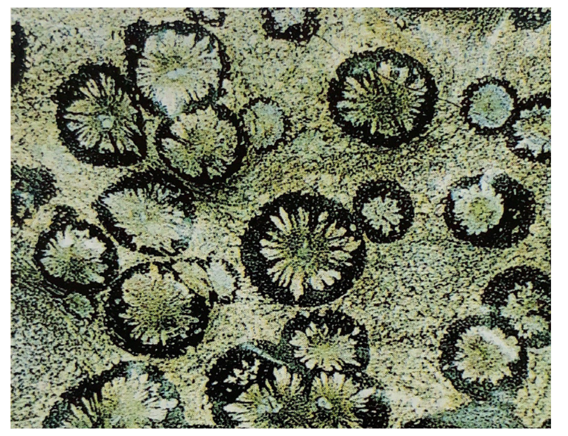




Migmatitic Gneiss at Daeijakdo

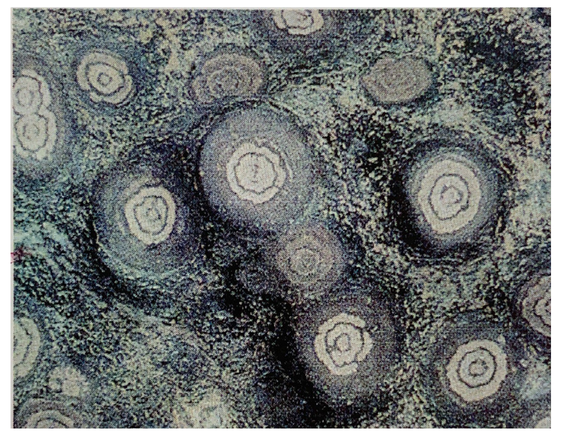


Thin Flakes of Daeijak Gneiss

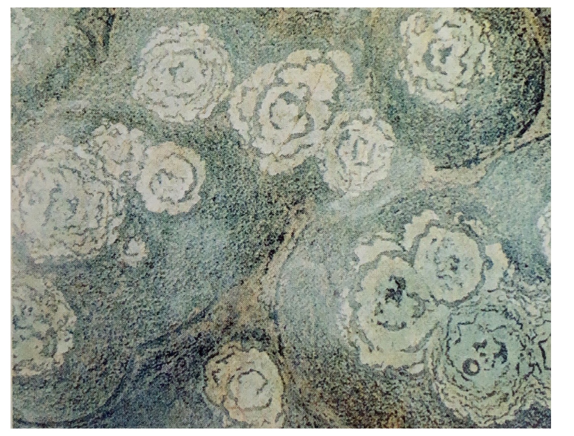


Chrysanthemum Type Spherulitic Rhyolites

Dahlia Type Spherulitic Rhyolites



Rose Type Spherulitic Rhyolites



Peony Type Spherulitic Rhyolites

The unique and important rocks on the Korean Peninsula are eclogite and serpentinized ultramafic rock in the Hongseong area. Eclogite can be formed by the metamorphism of mafic igneous rocks (basalt or gabbro) in the subducted oceanic or continental crust at a depth deeper than 50 km in the subduction zone or in the early stage of the collision zone.

Eclogite is a beautiful rock with red garnets in a green matrix consisting of omphacite. The occurrence of eclogite on a continental plate indicates that there was once an ocean and a subduction zone that disappeared by a continental collision during which the eclogite was pushed up to the surface from a deep depth.

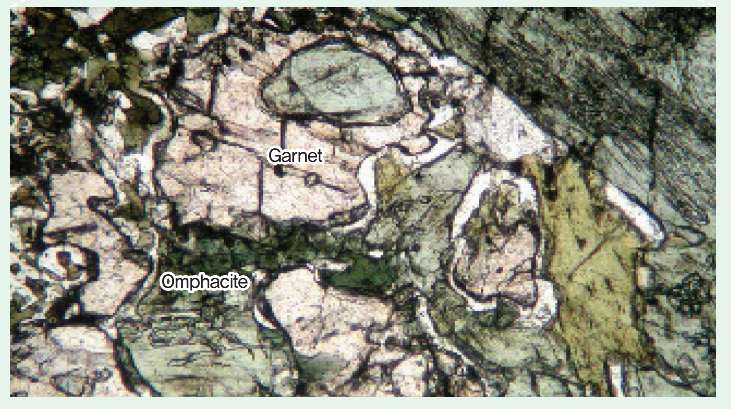
The serpentinized ultramafic rock found with the eclogite in the Hongseong area was originally lithospheric mantle formed at a depth of several tens of kilometers below the surface, and was uplifted to the surface during a continental collision. On the way to the surface, an ultramafic rock was metamorphosed into blueish-green serpentinite consisting of serpentine minerals formed by the reaction between the minerals in the ultramafic rock and water supplied from the surrounding area. Orthopyroxene often occurs as porphyroblast relicts within serpentinite because olivine and clinopyroxene in the ultramafic rocks are more easily metamorphosed into serpentine compared to orthopyroxene.

The oldest rock appearing in Korea is the tonalitic or granitic diorite granite, formed 2.58 Ga, appearing on Daeijakdo on the west coast. These granites were formed in the environment of continental volcanic arcs such as the Andes. In this rock, leucocratic layers made of quartz and feldspar and melanocratic layers made of amphibole appear irregularly alternating in various thicknesses.

The orbicular granite gneiss in Muju and spherulitic rhyolite in Cheongsong are rare, unique rocks on the Korean Peninsula. The Muju orbicular granite gneiss with orbicular texture formed from the metasedimentary xenoliths that sank within the parent magma of leucocratic mica granites. The xenoliths were metamorphosed into orbicules due to thermal metamorphism at around 1867±4 Ma. The orbicular granite gneiss in Muju is the only orbicular rock formed by metamorphism in the Korean Peninsula.

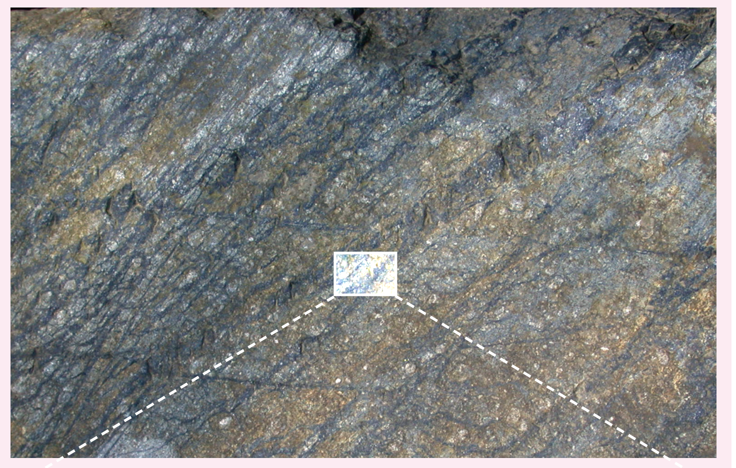
Spherulitic rhyolites found in Cheongsong formed during the fast cooling of dykes at a shallow depth. The chrysanthemum, dandelion, dahlia, and sunflower types were formed when specific minerals grew in a particular direction during fast cooling, while the peony, rose, and innominate types were formed by the growth of minerals in layers due to relatively slow diffusion during cooling. The apricot-patterned spherulites were formed during a medium cooling rate. The spherulitic rhyolites formed between 50–48 Ma.

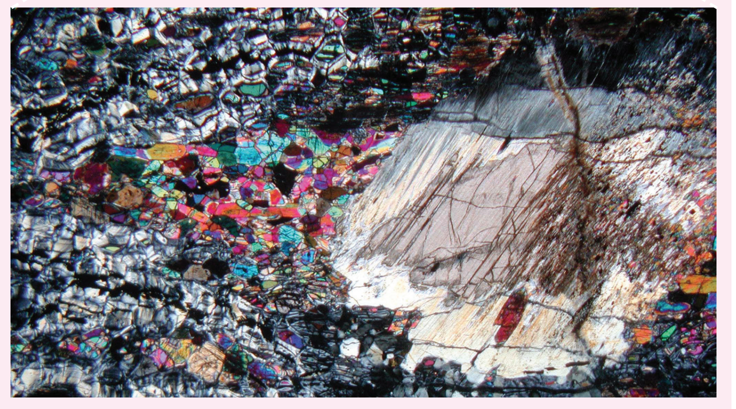
Appearance of Eclogite



Microphoto of Eclogite

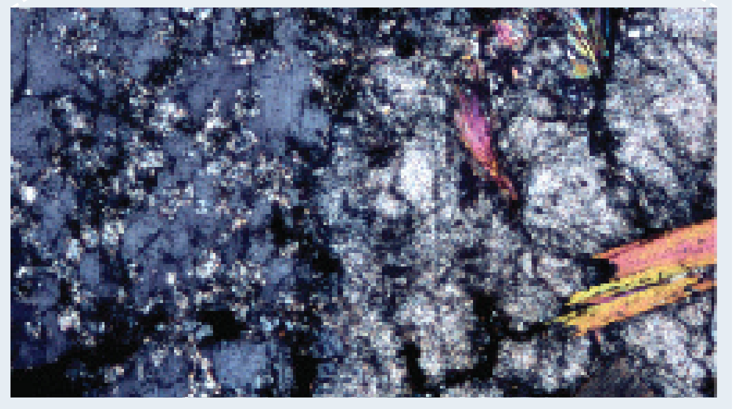
Appearance of Ultramafic Rock





Microphoto of Ultramafic Rock

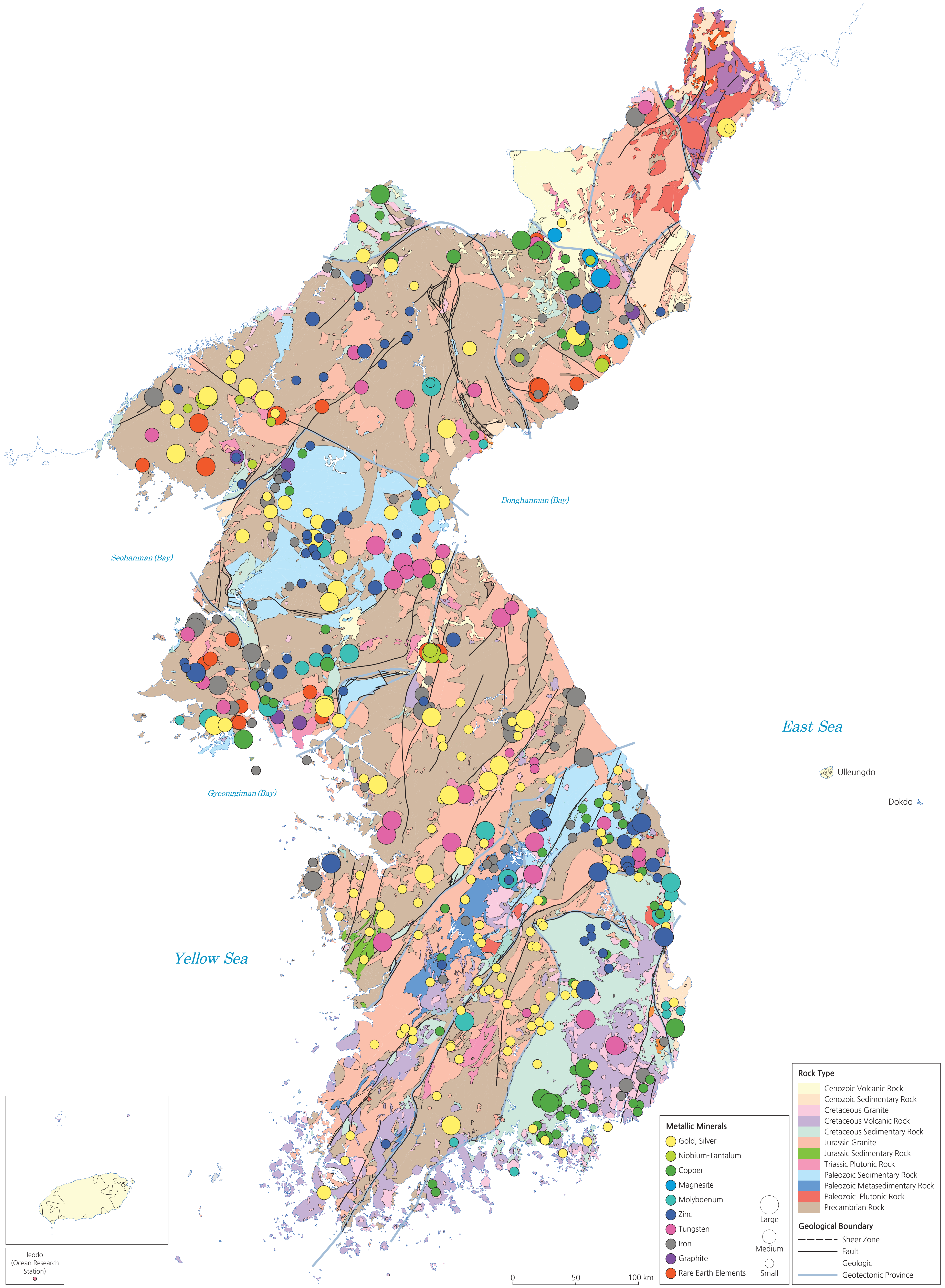
Appearance of Muju Orbicular Granitic Gneiss



Microphoto of Muju Orbicular Granitic Gneiss

Geological Resources

Major Metallic Minerals on the Korean Peninsula



Korea Institute of Geoscience and Mineral Resources (2020)

The main mineral resources on the Korean Peninsula are metal, nonmetal minerals, placer, fossil fuel, nuclear fuel, and building stone/aggregate. Proterozoic ore deposits in the southern region of the Korean Peninsula include the banded iron formation in Seosan; the titanium-bearing-iron deposit in Gonamsan-Soyeonpyeongdo-Boleumdo; the Tungsten, tin, and gold deposits in Bonghwa-Uljin-Sangdong; ilmenite deposits in Hadong-Sancheong; the iron deposits in the Chungju-Jungwon; and the uranium deposits in the Ogcheon Supergroup.

Proterozoic ore deposits in the southern region of the Korean Peninsula include the banded iron formation in Seosan; the titanium-iron bearing deposit in Gonamsan(Yeoncheon)-Soyeonpyeongdo-Boleumdo; the tungsten, tin, and gold deposits in Bonghwa-Uljin-Sangdong; ilmenite deposits in Hadong-Sancheong; the iron deposits in the Chungju-Jungwon; and the uranium deposits in the Ogcheon Supergroup. In the northern region of the Korean Peninsula, a banded iron formation developed in the Musan and Oryong mines of the Archean Musan Group. Proterozoic ore deposits include the copper deposits in the Hyesan Youth and Gabsan mines, lead-zinc mine in Geomdeok and magnesite mines in Ryongyang and Daeheung. REE (rare earth elements) deposit related to the Protozoic Sakju Complex in Jeongju was reported as a world-class deposits.

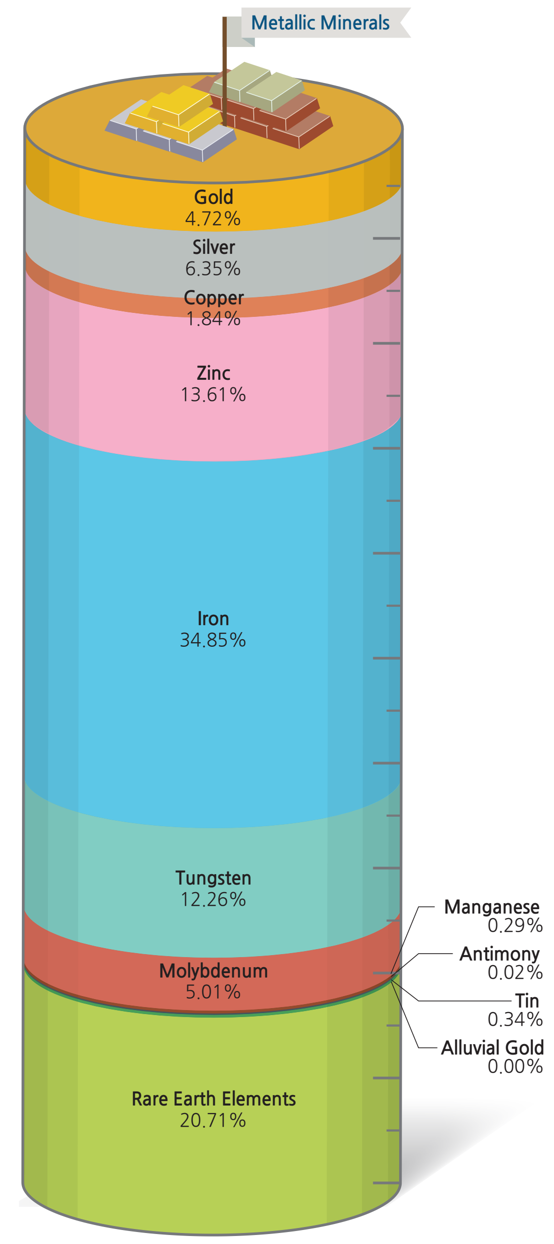
Anthracite is embedded in the late Paleozoic Pyeongan Supergroup and middle Mesozoic Daedong Supergroup. In the southern region of the Korean Peninsula, the mining regions for Paleozoic anthracite are Samcheok, Gangneung, Jeongseon, Pyeongchang, Yeongwol, Danyang, Mungyeong, Boeun, and Boseong, and mining regions for Mesozoic anthracite are Boryeong, Buyeo, Kimpo, and Yeoncheon. In the northern region of the Korean Peninsula, anthracite is concentrated in Pyeongannam-do, and also a number of coal mines are being developed in Hamgyeongbuk-do and Hamgyeongnam-do. Uranium deposits are mainly distributed in Pyeongsan, Suncheon, and Bakcheon. These deposits seem to have developed in connection with the development of anthracite. The Hoam, Bumbuk, and Sinseong Niobium-tantalum deposits, which is related to alkaline intrusive rocks in the late Paleozoic and early Mesozoic, are in the Pyeonggang area.

The Mesozoic mine includes Jurassic pegmatite ore deposits in the Gyeonggi Massif, which includes feldspar, columbite-tantalite, molybdenite, fluorite, uranium-bearing minerals, and beryl. The Jurassic and Cretaceous gold and/or silver mines are mostly hydrothermal vein type. Representative gold and/or silver mines are located in Mugeug, Bupyeong, Imcheon, Weolyu, Jeonjuil, Tongyeong, and Geochang. Tungsten-molybdenite also formed near Mesozoic granites during the Jurassic and Cretaceous. Copper, lead, and zinc deposits were formed by hydrothermal alteration related to the Cretaceous igneous activity. Cretaceous iron mines are located in the Gyeongsang Basin. Talc deposits formed by hydrothermal metasomatism are classified into two types: one type is of ultramafic origin and can be found in the Pyeongan and Cheongdang mines and the other type is of dolomite origin and can be found in the Dongyang, Pungjeon, and Chungju-Jaeil mines. The kaolinite-pyrophyllite deposits were formed by hydrothermal alteration of tuff, felsite, and andesite and are distributed in the Miryang-Yangsan-Changwon-Tongyeong region and the Jindo-Wando-Haenam-Yeongam region.

In the northern region of the Korean Peninsula, the mines related to Mesozoic igneous activity occur as skarn and vein-type deposits associated with various mineral resources, including gold. Representative gold and silver deposits can be found in the Unsan mine, the Daeyubong mine, the Seoncheon mine, the Holdong mine, the Suan mine, and the Rakyeon mine. Tungsten deposits are found in the Mannyeon mine, the Yangdeuk mine, the Jangjin mine, and the Beobdong and Goseong mines. Molybdenite mines include Ryonghong and Sakju mines and Gamuri and Yangam mines.

In the southern region of the Korean Peninsula, Cenozoic deposits can be found in the Wondong mine, the Dongjeom mine, and the Geumryeong mine. The mines contain skarn and porphyry type deposits, including various metals. The zeolite, bentonite, and acidic bentonite occur along the tuff stratigraphic horizon within the Tertiary sedimentary formations around the Pohang-Guryongpo-Ulsan.

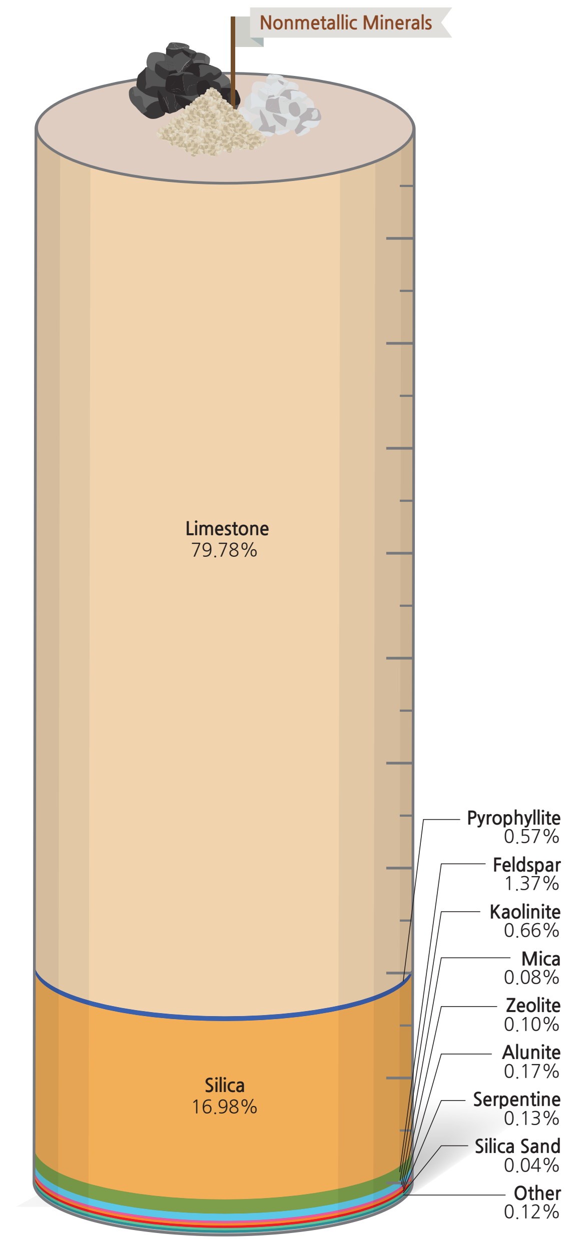
Metallic Mineral Reserves in South Korea



(Thousand Tons / Placer Au: kg)

Metallic Minerals	Grade	Reserves
Gold	Au 7.5 g/t	5,925.1
Silver	Ag 194.3 g/t	7,959.3
Copper	Cu 2.2%	2,307.4
Zinc	Pb 2.5%, Zn 2.7%	17,067.9
Iron	Fe 40%	43,702.0
Tungsten	WO_3 0.5%	15,373.0
Molybdenum	MoS_2 0.3%	6,277.5
Manganese	Mn 19.6%	360.0
Antimony	Sb 2.1%	22.0
Tin	Sn 1.9%	436.0
Placer Gold	Au 0.9 g/m^3	2,857.2
Rare Earth Elements	R_2O_3 2.1%	25,972.0
Total		125,402.2

Nonmetallic Mineral Reserves in South Korea



(Thousand Tons)

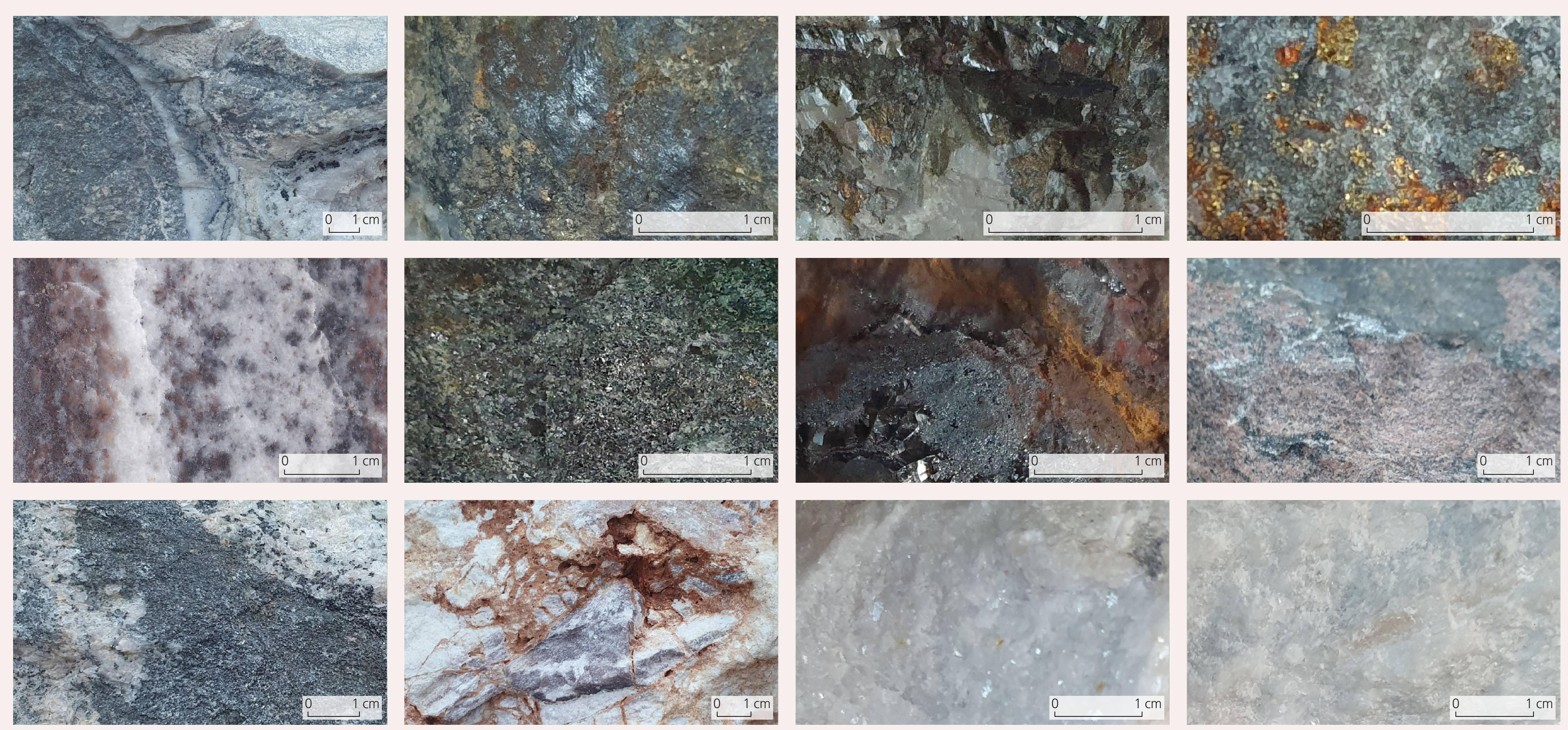
Nonmetallic Minerals	Reserves
Limestone	13,807,059.0
Pyrophyllite	98,482.2
Silica	2,939,109.9
Feldspar	236,433.7
Kaolinite	114,041.5
Mica	14,291.8
Zeolite	16,942.8
Alunite	29,297.2
Serpentine	22,509.9
Silica Sand	6,446.7
Other	21,349.2
Total	17,305,963.9

Korean Mineral Resources Cooperation (2020)

Representative Metallic and Nonmetallic Minerals

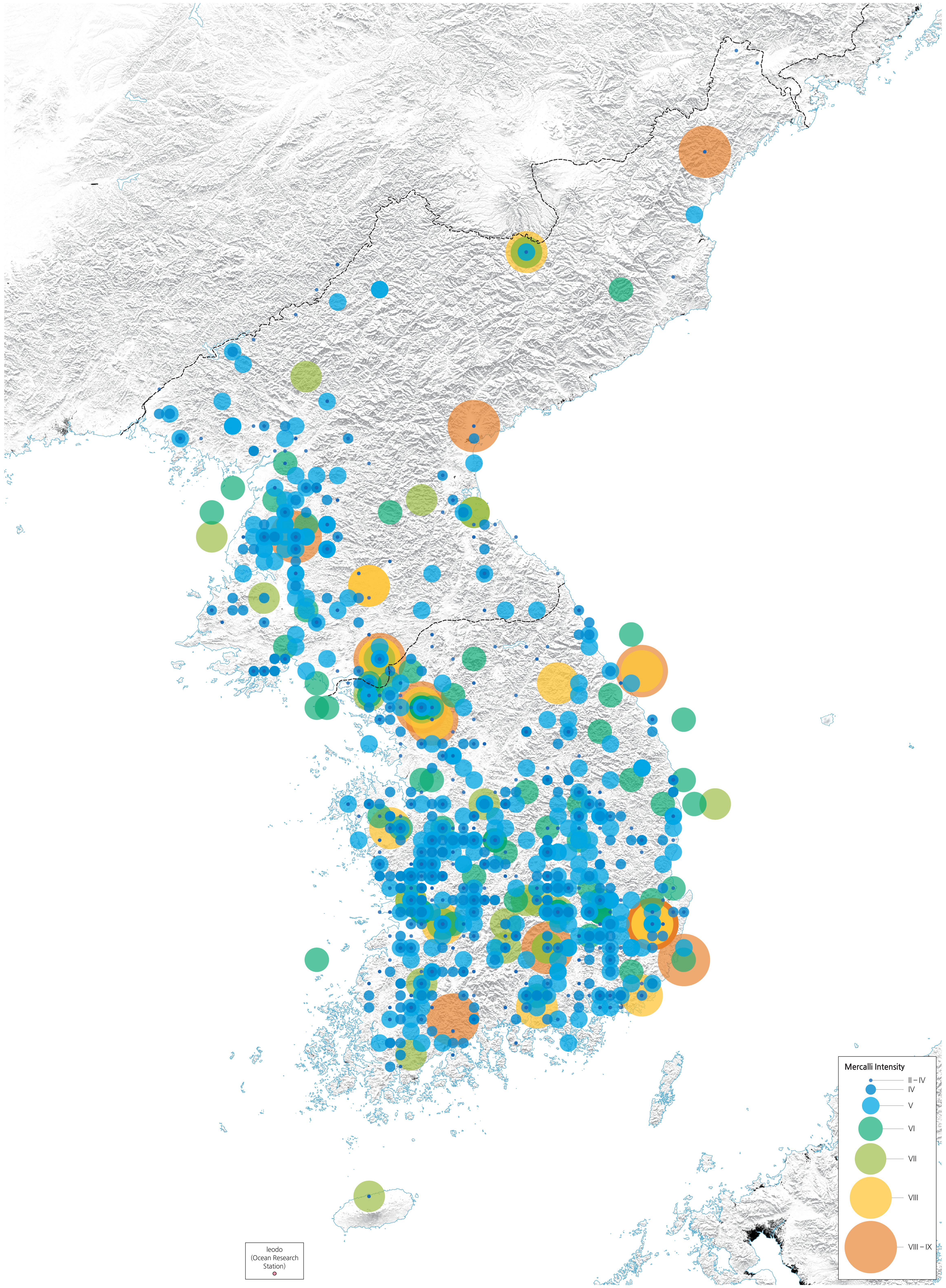
❶	❷	❸	❹
❺	❻	❼	❽
❾	❿	⓫	⓬

❶ Gold and Silver in Haenam
❷ Gold and Silver in Unsan
❸ Gold and Silver in Holdong
❹ Copper in Huchang
❺ Lead and Zinc in Geomdeok
❻ Iron in Musan
❼ Iron in Jaeryung
❽ Rare Earth Elements in Hongcheon
❾ Iron and Rare Earth Elements in Chungju
❿ Lithium in Uljin
⓫ Magnesite in Daeheung
⓬ Magnesite in Ryongyang



Earthquakes

Historical Earthquakes on the Korean Peninsula



Korea Meteorological Administration (2020)

The Korean Peninsula had long been recognized as relatively safe from strong earthquakes compared to other countries such as Japan and Taiwan. However, since the Korea Meteorological Agency (KMA) began to officially record seismic activity in 1978, there has been strong seismic activity, including the earthquakes at Hongseong-gun (a magnitude of 5.0) in 1978, Yeongwol-gun (a magnitude of 4.5) in 1996, Odaesan (a magnitude of 4.8) in 2007, Gyeongju (a magnitude of 5.8) in 2016, and Pohang (a magnitude of 5.4) in 2017. Further investigation using Korean historical records indicates that there were even larger magnitude earthquakes in the past. Thus, this evidence leads to the conclusion that the Korean Peninsula is not a seismically-safe region.

The epicenters of historical earthquakes with seismic intensity greater than a magnitude of 5.0 are mostly located in the south of Chungcheong-do and the western Pyeongan-do. These historical earthquakes caused casualties, damage to castles, and ground ruptures, leading to tsunamis. For example, during the 21st year of the reign of King Injo (1643 CE), a strong earthquake in Ulsan collapsed castle walls and caused a tsunami. Such historical information warns of the necessity of increased preparation for future earthquakes and tsunamis on the Korean Peninsula.

The observation of seismic activity officially began after the installation of a mechanical seismograph at Incheon in 1905; later, seismographs were installed in five more stations in Seoul, Busan, Daegu, Pyongyang, and Chupungryong. In 1937, quantitative seismic observations of seismic activity on the Korean Peninsula began at these six stations. As of 2020, two major seismic agencies, the KMA and KIGAM (Korean Institute of Geology and Mining), are operating 260 digital seismic stations to monitor seismic activity on the Korean Peninsula.

After introducing instrumental seismic observation in 1978, the strongest recorded earthquake (a magnitude of 5.8) occurred in September 2016 in an area located 8 km south-south-westward from Gyeongju. The second strongest earthquake occurred in November 2017 in Pohang, with a magnitude of 5.4. The next notable earthquakes occurred in May 2004 with a magnitude of 5.2 in Uljin-gun, Gyeongsangbuk-do, and in September 1978 in Sokrisan. Unofficially, an earthquake occurred in January 1980 in the Uiju-Sakju-Gwiseong area in Pyunganbuk-do, with a magnitude of 5.3.

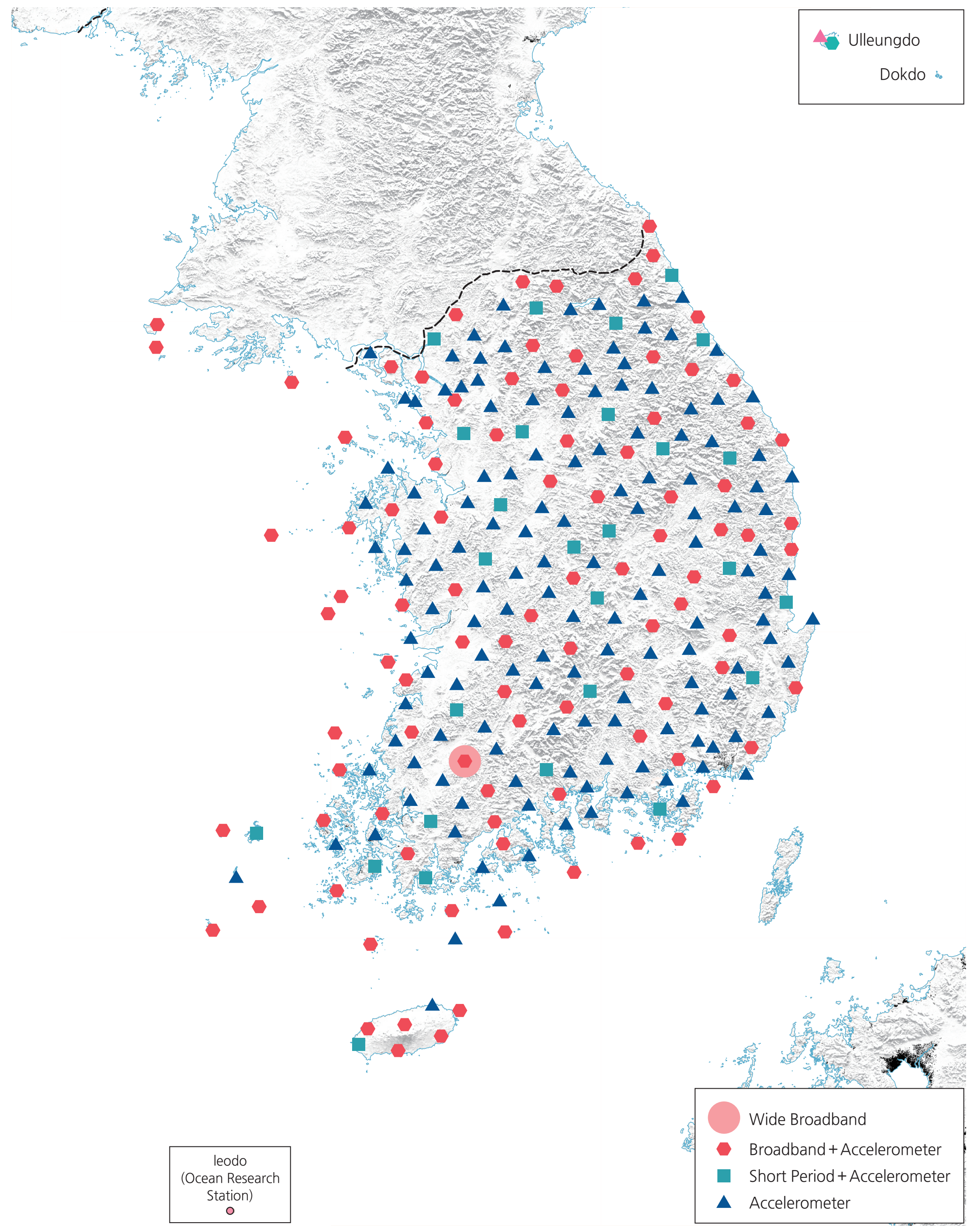
Earthquake Magnitude, Seismic Intensity, and Expected Damages

Richter Magnitude	Modified Mercalli Scale	Expected Damage in Populated Area
1.0 – 2.9	I	Not felt except by a very few under especially favorable conditions.
3.0 – 3.9	II, III	Felt only by a few persons (II). Felt quite noticeably by persons indoors (III).
4.0 – 4.9	IV, V	Felt indoors by many and felt outdoors by few. Dishes, windows, doors disturbed(IV). Felt by nearly everyone. Some dishes, windows broken (V).
5.0 – 5.9	VI, VII	Slight damage (VI), Considerable damage in poorly built or badly designed structur (VII).
6.0 – 6.9	VIII, IX	Considerable damage in poorly built or badly designed structures (VIII). Considerable damage in ordinary substantial buildings with partial collapse (IX).
7.0 –	X, XI, XII	Considerable damage in ordinary substantial buildings with partial collapse (X). Most masonry and frame structures destroyed (XI). Damage total (XII).

* Mercalli Intensity is determined by degree of damage and movement of ground.
This Scale is dependent on earthquake magnitude, epicentral distance, and observer's location (Indoor or Outdoor).

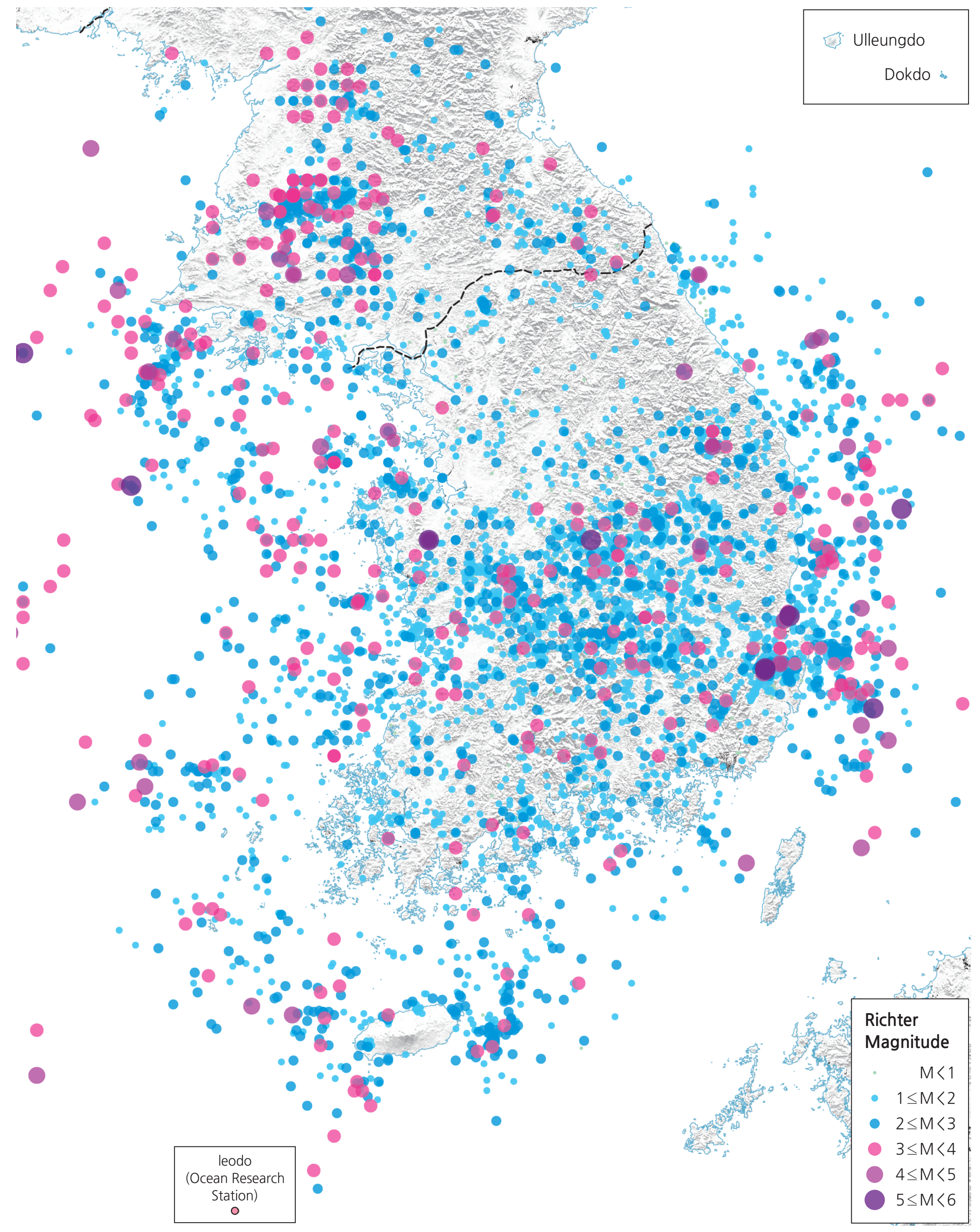
USTGS (United States Geological Survey)

Seismic Network and Seismic Stations



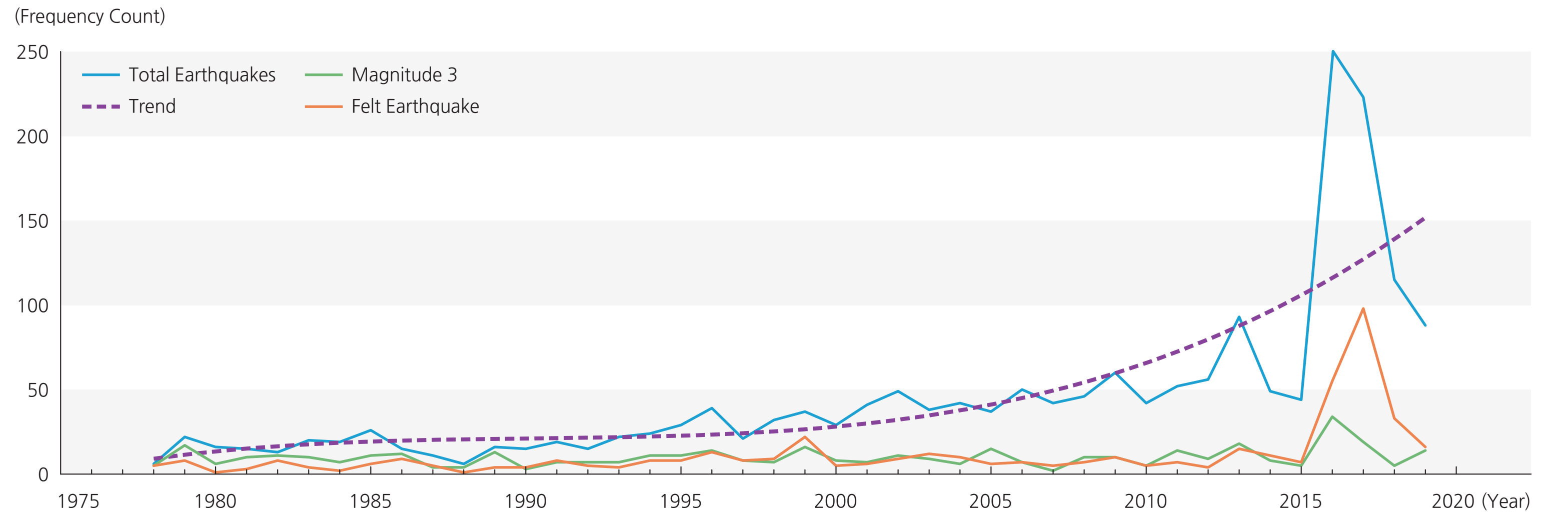
Korea Institute of Geoscience and Mineral Resources (2020)

Instrumental Earthquakes



National Volcano and Earthquake Center (2020)

Instrumental Earthquake Trend in South Korea



National Volcano and Earthquake Center (2020)

The instrumental earthquake data indicate that the epicenters of most earthquakes are located in seawater around the Korean Peninsula and the regions to the south of western Gyeonggi-do and Chungcheong-do. This result is similar to the distribution pattern of the epicenters of historical earthquakes mentioned above. Since instrumental seismic observation began in 1978, the frequency of seismic activity has increased. If felt earthquakes, those with a magnitude greater than 3, are considered, frequency has remained the same from 1978 to the present. However, the frequency of felt earthquakes increased temporarily between the Gyeongju earthquake in 2016 and the Pohang earthquake in 2017.

Based on both the instrumental and historical data, the probable maximum magnitude of an earthquake on the Korean Peninsula is estimated to lie between 6.9 and 7.5, with a recurrence period of a few hundred years.

International Cooperation

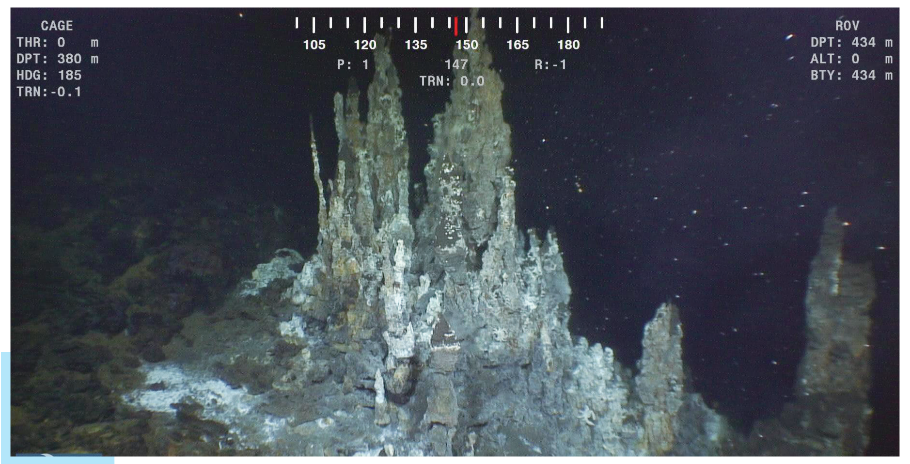
Recently geological surveys have been actively carried out in foreign countries by the Korea Institute of Ocean Science and Technology, the Korea Institute of Geoscience and Mineral Resources, and the Korea Polar Research Institute. In 1990, the Korea Ocean Research and Development Institute began to pursue a fullscale research project on deep ocean mineral resources, and in 1992 began efforts to acquire mining rights for manganese nodules in the deep oceans. In 1994, South Korea became the seventh country in the world to acquire mining rights for manganese nodules in the Clarion-Clipperton sea sector in the Pacific Ocean. Exploration efforts were expanded to include searches for manganese pavements, submarine hydrothermal deposits, and other deep-sea resources. South Korea further obtained exploration rights for submarine hydrothermal deposits in the EEZ areas of Tonga and Fiji and acquired mining rights for submarine hydrothermal deposits in the open sea within the Indian Ocean. In 2012, Korea expanded its research area from the eastern Pacific Ocean and southwestern Pacific Ocean to the Indian Ocean.

The oceanographic research ship *Onnuri* (1,442 tons), which can carry out ocean exploration, has made it possible for the Korea Institute of Ocean Sciences and Technology to pursue full-scale deep sea mineral resource exploration projects. The *Onnuri* was launched in 1992 and played an important role in acquiring mining rights for manganese nodules in the Pacific Ocean (1994), exploration rights for submarine hydrothermal deposits in Tonga (2008) and Fiji (2011), mining rights for submarine hydrothermal deposits in the Indian Ocean (2012), and manganese pavement deposits in the northern Atlantic Ocean. In 2016, a new oceanographic research ship *Isabu* (5,894 tons) was launched to conduct exploration activities in the deep ocean depository.

After acquiring exploration rights for a submarine hydrothermal deposit in the EEZ of Tonga in 2008, five leading domestic enterprises participated in the exploration to evaluate the reserve of deep sea mineral resources during the period of 2009 to 2012, initiating the first case of commercial exploration led by a private organization.

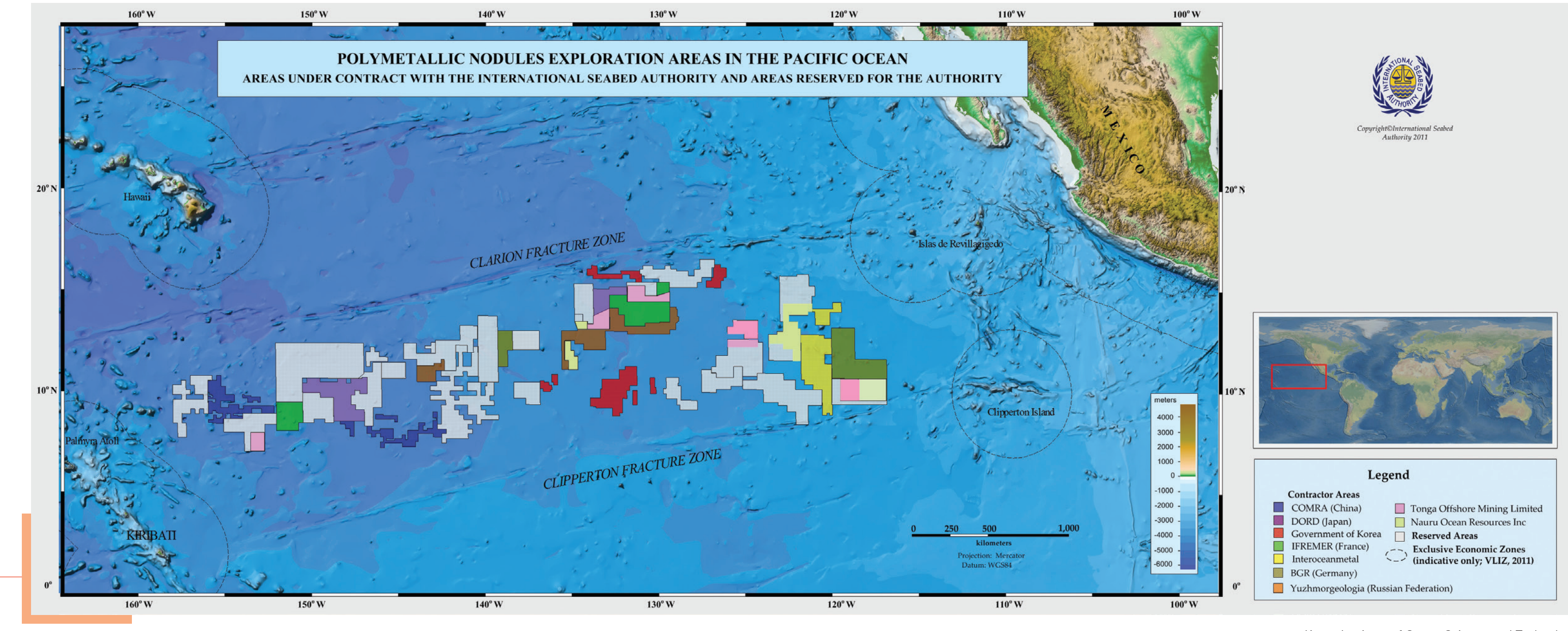
Through efforts during the last 30 years, the total area acquired for mining and exploration in the eastern and southern Pacific Ocean and the Indian Ocean is 112,000 km^2, which is 1.1 times larger than the area of South Korea.

Hydrothermal Deposit Appearing on an Oceanic Ridge



The Comprehensive Oceanic Research Ship, *Onnuri*

Exploration Area for the Northeast Pacific Manganese Nodule



Korea Institute of Ocean Science and Technology

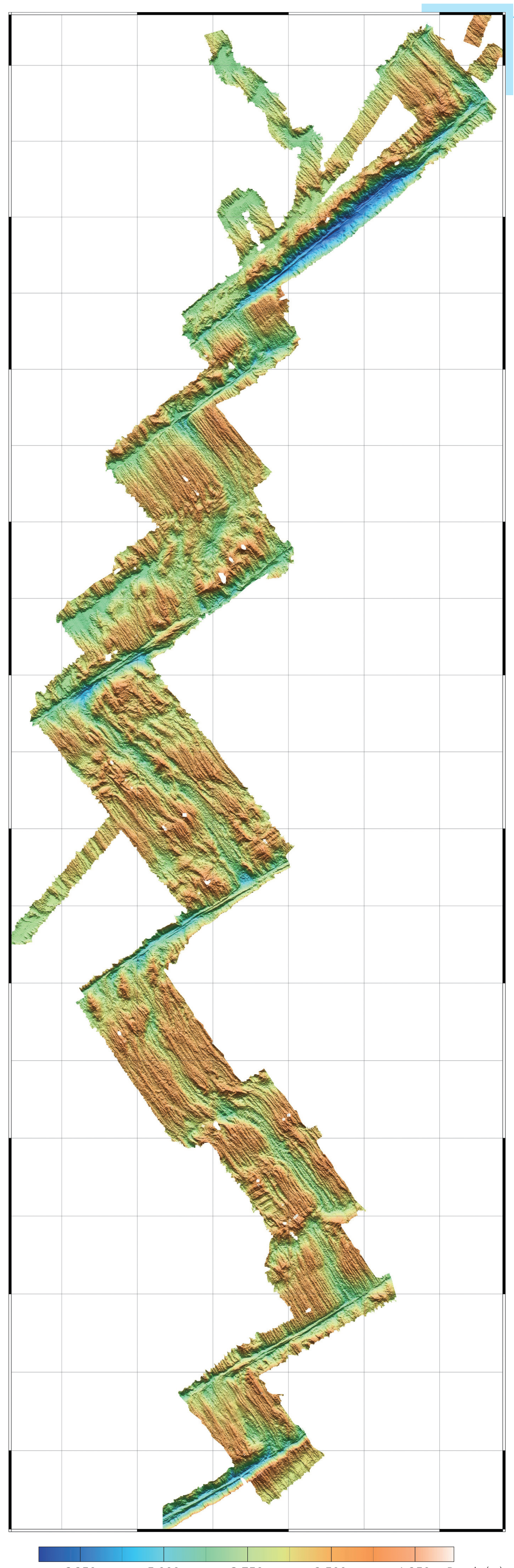
Overseas Geology and Mineral Resources Survey

The Korea Institute of Geoscience and Mineral Resources carried out the project titled Geological Mapping of the Suai District in Timor-Leste over a period of two and a half years from Dec. 29, 2010 to June 30, 2013, making a geologic map of the Fohorem area in the Suai district located in southwestern Timor-Leste. This is the first regular geologic map made for a foreign country by Korean geologists. The Timor-Leste is located in the intersection point of Indo-Australian, Pacific, and Asian plates. The geology of the Fohorem Quadrangle provides valuable geologic information because of its unique location at the collision boundary between the Banda Arc and Australian plate.

In 1987, the Polar Research Laboratory was established at the Korea Ocean Research and Development Institute. The Antarctic King Sejong Station and the Arctic Dasan Station were inaugurated in 1988 and 2002, respectively. After that, the Korea Polar Research Institute was established in 2004 and the Antarctic Jang Bogo Station was built in 2014. At the King Sejong and Jang Bogo Stations, researches on weather, atmosphere, glaciers, marine and terrestrial ecosystems, and species living under extreme conditions in Antarctica were conducted. Recently, at the Jang Bogo Station, researches on paleoclimate and glaciers have been carried out along with geochronological and geophysical studies on Antarctic inland and a route exploration toward the South Pole accompanied with seismic survey.

The Jang Bogo Station is located in the Terra Nova Bay in northern Victoria Land. Northern Victoria Land consists of the Wilson Terrane, the Bowers Terrane, and the Robertson Bay Terrane, which were juxtaposed in the early Paleozoic era. The Korea Polar Research Institute conducted geological studies on the formation and evolution of these terranes and the active volcanoes in northern Victoria Land. Detailed geological maps around the Jang Bogo Station were completed in 2018. Along with these, antarctic meteorite exploration is being conducted, and based on this, research on the formation of the solar system is also being conducted.

Exploration Area for the Submarine Hydrothermal Deposits along the Central Indian Ridge



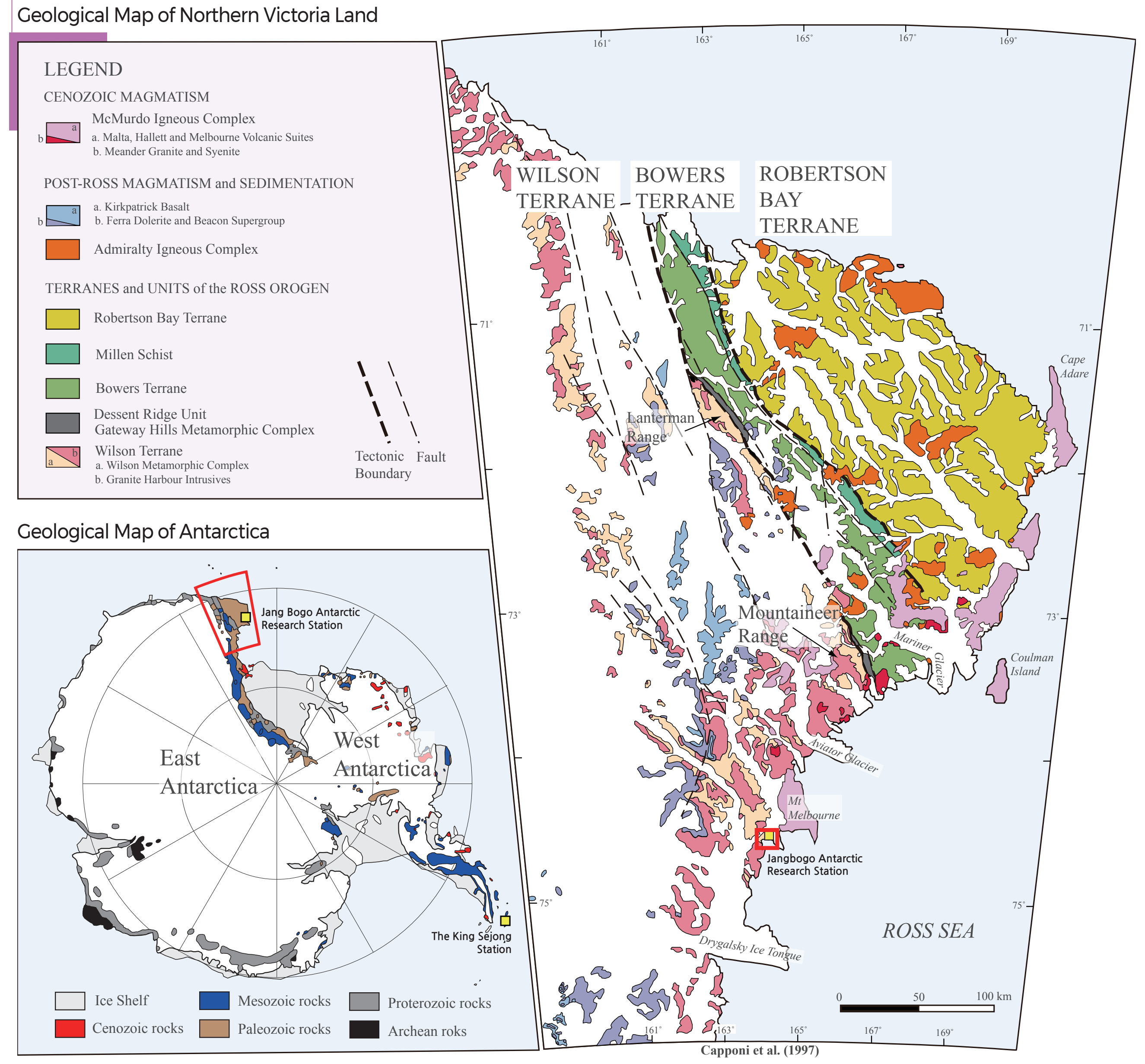
Korea Institute of Ocean Science and Technology

Route to the Interior of Antarctica

Antarctic Meteorite Research

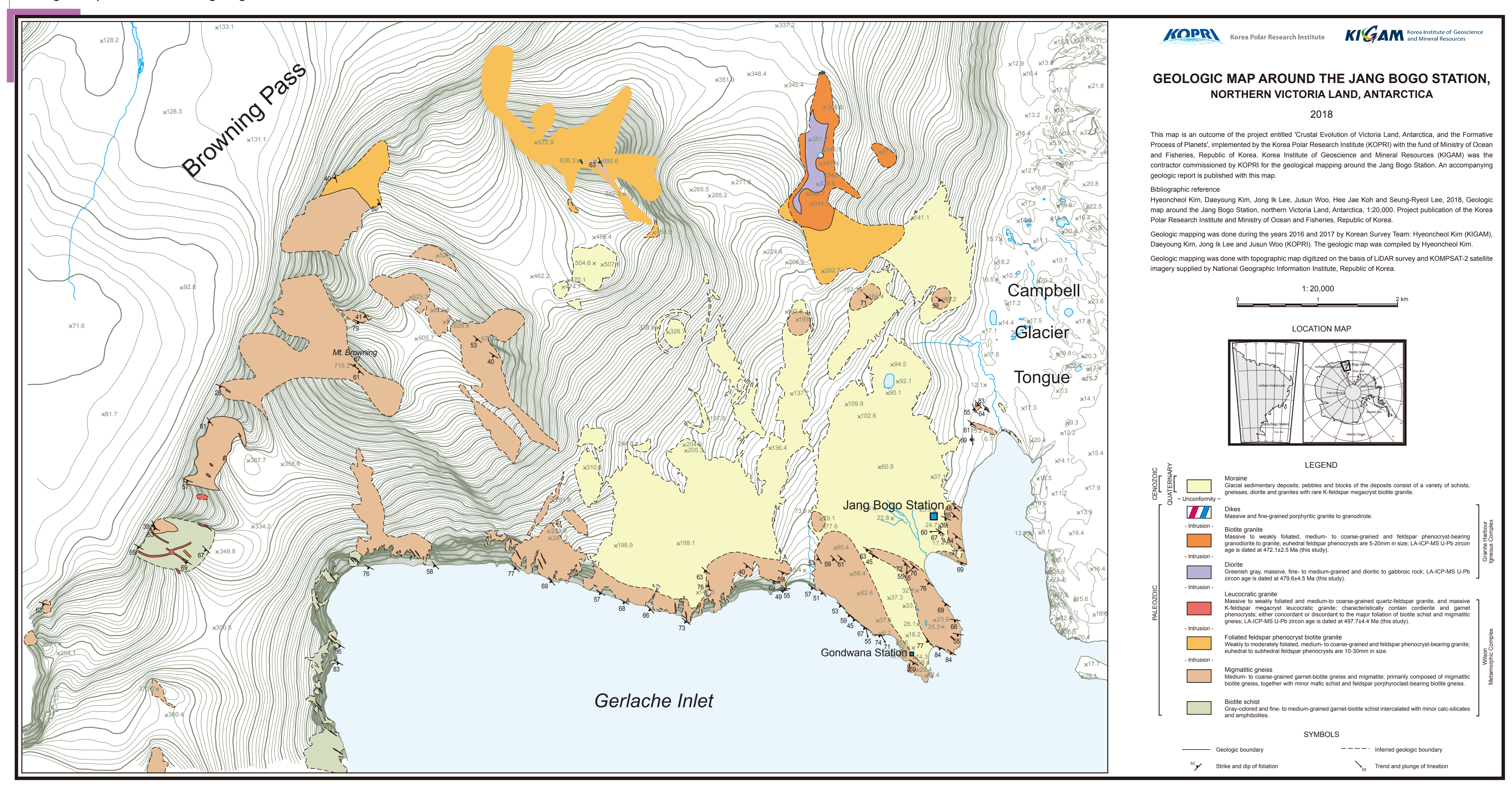
Geological Map of Northern Victoria Land

Geological Map of Antarctica



Korea Polar Research Institute

Geologic Map around the Jang Bogo Station



Korea Polar Research Institute and Korea Institute of Geoscience and Mineral Resources (2018)