Rocks and Minerals

The Korean Peninsula consists of various rocks formed in the space between a depth of 60 km and the surface of the Earth over the wide span of time from the Archean to Cenozoic. These rocks help geologists to interpret the tectonic evolution of the Korean Peninsula and Northeast Asia from 2.5 Ga (Ga: billion years ago) to the present. In particular, the geology of the Korean Peninsula is very important for interpreting the tectonic relationship between Korea, China, and Japan because of its geographical location between China and Japan.

On the Korean Peninsula, the oldest rocks are Neoarchean meta-igneous rocks with an age of ca. 2.5 Ga. Older rocks were recycled through the rock cycle into Paleoproterozoic metasedimentary and igneous rocks with an age of ca. 1.9 – 1.8 Ga. The Paleoproterozoic rocks make up the basement of the Korean Peninsula and are classified, from north to south, into the Nangrim, Gyeonggi, and Yeongnam Massifs. The Paleozoic Imjingang belt, which formed westward along the Imjingang to the Chugaryeong graben, divides the Nangrim and Gyeonggi Massifs. The 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 (including Hwasun) to Gangwon-do. The Yeongnam Massif runs through Jeolla-do and Gyeongsang-do. The Ogcheon belt contains the northeastern Taebaeksan Basin and the southwestern Ogcheon metamorphic belt. The Paleoproterozoic metamorphic and igneous rocks, which formed at a depth of about 35 km, are now exposed at the surface due to tectonic uplift and erosion.

Neoproterozoic rocks are widely distributed in the Sangwon System, which occupies the southern part of the Nangrim Massif, between Haeju and Wonsan and consists mostly sedimentary rocks. Neoproterozoic rocks were recently discovered from the area adjacent to the Imjingang belt, the Hongseong area in Chungcheongnam-do, and the northeastern Ogcheon metamorphic belt.

Paleozoic sediments are widely distributed in the Pyeongnam Basin in Pyeongan-do, the Taebaeksan Basin in Gangwon-do, and the Ogcheon metamorphic belt. They are also found in the Imjingang belt, and the northeastern Hamgyeong-do. 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, including limestone that played an important role in the industrialization of Korea by supplying the raw material for cement. Most coal mines in Korea locate in the Pyeongan Supergroup. Devonian sediments are found in the Imjingang belt, but the sedimentation ages of Paleozoic rocks in the Ogcheon metamorphic belt are not clear. 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 sediments 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 Cretaceous there was a subduction zone around the Korean Peninsula and subduction-related igneous rocks regionally intruded the Korean Peninsula. In particular, 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.

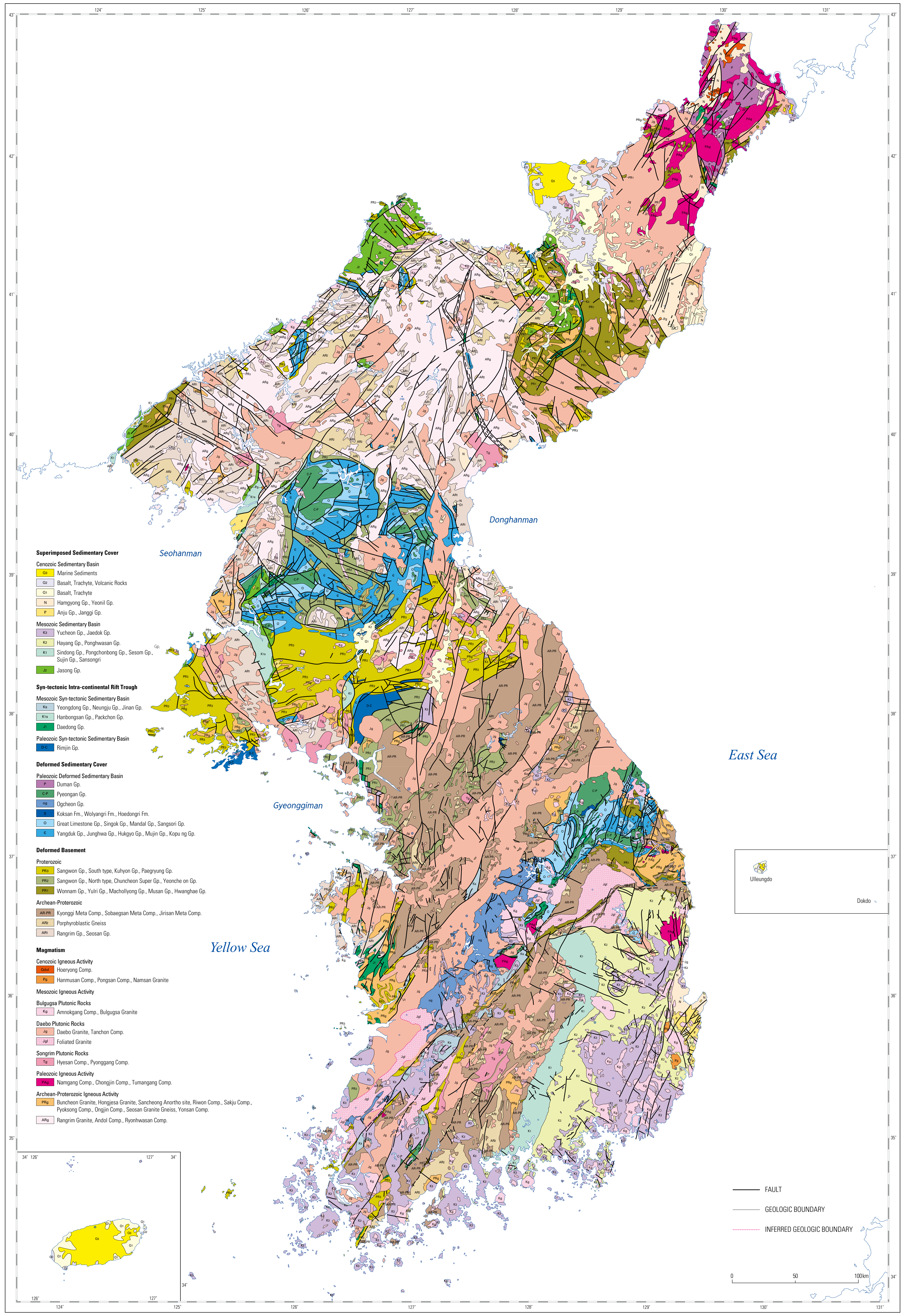
A recent study shows that part of Jurassic granites in the northern Gyeonggi Massif are in fact Triassic granites related to continental collision within the Korean Peninsula. Further evidence of Triassic continental collision is provided by the Triassic eclogite found in the area of Hongseong. On the Korean Peninsula, there are minor distribution of small scale Triassic and Jurassic sediments, and the Jurassic granites that formed at a depth of around 15 km are directly covered with Cretaceous volcanic and sediment 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. Due to the uplift, the eastern part of the Korean Peninsula was elevated higher than the western part, resulting in westward tilting. The Baekdusan, Ulleungdo, Dokdo, Jejudo volacanoes and the Chugaryeong graben also formed during the Cenozoic with the Cenozoic sedimentary in Hamgyeong-do and Pohang.

The Korean Peninsula is relatively safe from earthquakes compared to Japan, which is located on the plate margin, but it is not completely safe. Although not abundant in most cases, many kinds of mineral resources have been found on the Korean Peninsula. Recently Korean researchers have expanded the scope of research to overseas geology. As a result, mining areas for manganese nodules in the Pacific Ocean (1994), exploration rights for hydrothermal deposits in Tonga and Fiji (2008, 2011), and mining areas for hydrothermal deposits in the Indian Ocean (2012) were acquired and the geologic map of Suai in East Timor was made. Since 1987, research on the polar regions has also been carried out.

General Geology

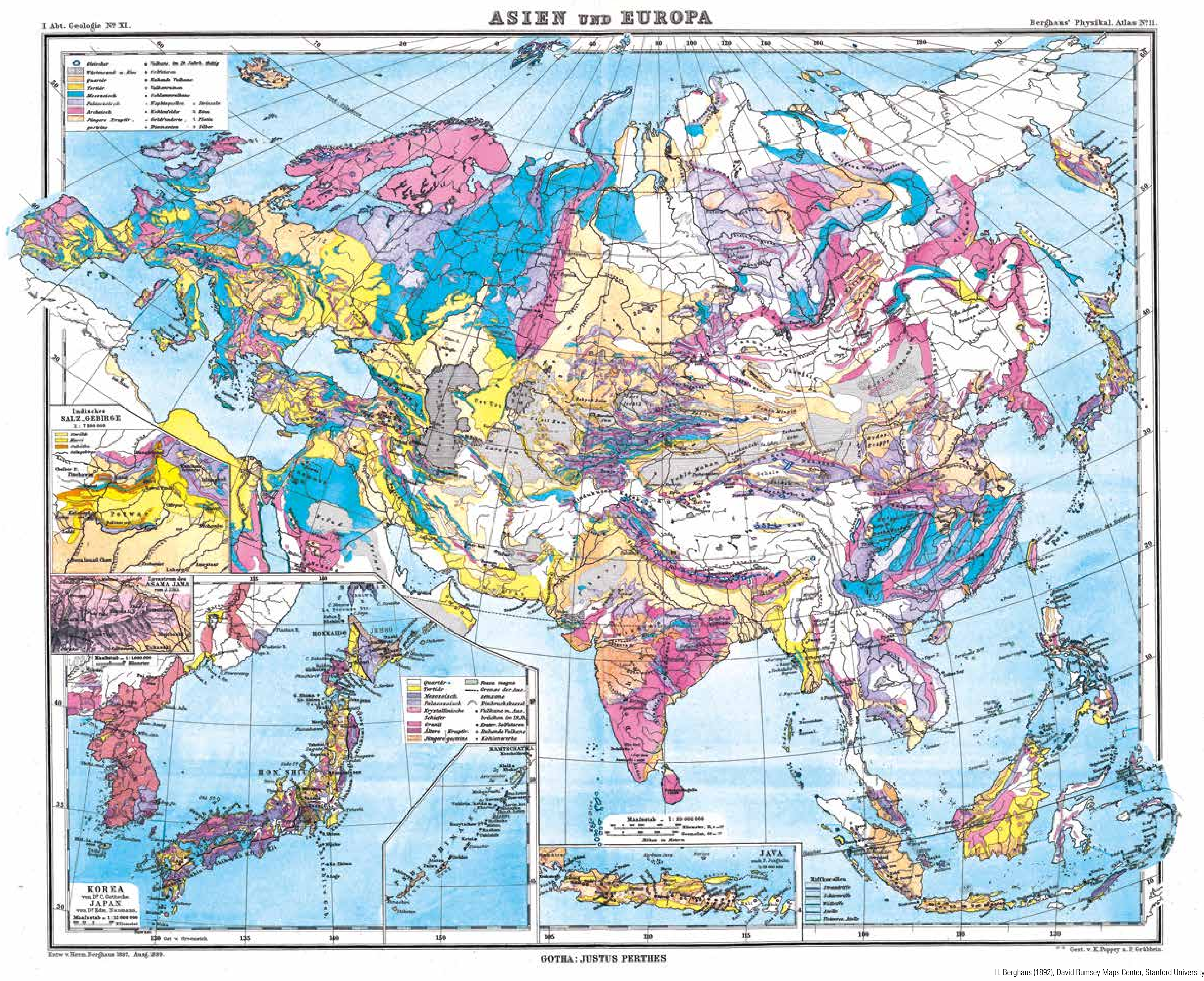
Geologic Map of the Korean Peninsula



Korean Institute of Geoscience and Mineral Resources (1995)

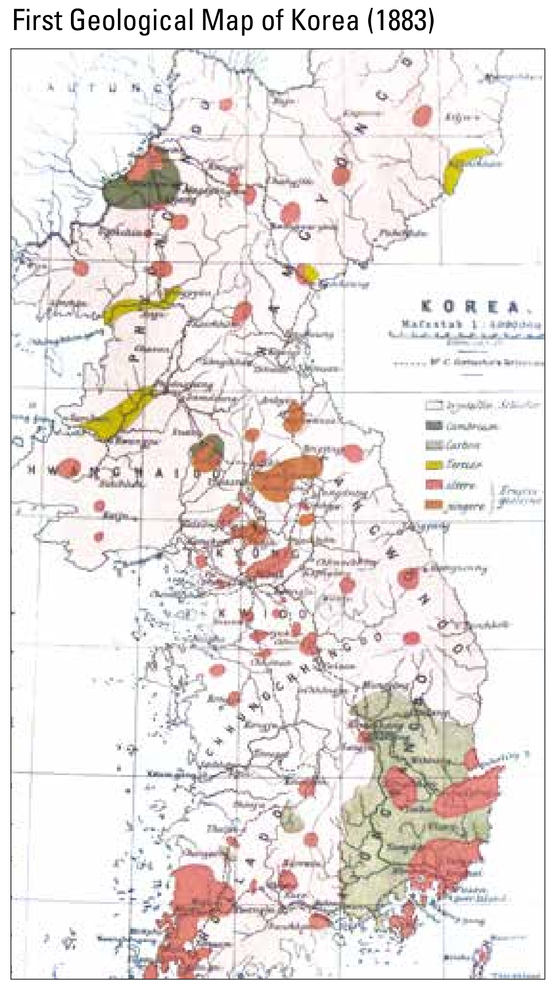
History of Geological Survey in Korea

Geological Map of Asia and Korea (1892)



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

First Geological Map of Korea (1883)

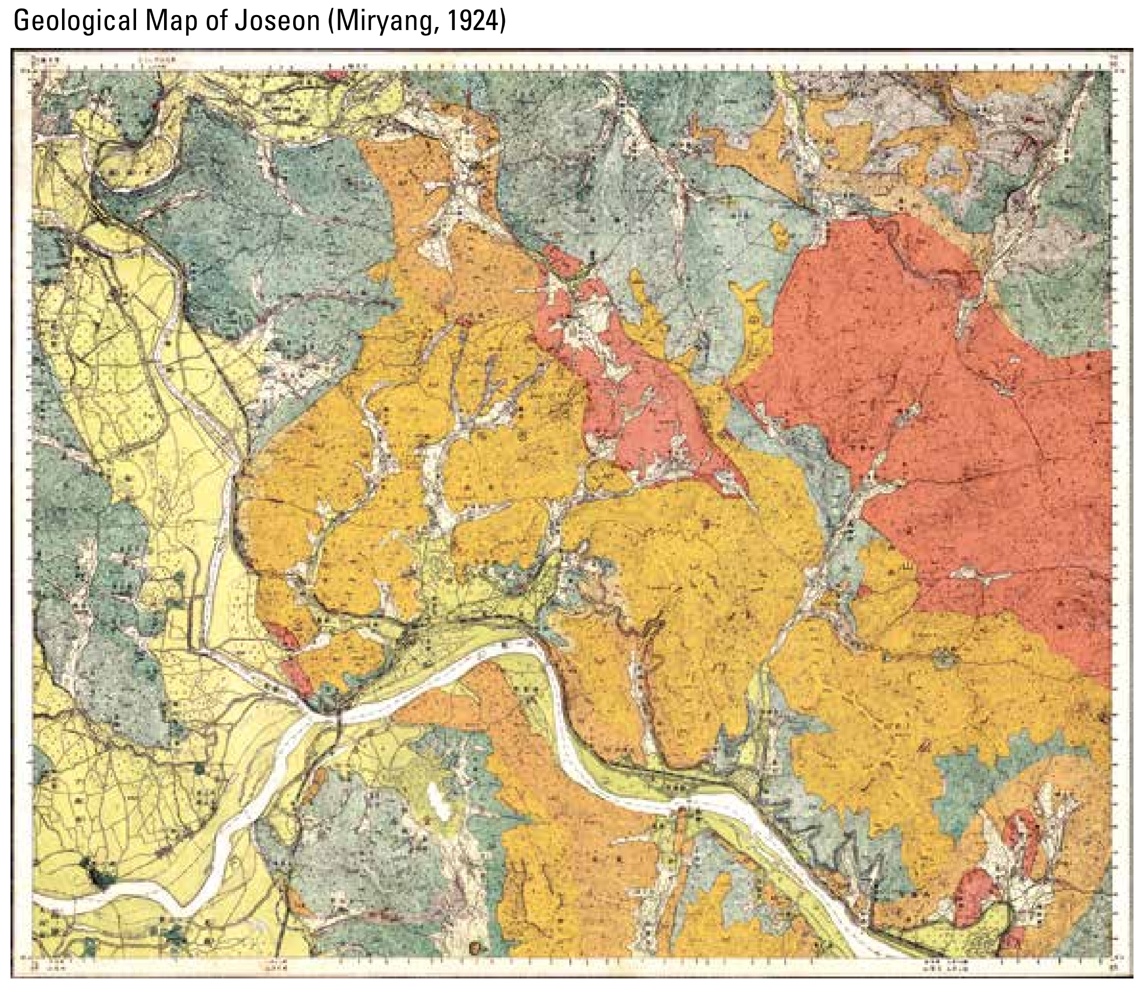


C. Gottsche (1883)

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 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.

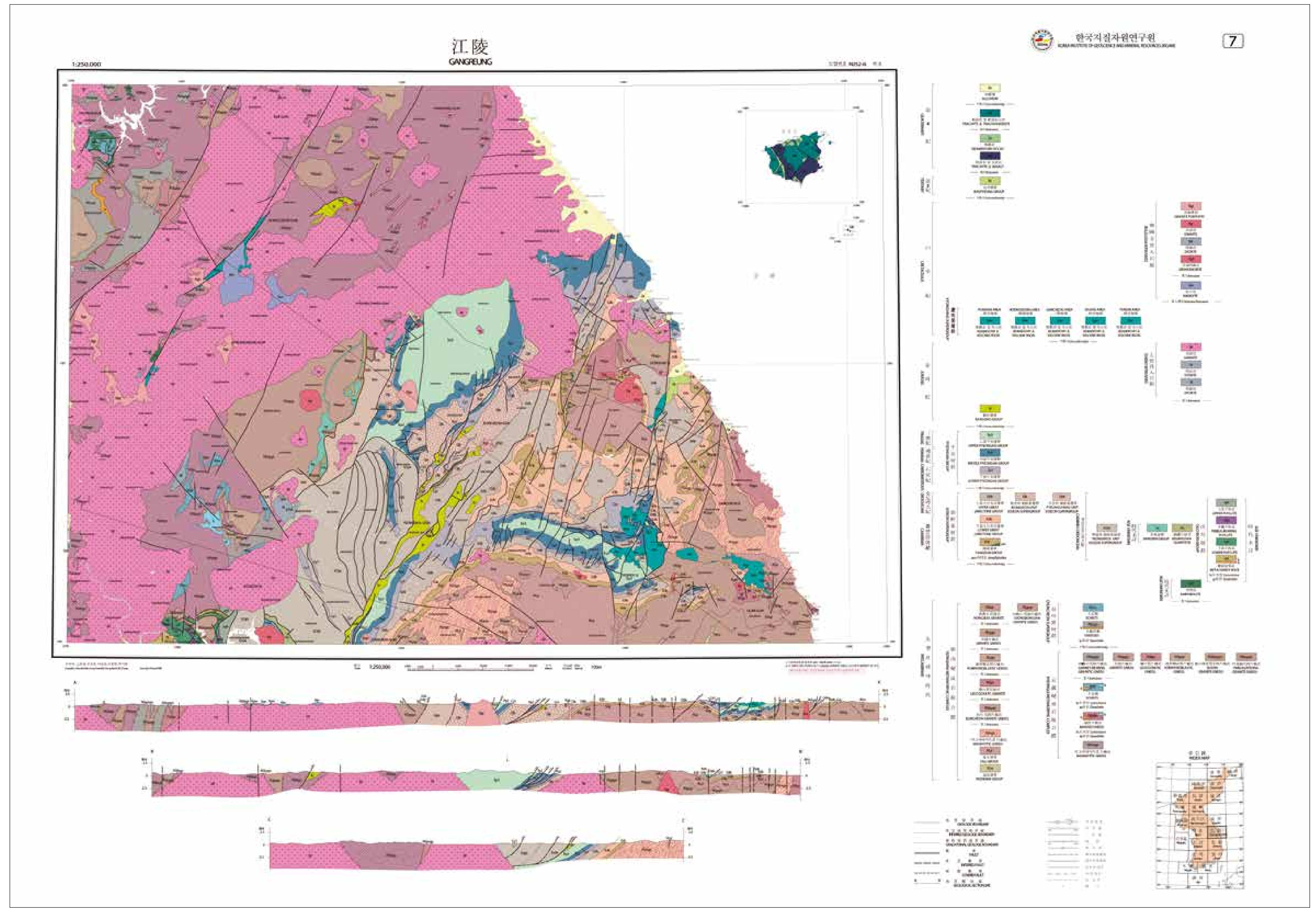
Carl Gottsche, a German geologist, visited Korea on a German diplomatic mission in 1883 and carried out geological research of the peninsula to publish the first geologic map of Korea in the paper *Geologische Skizze von Korea* (1886). The geological study on Korea by foreign geologists was intensified with increasing pressure from the great European powers to acquire mining rights after the Sino-Japanese war in 1894. In 1903, Goto Bunjiro produced *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.

Geological Map of Joseon (Miryang, 1924)



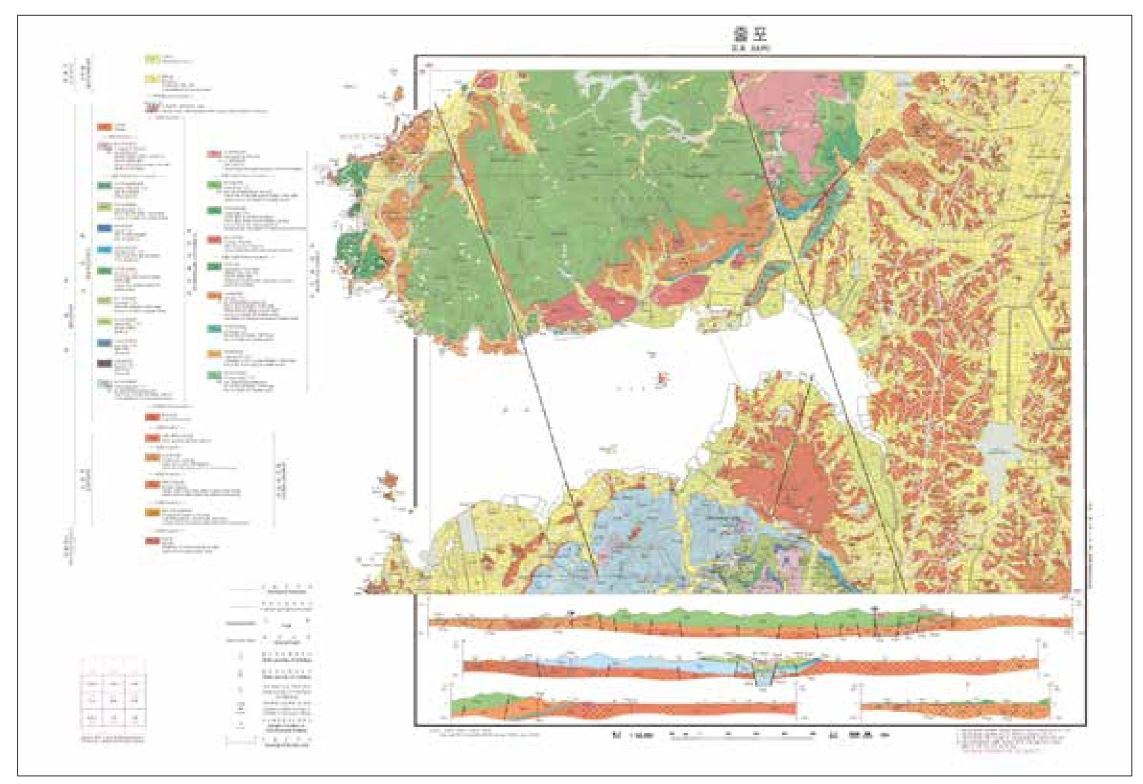
The Geological Survey of the Japanese Government-General of Korea

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



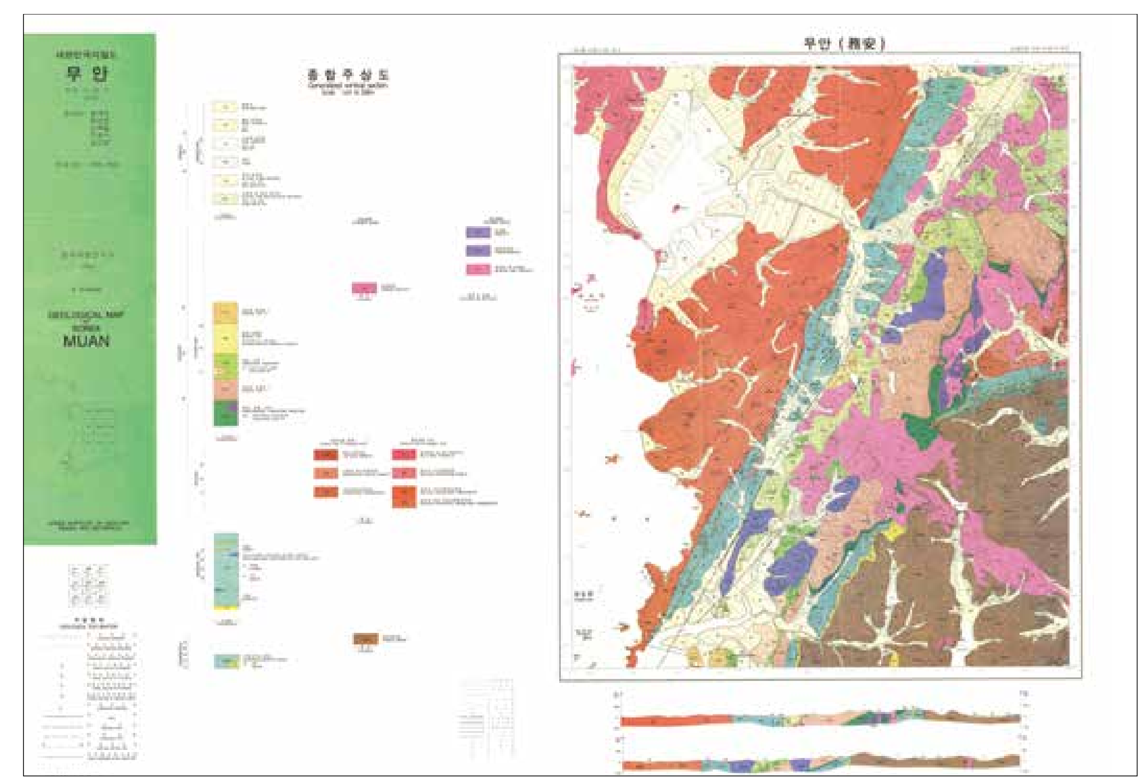
Korea Institute of Geoscience and Mineral Resources

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.

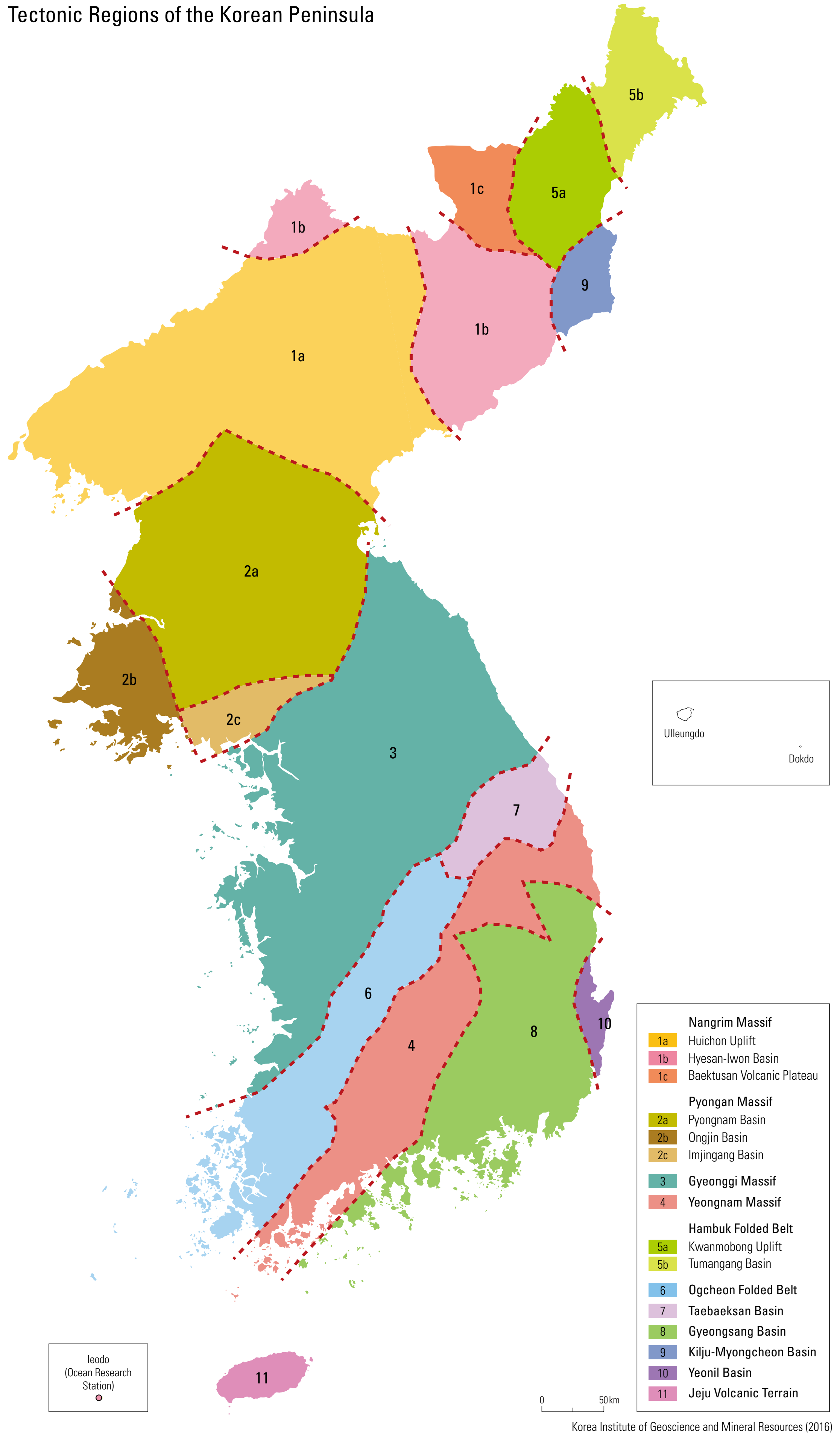
After restoration of independence, the 1:50,000 geologic maps for South Korea has been made by the Korea Institute of Geoscience and Mineral Resources (Previously, the Central Research Institute of Geoscience and Minerals, and the Korea Institute of Engergy and Resources). *The Geologic Map of Korea* (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 1995. Geologic maps of 1:250,000 and 1:25,000 scales have also been published, along with other geologic maps for special purpose, 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 the Southern Korea, Magmetic anomaly map of Korea, Geochemical Atlas of Korea, The Metallogenic Map of Korea, The Geologic Map of Coal Field,* and *The Hydrologic Map of Korea.*

Characteristics of Geological Periods

Geologic History of the Korean Peninsula

Geological Time			Age (Ma)	Stratigraphy	Magmatism	Tectonic Environment and Geologic Activities
Cenozoic	Quaternary	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		
	Neogene	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 and the formation of Taebaeksan and a lava plateau under Baekdusan
	Paleogene	Oligocene	33.9	Yongdong Group		
		Eocene	56.0	Bongsan Group		
		Paleocene	66.0	Gyeongsang Supergroup (Era of dinosaurs in the Korean Peninsula) Myogog formation	• Igneous activity related to the continental arc • Strike-slip fault movement	• Bulguksa orogeny related to subduction existing near the Korean Peninsula • Formation of the Gyeongsang basin and small pull-apart basins
Mesozoic	Cretaceous		145.0			
	Jurassic		199.6	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	• Continental collision related to the formation of the Pangea Supercontinent • Subduction at the southern margin of the Korean Peninsula
Paleozoic	Permian		298.9	Pyeongan Supergroup including Coal-Bed		
	Carboniferous		358.9		• Igneous activity related to subduction	• Subduction zone in the Hamgyong-do area
	Devonian		419.2	Imjin System	• Igneous and metamorphic activities related to continental collision	• Possibility of continental collision in the Hongseong area
	Silurian		443.8		• Igneous activity related to subduction	• Possibility of subduction at the southwestern Gyeonggi massif
	Ordovician		485.4	Oknyeobong Formation	• Igneous activity within plate	• Separation of southern Korea 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 within plate • Igneous activity related to subduction	• Break up of the Rodinia Supercontinent • Subduction before the formation of the Rodinia Supercontinent
	Mesoproterozoic		1600			
	Paleoproterozoic		2500	Gneiss in the Nangrim, Gyeonggi, Yeongnam Massifs	• Igneous and metamorphic activities related to subduction and continental collision	• Subduction before the formation of the Columbia Supercontinent • Continental collision during the formation of the Columbia Supercontinent
	Archean			Panmunjeom, Ganseoung, Daeijakdo Orthogneiss		

Tectonic Regions of the Korean Peninsula



Korea Institute of Geoscience and Mineral Resources (2016)

It was once believed that the Paleoproterozoic Nangrim, Gyeonggi, and Yeongnam Massifs were interconnected as one basement formed at ca. 1.9 – 1.8 Ga. Recently, however, it has been confirmed that the present shape of the Korean Peninsula is the result of a continental collision during the Permian-Triassic (250 – 230 Ma). In the area of Hongseong-gun Chungcheongnam-do, the evidence of Triassic eclogite was found that supports the continental collision theory. Additional confirmation of the continental collision is the Triassic post-collision granitoid found in the area of Odaesan in Gangwon-do. Although the location of the collision boundary is still uncertain, some parts of the Korean Peninsula is expected to be connected to the North China Craton while other parts to the South China Craton. Therefoe, in this Atlas, the North China Craton and some parts of the Korean Peninsula connected to it will be named as the North Korea-China Craton and the South China Craton and some parts of Korean peninsula connected to it as the South Korea-China Craton.

From 2.1 – 1.8 Ga, there was the supercontinent Columbia. The Paleoproterozoic igneous and metamorphic rocks of the Korean Peninsula formed due to the collision of continents that resulted in the supercontinent Columbia and the subduction before that collision. Neoproterozoic sedimentary and igneous rocks formed in several areas from 900 – 750 Ma. The Sangwon System (distributed between Haejui and Wonju), the Munjuri and Gyeomyeongsan Formations (distributed in the northeastern Ogcheon metamorphic belt), and the Wolhyeonri Formation and Deokjeongri granitic gneiss (in the area of Hongseong) are all Neoproterozoic rocks. The Paleoproterozoic supercontinent Columbia began to break into separate continental cratons from ca. 1.8 Ga and then the separated cratons assembled again to form the supercontinent Rodinia at around 1,000 – 900 Ma. Rodinia broke up again into separate cratons from 900 – 750 Ma. Most Neoproterozoic rocks on the Korean Peninsula formed during this breakup of Rodinia.

After the disintegration of Rodinia, most continents reassembled, forming the supercontinent Gondwana during the late Neoproterozoic, 600 – 550 Ma. At that time, the North Korea-China Craton and the South Korea-China Craton were located on the western side of Gondwana, near the equator. During the early Paleozoic, the North Korea-China and South Korea-China 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, which are absent from the Pyeongnam and Taebaeksan Basins, occur in the Imjingang belt. Between the Carboniferous and Permian, a subduction zone developed causing subduction-related igneous activity in the Hambuk fold belt in Hamgyeong-do. Recently, subduction-related Ordovician igneous activity was reported in the areas of Hongseong and Mungyung.

After the separation of the North Korea-China and South Korea-China Cratons from Gondwana during early Paleozoic, they moved northward, keeping close to each other, 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; in particular, the intrusion of a Jurassic granite, the Daebo granite, was most extensive, making up the basement of the Korean Peninsula along with Paleoproterozoic metamorphic rocks.

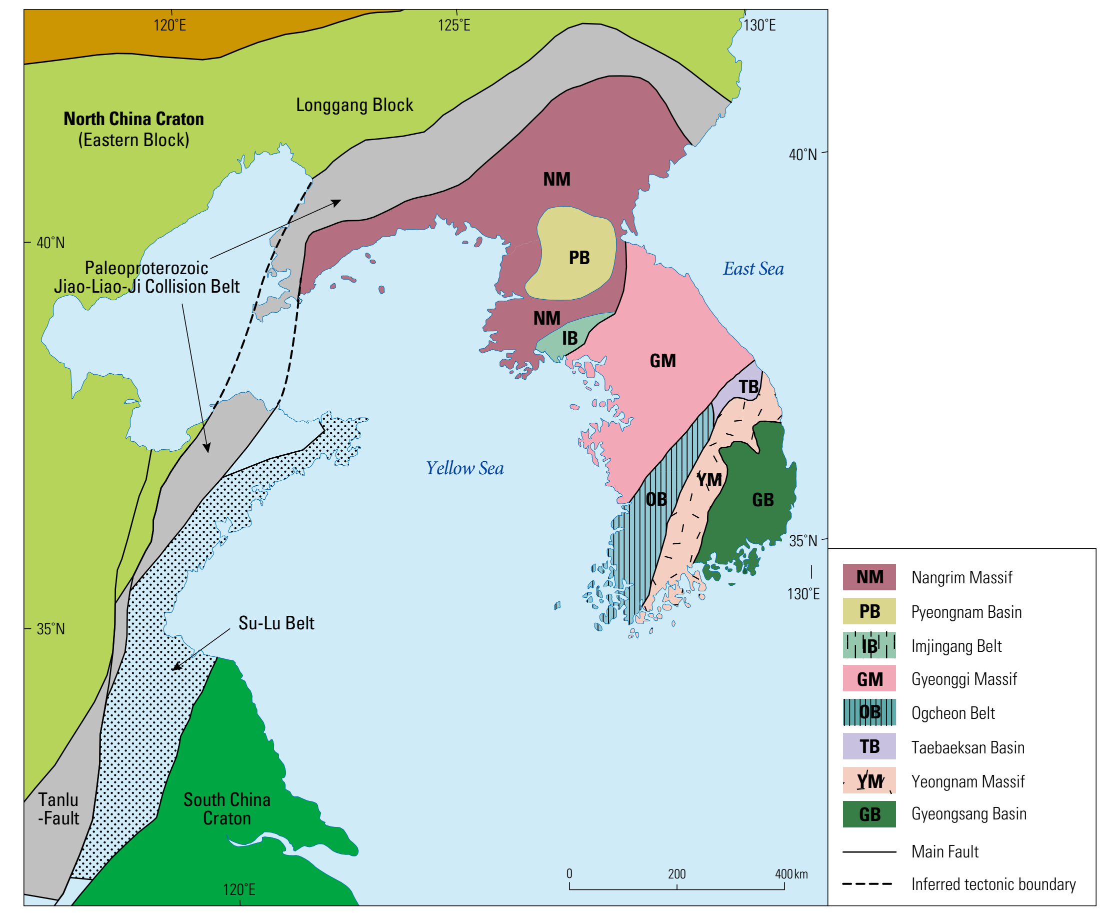
During the Cretaceous, many basins were formed on the Korean Peninsula and in the Yellow Sea, and the Gyeongsang Basin is the biggest among them. Lakes that formed in the basins provided good habitat for dinosaurs; thus, many dinosaurs were living on the Korean Peninsula during the Cretaceous.

During the Cenozoic, the East Sea was opened, separating Japan from the Korean Peninsula and forming the Taebaeksanmaek (Taebaek Mountain Range). 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.

LITHOSPHERE

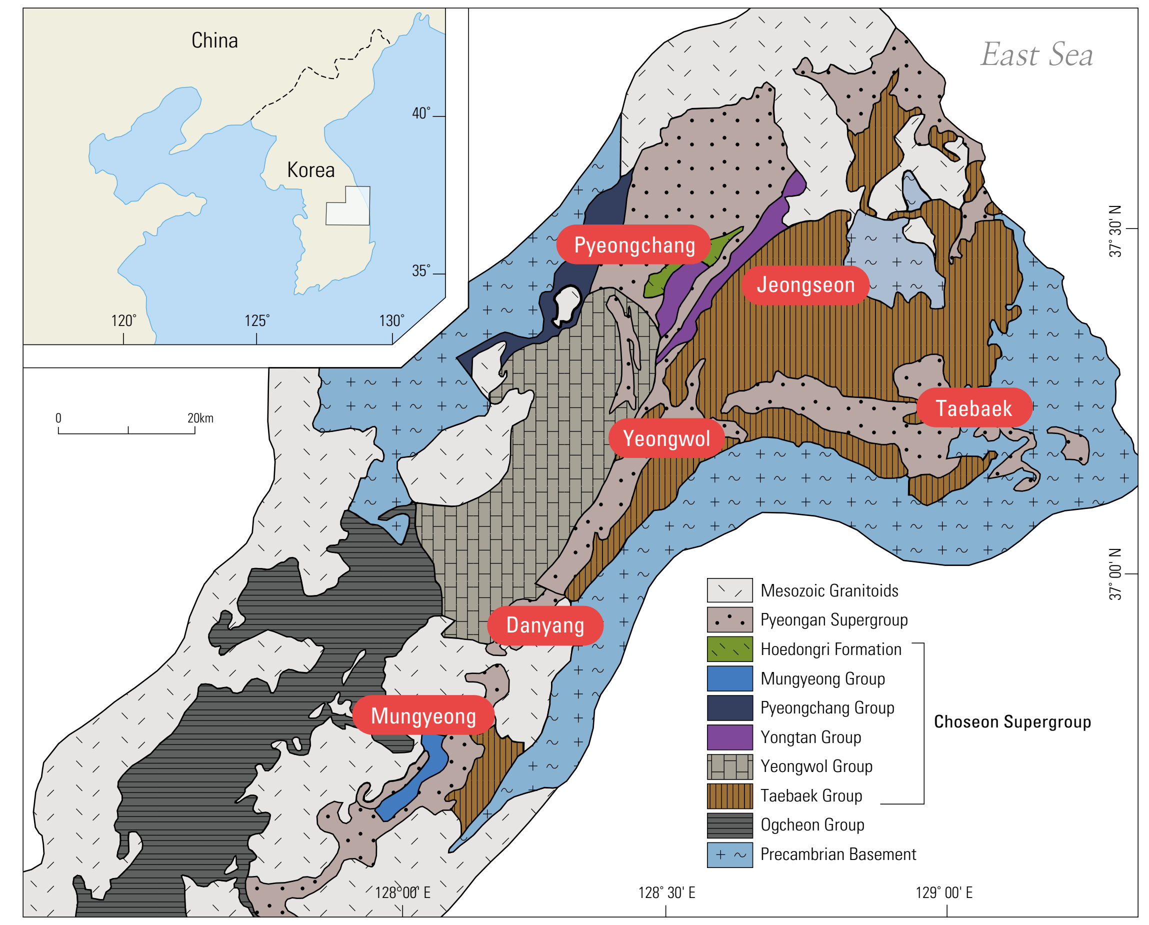
Rocks and Minerals
Characteristics of Geological Periods

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



Precambrian Research (2014)

Paleozoic Sedimentary Rocks in the Taebaeksan Basin



Association of Korean Geoscience Societies (1998)

Precambrian Geologic History of the Korean Peninsula

(Ga, Billion Years Ago)

Division	Nangrim Massif	Gyeonggi Massif	Gyeonggi Massif Wonju Area	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	2.5 Ga Post collisional igneous activity			
Paleoproterozoic	1.91 – 1.90 Ga Collision related metamorphic activity	1.92 Ga Collision related metamorphic activity	1.9 Ga Arc related igneous and metamorphic activities		1.99 – 1.98 Ga Arc related igneous activity	
	1.87 – 1.84 Ga Post collisional igneous and metamorphic activity	1.87 – 1.85Ga Post collisional igneous and metamorphic activity			1.85 Ga Arc and/or collision related igneous and metamorphic activities	1.87 – 1.86 Ga Post collisional igneous and metamorphic activity
			1.8 Ga Post collisional igneous activity			
Neoproterozoic	– 0.9 Ga Rifting related igneous activity and sedimentation	0.89 – 0.83 Ga Arc related igneous activity 0.85 – 0.76 Ga Rifting related igneous activity		0.87 – 76 Ga Rifting related igneous activity		0.91 – 0.90 Ga Igneous activity

Geologic history of the Paleozoic Era

(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 (Hwangyeong-do)
Carboniferous				
Devonian	Great Hiatus	Great Hiatus	Imjin System Guryong Formation	Metamorphic Activity Related to Subduction and Continental Collision (Hongseong)
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 oldest rocks on the Korean Peninsula are igneous rocks formed during the Neoarchean, 2.6 – 2.5 Ga, that are found in Panmunjom, Gosong, Daeijakdo and Wonju in small scales. Most Precambrian rocks in the Korean Peninsula are Paleoproterozoic rocks. The Nangrim Massif includes igneous rocks formed at ca. 1.91 – 1.90 Ga and ca. 1.87 – 1.84 Ga. The former may be related to the continental collision and and the latter to the post-collision stage accompanied by the transition from a compressional to extensional stress regime after the collision. Similarly, in the northern Gyeonggi Massif, metamorphism occurred at 1.92 Ga due to continental collision, and igneous activity and metamorphism also occurred at ca. 1.87 – 1.85 Ga during post-collision stage.

In addition, subduction-related igneous rocks intruded at ca. 1.9 Ga in the Wonju area in the southeastern Gyeonggi Massif. The Sobaeksan Block in the northeastern Yeongnam Massif also includes subduction-related igneous rocks of 1.99 – 1.98 Ga and igneous and metamorphic rocks formed at ca.1.85 Ga in a subduction or continental collision zone. Meanwhile the Jirisan Block in the southwestern Yeongnam Massif mainly consists of meta-igneous rocks formed in the continental collision tectonic setting of 1.85 – 1.86 Ga indicating a continental collision along the line connecting the areas of Sancheong and Hadong.

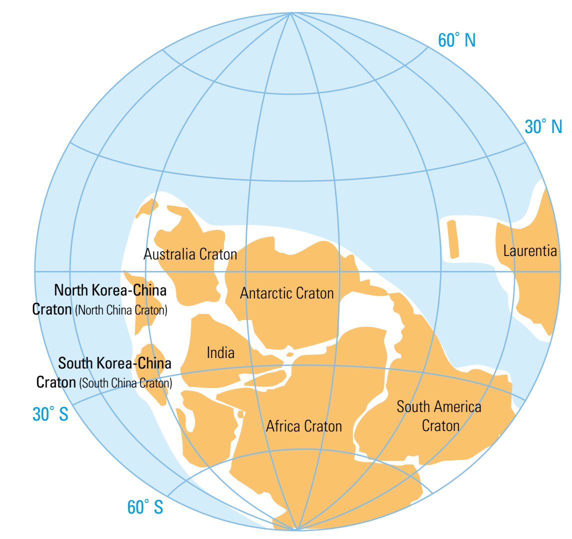
The Sangwon System, consisting of Neoproterozoic sediments, runs through the area connecting northern Gangwon-do and Hwanghae-do and extends out to Baengnyeongdo. The Sangwon System was intruded by basic dykes formed at 900 Ma in the continental rift tectonic setting. Recently, Neoproterozoic rocks were also found in several localities in the southern region of the Korean Peninsula. Neoproterozoic igneous rocks of 850 – 760 Ma that formed in the continental rift zone were found in the northern Gyeonggi Massif. 870 – 830 Ma and 760 Ma igneous rocks, which formed during subduction and continental rifting, respectively, were reported from the Hongseong area located in the southwestern Gyeonggi Massif. 870 – 760 Ma igneous rocks formed during continental rifting were also found in the northeastern Ogcheon metamorphic belt.

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 the alternation of siliciclastic and carbonate successions that were deposited from the Cambrian to Ordovician. In the lower Paleozoic sequence, macrofossils including trilobites (the index fossil of the Cambrian), brachiopods, cephalopods, gastropods, and graptolites 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 upper Paleozoic sequence was mainly deposited in non-marine environments.

The Ogcheon metamorphic belt mainly comprises of the 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 (acidic and mafic volcanic activities occur without intermediate volcanic activity) occurred at 452 – 445 Ma in the Ognyebong Formation near Mungyeong. The Ordovician bi-modal volcanism in the Ognyebong Formation is thought to have occurred when the southern part of the Korean Peninsula drifted apart from the supercontinent Gondwana during the early Paleozoic. As well, the igneous rocks that intruded in the subduction zone at 470 – 437 Ma and the intermediate- and high-pressure metamorphism that occurred at 418 – 381 Ma were recognized in the Hongseong area within the Gyeonggi Massif. Intensive igneous activity during the late Paleozoic in the Hamgyeong-do represents that a subduction zone existed in the province.

Korean Peninsula in the Gondwana Supercontinent



Modified from Paleontological Society of Korea (2011)

One of the most important finding of recent 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 was 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 Imjingang belt and Hongseong were also suggested as the continental collision boundary, but no clear evidences for the collision were found in those areas. Due to the Permian-Triassic continental collision in the Korean Peninsula, Permian-Triassic regional metamorphism occurred in the Gyeonggi Massif, Imjingang belt and O㉠cheon metamorphic belt.

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 that led to the creation of the Korean Peninsula in its current form, 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 the eastern margin of the Korean Peninsula and a subduction zone existed at the western and southern margins of the Korean Peninsula, resulting in the extensive regional intrusion of Jurassic granite between 200 and 160 Ma on the Korean Peninsula. This event is called the Daebo Orogeny.

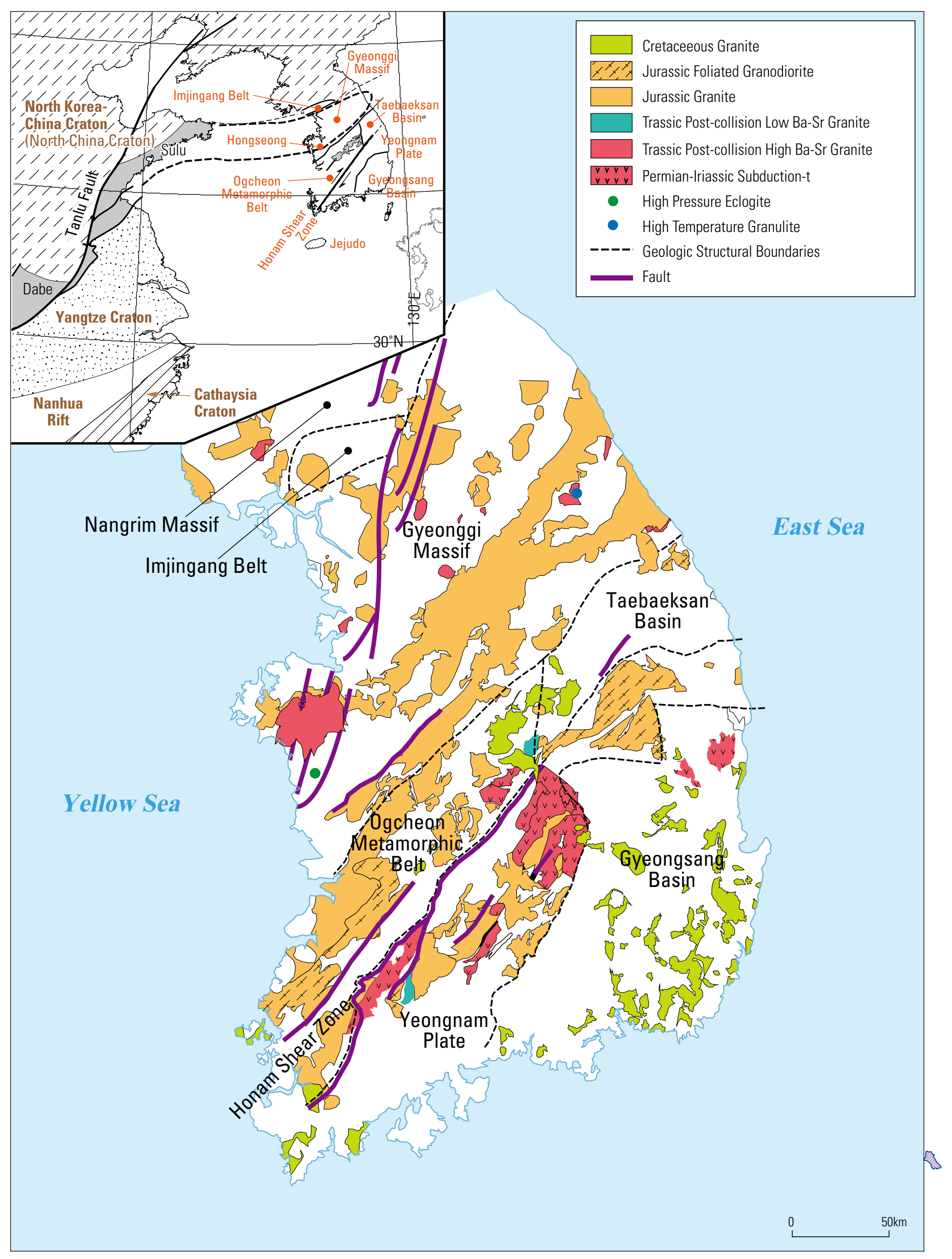
During the Cretaceous, a subduction zone was also developed along the margin of the Korean Peninsula and subduction-related Cretaceous igneous rocks intruded the Korean Peninsula regionally. The Cretaceous igneous activity mainly occurred in Gyeongsang-do, Jeolla-do, and southern Chungcheongbuk-do.

The Cretaceous Gyeongsang Supergroup consists of continental sedimentary rocks deposited in the alluvial fan, alluvial plain, fluvial and lacustrine environments and is distributed widely in the Gyeongsang Basin. Cretaceous sedimentary rocks which can be correlated to the Gyeongsang Supergroup also occur on a small scale in the Korean Peninsula. The small-scale Cretaceous sedimentary rocks include the Wuhangri Formation in Haenam within Jeollanam-do; the sedimentary rocks in the Gongju basin within Chungcheongnam-do; the Yeongdong Formation in the Yeongdong Basin within Chungcheongbuk-do; the Jinan Formation in the Jinan Basin within Jeollabuk-do; the sedimentary rocks in the Eumseong Basin within Chungcheongbuk-do; and the Jeokgakri Formation in the Tongri Basin within Gangwon-do. In the Yellow Sea, the Cretaceous sedimentary rocks formed in the Namhwanghae Basin.

The small-scale Cretaceous basins were pull-apart basins formed by the extension occurred between or along the strike-slip faults which underwent left lateral movement (the opposite part of the fault moves left) with a northeast strike.

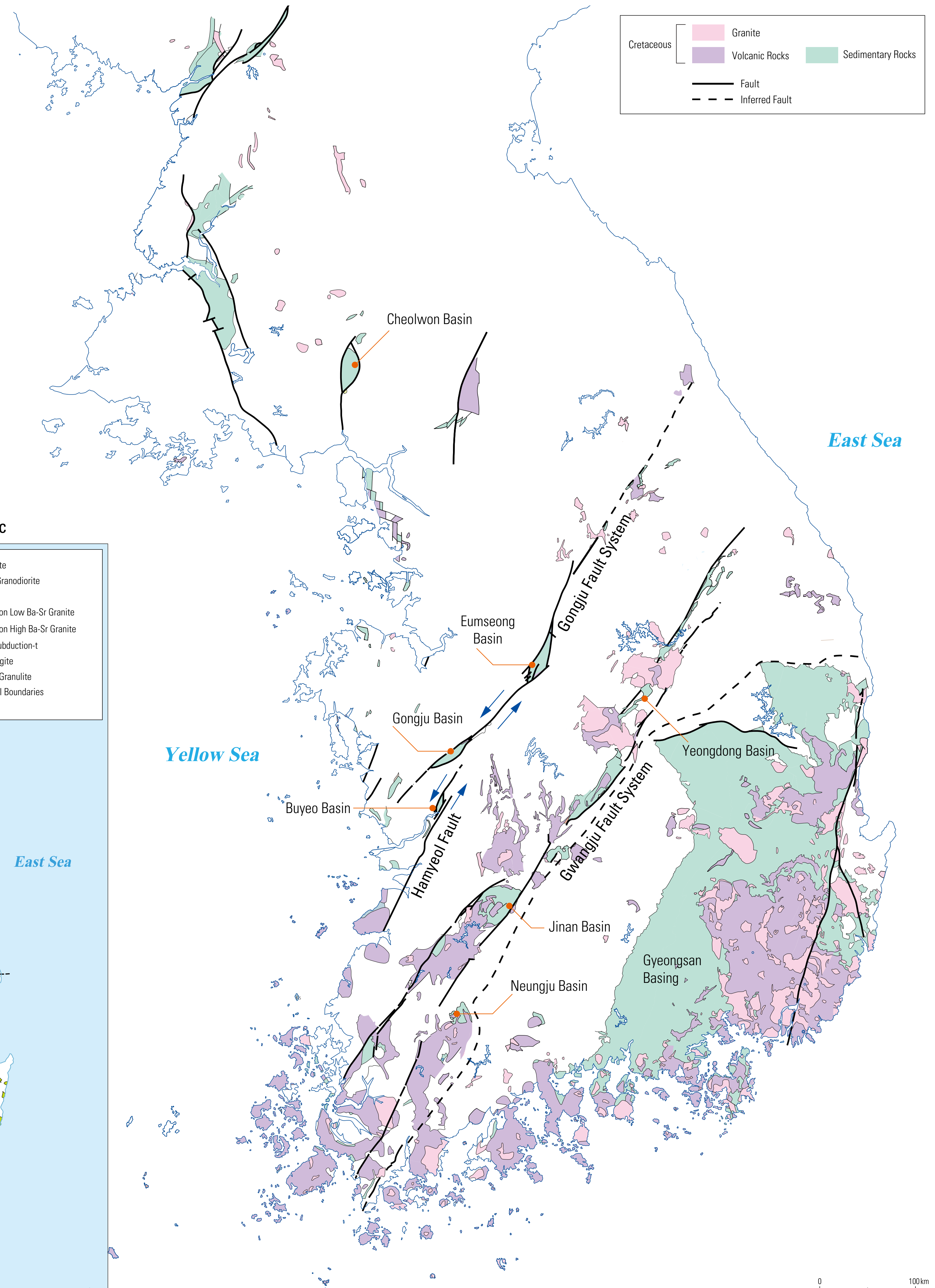
The Gyeongsang Basin consists of, from bottom to top, the Sindong, Hadong, and Yucheon supergroups and can be divided into 3 small basins: the southern small Milyang Basin, the small northern Uiseong Basin, and the small Yeongyang Basin. Three formations occur in the small Miryang and Uiseong basins but only the Hadong and Yucheon formations occur in the small Yeongyang Basin, indicating that each basin has different sinking rate from the other basins.

Distribution of Igneous Rocks in the Late-Paleozoic and Mesozoic



Petrological Society of Korea (2011)

Cretaceous Strike Slip Faults, Sedimentary Basins and Rocks



Geological Society of Korea (2015)

Distribution of Dinosaur Fossils in the Korean Peninsula

School of Earth and Environmental Sciences, Chonnam National University

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 in the Korean Peninsula was an egg fossil from the seaside of Hadong-gun in Gyeongsangnam-do. After that, in 1982, a dinosaur bone was found in Euiseong-gun in Gyeongsangbuk-do. Since 1996, many dinosaur footprints and egg and bone fossils have been found in Cretaceous sedimentary layers in Jeollanam-do and Gyeongsangnam-do.

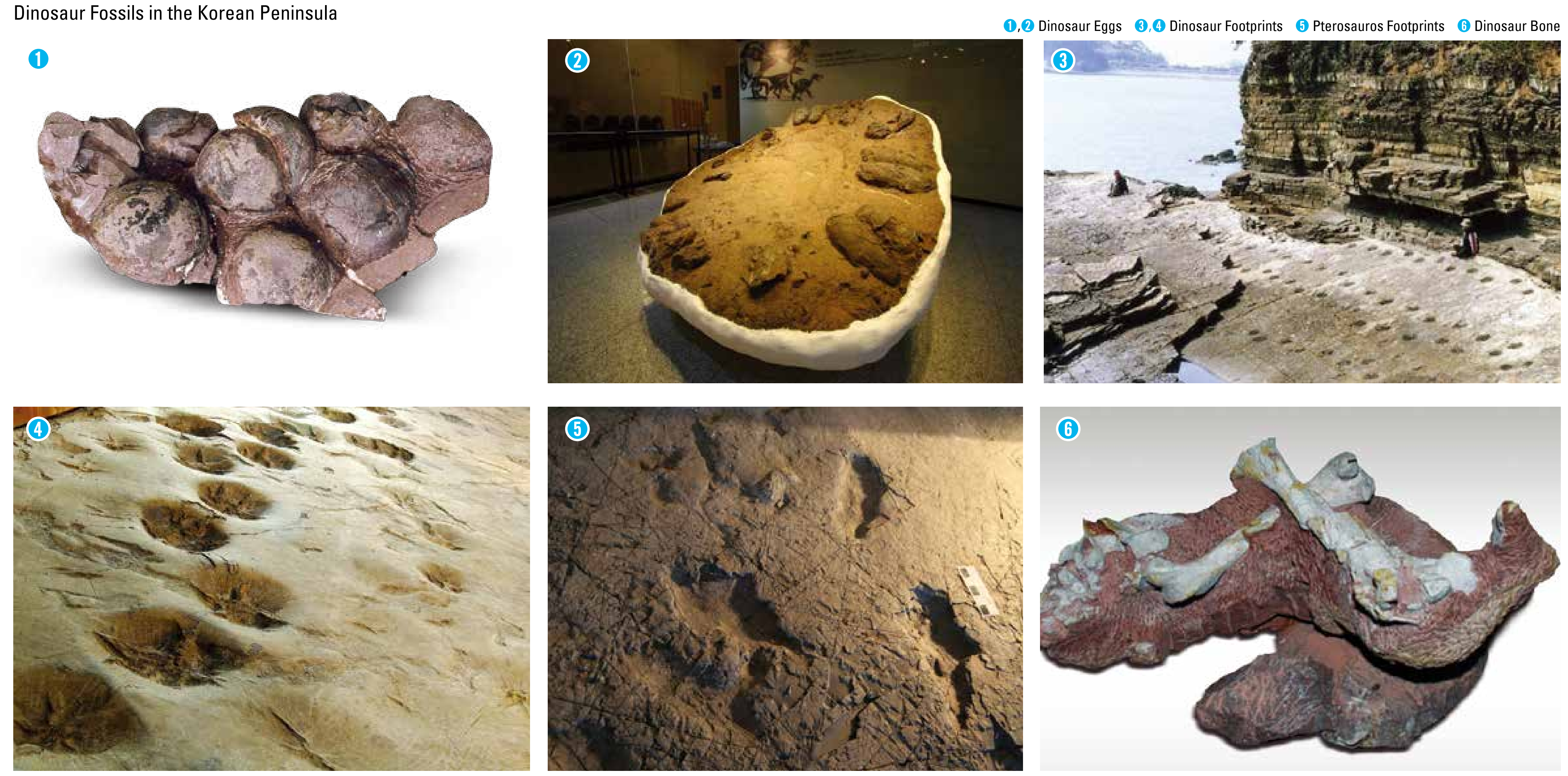
Dinosaur footprint fossil sites are found in the 27 Cretaceous terrestrial sedimentary layers in the southern region of the Korean Peninsula; the Cretaceous terrestrial sedimentary layers in Hanam-gun, Hwasun-gun, and Yeosu-si within Jeollanam-do, and Goseong-gun within Gyeongsangnam-do, are representative sites. Ornithopod footprints are very abundant in 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 in the Korean Peninsula. The pterosaur found in Uhangri, Hanam-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 which are well preserved enough to identify the species of dinosaurs, was found in the sedimentary layer in Hadong-gun, Gyeongsangnam-do, and it was identified as a new species and named as *Pukungosaurus millenniumi*. It was registered as the 931st dinosaur genus in the world inventory of dinosaurs.

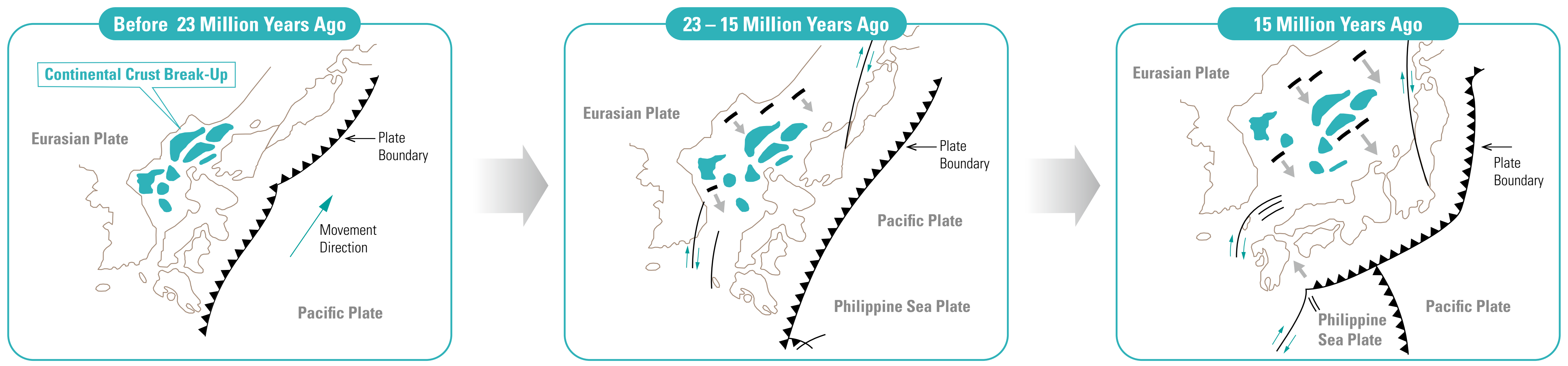
During the Cretaceous many lakes that could be used as a source of drinking water for dinosaur, existed in the southern region of the Korean Peninsula. Around the lakes, gymnosperms, including conifers and ferns, were abundant, providing enough food to dinosaurs. Vertebrates including tortoises, crocodiles, early mammals and fish and invertebrates including mollusks, arthropods and lugworms are also abundant in and around lakes. These lake environments made the Korean Peninsula a good habitat for dinosaurs during the Cretaceous. As a result, dinosaurs thrived on the Korean Peninsula during the late Cretaceous when dinosaurs were on the decline in other parts of the world. The Korean Peninsula was one of the last sanctuaries for dinosaurs in the world.

Dinosaur Fossils in the Korean Peninsula

❶,❷ Dinosaur Eggs ❸,❹ Dinosaur Footprints ❺ Pterosauros Footprints ❻ Dinosaur Bone

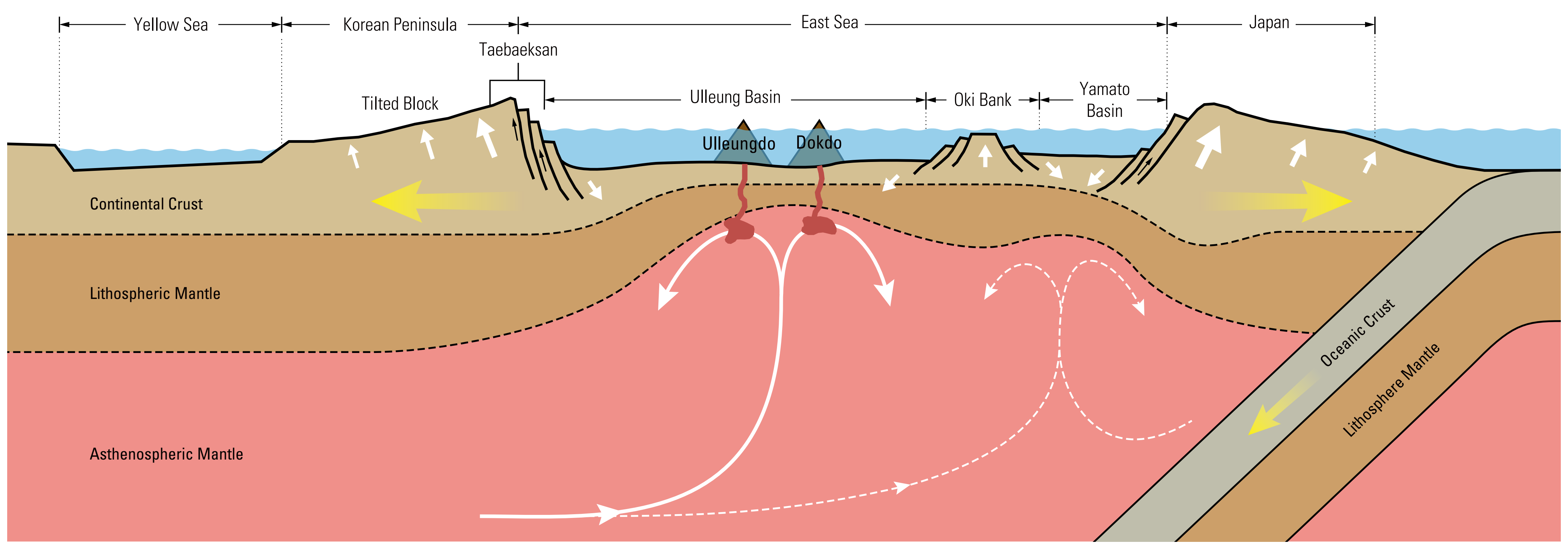


East Sea Opening Tectonic Model



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 formation process of the East Sea, Ulleungdo, and Dokdo is closely related to that of Baekdusan. 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 the northeastern Asia, including the Baekdusan area. This indicates that there was a regional extension in Northeast Asia. The extension caused enormously long fissures in the Baekdusan area and regional basaltic lava flow from the fissure was accumulated forming lava plateau. During the extension, in the East Sea, long fissure also formed in the ocean floor from which basaltic lava flowed out regionally forming oceanic crust in the northern East Sea.

From 15 Ma, compressional stress replaced the 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, Baekdusan experienced its strongest eruption, forming the Cheonji Caldera. During this eruption, the erupted volcanic mass rose to an altitude of 35 km and volcanic ash was transported to Japan and sedimented there. As explained, Baekdusan and the East Sea with Ulleungdo and Dokdo show similar forming process suggesting that they may have been formed by similar tectonic activity.

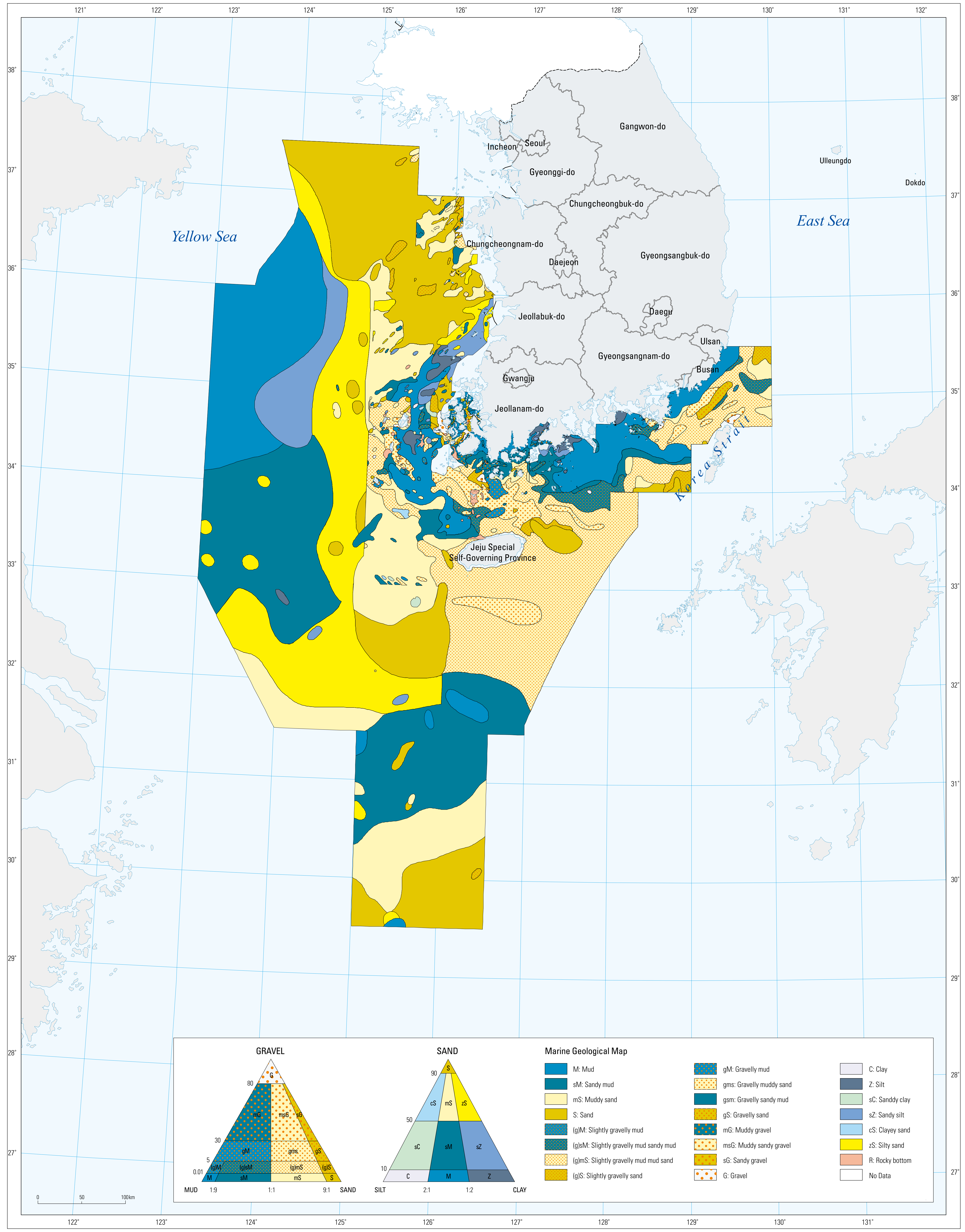
In the eastern coastal area, normal fault movement occurred due to the regional extension during the opening of the East Sea resulting in deepening of the East Sea. Together with the sinking of the East Sea, the Taebaeksanmaek formed by the uplift of the eastern coast tilting the Korean Peninsula westward.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

Jejudo shows different geological characteristics compared to Ulleungdo and Dokdo and formed in a different way compared to the typical oceanic island such as the Hawaiian Islands, which formed through one shield volcanic sequence. The volcanic activity of Jejudo can be divided into two stages: volcanic activity with sedimentation (1.88 – 0.5 Ma) and volcanic activity after sedimentation (0.5 Ma – 25 Ka). The volcanic activity occurred locally and sporadically during sedimentation of the Seogwipo Formation in the first stage, and volcanic activity occurred actively and regionally, forming the present shape of Jejudo, in the second stage.

Cenozoic Geologic Outline

Division	Baekdusan	East Sea	Hallasan
AD 969 – AD 1,903	Baekdusan Explosive Eruption and the Caldera Formation		
BP 9,300 – BP 6,300		Ulleungdo Explosive Eruption	
500 – 25 Ka			Formation of Present Shape of Hallasan
610 – 20 Ka	Formation of Stratovolcanic Upper Part of the Baekdusan area		
1880 – 500 Ka			Volcanic Activity with Sedimentation
2900 – 500 Ka		Formation of Stratovolcanic 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 Submarine Volcanic Part of Dokdo, Ulleungdo	
23 – 15 Ma		Opening of the East Sea	
28 – 13 Ma	Formation of Lava Plateau under the Baekdusan		

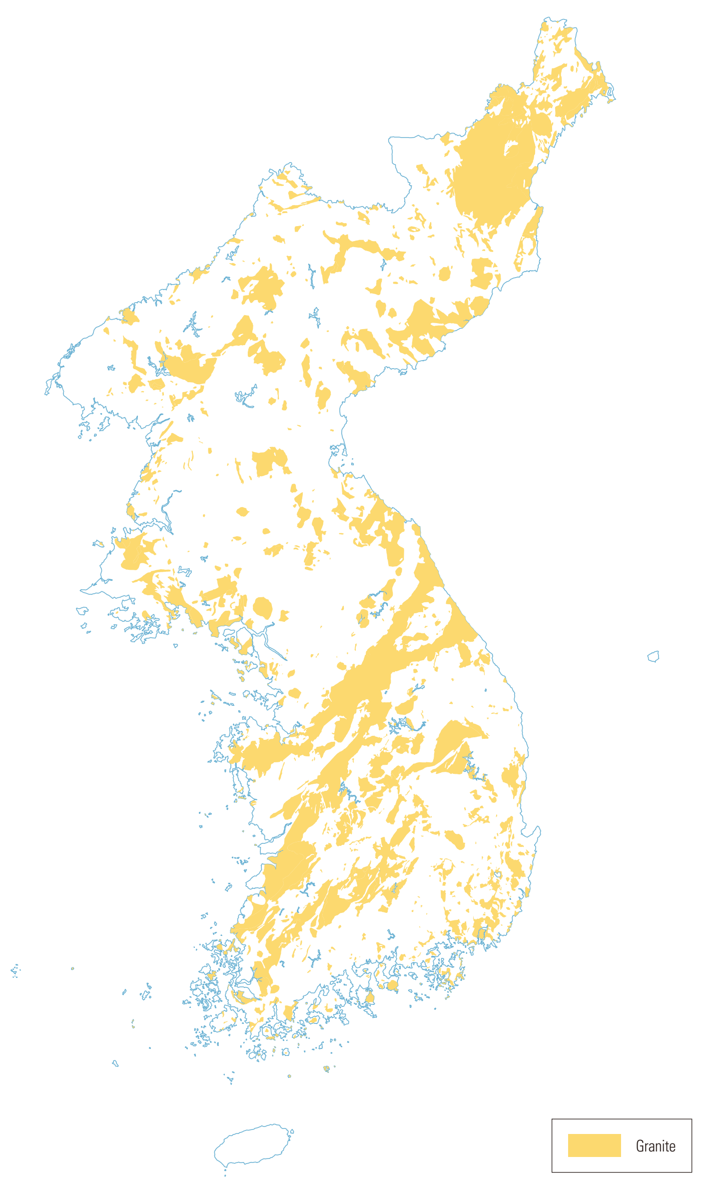
Marine Geological Map



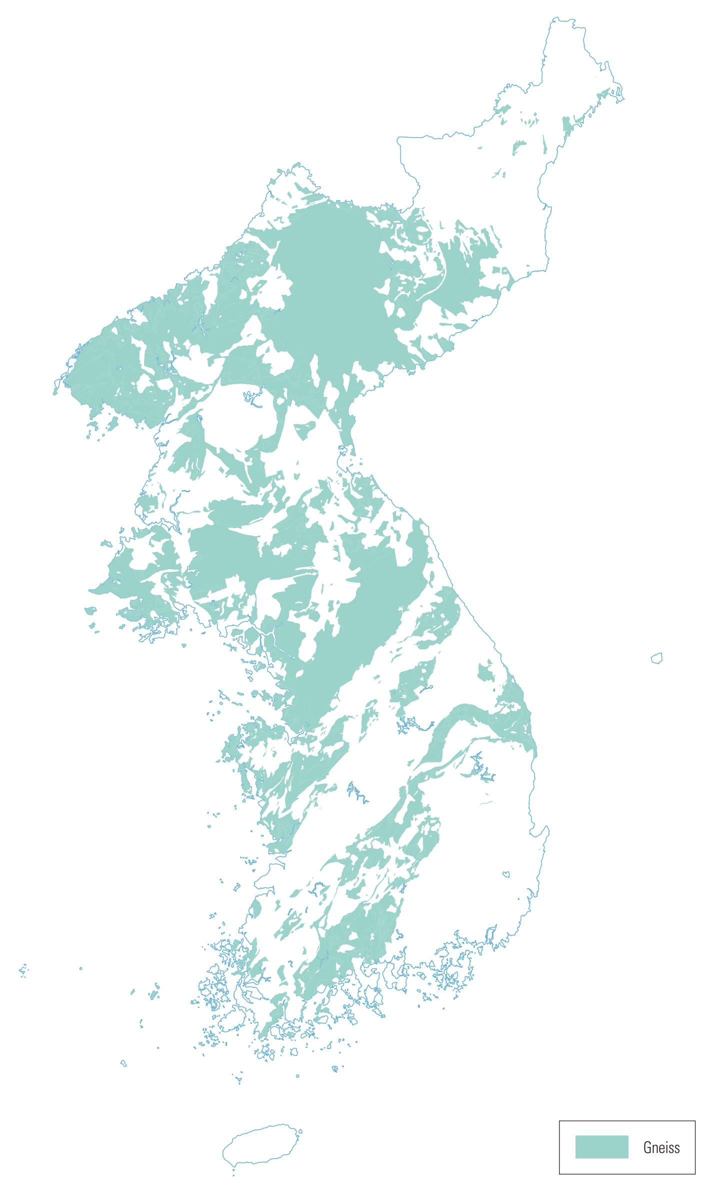
Korea Institute of Geosciences and Mineral Resources (2000)

Representative Rocks on the Korean Peninsula

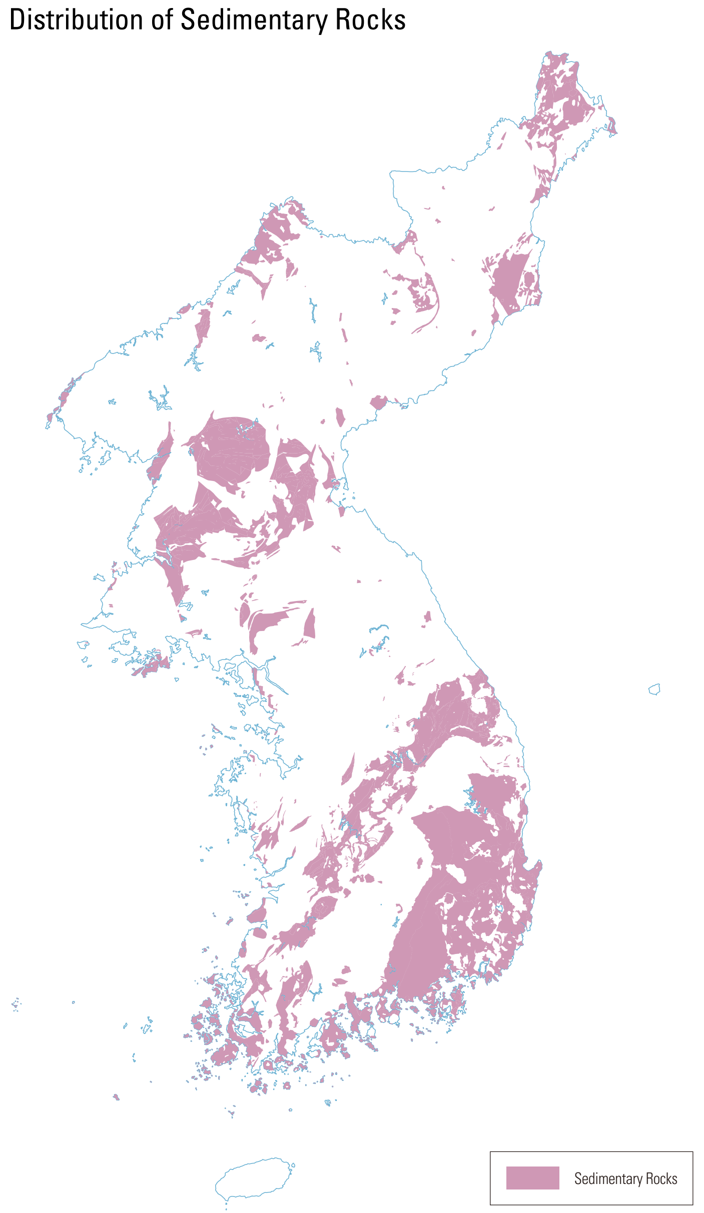
Distribution of Granite



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. Some granites were foliated due to shearing deformation at a deep depth and they are called foliated granites; they can be transformed into mylonite if the shearing deformation is very strong. The foliated granite appear along the strike-slip faults as in the case of the Honam shear zone.

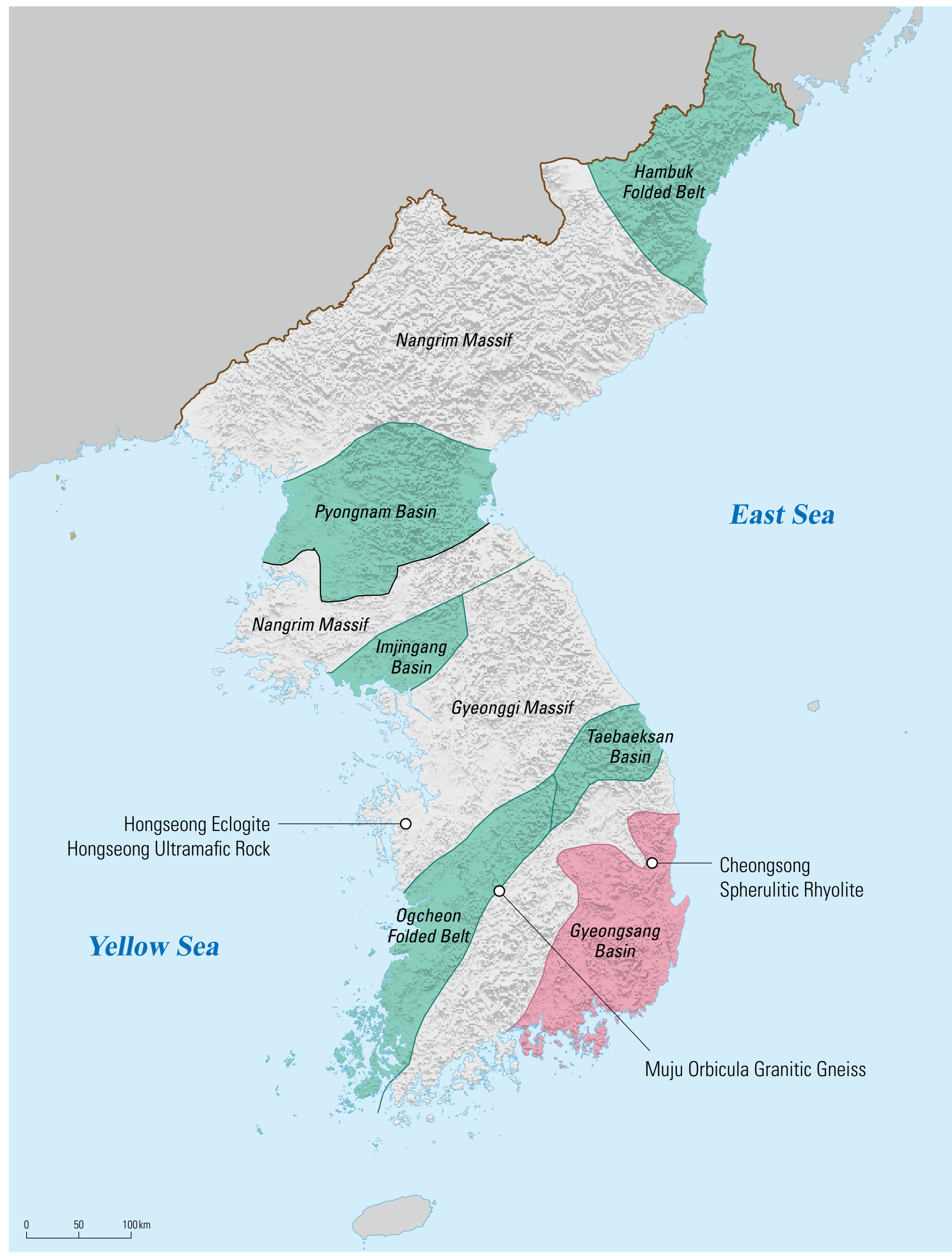
Metamorphic rocks consist of mainly gneiss and include schist, phyllite, quartzite, marble, and amphibolite, which formed by the metamorphism of shale, sandstone, limestone and basic igneous rocks. The gneiss can be classified into sedimentary origin gneiss (paragneiss) and igneous origin gneiss (orthogneiss). 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, and occur mainly in the Pyeongan, Taebaek, and Gyeongsang basins. The Cretaceous basins, including the Gyeongsang Basin, consist of volcano-sedimentary sequence formed by accumulation of erupted volcanic mass together with sedimentary rocks. The rhyolitic and andesitic volcanic and pyroclastic rocks constitute the stratovolcanic part of Baekdusan, Ulleungdo, and Dokdo, whereas the lava plateau under Baekdusan and shield volcanic part of Jejudo are composed of basic igneous rocks such as basalt and trachytic-basalt. Obsidian consisting of glass was formed by quick cooling of lava in Baekdusan, while scoria and pumice, which are pyroclastic rocks with many vesicles, are found in both Baekdusan and Jejudo. Red scoria commonly occurs in and around cinder cones on Jejudo, and the Korean side of Baekdusan is covered by white pumice, creating the illusion of a snowy white peak year round. As such, Baekdusan is translated to be the mountain with a white head in Korean.

Representative Rocks

❶ Migmatite
❷ Banded Gneiss
❸ Porphyroblastic Gneiss
❹ Granite
❺ Alkali Granite
❻ Basalt with Mantle Xenolith
❼ Andesitic Tuff
❽ Limestone
❾ Coarse Sandstone
❿ Black Shale

Distribution of Special Rocks



The unique and important rocks in the Korean Peninsula are eclogite and serpentinized ultramafic rock in the Hongseong area. Eclogite is a beautiful rock with red garnets in a green matrix consisting of omphacite. It 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 collision zone with a low geothermal gradient (the rate of increasing temperature with increasing depth). This is due to the cooling effects of the fast subduction of cold crust. 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 were pushed up to the surface from the deep depth. Thus, the occurrence of Triassic eclogite in the Hongseong area indicates that there was a Triassic continental collision within the Korean Peninsula.

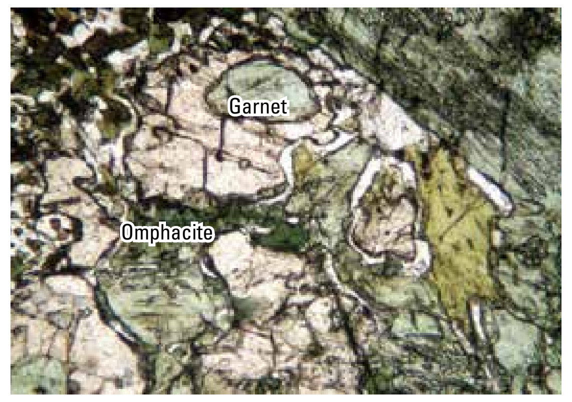
The serpentinized ultramafic rock found with the eclogite in the Hongseong area was originally lithospheric mantle formed at depth of several tens of kilometers below the surface and was uplifted to the surface during a continental collision. On the way to the surface, ultramafic rock was metamorphosed 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 occur as porphyroblast relicts within serpentinite because olivine and clinopyroxene in the ultramafic rocks are more easily metamorphosed into serpentine.

The orbicular granite gneiss in Muju and spherulitic rhyolite in Cheongsong are another very rare, unique rocks in 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 orbicular granite gneisses due to thermal metamorphism (650 – 740℃, 4 – 6.5 kbar) at around 1867±4 Ma. During the thermal metamorphism, the core of the orbicular granite gneiss (mainly consisting of cordierite) was developed. At this time, the leucocratic melt, formed by the melting of quartz and plagioclase, was squeezed out from the core and was crystallized as the outer white rim of some orbicular granite greiss. The Muju orbicular granite gneiss is more adequate to be called the granitic gneiss because it is originated from sedimentary rock and has much preservation value because it is the only orbicular rock formed by metamorphism in the Korean Peninsula.

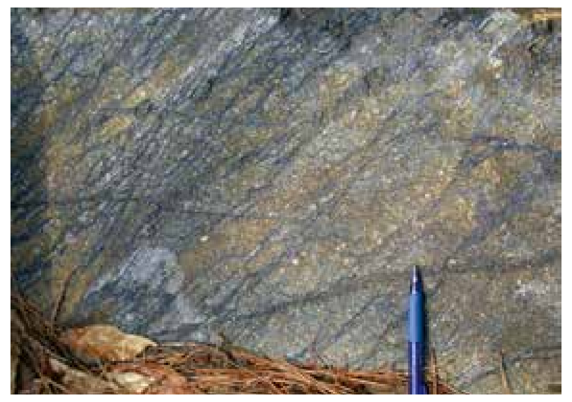
Spherulitic rhyolites with various flower patterns occur in Cheongsong. They formed during the fast cooling of dykes at a shallow depth. The chrysanthemum, dandelion, dahlia, and sunflower types were formed when specific mineral grew in a particular direction during fast cooling, while the peony, rose, and innominate types were formed by the growth of minerals in layers due to relatively slow diffusion during cooling. The apricot-patterned spherulite were formed during a medium cooling rate. The spherulitic rhyolites formed between 50 – 48 Ma and are valuable for research and preservation because of their rarity, beauty, and diversity.

Appearance of Eclogite

Microphoto of Eclogite



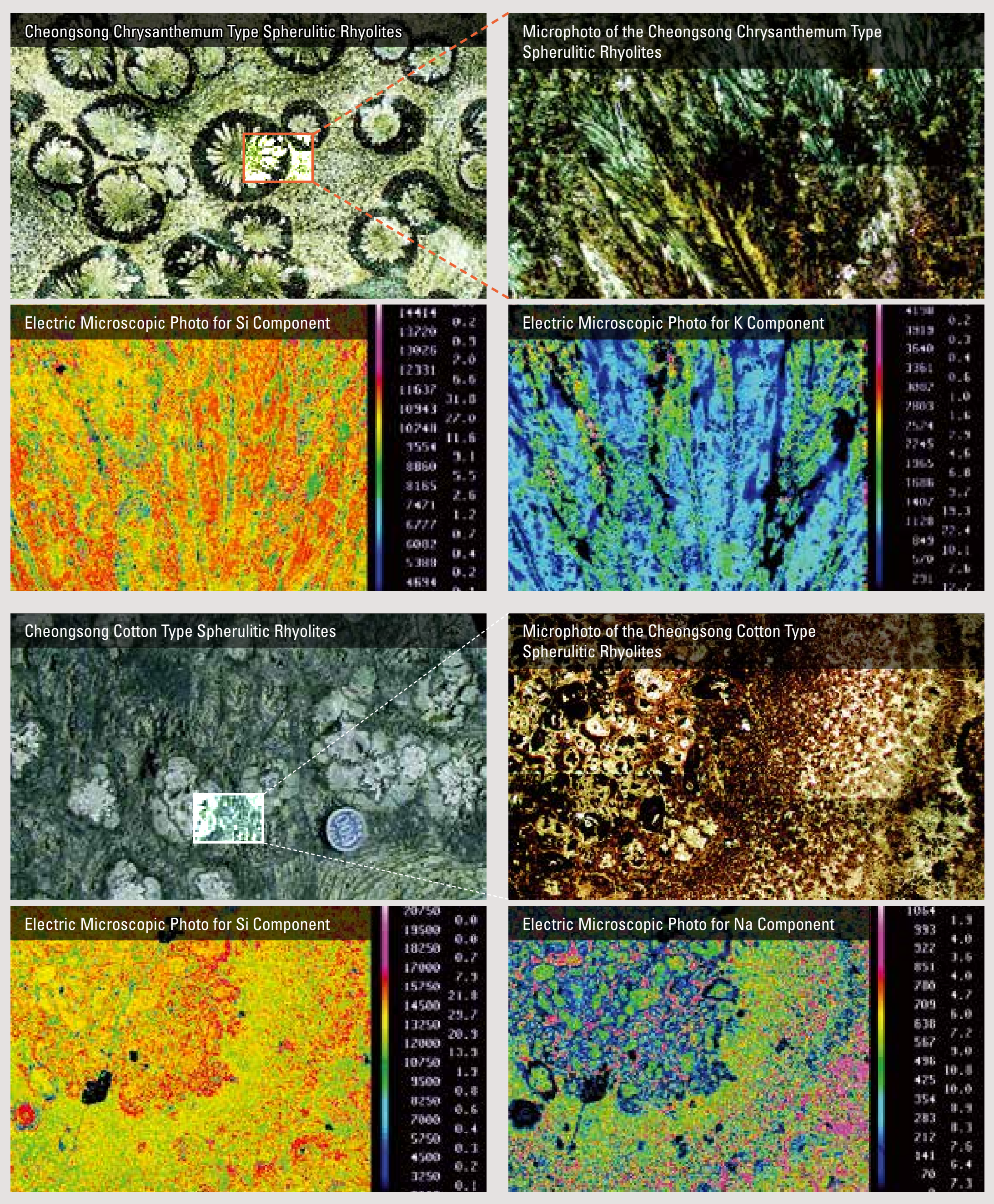
Appearance of Ultramafic Rock



Microphoto of Ultramafic Rock

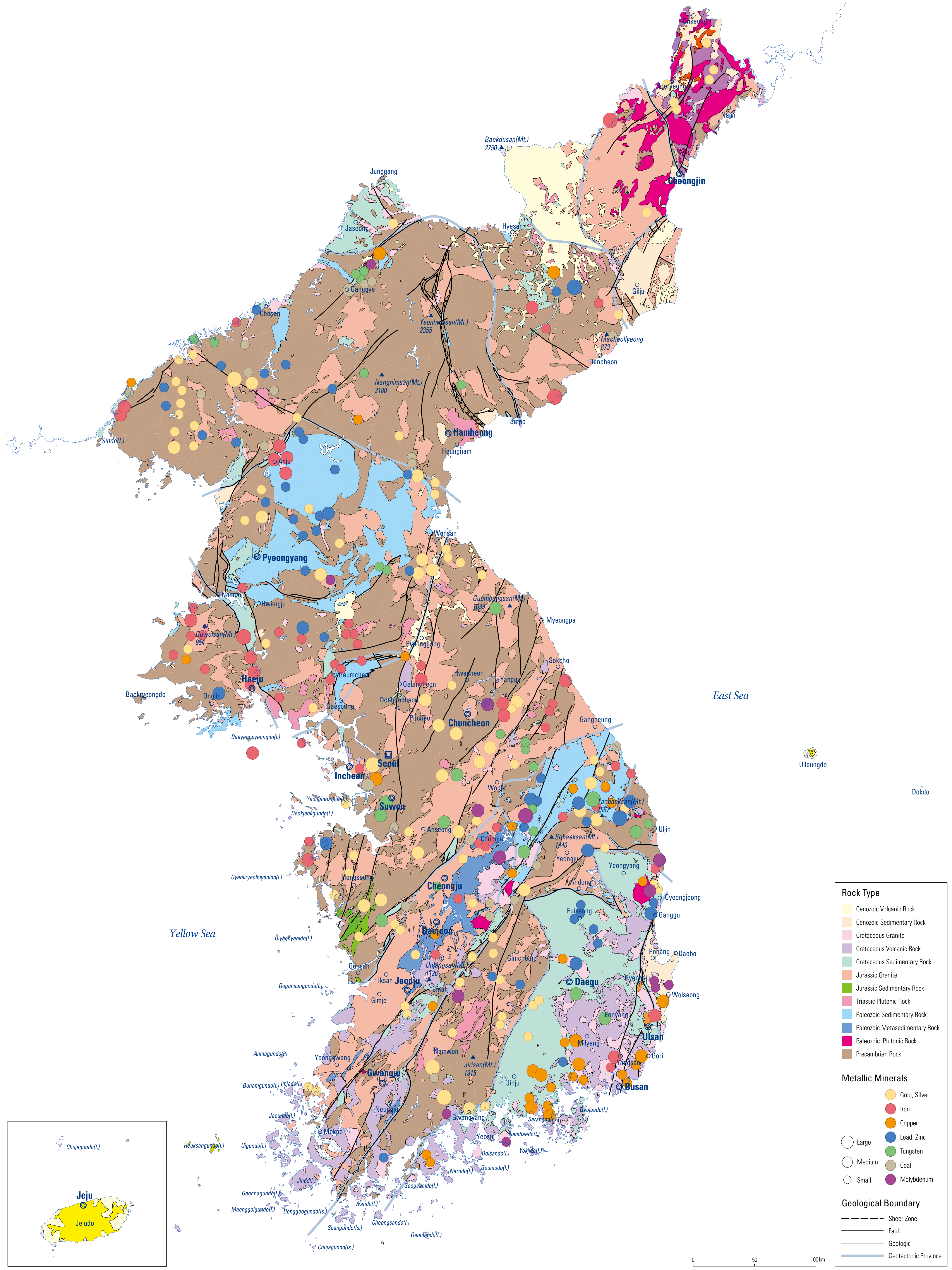
Appearance of Muju Orbicular Granitic Gneiss

Microphoto of Muju Orbicular Granitic Gneiss



Geological Resources

Major Metallic Minerals on the Korean Peninsula

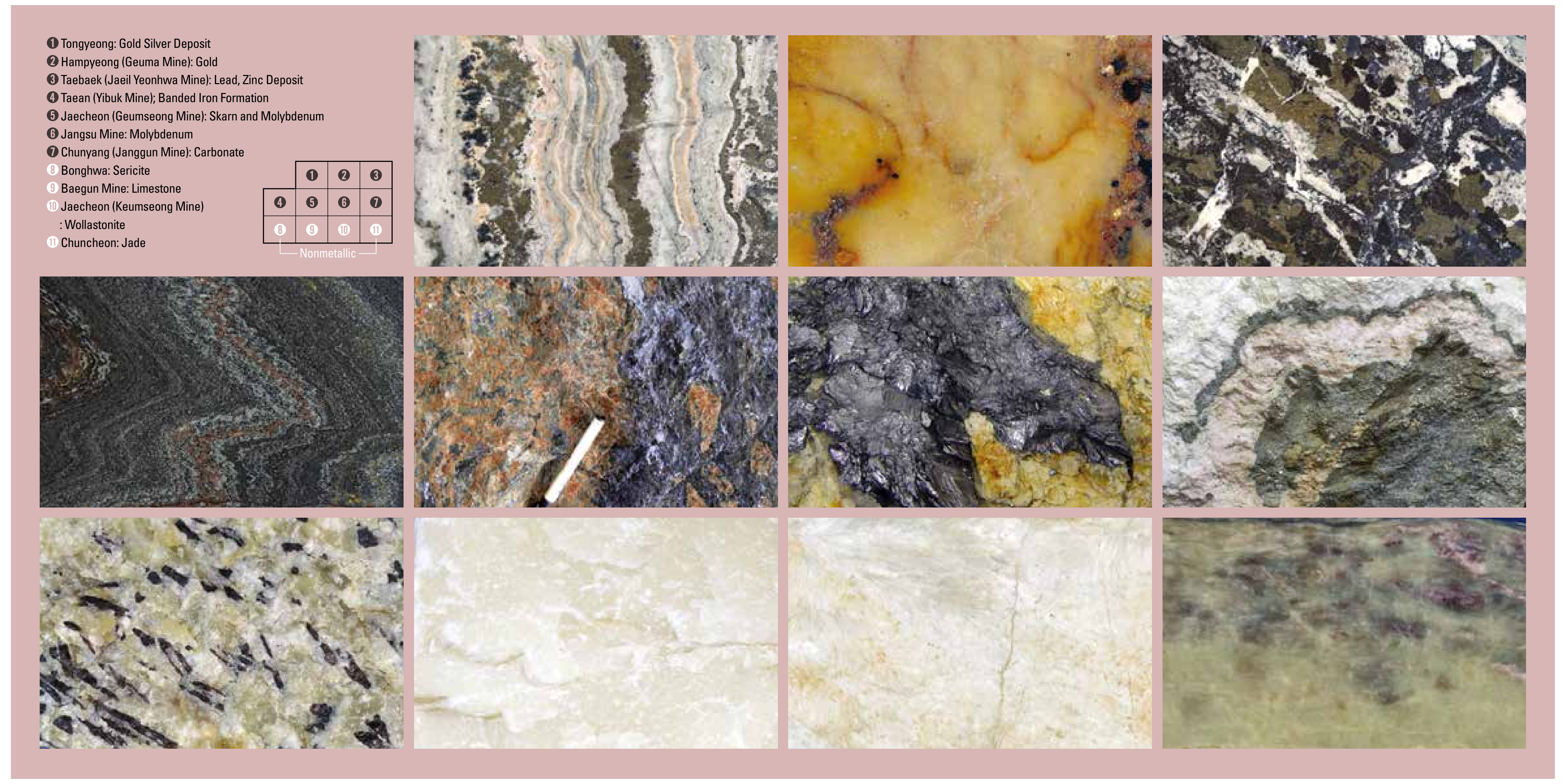


Korea Institute of Geoscience and Mineral Resources (2012)

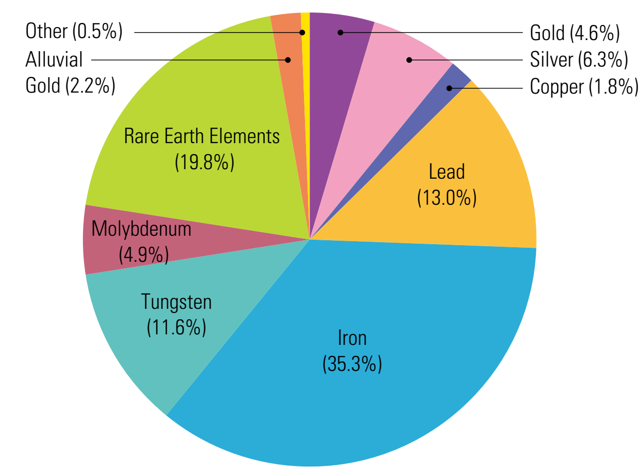
LITHOSPHERE

Rocks and Minerals
Geological Resources

Representative Metallic and Nonmetallic Minerals



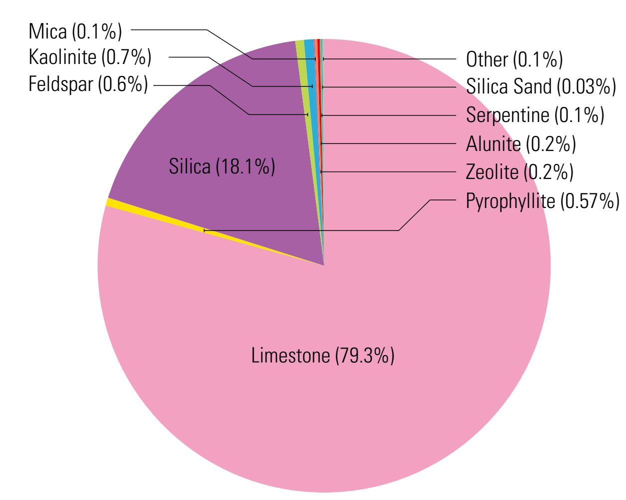
Metallic Mineral Reserves in South Korea



Metallic Minerals	Reserve (Thousands of Tons)
Gold (Au)	6,075.8
Silver (Ag)	8,228.3
Copper (Cu)	2,307.4
Lead (Pb)	17,043.0
Iron (Fe)	46,428.3
Tungsten (WO_3)	15,287.9
Molybdenum (MoS_2)	6,475.0
Rare Earth Elements (R_2O_3)	25,972.0
Alluvial Gold(Au)	2,857.2
Other	818.0
Total	**128,635.5**

Korean Mineral Resources Cooperation (2014)

Nonmetallic Mineral Reserves in South Korea



Nonmetallic Minerals	Reserve (Thousands of Tons)
Limestone	13,221,434.3
Pyrophyllite	94,809.6
Silica	3,019,626.0
Feldspar	102,332.3
Kaolinite	116,320.5
Mica	12,450.3
Zeolite	29.256.5
Alunite	29,297.2
Serpentine	22,973.7
Silica Sand	6,647.7
Other	21,449.8
Total	**16,676,597.9**

Korean Mineral Resources Cooperation (2014)

The main mineral resources in the Korean Peninsula can be classified into metallic, nonmetallic, placer, fossil fuel, nuclear fuel, and building stone/aggregate resources. Metallic resources include gold, silver, copper, lead, zinc, iron, manganese, tungsten, molybdenite, tin, bismuth, antimonite, rare earth elements, and so forth. Nonmetallic resources include limestone, dolostone, quartz sand, quartzite, serpentine, feldspar, kaolinite, graphite, talc, pyrophyllite, diatomite, asbestos, fluorite, mica, illite (sericite), andalusite, and so forth. Placer resources include placer gold, monazite, zircon, ilmenite, magnetite, and garnet. Anthracite and lignite are fossil fuel resources and uranium minerals are nuclear fuel resources. Building stone/aggregate resources include granite, limestone, marble, shale, sandstone, and aggregates.

The typical Precambrian banded iron formation in Seosan and the Ti-bearing-iron deposit in Gonamsan-Soyeonpyeongdo-Boleumdo are Precambrian ore deposits. Tungsten, tin, and gold deposits in Bonghwa-Uljin-Sangdong area and ilmenite deposits in Hadong-Sancheong are the Precambrian deposits in the Yeongnam Massif. The iron deposits in the Chungju-Jungwon area are embedded around the Gyemyeongsan Formation in the Ogcheon Supergroup and contain abundant rare earth elements. The uranium deposits are embedded in the coal-rich black phyllite or schist throughout the large area of Chungju-Goesan (Dukpyeong-Yuyong-ri-Miwon)-Boeun-Daejeon.

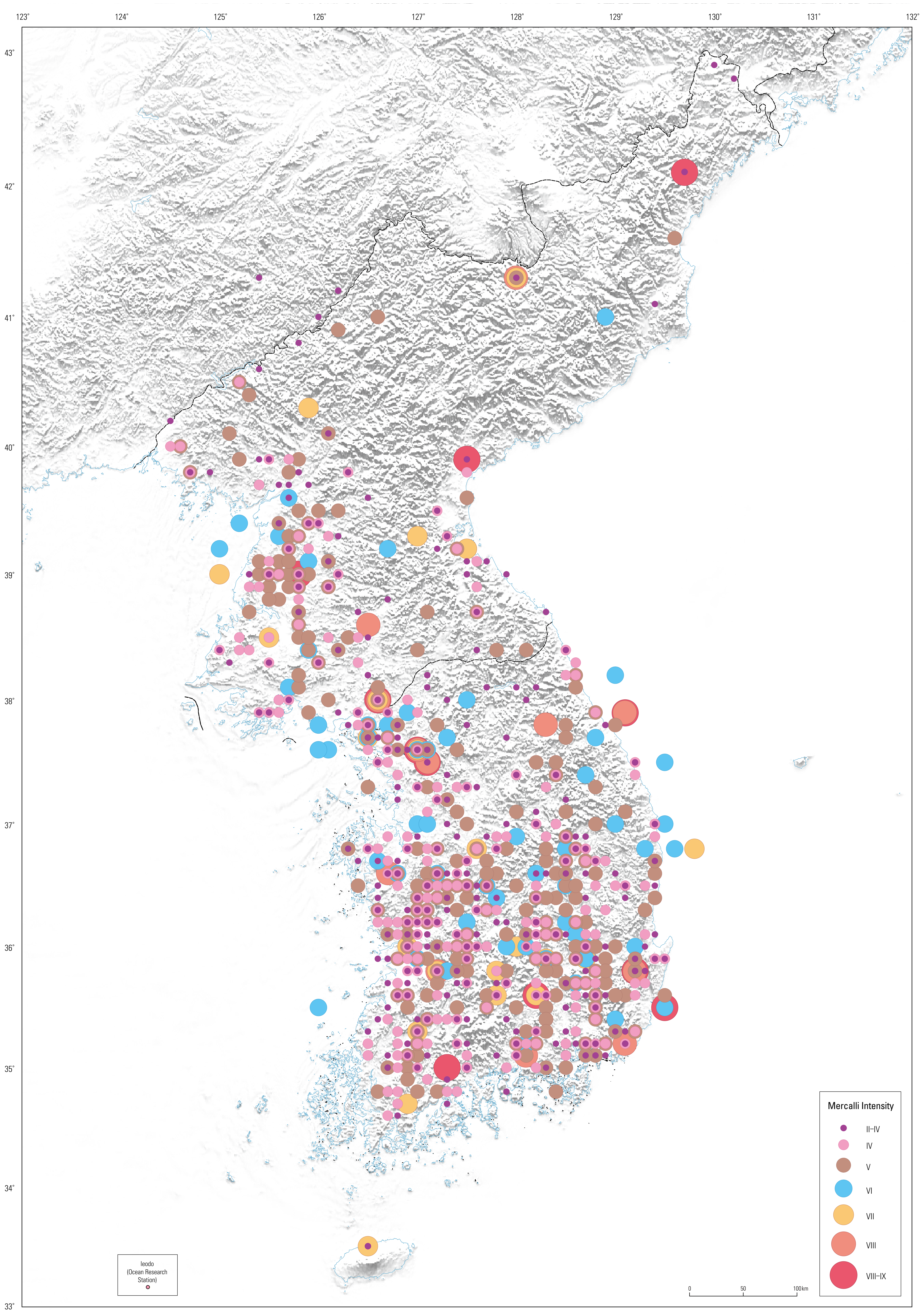
As a fossil fuel, anthracite is embedded in the late Paleozoic Pyeongyan Supergroup and middle Mesozoic Dadong Supergroup. The mining regions for Paleozoic anthracite are Samcheok, Pyeongchang, Boeun, and Boseong and mining regions for Mesozoic anthracite are Kimpo, Yeoncheon, Buyeo and Boryeong. The Mesozoic mine includes Jurassic pegmatite ore deposits in the Gyeonggi Massif which has feldspar, columbite-tantalite, molybdenite, fluorite, uranium-bearing minerals, and beryl. The Jurassic and Cretaceous gold and/or silver mines, as a representative mineral resource of the Korean Peninsula, are mostly vein ore deposits formed by the intrusion of hydrothermal fluid into the fractures of the Mesozoic granites and their surrounding rocks. Representative gold and/or silver mines are located in Mugeug, Bupyeong, Imcheon, Weolyu, Jeonjuil, Tongyeong, and Geochang. Another important mineral resource, tungsten-molybdenite, has also been formed near Mesozoic granites during Jurassic and Cretaceous. At the same period, copper, lead, and zinc mines were forged 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 ultramafic origin and includes the Pyeongdang and Cheongdang mines, and the other type is dolomite origin and includes the Dongyang, Pungjeon, and Chungju-Jaeil mines. The kaolinite-pyrophyllite mines were formed by hydrothermal alteration of tuff, felsite and andesite and are distributed in Gyeongsangnam-do and Jeollanam-do.

Cenozoic deposits include Wondong mine in Samcheok, Dongjeom mine in Changyeong, Geumryeong mine in Wolseong. The mines are skarn and porphyritic deposits including various metals. The zeolite, bentonite, and acidic white clay deposits occur along the tuff stratigraphic horizon within the Tertiary sedimentary formations around the Pohang-Guryongpo-Ulsan.

The northern region of the Korean Peninsula, holds a wider variety of mineral resources than the southern region. The main mineral resources are magnesite, limestone, graphite, zinc, iron, gold, and anthracite. Archean banded iron deposits are in Hamgyeongbuk-do and Neoproterozoic deposits are the Geomdeok zinc mine and Ryongyang and Daeheung magnesite mines in Hamgyeongnam-do and the Hyesan Cheongneon and Gabsan mines in Yanggang-do. Anthracite deposits are embedded in the Paleozoic sediments in Pyeongannam-do and 2·8 Jikdong is representative coal mine. Many coal mines are also developed in Hamgyeong-do. 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 are in Pyeonganbuk-do and in Hwanghaebuk-do. Uranium deposits are reported from Suncheon in Pyeongannam-do and Pyeongsan in Hwanghaebuk-do. Tungsten deposits have high reserves and include Mannyeon mine and the Jangjin mine in Hamgyeong-do, and the Beobdong and Goseong mines in Gangwon-do. Molybdenite mines include Ryonghong and Sakju mines in Pyeongannam-do and Gamuri and Yangam mines in Hwanghae-do and their reserves are small sacle.

Earthquakes

Historical Earthquakes on the Korean Peninsula

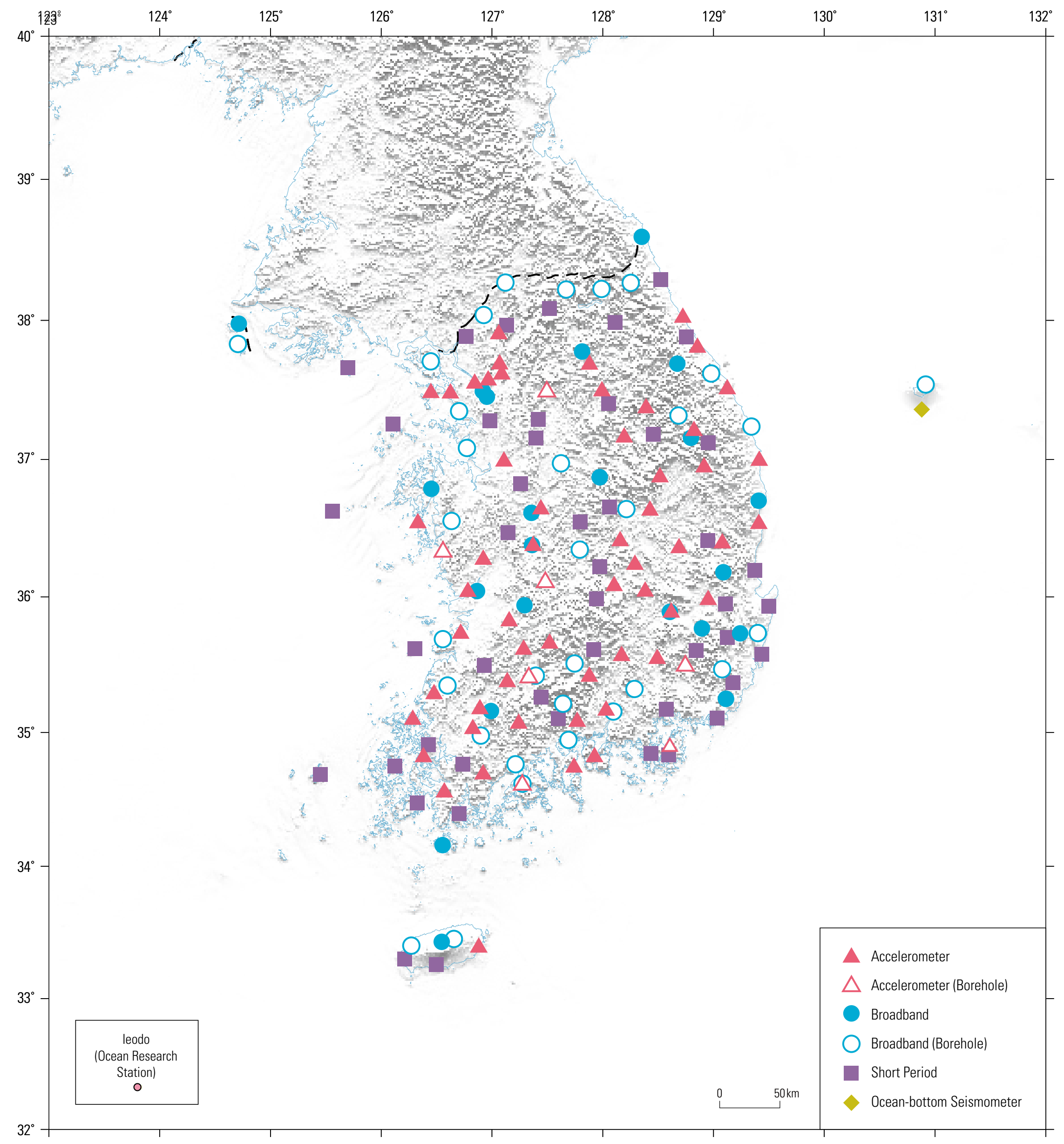


Korea Meteorological Administration (2012)

LITHOSPHERE

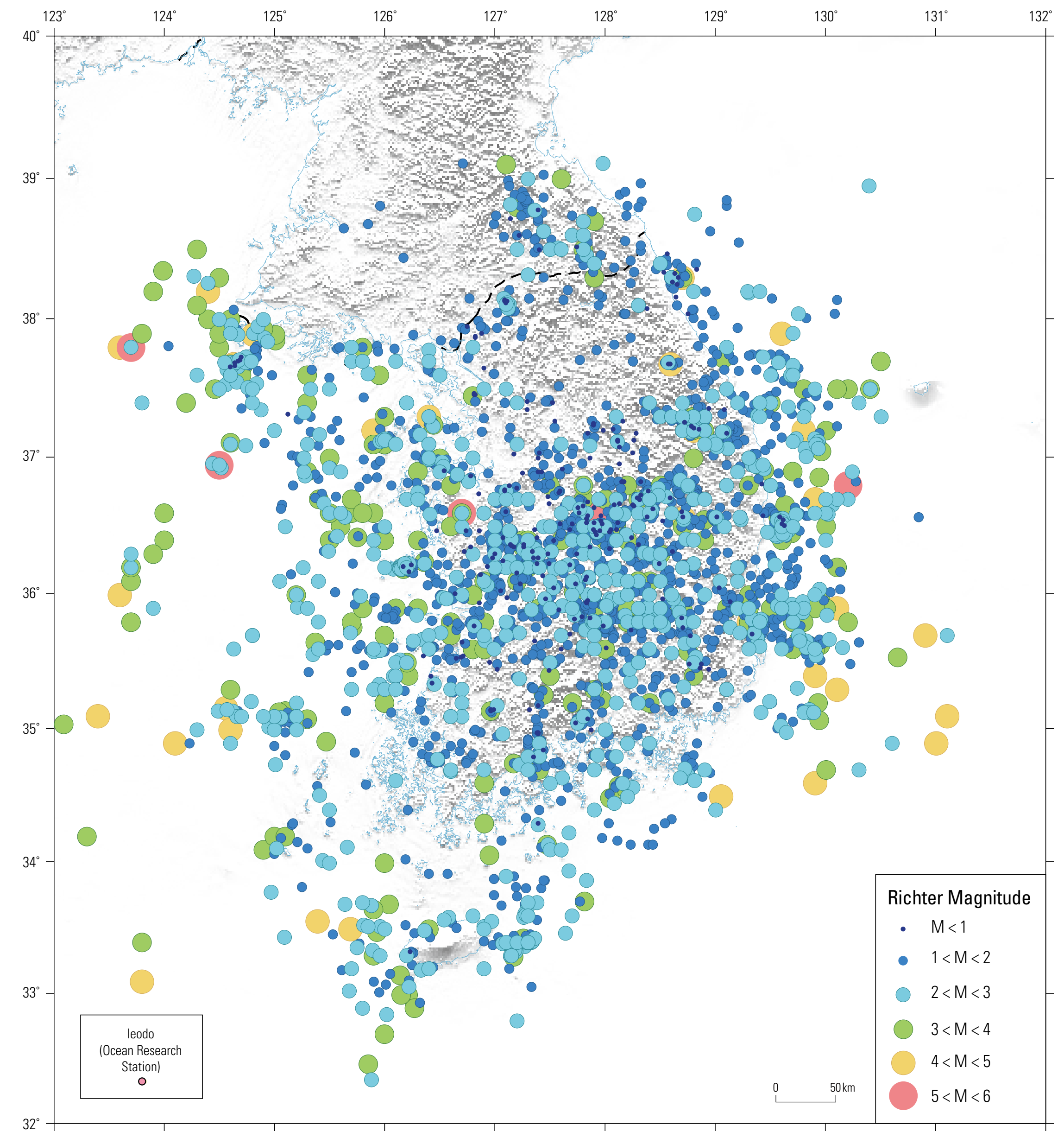
Rocks and Minerals
Earthquakes

Seismic Network and Seismic Stations



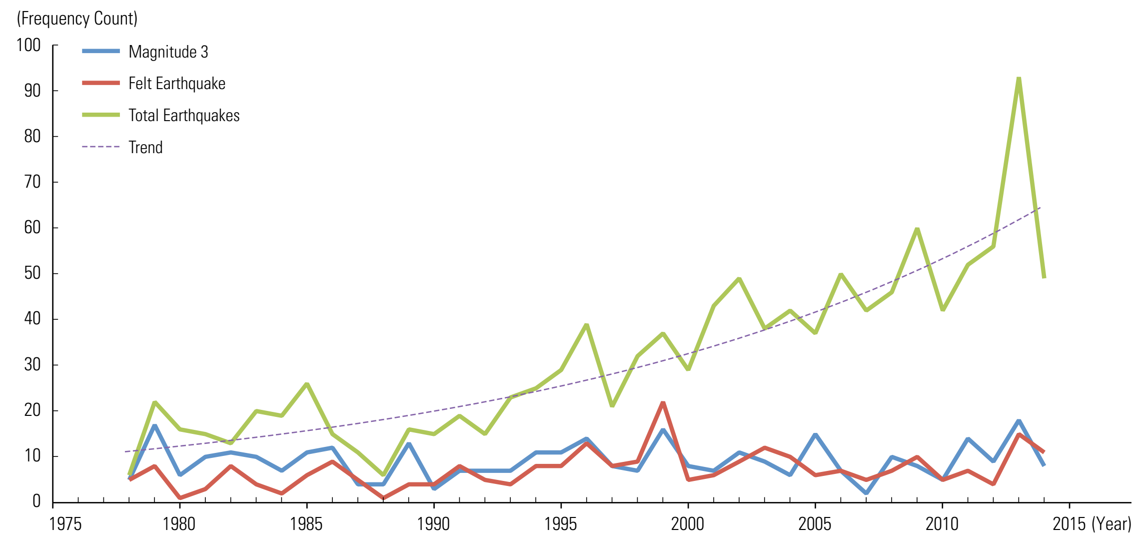
Korea Institute of Geoscience and Mineral Resources (2007)

Instrumental Earthquakes



National Volcano and Earthquake Center (2016)

Instrumental Earthquake Trend in South Korea



National Volcano and Earthquake Center (2016)

Earthquake Magnitude, Seismic Intensity, and Expected Damages

Richter Magnitude	Modified Mercalli Scale	Expected Damage in Populated Area
1.0 – 3.0	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	VI, 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 – 5.0	VI, VII	Slight damage (VI), Considerable damage in poorly built or badly designed structure (VII).
6.0 – 6.9	VII, IX	Considerable damage in poorly built or badly designed structures (VII), Considerable damage in ordinary substantial buildings with partial collapse (VIII).
7.0 –	VIII or Higher	Considerable damage in ordinary substantial buildings with partial collapse (VIII). Most masonry and frame structures destroyed (X). 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)

The Korean Peninsula located on the Eurasian plate had long been recognized as a relatively safe region from strong earthquakes compared to other countries such as Nepal and Japan, which are located along plate boundaries. However, ever since the Korea Meteorological Agency (KMA) began to officially record seismic activity in 1978, there has been fairly strong seismic activity within the Korean Peninsula including the earthquakes at Hongseong-gun (a magnitude of 5.0) in 1978, Yeongwol-gun (a magnitude of 4.5) in 1996, and Odaesan (a magnitude of 4.8) in 2007, Gyeongju (a magnitude of 5.8) in 2016. Further investigation using Korean historical records points out 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.

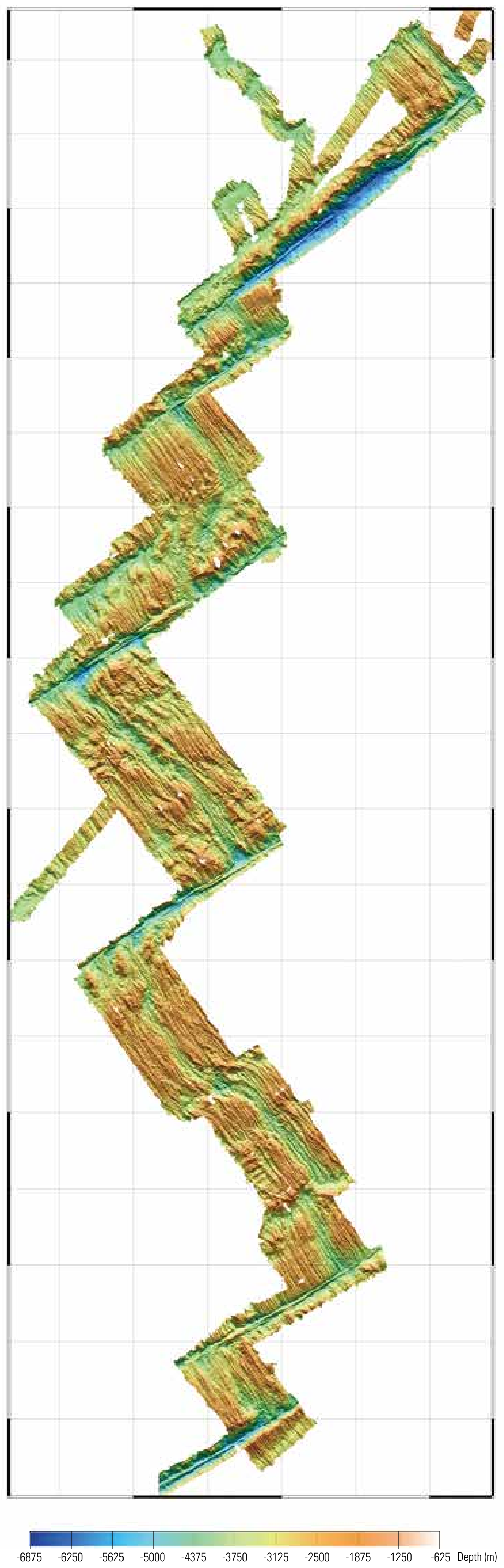
Based on estimates from historical records, the epicenters of historical earthquakes with seismic intensity greater than V (in the Midified Mercalli Scale) are mostly located in the areas to the south of Chungcheong-do and in the western Pyeongan-do. The epicenters estimated from historical observations are similar to the epicenters estimated by modern seismic observations, indicating that these historical seismic events can reliably reveal the characteristics of seismic activity on the Korean Peninsula. The most interesting findings in the historical records are the reports on strong earthquakes which resulted in casualties, damage to castles and ground ruptures, leading to tsunamis. For example, during the 21th year of the reign of King Injo (1643 AD), there were reports of a strong earthquake that collapsed casthle walls in the Ulsan area and caused a tsunami. Such historical information warns of the necessity in increased preparation for future earthquakes and tsunamis in 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 Busan, Gyeongsung, Daegu, Pyongyang, and Chupungryong. In 1937, quantitative seismic observations of seismic activity on the Korean Peninsula began at these six stations. In March of 1963, the United Stated Geological Survey (USGS) installed an international standard seismograph in Seoul as a member of the World Wide Standard Seismograph Network (WWSSN). In 1978, KMA installed two seismic stations. Today, two major seismic agencies, the KMA and KIGAM (Korean Institute of Geology and Mining) are operating 180 seismic stations to monitor seismic activity on the Korean Peninsula.

After the introduction of instrumental seismic observation in 1978, the strongest recorded earthquake (magnitude of 5.8) occurred in an area located 8 km south-south-westward away from the Gyeongju on September in 2016. Unofficially, the second strongest earthquake occurred in the Euiju-Sakju-Guisung region with a magnitude of 5.3. The following notable earthquakes occurred with a magnitude of 5.2 in Uljin-gun, Gyeongsangbuk-do on May 2004 and in Sokrisan on September in 1978. While it may be premature to prescribe patterns, the instrumental earthquakes data thus far indicate that most major earthquakes tend to occur in near-coastal regions, western Gyeonggi-do and in the regions to the south of Chungcheong-do. This result is similar to the distribution pattern of historical earthquakes with seismic intensity greater than V. Since the instrumental seismic observation from 1978, the frequency of seismic activity has increased, but if those events with a magnitude greater than 3 are considered, frequency has remained the same as in the past. However, the number of instrumental earthquakes with a magnitude greater than 3 in Gyeongju increased greatly after the 2016 earthquake with a magnitude of 5.8. Based on both the instrumental and historical data, the probable maximum magnitude of an earthquake on the Korean Peninsula is estimated to lie between 6.97 and 7.5, with a recurrence period of a few hundred years.

International Cooperation

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

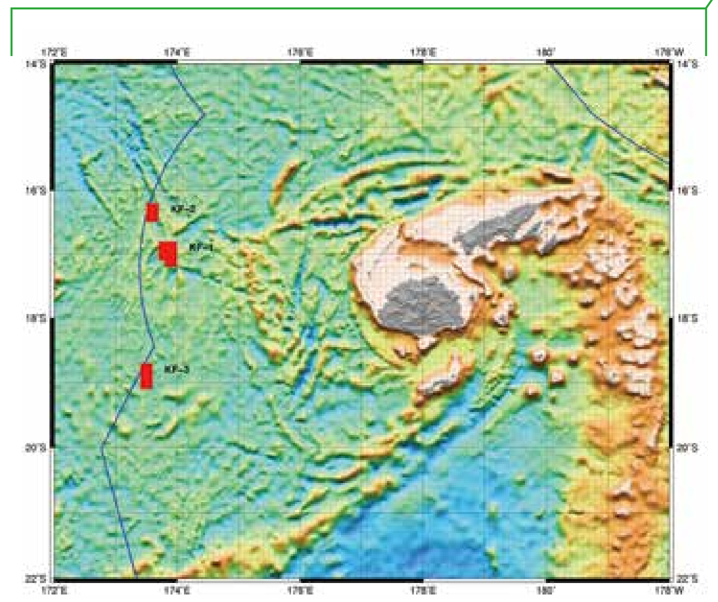


Korea Institute of Ocean Science and Technology

Submarine Geology and Resources Investigation

Hydrothermal Deposits along the Ridge

Exploration Area for the Fiji EEZ Hydrothermal Deposit



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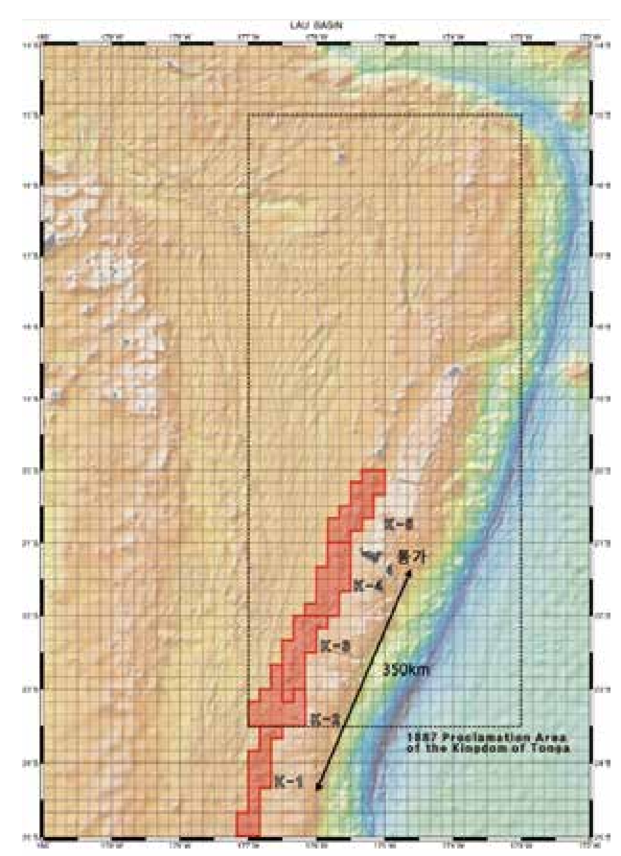
Exploration Area for the Tonga EEZ Hydrothermal Deposit

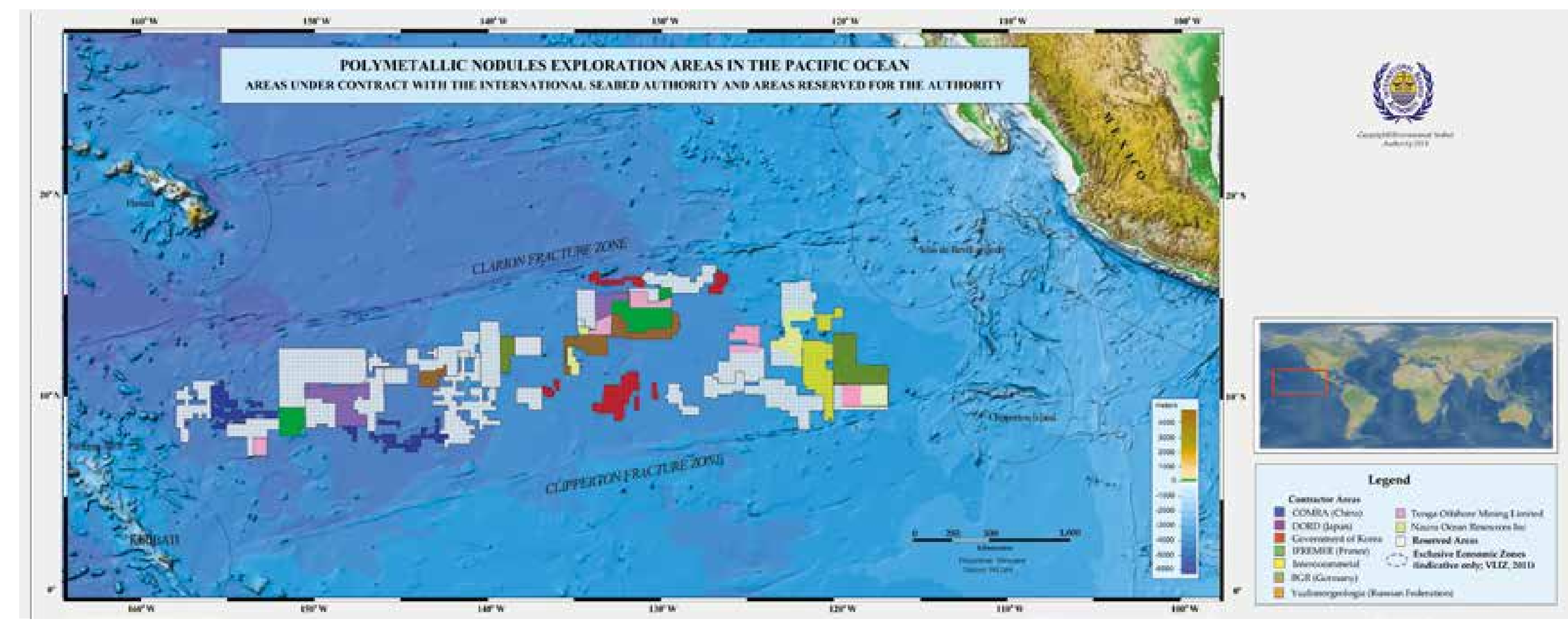


Korea Institute of Ocean Science and Technology

The Comprehensive Oceanic Research Ship, *Onnuri*

Korea Institute of Ocean Science and Technology

Exploration Area for the Northeast Pacific Manganese Nodule



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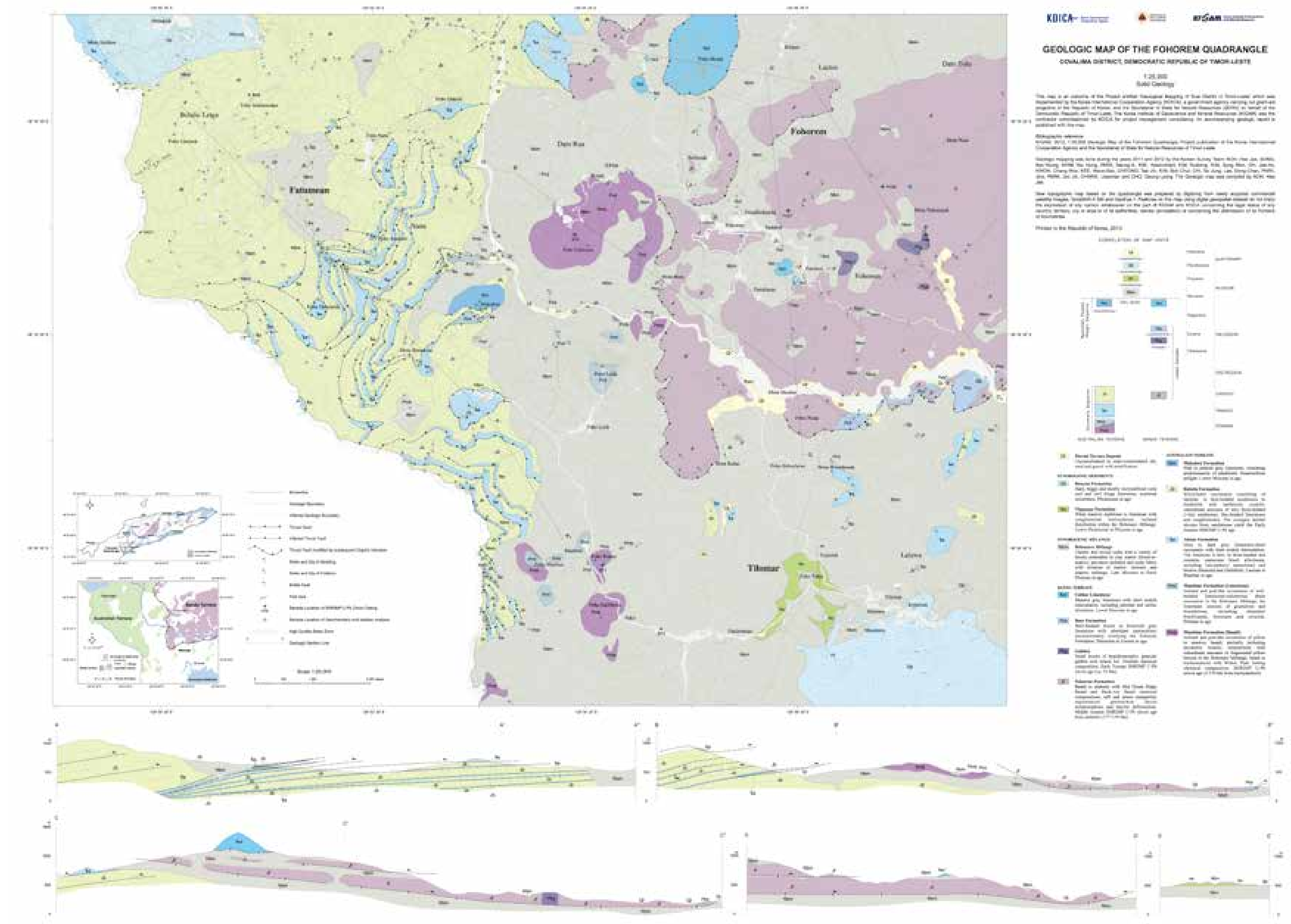
Geological Map of Timor-Leste



Korea Institute of Geoscience and Mineral Resources (2013)

Recently geological surveys have been actively carried out in foreign countries. In 1990, the Korea Ocean Research and Development Institute, the predecessor of the Korea Institute of Ocean Sciences and Technology, began to pursue a full-scale research 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 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. During 2008 – 2012, 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. Korea has expanded its research area from the eastern Pacific Ocean and southwestern Pacific Ocean to the Indian Ocean.

The oceanographic research ship *Onnuri* (1,442 ton), which can carry out ocean exploration, has made it possible for the Korea Institute of Ocean Sciences and Technology to pursue a 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), and mining rights for submarine hydrothermal deposits in the Indian Ocean (2012). 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 private organization. Through efforts during the last 25 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.

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. After that the Antarctic King Sejong Station and the Arctic Dasan Station were inaugurated in 1988 and 2002. The Jang Bogo Station was built in 2013 as a base for research on weather and atmosphere, glacial, marine, and land ecosystems and species living under extreme conditions in the Antarctic area. Surveys for finding meteorites, research on paleoclimate, geochronological, and geophysical studies on Antarctica; and research on the relationship between polar ice and tectonics are also currently being carried out. The metamorphism of the late Paleozoic Wilson Terrane, the Paleozoic stratigraphy of the Bowers Terrane, the paleoenvironment of the Beacon Supergroup, and the mineralization of northern Victoria are under investigation in these stations. Recently, chondrite meteorite of 36.7 kg was also collected together with many other meteorite samples.