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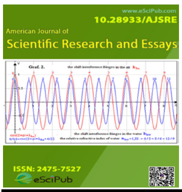

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Graphite mine and mineral assemblage of surrounding rock and its indicative significance to metamorphic facies

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ABSTRACT

The different metamorphic mineral assemblages can reflect the difference of metamorphic temperature and pressure and determine the different metamorphic facies. The identification and determination of the occurrence of characteristic metamorphic minerals and the symbiotic association of typical metamorphic minerals can determine the metamorphic phase of graphite and its surrounding rock, and further infer the formation conditions of graphite. In this paper, the mineral assemblage relationship of a graphite deposit and its surrounding rock in the south of Hebei province is studied by means of microscopic observation and Electron Probe Micro Analysis (EPMA), and the metamorphic facies of the graphite deposit and the temperature and pressure conditions of the deposit are deduced. The study shows that the metamorphic facies of the graphite deposit is low amphibolite facies and the ore-forming conditions are medium temperature and medium pressure.

Keywords: Graphite, Electron microscope, Metamorphic facies, Metamorphism

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Introduction

In 1922, Eskola (Eskola, 1922) [1] puts forward the concept of metamorphic phase when studying eclogists in Oslo, Norway. He believed that under certain conditions of temperature and pressure, mineral components in any rock or metamorphic unit that reached chemical equilibrium through metamorphism were controlled by chemical components, which was called metamorphic phase. Katz (Katz, 1987) [2] by means of in senior Precambrian metamorphic rock area, which is mainly composed of granulite facies Sri Lanka a vein graphite ore deposit is studied, based on the X-ray diffraction (XRD) data and stable carbon isotope of graphite thermometer support, show that the graphite deposit originated from deep crust, carbon-rich fluid and the condition of granulite facies through the metamorphic formation under the action of the earth's crust transportation. Rantitsch et al. (Rantitsch et al., 2016) [3] studied a number of major graphite ore samples in the world by means of reflectivity measurement, XRD, high-resolution transmission electron microscopy (HRTEM), selective electron diffraction (SAED) and Raman spectroscopy, and showed that the structural order of carbon-containing materials depends on the metamorphism degree of the host rock. Semi-graphite is present in lower green schist samples from the Kaisselsberg mine (Austria). During progressive graphitization within the green schist phase, semi-graphite is continuously transformed into graphite, and well-crystallized graphite is observed in granulite samples.

In recent years, many experts and scholars have conducted in depth research on large graphite deposits in China and conducted large-scale mining. The graphite deposits found in Hebei province are concentrated in the concentrated area of graphite mineralization in Zhangjiakou City, while the small graphite deposits in the south have not been paid attention to, and only the basic characteristics of the ore bodies have been studied. Therefore, this paper takes a small graphite deposit in the south of Hebei Province as the research object, and studies the mineral assemblage relationship of a graphite deposit and its surrounding rock by means of microscopic observation and Electron Probe Micro Analysis (EPMA), so as to infer the metamorphic phase of the graphite deposit and the temperature and pressure conditions of the deposit formation.

Geological setting and sample description

(1) Geological structure: The graphite deposit in the study area is located in the mineral metallogenic belt of southern Hebei Province (Figure1). Its tectonic location is the Sino-Korean quasi-platform (I) Central Shanxi Fault uplift (Ⅱ) Taihang Arch (Ⅲ) Zanhuangqiong Vault (Ⅳ) and Wuan depression (Ⅳ).

(2) Stratum: The stratum where the graphite ore is located is Dahezhuang Formation (Ar_3d). The upper part is dominated by plagioclase amphibole schist with biotite plagioclase granulite. The lower biotite plagioclase granulite is intercalated with plagioclase amphibolite and garnet amphibolite.

(3) Metamorphism: Early Neoarchean, in the north west - south east to the system under the action of tension, the district on the edge of the initial land on the earth's crust or nuclear form north east, south west to the distribution of long and narrow rift, bottom to form a set of basic volcanic rocks in volcanic clastic rock - terrigenous clastic rock to build (Dahezhuang Petrofabric), central for a set of carbonate rock in the siliceous mudstone - volcanic building (Liyanghe Petrofabric), The upper part is terrigenous clastic - acid volcanic rock formation (Ningjiazhuang Petrofabric). The Dahezhuang and Liyanghe Petrofabric, which deposited organic-containing

mudstone and sandstone in an unstable shallow marine sedimentary environment, experienced tectonothermal events, which resulted in the closure of rift valley and the occurrence of complex multi-stage structural deformation, accompanied by multi-stage magmatic activities and metamorphism (Zhao, 2019) [4].

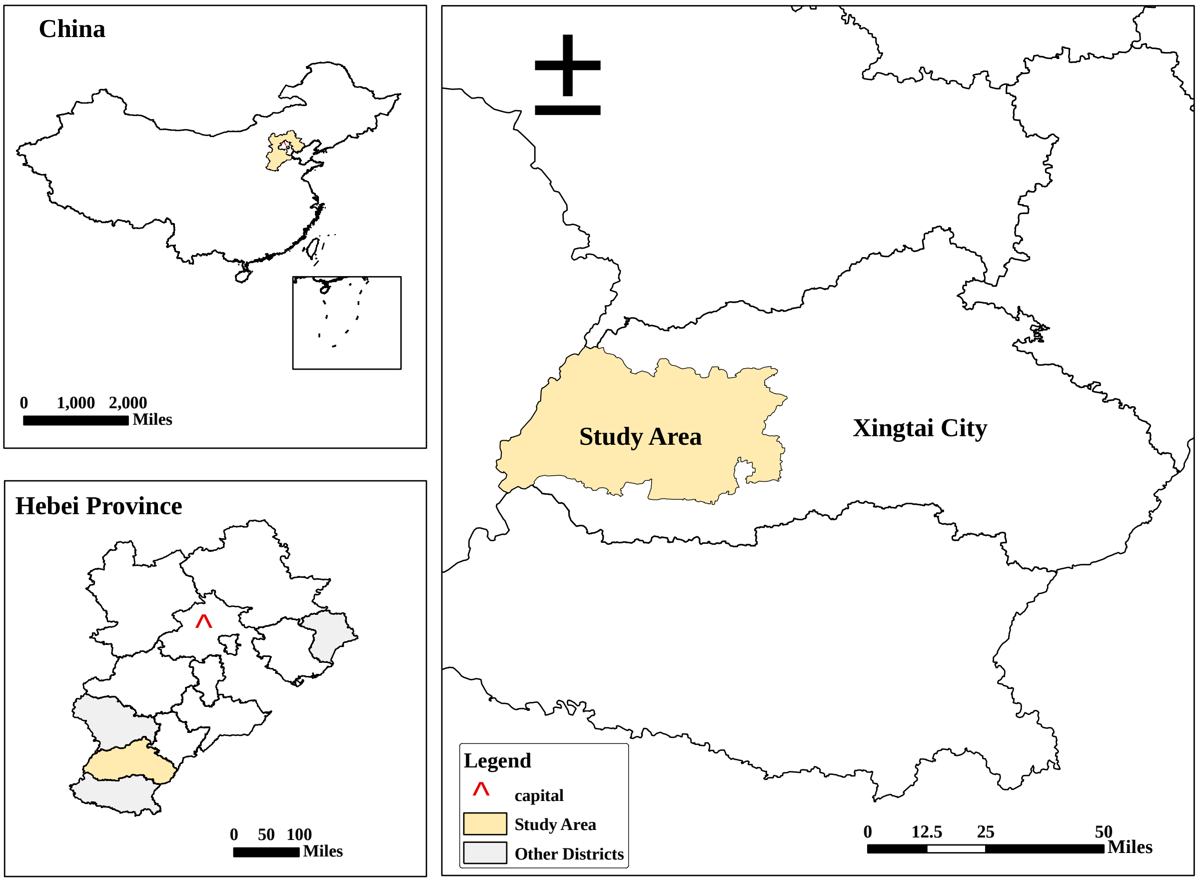


Figure 1 Location map of the study area

(4) The samples were collected from two standard drilling holes in the research area, and the control inclination depth was 200 meters. The ore exposed by deep drilling was primary ore. The graphite section in the drilling was taken for testing and research, and the total thickness of mineralized layer was 10-15m. The sample is graphite- kyanite eclogite schist, and the upper strata of the mineralized layer are mainly garnet muscovite biotite schist, garnet biotite plagioclase granulite, garnet plagioclase amphibolite, etc., and the lower strata are mainly marble.

Analytical methods

In this study, the graphite containing ore in the study area was observed by electron microscope and electron probe backscattering images. The sample was cut and ground to transparent thin slices and dried in the oven. Then the thin slices were placed on the slides and gently pressed and fixed with appropriate epoxy resin. Bubbles in the glue were removed and waited for about 12 hours to make standard rock slices (sample breakage or falling off should be avoided during the process).

The prepared standard rock flakes were placed under electron probe test to obtain backscattered electron images. The experimental instrument was JXA-8230 Electron probe microanalyzer (Figure2) from JEOL Corporation of Japan. The test conditions were as follows: the acceleration voltage was 15kV, the current was 1×10^{-8}A, the beam spot diameter was 1μm, and the image magnification was the appropriate multiple for each sample observation.

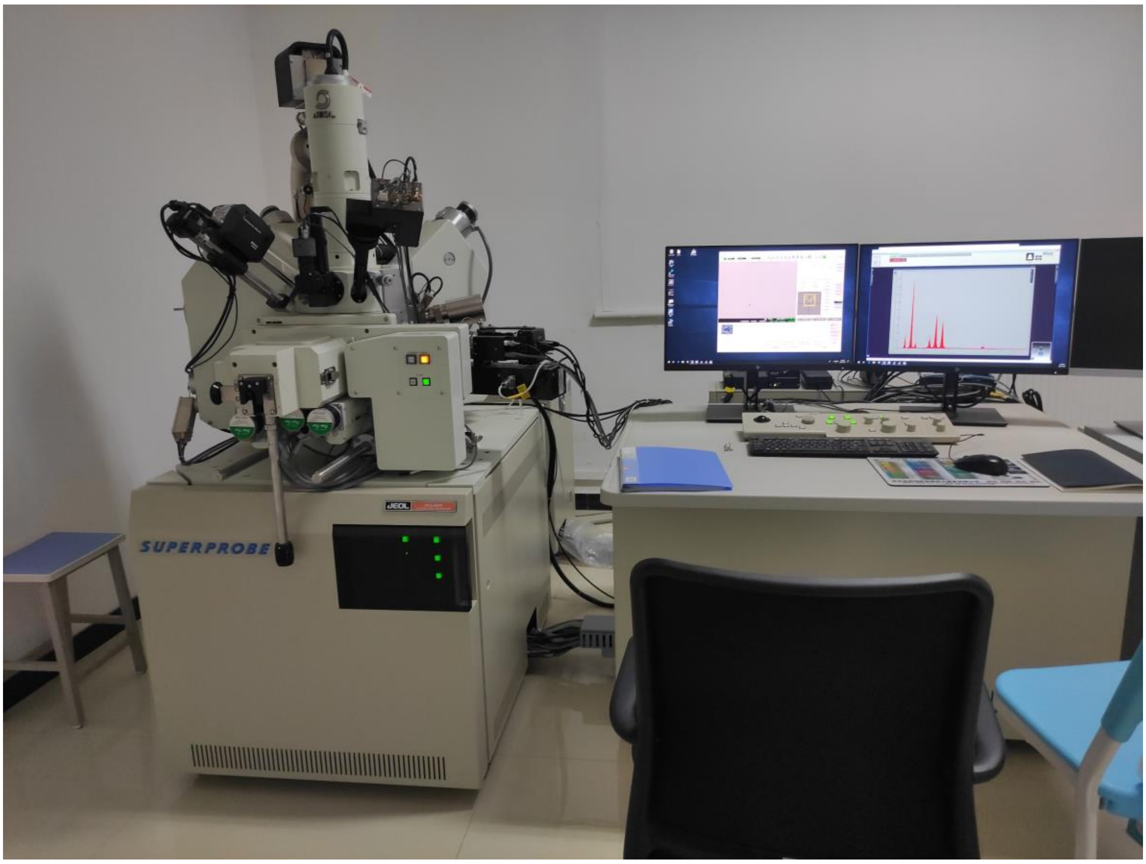
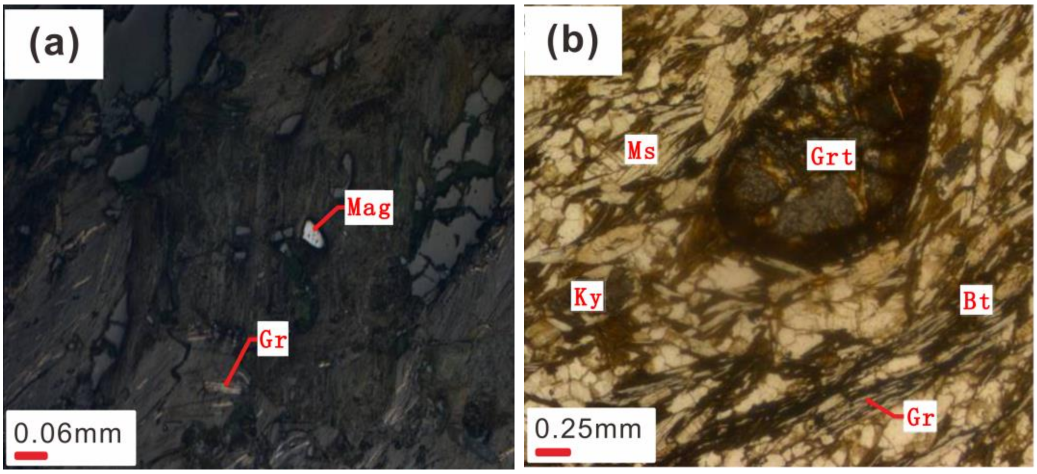


Figure 2 Electron probe instrument diagram

Results and discussion

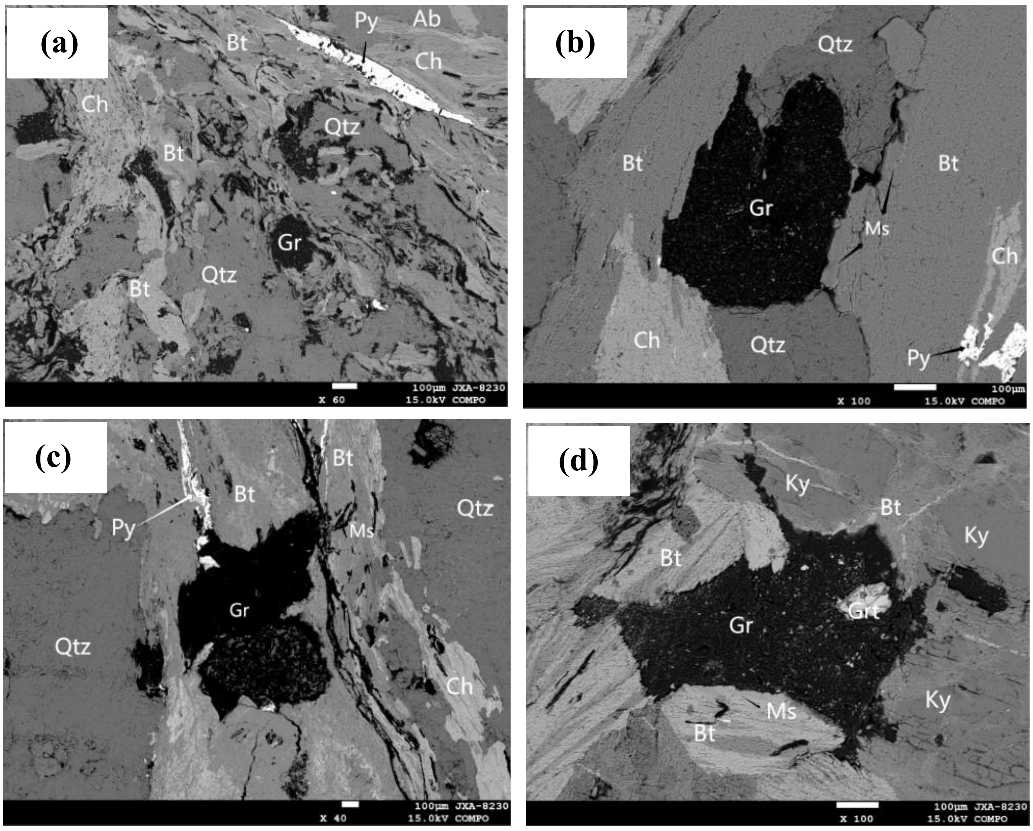
The graphitic sample was identified as kyanite garnet muscovite biotite schist (Figure3) by observing the original ore and polarizing microscope image. The ore structure is massive structure and flake structure, and the main ore mineral is graphite, which is crystalline graphite, steel gray, opaque, easy to stain hands, and smooth powder (Zhao, 2019) [4]. At the same time, we also found a small amount of magnetite, automorphic, granular, gray zone light brown, disseminated disseminated distribution, its main particle size is 0.04~1mm. The characteristic minerals are kyanite and garnet, and the gangue minerals are mainly quartz, muscovite, biotite, plagioclase and chlorite altered by biotite. Among them, kyanite is colorless, light gray, the structure is automorphic column, strong sericite retains its crystal characteristics, metasomatic residual or pseudomorphic structure, the main particle size is 0.4~3mm, the content of about 2%; Garnet stone is brown, the structure is euhedral granular, particle size 0.1~2mm, about 4~5%; Quartz is alloform, granular, particle size 0.24~1mm, content of about 30%; Plagioclase is allotriomorphic, columnar, slightly sericite, the main particle size of 0.2~1mm, content of about 20%; Biotite is brown, automorphic, flake, and decomposed in different degrees. Ferric limonite is precipitated, with a diameter of 0.4-2mm, directional arrangement and flake structure, and the content is about 25%. Muscovite is colorless, automorphic and lamellar, with a diameter of 0.4~2mm, directional arrangement and lamellar structure, and the content is about 15%.



Gr: Graphite, Mag: Magnetite, Ms: Muscovite, Ky: Kyanite, Bt: Biotite; Grt: Garnet

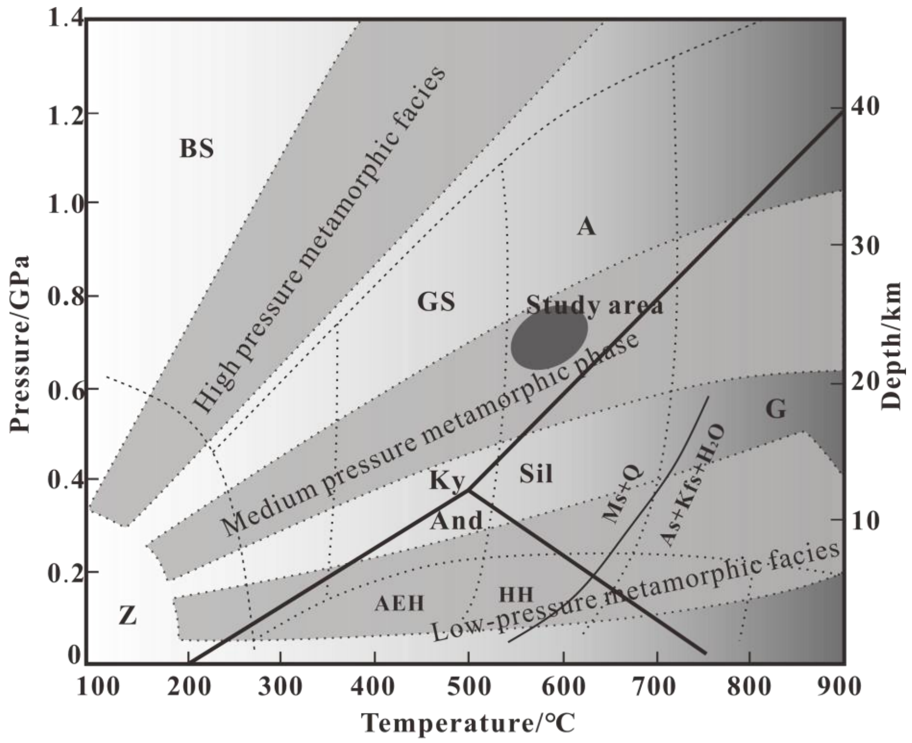
Figure 3 Image of graphite-kyanite garnet mica schist under microscope

Backscattering electron images (Figure4) show that the graphite is lamellar with slightly depressed surface, which is caused by grinding and polishing during the preparation of rock flakes. Graphite is mainly 0.01~0.4mm in diameter and it is self-shaped flake and oriented, mainly associated with muscovite and chlorite, and a small amount of flake aggregate in quartz, consistent with the direction of rock schistosity, uneven distribution, easy to be enriched in the rock bend slide surface. The fine particles included in the graphite are quartz, biotite, chlorite and other impurities, which are enriched and distributed along the fissure, and are associated with the graphite, presenting a fine granular uneven distribution.



Gr: Graphite, Ms: Muscovite, Bt: Biotite; Ch: Chlorite, Qtz: Quartz, Ab: Albite, Py: Pyrite

Figure 4 Backscattered electron image



Ms: Muscovite; Q: Quartz; And: Andalusite; Ky: Kyanite; Sil: Sillimanite; As: Al_2SiO_5; Kfs: K-feldspar; BS: Blueschist facies; A: Amphibolite facies; GS: Greenschist facies; G: Granulite facies; Z: Zeolite facies; AEH: Albite – epidote hornfels facies; HH: Hornblende hornfels facies

Figure 5 The mineral assemblages in the study area indicate metamorphic facies (Cheng et al., 2020) [5].

The samples in common minerals are quartz, muscovite, biotite, plagioclase and chlorite, part closer to the sample of ore body of garnet, kyanite, or hornblende, quartz existed in the form of independent minerals in mineral, not seen muscovite + quartz = k-feldspar + sillimanite/ andalusite + H_2O reaction of the melt, Ore in the overlying strata normal Angle of hornblende and plagioclase symbiosis, and the emergence of kyanite and garnet show metamorphic facies as the medium pressure metamorphic facies, therefore in combination with Table1, shows that the samples in the study area of graphite for low amphibolite facies metamorphic facies, graphite mine according to the genetic types of classification for regional metamorphism type, the research results on the metamorphic facies classification diagram shown as shown in figure 5.

Conclusion

(1) Polarizing microscope identification results show that the rock type of the graphite ore is kyanite garnet muscovite biotite schist. The main ore mineral is graphite, with a small amount of magnetite. Metamorphic minerals include kyanite and garnet, and gangue minerals are mainly quartz, muscovite, biotite, plagioclase and chlorite altered by biotite.

(2) Backscattering electron images show that graphite is mainly associated with muscovite and chlorite, and a small amount of graphite is a flake aggregate in quartz, consistent with the direction of rock schistosity and uneven distribution. Ore samples in common minerals are quartz, muscovite, biotite and plagioclase, chlorite, part closer to the sample of ore body of garnet, kyanite, or hornblende quartz exists in the form of independent minerals in mineral, not seen muscovite + quartz = k-feldspar + sillimanite/andalusite + H_2O reaction of the melt. In addition, hornblende

and plagioclase coexist in the overlying strata of the ore, and the occurrence of kyanite and garnet indicates that the metamorphic facies is medium-pressure facies.

(3) Combined with microscope observation and backscattering electron observation (EPMA), it is inferred that the metamorphic facies of the graphite deposit is low amphibolite facies, and the ore-forming conditions are medium temperature and medium pressure.

Acknowledgements

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Table 1 Metamorphic mineral assemblage and metamorphic facies division (He, 1985)[6]

Metamorphic facies	Metamorphic facies division	Temperature/(℃)	Pressure/(GPa)	Characteristic mineral association	Major metamorphic reaction
Regional metamorphic facies	Zeolite facies	200~300	0.2~0.3	(1) Albite + Laumontite + Chlorite + Quartz (2) Laumontite + Prehnite + Chlorite + Albite + Quartz (3) Prehnite + Chlorite + Calcite + Quartz	Analcime + Quartz = Albite (200℃) Heulandite = Laumontite + Quartz +H_2O(<200℃)
	Prehnite-Pumpellyite facies	300~360	0.25~0.35	(1) Albite + Prehnite + Pumpellyite + Chlorite +Quartz (2) Albite + Epidote + Pumpellyite + Chlorite + Quartz	Laumontite + Chlorite + Calcite = Prehnite + Quartz +CO2+ H_2O Laumontite + Prehnite + Chlorite = Pumpellyite + Quartz + H_2O)
	Blueschist facies	200~450	0.3~0.8	(Medium Pressure) Lawsonite + Albite + Chlorite + (Quartz, Calcite, Phengite) (High Pressure) Lawsonite + Glaucophane + nepheline (Very High Pressure) Lawsonite + Glaucophane + jadeite + Quartz	Laumontite = Lawsonite + Quartz +H2O Chlorite + Actinolite + Albite = Glaucophane + H_2O Albite = jadeite + Quartz
	Greenschist facies	400~500	0.3~0.8	(Argillite)Muscovite + Biotite + Chlorite + Quartz ± Chloritoid (Basic rock) Albite + Epidote + Chlorite + Actinolite ± Quartz ± Calcite	Pumpellyite + Chlorite + Quartz = Zoisite + Actinolite + H_2O
	Epidote-amphibolite facies	500~575	0.2~0.6	(Argillite) Almandite + Biotite + Muscovite + Quartz (Basic rock) Hornblende + Epidote + Chlorite + Albite ± Quartz	Actinolite + Clinozoisite + Chlorite + Quartz = Hornblende + H_2O chloritoid + Chlorite + Quartz = Almandite + H_2O Muscovite + Chlorite + Quartz = Almandite + Biotite + H_2O
	Low-Amphibolite facies	500~650	0.3~0.8	Argillite (Medium Pressure): Staurolite + Almandite + Biotite + Muscovite + Quartz ± Plagioclase	Chlorite + Muscovite = Staurolite + Biotite + Quartz + H_2O

Metamorphic facies	Metamorphic facies division	Temperature/(℃)	Pressure/(GPa)	Characteristic mineral association	Major metamorphic reaction
				Kyanite + Almandite + Biotite + Muscovite + Quartz± Plagioclase Argillite(Low Pressure)：Cordierite + Andalusite + Biotite + Muscovite + Quartz± Plagioclase ± Almandite Basic rock: Hornblende + Plagioclase An>30) ± Biotite± Epidote ± Quartz	Chlorite + Muscovite + Quartz = Cordierite + Biotite +Al_2SiO_5+H_2O
	High-Amphibolite facies	650~700	0.3~1.0	Pressure (Medium Pressure): Sillimanite + Garnet + Biotite + K-feldspar + Quartz ± Plagioclase Pressure (Low Pressure): Andalusite + Cordierite + Biotite + K-feldspar + Quartz ± Plagioclase Basic rock: Hornblende + Plagioclase ± Diopside ± Quartz	Muscovite + Quartz = K-feldspar + Sillimanite / Andalusite + H_2O
	Granulite facies	700~900 (high temperature)	0.3~1.2	Basic rock (Medium Pressure): Hypersthene + Diopside + Plagioclase ±Quartz ±Amphibole Basic rock (High Pressure): Diopside + Garnet + Plagioclase + Quartz Argillite: Sillimanite + Garnet + Cordierite + K-feldspar + Quartz ± Plagioclase	Basic rock (Medium Pressure): Hornblende + Quartz = Hypersthene + Plagioclase + H_2O High Pressure: Hypersthene + Plagioclase = Garnet + Diopside + Quartz (Argillite) Sillimanite + Biotite = Garnet + Cordierite
	Eclogite facies	300~900	>1	Basic rock: Omphacite + Garnet (Quartz、Kyanite、Amphibole、Epidote、Rutile) Argillite: Kyanite + Talc (Phengite、Garnet、Magnesium-riched Chloritoid)	