Petrology, Geochemistry and Geochronology of Paleozoic Granitoids and Metamorphic Rocks in Mandakh Subduction Zones, Southeastern Mongolia

SUMMARY

The country Mongolia is central (heart or key) part of the Central Asian Orogenic Belt, and foreign and local researchers believe that Mongolia can be well field laboratory of Central Asian Orogenic Belt. This enormous growth of the continental crust had evolved over about 800 Ma, from the late Neoproterozoic (ca 1.0 Ga) to the late Mesozoic (250 Ma), is comprised of variety tectonic units, including ancient island arc-back arc systems, ocean island, accretionary complexes, ophiolites, passive margins, and Precambrian microcontinental fragments (Khain et al., 2002; Jahn et al., 2004). Mongolia land is separated by a tectonic boundary along the Main Mongolian Lineament which Central Asian Orogenic Belt into northern and southern (Badarch et al., 2002, 2005; Windley at al., 2004).

Mandakh investigation area is located the southeastern part of the Mongolia, which is consist of Paleoproterozoic to Mesozoic that is named Paleozoic various rock types. That is why this study area is good explanation area of southeastern Mongolian geodynamic history farther it would be explain tectonic setting of Central Asian Orogenic Belts. Previous researchers could not lead to one hypothesis of Carboniferous geodynamic evolution of the south Mongolia, CAOB. This area's characteristic is that there is island-arc possibility coincide with the continental arc and post-accretion magmatism and Meso-Neoproterozoic metamorphic rocks may be relict of Tarim (South Korean) craton or correlate with Lake Zone in Western Mongolia. Furthermore, Meso-Neoproterozoic metamorphic rocks, are really poor studied and key part of unknown ancient microcontinent within in the CAOB, is found in the southeastern part of this study area.

This thesis highpoints, the first time establish P-T condition and absolute age analysis of the KhutagUul and the Norovzeeg metamorphic complexes, some age data lacked geochronological data of volcanic rocks and plutonic rocks.

The purposes for this survey are (1) to obtain the petrography and geochemical features of igneous rocks (2) to determine mineral assemblage, texture and metamorphic zones (3) to estimate pressure and temperature path during metamorphism (4) to release and speculate of implication of tectonic evolution of Mandakh study area in southeastern Mongolia, CAOB.

This Ph.D study has addressed three fundamental chapters that relate to geodynamic and petrogeochemical evolution of Mandakh study area in the Southeastern Mongolia was investigated based on result of the petrology, geochronological and P-T condition analyses.

In Chapter 2, the petrogeochemical characteristic of Paleozoic magmatic rocks was considered.

- Intrusive rocks in Mandakh area are composed of syenite, granite, quartz monzonite and granodiorite, while volcanogenic rocks consist of dominant basalt, andesite, dacite and their tuffs. Carboniferous magmatic rocks from the Mandakh area are silica saturated (SiO_2 =50-73 %), have high Al_2O_3 =12.9-19.4 %, Na_2O+K_2O=4-12 %, Sr=300-800ppm, Y ≤ 25 ppm, Nb =3-6 ppm, and Rb ≤ 150 ppm, and are hydrothermally altered.
- Late Devonian to Carboniferous igneous rocks (TS, BF, MA, DO, UD and SH) are calc-alkaline, magnetite-series, I-type and except for north part, igneous are close to

adakite island arc type. All magmatic rocks in this study area are widely distributed, but petrochemical characteristics of Devonian and Carboniferous magmatic rocks are slightly different from each other. The Permian magmatic rocks have more alkalic and siliceous composition.

- Carboniferous plutonic and volcanic rocks show co-magmatic features, formed during the Carboniferous subduction zone developed in Southeast Mongolia.
- Petrographic and geochemical characteristics of the Mandakh area indicate good possibility for new discovery of giant porphyry copper deposit, like Tampakan of adakite type. It implies that magmatic rocks source in Mandakh area may be melting subduction slab.

In Chapter 3, P-T condition of the KhutagUul and Norovzeeg metamorphic complex are estimated and petrographic chemical investigation was considered rely on mineral assemblage.

- The KhutagUul complex is consists of mafic gneiss, garnet bearing mafic gneiss, amphibolite, felsic gneiss, meta-volcanic rocks and felsic gneiss with garnet, while Norovzeeg complex composes of garnet bearing mafic gneiss, amphibolite, felsic gneiss and meta-volcanic rocks.
- Key and essential mineral assemblages mentioned follow:
  1. Garnet+Plagioclase+Biotite+Quartz (felsic gneiss with garnet)
  2. Amphibole+Plagioclase (amphibolite)
  3. Clinopyroxene+Plagioclase+Garnet (mafic gneiss with garnet).
- These rocks predominantely are cut and moved by EGFZ and following minor faults due to these metamorphic rocks existed on the East Gobi Fault Zone. Some without garnet felsic gneiss, amohibolite and meta-volcanic rocks are more deformed and cuted by minor faults than garnet bearing felsic gneiss and mafic gneisses, which indicate brittle behavior, grains are fractured. Espessially meta-volcainic rocks mineral's behavoir of deformetion refers in the brittle to ductile transiton zone. But all rocks minerals have affinities of plastic, weak deformation and high strain Additionally, some garnet bearing felsic gneiss are affected by micro-fold. The boundary among mafic gneiss and amphibolite is really sharp which there are non-reaction between amphibole and clinopyroxene or medium plagioclase and mafic plagioclase. Inclusions within garnet indicates syntectonic crystals growth that grow while regional deformation proceeds and the garnets rotated with respect to the foliation as they grew during deformation.
- Mafic gneiss garnet have medium almandine (Alm) and grossular (Grs) medium compositions, while garnet grains of felsic gneiss have a more enriched almandine and pyrope composition. Some garnet grains texture is like sieve, but felsic gneiss all garnet grains are poikiloblastic mostly contain quartz and a few amounts of biotite fine-laths. However, most garnet grains of mafic gneiss are isometric and euhedral. Clinopyroxene chemical composition are mostly diopsite and hedenbergite. The values of X_{Mg} tree types of clinopyroxene range from 0.24 to 0.43, and 0.54 to 0.69, and 0.6 to 0.73, hedenbergite and diopsite, respectively. In addition, some of these clinopyroxene grains

are weak composition zoning. Amphibole chemical composition are calcic magnesio hornblende and tschemakite. Additionally, their chemical composition X_{Mg} range is around 0.55-0.59, and Ca=1.85-1.89, Na+K=0.36-0.49, and Ti=0.08-0.1. Mafic gneiss plagioclase's chemical composition is anorthite, whereas plagioclase grains of amphibolite and felsic gneiss are labradorite to bytownite and andesite. Especially, in the Norovzeeg metamorphic complex, amphibolite consists of two distinct plagioclase that have opposite a composition zoning each other. It means that matrix type plagioclase anorthite (An) contain decrease from core to rim, whiles poikiloblastic type plagioclase An value increase from core to rim.

- Mafic gneiss yields maximum P-T condition which is 6.4 kbar at 800 °C, whereas felsic gneiss referred minimum P-T condition that is 0.5 kbar at 550 °C . Fig.3-60 illustrated that both of them prograde metamorphism proceeds that are clockwise metamorphic P-T path. Probably, Initial metamorphism starts from 550 to 600ºC and pressure sharply increase 0.8 to 4 kbar. Then pressure increase 4 to 6 kbar and temperature 600-650 ºC. After that P slowly increase to 6.4 kbar while temperature increase from 600 ºC to 800 ºC.

In Chapter 4, the geochronological evolution of this study area was considered.

- The oldest zircon grains were found from the KhutagUul metamorphic complex, which are Precambrian age. But, in the southeastern Mongolia, there isn't Precambrian microcontent basement. In addition, these a few much older Precambrian ages (ca.2500 – 800 Ma) are common in the Tarim craton (Rojas-Agramonte et al., 2010). It should mention that these samples protoliths related with sedimentary rock.
- Geochronological data shows us the KhudagUul metamorphic complex have two inherited age of magmatic core which are around Cambrian-Ordovician and Neoproterozoic. But they have mainly recrystallization texture.
- All igneous rocks zircons refer Carboniferous. But age is getting young to north in this study area.
- The Sainshandkhudag and UndurUud formations are first eruption during Carboniferous in the Mandakh area. Then the Mandakh (338.9±6.1 Ma) and Bronze Fox (330±6.1 Ma) intrusion which are somehow related ore mineralization intruded them.
- After around 3 Ma years, the Dushiinovoo formation exploited and overlapped other older Carboniferous igneous rocks. Subsequently, alkalic acidic non-mineralized pluton intruded early Carboniferous igneous rocks during late Carboniferous to Permian time. Because West Budar pluton is indicated the youngest Carboniferous that is 316.5±5.6 Ma.
- Metamorphism age is less than 457 Ma years, but metamorphic affinity rim part of zircon grains is indicated 250-234 Ma years. Magmatism was common during the Late Permian-Late Triassic, since evidenced by ca 290 Ma and 250-225 Ma igneous activity that occurred during and into the waning stages of collision between southern Mongolia and northern China (Kovalenko et al., 2006; Chen et al., 2009; Wu et al., 2002; Yarmolyuk et al., 2008). Webb et al (2010) identified East Gobi fault zone age as

Triassic, which is sinistral shear fault of collision between North China craton and South Mongolia. the KhutagUul and Nororvzeeg metamorphic complexes are occur on this fault. So, this would emplace a ca.250 Ma age on metamorphism, coinciding with the waning stages of collision between the northern China and the South Mongolia.

- The oldest zircons can be related with Tarim craton fragments. The KhutragUul metamorphic complex should be small north-west fragment of HutagUul metamorphic terrane. It would be moved by EGFZ to a resent existing in south-east part of this study area in the Southeastern Mongolia during the Triassic.
- The KhutagUul metamorphic rocks timing of metamorphism suspected during Permian to Triassic, and magmatism and sinistral shear fault zone, respectively.

In Chapter 5, the tectonic environmental evolution of the Mandakh area in southeastern Mongolia based on geochemical, geochronological and metamorphic rock pressure-temperature condition. There are several subductions were settled during various geological time.

- Precambrian time is somehow related with magmatic process. Then active continental arc developed in the Mandakh area during Ordivician to Silurian time.
- During Devonian to late Carboniferous, new warmer and deeper adakite-type island arc derived from slab melts in the Mandakh area. In addition, that time all of enriched porphyry copper deposits are created with magmatism.
- In this study area's tectonic evolution during the Late Carboniferous to the Permian, transition zone that is moved from adakite to non-adakite type and active continental island arc were developed southeastern Mongolia. Probably, subduction zones move to south and subduction-zone dips get shallow during that time.
- In the Triassic, the KhutagUul and Norovzeeg metamorphic complex were moved and metamorphosed by the East Gobi Fault Zone.