Overview of the Geology and Tectonic evolution of Southern Mongolia

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Southern Mongolia is a geologically complex region. It records a major portion of the Paleozoic tectonic history of amalgamation and formation of the Asian continent (13, 15). Identifying each tectonostratigraphic terrane is a necessary step in understanding the evolution of the orogen. The terranes in southern Mongolia are delineated, interpreted and classified with varying degrees of confidence as: 1) island arc terranes, 2) accretionary wedge terranes, 3) cratonic terranes, 4) continental arc terranes, 5) disrupted terranes, 6) metamorphic complexes of undetermined affinity.

The island arc terranes includes the Baruunhuuray, Edren, Gurvansayhan, Hashaat, Naransevestey and Sulinheer terranes. Most of these terranes are composed of Devonian tholeiitic to calc-alkaline volcanics, volcaniclastic rocks, lower Carboniferous flysch sediments and dismembered ophiolite and serpentinite melanges.

The Baruunhuuray composite terrane consists of two distinct, but related units, the Baaran to the north and the Baytag to the south. The Baaran unit is composed of 1) Lower -Middle Devonian volcaniclastic sandstone, argillite and chert and lenses of limestone; 2) Middle-Upper Devonian basalt, andesite, pyroxene porphyrite, shoshonite and quartz latite intruded by granodiorite, gabbro, picritic dolerite and granosyenite of Middle Carboniferous to Lower Permian ages. The overlap assemblage contains Lower Carboniferous sedimentary rocks and coeval trachybasalt, trachyandesite and latite. The Baytag unit is a structurally complex assemblage of 1) Lower-Middle Devonian island arc tholeiitic pillow basalt, andesitic basalt, dacite and tuffaceous sedimentary rocks, conglomerate and sandstone; and 2) Middle-Upper Devonian flysch containing sandstone, siltstone and chert, minor conglomerate and volcanic rocks. There is also block of subalkalic volcanic rocks covered by Middle Devonian coral-bearing limestone. This unit is overlapped by Lower Carboniferous conglomerate, sandstone, siltstone, chert and minor rhyolite which is intruded by sills and small bodies of gabbro, diorite and granosyenite (11).

The Edren composite terrane also includes two units,which are separated by the northwest trending Sumanhayrhan fault. The northern unit (Hovyn Har zone) is composed mainly of Lower-Middle Devonian sandstone and argillite, minor basalt, andesite, chert and limestone overlapped by Lower Carboniferous conglomerate, sandstone and siltstone with olistostrome,as well as minor rhyolite and dacite lavas.
The southern unit, named as Edren zone consists of: 1) Lower-Middle Devonian basalt, andesite, dacite, tuffaceous sandstone, breccia, minor chert and limestone; 2) Middle-Upper Devonian volcaniclastic sandstone, minor conglomerate and rhyolitic lava. Major and trace element geochemical analysis of basalts from Edren terranes suggest a volcanic arc and within plate setting (6, 7). The overlap assemblage includes: 1) Lower-Middle Carboniferous volcaniclastic rocks, minor limestone; 2) Middle-Upper Carboniferous basalt, andesite and dacite; 3) Lower Permian rhyolite, tuff and volcaniclastic rocks. The terrane is intruded by Carboniferous to Permian

granodiorite, granite and syenite (9).

The Gurvansayhan composite terrane consists of: 1) Pre-Upper Silurian dismembered ophiolite and serpentinite melange; 2) Upper Silurian -Lower Devonian tholeiitic pillow basalts and basaltic andesite, minor chert and volcaniclastic sandstone; 3) Middle-Upper Devonian volcaniclastic sandstone, siltstone, ash tuff and argillite, minor chert, conglomerate and olistostrome; 4) Lower Carboniferous conglomerate, sandstone and siltstone with olistostrome (8). Major and trace element geochemical analysis of basalts from Gurvansayhan terrane also suggests formation in a volcanic arc and intra-plate settings. Sandstone provenance data indicates dissected and intraoceanic arc fields (6, 7). The Gurvansayhan terrane is overlapped by Lower-Middle Carboniferous volcanic and volcaniclastic rocks and Permian subalkalic volcanic rocks and coal bearing strata (1, 8).

The Naransevestey terrane is composed of Ordovician - Silurian greenschist facies metamorphosed basalt, andesite, tuffaceous sandstone, argillite and chert and associated sills of gabbro, diorite and granodiorite. These unfossiliferous rocks have been intruded by granite plutons and are disconformably overlain by Lower-Middle Devonian conglomerate, sandstone and siltstone with fossiliferous limestone lenses and concretions. The overlap assemblages also include Carboniferous volcanics and volcaniclastic rocks, and granite intrusions of Upper Devonian to Permian age. The Naransevestey terrane is a continuation of the Dananshan unit in Beishan area, China (4, 20), which was interpreted as fragment of an island arc or back-arc basin.

The Hashaat terrane is composed of:1) Ordovician conglomerate and sandstone, minor fossiliferous limestone; 2) Silurian sandstone and argillite; 3) Lower

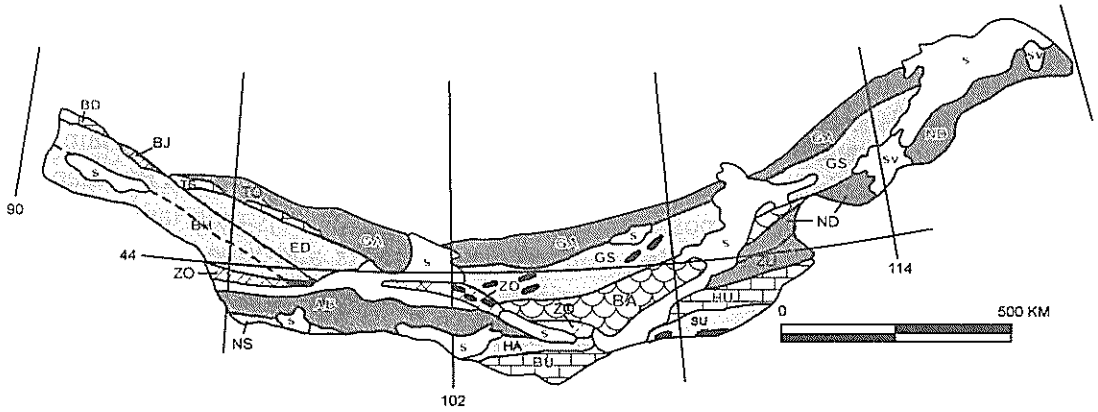

Fig 1. Lithotectonic terranes of Southern Mongolia (G. Badarch, 1998)

ISLAND ARC TERRANES
BH Baruunhuuray
ED Edren terrane
GS Gurbansayhan
HA Hashaat
NS Naransevestey
SU Sulinheer

ACCRETIONARY WEDGE
GA Govi Altai
AB Atas Bogd
ND Nuhet Davaa
ZU Zamyn Uud

METAMORPHIC BLOCKS
TS Tseel
TO Tsogt
BD Bodonch

CONTINENTAL ARC TERRANE
BA Barga

DISRUPTED TERRANES
BJ Bij
ZO Zoolen

CRATONIC TERRANES
BU Bulgan
HU Hutag Uul

SV Cretaceous and Cenozoic sedimentary and volcanic rocks

Ophiolite and oceanic crustal rocks

S Cenozoic overlap sedimentary rocks

- Middle Devonian andesite, dacite, tuffaceous sandstone and argillite, minor limestone; 4) Middle-Upper Devonian volcaniclastic sandstone, siltstone and conglomerate. The overlap assemblages includes Lower-Middle Carboniferous shallow-marine sediments and coeval basalt, andesite, tuff, chert and volcaniclastic rocks and Lower Permian fusulinid-bearing limestone and Upper Permian fossiliferous limestone, sandstone and conglomerate. The terrane is intruded by Devonian diorite and granodiorite and Middle-Upper Carboniferous subalkalic granite. The Hashaat terrane extends southwest to connect with the Yagan zone in China, which consists of Ordovician to Carboniferous island arc volcanics and granitic rocks (17).

The Sulinheer composite terrane is a structurally complex assemblage of: 1) Sulinheer dismembered ophiolite presumably Upper Devonian-Lower Carboniferous age; 2) Lower Carboniferous sandstone, siltstone and limestone, minor conglomerate; 3) Middle Carboniferous-Lower Permian fusulinid-bearing massive limestone, minor conglomerate and sandstone; 4) Upper Carboniferous-Lower Permian andesite, dacite, tuff, sandstone and siltstone, minor fossiliferous limestone; 5) Upper Carboniferous-Lower Permian tholeiitic pillow basalts, basaltic andesite, chert, tuffaceous sandstone and siltstone containing olistostrome and 6) Upper Permian conglomerate, sandstone, siltstone and chert (12). The terrane also includes undated greenschist to amphibolite facies metamorphosed rocks intruded by gabbro and granodiorite. The Sulinheer terrane is overlain by Lower Cretaceous conglomerate, sandstone and volcanics. This terrane is corresponds to the Solonshan belt in China, which contains Lower Carboniferous Enger Us ophiolite complex (17)

The accretionary wedge terranes are the Gobi Altai, Atas Bogd, Nuhetdavaa, and Zamyn Uud terranes. These terranes usually contain tectonic sheets, slivers, blocks and melanges. They are composed of Ordovician to Devonian greenschist metamorphosed sandstone, argillite, tuff, minor fossiliferous limestone overlain by the shallow marine sediments and coeval volcanic rocks of the Devonian to Permian age.

The Gobi Altai composite terrane is composed by 1) Cambrian (?) - Lower ordovician sandstone and argillite, minor volcanic rocks and limestone; 2) Middle-upper Ordovician sandstone and argillite containing coral-rich limestone and conglomerate; 3) Silurian sandstone, argillite and reef limestone. The overlap assemblage contains 1) Lower-Middle Devonian conglomerate, sandstone and fossiliferous reef limestone with minor rhyolitic flows and coeval flysch sediments and associated basalt and andesite lavas, 2) Middle-Upper Devonian volcaniclastic sandstone, siltstone, argillite, radiolarian chert and basaltic to rhyolitic, and Lower Carboniferous volcaniclastic sandstone and siltstone, minor rhyolite volcanic rocks, 3) Middle-Upper Carboniferous subarial volcanics and Lower Permian non-marine mainly bimodal volcanics and volcaniclastic rocks, and 4) Upper Permian conglomerate, sandstone and siltstone.

The Atas Bogd composite terrane is composed of: 1) Ordovician - Silurian greenschist metamorphosed unfossiliferous sandstone, argillite, phyllite and chert, minor basalt and andesite intruded by granodiorite and granite of Upper Devonian to Permian age.These are overlain by: 1) Lower Carboniferous shallow-marine sediments; 2) Middle-Upper Carboniferous subduction related volcanic and volcaniclastic rocks; 3) Lower Permian alkalic volcanic rocks and tuffs; 4) Upper Permian-Lower Triassic conglomerate, sandstone and siltstone; 5) Middle-Upper Triassic conglomerate, sandstone, minor siltstone; 6) Lower Jurassic oil-shale.

The Nuhet Davaa terrane is composed of: 1) Silurian greenshist metamorphosed tuffaceous sandstone and argillite; 2) Lower-Middle Devonian basalt, andesite, tuff, chert and conglomerate, minor limestone; 3) Middle-Upper Devonian volcaniclastic sandstone and siltstone. The overlap assemblage includes Lower Carboniferous shallow-marine sediments, Middle-Upper Carboniferous and Permian subalkalic and alkalic volcanic and volcaniclastic rocks. On the northeastern margin of this terrane are slivers of serpentinite and gabbro. This terrane also includes scattered blocks of granite-gneiss, schist, quartzite, amphibolite and phyllite of unkown age. The Nuhet Davaa terrane also consists of abundant granitic plutons: Silurian diorite and granodiorite, Carboniferous to Permian granite and leucogranite, and Triassic-Lower Jurassic rare metal granite. The Nuhet Davaa terrane coresponds to the Dong Ujumqin belt of China (5), which was interpreted as an early Paleozoic active continental margin of Siberia.

The Zamyn Uud terrane consists of sheared and faulted blocks and slivers containing: 1) undated greenschist facies metamorphosed and deformed schist and granite-gneiss, minor marble; 2) Devonian basalt, andesite, dacite and volcaniclastic rocks, minor fossiliferous limestone; 3) Lower-Middle Carboniferous shallow-marine sediments and coeval andesites and rhyolites. These rocks are unconformably overlain by Lower Permian andesite, dacite, tuffaceous sandstone and siltstone, minor fusulinid-bearing limestone and stitched by Middle-Upper Carboniferous and Permian granite and Triassic-Lower Jurassic alkalic granite.

The cratonic terranes includes Bulgan and Hutag Uul terranes and are composed of Lower Proterozoic granite-gneiss, amphibolite, schist and marble, Riphean quartzite, limestone and metasandstone unconformably overlain by Silurian to Permian shallow marine sediments and coeval volcanic rocks.

The Bulgan terrane consists of: 1) Middle-Upper Riphean marble, quartzite and metasandstone; 2) Silurian coral-bearing limestone, sandstone and argillite intruded by Devonian diorite and granodiorite. The overlap assebmlages includes Devonian - Carboniferous (?) basalt, andesite, dacite and volcaniclastic rocks , minor limestone and Lower-Upper Permian andesite, dacite, rhyolite, conglomerate and sandstone, minor limestone and Upper Permian flysch. These rocks intruded by Middle-Upper Carboniferous granodiorite and granite, Permian leucogranite and Triassic-Lower Jurassic rare metal granite. Located in the southern part of this terrane is metamorphic core complex presumably Cretaceous in age (16).

The Hutag Uul terrane is composed of: 1) Lower Proterozoic augen gneiss, schist and minor marble; 2) Riphean quartzite, marble and metasandstone intruded by Devonian diorite and granodiorite. The overlap assemblage inlcudes Devonian pillow lavas, chert, dacite, rhyolite, volcaniclastic sandstone and argillite. Also Lower Permian andesite, dacite, tuffaceous sandstone and siltstone and Upper Permian flysch containing scattered blocks and lenses of limestone and rhyolitic tuff intruded by well known carbonatite-bearing Lugyngol alkalic pluton. The Hutag Uul terrane stretched into Xilin Hot belt in China, where these gneiss were dated radiometrically as Lower Proterozoic (18, 19).

Continental arc terrane, named Barga terrane, is consists of Riphean - Lower Cambrian marble, quartzite, metasandstone, argillite and phyllite, Ordovician-Silurian olistostrome-bearing sandstone, argillite and phyllite and Devonian subduction related volcanic and volcaniclastic rocks, plus granodiorite and granite plutons. The overlap

assemblage includes Carboniferous shallow-marine sediments and coeval volcanic rocks.

The Barga terrane is composed of: 1) Riphean marble, quartzite, metasandstone and argillite; 2) Lower-Middle Cambrian weakly metamorphosed sandstone and argillite with olistostrome; 3) Middle-Upper Ordovician penetratively deformed fossiliferous sandstone, argillite and phyllite containing blocks of limestone and sandstone; 4) Silurian sandstone and siltstone, minor limestone; 5) Lower-Middle Devonian subduction-related volcanic and volcaniclastic rocks; 6) Middle-Upper Devonian tuffacaeous sandstone and siltstone,plus minor felsic tuff. The overlap assemblages include a Carboniferous sequence containing four formations of shallow-marine sediment and coeval basalt and andesite, Lower Permian subalkalic and alkalic volcanic rocks and Upper Permian-Lower Triassic coal-bearing conglomerate, sandstone and siltstone. Granitic lithic and mineral fragments are dominant in the Carboniferous and indicate unroofing and erosion of an island arc system. The Barga terrane is intruded by several granitic plutons of Upper Devonian to Lower Permian ages, including well known Permian alkalic Han Bogd circular pluton and Upper Devonian Tsagaan Subarga cooper-bearing intrusion.

The disrupted terranes includes the Bidz, Zoolen terranes and consists of Devonian tholeiitic basalt, tuffaceous sandstone, chert and slivers of serpentinite, peridotite, gabbro, olistostrome and melanges intruded by diorite and granodiorite intrusions. These terranes are overlapped by Carboniferous subduction-related volcanic and volcaniclastic rocks.

The structurally complex Bidz terrane is weakly metamorphosed unfossiliferous assemblage of Lower-middle Devonian (?) island arc tholeiitic basalt, diabase, tuff, chert, tuffaceous sandstone and argillite intruded by granodiorite.

The Zoolen terrane forms a narrow belt along the northern side of the Gobi Tienshan fault. The Zoolen terrane includes several tectonic sheets, slivers, blocks and melanges They are composed mainly of greenschist facies metamorphosed basalt, andesitic basalt, tuff, volcaniclastic rocks and chert presumably of Ordovician to Devonian age. These rocks includes blocks and slivers of peridotite, diorite, serpentinite, diabase and limestone. The terrane is overlain by Carboniferous volcanic rocks and flysch sediments.

The metamorphic complexes of undetermined affinity includes Bodonch, Uench, Tseel and Tsogt blocks located along the Bulgan and Transaltay fault systems. These are structurally complex polymetamorphosed and polydeformed assemblages which include tonalite gneiss, amphibolite, schist with relics of granulites. Resent work of Bibikova et al, (2) suggested that high-grade metamorphic rocks are Devonian, not Precambrian. Therefore these metamorphic complex is interpreted to be fragment of an older island arc complex.

The tectonic evolution and growth of the south Mongolia includes five stages.

1. The Ordovician-Silurian stage involved the formation of island arcs and accretionary wedges, which are recorded in the sediments of Gobi Altai, Zoolen and Atas Bogd terranes.
2. In the second, Early-Middle Devonian stage, started amalgamation of Edren and Gobi Altai, Naran Sevestey and Atas Bogd terranes. Intense volcanism occurred in the central part (Gurvansayhan terrane) of southern Mongolia.

3. The next, Middle Devonian to Lower Carboniferous stage is characterized by volcanic activity which migrated to the north across the Govi Altai terrane. Presumably at this time the Bagra terrane was collided with the Gurvansayhan terrane and stitched by late Devonian plutons.
4. The Early Carboniferous to Early Permian interval was characterized by the opening of Sulinheer ocean basin and formation of island arc systems and continental arcs superimposed on the northern terranes.
5. Lastly the Middle-Late Triassic stage is characterized by the closure of Sulinheer oceanic basin which was followed by the formation of complicated thrust fold structures in southern Mongolia.

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