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Tectonic framework of the Bayankhongor area, west Mongolia

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Abstract : The Bayankhongor area in the southeastern part of the Khangay Mountains is geotectonically divided, from south to north, into the Baydrag, Burdgol, Bayankhongor, Dzag, and Khangay Zones. The southernmost Baydrag Zone is an Archean to Early Proterozoic metamorphic terrane where amphibolite to granulite facies rocks, such as mafic gneiss, amphibolite, and charnockite, occur associated with gneissose granites. In the Burdgol Zone greenschist facies pelitic schists are widely exposed, including many olistoliths of higher-graded. Laterally persistent metachert also crops out along the southern margin of the zone. The Bayankhongor Zone is characterized by mafic schist and structurally overlying basite, mostly showing a pillow structure. These rocks are considered to range in age from latest Proterozoic to earliest Paleozoic. The metamorphic grade of the mafic schist varies from the pumpellyite-actinolite facies, through the greenschist facies, to the epidote-amphibolite facies, while that of the basite is the prehnite-pumpellyite facies. The Dzag Zone is underlain by Early Paleozoic pelitic and psammitic schists of the greenschist facies. The Khangay Zone is occupied by a Devonian to Carboniferous sedimentary sequence consisting mainly of sandstone in the lower and mudstone and sandstone in the upper parts. The sandstone unit occasionally contains large olistoliths composed of bedded radiolarian chert and schistose sandstone. The above-mentioned zones can be differentiated from each other on the basis of ages of folding and metamorphism, and these show a northward-younging tendency.

1. Introduction

Mongolia is situated between the Siberian and North China Platforms, and is characterized by Precambrian and Paleozoic orogenic belts (Janshin, 1989). These orogenic belts have been investigated by many geologists of Mongolia, Russia, and other member countries of the former COMECON, and yet the details still remain unknown.

Japanese technological aid to the Institute of Geology and Mineral Resources of Mongolia has been implemented since 1994 as one of the JICA (Japan International Cooperation Agency) projects. The first author (Y. T.) was dispatched to Mongolia by the JICA in the summer of 1995, and spent a couple of weeks investigating the orogenic belts in the Bayankhongor area with the other authors, except for the second one (M.S.), who made a petrographical study of the collected samples. K-Ar age measurement was made on muscovites from three samples of metamorphic rock.

This paper is a preliminary report on those investigations, and describes the geology of the Bayankhongor area with special emphasis on the tectonic framework. The authors are grateful to the JICA for giving us the opportu-

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nity to conduct this collaborative work, and for financial support.

2. Outline of Geology

The Bayankhongor area is situated in the southeastern part of the Khangay Mountains (Fig. 1). Sedimentary, metamorphic, and igneous rocks of Precambrian and Paleozoic ages are well-exposed in and around the area (Dzabotkin, 1988 ; Rauzer, 1990 ; Tumurchudur, 1990 ; Borsbold and Dorjnamjaa, 1993). Cretaceous terrestrial sediments capped by basalt lava also occur sporadically. Geotectonically, the area is roughly divided into the Baydrag, Burdgol, Bayankhongor, Dzag, and Khangay Zones, which are separated from each other by northwest-southeast trending faults (Figs. 2 and 3). The southernmost Baydrag Zone is a metamorphic terrane consisting mainly of gneiss, amphibolite, charnockite and gneissose granites, and belongs to the Central Mongolian Massif. Both the Burdgol and Dzag Zones are characterized by the occurrence of crystalline schists, while the Bayankhogor Zone by the occurrence of basite as well as crystalline schists. The Khangay Zone is occupied by non-metamorphosed sedimentary rocks.

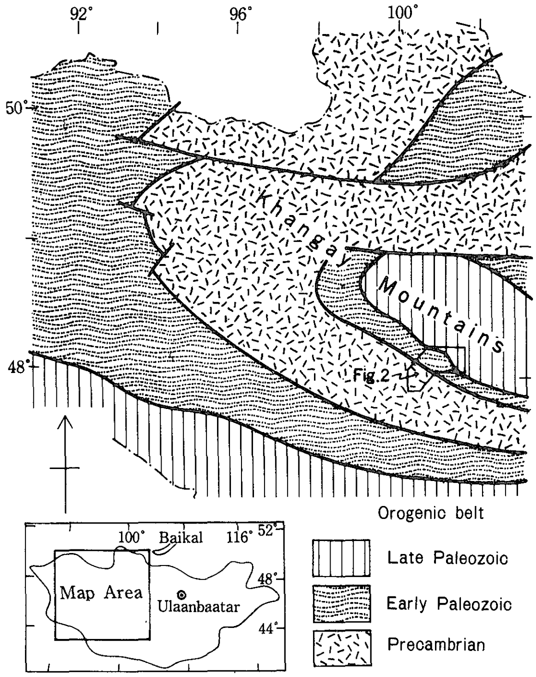

Fig. 1 Map showing the distribution of Precambrian and Paleozoic orogenic belts in west Mongolia.

3. Baydrag Zone

The Zone is subdivided by a fault into the Southern and Northern Belts.

The Southern Belt is underlain chiefly by charnockite and gneissose granite, which are folded in a broad dome. The charnockite is medium-grained and shows a distinct gneissosity. The main constituent minerals are orthopyroxene, clinopyroxene, brownish hornblende, plagioclase, and quartz. Colorless to greenish amphiboles occur as secondary minerals around clinopyroxene and hornblende. Epidote replaces plagioclase. The mineralogy indicates that the charnockite has been derived from mafic rocks. The gneissose granite shows a distinct compositional banding represented by the alternation of leucocratic and melanocratic layers. It is composed mainly of biotite, microcline, plagioclase and quartz with accessory apatite, zircon, and Fe-Ti oxides. Anti-perthite structure is common in plagioclase. Biotite shows a parallel arrangement, but is almost completely pseudomorphosed by aggregates of epidote and chlorite.

The Northern Belt is composed of mafic gneiss and amphibolite associated with gneissose granite and granodiorite. A small amount of meta-ultramafite is also found locally. All of these metamorphic rocks are highly folded with northwest-southeast trending axes. The mafic gneiss and amphibolite are greenish and intensely foliated. Common mineral assemblages are brownish hornblende ±plagioclase±clinopyroxene±orthopyroxene ±quartz with rare garnet. Clinopyroxene and hornblende are altered to colorless amphibole, while plagioclase is repalced by epidote. The ultramafic metamorphic rock is distinctly foliated and composed mainly of greenish hornblende with a lesser amount of orthopyroxene and clinopyroxene which are

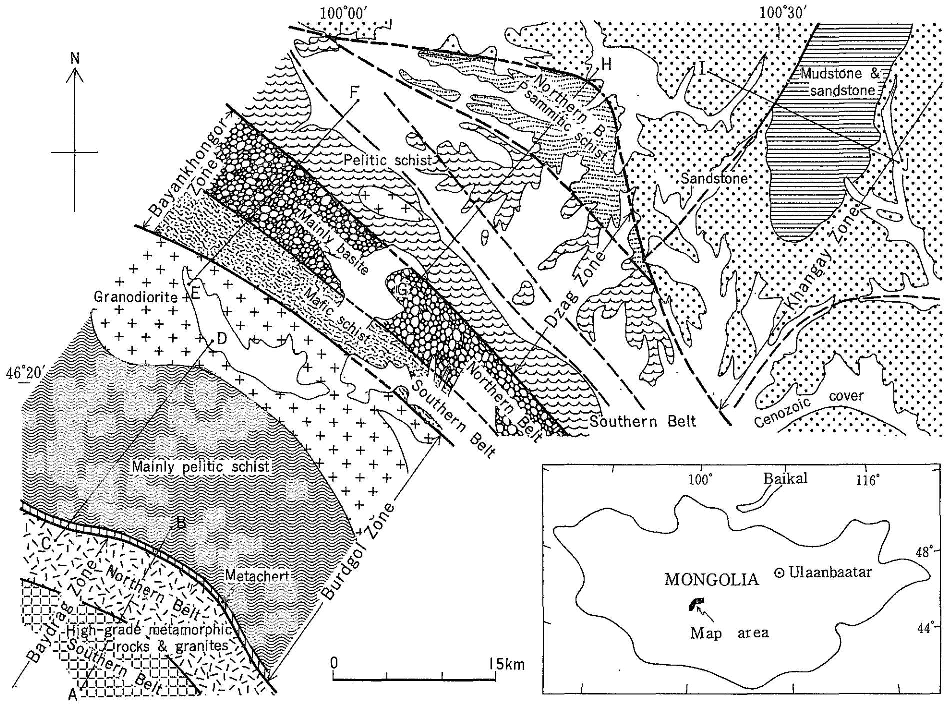

Fig. 2 Simplified geologic map of the Bayankhongor area.

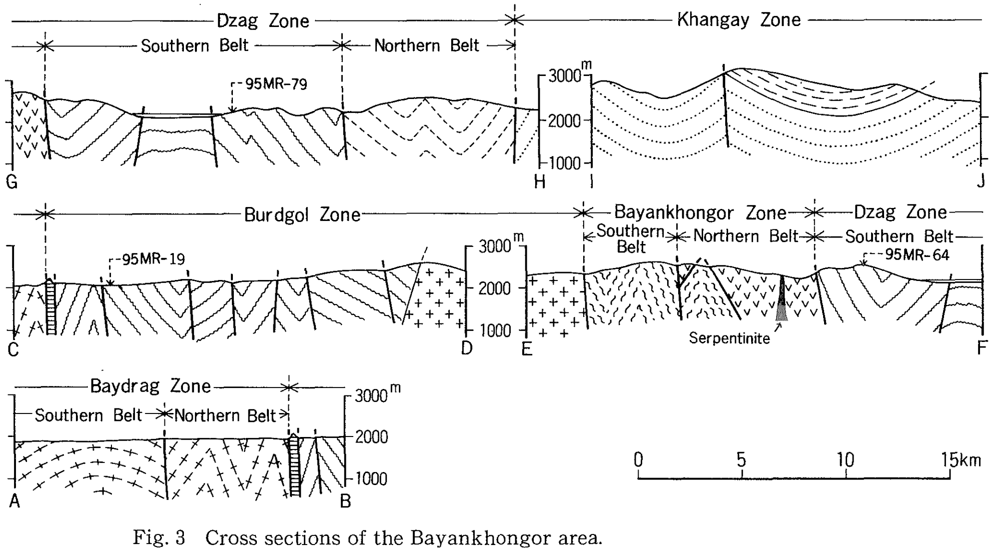

Fig. 3 Cross sections of the Bayankhongor area.
For section lines see Fig. 2. 95 MR-19, -64 and -79 are dated samples.

almost changed to secondary colorless amphibole. The gneissose granites show the distinct gneissosity characterized by the alternation of leucocratic and melanocratic layers. Mylonitic bands are developed locally. Common minerals are biotite, brownish hornblende, microcline, plagioclase, and quartz with accessory apatite, zircon, and Fe-Ti oxides. Anti-perthite structure is common in plagioclase, which also sometimes shows a mesoperthitic structure. Mafic minerals tend to have been changed to aggregates of epidote and chlorite.

It is noteworthy that metamorphosed andesitic dikes frequently occur all over the zone, cutting the gneissosity of metamorphic and plutonic rocks. They are dark green and range in width from 5 to 30 meters. The dike rock preserves original igneous textures and phenocrysts of brownish hornblende and clinopyroxene lie in a groundmass of plagioclase laths. Greenish to colorless amphiboles, epidote, and chlorite are found as metamorphic minerals. Granitic pegmatite dikes are sometimes found in and along the andesitic dikes.

The petrographic characteristics suggest that the metamorphic grades in the Southern and Northern Belts of the Baydrag Zone are the granulite facies and the amphibolite facies, respectively. All of the metamorphic and plutonic rocks in the zone underwent the greenschist facies metamorphism after the intrusion of the andesitic dikes.

4. Burdgol Zone

Pelitic schist with minor psammitic schist are dominant in this zone, except for the southern border, where metachert crops out. These rocks are highly faulted and folded, and are intruded by granodiorite in the northern part of the zone (Figs. 3 and 4).

The metachert is 100 to 150 meters thick, and is in fault contact with the surrounding rocks. It is laterally persistent to form a series of ridges (Fig. 5). It is milky white to dark gray, massive, partly thin-bedded, and consists mostly of elongated quartz, showing a mosaic texture.

The pelitic schist is dark gray to black, having a distinct compositional banding represented by the alternation of mica-rich and quartz-rich layers. A penetrative crenulation cleavage is widely present. The representative mineral association is muscovite + chlorite + plagioclase + quartz + carbonaceous matter. Calcite and epidote are also present in more calcareous compositions. Estimated metamorphic grade is the greenschist facies.

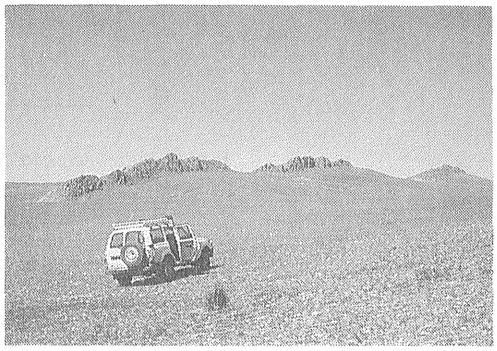

Fig. 5 Metachert ridge marking the southern margin of the Burdgol Zone.
Location : Lat 46°14.1′N., Long 99°41.6′E.

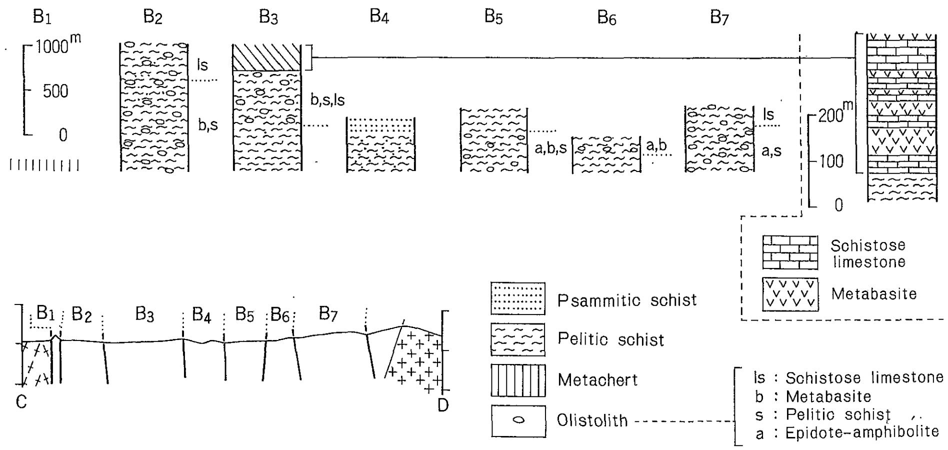

Fig. 4 Columnar sections of the Upper Proterozoic in the Burdgol Zone.

The psammitic schist occurs mostly in segment B5, and is derived from quartzose sandstone.

As shown in Fig. 4, the pelitic schist contains many olistoliths composed of metabasite, schistose limestone, epidote-amphibolite, and pelitic schist. The long axis of the olistoliths commonly ranges from several to 200 meters, exceeding 500 meters in some cases. Huge olistoliths, over 300 meters thick, of alternating metabasite and schistose limestone are found in segment B3. The metabasite comprises metadolerite and metagabbro, which preserve original igneous textures and relic minerals of greenish hornblende and plagioclase. The metamorphic mineral assemblage is actinolite + epidote + chlorite + calcite. Zoisite replacing plagioclase is sometimes found. The epidote-amphibolite has a mineral association of epidote + green hornblende + chlorite + plagioclase. The paragenesis of muscovite + chlorite + plagioclase + quartz + carbonaceous matter is common in the pelitic schist of the olistoliths as well as in the matrix, but the former is coarser than the latter. Some olistoliths in segments B5 and B7 consist of pelitic schist containing porphyroblastic grains of garnet and biotite. Therefore, the rocks occurring as olistoliths are inferred to have been subjected to metamorphism of the greenschist to the epidote-amphibolite facies.

The granodiorite is massive and lacks gneissosity. The constituent minerals are biotite, brownish hornblende, orthoclase, plagioclase, and quartz with accessory apatite, zircon, sphene, and Fe-Ti oxides. Myrmeckite structure is common in plagioclase. Biotite is sometimes replaced by chlorite.

5. Bayankhongor Zone

This zone is subdivided by a fault into the Southern and Northern Belts (Figs. 3 and 6). Strongly silicified rocks occur in a width of several tens of meters along the southern margin of the zone.

The Southern Belt is underlain by mafic schist with a small amount of pelitic schist, which are intensely folded into a set of anticline and syncline. The mafic schist usually contains relic clinopyroxene, suggesting that most of the original rock is of basaltic nature, though schists derived from ultramafic rocks are found in small bodies. Toward the axis of anticline, the metamorphic grain size increases and the critical paragenesis changes from pumpellyite + actinolite + chlorite, through actinolite + epidote + chlorite, to garnet + greenish hornblende + epidote + porphyroblastic plagioclase. These changes suggest that the metamorphic grade increases from the pumpellyite-actinolite facies, via the greenschist facies, to the epidote-amphibolite facies.

In the Northern Belt, basite is widespread and mafic schist appears in the axial part of the anticline. The latter has an association of actinolite + epidote + chlorite + calcite + plagioclase + quartz, indicating that it underwent the greenschist facies metamorphism. This mafic schist is correlative with that of the Southern Belt and is in fault contact with the overlying basite unit, which has been called the

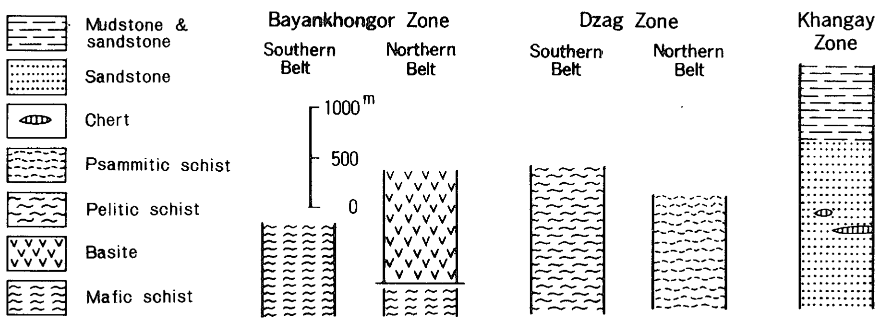

Fig. 6 Columnar sections of the uppermost Proterozoic and Paleozoic in the Bayankhongor, Dzag, and Khangay Zones.

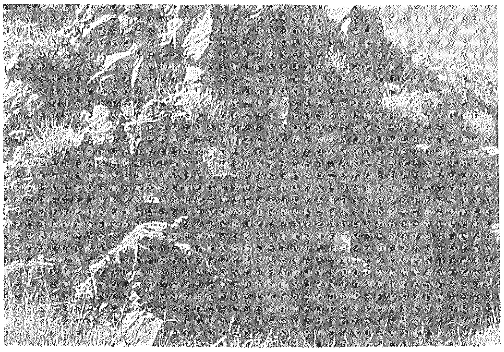

Fig. 7 Pillow basalt in the Northern Belt of the Bayankhongor Zone.
Location : Lat 46°29.94′N., Long 99°54.72′E.

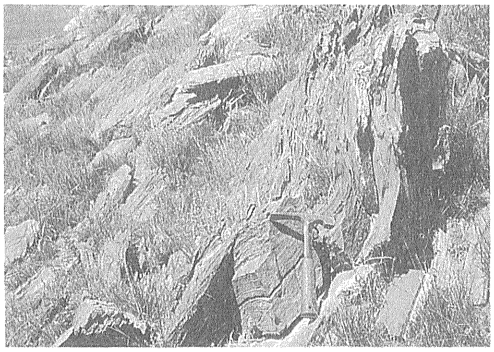

Fig. 8 Pelitic schist in the Southern Belt of the Dzag Zone.
Location : Lat 46°30.27′N., Long 100°8.82′E.

Bayankhongor Ophiolite. The unit consists mostly of pillow basalt (Fig. 7), accompanied by gabbro, diabase, and serpentinite. Its lower part contains rare intercalations of basaltic hyaloclastite, siliceous mudstone, and limestone. The basalt is massive with the exception of the basal part of the unit, and is classified into two types. One is rich in amygdules and large phenocrysts of plagioclase, and the other is megascopically nonporphyritic without amygdules. They alternate in an order of 40 to 150 meters thick in general, and grade into one another. The gabbro and diabase occur as small intrusive bodies, and the serpentinite as fusiform bodies along faults. The basalt preserves porphyritic clinopyroxene and plagioclase embedded in a groundmass of plagioclase laths, while the gabbro and diabase contain brownish hornblende, plagioclase, and clinopyroxene. The amygdule minerals include calcite, quartz, and chlorite. Pumpellyite and chlorite are found as metamorphic minerals in the rocks of the basite unit, suggesting that the metamorphic grade is as low as the prehnite-pumpellyite facies.

6. Dzag Zone

This zone is subdivisible into two belts which are in fault contact (Figs. 2 and 3). The Southern Belt is occupied mostly by pelitic schist, while the Northern Belt by psammitic schist (Figs. 6 and 8). They are moderately folded to form an anticlinorium in the Southern Belt and a synclinorium in the Northern Belt. The fold axes trend northwest-southeast in general, but are convex facing the north near the northern margin of the zone.

Both the pelitic and psammitic schists are greenish in most cases, and have a mineral assemblage of muscovite+chlorite+plagioclase+quartz+carbonaceous matter. Calcareous pelitic schist contains calcite in addition to the minerals above-mentioned. Detrital grains of psammitic schist consist mainly of quartz and plagioclase, but lack K-feldspar. Mafic schist occurs in a small scale along the southern margin of the zone, and its mineral assemblage is actinolite+epidote+chlorite+plagioclase + quartz. The mineral assemblages indicate that the metamorphic grade of the Dzag Zone is the greenschist facies.

7. Khangay Zone

The non-metamorphosed sedimentary sequence of this zone forms northeast-southwest trending gentle folds, and is lithologically divided into lower and upper units which are conformable (Fig. 6). The fold axes are nearly perpendicular to those of the metamorphic rocks in the Dzag Zone.

The lower unit consists mainly of greenish gray, fine- to medium-grained, and well-bedded sandstone with frequent intercalations of siliceous mudstone. The thickness is more than 1,600 meters. The unit contains some horizons with large olistoliths consisting of bedded manganiferous chert and schistose green sandstone similar to the psammitic schist of the Dzag Zone (Fig. 9). The chert olistoliths attain a maximum thickness of 50 meters, yielding abundant but ill-preserved radiolarians. The upper unit is over 800 meters thick, and consists of thinly alternating beds of siliceous mudstone and gray fine-grained sandstone. The sandstones from the Khangay Zone have a matrix of 18 to 28 percent, averaging 24 percent, and are composed of quartz, plagioclase, K-feldspar, and fragments of volcanic rocks, granophyre, fine-grained granite, and mudstone (Fig. 10). The volcanic rock fragments are mostly of felsic composition in the lower unit and intermediate in the upper unit. Furthermore, the upper unit sandstones differ from the lower unit ones in that they are lower in K-feldspar/feldspars ratio than the latter, and contain greenish common hornblende as a heavy mineral constituent. The sedimentary sequence of the Khangay Zone yields brachiopods, corals, and plant fossils, and ranges in age from Devonian to Carboniferous (Borsbold and Dorjnamjaa, 1993).

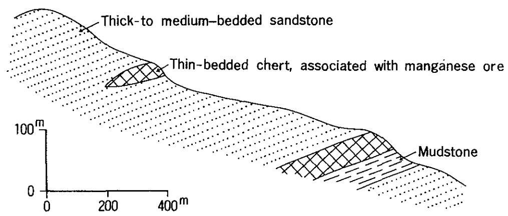

Fig. 9 Panoramic view of the lower unit containing chert olistoliths in the Khangay Zone. Location : Lat 46°31.4′N., Long 100°26.5′E.

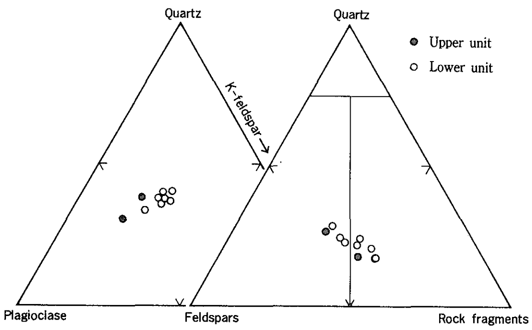

Fig. 10 Modal composition of sandstones from the Khangay Zone.

8. Concluding Remarks

The southernmost Baydrag Zone is composed of amphibolite to granulite facies rocks associated with gneissose granites. Zircons from these rocks range in U-Pb and Pb-Pb ages from 1,900 to 2,800 Ma, and phlogopites from the skarn related to lenticular marble give a K-Ar age of 1,900 Ma (Borzakovskii, 1990). Mitrofanov *et al.* (1981) reported granulite facies metamorphic rock of 2,750 Ma. Therefore, the Baydrag Zone is regarded as an Archean to Early Proterozoic orogenic belt. All of the rocks of the zone have undergone the greenschist facies metamorphism after the intrusion of andesitic dikes.

Table 1 K-Ar ages of muscovites from pelitic schists in the Burdgol and Dzag Zones. Sample locality 95MR-19 : Lat 46°14.835′N., Long 99°43.261′E., 95MR-64 : Lat 46°32.825′N., Long 99°56.650′E., 95MR-79 : Lat 46°28.670′N., Long 100°11.913′E.

Tectonic unit	Sample no.	Mineral	K (%)	^{40}Ar rad scc/gm · 10^{-5}	Atm. ^{40}Ar (%)	Age (Ma)
Dzag Zone	95MR-79	Muscovite	3.98	6.88	98.9	395±20
			3.98	6.79	99.6	
	95MR-64	Muscovite	2.94	5.73	98.3	440±22
			2.91	5.60	98.8	
Burdgol Zone	95MR-19	Muscovite	2.99	9.95	99.4	699±35
			2.97	9.82	99.6	

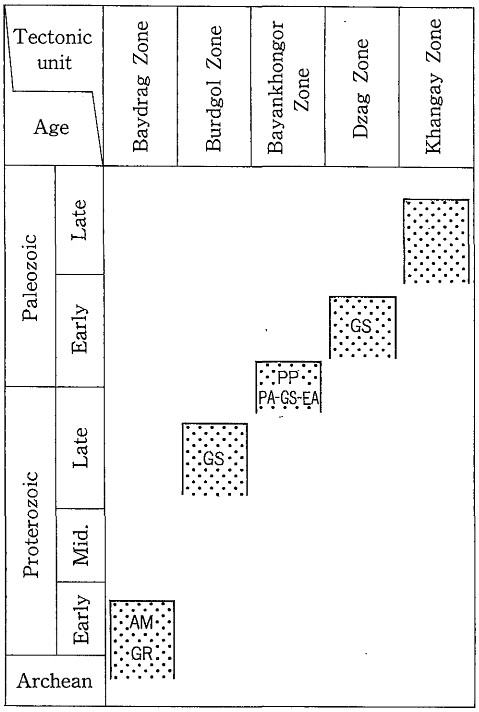

Fig. 11 Stratigraphic succession and metamorphic facies in the Bayankhongor area.
GR : granulite facies, AM : amphibolite facies, EA : epidote-amphibolite facies, GS : greenschist facies, PA : pumpellyite - actinolite facies, PP : prehnite-pumpellyite facies.

The Burdgol Zone is characterized by the dominance of greenschist facies pelitic schist with subordinate psammitic schists and metacherts. The pelitic schist has been dated by the K-Ar method as 600, 700 and 840 Ma (Borzakovskii, 1990 ; Dzabotkin, 1988), and was newly dated as 699±35 Ma (Table 1). Epidote-amphibolite, metabasite, schistose limestone, and higher-grade pelitic schist occur as olistoliths in the zone. The age data indicate that the Burdgol Zone is a Late Proterozoic orogenic belt.

The Bayankhongor Zone is composed of basic schist and structurally overlying basite, which consists mostly of pillow basalt with minor gabbro, diabase, and serpentinite. The metamorphic grade of the basite is the prehnite -pumpellyite facies, while that of the schist ranges from the pumpellyite-actinolite facies, via the greenschist facies, to the epidote-amphibolite facies. Previously reported K-Ar ages are 535 Ma for basite (Boishenko, 1977) and 600 Ma for basic schist (Dzabotkin, 1988). Fossiliferous clastic rocks of Ordovician and Carboniferous ages occur in fault contact with the surrounding rocks in the zone outside the studied area (Tumurchudur, 1990 ; Borsbold and Dorjnamjaa, 1993). These facts suggest that the Bayankhongor Zone is a latest Proterozoic to earliest Paleozoic orogenic belt.

The Dzag Zone is occupied by pelitic and psammitic schists of the greenschist facies. The pelitic schist was newly dated as 395±20 Ma and 440±22 Ma, showing some regional difference in age (Fig. 3 and Table 1). The Khangay Zone is underlain by a non-metamorphosed sedimentary sequence of Devonian to Carboniferous age. The sequence is widely distributed in the Khangay Mountains and further eastwards, being unconformably covered by Permian sediments and intruded by Permian to Jurassic granitic rocks (Borsbold and Dorjnamjaa, 1993). Therefore, the Dzag and Khangay Zones are Early Paleozoic and Late Paleozoic orogenic belts, respectively.

In conclusion, five orogenic belts are zonally arranged in the studied area, showing a northward-younging tendency (Fig. 11).

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西モンゴル，バヤンホンゴル地域の地体構造

寺岡易司・鈴木盛久・F. Tungalag・N. Ichinnorov・坂巻幸雄

要　旨

シベリア・北中国両プラットフォームに挟まれたモンゴルには，先カンブリア時代から古生代後期にかけて形成されたいくつもの変動帯が帯状に分布している．この論文では，ハンガイ山地南東部のバヤンホンゴル地域のものについて述べる．

地体構造上，本地域は Baydrag 帯（始生代-原生代前期），Burdgol 帯（原生代後期），Bayankhongor 帯（原生代末-古生代初頭），Dzag 帯（古生代前期）及び Khangay 帯（古生代後期）とに区分される．カッコ内に形成年代を示してあるが，これらは北西-南東方向に伸び，南から北へ順次配列している．最南列の Baydrag 帯には，苦鉄質片麻岩・角閃岩・チャーノカイトなど角閃岩相-グラニュライト相の変成岩が片麻状花崗岩類を伴って露出する．また，安山岩質の変成岩脈もみられる．Burdgol 帯の南縁部には変成したチャート，南部には緑色片岩相の泥質片岩，一部砂質片岩，北部には花崗閃緑岩が分布する．泥質片岩中には，緑色片岩相-緑簾石角閃岩相の変成岩からなるオリストリスが多数含まれている．Bayankhongor 帯では，構造的下位に苦鉄質片岩，上位に玄武岩の枕状溶岩を主とする苦鉄質岩がある．苦鉄質片岩の変成岩度は，パンペリー石-アクチノ閃石相から緑色片岩相をへて，緑簾石角閃岩相に達し，一方，苦鉄質岩の場合はブドウ石-パンペリー石相である．Dzag 帯の南部は泥質片岩，北部は砂質片岩で占められ，これらはいずれも緑色片岩相のものである．最も北に位置する Khangay 帯には，非変成のデボン-石炭紀堆積岩層が広く分布する．この地層の下部は主として砂岩，上部は泥岩砂岩互層からなり，前者中には縞状の放散虫チャートや片状砂岩からなるオリストリスが含まれている．

上述のように本地域では，原生代前期以前の高度変成岩地帯を核とし，原生代後期から古生代後期にかけ，その北側により新期の変動帯が順次つけ加えられている．なお，この論文は，JICA プロジェクトの一環として，1995 年度に行った日本とモンゴルの共同研究の成果をまとめたものである．

（受付：1996 年 7 月 2 日；受理：1996 年 8 月 23 日）

[1] Open file report in geological funds of Mongolia.