PROVENANCE AND PALEOCLIMATE OF MIDDLE PERMIAN TAVANTOLGOI FORMATION SANDSTONES IN BARUUNNARAN COAL DEPOSIT, SOUTHERN MONGOLIA

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ABSTRACT

Baruunnaran coal deposit is located in southern Mongolia; belongs to Tavantolgoi coal zone of South Gobi Basin (Bat-Erdene, 1992). Coal seams are hosted by Middle Permian Tavantolgoi Formation which is subdivided into lower and upper member, based on lithological characteristics. Ten core samples, consisting of sandstones were collected from exploration drill holes.

Sandstones from Middle Permian Tavantolgoi Formation in Baruunnaran coal deposit are investigated for unravel their provenance and paleoclimate conditions andtectonic settings. Detrital modes of sandstones in lower member are characterized as slightly high amount of mineral grains (quartz and feldspar) and slightly low amount of lithic fragments (litharenite, feldspathic litharenite and lithic arkose) comparing to sandstones from upper member (litharenite and lithic arkose). Provenance study of sandstones are shown signature of recycled orogens and mixed orogenic sands. Whereas, paleoclimate condition of sandstones from lower and upper members are interpreted as they were deposited in semi humid and arid environments, respectively.

Keywords: Sandstone, petrology, Middle Permian Tavantolgoi Formation, provenance, paleoclimate.

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1. Introduction

The study area is situated in southern Mongolia and southeast part of Central Asian Orogenic Belt (Jahn et al., 2000). The geology of the south Mongolia is subdivided into several terranes, including cratonal, island arc terranes, and forearc/back arc basins. The Devonian and Carboniferous periods represent a time of continental growth and accretion within a long lived volcanic arc system. Amalgamation was completed by Permian period except for the Sulinkheer terrain, located in the south eastern most part of Mongolia (Lamb and Badarch, 1997, 2001; Badarch et al., 2002; Badarch, 2005). The terranes are overlain by Permian, Triassic, Jurassic and Cretaceous volcanic and sedimentary rocks (Hendrix et al., 2001; Badarch et al.).

The Baruunnaran coal deposit is located in southern Mongolia and contained in the middle Permian Tavantolgoi Formation (Fig 1). The Tavantolgoi Formation is distributed widely in Ulaannuur basin of south Mongolia. The Tavantolgoi Formation also contains world largest coal deposits such as Tavantolgoi and Uhaahudag (Bat-Erdene, 1989). The Ulaannuur basin is located 80-90 km from Dalanzadgad and 5 km southwest from Tsogttsetsii soum. The middle Permian Tavantolgoi Formation belongs to the south Gobi basin and Tavantolgoi coal-bearing zone (Fig 1) (Bat-Erdene, 1989).

Coal exploration and all kind of regional geological, geophysical mapping and some research work had been made in the study area since 1940 by Russian and Mongolian geologists. The exploration work of Baruunnaran coal deposit was started in 1950 by incorporated group of Russian and Mongolian geologists and it was established in 1983. The zone of Tavantolgoi coal-bearing has 7.4 billion tonnages and Baruunnaran coal deposit has 330 million tonnages of coal resources.

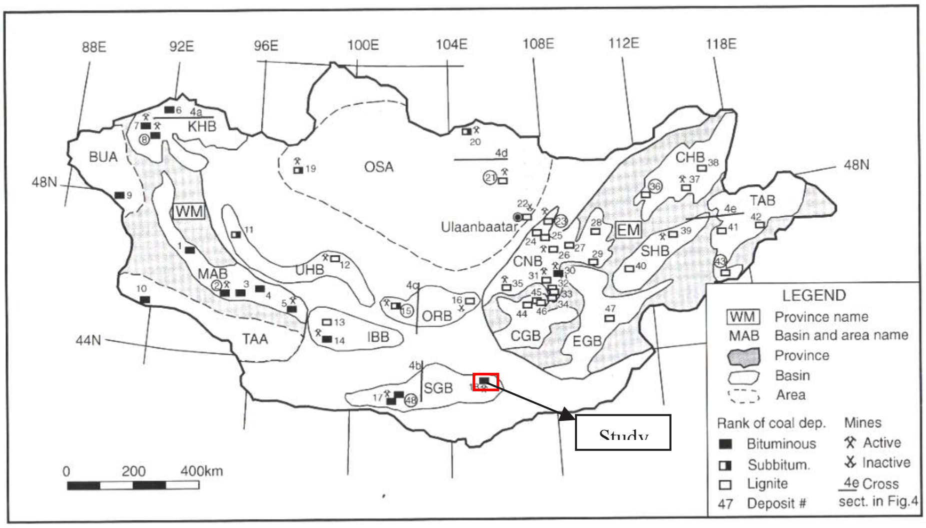

Fig 1. A location map of Mongolian coal-bearing provinces, basins and deposits (modified after Bat-Erdene, 1989). **Provinces:** WM-Western Mongolia; EM-Eastern Mongolian; Basins; KHB-Kharkhiraa; MAB-Mongol-Altai; SGB-South Gobi; UHB-South Khangai; IBB-Ikh Bogd; ORB-Ongi river; CNB-Choir-Nyalga, CHB-Choibalsan; TAB-Tamsag; SHB-Sukhbaatar; EGB-East Gobi; CGB-Central Gobi basin; **Areas:** BUA-Bayan-Ulgii; TAA-Trans-Altai; OSA-Orkhon-Selenge; **Coal deposits:** 1-Khushuut; 2-Maanit; 3-Khuren gol; 4-Tsagaan gol; 5-Zeegt; 6-Khuden; 8-Khartarvagatai; 9-Rashaant; 10-Olonbulag; 11-Tsakhiurt Urt; 12-Uvurchuluut; 13-Alagtsakhir; 14-Khotgor; 15-Bayanteeg; 16-Tsagaan-Ovoo; 17-Nariin sukhait; 18-Tavantolgoi; 19-Mogoin gol; 20-Ulaan-Ovoo; 21-Shariin gol; 22-Nalaikh; 23-Baganuur; 24-Maint; 25-Tsaidam; 26-Tugrug; 27-Khumuult; 28-Tsaidam nuur; 29-Olongiin Ukhaa; 30-Alagtogoo; 31-Shivee-Ovoo; 32-Ulaan nuur; 33-Ikh Ulaannuur; 34-Uvdugkhudag; 35-Tevshiin gobi; 36-Khulstnuur; 37-Aduunchuluun; 38-Utaat minjuur; 39-Talbulag; 40-Ulziit; 41-Zuunbulag; 42-Bulangiin khooloi; 43-Bayantsogt; 44-Taliin khudag; 45-Nukhet; 46-Khootiin khonkhor; 47-Khamriin khural; 48-

2. Geology

The Middle Permian Tavantolgoi Formation distributed in the Ulaannuur basin, part of large basin of South Gobi (Fig 1) (Bat-Erdene, 1989). The Ulaannuur basin is extend from west to east and it is approximately 50 km long, 15 km width. It is subdivided into several sub basins (Tavantolgoi, Uhaahudag and Baruunnaran) and those of subbasins are folded and faulted by normal and thrust faults (Fig 2). Baruunnaran coal deposit is situated in synclinal fold zone. The fold axis direction is from southwest to northeast, situated in west part of Ulaannuur basin. Accumulated data of Mongolian sedimentary basins provide to update former geodynamic models of coal-bearing basins. First type of basins formed as a result of crustal extension. And second are formed by flexure. Depending on the plate tectonic setting, sedimentary basins can be classified into several categories (Dickinson, 1974; Miall, 1990). Two of these basin types are characterized asrift basins related to extension and foreland basins related to compression (Erdenetsogt et al., 2009). South Gobi basin classified as foreland basin related with compression. The tectonic interpretations of South Gobi basin suggest collision between the North China block and Mongolian continent.

In Permian period, the Paleoasian Ocean between southern Mongolia and northern China closed (Lamb et al., 2008). Because of this collision, predominant structures of the South Gobi basin were formed with peat accumulating in the foreland troughs (without marine influence). In addition, the valley, formed as foreland settings during the Carboniferous, was influenced by the collision and Permian coal accumulation.

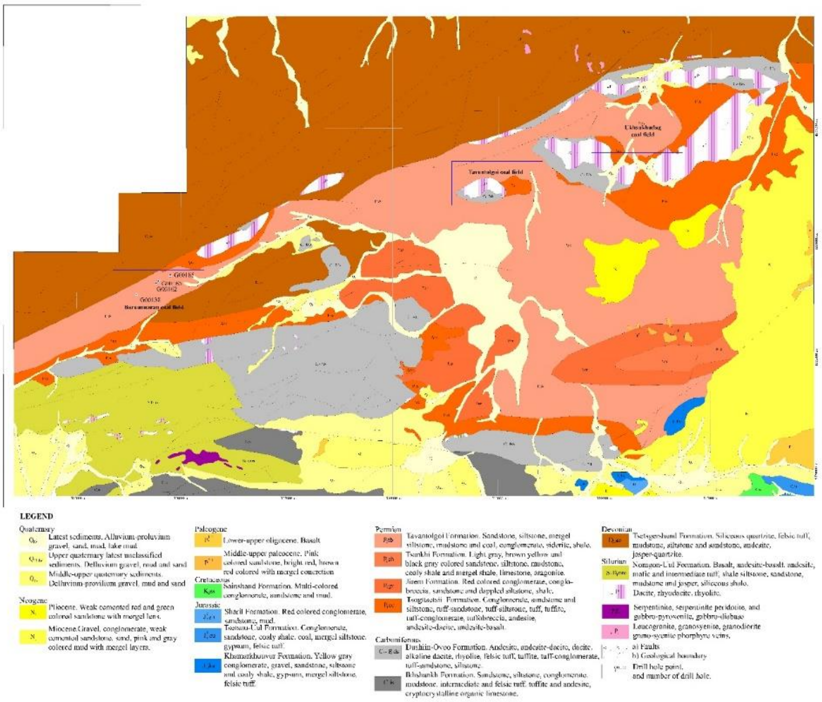

Fig 2. Geological map of the study area (modified after Khosbayar et al., 1984)

3. The integrated lithostratigraphy of Baruunnaran coal deposit

Middle Permian Tavantolgoi Formation was studied by Russian geologists in 1966 and 1976, 1978. It was then studied by P. Khosbayar in 1984, the Tavantolgoi Formation is subdivided into lower and upper subformations. We made new integrated lithostrarigraphy of the Baruunnaran coal deposit (unpublished data of Demberelsuren and Sersmaa). The data were collected from four drill holes information. The new integrated lithostratigraphy is generally same with the previews one (Khosbayar, 1984). And the new one is subdivided into lower and upper members, based on lithological character and total thickness is approximately 1556 m (Fig 2A). The strata of lower member consist of from medium to fine grain sized sediment units and thick coal seams and their thickness are from 690 to 700 m. The strata of upper member consist of medium and coarse grain sized sediments units and thin coal seams and their thickness are from 860 to 900 m. This formation hosts 17 coal seams. The absolute age of Tavantolgoi Formation is established from flora, which is same as that found in the central region of Angaraland (Durante, 1976; Uranbileg, 2003).

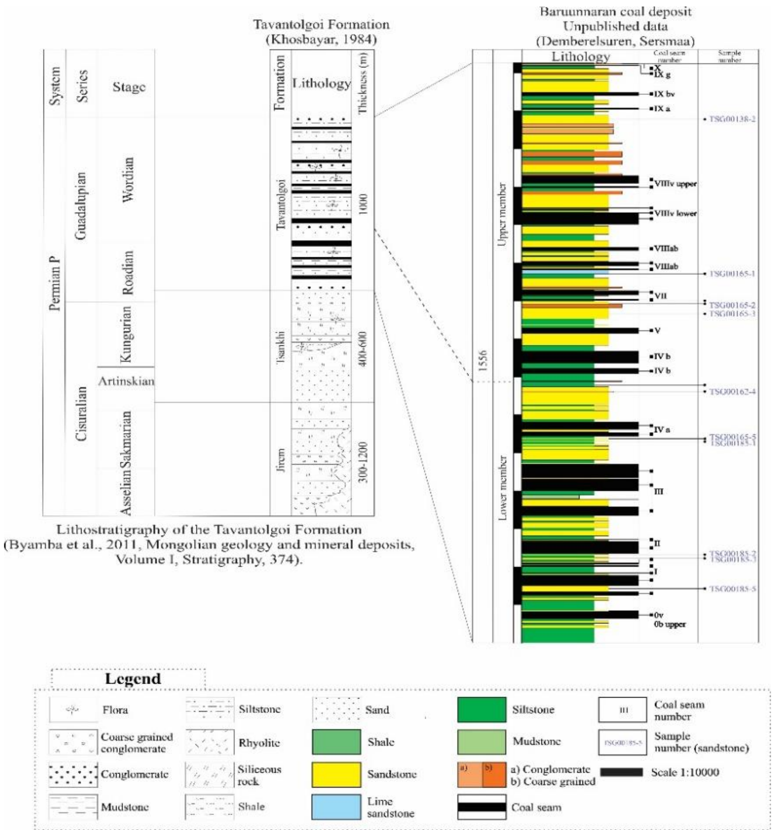

Fig 2A. The integrated lithostratigraphy of Baruunnaran coal deposit, which is compared with the Tavantolgoi Formation Lithostratigraphy (Khosbayar, 1984).

4. Sampling and methods

Totally ten samples of sandstones were collected from four drill holes (Fig. 2). The six sandstone samples (thin-section 162-4, 165-5, 185-1, 185-2, 185-3, 185-5) and four sandstone samples (thin-section 138-2, 165-1, 165-2, 165-3) were collected from lower and upper members, their deep locations are shown in Figure 2A. The sandstone classification and provenance, paleoclimate analysis of the middle Permian coal-bearing Tavantolgoi Formation were based on petrographical detrital modes method.

4.1 Detrital modes

Standard thin-sections were prepared in laboratory of Field Research Center. The thin-sections were examined under polarizing NIKON microscope and point-counted using Gazzi-Dickinson method. The modal compositions of detrital and diagenetic components and pore types were determined by counting three hundred points per thin-section. The definition grain parameters are explained in Table 1; recalculated point-counting data is shown in Table 2. The grain sizes of sandstones were measured using a micrometer ocular.

Table 1. Definitions of grain parameters

Q-F-L	**Qm-F-Lt**
Q=Qm+Qp, where: Qt=total quartz grains Qm-monocrystalline quartz Qp-polycrystalline quartz F=Pl+K, where: F=total feldspare grains Pl=plagioclase K-potassium feldspar L=Lv+Ls+Lm, where: (L=R) Lv-total volcanic lithic fragments Ls-total sedimentary fragments Lm-total metamorphic lithic fragments	Qm-monocrystalline quartz F=total feldspar Lt=total lithic fragments+polycrystalline quartz Qp-Lvm-Lsm Qp= polycrystalline quartz Lvm= total volcanic and metavolcanic lithic fragments Lsm= total sedimentary and metasedimentary lithic fragments

Table 2. Recalculated point-counting data from lower and upper member of middle Permian Tavantolgoi Formation.

Sample number	**Qt-F-L, %**			**Qm-F-Lt, %**			**Qp-Lvm-Lsm, %**		
	Qt	**F**	**L**	**Qm**	**F**	**Lt**	**Qp**	**Lvm**	**Lsm**
Sandstones of lower member									
162-4	61.6	12.3	26.1	24.0	12.3	63.7	68.4	26.3	5.3
165-5	63.0	23.6	13.4	17.3	23.6	59.0	78.4	21.6	0
185-1	59.8	25.5	14.7	13.1	25.5	61.4	87.7	9.2	3.1
185-2	37.3	2.1	60.6	14.8	2.1	83.1	30.0	62.6	7.4
185-3	50.0	4.6	45.4	7.0	4.6	88.4	52.8	29.2	18.0
185-5	13.7	0.5	85.8	5.7	0.5	93.8	9.5	66.3	24.2
Sandstones of upper member									
138-2	1.3	1.8	96.9	1.3	1.8	96.9	0	64.1	35.9
165-1	10.9	7.2	81.9	5.1	7.2	87.7	6.8	66.7	26.5
165-2	1.8	0	98.2	1.4	0	98.6	0.5	56.4	43.1
165-3	4.0	1.0	95.0	1.0	1.0	98.0	3.2	71.1	25.7

5. Results

5.1 Sandstone petrography of Middle Permian Tavantolgoi Formation

Totality ten sandstone samples were collected from Middle Permian Tavantolgoi Formation.Six sandstone samples (thin-sections 162-4, 165-5, 185-1, 185-2, 185-3, 185-5) are collected from the lower member and four sandstone samples (thinsection 138-2, 165-1, 165-2, 165-3) collected rom the upper member (Fig. 2A).

5.2 Lower member sandstones of middle Permian Tavantolgoi Formation

Six sandstone samples (thin-sections 162-4, 165-5, 185-1, 185-2, 185-3, 185-5) from lower member of middle Permian Tavantolgoi Formation were investigated by microscopical observation. The sandstones consist of from 60% to 90% detrital grains and from 10% to 40% cement. Detrital grains are composed of mineral grains and lithic fragments. They are generally sub-rounded and moderately sorted. Size of detrital grains are ranges from 0.04 mm up to 0.8 mm and sometimes occurs up 5 mm. Sandstones of lower member consist of more mineral grains ranges from 30% to 70% than sandstones of upper member. Detrital minerals are quartz (Fig. 3A1), plagioclase and potassium feldspar (Fig. 3B). Polycrystalline quartz is dominant over monocrystalline quartz. Plagioclase is altered to sericite and clay mineral, which is carbonate minerals. Potassium feldspar is strongly altered by clay mineral and slightly altered by albite. Modal amounts of plagioclase grains are more than potassium feldspar grains in sandstones of lower member. Lithic fragments are composed 25-65% in sandstone, and 30-95% of the total lithic fragments are volcanic lithic fragments. Texture of volcanic lithic fragments in andesite composition are shown micropoikilite, pilotaxite, and microlite. Whereas texture of felsic volcanic rocks are shown microfelsite and microspherolitic texture (Fig. 3C). Sometimes sandstones rarely contain intrusive lithic fragments. Fragments of sedimentary rocks are sandstone, siltstone, siliceous rocks (Fig. 3D1) and less amount of tuff. Metamorphic lithic fragments consist of micro quartzite with microgranomorphic texture (Fig. 3A2, 3D2) and microlepidiomorphic texture schist. Cement is comprised with dominant sericite and siliceous, carbonate materials. The detrital accessory minerals are opaque minerals and zircon.

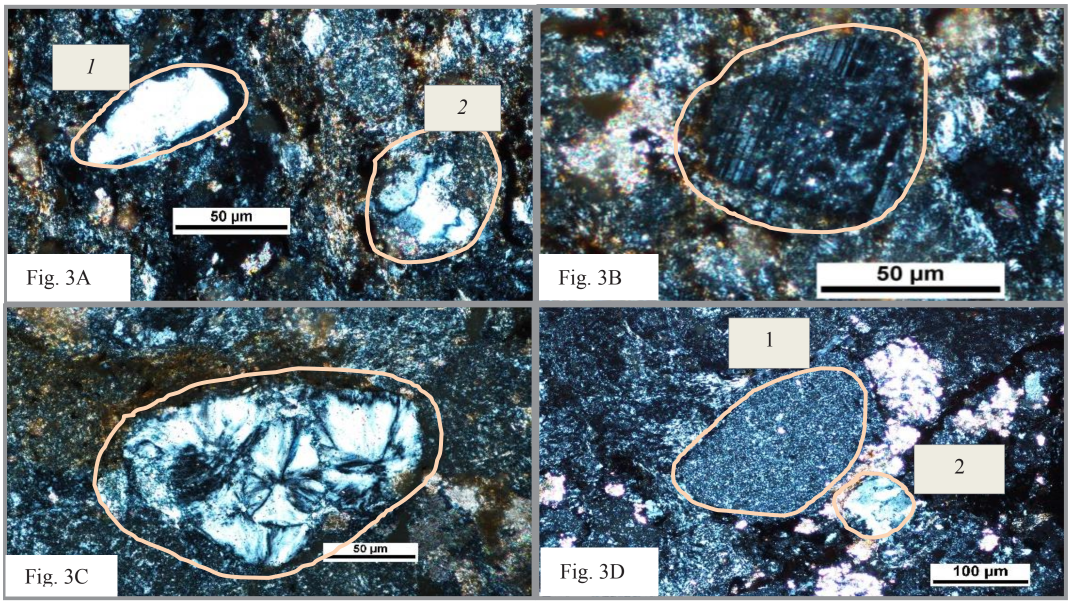

Fig. 3C. Microspherolitic texture of felsic volcanic rock fragment.
Fig.3D.Cryptograined texture of siliceous rock fragment and microgranomorphic texture of microquartzite fragment in sandstones of lower member.

5.3 Upper member sandstones of middle Permian Tavantolgoi Formation

Detrital grains are generally sub-rounded and moderately sorted similar with lower member sandstones. Four sandstone samples (thinsection 138-2, 165-1, 165-2, 165-3) were studied. They consist of from 90% to 95% detrital grains and from 5% to 10% cement. Detrital grains are composed of mineral grains and lithic fragments. Especially content of lithic fragments are more (from 75% up to 90%) than lower member sandstones. Detrital minerals are quartz (Fig. 4B2), plagioclase and potassium feldspar. Plagioclase is generally more abundance than k-feldspar. Plagioclase is altered by clay mineral, sericite and rarely to carbonate. K-feldspar is strongly altered by clay mineral and slightly altered by albite. Lithic fragments are composed fragments of volcanic, sedimentary and metamorphic rocks. Sizes of lithic fragments are mainly from 0.09 mm to 1.2 mm, sometimes reach larger than 2 mm. Volcanic lithic fragments are andesite with textures of hyalopilitic, pilotaxite, microlite (Fig. 4B1, 4D) and microfelsite and microspherulitic textured felsic volcanic rocks (Fig. 4C) are shown. Volcanic lithic fragments abundance ranges from 55% to 70% in sandstone of upper member similar with lower member sandstone. The sedimentary lithic fragments include siliceous rocks and siltstone, sandstone rocks, which show cryptograined and aleurite, psammite textures. Metamorphic lithic fragments are composed of microquartzite with microgranomorphic texture (Fig.4A) and microlepidiomorphic textured schist. Sandstone is consisted of rarely intrusive lithic fragments and tuff. Cement of upper member sandstone is overprinted by mainly sericite, siliceous material and carbonate (Fig. 4B3). The detrital accessory minerals are opaque minerals and zircon.

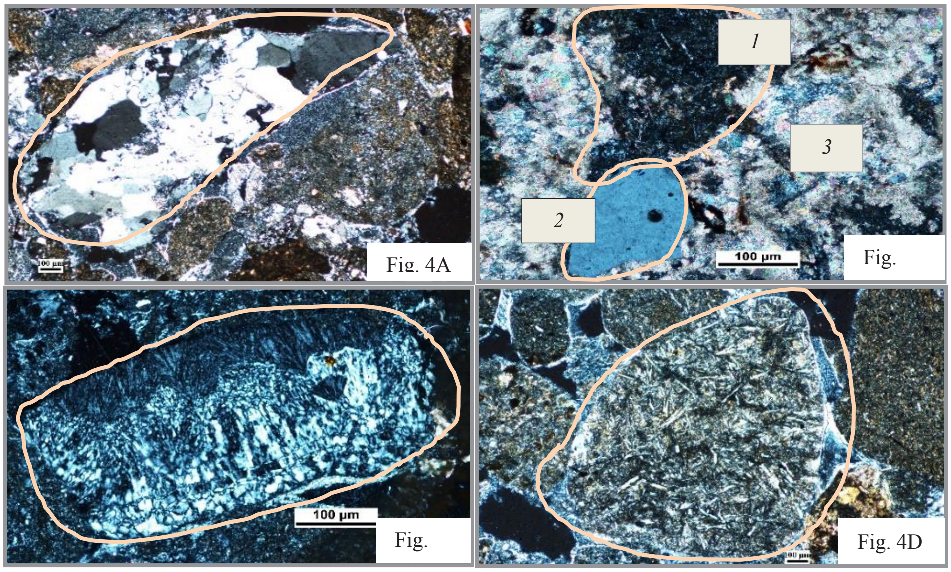

Fig. 4A. Microgranomorphic texture of microquartzite fragment in sandstones of upper member.
Fig. 4B. 1) Hyalopilitic texture of andesite fragment 2) cement of carbonate 3) quartz grain in sandstones of upper member.
Fig. 4C. Microspherulitic texture of felsic volcanic rock fragment in sandstones of upper member.
Fig. **4**D. Microlite texture of andesite fragment in sandstones of upper member.

5.4 Sandstone classification

Four sandstones of lower member are classified as litharenite, one is feldspathic litharenite and another one is lithic arkose (Table 2, Fig. 5A) in the sandstone classification diagram of Folk (1968). Three sandstones of upper member are mostly characterized by litharenite and one sample as lithic arkose (Fig. 5A).

The content of lithic fragments in studied sandstones is shown in Figure 5B. All types of lithic sand grains occur throughout the sequence, which indicates greater dispersion of sand-sized detritus across the basin from provenance with similar geology. The three lithic grain types are discernible from lower to up of section. Volcanic lithic fragments predominate in sandstones of members.

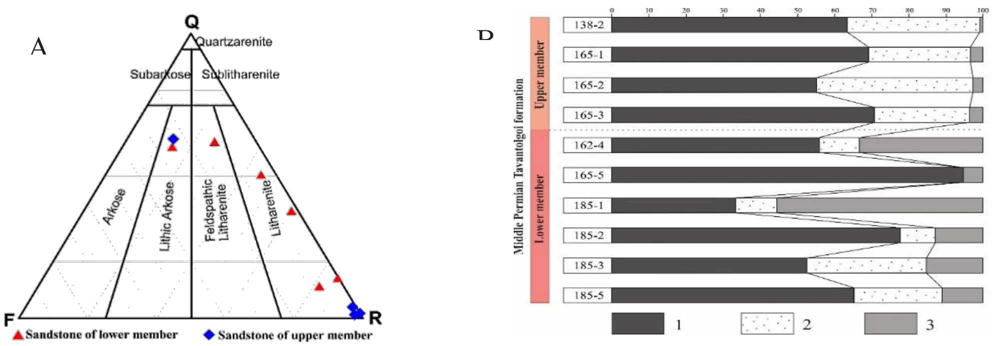

Fig. **5**. A) Classification diagram of sandstones of middle Permian Tavantolgoi Formation after Folk (1968). B) Lithic fragments composition data plotted according to stratigraphic position. 1-volcanic lithic fragments, 2-sedimentary lithic fragments, 3-metamorphic lithic fragments.

5.5 Provenance analysis of middle Permian Tavantolgoi Formation

Qt-F-L Diagram

Figure 6A, Table 2 shows plots of detrital modal data for middle Permian Tavantolgoi Formation sandstones on the Qt-F-L diagram with compositional fields defined by Dickinson (1985). Four sandstones plot in the recycled orogen and two sandstones plot in the undissected arc of lower member.

Qp-Lvm-Lsm Diagram

On the Qp-Lvm-Lsm diagram (Fig. 6C), sandstones of lower member plot in the Mixed orogenic sands field. Sandstone, which is consists in lower member, plot in the arc orogenic sources field. Whereas sandstones of upper member plot in the arc orogen sources fields.

Various provenance interpretations based on detrital modal data are summarized in Table 3.

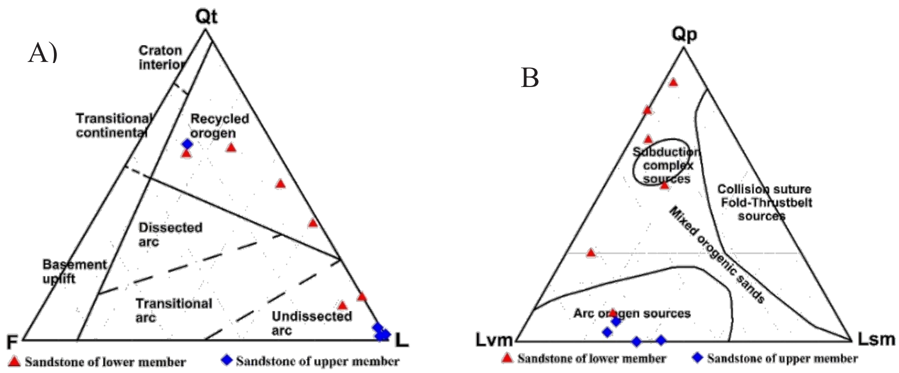

Fig. 6. A) Qt-F-L B) Qp-Lvm-Lsm diagram. A, B-provenance field diagrams of middle Permian Tavantolgoi Formation after Dickinson (1985).

Table 3. Various provenance types of middle Permian Tavantolgoi Formation

Age	Qt-F-L	Qp-Lvm-Lsm
Lower member	Recycled orogen	Mixed orogenic sands
	Undissected arc	Arc orogeny sources
Upper member	Undissected arc	Arc orogeny sources

Although, tectonics is the dominant factor affecting framework mineralogy but climate also plays a significant role (Suttner and Dutta, 1986) and the climatic signatures are well preserved in the deposited sediments. The sandstones composition frameworks of Tavantolgoi Formation were calculated for petrological studies. These results were computed and plotted to construct the bivariant log/log plots of the ratios of polycrystalline quartz (Qp), to feldspar plus lithic fragments (F+R), against the ratios of total quartz (Q=Qm (monocrystalline quartz) +Qp) to feldspar plus lithic fragments (F+R). Paleoclimatic fields are indicated by arrows for separate climatic fields (Suttner and Dutta, 1986) (Fig. 7). Symbols Q, Qp, F and L as in Table 4. Q/(F+L) and Qp/(F+L) ratio are high in lower member, indicating generally semi humid condition, decrease in upper member with ratios typical of arid condition.

Table 4. Mineralogical composition (in normalized to 100%) sandstones from Tavantolgoi Formation

Thin section number	Q%	F%	L%	Qp%	Q/(F+L)	Qp/(F+L)
Sandstones of lower member						
162-4	61.59	12.32	26.09	37.68	1.60	0.98
165-5	62.99	23.62	13.39	45.67	1.70	1.23
185-1	59.78	25.54	14.67	46.74	1.49	1.16
185-2	37.32	2.11	60.56	22.54	0.60	0.36
185-3	50.00	4.62	45.38	43.08	1.00	0.86
185-5	13.74	0.47	85.78	8.06	0.16	0.09
Sandstones of upper member						
138-2	61.59	12.32	26.09	37.68	0.01	0.00
165-1	62.99	23.62	13.39	45.67	0.12	0.07
165-2	59.78	25.54	14.67	46.74	0.02	0.00
165-3	37.32	2.11	60.56	22.54	0.04	0.03

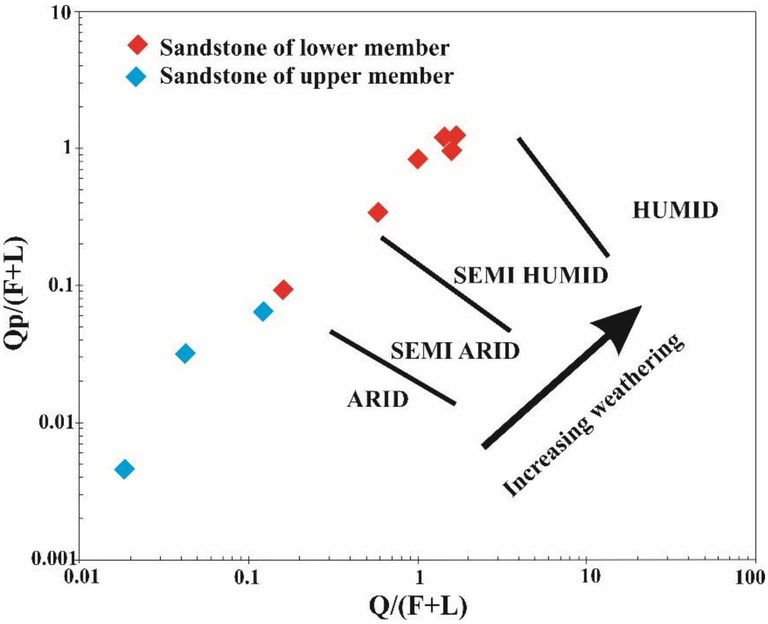

Fig. 7. Bivariate log/log plot of Q/(F+L) and Qp/(F+L) ratios of Tavantolgoi Formation sandstones on the climate discrimination diagram of Suttner and Dutta (1986).

6. Discussion

Lower and upper member sandstones of Tavantolgoi Formations are sub-rounded and moderately sorted. It is suggested that, sediments were transported same distance whereas source rock of lower and upper sandstones were not distributed far away.

However their mineralogical compositions are slightly different in sandstones of lower and upper members. Otherwise the lithic fragments are increased in up section of Tavantolgoi Formation.

Sandstones of lower member consist slightly more mineral grains, ranges from 30% to 70% than upper member. Detrital minerals are quartz, plagioclase and potassium feldspar in sandstones. Polycrystalline quartz is dominant over monocrystalline quartz, whereas plagioclase is consists more than potassium feldspar in sandstones of lower member. Lithic fragments, sedimentary and metamorphic, volcanic rocks are composed 25-65%, of which abundance of volcanic lithic fragments (andesite and felsic volcanic rocks) are 30-95% of the total lithic fragments in sandstones of lower member.

Furthermore, sandstones of upper member are more rich in lithic fragments (from 75% up to 90%). Types of lithic fragments are volcanic, sedimentary and metamorphic rocks similar with lower member. Also volcanic rock fragments range from 55% to 70% of the total lithic fragments in sandstones of upper member. The mineral grains are contained range from 5% to 15% in sandstones. Detrital minerals are quartz, plagioclase and potassium feldspar hence plagioclase is generally more abundance than potassium feldspar. Sandstones of lower member of Tavantolgoi Formation are classified mostly litharenite except two another. One of another two is classified feldspathic litharenite and other one is lithic arkose. Accordingly, all sandstones of upper member are classified to litharenite.

Composition of mineralogy in sandstone related with their tectonics, climate, weathering, transported distance, and digenesis for (Suttner and Dutta, 1986). Weathering intense is increased in warm, humid and stable tectonic condition besides stable detrital minerals (quartz and potassium feldspars) increased in deposition.

Bivariant plot, suggests semi humid paleoclimatic condition during the deposition of sandstones lower member of Tavantolgoi Formation either dominated detrital mineral fragments in sandstones. Also lithic fragments dominated in sandstones of upper member, their deposition paleoclimate are defined as arid condition. Other hand source rock of upper member sandstones were weathered as weak.

The study area is subjected in Southern Mongolia. The Devonian and Carboniferous periods represent a time of continental growth and accretion within Southern Mongolia was covered long lived by volcanic arc system. Amalgamation was completed by Permian period reason for collision between the North China block and Mongolian continent (Lamb and Badarch, 1997, 2001; Badarch et al., 2002; Badarch, 2005). Depending on the plate tectonic setting, sedimentary basins can be classified into several categories (Dickinson, 1974: Miall, 1990). Mongolian coal-bearing basins are classified two types are: rift basins related to extension; and, foreland basins related compression. Whereas south Gobi basin is classified foreland basin, which is related compression tectonic condition. Using various ternary diagrams of Dickinson (1985), provenance of sandstones was derived from recycled orogens and mixed orogenic sands in lower member whereas it was derived magmatic arcs in upper member provenances respectively, contained more volcanic lithic fragments during collision between the North China block and Mongolian continent (Lamb and Badarch, 1997, 2001; Badarch et al., 2002; Badarch, 2005).

7. Conclusions

On the basis of petrological studies on Middle Permian Tavantolgoi Formation sandstones, we conclude the following:

1. The sandstones of Middle Permian lower member of Tavantolgoi Formation have been classified as litharenite and feldspathic litharenite, lithic arkose. All sandstones of upper member have been classified to litharenite.
2. Constituent grains of these sediments suggest that signature of recycled orogens and mixed orogenic sands in lower member and signature of magmatic arc sands in upper member provenances.
3. The sandstones of lower member were deposited during the semi humid paleoclimate conditions with more intense weathering and slightly stable tectonic condition. Whereas upper member sands were deposited in arid paleoclimate condition. Therefore sediments of upper member were accumulated in arid environment indicate weak weathering and more active tectonic condition.

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References

Bat-Erdene, D, 1992, Nature of distribution and Formational condition of coal basins in the Mongolian orogenic belt. Summery of Sc.D. thesis, Moscow, 6-52 [in Russian].

Bat-Erdene, D, 2009, Mongolian geology and mineral deposits, vol V, Fossil fuels, Ulaanbaatar, 53-55.

Byamba, J et al, 2011, Mongolian geology and mineral deposits, vol I, Stratigraphy, Ulaanbaatar, 374-378.

Dickinson W.R, 1974, Plate tectonics and sedimentation. In: Dickinson (Ed), Tectonics and sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication, 22, 1-27.

Dickinson W.R, 1985, Interpreting provenance relations from detrital modes of sandstones.

Folk R, 1968, Sedimentary rocks, 170.

Lamb, M.A, Badarch, G, 1997, Paleozoic sedimentary basins and volcanic arc systems of southern Mongolia: new geochemical stratigraphic and sedimentologic constrains. International Geology Review 39, 542-576.

Lamb, M.A, Badarch, G, 2001, Paleozoic sedimentary basins and volcanic arc systems of southern Mongolia: new geochemical and petrographic constrains. In: Hendrix, M.S, Davis, G.A, (Eds), Paleozoic and Mezozoic Tectonic Evolution of Central Asia-From Continental Assembly to Intracontinental DeFormation: Geological Society of America Memoir, vol, 194, 117-150.

Suttner, L.J and Dutta,P.K, 1986. Alluvial sandstone composition and paleoclimate, I. Framework Mineralogy., Jour. Sed. Pet., v.56(3)., pp.329-345.