名古屋大学博物館報告
Bull. Nagoya Univ. Museum
No. 28, 27–38, 2012

Description of sandstones in the Ulaanbaatar area, Mongolia.

Toshiya SUZUKI[1)], Yuki NAKANE[1)], Bakhat NURAMKHAAN[2)], Makoto TAKEUCHI[1)], Kazuhiro TSUKADA[3)], Sersmaa GONCHIGDORJ[2)], Khishigsuren SODNOM[2)] and Manchuk NURAMKHAAN[2)]

1) Graduate School of Environmental Studies, Nagoya University, Nagoya 464-8602, Japan
2) School of Geology and Petroleum Engineering, Mongolian University of Science and Technology, Ulaanbaatar, Mongolia
3) Nagoya University Museum, Nagoya 464-8601, Japan

Abstract

The texture and the grain composition of sandstone provide information about the tectonic setting of basins of deposition and associated provenances. The geological history of the Khangay-Khentey belt composed of pre-Carboniferous accretionary complex and Carboniferous shallow-marine strata was linked with the evolution of the Mongol-Okhotsk Ocean. This paper describes the sandstones of the Gorkhi, Altan-Ovoo & Orgioch-Uul Formations and Carboniferous shallow marine system, that occurs around Ulaanbaatar city

The sandstones in the Gorkhi and Altan-Ovoo & Orgioch-Uul Formations are classified as feldspathic arenite. They are clast supported and poorly-sorted, with dominantly angular to very angular grains mainly composed of quartz, potassium feldspar, plagioclase and rock fragments of rhyolite and tuff. The modal framework grain analysis shows that sandy detritus was derived from "continental crust" where erosion has cut deep into volcanic cover. The sandstone in the Carboniferous shallow marine system classified as feldspathic wacke is rich in muddy matrix and poorly-sorted, dominantly includes rounded to little angular grains of quartz, potassium feldspar, plagioclase and rock fragments of rhyolite, felsic tuff, andesite and basalt. The Qm-F-Lt diagram suggests that the sandstone is originated from the "transitional arc".

The sandstones from the Gorkhi and Altan-Ovoo & Orgioch-Uul Formations are significantly similar and they can not be distinguished to each other in their textures, grain compositions and poor in rock fragments, and they were originated from the same kinds of source, i.e. continental crust where erosion has cut deep into volcanic cover which related to the subduction of oceanic plate. However, the lithostratigraphies of these formations are quite different each other and they were likely to have been formed at different places, or formed in different ages each other. The volcanism evidenced by the felsic tuff intercalations in the Altan-Ovoo & Orgioch-Uul Formation at the provenance area was likely enough immature which could not provide much volcanic rock fragments to the basin. The sandstone of the "Carboniferous formation," rich in volcanic rock fragments, strongly indicates that the volcanic activity had developed to supply volcanic rock fragments into the sedimentary basin of this formation.

1. Introduction

The Mongolian territory lies in the heart of the Central Asian Orogenic Belt (CAOB), that developed between the Angara craton to the north and the North China and Tarim blocks to the south (Fig. 1). Tectonic history of the CAOB has important implications for the growth mechanisms of continental crust in Earth's history (Kovalenko *et al*., 2004). Sengör and Natal'in (1993) envisaged that the Khangay-Khentey belt, central Mongolia (Fig. 2), has been formed by closer of the Mongol-Okhotsk Ocean between the Angara craton and the North China block; however its closure process and tectonic setting are still debated (e.g. Enkin *et al*., 1992; Zorin *et al*., 1993). The provenance analysis of the Khangay-Khentey belt, which is composed of accretionary complex and Carboniferous shallow-marine strata, would give a contribution to examine the closure process and tectonic setting of this ocean. The texture and grain composition of clastic rocks let us know the nature of the source rocks in the provenance area which can

be depended on their tectonic settings. Consequently, detrital framework modes of sandstone suites provide important information in considering the tectonic setting of basins of deposition and associated provenances. This paper presents microscopic description of the sandstone in the Khangay-Khentey belt at the Ulaanbaatar area to examine the tectonic setting of this belt.

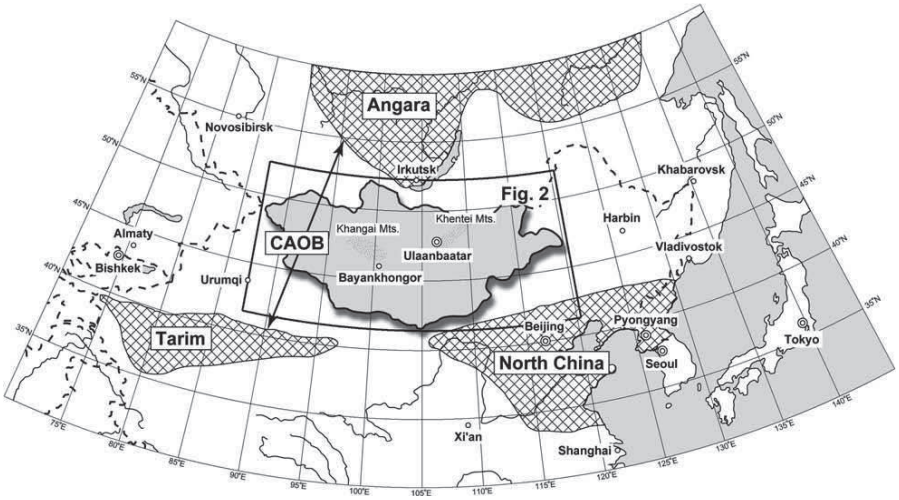

Fig. 1 Tectonic map of Northeast Asia showing the locations of the Central Asian Orogenic Belt (CAOB) (Kurihara *et al*., 2008).

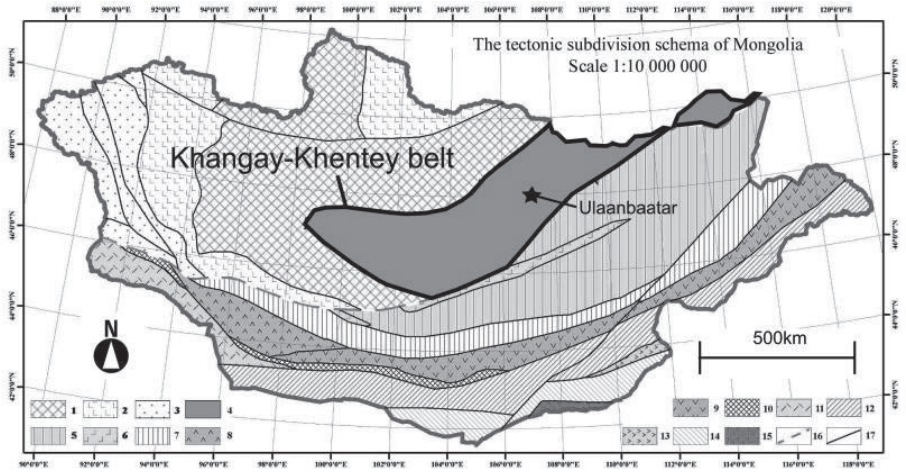

Fig. 2 Tectonic division of Mongolia showing the distribution of the Khangay-Khenety belt (modified from Tomurtogoo, 2003). 1: Central Mongolia superterrane, 2: complex terrane, 3: Mongol Altai orogenic belt, 4: Khangay-Khentey belt, 5: Idermeg terrane, 6: Undur haan terrane 7: Gobi Altai-Baruun Urt terrane, 8: Edren terrane, 9: Mandah terrane, 10: Gurvansaihan terrane, 11: Baruun khuurai terrane, 12: South Gobi superterrane, 13: Zamiin Uud terrane, 14: Khutag Uul terrane, 15: Sulinheer and Duulgant terrane, 16: Main Mongolian Lineament fault, 17: Other faults.

2. Geological outline in the Ulaanbaatar area

The Paleozoic rocks in the Ulaanbaatar area are divided into the Gorkhi and Altan-Ovoo & Orgioch-Uul Formations of accretionary complexes and the Carboniferous shallow marine system (Takeuchi *et al*., 2013, Fig. 3).

The Gorkhi and Altan-Ovoo & Orgioch-Uul Formations occupy the southeastern and eastern to central parts of this area respectively (Fig.3). The Carboniferous shallow marine system (here, "Carboniferous formation") is distributed in the northwestern part of this area (Fig. 3). Mesozoic Granite (Tomurtogoo

et al., 1998) intrudes into the Altan-Ovoo & Orgioch-Uul Formation in the southeast area. The Cretaceous system (Tomurtogoo *et al*., 1998) composed of white claystone and conglomerate exposed in the northwest of central Ulaanbaatar unconformably covers the rocks of the accretionary complex. The Gorkhi Formation consists mainly of massive sandstone with small amounts of mudstone, siliceous mudstone and chert. The chert contains Upper Silurian to Upper Devonian radiolarians (Kurihara *et al*., 2009; Nakane *et al*., 2013). The Altan-Ovoo & Orgioch-Uul Formation consists mainly of sandstone, mudstone and alternating beds of sandstone and mudstone with small amounts of conglomerate, felsic tuff, siliceous mudstone, chert and basalt. The "Carboniferous formation" consists mainly of sandstone and mudstone with small amounts of conglomerate. The "Carboniferous formation" yields brachiopods (Takeuchi *et al*., 2013). The Gorkhi Formation is in fault contact with the Altan-Ovoo & Orgioch-Uul Formation. The Altan-Ovoo & Orgioch-Uul Formation is uncomformably overlain by the "Carboniferous formation" (Takeuchi *et al*., 2013).

The Gorkhi and Altan-Ovoo & Orgioch-Uul Formations are complexly folded with northeast-trending sub-horizontal axes (Fig. 3). Northwest-trending faults cut the above three formations to form fault-bound-blocks at the northwestern part of the study area (Fig. 3).

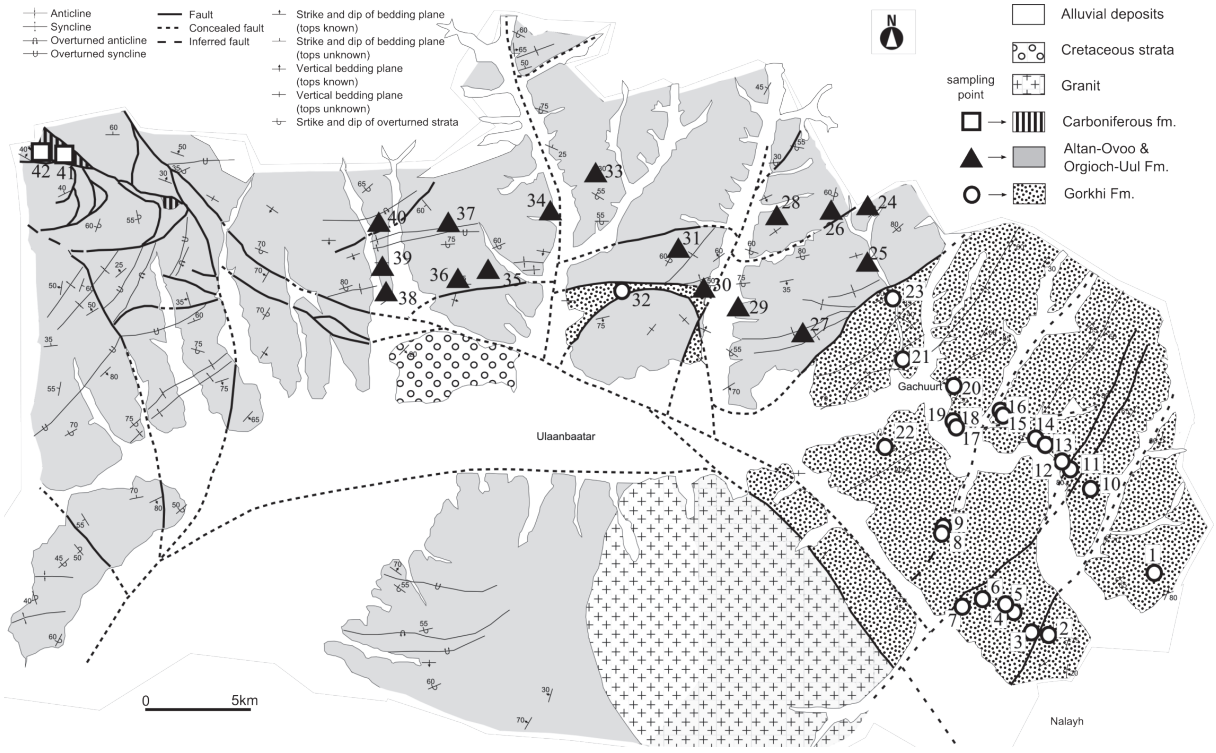

Fig. 3 Simplified Geologic map of the Ulaanbaatar area (modified from Takeuchi *et al*., 2013) with sampling point of the sandstone.

3. Methodology – classification and modal framework grain analysis of sandstone

Sandstone is divided into wacke and arenite by its matrix quantity. The sandstone can be furthermore classified into the quartzose arenite/wacke, feldspathic arenite/wacke, and lithic arenite/wacke with their quantitative ratio of monomineralic quartz (Q), feldspar (F) and polycrystalline lithic fragments (R) (Okada, 1971, Fig. 4a).

In addition, the modal framework grain analysis in sandstone with monomineralic quartz (Qm), feldspar (F) and polycrystalline lithic fragments (Lt) allows the interpretation of the plate tectonic position of the source terranes divided into continental blocks, magmatic arcs and recycled orogens (Dickinson *et al*.,

1983, Fig. 4b). The "continental blocks" include craton interior, basement uplift where erosion has cut deep into the continental crust and their transition (Dickinson *et al*., 1983, Fig. 4b). The "magmatic arcs" are subdivided into the dissected arc in which plutons are exposed from erosional unroofing, undissected arc in which volcanic cover present, and their transition (Dickinson *et al*., 1983, Fig. 4b).

The above two methods, i.e., traditional classification of sandstone (Okada, 1971) and modal analysis of framework grains (Dickinson *et al*., 1983) for forty-two medium-grained sandstone samples were examined in this study. Twenty-four, sixteen, and two samples in which of them were from the Gorkhi, Altan-Ovoo & Orgioch-Uul, and "Carboniferous" Formations respectively (Fig. 3). Five hundred grains for each sample were counted using the Gazzi-Dickinson method (Dickinson et al., 1983) in thin sections stained for potassium feldspar by sodium cobaltinitrite.

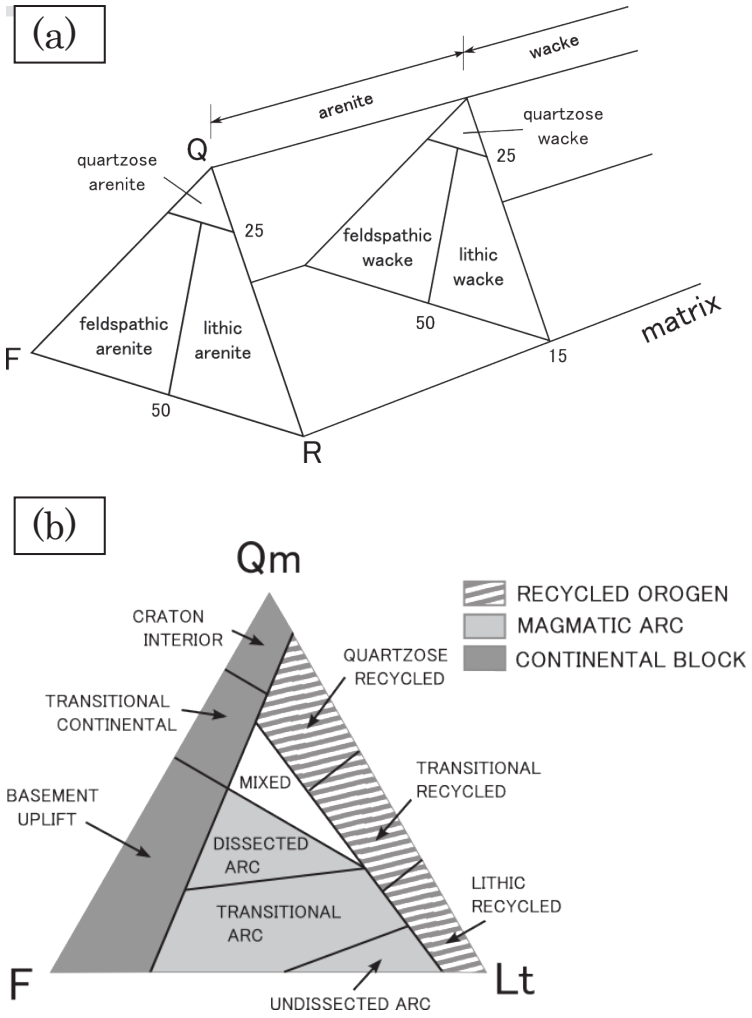

Fig. 4 (a) Petrographic classification of sandstone (Okada, 1971). (b) Compositional fields indicative of sandstone derivation from different types of provenance (Dickinson *et al*., 1983).

4. Description of the sandstone

4.1. Gorkhi Formation

The sandstone of this formation, clast-supported (< 5 % of muddy matrix) and poorly-sorted, dominantly includes angular to very angular grains of quartz, potassium feldspar, plagioclase and rock fragments of rhyolite and felsic tuff with lesser amounts of biotite, muscovite, sphene, zircon, epidote, hornblend, chrolite and rock fragments of sandstone, mudstone, andesite and basalt (Figs. 5a and b). Allanite is rarely present.

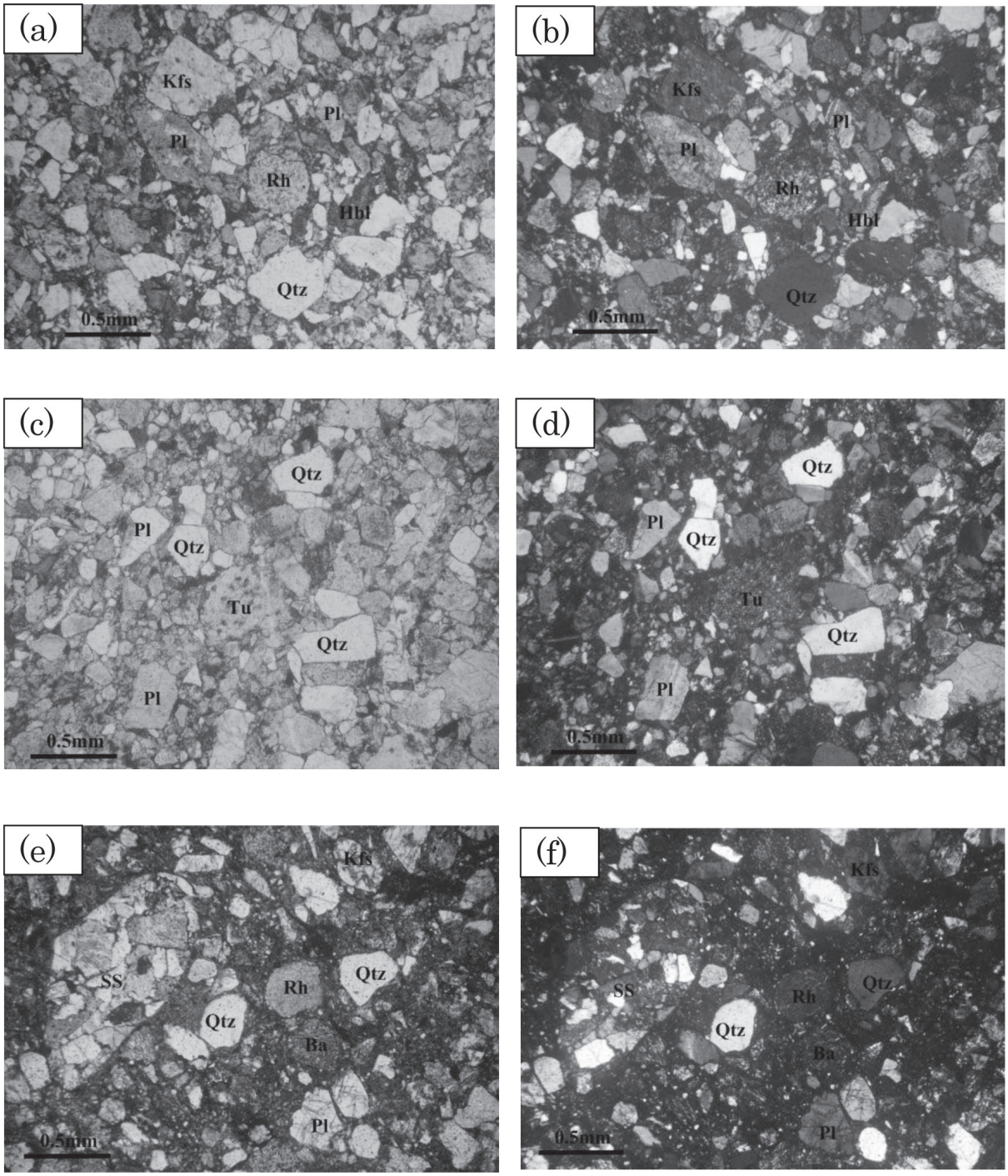

Fig. 5 Photomicrographs of sandstone of the Gorkhi Formation, (a): plane polarized light (b): crossed polars, the Altan-Ovoo & Orgioch-Uul Formation, (c): plane polarized light (d): crossed polars, and the Carboniferous formation, (e): plane polarized light (f): crossed polars. Qtz: quartz, Pl: plagioclase feldspar, Kfs: potassium feldspar, Hbl: hornblend Rh: rhyolite, Tu: tuff, Ba: basalt, SS:sandstone.

It is classified as feldspathic arenite in the Q-R-F diagram (Okada, 1971, Fig. 6a). According to the modal framework grain quantification, the most of the samples are plotted in the field of "basement uplift" where erosion has cut deep into the continental crust, and a few samples are plotted in the field of "dissected volcanic arc" where erosion has exposed batholiths beneath volcanic cover (Fig. 6b).

4.2. Altan-Ovoo & Orgioch-Uul Formation

The sandstone of this formation, clast-supported (< 3% of muddy matrix) and poorly-sorted, dominantly includes angular to very angular grains (Figs. 5c and d). It contains quartz, potassium feldspar, plagioclase and rock fragments of rhyolite and tuff with lesser amounts of biotite, muscovite, sphene, zircon, epidote, chrolite, and rock fragments of sandstone, mudstone, andesite and basalt. Hornblend, allanite and pumpellyite are rarely present.

The present sandstone is classified as feldspathic arenite in the Q-R-F diagram (Okada, 1971, Fig. 6a). The most of the samples are plotted in the field of "basement uplift" of the "continental block" in the Qm-F-Lt diagram for the modal framework grain quantification (Fig. 6b).

4.3. "Carboniferous formation"

The sandstone of this formation, rich in muddy matrix and poorly-sorted, dominantly includes rounded

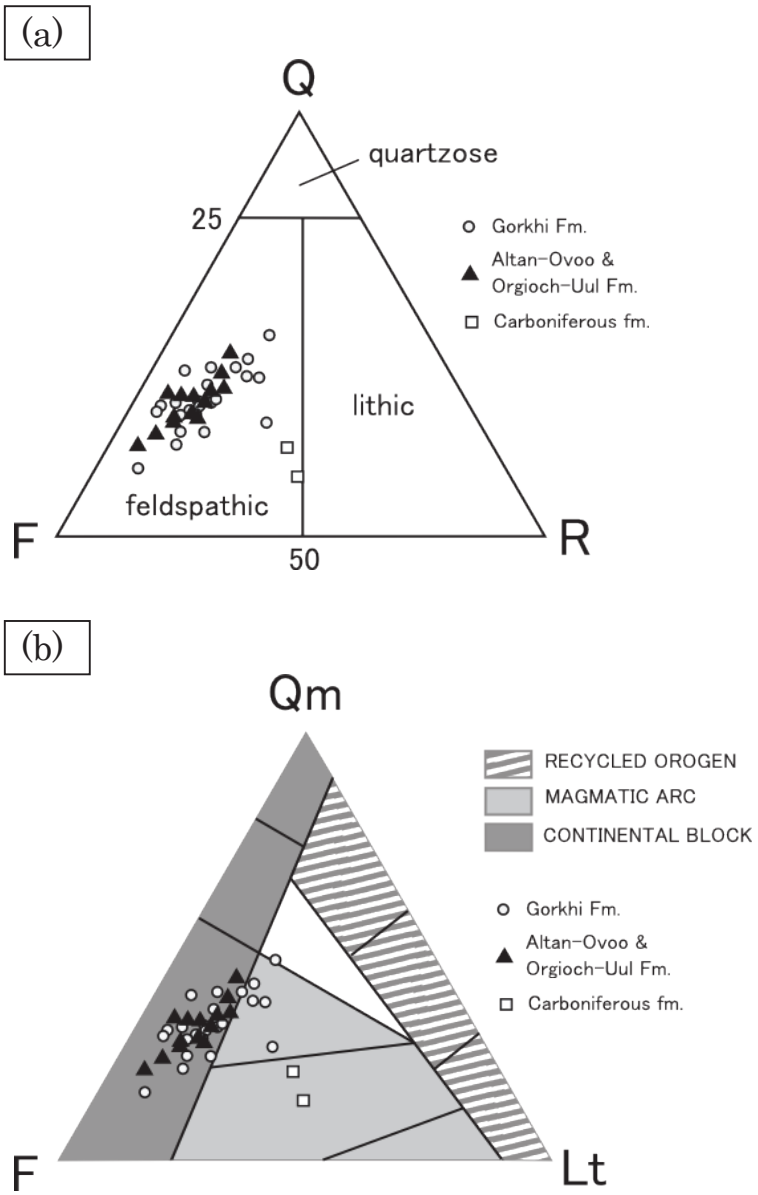

Fig. 6 (a) Petrographic classification and (b) modal framework grain quantification of the sandstones in the Gorkhi and Altan-Ovoo & Orgioch-Uul Formations and Carboniferous formation.

to little angular grains of quartz, potassium feldspar, plagioclase and rock fragments of rhyolite, felsic tuff, andesite and basalt with lesser amounts of biotite, muscovite, chrolite, zircon, and rock fragments of sandstone and mudstone with 20 to 25% of muddy matrix (Figs. 5e and f). Allanite and augite are rarely included in.

It is classified as feldspathic wacke in the Q-R-F diagram (Okada, 1971, Fig. 6a). The Qm-F-Lt diagram suggests that the sandstone is originated from the "transitional volcanic arc" which is intermediate between the dissected and undissected arcs (Fig. 6b).

5. Discussion

The sandstones from the Gorkhi and Altan-Ovoo & Orgioch-Uul Formations are significantly similar and they can not be distinguished to each other in their textures, grain compositions and poor in rock fragments (Figs. 5, 6, and 7, Table.1). Moreover, they are plotted in the same field of the "basement uplift" in the Qm-F-Lt diagram for the modal framework grain quantification (Fig. 6b). In addition, the sandstones

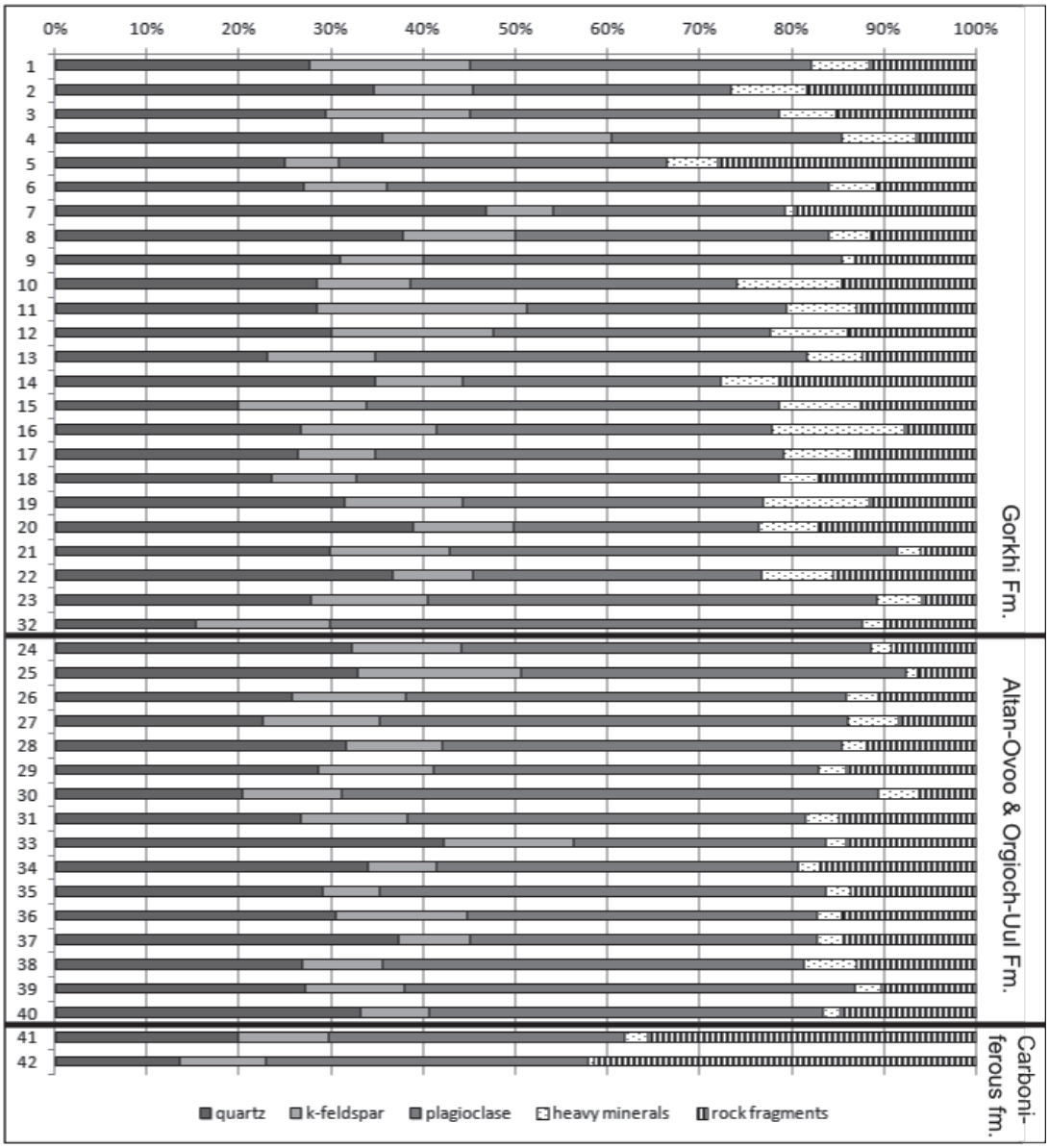

Fig. 7 The proportion of minerals and rock fragments in sandstones of the Gorkhi and Altan-Ovoo & Orgioch-Uul Formations and Carboniferous formation.

Table. 1 Point-count data for the sandstones of the Gorkhi Formation (a), the Altan-Ovoo & Orgioch-Uul Formation (b) and the Carboniferous formation (c).

(a)

rock No	quartz (%)	K-feldspar (%)	plagioclase (%)	heavy minerals (%)	rock fragments (%)
1	27.6	17.4	37.0	6.4	11.6
2	34.6	10.8	28.0	8.2	18.4
3	29.4	15.6	33.6	6.2	15.2
4	35.6	24.8	25.0	8.0	6.6
5	25.0	5.8	35.6	5.6	28.0
6	27.0	9.0	48.0	5.2	10.8
7	46.8	7.2	25.2	1.0	19.8
8	37.8	12.2	34.0	4.6	11.4
9	31.0	9.0	45.4	1.4	13.2
10	28.4	10.2	35.4	11.4	14.6
11	28.4	22.8	28.2	7.6	13.0
12	30.0	17.6	30.0	8.4	14.0
13	23.0	11.8	46.8	6.0	12.4
14	34.8	9.4	28.0	6.4	21.4
15	19.8	14.0	44.8	8.8	12.6
16	26.6	14.8	36.4	14.4	7.8
17	26.4	8.4	44.2	7.8	13.2
18	23.5	9.2	45.8	4.3	17.2
19	31.4	12.8	32.6	11.6	11.6
20	38.8	11.0	26.6	6.4	17.2
21	29.9	13.0	48.5	2.6	6.0
22	36.6	8.8	31.2	7.8	15.6
23	27.8	12.7	48.8	4.9	5.9
32	15.3	14.5	57.8	2.4	10.0

(b)

rock No	quartz (%)	K-feldspar (%)	plagioclase (%)	heavy minerals (%)	rock fragments (%)
24	32.2	11.9	44.5	2.2	9.3
25	32.9	17.6	41.9	1.2	6.4
26	25.8	12.3	47.9	3.4	10.7
27	22.5	12.7	50.8	5.6	8.4
28	31.6	10.3	43.4	2.6	12.0
29	28.6	12.4	41.8	3.1	14.1
30	20.3	10.8	58.2	4.4	6.2
31	26.7	11.5	43.1	3.6	15.0
33	42.3	14.1	27.4	2.2	14.1
34	33.9	7.5	39.3	2.4	16.9
35	29.0	6.2	48.5	2.6	13.7
36	30.5	14.1	38.0	2.8	14.5
37	37.3	7.7	37.7	2.8	14.5
38	26.8	8.7	45.7	5.7	13.0
39	27.1	10.9	48.9	2.8	10.3
40	33.1	7.4	42.8	1.9	14.8

(c)

rock No	quartz (%)	K-feldspar (%)	plagioclase (%)	heavy minerals (%)	rock fragments (%)
41	19.8	9.8	32.2	2.6	35.6
42	13.6	9.2	35	0.6	41.6

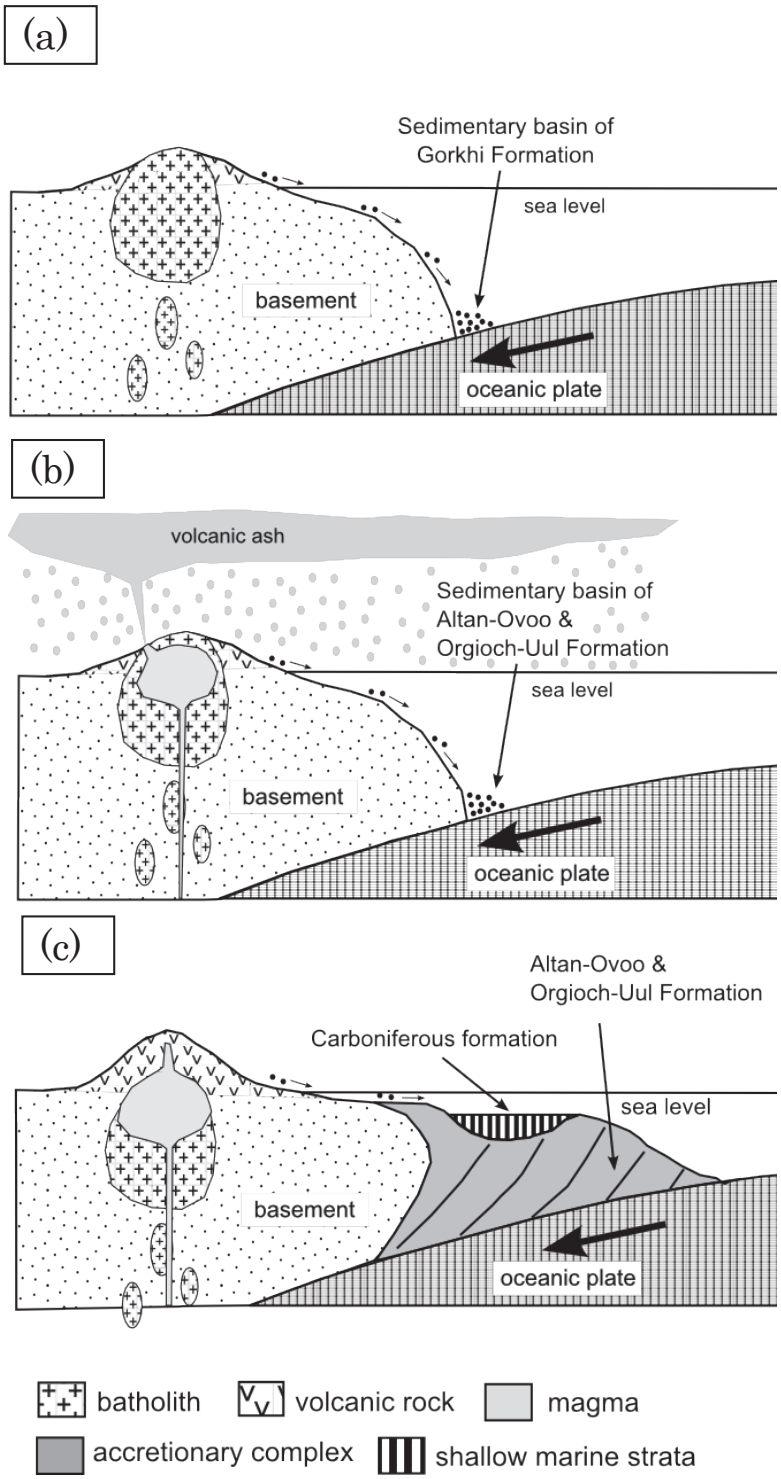

Fig. 8 Schematic illustrations of inferred sedimentary environments of the Gorkhi Formation (a), the Altan-Ovoo & Orgioch-Uul Formation (b) and the Carboniferous formation (c).

of these formations have same age-peaks, ca. 340 to 350 Ma and ca. 400 Ma (Bussien *et al*., 2011; Kelty *et al*., 2008), of detrital zircons. These facts suggest that the sandstones of these formations were originated from the same kinds of source, i.e. continental crust where erosion has cut deep into volcanic cover which related to the subduction of oceanic plate (Figs. 8a and b). However, the lithostratigraphies of these formations are quite different each other. The Gorkhi Formation is dominant in thick massive bedded

Table. 2 Representative point-count data for the sandstones of the Gorkhi and Altan-Ovoo & Orgioch-Uul Formations and the Carboniferous formation. Qtz: quartz, Kfs: potassium feldspar, Fld: plagioclase feldspar, FVo: felsic volcanic rock, And: andesite, Ba: basalt, SS: sandstone, MS: mudstone, Bt: biotite, Chl: chlorite, Ep: epidote, Ms: muscovite, Spn: sphene, Zrn: zircon, Hbl: hornblend

	rock No.	Qtz	Kfs	Pl	Rock fragments					Heavy minerals							matrix	total
					FVo	And	Ba	SS	MS	Bt	Chl	Ep	Ms	Spn	Zrn	Hbl		
Gorkhi Fm.	21	149	65	242	28	0	1	0	1	3	5	0	1	2	1	1	0	499
	23	136	62	239	25	3	0	0	1	3	15	4	0	2	0	0	10	500
	32	75	71	283	43	5	0	0	1	3	6	2	0	0	1	0	10	500
Altan-Ovoo & Orgioch-Uul Fm.	24	160	59	221	45	1	0	0	0	2	5	1	0	3	0	0	3	500
	25	164	88	209	28	1	1	0	2	2	2	1	0	1	0	0	1	500
	26	128	61	238	49	4	0	0	0	4	7	3	1	2	0	0	2	499
	27	112	63	253	38	1	2	0	1	9	6	10	0	3	0	0	1	499
	28	156	51	214	58	1	0	0	0	7	3	0	0	3	0	0	7	500
	29	140	61	205	64	2	1	0	2	4	6	3	0	2	0	0	10	500
	30	101	54	290	29	0	1	0	1	4	2	14	0	2	0	0	2	500
	31	132	57	213	74	0	0	0	0	8	4	3	1	2	0	0	5	499
	33	210	70	136	69	0	0	0	1	5	0	0	1	0	0	5	3	500
	34	168	37	195	81	2	1	0	0	5	4	2	0	1	0	0	4	500
	35	144	31	241	65	2	0	0	1	4	3	4	0	2	0	0	3	500
	36	151	70	188	72	0	0	0	0	4	5	3	0	2	0	0	5	500
	37	185	38	187	71	1	0	0	0	0	2	9	1	2	0	0	4	500
	38	132	43	225	62	1	1	0	0	9	5	7	2	5	0	0	7	499
	39	134	54	242	50	0	1	0	0	3	2	8	0	1	0	0	5	500
	40	161	36	208	71	0	0	0	1	2	4	1	0	2	0	0	14	500
Carboniferous fm.	41	99	49	161	127	12	36	2	1	6	5	1	2	1	0	1	122	625
	42	68	46	175	123	24	57	3	1	2	0	0	0	0	1	0	114	614

sandstone, on the other hands the Altan-Ovoo & Orgioch-Uul Formation is largely occupied by mudstone-rich strata with felsic tuff intercalations (Takeuchi *et al*., 2013). Although it is difficult to make an accurate discussion because there is no information about the age of their sedimentation, this fact may show that these formations had been formed at different places, or formed in different ages each other.

The poorness of the volcanic rock fragments in the Altan-Ovoo & Orgioch-Uul Formation suggest that less volcanic rocks had been exposed at the provenance area to provide it into the sedimentary basin (Fig. 8b, Tables 1 and 2). The volcanism evidenced by the felsic tuff intercalations in the Altan-Ovoo & Orgioch-Uul Formation at the provenance area was likely enough immature which could not provide much volcanic rock fragments (Fig. 8b).

The "Carboniferous formation" yielding brachiopod fossils unconformably overlies the Altan-Ovoo & Orgioch-Uul Formation. It indicates that the Altan-Ovoo & Orgioch-Uul Formation had already been exposed when the "Carboniferous formation" was formed (Fig.8c). The sandstone of the "Carboniferous formation" is rich in volcanic rock fragments (Fig.7, Table.3). The modal framework grain quantification by Qm-F-Lt diagram suggests that the sandstone of this formation is originated from the "transitional arc". It strongly indicates that the volcanic activity had developed to supply volcanic rock fragments into the sedimentary basin of the "Carboniferous formation" (Fig. 8c).

Acknowledgements

We wish to thank the all staffs and students at the Mongolian University of Science and Technology involving our field research for their helpful support. Special thank goes to Dr. Sersmaa Gonchigdorj for arrangement of our study. This work was supported by Grant in Aid for scientific research by the Ito Kagaku Shinko-kai and the Japan Society for the Promotion of Science (No. 20403013), Grant in Aid for JSPS Fellowship (No. 02087), and the Socho-Sairyo-Keihi of the Nagoya University, Japan.

References

Bussien, D., Gombojav, N., Winkler, W. and Quadt, A. (2011) The Mongol-Okhotsk Belt in Mongolia — An appraisal of the geodynamic development by the study of sandstone provenance and detrital zircons. *Tectonophysics*, **510**, 132-150.

Dickinson, W.R, Beard, L.S., Brakenridge, G.R, Erjavec, J.L., Ferguson, R.C., Inman, K.F. (1983) Provenance of North American Phanerozoic sandstones in relation to tectonic setting. *Geological Society of America Bulletin*, **94(2)**, 222–35.

Enkin, R.J., Yang, Z.Y., Chen, Y., Courtillot, V. (1992) Paleomagnetic constraints on the geodynamic history of China from the Permian to the present. *Journal of Geophysical Research,* **97**, 13, 953-13, 989.

Kelty, T.K., Yin, A., Dash, B., Gehrels, G.E. and Ribeiro, A.E. (2008) Detrital-zircon geochronology of Paleozoic sedimentary rocks in the Hangay—Hentey basin, north-central Mongolia: Implications for the tectonic evolution of the Mongol—Okhotsk Ocean in central Asia. *Tectonophysics*, **451**, 290-311.

Kovalenko, V.I., Yarmolyuk, V.V., Kovach, V.P., Kotov, A.B., Kozakov, I.K., Salnikova, E.B., Larin, A.M. (2004) Isotope provinces, mechanisms of generation and sources of the continental crust in the Central Asian mobile belt: geological and isotopic evidence. *Journal of Asian Earth Sciences*, **23**, 605-627.

Kurihara, T., Tsukada, K., Otoh, S., Kasiwagi, K., Minjin, ch., Dorjsuren, B., Bujinlkham, B., Sersmaa, G., Manchuk, N., Niwa, M., Tokiwa, T., Hikichi, G., Kozuka, T. (2009). Upper Silurian and Devonian pelagic deep-water radiolarian chert from the Khangai-Khentei belt of Central Mongolia: Evidence for Middle Paleozoic subduction-accretion activity in the Central Asian Orogenic Belt. *Journal of Asian Earth Sciences*, **34**, 209-225.

Nakane, Y., Bakht, N., Kurihara, T., Manchuk, N., (2013) Lower Devonian radiolarian chert from the Orgioch Formation at southeast of Ulannbaatar (Gachuunt-Nalaikh), central Mongolia. *Bulletine of the Nagoya University Museum*, No.28, 19-26.

Okada, H. (1971) Classification of Sandstone: Analysis and Proposal. *The Journal of Geology*, **79(5)**, 509-525

Sengöl, A.M.C., Natal'in, B.A. and Burtman, V.S. (1993 Evolution of the Altaid tectonic collage and Palaeozoic crustal growth in Eurasia. *Nature*, **364**, 299-307.

Takeuchi, M., Tsukada, K., Suzuki, T., Nakane, Y., Sersmaa, G., Manchuk, N., Kondo, T., Matsuzawa, N., Bacht, N., Khishigsuren, S., Onon, G., Katsurada, Y., Hashimoto, M., Yamasaki, S., Matsumoto, A., Oyu-Erdene, B., Bulgantsetseg, M., Kundyz, S., Enkhchimeg, L., Ganzorig, R., Myagmarsuren, G., Jamiyandagva, O., Molomjamts, M. (2013) Stratigraphy and geological structure of the Paleozoic system around Ulaanbaatar, Mongolia. *Bulletine of the Nagoya University Museum*, No.28, 1-18.

Tomurtogoo, O., Byamba, J., Badarch, G., Minjin, Ch., Orolmaa, D.,Khosbayar, P. and Chuluun, D. (Eds.) (1998) *Geologic map of Mongolia, Scale 1:1,000,000 and summary*. Mineral Resources Authority of Mongolia, Ulaanbaatar.

Tomurtogoo, O. (2003) Tectonic Map of Mongolia at the scale of 1:1,000,000, and Tectonics of Mongolia (Brief explanatory notes to Tectonic of Mongolia at the scale of 1:1,000,000). Mineral Resources Authority of Mongolia, Ulaanbaatar.

Zorin, Yu.A., Belichenko, V.G., Turutanov, E.Kh., Kozhevnikov, V.M., Rushentsev, S.V., Dergunov, A.B., Filippova, I.B., Tomurtogoo, O., Arvisbaatar, N., Bayasgalan, Ts., Biambaa, Ch. And Khosbayar, P. (1993) The South Siberia-Central Mongolia transect. *Tectonophysics*, **225**, 361-378.

（2012 年 10 月 15 日受付，2012 年 12 月 25 日受理）