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Stratigraphy and geological structure of the Paleozoic system around Ulaanbaatar, Mongolia

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Abstract

Recent mapping study in the Ulaanbaatar area has revealed that the geology around Ulaanbaatar previously reported should be revised in regard to stratigraphy and geological structure. Here, the new division of strata and geological structure are presented.

Detailed field mapping with careful observation of sedimentary structures such as grading, loadcast, cross lamination, channel structure, and so on which indicate stratigraphic top have been carried out. The results show that many parts of strata were overturned and the geological structure is characterized with overturned folds with south vergence. In particular, the Paleozoic system is newly divided into two accretionary complexes (Altan-Ovoo & Orgioch-Uul Formation and Gorkhi Formation) and a shallow marine formation. Most of the previous shallow marine Carboniferous system is replaced by the two accretionary complexes and the shallow marine Carboniferous system which occurs with fossils indicating shallow sea environment only distributed in narrow area between two faults, although the latter has been regarded as extensively distributed around Ulaanbaatar. The geology suggests that the shallow marine sediments overlie the accretionary complex (Altan-Ovoo & Orgioch-Uul Formation), unconformably.

The accretionary complexes are classified with quite different from the stratigraphy observed in clastic rocks. The Gorkhi Formation is composed of chert, siliceous shale and clastic rocks dominating massive and thick-bedded sandstone in ascending order. The Altan-Ovoo & Orgioch-Uul Formation consists of basalt, chert, siliceous shale and clastic rocks dominating thick- to thin-bedded sandstone and mudstone in ascending order.

Furthermore, it is found out that the previous Gorkhi Formation in the northwest area and the previous Carboniferous system in the central south area are regarded as weakly metamorphosed and strongly deformed equivalents to the Altan-Ovoo & Orgioch-Uul Formation. Geological structure of these strata represents south vergence such as north-dipping thrust and fold-axial plane. The fact strongly suggests that north-directing subduction formed these geological structures.

Introduction

The Central Asian Orogenic Belt (CAOB) is an orogenic belt that developed between the Eastern European, Siberian, Tarim and North China blocks associated with subduction, magmatism, accretion and collision. The tectonic interpretation for constituents in the CAOB can be improved by recent detailed studies of stratigraphy, petrology, structural geology and geochronology. Badarch *et al.* (2002) summarized geology of whole Mongolia and described geotectonic division. Within the unit of the geotectonic division, the Hangay-Hentey basin is an important key unit with regard to the end stage of geological evolution of the CAOB. The tectonic interpretation of the Hangay-Hentey basin is however still controversial. Several major hypotheses have been proposed, including an oroclinal rotation model (Sengör *et al.*, 1993), a model involving collision followed by oroclinal bending (Zorin *et al.*, 1993), a back-arc basin model (Badarch *et al.*, 2002), a two-subductions model between island-arc system in the south and continental-margin arc in the north (Kelty *et al.*, 2008; Bussien *et al.*, 2011).

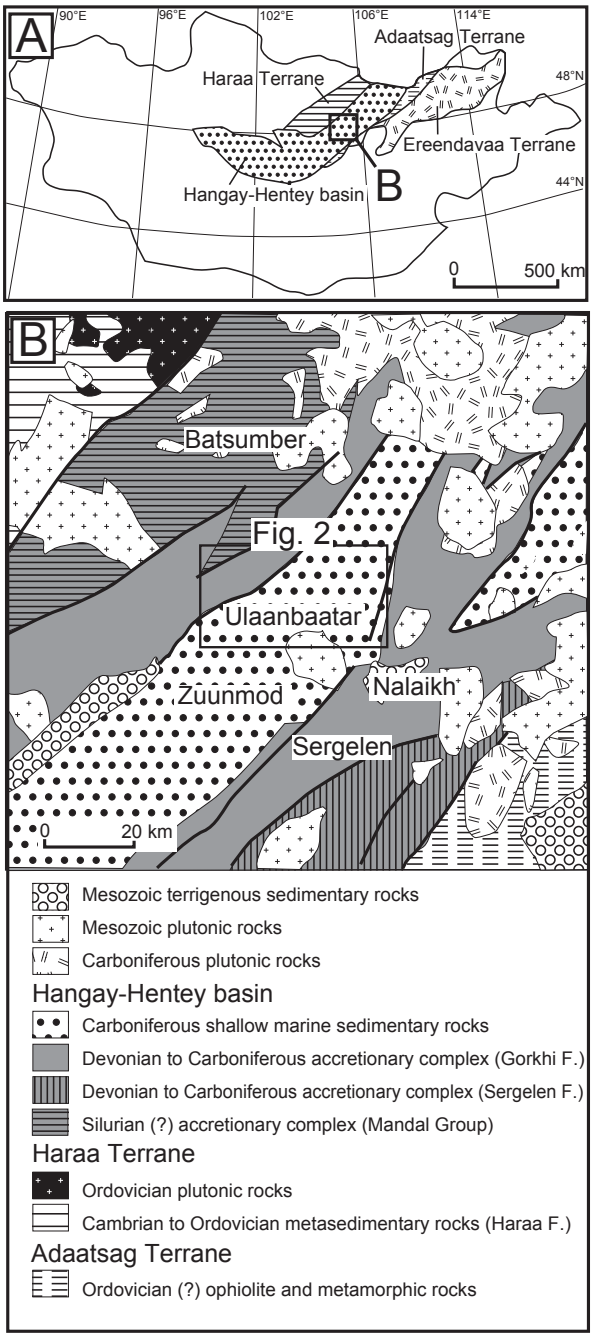

Fig. 1 **(A)** Distribution of the Hangay-Hentey basin based on Badarch *et al.* (2002).
(B) Simplified geological map around Ulaanbaatar area (modified from Tomurtogoo *et al.*, 1998).

Geology around Ulaanbaatar is divided into the Haraa Terrane which consists of Cambrian to Lower Ordovician metasedimentary rocks originated from back-arc or fore-arc basin, the Hangay-Hentey basin and the Adaatsag Terrane which consists of metasedimentary rocks with ophiolite (Badarch *et al.*, 2002). The Hangay-Hentey basin is subdivided into the Silurian Mandal Group (Tomurtogoo *et al.*, 1998), the Lower Devonian Sergelen Formation, the Middle-Upper Devonian Gorkhi Formation, the Lower Carboniferous Altan-Ovoo Formation and the Lower-Upper Carboniferous Orgioch-Uul Formation (Minjin *et al.*, 2006) (Fig. 1). Kurihara *et al.* (2009) reported Upper Silurian to Upper Devonian radiolarian fossils from chert and tectonic stacking structure basalt-chert and chert-turbidite successions. They interpreted the Sergelen and Gorkhi Formations as a Early Carboniferous accretionary complex comprising of Upper Silurian to Upper Devonian pelagic rocks and Early Carboniferous turbidite. On the other hand, they proposed the Orgioch-Uul and Altan-Ovoo Formations as Early Carboniferous (Serpukhovian in Visean) shallow marine strata.

However, the stratigraphic relationship between the accretionary complex and the shallow marine strata, stratigraphy of the shallow marine strata and their geological structures are obscured. It is therefore

important to understand these facts on discussion of tectonic evolution of the CAOB. Especially, geological structure can make a direction of subduction clear, and which has formed the accretionary complex of the Hangay-Hentey basin. We also examined stratigraphy and geological structure of the Gorkhi, Orgioch-Uul and Altan-Ovoo Formations.

Geological outline

The study area is located around Ulaanbaatar, extends 40 km east-west and 25 km north-south and belongs the Hangay-Hentey basin (Badarch *et al.*, 2002) (Fig. 1). This study reports stratigraphy, geological structure and distribution of the shallow marine strata and accretionary complex, and which are quite different from the geology previous reported.

Basement units in this area are composed of two formations with different stratigraphy (Figs. 2–5). One is the Gorkhi Formation (Kurihara *et al.*, 2009) abundant in sandstone, and the other is the Altan-Ovoo & Orgioch-Uul Formation abundant in sandstone and mudstone. Here, "the Altan-Ovoo & Orgioch-Uul Formation" is used because this study clarified that the geological structure of the previous Altan-Ovoo and Orgioch-Uul Formations in the study area was quite different from those in previous studies and the strata could not be stratigraphically divided into the two formations, Altan-Ovoo and Orgioch-Uul Formations.

The Gorkhi Formation yields Upper Silurian to Upper Devonian radiolarian fossils from chert (Kurihara *et al.*, 2009). The sandstones of the Gorkhi and Altan-Ovoo & Orgioch-Uul Formations yield detrital zircons with peak U-Pb age distributions of 339 Ma, 340 Ma, 349 Ma (Kelty *et al.*, 2008), 394 Ma and 404 Ma (Bussien *et al.*, 2011), and the clastic rocks are considered as the Devonian and partly Lower Carboniferous.

The shallow marine Carboniferous system is composed of conglomerate and sandstone in the lower part and mudstone with thin sandstone beds. The conglomerate in the lower part yields some kind of fossils such as brachiopods. The strata could not stratigraphically divided because the distribution is limited narrowly along the fault in the northwest area.

Mesozoic Bogd Uul Granite dated as 181±7.7 to 212±10.8 Ma (Tomurtogoo *et al.*, 1998, Khishigsuren, *et al.*, 2013) intrudes into the Altan-Ovoo & Orgioch Formation in the southeast area, and rhyolite, andesite and granite dikes intrude into the Altan-Ovoo & Orgioch-Uul Formation in the northwest area. Granitic dikes with ages 223.5±30.2 and 294.2±51.4 Ma were reported by Khishigsuren *et al.* (2009).

Cover sediments on the basement rocks only outcrop in a small part of the study area. The Cretaceous system (Tomurtogoo *et al.*, 1998) composed of white claystone and conglomerate is exposed in the northwest of central Ulaanbaatar.

Talus deposits mainly consisting of gravel bed are distributed along rivers and in the valley with slightly higher surface than recent river bed.

Fault with large displacement cuts these strata except talus deposits from northwest to southeast. There are many folds with northeast-directing fold axis in the both accretionary complexes. The folds represent south vergence (Fig. 3).

Altan-Ovoo & Orgioch-Uul Formation

Difinition: Minjin *et al.* (2006) divided the strata in this area into the Lower Carboniferous Altan-Ovoo Formation and the Lower-Upper Carboniferous Orgioch-Uul Formation. However, "the Altan-Ovoo & Orgioch-Uul Formation" is used because it was found out that the strata could not divided into the two formations in lithostratigraphy. The Altan-Ovoo & Orgioch-Uul Formation includes basalt and chert in addition with sandstone and mudstone in the north and west of Ulaanbaatar.

Type locality: Mountain range with Ondor tolgoi (section C-D in Fig. 2).

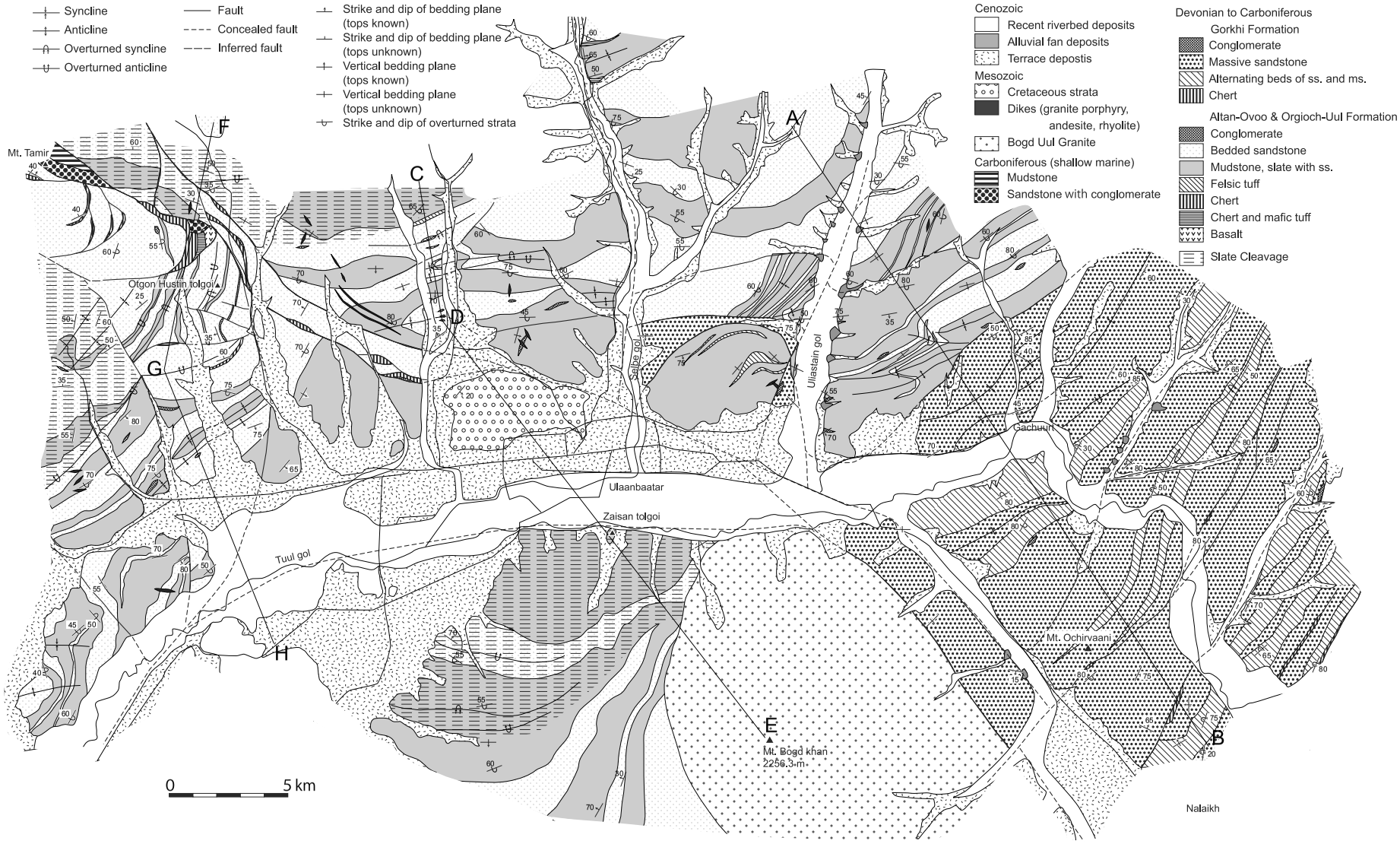

Fig. 2 Geological map around Ulaanbaatar. See Fig. 1 for the location of the mapped area. The base map is complied from Google (2012).

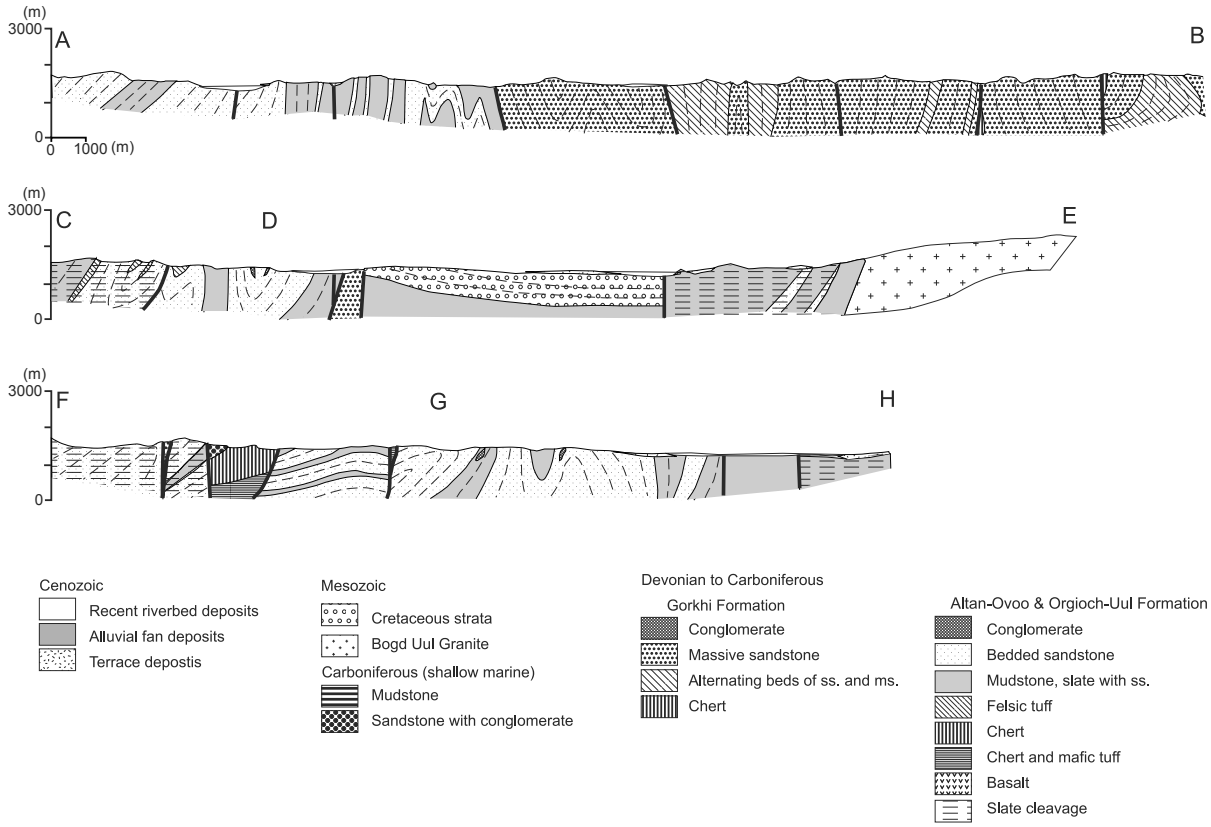

Fig. 3 Geological cross section.
The routes of cross sections are shown in Fig. 2.

Fig. 4 Index map showing the route of columnar section.

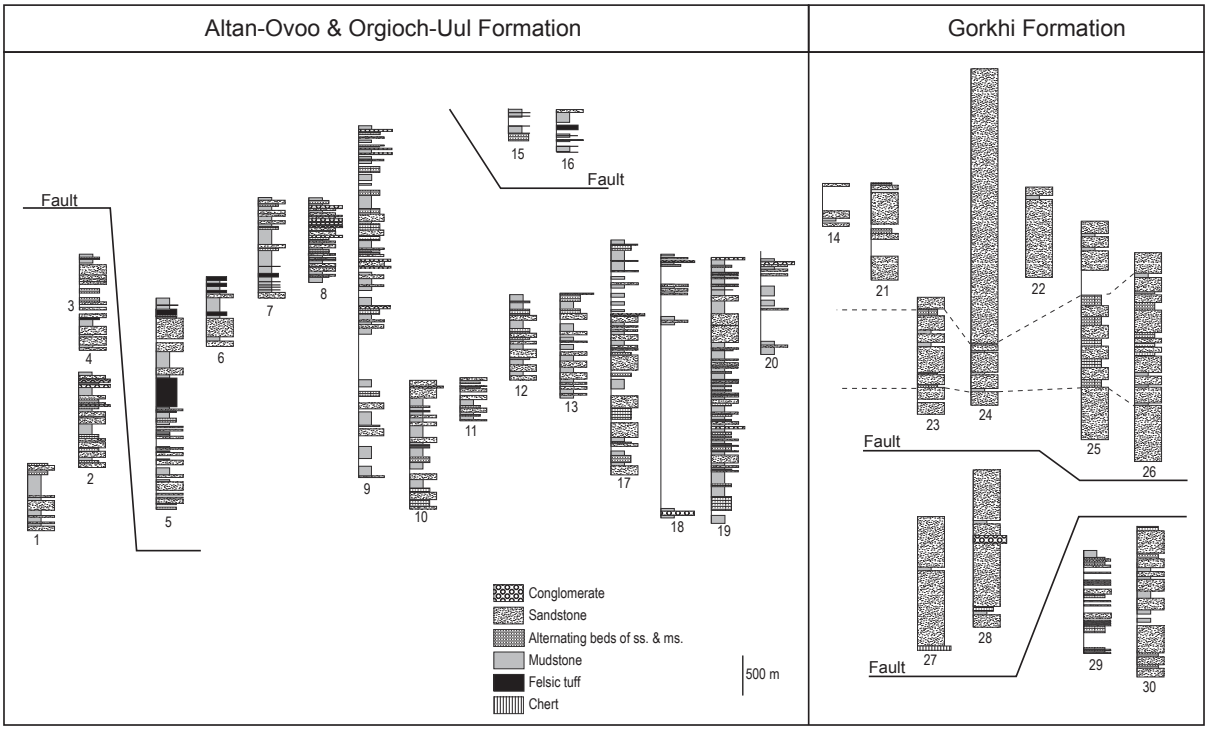

Fig. 5 Columnar sections measured within the Altan-Ovoo & Orgioch-Uul and the Gorkhi Formations. See Fig. 4 for location details. Correlations indicated by broken lines are based on the correlation of key lithostratigraphic boundaries.

Stratigraphy and lithology: The basal bed of the Altan-Ovoo & Orgioch-Uul Formation consists of pillow and massive lavas of basalt. It is overlaid by alternating beds of reddish purple mafic tuff, green basalt and mudstone, alternating beds of red chert and mudstone, siliceous mudstone and clastic rocks in ascending order (Fig. 6).

The pillow basalt (Fig. 7A) contains white limestone (Fig. 7B), dolostone (Fig. 7C) and red jasper among pillows. Some basalt shows amygdule. White chert lamination in red chert is characteristic (Fig. 7D), and rare bedded chert intercalates with siliceous mudstone. Black MnO2 is observed in red chert (Fig. 7E). There is no outcrop where upper contact with chert is recognized, but mudstone overlies on siliceous mudstone in the northwesternmost area.

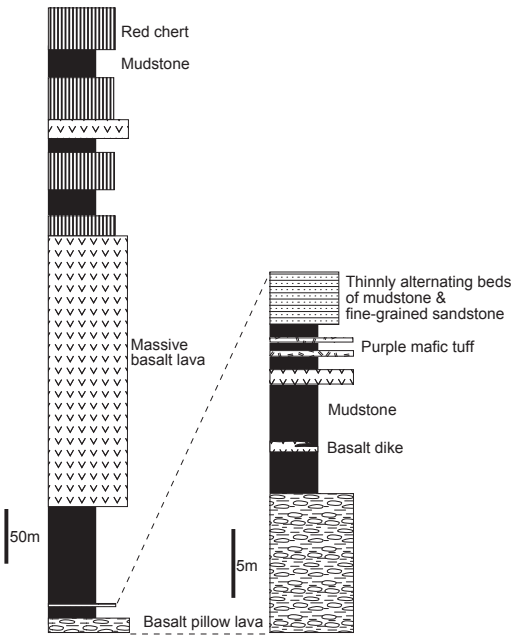

Fig. 6 Columnar section of pelagic sequence (left) and detail lithology (right). See Fig. 4 for the location.

Lithology of clastic rocks highly varies laterally and upward (Fig. 5). Sandstone-dominant turbidites are intercalated with mudstone (Fig. 8). The turbidites are composed of sandstone beds of several millimeters to several meters thick, and show grading and load cast (Fig. 9A-C). Parallel and cross laminations are characteristic in some medium- to thick-bedded sandstones. Some massive sandstone and conglomerate scour underlying strata as channel (Fig. 10). The bottom of channel-fill sandstone contains many mudstone intraclasts. Loadcast is rarely observed at the base of sandstone bed.

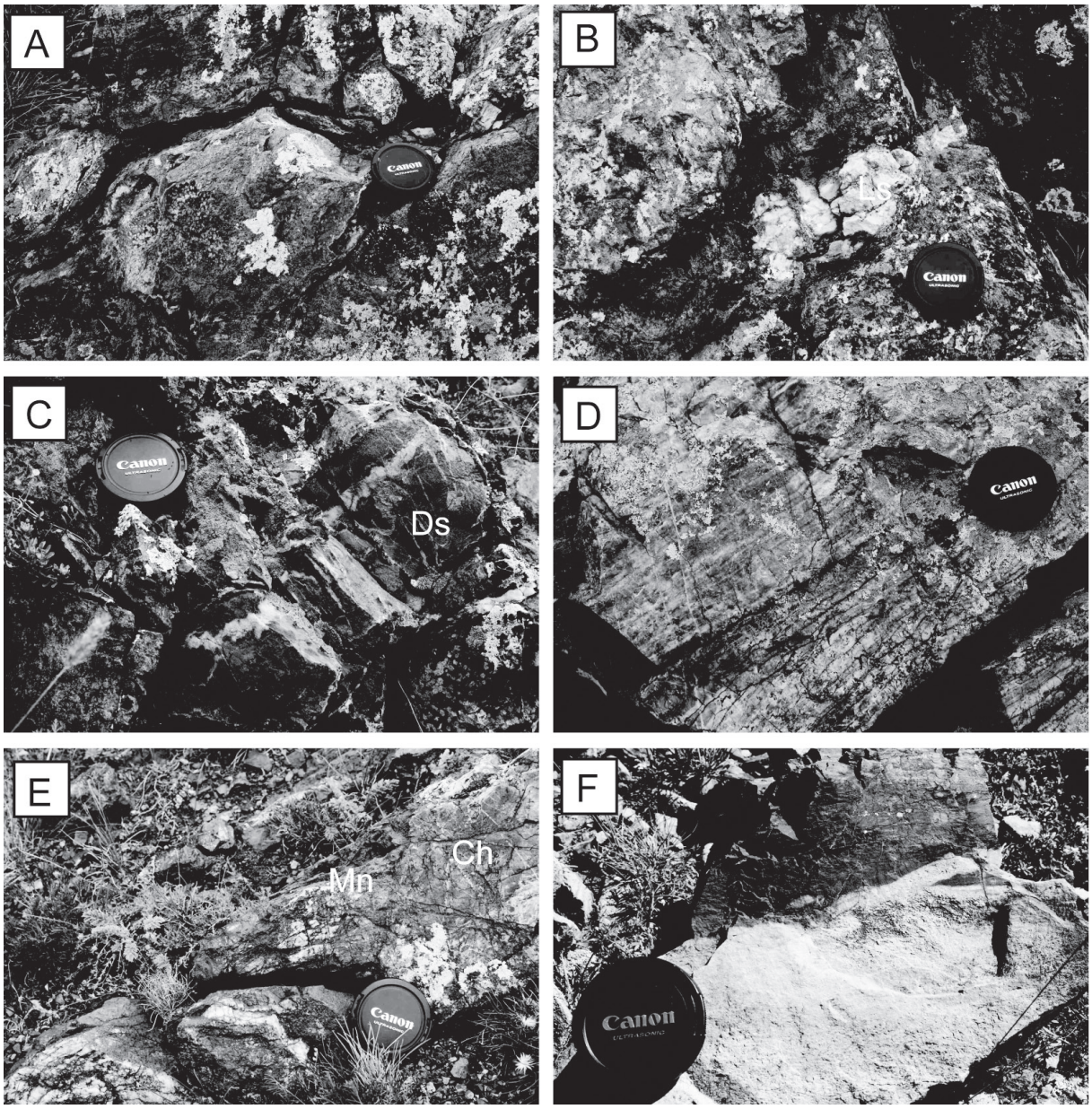

Fig. 7 Lithologies of basalt and chert of the Altan-Ovoo & Orgioch-Uul Formation. See Fig. 4 for the location of following outcrops.
(**A**) Pillow lava of basalt. (**B**) Limestone lens (LS) within pillow basalt. (**C**) Red dolostone lens (Ds) within pillow basalt. (**D**) Red bedded chert. (**E**) Black MnO_2 (Mn) with red chert (Ch). (**F**) Red tuff (upper) and white sandstone (lower).

Conglomerate is matrix-supported and varies in grainsize from granule to boulder. Clasts larger than granule are well-rounded (Fig. 9C, D). The clasts consist of granite, quartzite, crystalline schist, acidic volcanic rocks, sandstone and mudstone (Minjin *et al.*, 2006). Adachi *et al.* (2007) reported granophyre cobble also.

Felsic tuff yields in mudstone-dominant horizon. It yields as alternating beds of medium-grained white tuff and fine-grained pale green tuff (Fig. 9E). These beds are several-centimeters thick. Red or green tuff is rarely intercalated with sandstone (Figs. 7E, 11). The tuff is partly siliceous like chert.

The Altan-Ovoo & Orgioch-Uul Formation in the north of fault which is situated in the northwest to southeast area is suffered from higher metamorphism and deformation toward the northwest. Slate cleavage (Fig. 9F) is characteristic in mudstone of the northwest area. Outlines of clastic particles in sandstone of

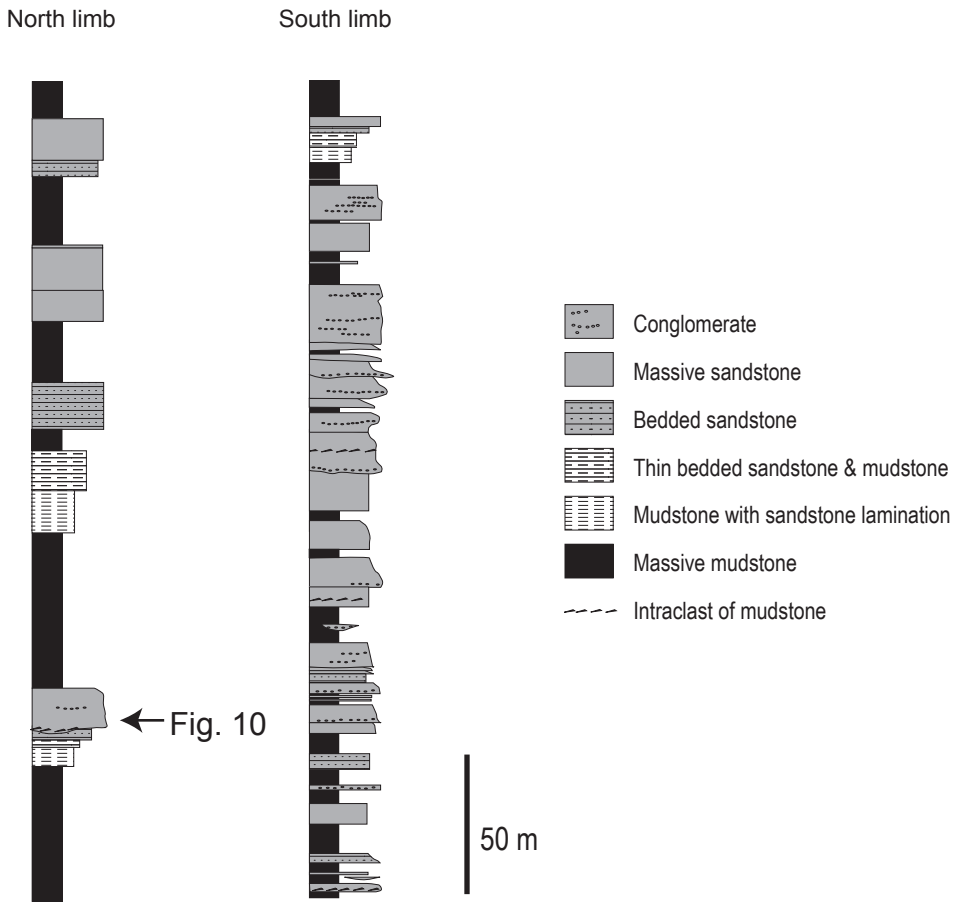

Fig. 8 Detail columnar section of the conglomeratic facies in the Altan-Ovoo & Orgioch-Uul Formation.
The two columnar sections were measured from the north limb (left, upper part of columnar section 7 in Fig. 5) and the south limb (right, columnar section 8 in Fig. 5) of fold. Lithology largely varies laterally and vertically because of channel facies.

the northwest area are not distinct because of recrystallization with metamorphism. Basalt has been metamorphosed into greenschist in the northwest area, and which is composed of metamorphic minerals such as actinolite, epidote, titanite and chlorite (Fig. 12). Chert has also been recrystallized into quartz schist yielding elongated quartz and stilpnomelane. The Altan-Ovoo & Orgioch-Uul Formation in the south of the fault is also suffered from higher deformation toward northwest and in Zaisan tolgoi south of central Ulaanbaatar where slate cleavage is developed typically (Fig. 2).

Thickness of strata: 4500 m in clastic rocks and 500 m in chert and basalt.

Age: No fossil has been reported. 404 Ma of peak U-Pb age from detrital zircons in sandstones of the Altan-Ovoo & Orgioch-Uul Formation were reported in the western area and its extension (Bussien *et al.*, 2011). Then this formation is the Devonian or the younger at least. Kelty *et al.* (2008) reported 349 Ma of peak U-Pb age from detrital zircon in the extension in the western area. It indicates that the clastic rocks are Lower Carboniferous or the younger.

Gorkhi Formation

Definition: This strata has not been defined formally, but Minjin *et al.* (2006) assigned the Gorkhi Formation an accretionary complex composed of sandstone, mudstone, siliceous shale, radiolarian chert, basalt, dolerite, mafic tuff, gabbro and crystalline limestone around Ulaanbaatar.

Stratigraphy and lithology: In the Zuunmond ca. 30 km south of Ulaanbaatar, the Gorkhi Formation is typically distributed (Kurihara *et al.*, 2009). The oceanic plate stratigraphy which consists of ca. 30 m

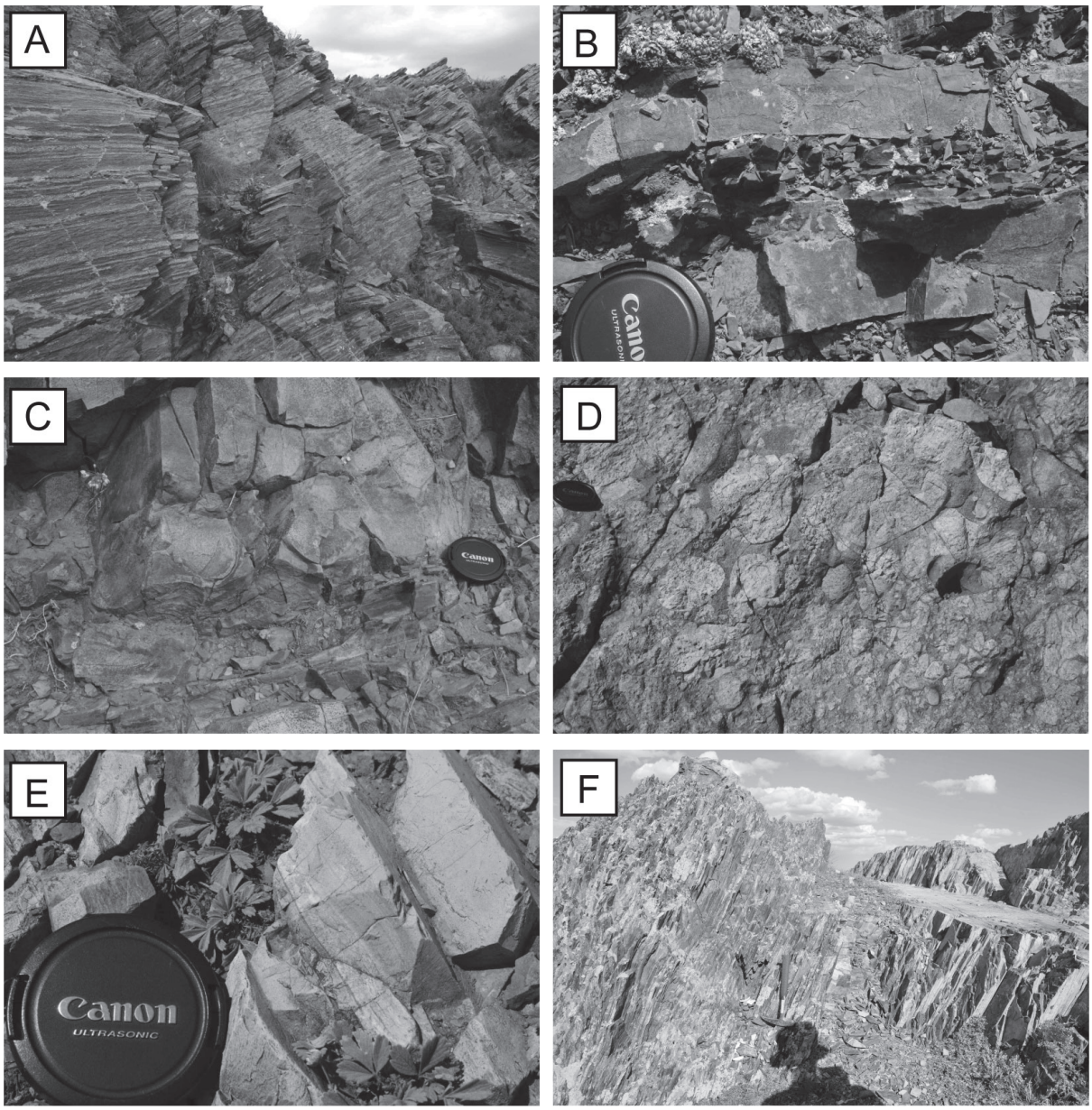

Fig. 9 Lithology and sedimentary structures in the Altan-Ovoo & Orgioch-Uul Formation. See Fig. 4 for the location. (**A**) Very thin-bedded turbidite. (**B**) Thin turbidite with grading. Stratigraphic top is upper on the picture. (**C**) Load cast at the base of sandstone bed (upper). (**D**) Cobble conglomerate. (**E**) Felsic tuff. Fine-grained part is pale green and medium-grained part is white. (F) Mudstone with strong slate cleavage.

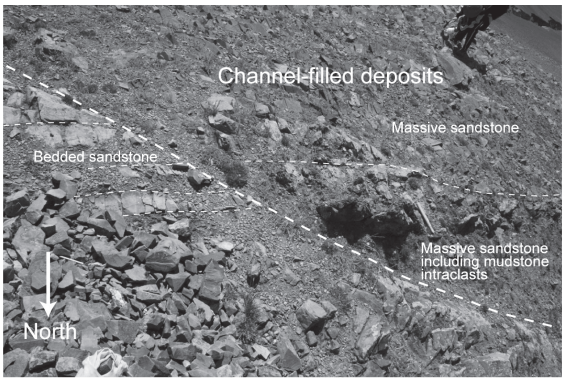

Fig. 10 Channel-filled sediment in the Altan-Ovoo & Orgioch-Uul Formation. See Fig. 8 for the location.

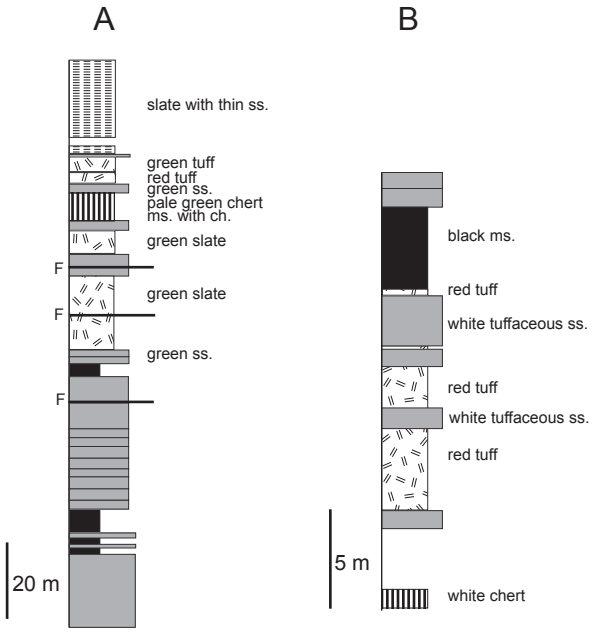

Fig. 11 Columnar sections showing occurrence of tuffaceous beds in the Altan-Ovoo & Orgioch-Uul Formation. See Fig. 4 for the location.

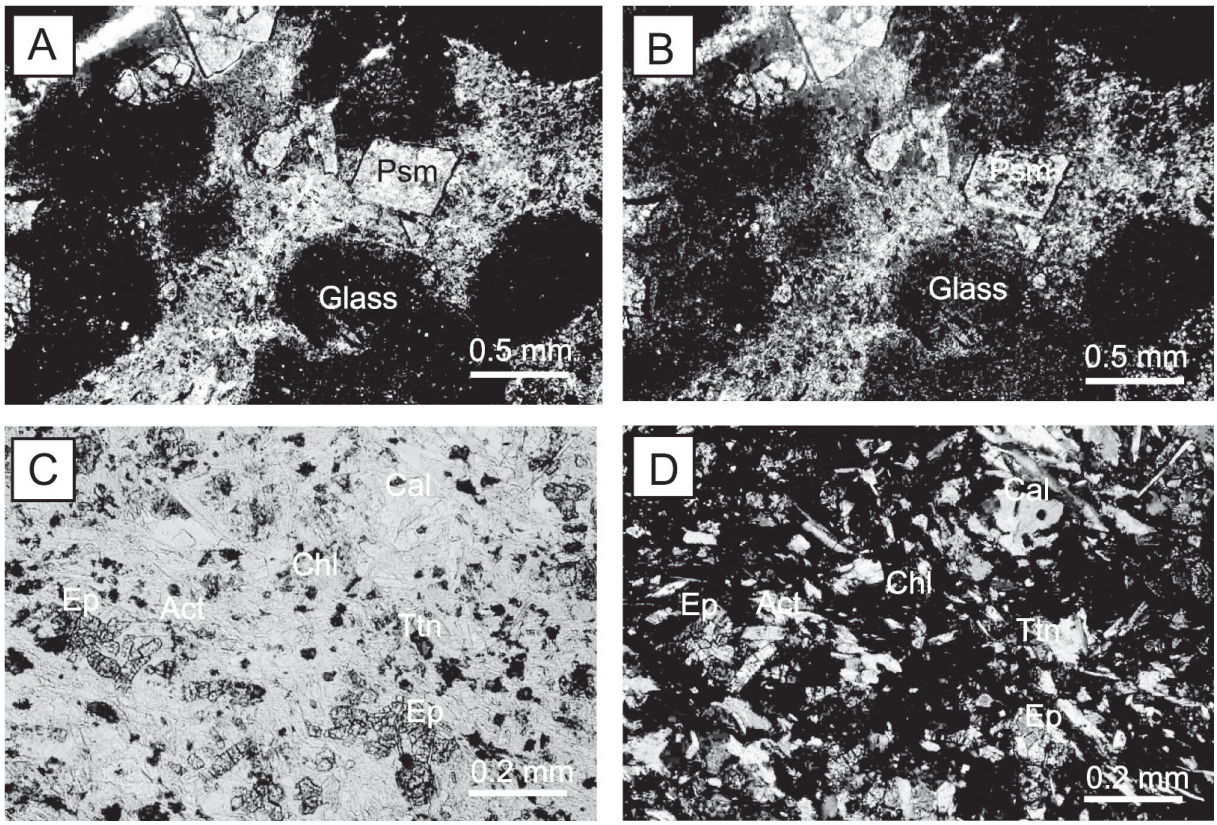

Fig. 12 Photomicrographs of thin sections of mafic rocks.
(**A**) Glassy basalt of the Altan-Ovoo & Orgioch-Uul Formation (Fig. 7A). Pyroxene pseudomorph (Psm) has been replaced by epidote. Plane-polarized light. (**B**) Same as (A). Cross-polarized light. (**C**) Weakly metamorphosed basalt of the Altan-Ovoo & Orgioch-Uul Formation (Fig. 7C), which is composed of epidote (Ep), actinolite (Act), chlorite (Chl), titanite (Ttn) and calcite (Cal). Plane-polarized light. (**D**) Same as (C). Cross-polarized light.

thick of basalt lava, hyaloclastite and tuff, ca. 5 m thick of alternating beds of chert and dark red tuff, ca. 100 m thick of chert, 10 to 20 m thick of siliceous shale and clastic rocks showing upward-thickening and coarsening was reported by Kurihara *et al.* (2009). The thickness of the clastic rocks is highly thicker than pelagic rocks judging from their geological map.

In this study area, there are abundant clastic rocks and a few chert and siliceous shale. Total thickness is unknown because the Gorkhi Formation cut by several faults. In Gachuurt area, the Gorkhi Formaiton consists only of clastic rocks, massive and thick-bedded sandstones in the upper and lower parts and alternating beds of sandstone and mudstone and thick-bedded sandstone in the middle part (Fig. 5). In the east of Ochirvaani Uul, siliceous shale overlies chert (Fig. 13A) and underlies sandstone (columner section 27 in Fig. 5). The siliceous shale contains sand-sized clastic grains. The Gorkhi Formation in the easternmost area is dominant in mudstone and thin-bedded turbidite (Fig. 5).

Massive sandstone is medium- to coarse-grained and poor sedimentary structure. Thick-bedded sandstone is also medium- to coarse-grained, and shows parallel and cross laminations and grading (Fig. 13B). Thin-bedded turbidite is ca. 10 cm thick of a bed, shows grading from medium- or fine-grained sandstone to mudstone and parallel and cross laminations. In the route of columnar section 28 (Figs. 4, 5), the upper sandstone includes red chert block (Fig. 13C), ca. 100 cm × 30 cm, and medium-grained clastic chert fragments. There is conglomerate dominated with sandstone clasts in the easternmost unit (Fig. 13D).

Fossil and age: Upper Silurian to Upper Devonian radiolarian and conodont fossils were reported from chert in the Zuunmod area (Kurihara *et al.*, 2009). Nakane *et al.* (2013) reported Devonian radiolarian fossils from chert in this formation of the east of Ochirvaani uul. The deposition of the sandstone is

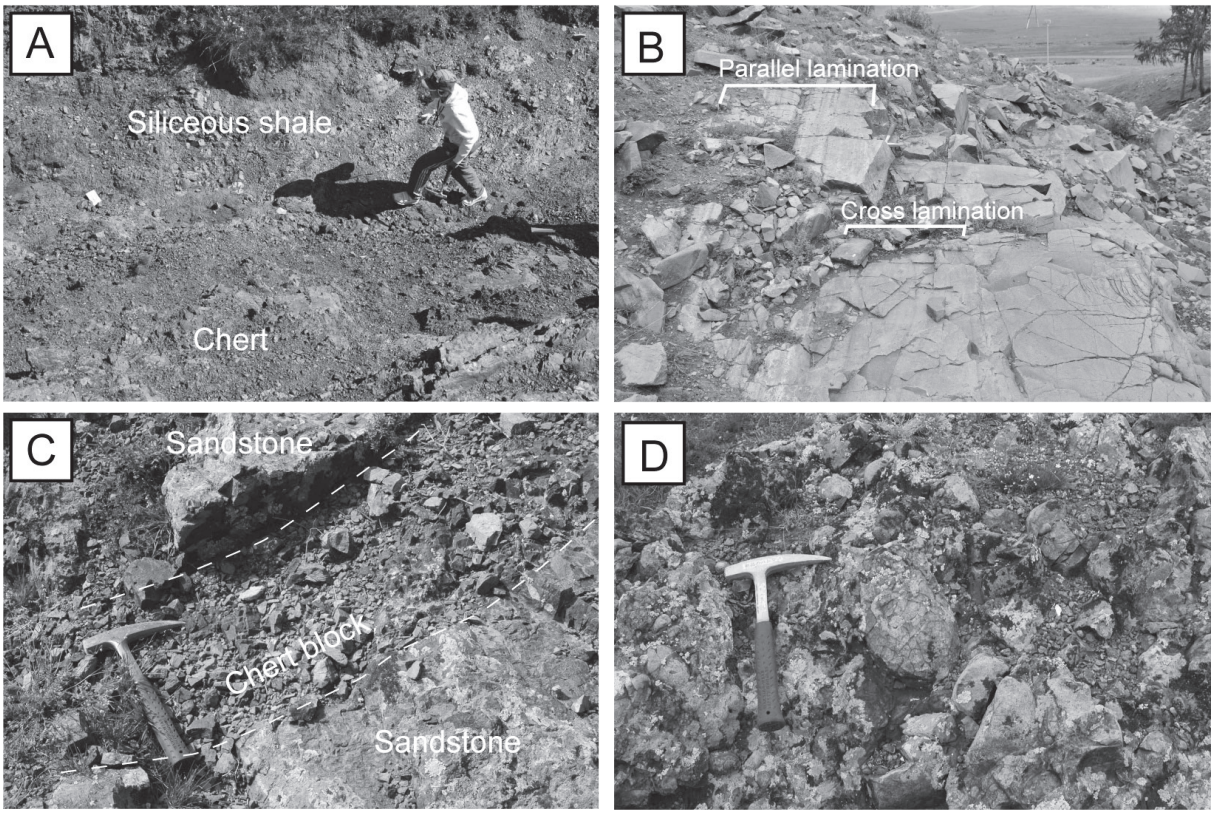

Fig. 13 Lithology of the Gorkhi Formation. See Fig. 4 for the location.
(**A**) Siliceous shale overlying red bedded chert. (**B**) Thick bedded sandstone with parallel and cross laminations. Stratigraphic top is left on the picture. (**C**) Sandstone including exotic red chert blocks. The chert block is sedimentary but not tectonic, because the sandstone contains also chert fragments. (**D**) Conglomerate containing many sandstone cobbles.

after Mississippian of Early Carboniferous because 394 Ma of peak U-Pb age from detrital zircon in the sandstones in the southwest of Gachuurt (Bussien *et al.*, 2011) and 339 Ma and 340 Ma near Nalaikh (Kelty *et al.*, 2008) were reported.

Shallow marine Carboniferous system (undivided)

This formation is composed of sandstone and conglomerate in the lower part and mainly of mudstone with conglomerate and sandstone in the upper part which is distributed along the fault in the northwest area (Figs. 2, 14, 15).

Type locality: Mountain range east of Mt. Tamir, 25 km northwest of central Ulaanbaatar.

Stratigraphy and lithology: We found new locality of sandstone and conglomerate containing brachiopods fossils (mostly impression fossil) in mountain range at 2.5 km north of Otogon Hustin Tolgoi which is 8 km southeast of the type locality. The conglomerate is considered to overlie basalt and chert of the Altan-Ovoo & Orgioch-Uul Formation unconformably, although outcrop of unconformity is not observed. The upper part of this formation in the area is composed of mudstone with thin sandstone beds.

In the type locality, this formation is composed of bedded fine- to medium-grained sandstone containing brachiopods, gastropods and bryozoan fossils (Fig. 15D-G). Twenty-five meters thick of mudstone overlying the sandstone intercalates sandstone beds with ill-sorted granule to pebble conglomerate (Fig. 14). The conglomerate bed yields fossils above mentioned. It is inferred that the fossils were transported and deposited together with gravels, because the fossils occur randomly oriented in a bed. The upper part of the strata consists mainly of mudstone with medium- to thin-bedded and fine- to medium-grained sandstone beds (Fig. 15A).

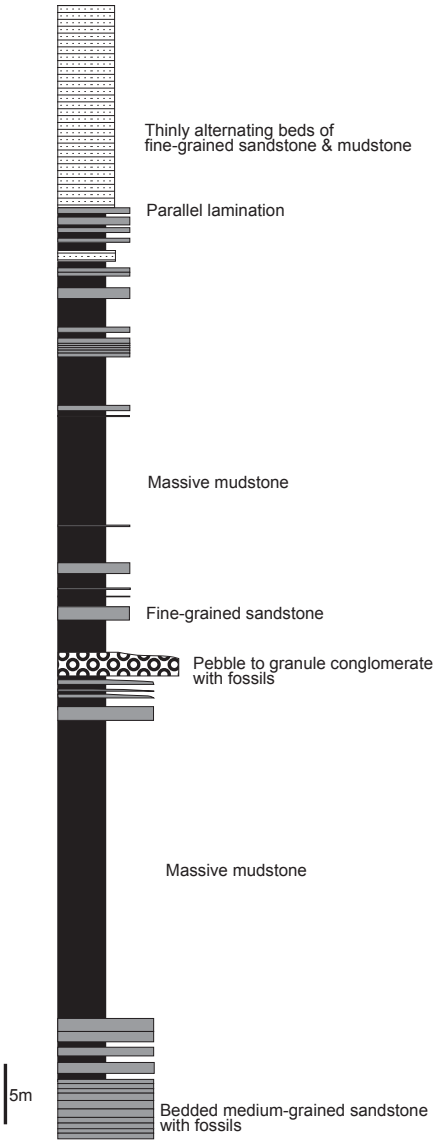

Fig. 14 Columnar section of the shallow marine Carboniferous system. See Fig. 4 for the location.

Fossil and age: Minjin *et al.* (2006) described that the aleurosandstone horizon of the Altan-Ovoo Formation contains Lower Carboniferous, Visean bryozoans: *Fenestella invulgata* Shishiva, *Lyrocladia mariae* Shishova, *Sulcoretepora mergensis* Nekhoroshev (Donakova, 1961, not listed within Minjin et al's references). Furthermore, they also reported that Popeko (1961) found brachiopods: *Spirifer dublicicostus* Mart, and Radchenko (1961) collected ferns: *Asterocalamites* sp. and *Zalesskyodendron* sp. (both literatures do not listed within Minjin et al's references), although fossil localities are unknown. We also found some fossils at two localities mentioned above, with the details to be reported in a separate paper.

Geological structure

We have carried out detailed field mapping with careful observation of sedimentary structures such as grading, loadcast, cross lamination, channel structure, and so on, which indicate stratigraphic top. It was recognized that many parts of the strata in this area were overturned (Fig. 17A) and the geological structure is characterized with overturned folds with south vergence (Figs. 2, 3). The axial planes of folds

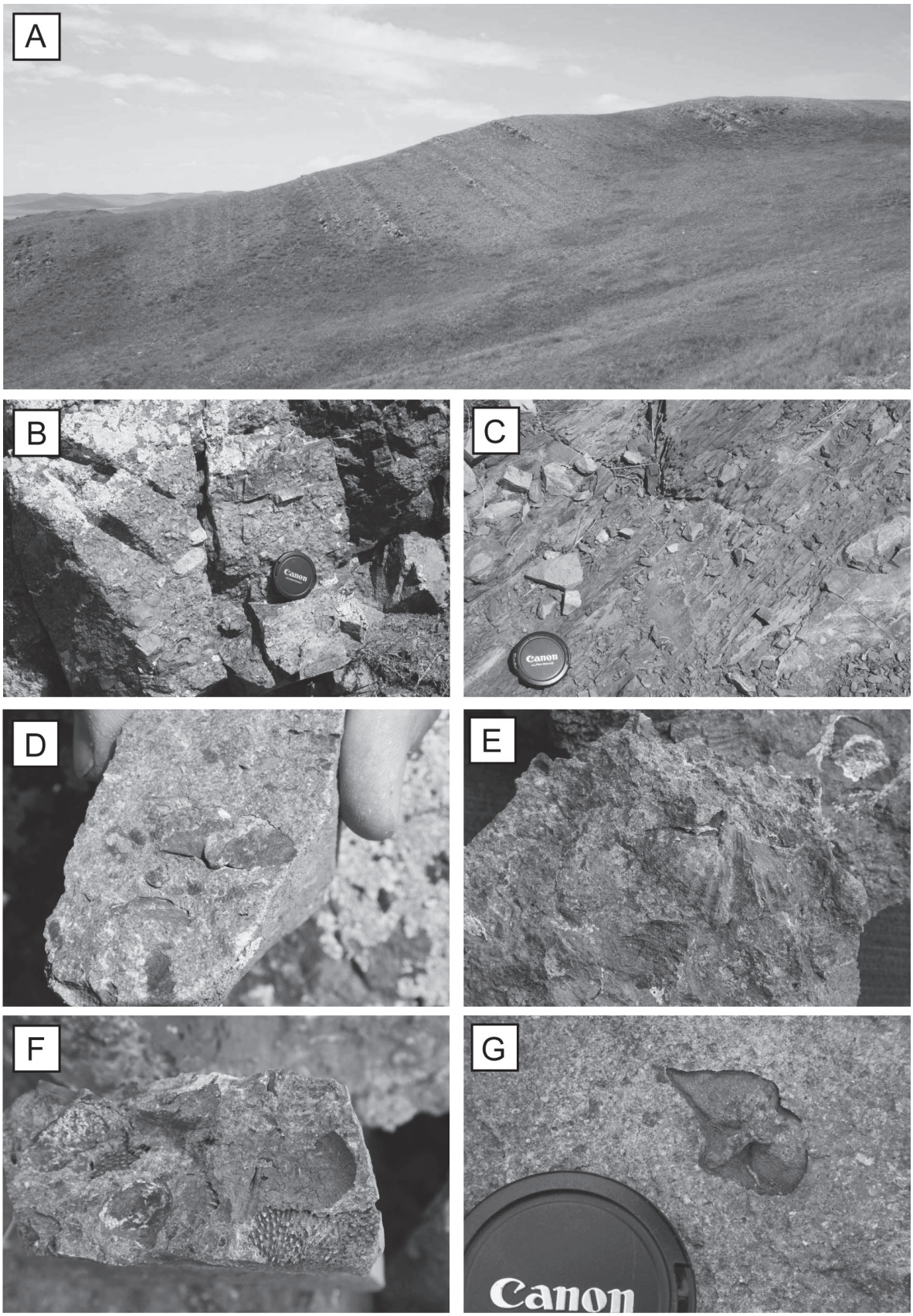

Fig. 15 Lithology of the shallow marine Carboniferous system. See Fig. 4 for the location.
(**A**) Alternating beds of sandstone and mudstone of the upper part. (**B**) Ill-sorted conglomerate. (**C**) Mudstone. (**D**) Impression fossil of brachiopod. (**E**) Impression fossil of brachiopod. (**F**) Impression fossils of bryozoan. (**G**) Impression fossil of brachiopod.

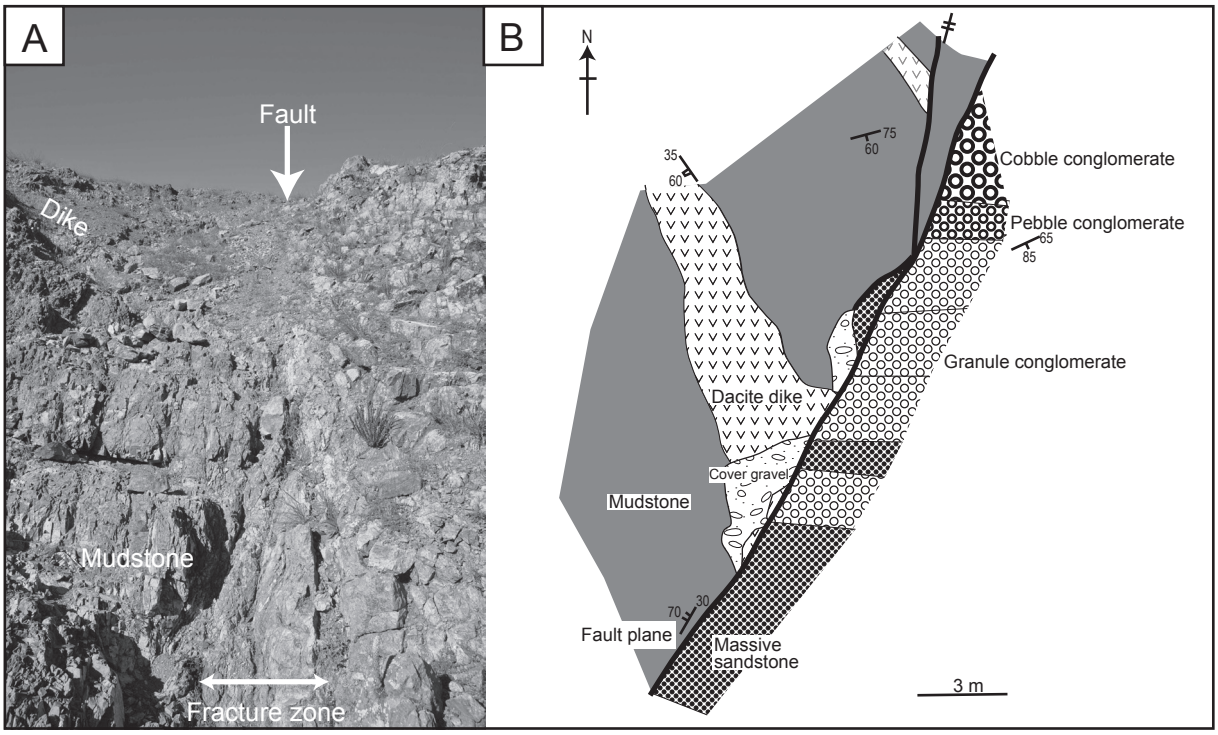

Fig. 16 Occurrence of fault cutting dacite dike (**A**) and its sketch. See Fig. 4 for the location.

strike northeast and dip 20 to 80° to the north, and they are overturned or recumbent fold. The wave length is ca. 5 km.

The Gorkhi Formation is in fault contact with the Altan-Ovoo & Orgioch-Uul Foramtion. The fault trending to the northeast cuts the fold structures within the both formations. This type of fault is developed in the Gorkhi Formation and active before the formation of northeast-trending fault.

There is a major fault distributed from the northwest to the southeast in this area. This fault diverges in the northwest, and exotic blocks of massive sandstone, chert, basalt and limestone occur between the diverging faults. The fault seems to have moved after Cretaceous time, because the Cretaceous system in the northwest of central Ulaanbaatar which is bounded by the fault dips 20°to the south.

There are east- and north-ternding faults around the Uliastain gol, which cut fold structure. The north-trending fault is associated with 80 cm wide of cataclasite zone and cut dacite dike (Fig. 16). It is oblique fault because slicken line plunges at 25°to the north. Fault plane of east-trending fault dips to the north, on which vertical slicken lines are recognized (Fig. 17A, B). Fault gouge and breccia with the fault have been consolidated. Direction of displacement of the fault is unknown. There several quartz veins several meters long and 10 cm wide around the faults (Fig. 17C, D).

North-trending fault in the west area is associated with several meters wide of fracture zone and there are small faults in 20 m wide. The fracture part was weathered into white material (Fig. 17E).

Discussion

Shallow marine Carboniferous system has been previously divided into the sandstone-dominant Altan-Ovoo Formation and the mudstone and sandstone-dominant Orgioch-Uul Formation only with lithology. Bedding plane of stara in the northern-half of this area dips to the north. Then the Carboniferous system has been considered as monocline and that the Orgioch-Uul Formation overlies the Altan-Ovoo Formation (Magic project, 1998, Tomurtogoo *et al.*, 1998) (Fig. 18).

We carefully observed sedimentary structures and judged stratigraphic top on outcrops to understand stratigraphy and geological structure. Consequently, it is found out that many parts of strata were overturned

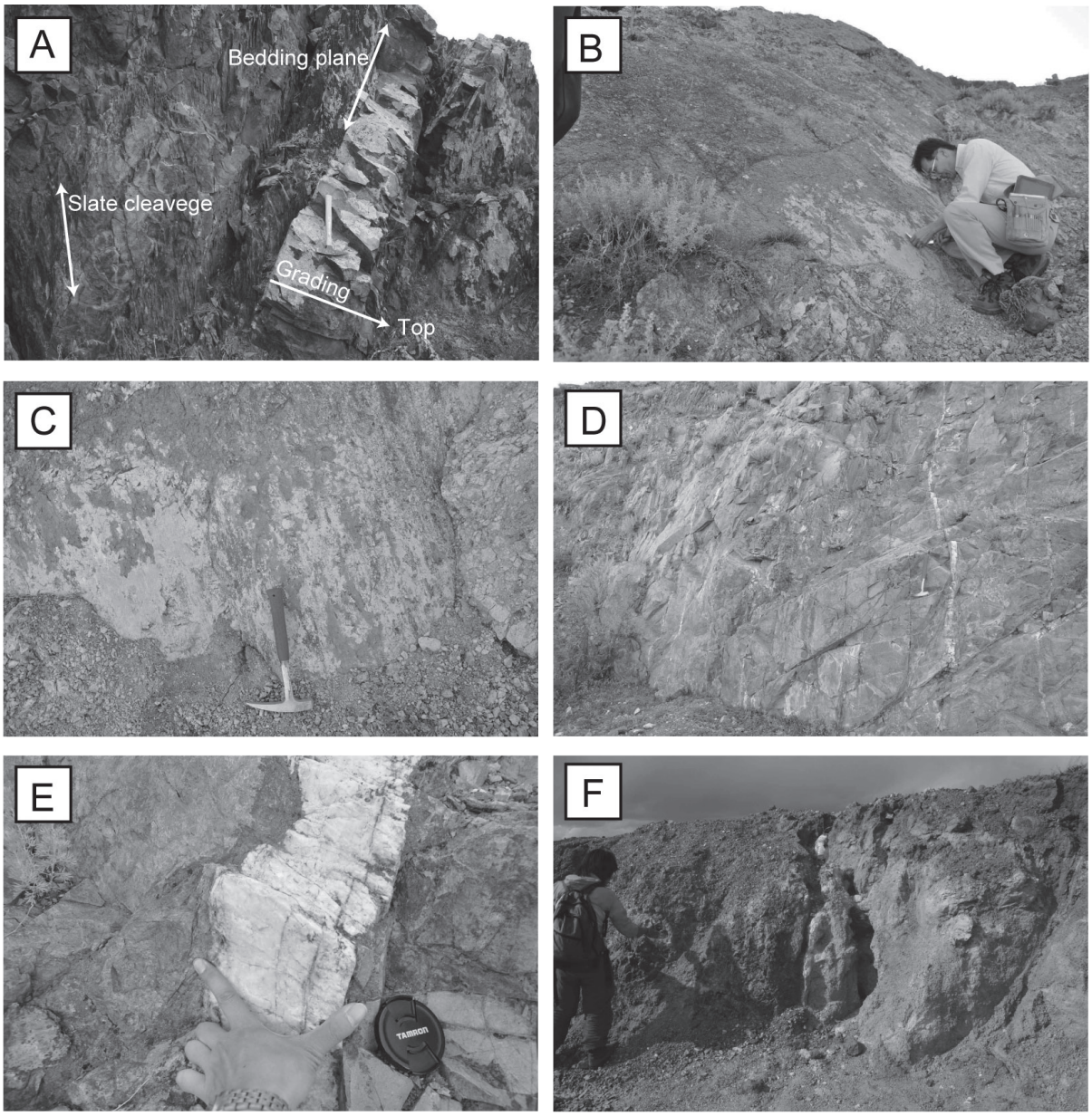

Fig. 17 Deformation structures. See Fig. 4 for the location.
(**A**) Overturned sandstone and mudstone (slate) with vertical slate cleavage. Stratigraphic top is right on the picture. The sandstone bed grades into mudstone (slate) to right. (**B**) Outcrop of dip-slip fault. Fault plane is visible. (**C**) Close up of (B). Vertical slicken line on the fault plane. (**D**) Quartz vein in sandstone. (**E**) Close up of (D). (**F**) Outcrop of fault with wide fracture zone.

and that the geological structure is occupied by overturned folds which are quite different structure. Although the younger Altan-Ovoo Formation is distributed in the north and the older Orgioch-Uul Formation is distributed in the south in the geological map (Magic project, 1998; Tomurtogoo *et al.*, 1998), previously, the stratigraphy itself should be reexamined because of the new facts by our observation.

Distribution of chert seems to have been regarded as important to decide the previous boundary between the Gorkhi Formation and the shallow marine Carboniferous system (Magic project, 1998; Tomurtogoo *et al.*, 1998). This study made this problem clear and found two obviously different stratigraphies (Fig. 5). Consequently, two formations are newly defined as the Gorkhi and the Altan-Ovoo & Orgioch-Uul Formations. The Gorkhi Formation in this area is regarded as an accretionary complex because the formation is characterized by an oceanic plate stratigraphy from chert, through siliceous shale to clastic

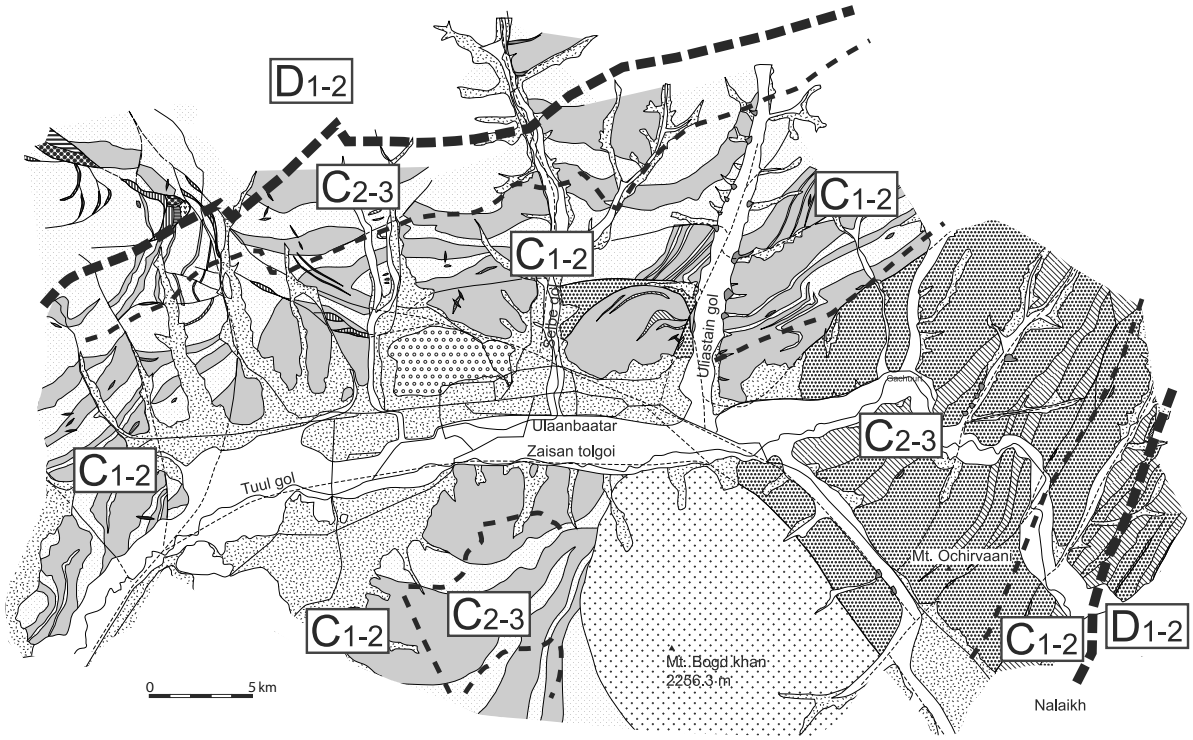

Fig. 18 Comparing of distribution of the geological boundaries between previous map (Tomurtogoo *et al.*, 1998) and this study. $C_{1–2}$, $C_{2–3}$ and $D_{1–2}$ represent the early to middle Carboniferous Altan-Ovoo Formation, the middle to late Carboniferous Orgioch-Uul Formation and the Early to Middle Devonian Gorkhi Formation, respectively. Thick and thin broken lines represent fault and formation boundary, respectively, in the previous map.

rocks in ascending order (Nakane *et al.*, 2013) and the Gorkhi Formation can be correlated with the Gorkhi Formation in the Zuunmod area which is regarded as an accretionary complex (Kurihara *et al.*, 2009). Such strata are distributed extensively to the northwest of Gachuurt. Then the boundary northern end of the Gorkhi Formation should be revised (Fig. 18).

On the other hand, the Altan-Ovoo & Orgioch-Uul Formation shows different stratigraphy from the Gorkhi Formation (Fig. 5), and is characteristic with variable lithological changes towards horizontally and vertically by sandstone and mudstone. It is impossible to divide simply into the Altan-Ovoo and the Orgioch-Uul Formations in lithofacies. The formation is associated with chert and siliceous shale in the northwest area. Furthermore, the Altan-Ovoo & Orgioch-Uul Formation never yields fossils indicating shallow marine environment, even any fossils. So the Altan-Ovoo & Orgioch-Uul Formation is regarded as an accretionary complex. However, it is necessary that the Altan-Ovoo & Orgioch-Uul Formation should be correlated with the Altan-Ovoo and Orgioch-Uul Formations in the type localities because these formations are regarded as shallow marine sediments (Minjin *et al.*, 2006).

The stratigraphy of the Altan-Ovoo & Orgioch-Uul Formation is quite different from one of the Gorkhi Formation. This fact indicates that these formation are deposited originally apart far each other.

In the northwest area of this study, the Devonian system in the northwest and the Carboniferous system in the southeast are illustrated in the geological map (Magic project, 1998; Tomurtogoo *et al.*, 1998) (Fig. 18). However, the previous Devonian system is regarded as the lower part of the Altan-Ovoo & Orgioch-Uul Formation which has been strongly deformed and weakly metamorphosed.

This study revised that the shallow marine Carboniferous system is distributed in narrow area only along the faults in the northwest area, although it has been regarded to be distributed in wide area around Ulaanbaatar, previously (Magic project, 1998; Tomurtogoo *et al.*, 1998; Minjin *et al.*, 2006). It is largely possible to overlie unconformably the Altan-Ovoo & Orgioch-Uul Formation. This suggests that the

Altan-Ovoo & Orgioch-Uul Formation was accreted in the Early Carboniferous time and the shallow marine Carboniferous system unconformably overlaid the Altan-Ovoo & Orgioch-Uul Formation after the Altan-Ovoo & Orgioch-Uul Formation was uplifted to shallow sea environment, and that the shallow marine Carboniferous system fell down between faults with younger faulting. Most of the shallow marine Carboniferous systen might be eroded with uplifting the accretionary complex.

The Altan-Ovoo & Orgioch-Uul Formation and the Gorkhi Formation are occupied with south vergence (Fig. 19). The Gorkhi Formation in the Zuunmod area also shows stacking thrust sheets indicating south vergence (Kurihara *et al.*, 2009). On the other hand, in the upper reaches of the Haraa Gol River north-northwest of Ulaanbaatar, the Haraa and the Mandal Groups also show stacking thrust sheets dipping to the north, i.e., south vergence (Gordienko *et al.*, 2012). Metamorphic and deformation grades in the Altan-Ovoo & Orgioch-Uul Formation increase toward northwest and it is considered that the Altan-Ovoo & Orgioch-Uul Formation is continuous with the neighbor Mandal Group which is composed of similar lithology with the Altan-Ovoo & Orgioch-Uul Formation, i.e., quartz schist with mafic and intermediate metavolcanics, polymictic sandstone and flyschoid sand-siltstone (Gordienko *et al.*, 2012). This means that whole strata in the Hangay-Hentey basin show south vergence and strongly suggests that north-directing subduction formed these geological structures.

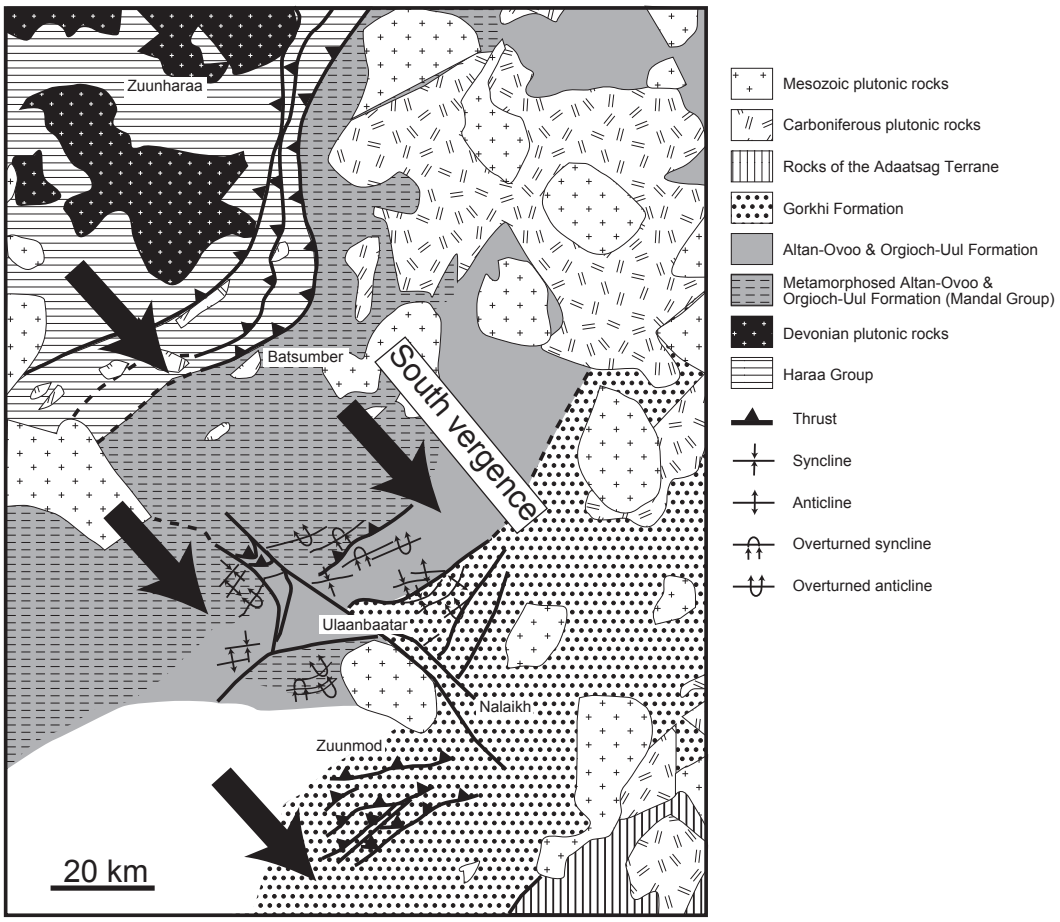

Fig. 19 Map showing geological structure of the Haraa Terrane, the Hangay-Hentey basin and the Adaatsag Terrane. Complied with Tomurtogoo *et al.* (1998), Kurihara *et al.* (2009), Gordienko *et al.* (2012) and this study.

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