# DETRITAL MODES OF THE EAST GOBI BASIN (ONDOR-BOGD AREA) SANDSTONES IN THE SOUTHEASTERN MONGOLIA AND THEIR GEOLOGICAL IMPLICATIONS

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## Introduction

In Mongolia, Jurassic to Cretaceous non-marine sedimentary rocks are widely distributed. Lower Cretaceous deposits overlie coarse-grained Upper Jurassic red beds and are in turn unconformaby overlain by Upper Createaceous deposits. The Upper Cretaceous sediments are subdivided into five stratigraphic units: from the base up, they are the Barun-Bayan, Bayan-Shire, Bayan-Dzag (=Djadokhta), Barun-Goyot and Nemegetu formations (Gradzinski et al., 1977; Martinson et al., 1969; Martison, 1975: Barsbold, 1983: Shuvalov, 1982: Khand, 1987: Jerzykiewicz and Russell, 1991). Jurassic and Cretaceous sediments contain abundant animal fossils including numerous world-famous dinosaurs. Also, the Jurassic and Cretaceous rocks contain important mineral resources such as coal, oil, bituminous shales, gypsum, quartz, fluorite, zeolite, rare metals and gold.

Sandstones of Late Jurassic and Early Cretaceous age of the East Gobi Basin, Ondor-Bogd area are studied for the first time to infer the provenance and tectonic settings of the source areas.

The composition of sandstones can give information about provenance, weathering, sediment transport and tectonic setting. In Mongolia, very few studies of sedimentary rocks have been carried out for sedimentological and petrological studies. The present study is intended to increase our information on the Mongolian late Mesozoic by studying sedimentary rocks. The East Gobi Basin (Fig. 1) was chosen for this study because this basin contains petroliferous sediments whose petrological characteristics are important for further petroleum exploration in the basin. In order to better understand sedimentary deposits and evolution of the East Gobi Basin we studied sandstone compositions of the Late Jurassic to Early Cretaceous in age.

The results of this petrographic study provide new information about the characteristics and provenance of non-marine Upper Jurassic, Lower Cretaceous and Upper Cretaceous sedimentary rocks of the Ondor-Bogd area, the East Gobi Basin which is located in southernmost Mongolia. Also, this study would provide information to understand characteristics of potential reservoir and source rocks in the basin.

### *Geologic setting of the East- Gobi basin*

Mesozoic sedimentary basins of China have been studied for a long time and these in Eastern China are recognized as intracontinental rift basins (Watson et al., 1987; Okada, 2002). Extension occured in the Late Jurassic to Early Cretaceous in north-central China, (e.g., Erlian Basin; Lin et al., 1997), younging eastward to the Tertiary offshore basins (e.g., Bohai Bay Basin; Watson et al., 1987). This extensional regime has also been identified in the Tamsag and East Gobi basins of eastern Mongolia (Fig.1). Both basins form large basins that are extended and connected to the Hailar and Erlian basins of China across the national border, respectively (Shuvalov,1975; Traynor and Sladen, 1995; Fig. 1).

Mesozoic stratigraphic succession of Mongolia is subdivided into three sequences, prerift, synrift and postrift sequences, by outcrop and subsurface relationships (Lower to Middle Jurassic - prerift, Upper Jurassic to Lower Cretaceous – synrift, Upper Cretaceous – postrift). The synrift sequence rests unconformably on Paleozoic rocks in many places along the exposed margins of basement uplifts. The prerift sequence reflects sandy braided-stream settings that evolved to meandering-stream flood-plain and lacustrine environments with time (Graham et al., 2001). Fluvial-lacustrine deposits and coaly beds indicate that a humid environment prevailed during deposition of the prerift Mesozoic sequence, which is consistent with the presence of organic-rich Lower to Middle Jurassic strata that are well developed elsewhere in Mongolia and adjacent China (Hendrix et al., 1992, 1996; Graham et al., 1997). Structural and sedimentary data from part of the East Gobi Basin indicate that high- and low-strain extensional regimes were active during the Early Cretaceous in southern Mongolia (Johnson et al., 2001). The timing of extension in Southeast Mongolia is inferred to be related to mantle-plume upwelling and continental rifting (Filippova et al., 1984; Enkhtuvshin, 1999; Kovalenko et al., 1995; Gerel, 1998).

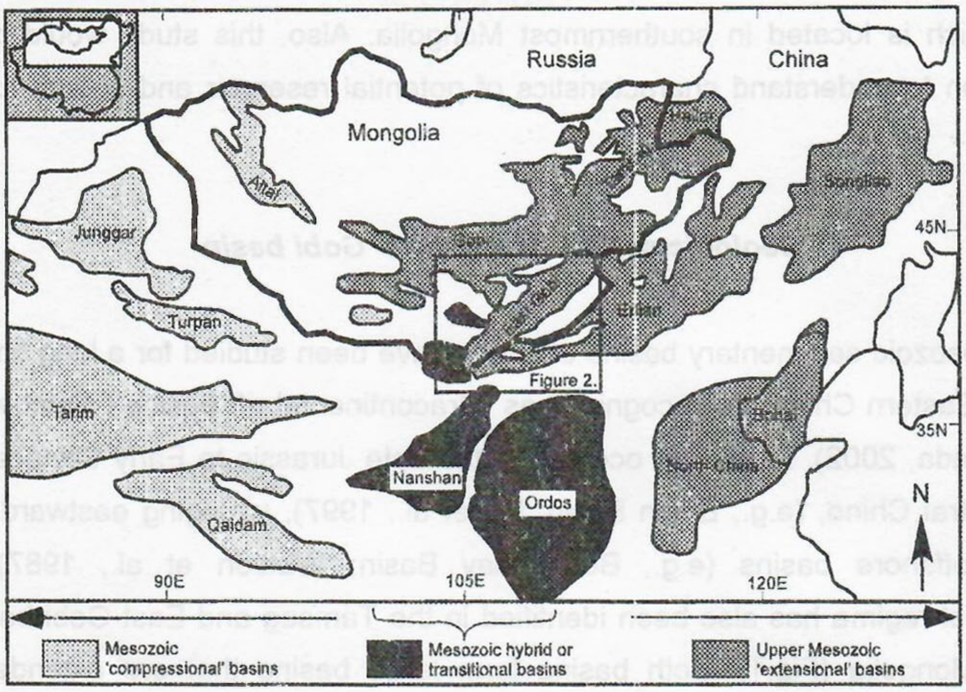


**Figure 1. Mesozoic sedimentary basins of central Asia. Basins are generally divided into western basins formed by contractional tectonics during the Triassic-Jurassic, eastern basins formed during Jurassic-Cretaceous intracontinental rifting, and hybrid or transitional basinswith multiphase, transtensionaland/or transpressional tectonic histories (modified from Waston et al., 1987; Johnson et al., 2001).**

The East Gobi Basin is located in the southeastern part of Mongolia which is a northeast-southwest-oriented elongate basin that includes the petroliferous Unegt, Zuunbayan and Galb Gobi subbasins (Fig. 2). Along its southern margin, the East Gobi Basin is separated from the Erlian Basin in China by an uplifted block of Precambrian-Paleozoic basement rocks (the Toto Shan block of Zonenshain et al., 1971) and by the Zuunbayan fault (Suvorov, 1982 Fig. 2).

During the Paleozoic time Mongolian arcs collided and accreted to the Precambrian North China block and formed crustal thickening, fold and thrust belt and foreland basin (Hendrix et al., 1996; Webb et al., 1999; Johnson et al., 2001) (Fig. 3). Rifting in the East Gobi Basin was initiated in Late Jurassic-Early Cretaceous time; as much as 2-3 km thick nonmarine synrift sediment and volcanic flows filled asymmetric half-grabens and also formed metamorphic core complex. (Hendrix et al., 1996; Webb et al., 1999; Johnson et al., 2001) (Fig. 4a). The sedimentary sequences of synrift portion of the East Gobi basin succession are associated with the high-strain extensional regime of the Yagan Onch Hayrhan core complex (Johnson et al., 2001) (Fig. 2).

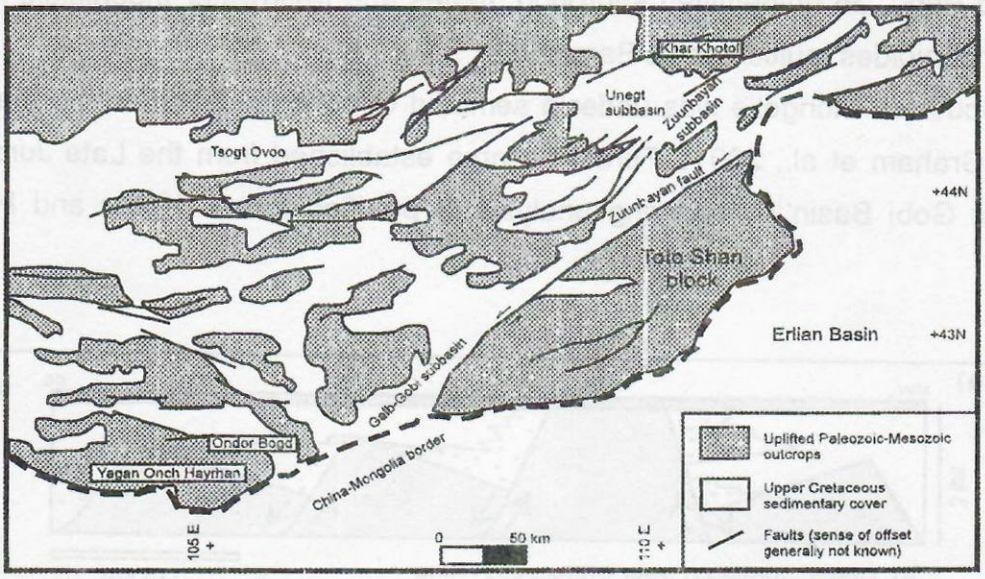


**Figure 2. Generalized structures of the East Gobi Basin. Shaded areas represent uplifted regions with outcrops of Paleozoic-Lower Cretaceous strata separating fault-bounded subbasins (modified from Johnson et al., 2001).**

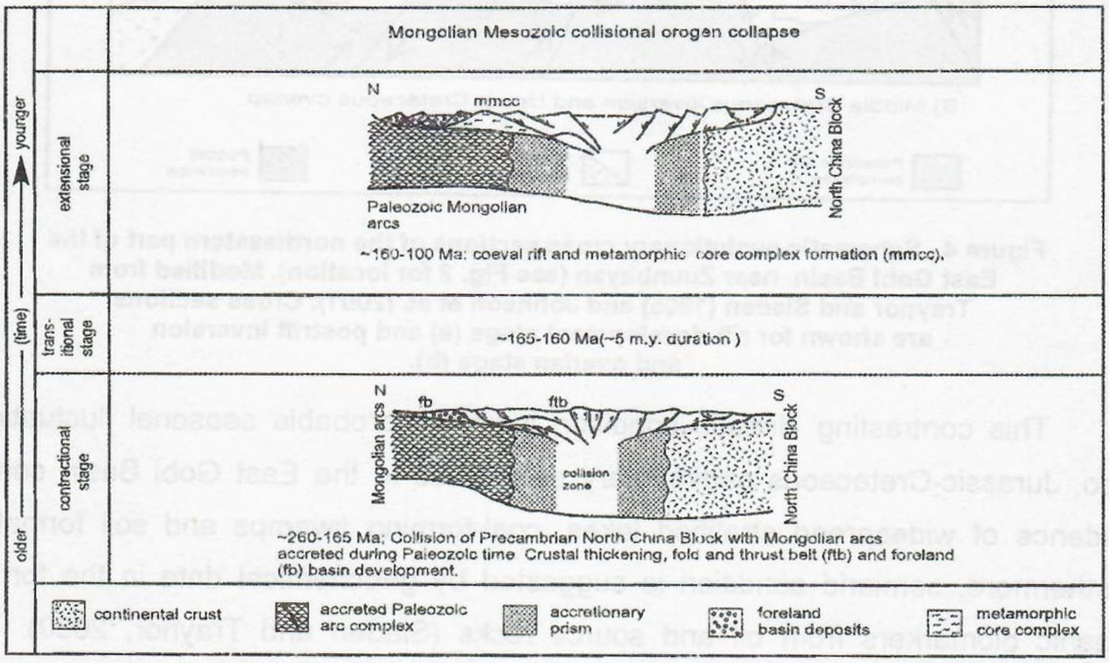


**Figure 3. Comparison of contractional, transitional and extensional phases of development in the Mesozoic of Mongolia. Cross sections are schematic representations only,modeled after Dickinson (1976) and Munoz (1992) (after Hendrix et al., Webb et al., 1999; Johnson et al., 2001).**

Post-rift Upper Cretaceous strata unconformably overlie the synrift sequence of the Early Cretaceous (Traynor and Sladen, 1995) (Fig. 4b). The Late Cretaceous age is verified by the occurrence of fossils such as segnosaur Enigmosaurces barsbold Perle, an unidentified sauropod, turtles and freshwater trigonioidid mollusk Plicatotriponioides multicostatus Barsbold.

Southern Mongolia was under a semiarid climatic condition during the synrift period (Graham et al., 2001). Forest became established from the Late Jurassic in the East Gobi Basin by tree-ring analysis of petrified forest (Keller and Hendrix, 1997).

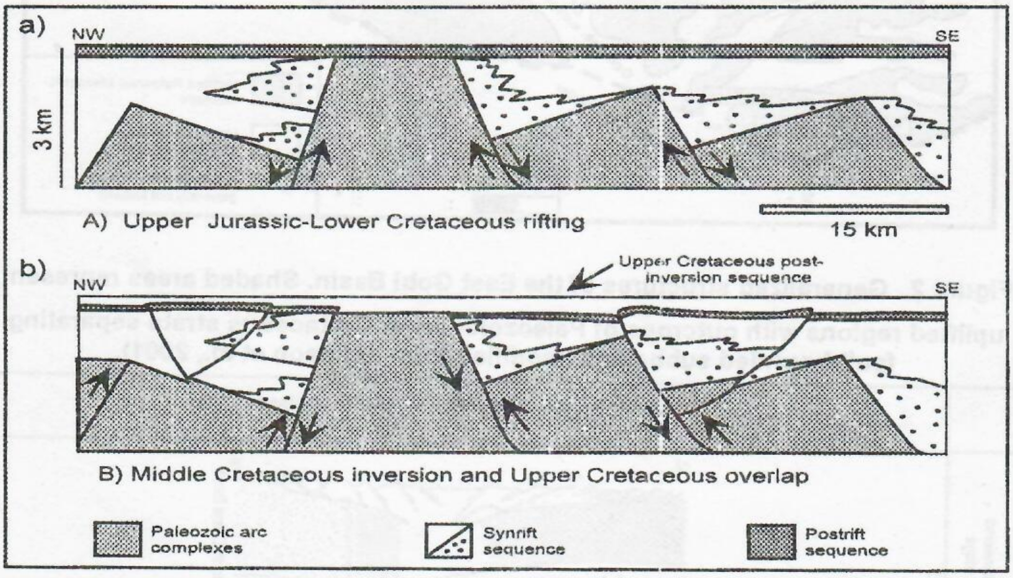


**Figure 4. Schematic evolutionary cross sections of the northeastern part of the East Gobi Basin near Zuunbayan (see Fig. 2 for location). Modified from Traynor and Sladen (1995) and Johnson et al. (2001). Cross sections are shown for rift development stage (a) and postrift inversion and overlap stage (b).**

This contrasting climatic condition indicates probable seasonal fluctuations. Also, Jurassic-Cretaceous sedimentary sequences in the East Gobi Basin contain evidence of widespread stratified lakes, coal-forming swamps and soil formation. Furthermore, semiarid condition is suggested by geochemical data in the form of organic biomarkers from oil and source rocks (Sladen and Traynor, 2000). This interpretation is supported by the presence of analcime cements in lacustrine sediments ( Surdam and Sheppard, 1978; Parrish, 1998). They observed analcite cement in ashes and sandstones input that is consistent with at least periodically alkaline and/ or salina lakes having volcanic materials. Dendroclimatologic analysis reveals seasonally wet, rather than permanent humid paleoclimate (Keller and Hendrix, 1997). The climate was also arid, as suggested by the occurrence of Lower Cretaceous, Calcisol-bearing, alluvial facies above the basalt at Har-Hotol which is located in the East Gobi Basin. (Graham et al., 2001). By previous study such as Onch-Hayrhan area and Unegt-Zuunbayan subbasin, paleo-flows were derived mostly from the southeast, south, southwest, and west indicating wide varieties of drainage from the footwall blocks of half-grabens located within the Paleozoic basement (Graham et al., 2001; Johnson et al., 2001)

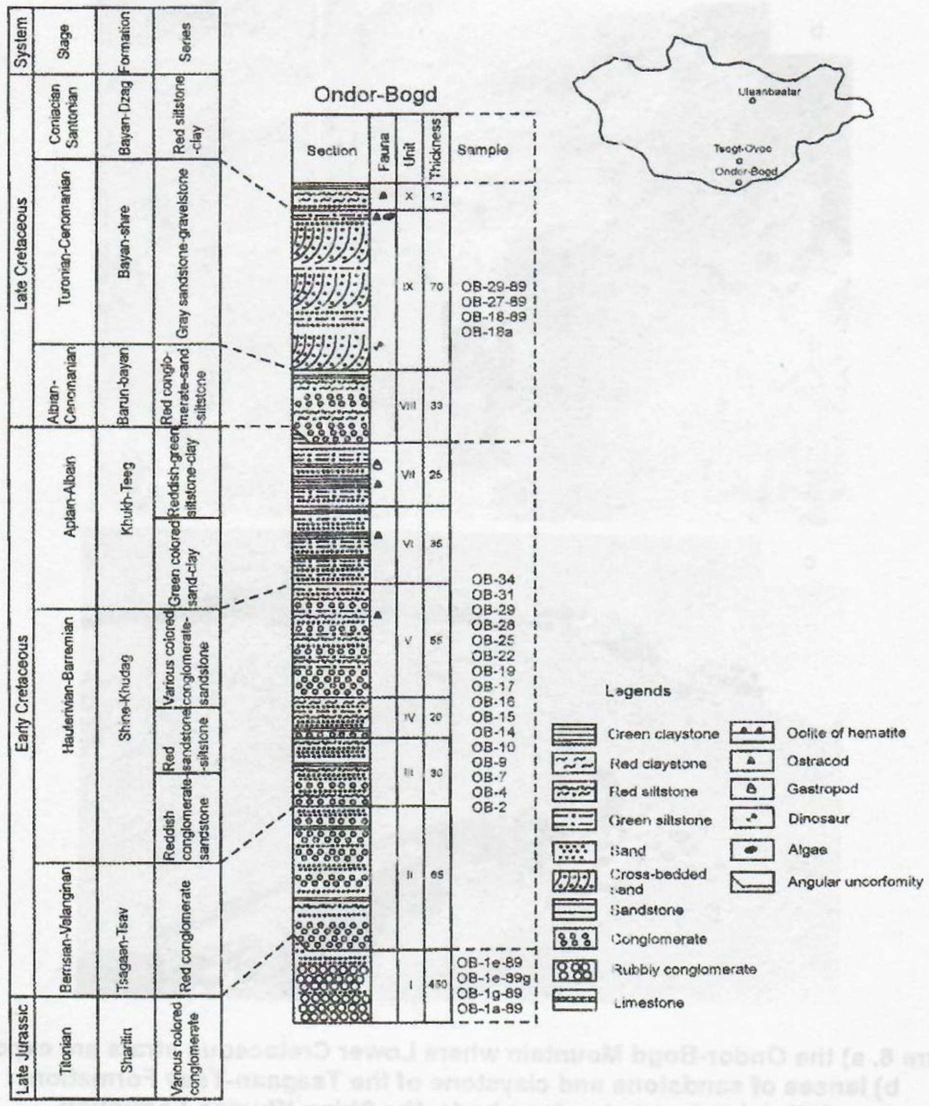


**Figure 5. Schematic columnar section of the East-Gobi Basin in Ondor-Bogd area, southeastern Mongolia (after Knand and Badamgarav, 1995).**

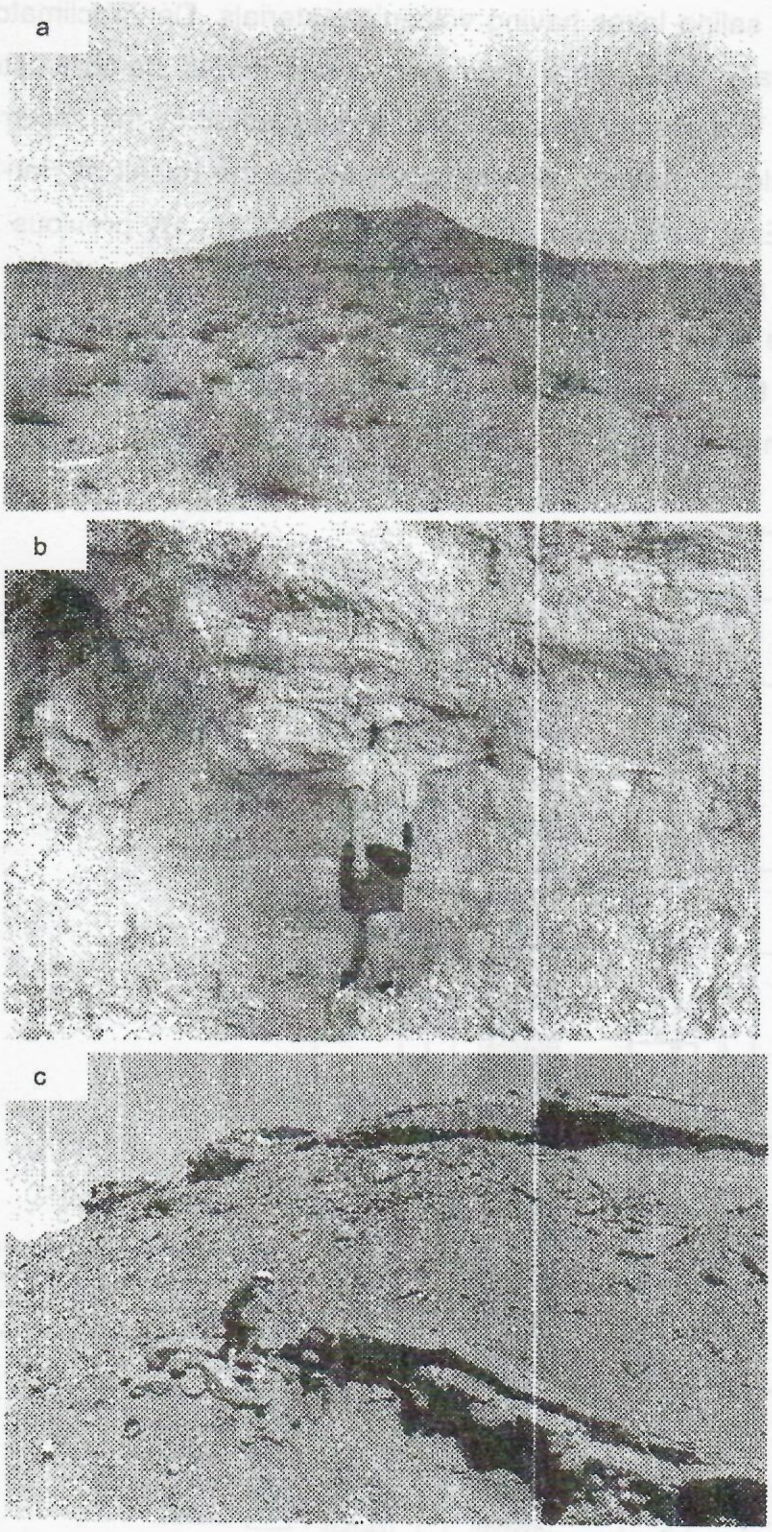


**Figure 6. a) the Ondor-Bogd Mountain where Lower Cretaceous strata are exposed, b) lenses of sandstone and claystone of the Tsagaan-Tsav Formation, and d) red-colored claystone beds, the Shine-Khudag Formation.**

The East Gobi Basin contains Cretaceous sediments deposited in relatively mature, stable fluvial-lacustrine environments developed in the typical rift systems. Alluvial fan environments existed in some places such as Onch-Hayrhan area of the East Gobi Basin, but fluvial-lacustrine environments predominated in the East Gobi Basin.

***Strantigraphy of the study area***

The study area is located on the eastern slope of Ondor-Bogd Mountain in the southernmost part of Mongolia (Fig. 2). In the Ondor-Bogd area, Upper Jurassic, Lower Cretaceous and Upper Cretaceous sedimentary rocks are well exposed (Khand and Badamgarav, 1995) (Fig. 5). Here occur distinct 10 lithologic units; from the base up, I- vari-colored conglomerate (450 m), II- red conglomerate (65 m), III- alternation of reddish conglomerate-sandstone (30 m), IV- red sandstone-siltstone (20 m), V- vari-colored conglomerate-sandstone (55 m), VI- green-colored sandstone-claystone (35 m), VII- reddish-green siltstone-claystone (25 m), VIII- red conglomerate-sand-siltstone (33 m), IX- gray sandstone-gravelstone (70 m), and X- red siltstone-claystone (12 m).

The Upper Jurassic strata overlie angular-unconformably the Lower-Middle Jurassic strata and are unconformably covered by the Lower Cretaceous strata. The general thickness of the Sharilin Formation (unit I) is 450 m. Different from the underlying and the overlying gray-colored rocks, the Sharilin Formation is characterized by red and variegated coloration. The Sharilin Formation contain organic remains such as *Psaudograpta andrewsi (Jones), P.olonhurensis Novoj., P.murchisoniae(Jones)* (personal communication with I.B Stepanova), *Lycoptera sp. Nov., Bithynia minima Martins., Valvata predoalina Martins., Liimnocyrena sp.* (personal communication with G.G Martinson ), *Podozamites Lanceolatus (L.etH.) Braun and Ginkgo ex gr. Sibirica Heer* (personal communication with E.M. Markobich). The organic remains are indicative of Late Jurassic in age.

Sedimentary rocks of the Early Cretaceous are divided into three formations; the Tsagaan-Tsav (unit II), Shine-Khudag (units III-V) and Khukh-Teeg (units VI and VII) formations (Fig. 5). Type sections of these formations are exposed near the Ondor-Bogd Mountain (Fig. 6a), Botgo Mountain and Tsagaan-Khairkhan Am, Gants

Sukhain Khudag which are located in the Galb-Gobi and in the northern part of the Borzon-Gobi.

The Tsagaan-Tsav Formation, 65m thick, consists of conglomerate with gray-colored sandstone lenses (Fig. 6b) and beds, conglomerate-breccia, and gravelstone and yellow green sandstone, zeolite-bearing tuff, tuffaceous sandstone, andesite-basalt and basalt. The Tsagaan-Tsav Formation overlies unconformably volcanic rocks of the Paleozoic.

The Shine-Khudag Formation overlies conformably the Tsagaan-Tsav Formation. This formation is composed of reddish-brown conglomerate-sandstone with siltstone and red-colored claystone (Fig. 6c). Thickness of the Shine-Khudag Formation is 105 m. The Shine-Khudag Formation contains ostracods *Cupridea Unicostata Gal.*, and age of this formation was established to be the Hauterivian-Barremian by these ostracods. The Khukh-Teeg Formation lies conformably on the Shine-Khudag Formation. It is composed green sandstone-claystone, reddish-green siltstone-claystone with thin beds of limestone and sandstone. This formation contains ostracods and gastropods. Ostracods are *Cypridea faveolata (Egger), C.unicostata Galeeva, C.aragangensis Scoblo, C.trita Lubimova, Mongolianella palmosa Mandelstam, Lycopterocypris infantilis Lubimova, L.ingloria Lubimova, Timiriasevia polymorpha Mandelstam, Candona sp.rov, Zizphocypris duatritimulla (Galeeva)* (Goldenverg et al., 1974; Khand et al., 2004).

According to fossil assemblages, the Tsagaan-Tsav Formation is assigned to the Berriasian-Valanginian, the Shinekhudag to the Hauterivian-Barremian and the Khukh-Teeg to the Aptian-Albian.

The Lower Cretaceous strata are overlain unconformably by the Upper Cretaceous deposits. The Upper Cretaceous deposits are subdivided into three formations: the Barun-Bayan, Bayan-Shire, Bayan-Dzag formations with decreasing age. Most sedimentlogical studies on Cretaceous strata of Mongolia have been focused on Upper Cretaceous deposits (Sochava, 1975; Gradzinski, 1970; Verzilin, 1982; Gradzinski and Jerzykiewicz, 1974; Jerzykiewicz et al., 1993). The Barun-Bayan Formation consists mainly of conglomerates, coarse- and medium-grained sandstones, poorly sorted siltstones of alluvial origin (Badamgarav et al., 1995). The Bayan-Shire Formation comprises the complex coarse- and fine–grained sediments, and trough cross-stratified sandstone beds associated with fine-grained sediments which were deposited in a fluviolacustrine setting. The Bayan-Dzag Formation is characterized by fine- to very fine-grained sandstones with local beds of conglomerates, caliche nodules, and hardpan deposits and this formation is interpreted to have been deposited in eolian environments with syndepositional pedogenesis. Fossil assemblages indicate that the Barun-Bayan Formation is of the Albian-Cenomanian, the Bayan-Shire of the Cenomanian, and the Bayan-Dzag of the Coniacian-Santonian (Badamgarav et al., 1995).

## *Methods*

24 samples of Upper Jurassic and Cretaceous sandstones were collected from the Ondor-Bogd area (Fig. 5). Also, two samples were collected from the Lower Cretaceous sedimentary rocks which are distributed near Tsogt-Oboo Sumon (Fig. 5). Thus, 11 samples of Lower-Middle Jurassic sandstones were collected from Saihan-Ovoo Basin. Rock samples were cut into thin slices perpendicular to bedding plane, and standard thin sections were prepared from the slices. Thin sections were examined under the polarizing microscope and point-counted using the 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 grain size of sandstones was measured using a micrometer ocular. One hundred quartz grains in each thin section from the Lower Cretaceous sandstones were counted separately to determine quartz types.

## *Results*

### *Detrital modes*

Size of detrital grains ranges from 0.07 mm to 1.3 mm across. A few sandstones contain detrital grains with size ranging from 1.6 mm to 2.0 mm but rarely up to 3.6 mm. Recalculated point-counting data is shown in Tables 1, 2. Some unidentified framework and accessory mineral grains were not counted, but they are minor and thus unimportant. Petrographic characteristics of sandstones in the Ondor-Bogd area are described as follows.

**Recalculated point-count data from Upper Jurassic and Cretaceous sandstones of the Ondor-Bogd area.**

**Table-1**

| Sample | Q-F-L,% | | | Qm-F-Lt, % | | | Qp-Lvm-Lsm,% | | |
|---|---|---|---|---|---|---|---|---|---|
| | Q | F | L | Qm | F | Lt | Qp | Lv | Ls |
| Upper Cretaceous sandstones | | | | | | | | | |
| OB-18a | 12.783 | 4.394 | 82.823 | 3.063 | 4.394 | 92.543 | 12.394 | 24.788 | 62.818 |
| OB-18-89 | 8.401 | 5.368 | 86.231 | 4.201 | 5.367 | 90.432 | 6.406 | 28.470 | 65.124 |
| OB-27-89 | 24.376 | 14.010 | 61.527 | 13.216 | 14.010 | 72.687 | 20.267 | 44.267 | 35.466 |
| OB-29-89 | 48.290 | 27.223 | 24.487 | 39.672 | 27.223 | 33.105 | 28.378 | 29.730 | 41.892 |
| Lower Cretaceous sandstones | | | | | | | | | |
| OB-2 | 20.905 | 33.822 | 45.273 | 15.579 | 33.822 | 50.599 | 10.989 | 23.901 | 65.110 |
| OB-4 | 58.831 | 21.601 | 19.568 | 16.518 | 21.601 | 61.880 | 70.851 | 3.617 | 25.532 |
| OB-7 | 27.894 | 13.947 | 58.159 | 19.107 | 13.947 | 66.946 | 15.517 | 24.630 | 59.852 |
| OB-9 | 21.571 | 10.428 | 68 | 14.857 | 10.429 | 74.714 | 10.682 | 27.954 | 61.364 |
| OB-10 | 31.592 | 27.946 | 40.462 | 22.236 | 27.946 | 49.818 | 22.849 | 16.914 | 60.237 |
| OB-14 | 33.824 | 3.382 | 62.794 | 4.412 | 3.382 | 92.206 | 33.898 | 6.780 | 59.322 |
| OB-15 | 32.301 | 8.882 | 58.816 | 5.384 | 8.882 | 85.734 | 34.071 | 9.199 | 56.729 |
| OB-16 | 14.888 | 10.298 | 74.814 | 5.335 | 10.298 | 84.367 | 13.580 | 16.402 | 70.018 |
| OB-17 | 29.740 | 14.498 | 55.762 | 11.524 | 14.498 | 73.978 | 31.013 | 20.464 | 48.523 |
| OB-19 | 25.656 | 13.557 | 60.787 | 12.100 | 13.556 | 74.344 | 19.662 | 15.433 | 64.905 |
| OB-22 | 22.727 | 20.154 | 56.818 | 15.10 | 20.455 | 64.448 | 13.545 | 25.072 | 61.383 |
| OB-25 | 24.311 | 17.342 | 58.347 | 9.724 | 17.342 | 72.934 | 22.5 | 20 | 57.5 |
| OB-28 | 36.173 | 13.209 | 50.617 | 27.160 | 13.210 | 59.630 | 16.743 | 13.761 | 69.495 |
| OB-29 | 36.694 | 8.206 | 55.010 | 25.322 | 8.206 | 66.471 | 20.771 | 7.066 | 72.163 |
| OB-31 | 35.664 | 10.373 | 53.963 | 27.506 | 10.373 | 62.121 | 18.277 | 11.227 | 70.496 |
| OB-34 | 5.531 | 7.092 | 87.376 | 5.106 | 7.092 | 87.801 | 0.527 | 22.144 | 77.329 |
| | | | | | | | | | continued |
| Upper Jurassic sandstones | | | | | | | | | |
| OB-1a-89 | 26.993 | 16.687 | 56.319 | 15.950 | 16.687 | 67.362 | 19.313 | 10.729 | 69.957 |
| OB-1g-89 | 45.238 | 12.044 | 42.717 | 7.002 | 12.045 | 80.952 | 54.709 | 24.649 | 20.641 |
| OB-1e-9g | 46.795 | 5.288 | 47.917 | 28.205 | 5.288 | 66.506 | 38.411 | 16.556 | 45.033 |
| OB-1e-89 | 48.290 | 27.223 | 24.487 | 39.672 | 27.223 | 33.105 | 28.378 | 29.730 | 29.255 |

*Upper Jurassic sandstones (Sharilin Formation)*: Detrital grains are composed of mineral grains and rock fragments. They are generally sub-rounded and moderately sorted to well sorted. Size of detrital grains ranges from 25 μm up to 1.2 mm and sometimes up to 2 mm. Mineral detrital grains are quartz,plagioclase and potassium feldspar comprising 33-43% of the rock volume. Quartz comprises 23-32% of the rock and polycrystalline quartz dominates over monocrystalline quartz. In feldspar grains, plagioclase is more abundant than K-feldspar. Plagioclase was partly altered to clay minerals and replaced by carbonate minerals, whereas potassium feldspar is slightly replaced by clay minerals. Also, in the sandstones biotite with warp form occurs.

**Recalculated point-count data from Lower Cretaceous sandstones of the Tsogt-Ovoo Sumon.**

**Table-2**

| Sample | Q-F-L, % | | | Qm-F-Lt, % | | | Qp-Lvm-Lsm,% | | |
|---|---|---|---|---|---|---|---|---|---|
| | Q | F | L | Qm | F | Lt | Qp | Lvm | Lsm |
| Ts-Ov-2 | 8.342 | 5.330 | 86.327 | 18.568 | 5.172 | 76.259 | 14.763 | 11.978 | 73.259 |
| Ts-Ov-1 | 12.783 | 4.394 | 82.822 | 6.275 | 6.668 | 87.039 | 85.820 | 0 | 14.179 |

Lithic fragment comprises 32~46% of the rock volume, of which sedimentary rock fragment predominates. Sedimentary rock fragments are chert, carbonate and argillite, of which chert grain is most abundant. Fragments of volcanic rocks are dacite and rhyolite with rare andesite, showing microfelsite, micro granophyric and microlite texture. Metamorphic rock fragments consist of gneiss, slate and schist which show microgranolepidoblastic, microlepidogranoblastic and foliated texture.

Cement is calcite partly enriched in iron oxide, resulting in reddish color. The detrital accessory minerals are opaque minerals, mostly tourmaline.

*Lower Cretaceous sandstones*: Detrital grains are generally sub-rounded to rounded and moderately sorted to well sorted. The sandstones are composed of detrital grains cemented by calcite (Fig. 7a). The detrital minerals are quartz, plagioclase and potassium feldspar comprising about 61-71% of the rock. Quartz (Fig. 7b) is the most abundant mineral in Lower Cretaceous sandstones. Some quartz grains were partly replaced by calcite. Quartz grains are classified as monocrystalline and polycrystalline quartz, in which the former is generally more abundant than the latter. Generally, plagioclase is more abundant than K-feldspar. Plagioclase is altered to sericite, clay minerals and calcite. The potassium feldspar was partly replaced by clay minerals and calcite. Microcline with typical grid twinning (Fig. 7c) is rarely observed. Biotite and muscovite also occur as an accessory component. Occasionally, mica is present in amount of 0.7% of rock volume (Fig. 7d). Micas often show deformation and bending between rigid grains. Sometimes biotite is replaced by chlorite.

Rock fragments are of plutonic, volcanic, sedimentary and metamorphic, of which sedimentary rock fragments predominate. Volcanic rock fragments are composed of dacite, andesite (Fig. 7e) and basalt which show fine-grained crystalline, microlite and felsite texture, sometimes with phenocrysts floating in the groundmass. Rarely, they have amygdaloidal structure which is filled by chlorite and siliceous minerals. Metamorphic rock fragments are composed of gneiss, slate and schist. They show foliated texture and contain quartz, feldspar and mica. Sedimentary rock fragments include fine-grained sandstone, siltstone, claystone and chert. Plutonic rock fragments consist of quartz, plagioclase and sometimes potassium feldspar (microcline). Accessory minerals are opaque mineral, tourmaline, zircon and garnet, sometimes ranging up to 1.2% by volume.

Calcite forms the dominant cement and detrital grains are extensively replaced by calcite, too. Also, the rock is cut by discontinuous, thin veins of carbonate (Fig. 7f), whose width ranges from 0.025 mm to 0.075 mm. Sometimes cement contains iron oxide, resulting by calcite.

*Upper Cretaceous sandstones*: Size of detrital grains ranges from 0.1 mm to 2 mm. Detriral mineral grains occupy 12-55% by volume of sandstones and comprise quartz, plagioclase, potassium feldspar and biotite. Upper Cretaceous sandstones are characterized by the predominance of lithic fragments comprising up to 75% of the rock volume. The abundance of lithic fragments is sedimentary, volcanic and metamorphic in that order.The sedimentary rock fragments include mostly chert with some argillite, carbonate and siltstones. The volcanic rock fragments contain persilicic-medium rocks (dacite, phyolite and andesite). Metamorphic rock fragments are slate, schist and epidosite. Accessory minerals consist of opaque minerals and tourmaline. The Upper Cretaceous sandstones are distinguished from Upper Jurassic and Lower Cretaceous sandstones by a cement mineral. Cement of Upper Cretaceous sandstones consists of clay to micaceous mineral with iron oxides, whereas Upper Jurassic and Lower Cretaceous sandstones are cemented by calcite.

## *Sandstone classification*

Three sandstones of the Late Jurassic in the Ondor-Bogd area are classified as litharenite and one as feldspathic arenite (Fig. 8a). Most of sandstones of the Early Cretaceous in the Ondor-Bogd area are classified as lithic arenite clan with three samples as feldspathic litharenite and one sample as lithic arkoses (Fig. 8b)

. Sandstones of the Late Createceous are mostly characterized by litharenite and one by lithic arkose. (Fig. 8c). Two Early Cretaceous sandstones of the in Tsogt-Ovoo Sumon area are classified as litharenite (Fig. 8d).

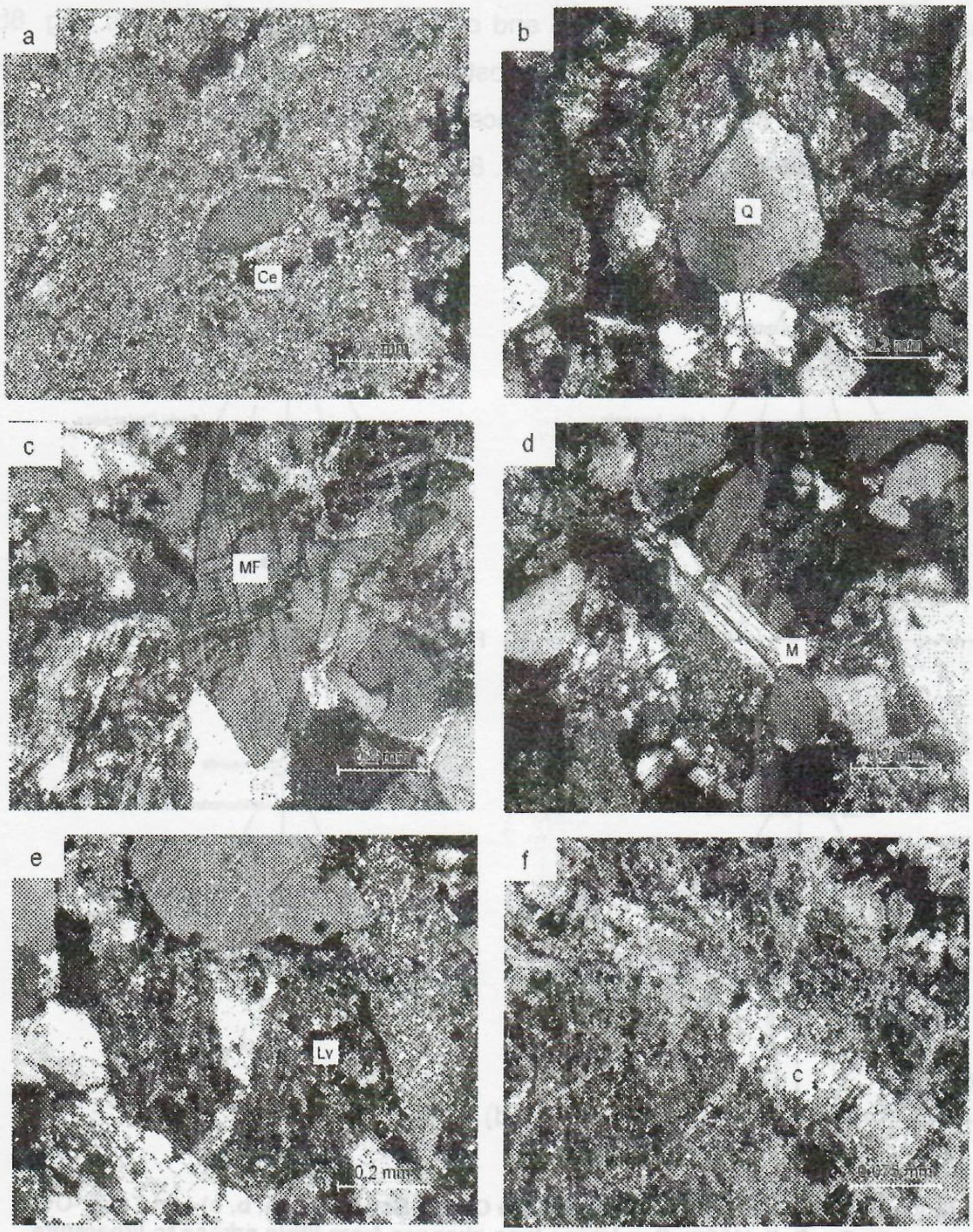


**Fig. 7. Photomicrographs of sandstones of the Ondor-Bogd study area; crossed polarizers Sandstone is cemented by microcrystalline calcite (Ce) rims,b) Undulose monocrystalline quartz (Q), c) Microcline feldspar (MF) with typical microclinegrid twinning, d) Mica (M) grain, e) Volcanic lithic a) fragments (Lv), and f) Carbonate-filled veins (C).**

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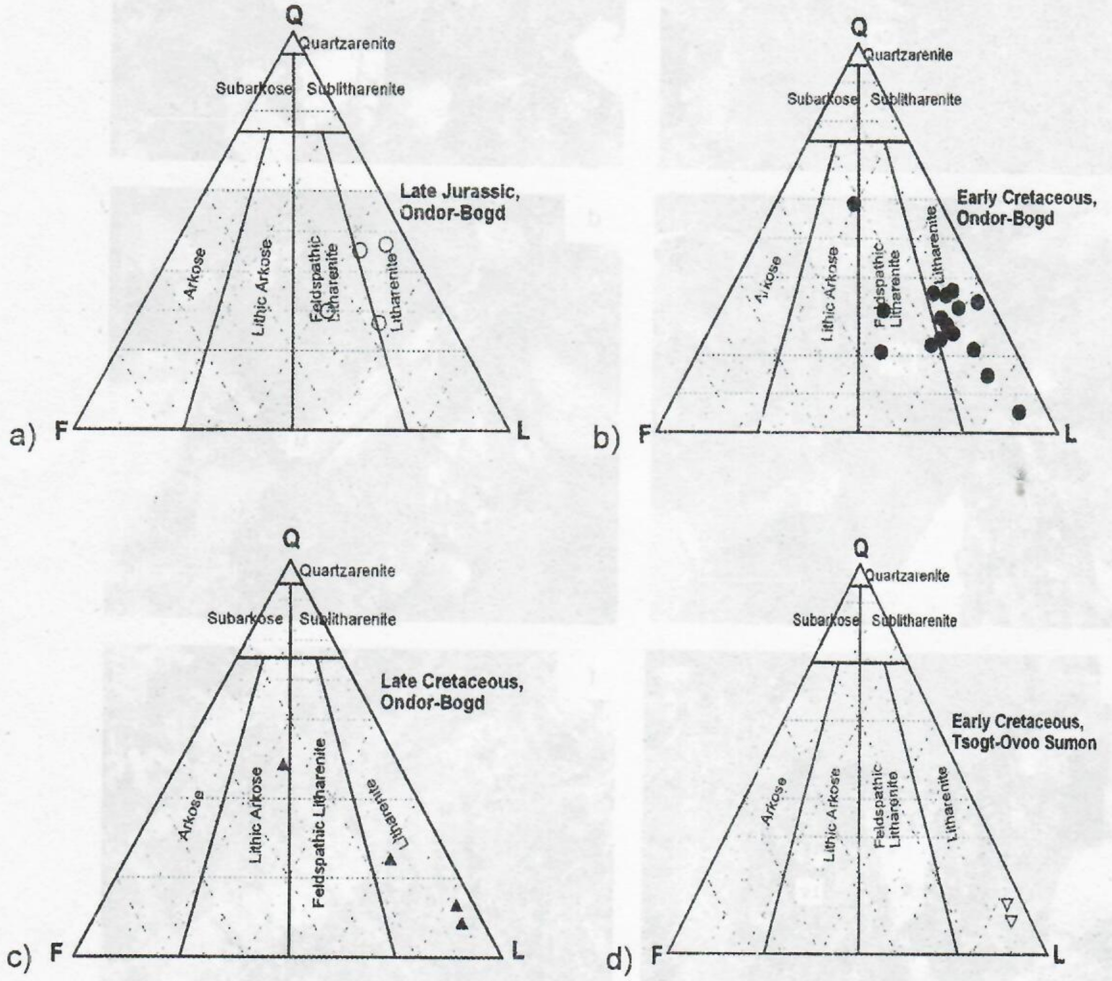


**Figure 8. Classification of sandstones of the Ondor-Bogd area (a, b, c) and Tsogt-Ovoo Sumon (d) after Folk (1968). Sandstone type changes from lithic arkose to litharenite.**

The content of lithic fragments in studied sandstones is shown in Fig. 9 table 3. All types of lithic sand grains occur throughout the sequence, which indicates greater dispersion of sand-sized detritus across the basin. However, there is no discernible trend of proportion change among three lithic grain types upsection, except for the increase in volcanic rock fragments at the expense of sedimentary rock fragments upsection in the Late Cretaceous sandstones. In general, sedimentary lithic fragments predominated in the studied sandstones.

**Content of lithic fragments of the Ondor-Bogd area.**

**Table-3**

| | Sample | Lv | Ls | Lm |
|---|---|---|---|---|
| 1. | OB-34 | 5.0 | 21.2 | 73.8 |
| 2. | OB-31 | 6.8 | 12.8 | 80.4 |
| 3. | OB-29 | 7.5 | 8.3 | 84.2 |
| 4. | OB-28 | 7.6 | 15.3 | 77.1 |
| 5. | OB-25 | 3.1 | 25.0 | 71.9 |
| 6. | OB-22 | 19.6 | 23.3 | 57.1 |
| 7. | OB-17 | 4.9 | 28.2 | 66.9 |
| 8. | OB-16 | 2.7 | 18.4 | 78.9 |
| 9. | OB-15 | 5.6 | 13.2 | 81.2 |
| 10. | OB-14 | 3.2 | 9.9 | 86.9 |
| 11. | OB-10 | 19.6 | 17.6 | 62.8 |
| 12. | OB-9 | 2.5 | 30.5 | 67.0 |
| 13. | OB-7 | 6.3 | 27.3 | 66.4 |
| 14. | OB-4 | 27.9 | 8.9 | 63.2 |
| 15. | OB-2 | 26.6 | 19.7 | 53.7 |

## *Provenance*

### *Qt-E-L Diagram*

Fig. 10 shows plots of detrital modal data for Upper Jurassic to Cretaceous sandstones in the Ondor-Bogd area on the Qt-F-L diagram with compositional fields defined by Dickinson (1985). The Upper Jurassic sandstones plot in the recycled orogen and transitional to dissected arc fields (Fig. 10a).

Six sandstones of the Early Cretaceous plot in recycled orogen field (Fig. 10b) and ten sandstones plot in undissected to transitional arc field. Only one sample plots in the dissected arc field. Arc terranes generate much volcanic lithic debris, so sediments derived from these terranes would cluster near the L or Lt pole, which is well represented in the sandstones of the Early Cretaceous. Three sandstones of the Upper Cretaceous sandstones plot in the magmatic arc such as undissected arc to transitional arc fields (Fig. 10c) with one sample in the recycled orogen field.

Sandstones of the Early Cretaceous in the Tsogt-Ovoo Sumon plot in the undissected arc field (Fig. 10d).

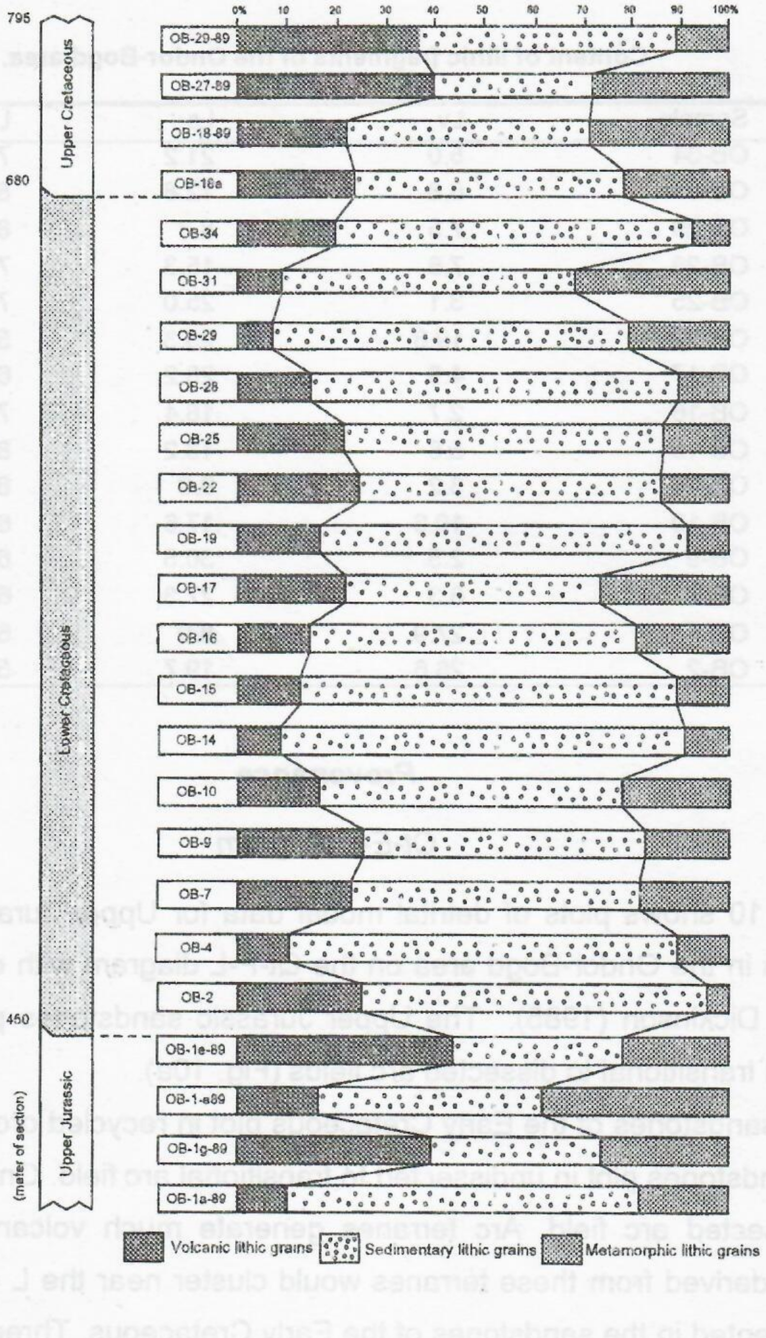


**Figure 9. Lithic fragments composition data plotted according to stratigraphic position.**

*Qm-F-Lt Diagram*

Fig. 11 displays Qm-F-Lt plots after Dickinson (1985). Sandstones of the Late Jurassic in the Ondor-Bogd area plot lithic recycled to transitional recycled orogen field and in the transitional arc field (Fig. 11a). Thirteen sandstones of the Early Cretaceous plot in the lithic recycled orogen field and three samples in the transitional arc field (Fig. 11b). This is due to the minor input from volcanic rocks rather due to the dilution effect due to the transfer of Qp to Lt.

Three samples of the Late Cretaceous plot in the recycled orogen field with one sample plotting between dissected arc and mixed fields (Fig. 11c). Again, two sandstone samples of the Tsogt-Ovoo Sumon area plot in the lithic recycled field (Fig. 11d).

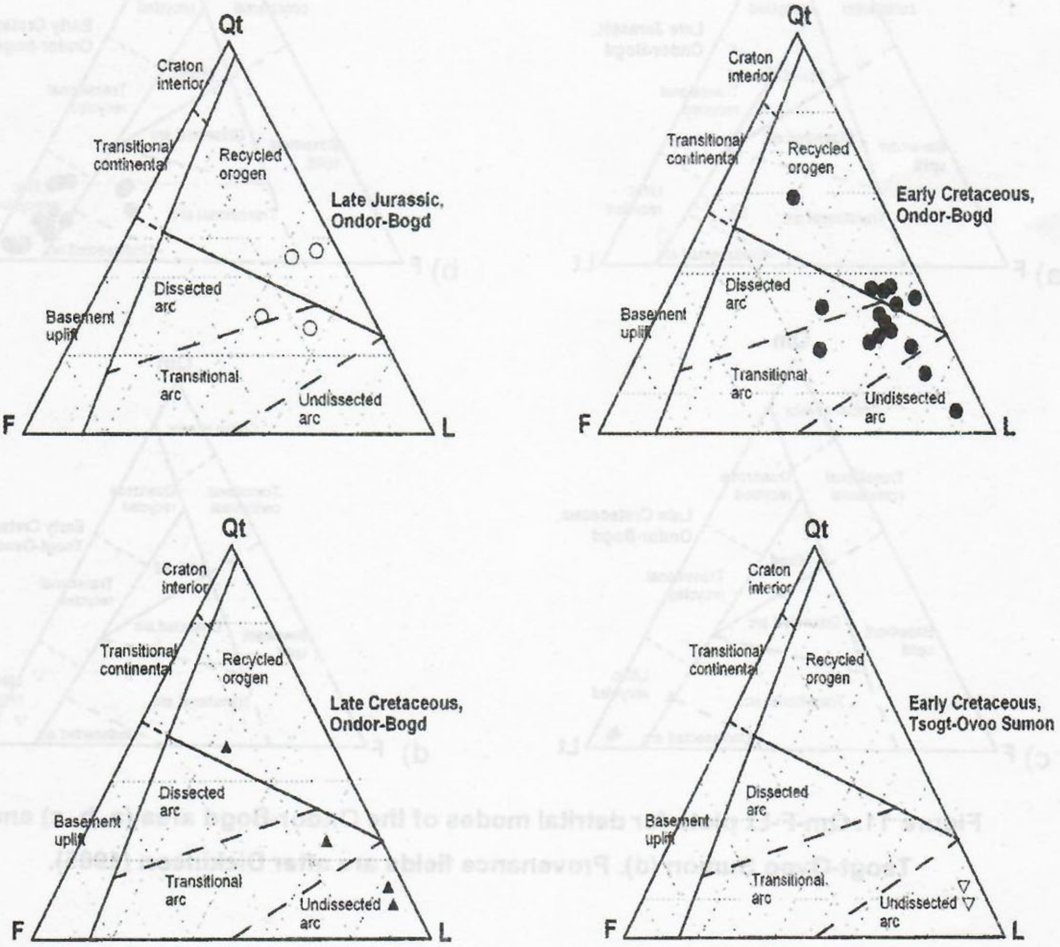


**Figure 10. Qt-F-L plots for detrital modes of the Ondor-Bogd area (a, b, c) йnd Tsogt-Ovoo Sumon (d). Provenance fields are after Dickinson (1985).**

*Qp-Lvm-Lsm Diagram*

On the Qp-Lvm-Lsm diagram (Fig. 12), sandstones of the Late Jurassic and Early Cretaceous in the Ondor-Bogd and Tsogt-Ovoo Sumon areas plot in the two fields: collision suture and fold-thrust belt sources and mixed orogenic sources (Figs. 12a, b, d), suggestive of some sediment input from magmatic arc source. In other words, a large amount of sandstones scatter toward the arc orogen source area. This result suggests that some detritus input from arc orogen source.

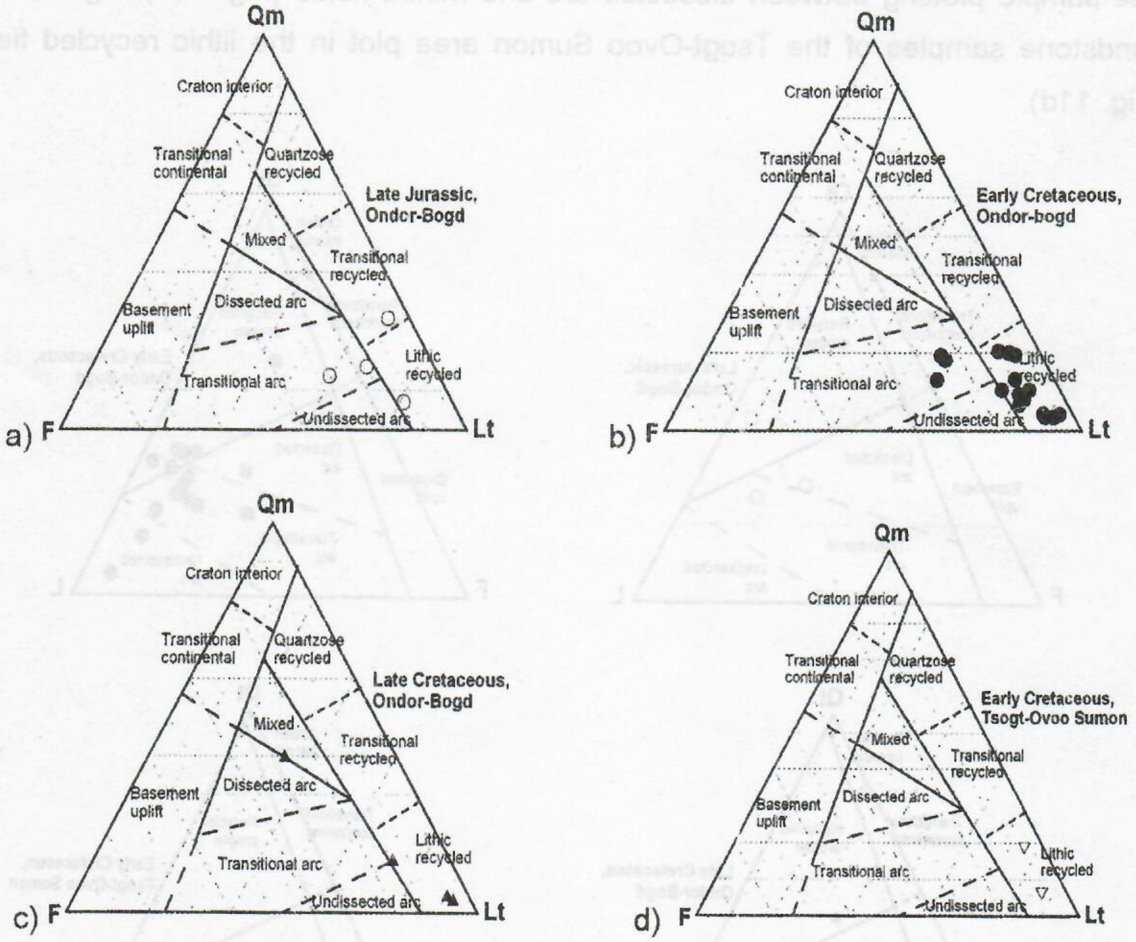


**Figure 11. Qm-F-Lt plots for detrital modes of the Ondor-Bogd area (a, b, c) and Tsogt-Ovoo Sumon (d). Provenance fields are after Dickinson (1985).**

This result is consistent with those from Qm-F-Lt and Qt-F-L diagrams. For detritus of the Upper Jurassic and Lower Cretaceous sandstones, some input from fold-thrust belt is suggested in the Qp-Lvm-Lsm diagram. However, sandstones of the Late Cretaceous plot in the arc orogen and mixed orogenic fields (Fig. 12c),indicating that magmatic arc sources become more significant than in the older sandstones.

Various provenance interpretations based on detrital modal data are summarized in Table 4. Both recycled orogen and magmatic arc provenance settings are interpreted as most important provenances for Upper Jurassic-Cretaceous sediments in both Ondor-Bogd and Tsogt-Ovoo Sumon areas.

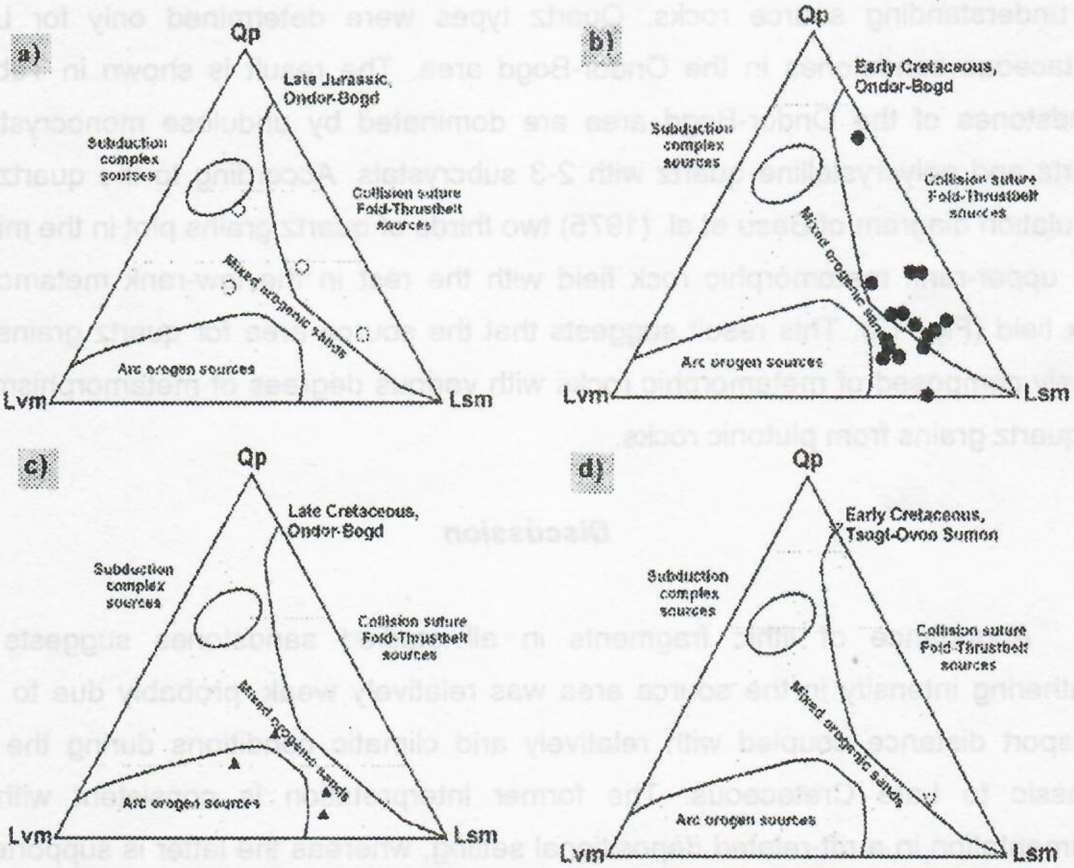


**Figure 12. Qp-Lvm-Lsm plots for detrital modes of the Ondor-Bogd area (a, b, c) and Tsogt-Ovoo Sumon (d). Provenance fields are after Dickinson (1985).**

**Various provenance types of late Mesozoic sandstones in the Ondor-Bogd area.**

**Table-4**

| Age | Q-F-L | Qm-F-Lt | |
|---|---|---|---|
| Upper Cretaceous | Transitional to undissected arc | Lithic recycled orogen | Mixed and arc orogen sources |
| Lower Cretaceous | Transitional to undissected arc | Lithic recycled orogen | Collision suture and fold-thrustbelt sources |
| Upper Jurassic | Dissected to transitional arc | Transitional arc | Mixed orogenic sands |

*Determination of Quartz Types*

Undulosity and number of subcrystals in polycrystalline quartz can be useful for understanding source rocks. Quartz types were determined only for Lower Cretaceous sandstones in the Ondor-Bogd area. The result is shown in Table 5. Sandstones of the Ondor-Bogd area are dominated by undulose monocrystalline quartz and polycrystalline quartz with 2-3 subcrystals According to the quartz-type population diagram of Basu et al. (1975) two thirds of quartz grains plot in the middle- and upper-rank metamorphic rock field with the rest in the low-rank metamorphic rock field (Fig. 13). This result suggests that the source area for quartz grains was largely composed of metamorphic rocks with various degrees of metamorphism, but no quartz grains from plutonic rocks.

***Discussion***

Abundance of lithic fragments in all studied sandstones suggests that weathering intensity in the source area was relatively weak, probably due to short transport distance coupled with relatively arid climatic conditions during the Late Jurassic to Late Cretaceous. The former interpretation is consistent with the sedimentation in a rift-related depositional setting, whereas the latter is supported by the seasonality in precipitation (Sladen and Traynor, 2000; Graham, et al., 2001). The results of modal composition data of Upper Jurassic – Upper Cretaceous sandstones in the East Gobi Basin suggests that source tectonic settings were recycled orogen and magmatic arcs.

**Determination of quartz types of Lower Cretaceous Sandstones in the Ondor-Bogd area.**

**Table-5**

| Sample number | Non-undulose monocrystalline quartz,% | Undulose monocrystalline quartz,% | Total monocrystalline quartz,% | Polycrystalline quartz with 2-3 subcrystals,% | Polycrystalline quartz with >3 subcrystals ,% |
|---|---|---|---|---|---|
| OB-2 | 24.0 | 47.0 | 71 | 18.0 | 9.0 |
| OB-4 | 2.0 | 42.0 | 44.0 | 45.0 | 9.0 |
| OB-7 | 16.0 | 54.0 | 70.0 | 29.0 | 1.0 |
| OB-9 | 12.0 | 40.0 | 52.0 | 44.0 | 3.0 |
| OB-10 | 16.0 | 49.0 | 65.0 | 34.0 | 1.0 |
| OB-14 | - | 19.0 | 19.0 | 74.0 | 7.0 |
| OB-15 | 8.0 | 31.0 | 39.0 | 58.0 | 3.0 |
| OB-16 | 28.0 | 54.0 | 82.0 | 18.0 | - |
| OB-17 | 11.0 | 47.0 | 58.0 | 41.0 | 1.0 |
| OB-19 | 6.0 | 42.0 | 48.0 | 52.0 | - |
| OB-22 | 22.0 | 62.0 | 84.0 | 16.0 | - |
| OB-25 | 3.0 | 34.0 | 37.0 | 58.0 | 5.0 |
| OB-28 | 21.0 | 61.0 | 83.0 | 18.0 | - |
| OB-29 | 12.0 | 62.0 | 74.0 | 25.0 | 1.0 |
| OB-31 | 12.0 | 47.0 | 59.0 | 37.0 | 4.0 |
| OB-34 | 10.0 | 62.0 | 72.0 | 28.0 | - |

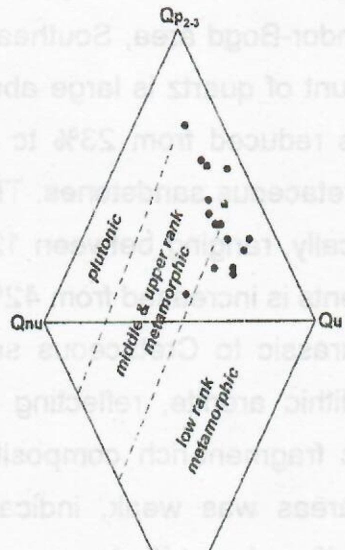


**Figure 13. Quartz-type population diagram plotted using the scheme of Basu et al (1975,1985). Qnu: non-undulose monocrystalline quartz; Qu: undulose monocrystalline quartz; $Qp_{2-3}$: Polycrystalline quartz with 2-3 subcrystals and $Qp_{>3}$: polycrystalline quartz with >3 subcrystals.**

This indicates that most of the sediments were derived from source areas which underwent fold-thrust tectonism formed by plate collisions. In other words, Upper Jurassic – Upper Cretaceous sediments in the East Gobi Basin are suggested to be recycled sediments that were deposited in the foreland basins formed as a result of collision between the North China and Mongolian arcs. However, the collision between the Mongolian arcs and the North China block occurred in the Paleozoic, long before the basin formation and the East Gobi Basin is interpreted to have formed due to rifting under the extensional tectonic regime (Graham et al., 2001; Johnson et al., 2001). s calcite cement. However, to have good porosity, these sandstones should have undergone secondary porosity formation through dissolution prior to hydrocarbon migration.

### *Conclusions*

On the basis of petrological studies on Late Mesozoic sandstones, we conclude the following:

1. Modal compositions of Upper Jurassic to Upper Cretaceous sandstonesin the East Gobi Basin in the Ondor-Bogd area, Southeast Mongolia have a distinct up section change. The amount of quartz is large about 42% in the Upper Jurassic sandstones, whereas it is reduced from 23% to 28% by volume in the Lower Cretaceous and Upper Cretaceous sandstones. The amount of feldspar remains little changed stratigraphically, ranging between 12% and 15%. On the contrary, the amount of lithic fragments is increased from 42% to 63% upsection.
2. Composition of Upper Jurassic to Cretaceous sandstones of the Ondor-Bogd area is lithic arkose to lithic arenite, reflecting studied sandstones are lithic fragment rich. Such lithic fragment-rich composition suggests that weathering intensity in the source areas was weak, indicating arid to semiarid climatic conditions during both synrift and postrift stages.
3. Sandstones of the Late Jurassic and Early Cretaceous may have been derived from collisional fold-thrust belt source area which was formed during the accretion of Mongolian arcs with the North China block. Although the East Gobi Basin was formed due to rifting, the sandstone modal compositions indicate that they were derived from orogenic sources. This discrepancy suggests that employing the

4. ternary diagrams for provenance tectonic-setting interpretation needs a careful attention.

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# МОНГОЛЫН ЦАЙР- ХАРТУГАЛГАНЫ ӨНӨӨ БА ИРЭЭДҮЙ

Д. ДОРЖГОТОВ
*Монгол Улсын Их Сургууль*

## Оршил

Монгол улсын нутаг дэвсгэрийг олон томоохон структуруудийн уулзвар зангилаа хэсэгт байрладаг, ашигт малтмалын хувьд харьцангуй баян гэж үздэг. Сүүлийн 10 гаруй жилд олон улс орон монголын геологийн судалгаанд хөрөнгө оруулалт хийж ашигт малтмалын ордын эрэл, хайгуулын ажлыг хийж байгаагийн зэрэгцээ зарим ашигт малтмалын ордуудыг олборлон ашиглаж эхлээд байна. Нөгөө талаас дэлхий дахины хэмжээнд цайр, хартугалга ба тэдгээрийн дагалдагч элементүүдийн хэрэглээ , үнэ ханш ерөнхийдөө өсөх хандлагатай байна. Үүнтэй уялдаж манай орны цайр, хартугалганы нөөцийн байдалд үнэлэлт өгч цаашид түүнийг өсгөх, геологи хайгуулын ажлыг орчин үеийн арга аргачлалаар явуулах, эрчимжүүлэх шаардлага гарч байгаа юм.