


Chapter 8

Mongolia

Although uranium occurrences are widespread in Mongolia, minable or potentially economic deposits are restricted to date to the *North Choibalsan* region (Mardai/Dornod District, referred to as Mardai in Mongolian and Dornod (or Dornot) in Russian papers) in NE Mongolia and to the *Gobi Desert* in S Mongolia (e.g. Choir, Khairkan, Undurshil, Sainshand Basins) (Note: data given for U deposits in Mongolia are based on 1995 status unless otherwise cited). Deposits in these two regions are of volcanic and sandstone type, respectively. Other types of U mineralization found in Mongolia include vein-, surficial-, metasomatite-, intrusive-, metamorphite-, lignite-, and phosphorite-types.  **Figure 8.1** shows the distribution of principal uranium regions and districts or areas.

Proven and probable in situ uranium resources (RAR + EAR-I) amount to 80 000 t U, 57 000 t U of which are contained in volcanic-type deposits and about 19 000 t U in sandstone-type deposits. Other types of deposits contain 4 000 t U (Mironov et al. 1993). OECD-NEA/IAEA (2005) reports recoverable resources of 46 200 t U RAR and 15 750 t U EAR-I.

The *Dornod*, *Gurvanbulag*, and *Mardaingol* deposits in the Mardai District, North Choibalsan region were developed for mining in the late 1980s. Mining lasted from 1989 to 1995 and produced 535 t U at grades ranging from 0.098% to 0.145% U. ERDES Mining Enterprise (a state-owned JV of Mongolia and USSR/Russian Federation) was the operator. Ore was shipped by rail (485 km) to the mill at Krasnokamensk in Transbaykalia, Russia.

Uran Company Ltd., a state-owned Mongolian enterprise, is in charge of uranium-related activities.

Sources of information. Batbold 2001; Filonenko et al. 1993; IAEA 1995, 2007; Mironov 2003; Mironov and Rogov 1992, 1993; Mironov et al. 1993, 1995; OECD-NEA/IAEA 1993, 1995, 1997, 2005; pers. commun. by Chuluun O and staff of Uran Company of Mongolia Ltd., and staff of ERDES Mining Enterprise.

After finishing the manuscript, some new publications became available and the interested reader is in particular referred to the books by Ischukova et al. (2002) and Mironov (2003). Mironov's (2003) book "Uranium of Mongolia" provides the most comprehensive and specific compilation on uranium deposits and resources of this country based on material that was obtained from the 1950s to the early 1990s by Soviet geologists working in the Mongolian People's Republic.

(Note: Due to discrepancies in the various sources of available information and errors in the English translation or transcript of Russian or Mongolian terms and names, some of the here presented descriptions and figures may be incorrect and names may be spelled differently.)


Historical Review

Limited uranium exploration from 1945 to 1960 resulted in the discovery of uraniumiferous lignite occurrences in eastern Mongolia. Systematic exploration for uranium and other metals was conducted from 1970 to 1990 by the former Soviet "Mongolian Geological Survey Expedition" (renamed "Eastern Complex Exploration Expedition" in 1990, a subsidiary of the "USSR Ministry of Geology") and "May Survey Expedition" (VSEGEL/Geological Institute in St. Petersburg). As a result, in excess of 1 600 uranium showings or radioactive anomalies, about 100 U occurrences, and 6 deposits were detected.

Dornogovi (Dorno Gobi) region: Uranium-related exploration was first conducted in 1955–1958 and resulted in the discovery of three lignite-type uranium occurrences. Subsequent exploration identified several volcanic-type occurrences, including Ulaan-nuur, in 1971–1973, and sandstone U mineralization including the Kharaat deposit and several occurrences in the Choir Basin in 1986–1988.

Exploration in the *northern Choibalsan region* was successful in the 1970s with the discovery of four uranium deposits, Dornod in 1973, Gurvanbulag in 1974, Mardaingol in 1979, and Nemer in 1987, and several occurrences, which became the Mardai/Dornod District. Since the 1990s, several foreign companies continued exploration in joint ventures with Russian and/or Mongolian institutions.

Regional Features of Uranium Distribution in Mongolia

Uranium Provinces and Associated Uranium Occurrences Four metallogenetic provinces are outlined in Mongolia (from N to S): Northern Mongolian, Khentei-Daur, Mongol-Priargun, and Gobi-Tamtsag ( **Fig. 8.1**). Each of these provinces differs by its geological setting, type of uranium mineralization, association of minerals, and mineralization age. Some forty areas with U mineralization occur in these provinces.

The Mongol-Priargun metallogenetic province spatially coincides with the homonymous continental Mesozoic volcanic belt in eastern Mongolia. This belt can be traced for 1 200 km in NE-SW direction and 70–250 km in width and includes several caldera structures with volcanic-type U deposits in North Choibalsan, Berkh, Eastern, and Middle Gobi regions as well as sandstone and lignite U mineralization in Cretaceous basins. Sandstone U deposits include Kharaat in the Choir Basin and some small deposits/occurrences in the Gurvansaikhan, Khairkan, Oshiin-nuur, Tavansuveet, Undurshil (Ongiingol) basins; uraniumiferous lignite is reported from the Choibalsan and Ulziit basins.

The Gobi-Tamtsag U province covers 1 400 km in NE-SW length and 60–180 km in width at the southeastern periphery of Mongolia. This province encompasses the Tamtsag, Sainshand,

Zuunbayan, and Undurshil Cretaceous basins with sandstone-type U occurrences including the Nars deposit in the Sainshand Basin.

The Khentei-Daur U province is 700 km long and 250 km wide and covers the Khangai and Khentei mountains in central and NE-central Mongolia. Vein U-Th-REE mineralization in fractured Mesozoic leucogranite as known, e.g. from the Janchivlan granitic massif, are typical for this U province. The Chuluut area, northern Khangai region, contains sandstone hosted U mineralization (basal channel type?) in Cenozoic sediments of the Suimin-gol Basin.

The North Mongolian U province covers a 1 500 km long and 450 km wide terrane in northern and northwestern Mongolia. Various types of complex U mineralization associated with a variety of rocks of mainly Late Proterozoic and Paleozoic age occur in this province.

Types of Uranium Deposits

Uranium in Mongolia may be attributed to volcanic, sandstone, lignite, metasomatite, intrusive, and phosphorite types as well as to vein and/or structure controlled surficial types in leucocratic granite and metamorphics. Deposits of economic interest are restricted to volcanic and sandstone types.

Volcanic-type deposits include structure-bound and strata-bound ore bodies (in Russian literature referred to as F-Mo-U deposits in volcanic-tectonic structures). Most deposits are associated with Upper Jurassic-Lower Cretaceous effusives and sediments of rhyolite and basalt-rhyolite composition within the intracontinental Mongol-Priargun volcanic belt. Significant deposits exist in the North Choibalsan region (Mardai/Dornod District); they are similar to the volcanic-type deposits in the Strel'tsovsk District in Transbaikalia, Russia. Small deposits/occurrences are known from the North Kherlen and Baiderin uplifts in the Central Mongolian fold belt, as well as from the South Mongolian, Mongol-Transbaykal, and North Mongolian fold belts/systems.

Sandstone-type deposits include tabular/peneconcordant (related to surface-bound oxidation and at depth to partially oxidized permeable strata), basal channel, and rarely roll-shaped subtypes (referred to as uranium in weakly lithified deposits associated with zones of ground and stratum oxidation and reduction). Sandstone-type mineralization is widespread in intermontane Cretaceous basins in the Dornogovi (Eastern Gobi) and Gobi-Tamtsag regions in southern and southeastern Mongolia. Some basal channel(?) U occurrences were discovered in Cenozoic sediments in the Chuluut area, Khentei-Daur U province.

Vein-type uranium occurrences consist mainly of disseminated U^{6+} minerals (of surficial/supergene origin?) within fractured, highly radioactive Mesozoic leucogranite massifs such as

in the Khangai and Khentei-Daur uplifts in the Mongol-Transbaykal fold belt.

Lignite-type U concentrations are reflected by syngenetic and redistributed U in lignite seams in Lower Cretaceous basins. Grades average up to 0.05% U. Uraniferous lignite is reported from the Sumiin-nur basins in the North Choibalsan region and several basins in the Dornogovi and Gobi-Tamtsag regions.

Metasomatite-type U occurrences and showings with U-Th-REE or U-Th mineralization are known from metasomatized (mainly albitized) zones in subalkaline and alkaline granite and syenite intrusions, and in pegmatite in the North Mongolian U province. Mineralization occurs in the form of discontinuous lenses, pods, or aggregates with impregnated uraninite, uraniferous titanate, zircon, monazite, thorite, and orthite.

Phosphorite-type U mineralization consists of small occurrences of uraniferous apatite in Cretaceous continental clastic sediments. Grades average a few hundred ppm U but can locally be up to 0.3% U with P_2O_5 contents of commonly a few percent with local maxima of 20%.

Many of the identified U occurrences and particularly those described as migmatite, metamorphite, phosphorite, and lignite type are mainly reflected by elevated U and/or Th background values. Some of the sites have minor uranium enrichments mostly due to locally restricted supergene concentrations in the form of fracture-bound, surficial-type mineralization.

8.1 North Choibalsan Region, Dornod Aimag

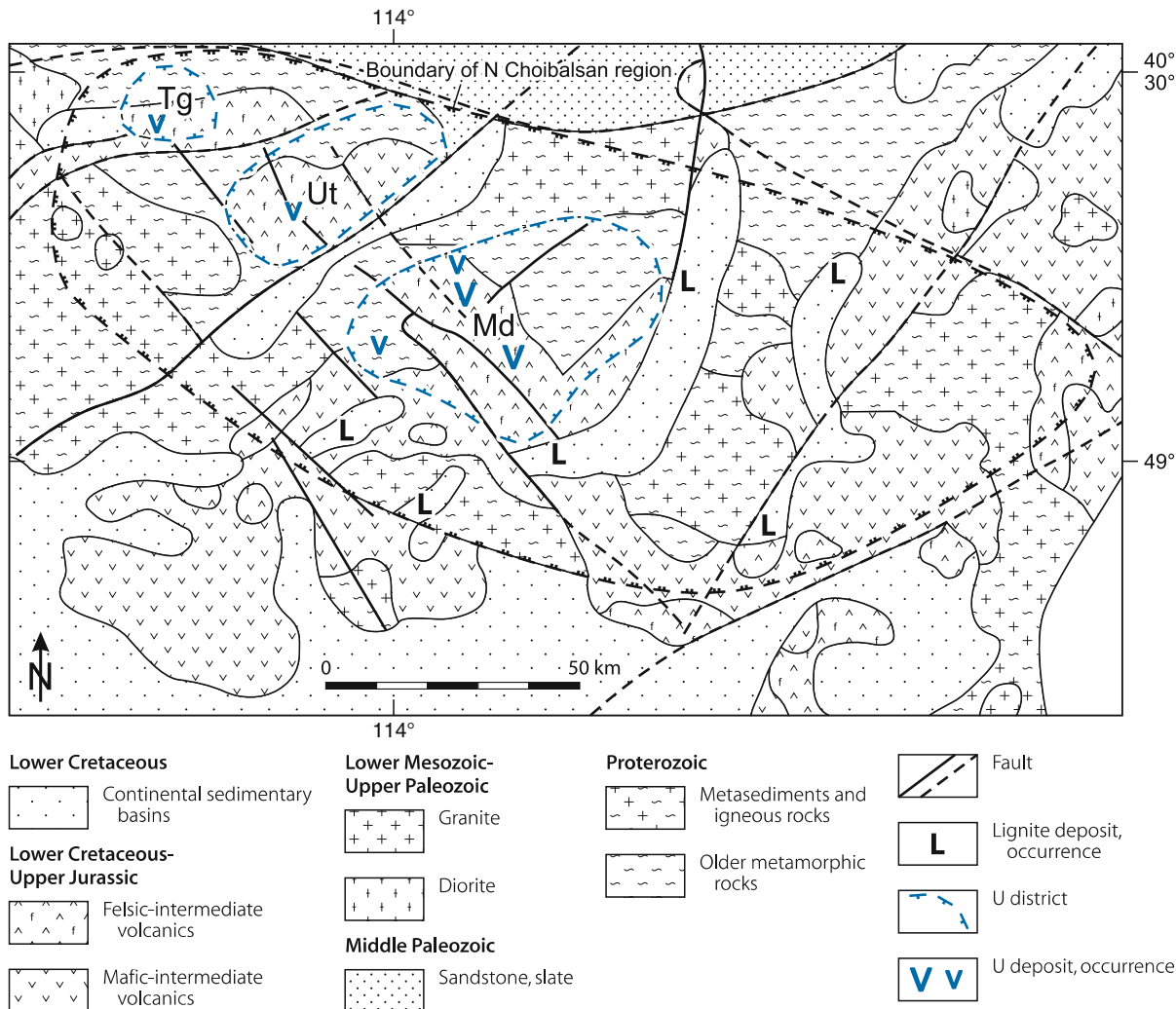
Four uranium districts have been established in the North Choibalsan volcanic region, Mardai (Dornod), Ugtam, Turgen, and Engershand (Fig. 8.2). All contain volcanic-type (fluorine-molybdenum-uranium-type in volcano-tectonic structures in Russian terminology) uranium deposits.

Uraniferous lignite occurs in the Cretaceous Sumiin-nuur Basin (Delger-nuur, Shinebulag, and Bagazos-nuur occurrences) located adjacent to the southwest of the North Choibalsan volcanic region, and further to the south in the Cretaceous Choibalsan Basin (e.g. Choibalsan, Bayan-bulag, and Khashaat occurrences).

8.1.1 Mardai (Dornod) District, Dornod Aimag

The Mardai District (in Russian literature referred to as Dornod or Dornot District) is located in Dornod aimag (= province) in northeastern Mongolia, some 600 km east of Ulaan Baatar. This district includes the uranium deposits *Dornod*, *Gurvanbulag*, *Mardaingol*, and *Nemer*, and a number of occurrences (Fig. 8.3) (although termed deposits in Mongolian and Russian papers, these are actually ore fields composed of ore zones with several deposits/ore bodies). Original resources (RAR + EAR-I) of the four deposits total about 50 000 t U at a grade of 0.16% U.

Fig. 8.2. North Choibalsan region, generalized geological map with location of U districts (*Md* Mardai, *Tg* Turgen, *Ut* Ugtam) (after Mironov and Rogov 1992)



The district also contains deposits of Pb-Zn-Ag with some U (Bayandun, Muhar, Tsav, Ulaan), fluorite (Baruun-su, Hubbulag, Khooley), gold (Urlinobin), molybdenum (Arbulag, Avdar-Tolgoy), and tungsten (Chuulun-Khuriete).

In 1989 the Dornod, Gurvanbulag, and Mardaingol deposits had been developed for underground mining and ore bodies # 2a-2b of the Dornod deposit had been developed for open pit mining. Production capacity was planned at 2 million t of ore annually. Underground mining ceased, however, in 1992, while open pit mining continued until 1995. Production amounted to 93.6 t U (at a grade of 0.117% U) in 1989, peaked at 105.2 t U (0.118% U) in 1992, and dropped to 20.2 t U (0.145% U) in 1995. A total of 535 t U were recovered during this period. All ore was transported 485 km by rail to the Krasnokamensk mill in Transbaykalia, Russia.

Sources of information. Batbold 2001; Filonenko et al. 1993; IAEA 1995, 2007; Mironov 2003; Mironov and Rogov 1992, 1993; Mironov et al. 1993, 1995; OECD-NEA/IAEA 1993, 1995, 1997; Petrov et al. 2002, 2003; and pers. commun. by Chuluun O and

staff of Uran Company Ltd. of Mongolia and ERDES Mining Enterprise. Additional information is available in the more recent publications by Ischukova et al. (2002) and Mironov (2003).

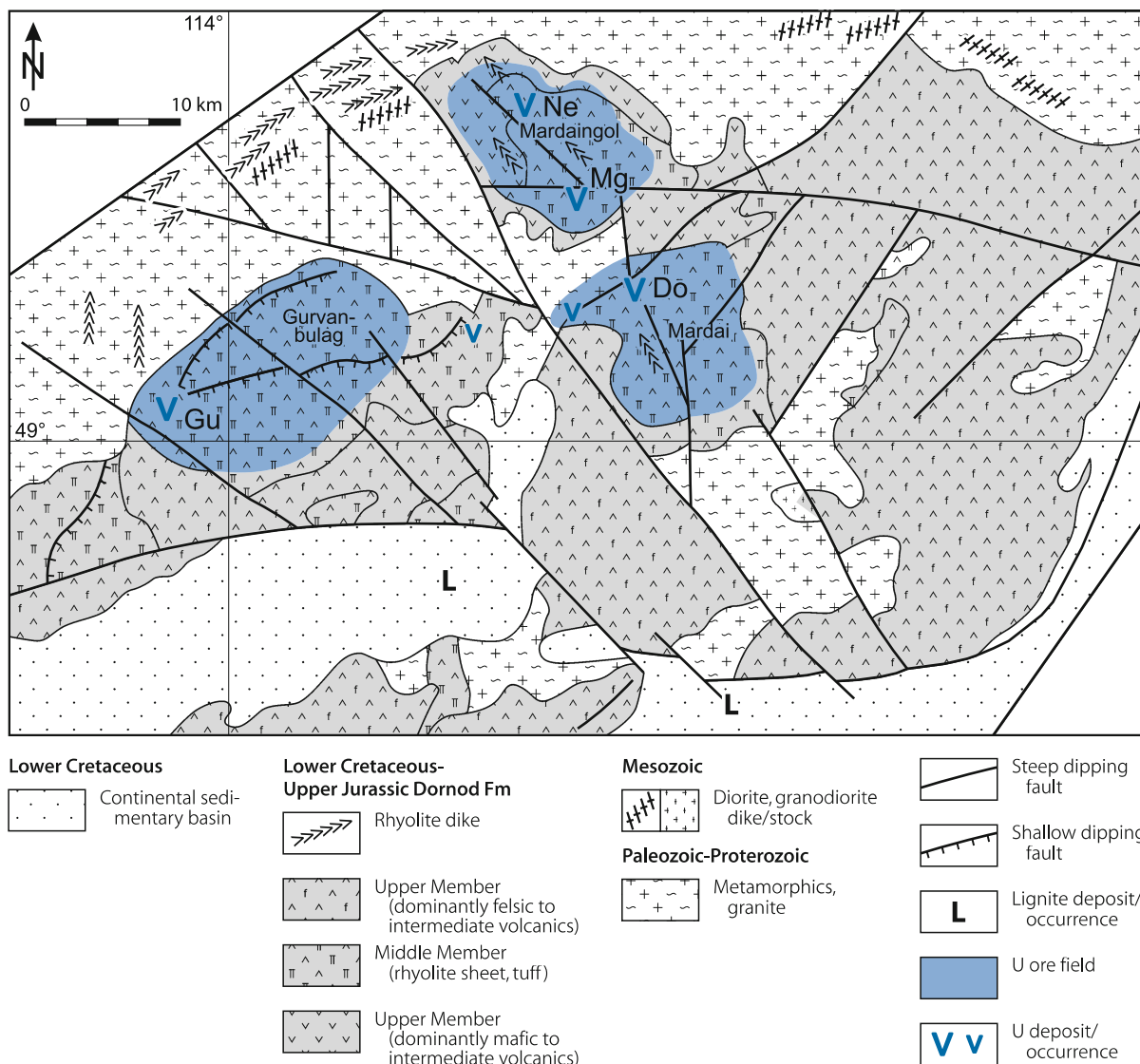
Regional Geological Setting of Mineralization

The Mardai District is at the northern margin of the *Dornod Volcano-Tectonic Structure*. This is one of the largest volcanic complexes within the Mongol-Argun intracontinental volcanic belt. It evolved during Late Mesozoic tectonic-magmatic activation that affected the Precambrian Manzhur-Chinese Platform. The belt extends for 1 200 km in SW-NE direction from the edge of the Mongolian Altai mountains in southern Mongolia to the Pri-Argun area in southeastern Transbaykal in Russia where volcanic-type U deposits are exploited in the Streltsovsk District.

The Mardai area is underlain by two geological units: a Late Mesozoic continental sedimentary-volcanic sequence that rests unconformably upon a crystalline basement of Proterozoic to early Mesozoic age.

Fig. 8.3.

North Choibalsan region, Mardai (Dornod) U District, generalized geological map with location of volcanic-type U ore fields and deposits (after Mironov and Rogov 1992). (U deposits: *Do* Dornod, *Gu* Gurvanbulag, *Mg* Mardaingol, *Ne* Nemer)



The *Late Mesozoic upper unit* consists of the Zuunbayan Formation composed of Early Cretaceous lignite-bearing continental sediments and the underlying Dornod Formation of Early Cretaceous-Late Jurassic continental, subalkalic, volcanogenic, and sedimentary facies, which fill graben structures. The *Dornod Formation*, 1 000–1 500 m thick, is subdivided into three members each characterized by volcanogenic suites derived by subsequent cycles of volcanism:

- an *Upper Member* (>1 000 m thick) of rhyolite-trachyrhyolite-trachyandesite
- a *Middle Member* of rhyolite, and
- a *Lower Member* (<400 m thick) of basalt-trachyandesite/dacite-rhyolite

About 75% of the Dornod lithologies consist of stratified pyroclastic and outflow volcanic rocks composed of rhyolite, quartz-feldspar porphyry, andesite-basalt, and weakly fluidal felsite. Intercalated continental clastic and lacustrine

sediments containing organic matter constitute the remainder. Conglomerates overlain by gritstone, sandstone, and siltstone beds occur at the base of the Dornod Formation in paleo-depressions.

The *crystalline basement* includes

- Jurassic granite-porphyry, granodiorite and diorite bodies, syenitic, dioritic, and diabase dikes, and subsequent subvolcanic bodies and dikes of felsic and andesitic porphyries
- large bodies of Late Paleozoic granite, diorite, and gabbrodiorite (Tsenkher-gol Complex)
- widely distributed Early Paleozoic K- and Na-metasomatized granodiorite and diorite (Modochudag Complex)
- Proterozoic granite-gneiss and porphyroblastic granite, and
- an older complex of Proterozoic to Early Paleozoic regionally metamorphosed (amphibolite facies) geosynclinal and continental sediments (schist, gneiss, marble) and volcanics

Structural elements of the region are characterized by arched uplifts and downfaulted grabens largely controlled by NE-SW- and NW-SE-trending regional faults.

Principal Host Rock Alteration

Ore-related host rock alteration is primarily argillization. Alteration products include hydromica, montmorillonite, kaolinite, chlorite, carbonate, fluorite, quartz, and hematite. Most intense is hydromica-montmorillonitization. Hematitization tends to be related to mineralized zones and its intensity seems to correlate with the uranium grade.

A distinct primary geochemical dispersion halo of U and associated elements such as Pb, As, Ag, and Mo envelopes ore bodies. The halo is controlled by, and commonly confined to the ore-hosting permeable cataclastic lithologies and/or faults. Fault-related halos are generally of elongated shape. Halo dimensions surpass those of ore bodies by one to three times. Uranium forms the most extensive aureole and may extend in excess of 500 m from ore bodies.

Weathering-related alteration is very limited and is essentially restricted to major fault zones along which it persists to depths up to 300 m.

Principal Characteristics of Mineralization

Coffinite and pitchblende are the principal U minerals. Brannerite, uraniferous leucoxene and titanite occur in minor or accessory amounts. Hexavalent U phases such as uranophane, beta-uranotile, curite, woelsendorfite, kasolite, or amorphous U-hydroxides replace primary uranium minerals in oxidized zones.

Associated ore minerals include arsenopyrite, chalcopyrite, galena, marcasite, molybdenite, pyrite, sphalerite, and hematite. Gangue minerals are dominated by quartz, biotite, hydromica, montmorillonite, and chlorite (chamosite); K-feldspar, fluorite, muscovite, ankerite, calcite, siderite, baryte, leucoxene occur in minor amounts; and sericite, tourmaline, zircon, titanomagnetite, and anatase occur in traces.

Uranium minerals occur mostly as fine- to coarse-grained aggregates, 0.001–0.5 mm in size, and more rarely as up to 2 mm thick veinlets. Ore textures exhibit impregnation, stringer, reticulate, rarely banded and earthy, and, in high grade mineralization (>0.3% U), breccia and cement modes.

Mineralization can be monometallic or polymetallic consisting of uranium and molybdenum as in the Mardaingol deposit. Both elements correlate geochemically and their spatial distribution is often identical. Similar to uranium, molybdenum distribution and tenor are commonly highly irregular.

The principal host is the Dornod Formation but some uranium veinlets also occur in the crystalline basement. In the Dornod Formation, U is distributed in almost all types of rocks. Sizable ore-grade accumulations, however, are restricted to permeable, mostly cataclastic horizons within certain sedimentary and volcanogenic horizons at the base and within the Lower and

Middle Member of the Dornod Formation, in which principal ore-hosting lithologies include

- brecciated andesitic-basaltic pillow lava (example: Dornod ore body 7),
- clastic sediments (sandstone/arkose, conglomerate) containing detrital plant remains (ex.: Dornod ore bodies 2, 3a, 3b; Gurvanbulag, and Nemer deposits),
- oligophytic rhyolite lava and related tuff (ex.: Dornod ore bodies 1, 4, 5, 6, 8, 10; and Mardaingol deposit), and
- vitroclastic felsic tuff and vitric felsite (ex.: Gurvanbulag deposit).

Most sites favorable for tabular mineralization are controlled primarily by strata-peneconcordant, flat to shallow dipping faults and, to a lesser degree, by steeply dipping faults. The latter also constitute the host for veinlike to stockwork-type mineralization particularly at their intersections with shallow structures.

General Shape and Dimensions of Deposits/ Characteristics of Individual Ore Bodies

Deposits consist of several ore zones containing one to several ore bodies enveloped in a geochemical dispersion halo. Ore bodies are composed of ore lenses or lodes defined by a minimum uranium content of 0.06% U. Sub-ore grade mineralization commonly intervenes between ore shoots. Distances between ore bodies within an ore zone vary from 50 m to 350 m. Ore bodies are distributed blindly over a vertical interval from 30 to 600 m below surface.

Ore bodies are of peneconcordant-tabular and veinlike to stockwork configuration and exhibit the following characteristics:

Tabular ore consists of heterogeneously distributed uranium forming strata-peneconcordant tabular to lenticular, in plan view elongated to trapezoid-shaped bodies controlled by cataclastic zones along flat to shallow dipping faults. Ore bodies may contain several, laterally adjacent and/or superjacent ore lenses enveloped by weak mineralization. Dimensions of tabular ore are given in [Table 8.1](#).

Veinlike to stockwork ore bodies are predominantly of irregular shape and may grade laterally into tabular ore. They consist of low-grade mineralization enveloping unpredictably distributed, variably structured lodes composed of ore pods, pockets, and/or lenses interconnected by joint fillings, stringers, and veinlets of ore-grade material. Subparallel, steeply dipping NW-SE- or N-S-oriented faults cutting (1) intraformational and (2) flat to shallow inclined fault and fracture zones positioned at strata contacts control the position of these lodes. Dimensions of vein-stockwork ore are of the order of magnitude shown in [Table 8.2](#).

Regional Geochronology

U-Pb systematics of U minerals yield ages from 153 to 136 Ma. Golubev et al. (1994) report an age of 138–136 Ma for U deposition in the Dornod volcano-tectonic structure. These Late

Table 8.1.

Mardai District, order of dimensions of ore zones with tabular uranium mineralization

Parameter	Ore zones	Ore bodies	Ore lenses
Length (m)	<100–3100	<100–1700	<10–>1000
Width (m)	<50–1600	<50–900	<10 to several 100
Area		Several 10 m ² to 0.5 km ²	
Thickness (m)		<1–40	0.3–9
– ore bearing interval	<1–40		
Resources (t U)	<10–14000	<10–5000	<1–>1000
Grade (% U)	0.09–0.6	0.06–0.7	0.06–>1

Table 8.2.

Mardei District, order of dimensions of ore zones with vein-stockwork uranium mineralization

Parameter	Ore zones	Ore bodies
Length (m)	40–1200	10–100
Width (m)	<1–500	0.3–25
Depth extension (m)	50–370	<10–60
Thickness of individual lodes (m)		0.3–20
Resources (t U)	Some 10s to 7000	Few 10s to 150
Grade (% U)	0.09–0.18	0.06–0.7

Jurassic to Early Cretaceous ages are practically time equivalent to deposits in the Streltsovsk Caldera in Russia (136–134 Ma).

Dating of sericite derived by propylitization associated with polymetallic mineralization give K-Ar ages of 161 ± 7 Ma while K-Ar ages of pre-uranium hydromicas yield 145–143 Ma. Rb-Sr ages of 170–140 Ma were obtained for rocks of the Lower Member of the Dornod Formation.

Potential Sources of Uranium

Felsic volcanics tend to constitute potential sources for uranium and other metals. These rocks contain from 6 to 21 ppm U or more with highest amounts in vitric rocks. Chemillac et al. (2005b) report 13.6–24.9 ppm U contained in melt inclusions in comanditic rhyolite.

Principal Ore Controls and Recognition Criteria

Ore bodies are predominantly of tabular and subordinately of vein-stockwork configuration controlled by lithology and structure as reflected by the following criteria:

Host environment

- Calderas composed of felsic to mafic effusives and pyroclastics, and terrigenous sediments (Dornod Formation)
- Preferential host rocks include cataclastic, permeable
 - tuffaceous horizons (vitroclastic felsic ash tuff, felsite/rhyolitic tuff,

- felsic and mafic volcanic lava sheets (oligophyric rhyolite lava, volcanic glass and vitric felsite horizons, andesitic-basaltic pillow lava),
- quartz-feldspar porphyry/felsic porphyry dikes,
- clastic sediments with abundant vegetal matter.
- Brittle deformation is associated with
 - major and regional faults of steep dip and oriented mainly NW-SE and NE-SW and their intersection, and
 - flat to shallow dipping fault-fracture zones positioned intraformational and at facies boundaries of favorable lithologies (andesitic-basaltic pillow lava, vitrophyric felsic ash tuff, felsite/oligophyric rhyolite).

Alteration

- Pre-ore hydromicazation-montmorillonitization
- Syn- or post-ore argillization, carbonatization, hematitization
- Direct relation of hematitization to U mineralization and grade of ore
- Limited weathering effects but extending to great depths along major faults

Mineralization

- U-oxide and U-silicate minerals with sulfides of Fe, Mo, Pb, Zn, Cu, and quartz, phyllosilicates, carbonates are the principal ore constituents
- Ore texture is largely of impregnation nature
- Ore bodies are enveloped in halos of low grade U, As, Mo, and Pb concentrations

- U mineralization is structure-bound and occurs in strata-peneconcordant tabular or vein-stockwork lodes of highly variable dimension and configuration
- Ore bodies are controlled by
 - steeply dipping major faults and their intersection,
 - flat to shallow inclined fault-fracture zones positioned intraformational and at facies boundaries,
 - intersections of steeply dipping with flat to shallow fault zones.
- Tabular mineralization is restricted to flat or shallow dipping fault, shear, and breccia zones, which occur particularly
 - at the contact of volcanic sheets with tuffaceous and sedimentary horizons and most intensely at the base of oligophyric rhyolite,
 - in tuffaceous-sedimentary beds, which separate the Lower and Middle Member, and
 - in andesitic-basaltic pillow lava of the Lower Member of the Dornod Formation.
- Some intraformational, flat lying faults form hanging or footwall boundaries of ore lodes in some deposits suggesting that these faults acted as impermeable barriers to ore-forming solutions
- High angle faults form lateral boundaries of, and partly govern the grade distribution of uranium in tabular ore bodies
- Vein and stockwork mineralization favor high angle faults trending NW-SE and, to a minor extent, N-S, and their intersections with favorable lithologies such as tuff, felsite, and/or quartz-feldspar porphyry
- Vein-stockwork ore lodes are generally small
- Potential sources of uranium and other metals are provided by U-bearing felsic volcanics
- Reducing potential is provided by
 - abundant detrital vegetal matter in terrigenous sediments, and possibly by
 - ferric iron or other elements of reducing capacity in mafic volcanics.

Principal Aspects of Metallogenesis

The metallogenesis of U deposits in the Mardai District is still enigmatic. U mineralization tends to be related to volcanics, particularly of felsic composition. These felsic volcanics constitute a potential source of uranium and other metals associated with uranium mineralization as documented by Chemillac et al. (2005b). These authors investigated hydrothermally altered and brecciated samples of alkali rhyolite of the second volcanic cycle, and, in addition, melt inclusions in quartz phenocrysts unaffected by alteration.

Relic primary minerals consist of quartz, rare K-feldspars (Or 91–94), plagioclase (An 20–32), biotite, and zircon embedded in an argillized matrix (mainly sericite). Late carbonate and fluorite occupy fractures and hematite occurs within sericite aggregates in extremely altered material. Devitrification features such as spherulites and perlitites are common. Mineralized samples with up to 0.1% U contain hydrothermal uraniferous zircon, brannerite, coffinite, and, as late phases, bastnaesite and strontianite. *Bulk*

rock chemistry of rhyolite and rhyolitic breccia show medium to high silica (72.87–78.85% SiO₂), high alkalis (3.8% Na₂O + 8.3% K₂O), medium Fe (1.0–2.2% Fe₂O₃), and extremely low Ca, Mg, Mn, Ti, and P contents. Trace elements amount to 205–288 ppm REE, 49–93 ppm Nb, 4.2–8.2 ppm Ta, 32–53 ppm Th, 63–157 ppm Y, 257–418 ppm Zr, 3–233 ppm Ba, and 24–141 ppm Sr, values, which are typical for fractionated peralkaline magmas. The chemistry of *melt inclusions* is also characterized by high silica (74%) and alkalis (8.1–11.4%), and low Ca, Ti, P, and Cl contents, but show high F (0.8–3.5%) contents, and elevated U (13.6–24.9 ppm), Th (21–49 ppm), REE (215–224 ppm), Zr (233–263 ppm), Y (53–76 ppm), and Nb (52–76 ppm) values whereas Ba (11–32 ppm) and Sr (1–10 ppm) are clearly depleted.

Chemillac et al. (2005b) deduce from these data that the initial rhyolitic magma preserved as melt inclusions in quartz had a highly evolved comenditic composition, was mildly peralkaline, and enriched in F, U, Th, REE, and Zr. Their U and Th contents match those in rhyolitic melts of the Streltsovsk Caldera, Russia (Chabiron et al. 2001). These comenditic rhyolites constitute substantial sources of uranium. The initial U content in the melt combined with the volume of erupted rhyolite are largely sufficient to explain the ore resources. Mobilization of the ore-forming elements was by hydrothermal activity, which is indicated by the largely aphyric nature of these rhyolites.

According to the various papers by Mironov and co-workers, the postulated hydrothermal solutions were either of late volcanic, intraformational, or meteoric origin, or a combination thereof. Late volcanic events may have provoked mobilization of such fluids. Reducing conditions required for reduction and arrest of uranium existed particularly at sites where sediments contained abundant plant remains. An additional reductant may have been ferric iron of mafic minerals as found in andesite and basalt. Physico-chemical conditions (effervescence, break up of fluid components etc.) may have otherwise contributed to uranium precipitation particularly in volcanic outflow facies.

Tectonic activity was an additional crucial prerequisite for ore formation. Large, high-angle and flat to shallow dipping, strata-peneconcordant faults and associated cataclastic zones in volcanic effusive and pyroclastic rocks, and permeable continental clastic sediments provided favorable pathways for migration of mineralizing fluids and open space for ore accumulation as reflected by the containment of the major portion of tabular mineralization in these zones. Cataclasis of felsic volcanics may also have been a prerequisite for uranium leaching in case, these facies are considered the source of ore-forming uranium and other metals.

Isotope dating of uranium minerals indicate a time interval for metallogenic event(s) between 153 and 136 Ma and a most likely time interval for U ore formation 138–136 Ma ago, i.e. during Late Jurassic and Early Cretaceous periods. This latter time bracket virtually corresponds to U ore formation in the Streltsovsk Caldera, located to the northeast in the same volcanic belt in Asian Russia. Hence it may be assumed that the formation of the volcanic-type U-Mo deposits in the Mardai District evolved by similar complex and perhaps multistage processes as deposits in the Streltsovsk Caldera (see Chap. 10: *Russian Federation, Asian Territory*).

8.1.1.1 Dornod Deposit

The Dornod deposit is located some 90 km north of Choibalsan. This volcanic-type deposit contains twelve ore zones composed of one or more ore bodies of monometallic, peneconcordant-tabular and/or veinlike to stockwork mineralization (► Fig. 8.4). Original resources totaled 33 000 t U, including 29 000 t U RAR + EAR-I at a grade of 0.17% U.

Ore bodies 2b and 2c were mined by open pit methods (130 m deep) from 1988 to 1995. The # 7 ore body was mined by underground techniques (520–580 m deep) from 1989 to 1992 when exploitation was stopped. Planned underground production (partly by underground leaching) was 1.5 million t ore per year.

Sources of information. IAEA 1995, 2007; Mironov 2003; Mironov and Rogov 1992, 1993; Mironov et al. 1995; pers. commun. by Chuluun O and staff of Uran Company Ltd. of Mongolia and ERDES Mining Enterprise.

Geological Setting of Mineralization

Situated in the central part of the Dornod Volcanic-Tectonic Structure, the Dornod deposit exhibits a geologic setting, which comprises a crystalline *basement* of predominantly palaeogenetic, K- and Na-metasomatized granodiorite of the Paleozoic Motochudag Complex, and which contains xenoliths of Proterozoic schist, gneiss, and marble. Separated by a distinct unconformity, Late Jurassic-Early Cretaceous sedimentary and volcanogenic facies of the Dornod Formation overly the basement. Dominant facies are stratified volcanics covering approximately 90% of the area.

The *Dornod Formation* consists of three members derived by subsequent cycles of volcanism. The *Upper Member* is weakly developed and consists of trachy-andesite sheets. The *Middle Member* includes 750 m thick stratified (from top to bottom) feldspathic rhyolite, lithic ignimbrite, oligophyric rhyolite, and a basal rhyolitic tuff horizon. The *Lower Member* is composed of, from top to bottom, lacustrine sediments, sheets of andesitic-basaltic pillow lava, which are dominant, an assemblage of interbedded carbonaceous lacustrine sandstone, mudstone and tuffite, and a basal conglomerate in paleo-depressions.

Fault systems are oriented NE-SW, N-S, and NW-SE. Horsts and grabens are primarily controlled by NE-SW-trending faults. Repeated reactivation of N-S and NW-SE structures generated high angle and shallow dipping faults, shear and breccia zones. Shallow dipping cataclastic zones with good permeability developed preferentially at or near the contact of volcanic sheets with tuffaceous and sedimentary beds. Their development is most intense in tuffaceous-sedimentary beds at the base of oligophyric rhyolite, which separate the Lower and Middle Member, and in andesitic-basaltic pillow lava of the Lower Member.

Host Rock Alteration

Most prominent is pre-ore hydromica-montmorillonitization. Ore-related alteration features include carbonatization, hydromicization, montmorillonitization, kaolinization, chloritization, and hematitization. Hematitization is directly

related to mineralized zones and its intensity tends to correlate with the grade of mineralization.

A distinct geochemical halo of U and associated elements such as Pb, As, and Mo is developed around ore bodies. Halos are commonly of elongated shape largely controlled by faults. The dimensions of halos surpass those of ore bodies by 2–3 times. Uranium forms the most extensive aureole extending in excess of 500 m from ore bodies.

Alteration by weathering is very limited and essentially restricted to major fault zones along which it locally extends to depths in excess of 400 m.

Mineralization

Coffinite and pitchblende are the principal U minerals. Uraniferous leucosene and titanate, minor brannerite and uranophane are ubiquitous in ore body # 7. Secondary U minerals include uranyl silicates (uranophane, beta-uranotile) and hydroxides (clarkeite, masuyite).

Associated ore minerals include chalcopyrite, galena, marcasite, molybdenite, pyrite, sphalerite, hematite, and minor arsenopyrite. Quartz, biotite, hydromica, montmorillonite, chamosite, minor ankerite, calcite, siderite, fluorite, baryte, leucosene, K-feldspar, muscovite, and rare tourmaline and anatase occur as gangue or ore accompanying minerals.

Uranium minerals occur mostly as fine- to coarse-grained aggregates, 0.001–2 mm in size. Ore texture is of impregnation type reflected by finely disseminated, globular, stringer, rarely banded and earthy features. Rich uranium mineralization has breccia and cement textures.

Ore-grade uranium is restricted to the Dornod Formation but low-grade mineralization occurs as stringers also in the basement.

Although uranium is found in almost all types of Dornod rocks, sizable ore-grade accumulations are confined to sedimentary and volcanogenic horizons at the base of and within the Lower and Middle Member of the Dornod Formation, and to faults cutting volcanic horizons at shallow angles. The principal host lithologies are

- brecciated andesitic-basaltic pillow-lava (ore bodies in zone # 7),
- carbonaceous sandstone/arkose containing up to 4% detrital vegetal matter (ore bodies 2a–c, and 3a–c), and
- oligophyric rhyolite sheets and vitroclastic felsic tuff (ore bodies 1, 4, 5, 6, 8, 10).

Three varieties of uranium assemblages related to host rock settings are noted:

- pitchblende-coffinite with uraniferous titanate in brecciated andesitic-basaltic pillow-lava (ore bodies in zone 7),
- pitchblende-coffinite in clastic sediments containing detrital plant remains (ore bodies 2a–c, and 3a–c), and
- pitchblende-coffinite in felsic effusive and pyroclastic rocks (ore bodies 4 and 5).

U⁶⁺ minerals occur in vein-stockwork ore bodies to depths of 500 m. They constitute 35% of the entire U mineralization in ore body 5.

Fig. 8.4.

Mardai/Dornod deposit, generalized **a** geological map with location of ore bodies, **b** E-W and **c** N-S section illustrating the litho-stratigraphic position of ore bodies in the Dornod Formation (after a, b Mironov et al. 1995; c Mironov and Rogov 1992)

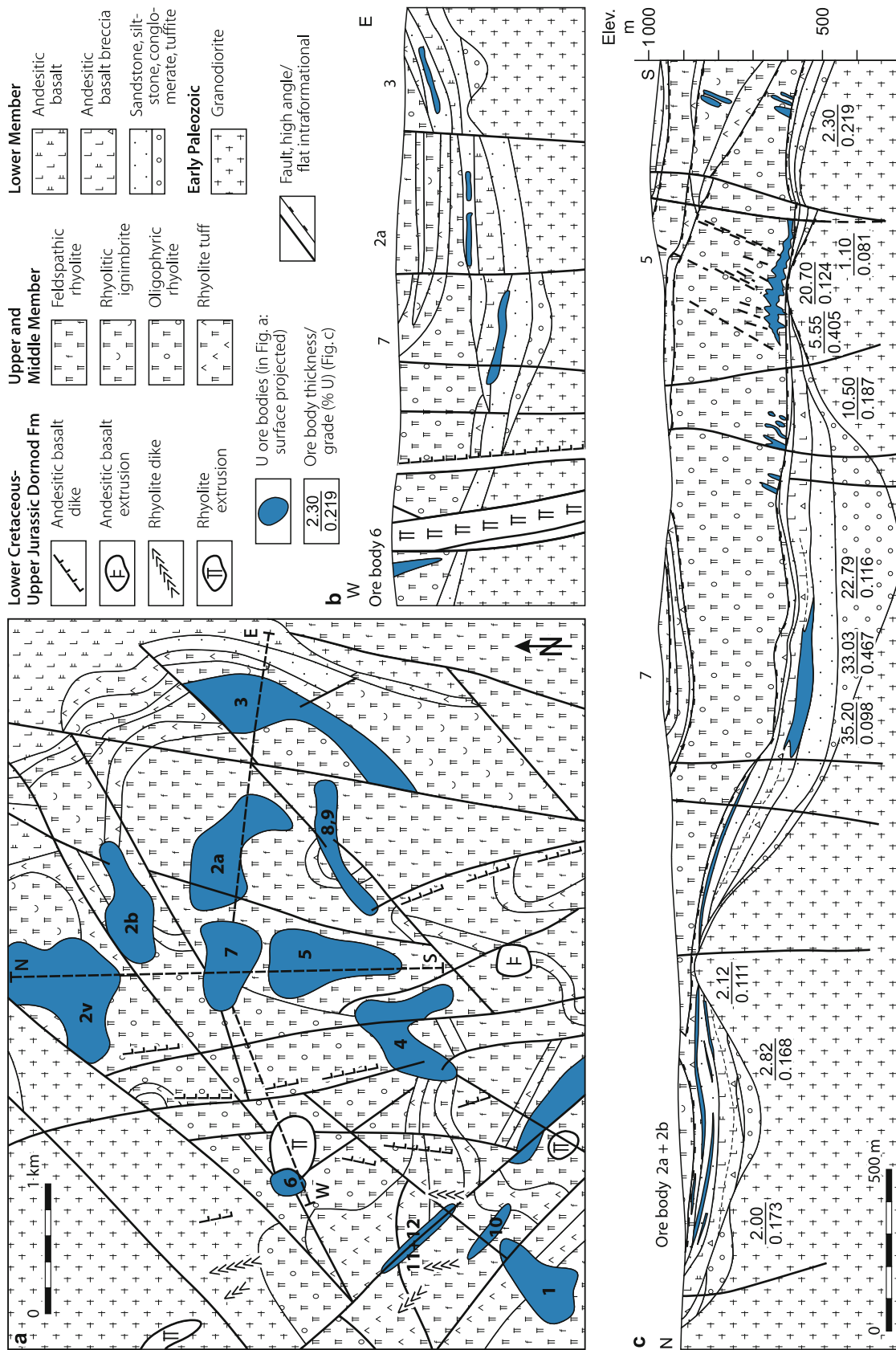
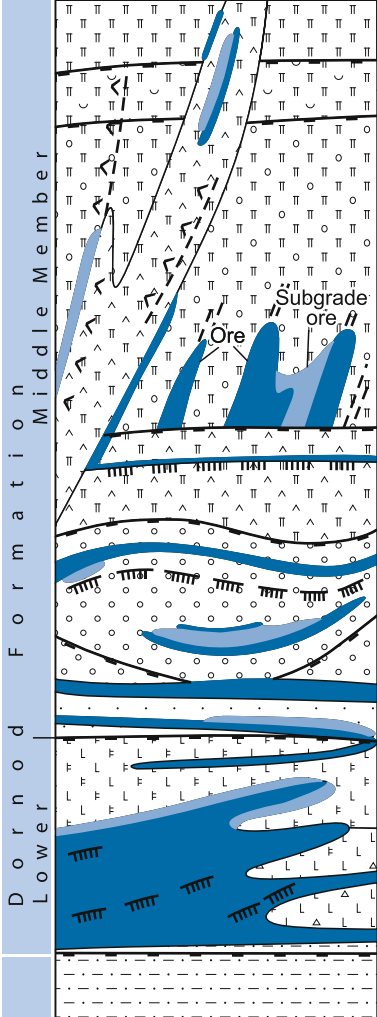


Fig. 8.5.

Mardai/Dornod deposit, scheme of geological setting, distribution, and configuration of ore bodies, and their percentage contribution to the reserves of the deposit (legend see Fig. 8.4) (after Mironov and Rogov 1993)

Litho-stratigraphic column	Lithologic-structural levels	Shape of ore bodies	Ore zone (number)	Ore body (number)	Percent of total reserves
	Contact of felsic extrusions and flow sheets	Small complex veinlike and stockwork	6		
			10		
			11		
			12		
	Steep fracture zone in basal oligophyric rhyolite sheet	Vein and stockwork	1		4
			4		13
			5		1
			8		
	Cataclastic zone in tuff, conglomerate, and fine clastic rocks enriched in organic matter located at contact of Lower and Middle members of Dornod Fm	Strata-bound tabular flat-lying	2	2a	4
				2b	10
				2c	12
		3	3a	3	
3b			1		
3c			2		
9		1			
Cataclastic zone of coarse-fragment breccia in basal basaltic andesite sheet	Lenticular and tabular bodies with irregular margins	7		49	

Shape and Dimensions of Deposits/Characteristics of Individual Ore Bodies

The Dornod deposit comprises twelve ore zones within an area of about 20 km². Individual zones contain one or more ore bodies (Fig. 8.4). The bulk of U resources is contained in ore zones 2, 3, 4, 5, 7, 8, and 9, which are grouped in an area 3 700 m long and 2 500 m wide. These zones account for 29 000 t U RAR + EAR-I at a grade of 0.175% U. Some 4 000 t U of subeconomic resources are delineated in ore zones 1, 6, 10, 11, and 12 in the Khavar sector in the W to SW part of the deposit. (Calculation of grades for (a) underground and (b) open pit mining is based on a cutoff grade of (a) 0.04% U, (b) 0.03% U, a minimum grade for ore sections in planview of (a) 0.06, (b) 0.05% U, and a minimum grade for mining blocks of (a) 0.10, (b) 0.08% U.)

Ore bodies are of peneconcordant-tabular and veinlike to stockwork configuration with characteristics as outlined below and shown in Fig. 8.5. All ore bodies are blind and occur over

a vertical interval from 30 to 600 m below surface. Distances between ore bodies are 50–350 m. Zones # 2, 3, and 7 contain the largest ore bodies.

Tabular Ore Bodies

Peneconcordant-tabular mineralization forms ore bodies in ore zones # 2, 3, 7, and 9 (Figs. 8.4a,c).

Ore zone # 7 is the largest ore zone of the Dornod deposit. It is located in the central part of the deposit at a depth of some 500 m and accounts for about 14 000 t U at a grade of 0.23% U contained in nine ore bodies (# 1–9). This peneconcordant, subhorizontally dipping zone has in planview a trapezoidal shape 800 m in length and 480 m in width. The upper edge of the zone dips from 540 m to 505 m a.s.l. Ore is hosted in a 20–40 m thick brecciated section within the ca. 40 m thick third

andesitic-basaltic pillow-lava sheet of the Lower Member of the Dornod Formation. The cumulative thickness of superjacent ore shoots averages 11 m. Ore shoots are separated by sterile intervals up to 3 m thick. The lava is interbedded with terrigenous, lacustrine sediments and fills a large paleovalley incised into the basement. Ore is restricted to the marginal part of the brecciated lava sheet where the sheet gradually pinches out. Uranium associates predominantly with matrix material. High-grade mineralization is confined to intervals of fine-grained fractions within the brecciated lava. Richest ore with a grade of 0.2–0.45% U is concentrated in the central part of zone # 7, which averages 30–33 m in thickness and contains the bulk of the ore. The grade gradually decreases laterally. A large low-grade uranium aureole surrounds this ore zone.

Ore zones # 2, 3, and 9 (ore bodies # 2a, 2b, 2c; 3a, 3b, 3c; and 9) are located in the northern and eastern part of the Dornod deposit and account for about almost 10 000 t U, some 8 000 t of which are contained in ore zone # 2 and some 1 700 t U in zone # 3. Grades vary between 0.06 and 0.6% U (2b + 2c: av. 0.1–0.175% U at 2 m thickness). The shallow dipping, tabular ore bodies occur immediately below a rhyolite sheet in sandstone, siltstone, and conglomerate, which fill a paleovalley. Mineralization occurs in several superjacent levels associated with jointed zones within lenses and interbeds of highly carbonaceous, fine- and coarse-grained sediments and tuffs at the contact between the Lower and Middle Member of the Dornod Formation. Distance between ore bodies is up to 40 m. A wide aureole of low-grade mineralization envelops the ore bodies.

Veinlike-Stockwork Ore Bodies

Ore zones 4, 5, and 8 are located in the central and *ore zones 1, 6, 10, 11, and 12* in the western and southwestern (Khavar) sector of the Dornod deposit (Fig. 8.4a). These zones contain about 7 000 t U, some 5 000 t U of which are considered of economic magnitude. Ore zones consist of one or several ore bodies at depths from 280 to 520 m. Grades of ore bodies average 0.1–0.2% U but ore grades are highly variable ranging from 0.05 to 1% U due to concentration of uranium in small, separated ore shoots. Thicknesses range from 0.5 to 20 m and vertical persistence is commonly less than 50 m but can be up to 80 m.

Ore zones and related ore bodies are controlled by the Central and Baga-Erchtyyn fault zones. The major part of the ore occurs as fault, fracture, and joint fillings in the form of stockworks controlled by shallow dipping, about N-S and NW-SE-oriented en echelon faults in the basal part of a sheet of oligophyric rhyolite and associated vitroclastic felsic tuff.

8.1.1.2 Gurvanbulag Deposit

This monometallic volcanic-type deposit is located some 90 km north of Choibalsan, and ca. 30 km west of the Dornod deposit (Fig. 8.3). It includes three sectors, Central, Intermediate, and

Southwest (Fig. 8.6). Each sector contains several ore zones with several ore bodies predominantly of peneconcordant-tabular and minor vein-stockwork configuration. Resources total some 17 000 t U, which include 9 000 t U at a grade of about 0.2% U RAR and about 7 000 t U at 0.12% U EAR-I. The Central sector was prepared for underground mining in the late 1980s (planned depth 526 m) but not mined.

Sources of information. IAEA 1995, 2007; Mironov 2003; Mironov and Rogov 1992, 1993; Mironov et al. 1993, 1995; pers. commun. by Chuluun O and staff of Uran Company Ltd. of Mongolia and ERDES Mining Enterprise.

Geological Setting of Mineralization

The deposit is situated in the western Dornod Volcanic-Tectonic Structure. Proterozoic amphibolite, schist, and gneiss intruded by gabbro-diorite, diorite, and granite of Paleozoic age constitute the *basement*. Late Jurassic-Early Cretaceous sedimentary and volcanogenic facies of the *Dornod Formation* overly unconformably the basement. The strata form a flat, 5–20° SE-dipping monocline.

The *Dornod Formation* consists of three members derived by successive cycles of volcanism. The *Upper Member* is restricted to the SE part of the deposit and consists of a trachyandesite sheet underlain by terrigenous sediments. The *Middle Member* consists of a 300–800 m thick sequence of felsic volcanic sheets, the thickness of which increases towards SE. Facies are, from top to bottom: fluidal felsic ignimbrite, massive felsic ignimbrite, rhyolitic tuff (vitroclastic felsic ash tuff, felsite tuff), oligophyric rhyolite (including volcanic glass and vitric felsite horizons), and trachydacite. Mudstone, sandstone, and conglomerate beds are intercalated with, and occur at the base of the volcanics. The *Lower Member* is composed of sheets, from top to bottom, of andesite-basalt, trachydacite and quartzfeldspar porphyry interbedded with clastic sediments and tuffs. A basal unit of conglomerate and sandstone fills paleodepressions.

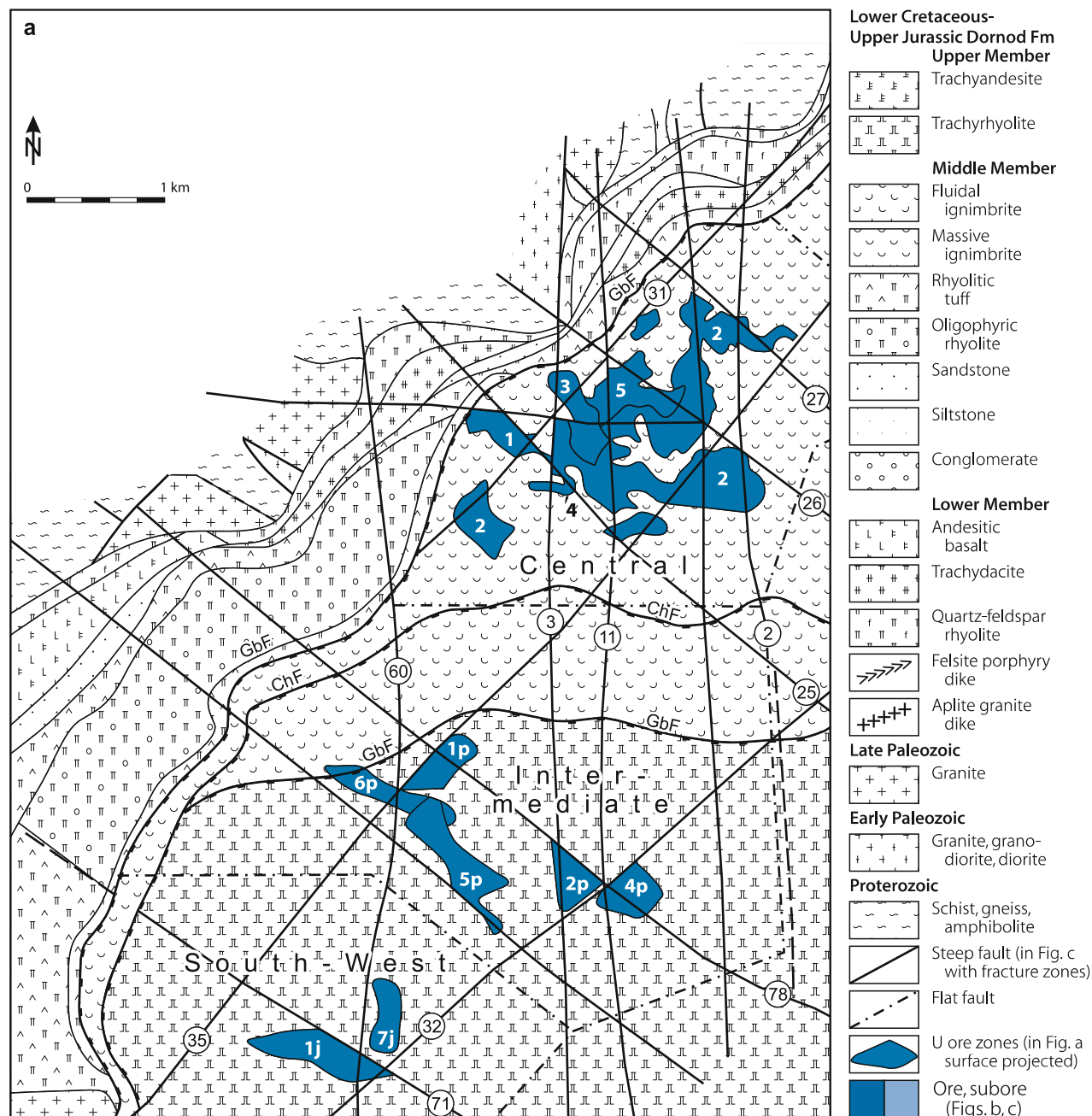
The *structural pattern* is dominated by steeply dipping, NE-SW-, N-S- and NW-SE-oriented fault systems, and large, flat to shallow dipping intraformational fault- and fracture zones. NW-SE-trending fault zones can be up to 300 m wide and several tens of kilometers long. NE-SW-oriented faults are commonly of small extension but are accompanied by highly fractured zones up to 30 m wide.

Flat to shallow, 5–10° SE dipping faults and cataclastic zones occur as peneconcordant structures particularly at the interface of volcanic and sedimentary horizons. Lateral extension and thickness of these zones vary considerably. Largest faults of this kind are the Gurvanbulag, Chayach, and Churtyynbulag faults, which could be traced for several kilometers.

The Gurvanbulag fault zone, up to 80 m thick, dipping 5–15° SE, is the most prominent ore host. This zone is confined to a vitric horizon of the Middle Member that is embedded between a coarse fluidal felsite sheet on top and felsic tuff on bottom. This zone has a complex inner structure of branching, shallow dipping faults associated with subparallel and diagonal fractures,

Fig. 8.6.

Gurvanbulag deposit, **a** simplified geological map showing the location of the Central, Intermediate, and South-West sections and related ore zones/bodies (with numbers); **b** geological plan of ore zones 1 and 2 at level +800 m in the central section, and **c** NW-SE section across ore body 2 (see **b** for location) (after Mironov and Rogov 1993). Major shallow inclined faults: *CbF* Churtinbolag; *ChF* Chayach, *GbF* Gurvanbulag



shears, and joints. Two distinct faults, which coincide with the upper and lower boundaries of the vitric horizon, form the hanging and footwall of the Gurvanbulag fault zone. The Chayach and Churtynbulag faults have a structural pattern similar to that of the Gurvanbulag fault. They also contain ore.

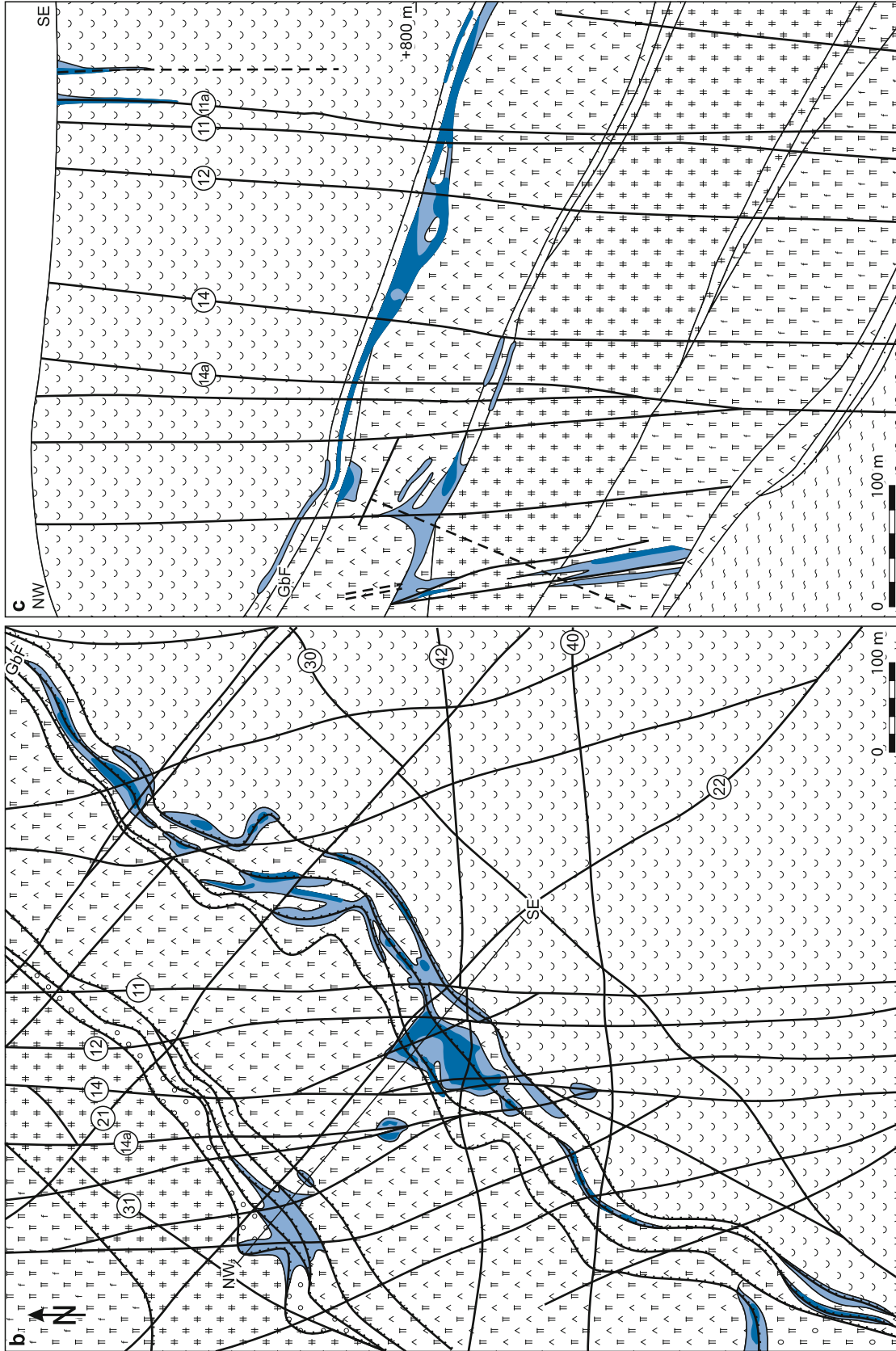
Host Rock Alteration

Regional alteration phenomena include feldspathization and silicification, and ore-related alteration features carbonatization,

hydromicazation, montmorillonitization, kaolinitization, chloritization, and hematitization. Hydromicazation and montmorillonitization are most intense. Hematitization is directly related to mineralized zones and its intensity tends to correlate with the grade of mineralization.

A distinct geochemical halo of U and associated elements such as Pb, As, and Mo surrounds ore bodies. The halo is commonly of elongated shape and largely controlled by faults. The dimensions of halos surpass those of ore bodies by 2–3 times. Uranium forms the most extensive aureole extending in excess of 500 m from ore bodies.

Fig. 8.6. (Continued)



Weathering-related oxidation persists to depths of 250–300 m and up to 400 m along high-angle faults in the central part of the deposit.

Mineralization

Coffinite, pitchblende, and uranophane are the dominant U minerals. Coffinite prevails in most ore bodies except in the central and NE part of ore body 2, where pitchblende and uranophane dominate over coffinite. U⁶⁺ minerals (uranophane, β -uranotile etc.) occur throughout the weathering zone and along high-angle faults in the central part of the deposit where they constitute 30–60% of the U mineralization.

Associated ore minerals include chalcopyrite, galena, marcasite, molybdenite, sphalerite, hematite, and minor arsenopyrite. Gangue or ore accompanying minerals include quartz, biotite, hydromica, montmorillonite, minor ankerite, fluorite, K-feldspar, muscovite, and rare anatase, leucocoxene, sericite, and tourmaline.

U minerals occur mostly as fine- to coarse-grained aggregates, 0.001–2 mm in size. Ore texture is of impregnation nature featuring disseminated, globular, stringer, rarely banded, and earthy varieties. High-grade mineralization with 0.3% U or more exhibits breccia and cement textures.

Uranium mineralization is stratigraphically restricted to the Dornod Formation. In its Middle Member, uranium occurs on six lithologic-structural levels associated with peneconcordant, flat to shallow dipping fault-fracture zones within vitroclastic felsic ash tuff, felsite tuff, volcanic glass, and vitric felsite horizons. Other host rocks are clastic sediments containing detrital vegetal matter; they separate the volcanics of the Middle and Lower Member, and quartz-feldspar porphyry of the Lower Member.

Tabular ore lodes are confined to the large Gurvanbulag, Chayach, and Churtybulag faults. High-angle faults bound these ore bodies and also control the grade distribution of uranium. Veinlike to stockwork mineralization, which is of only subordinate importance, is associated with steeply dipping, NW-SE and, to a minor extent, N-S faults in which ore is restricted to intersections with tuff, felsite, and quartz-feldspar porphyry.

Shape and Dimensions of Deposits/Characteristics of Individual Ore Bodies

The Gurvanbulag deposit covers an area ca. 9 km in NE-SW length and 1.5–4 km in width. Twelve ore zones contained in the Central, Intermediate, and Southwest sectors are delineated. Nine ore zones contain tabular and three contain vein-stockwork ore bodies.

Ore bodies are distributed over a depth interval from 15–40 m to 750 m below surface. Ore bodies consist of lenses or shoots with lateral dimensions ranging from several tens of square meters to 0.5 km². Thickness varies between 0.6 and 10 m and rarely 30 m. Low-grade mineralization or barren ground some tens to a few hundred meters wide in lateral and vertical direction separates individual ore shoots.

Tabular ore bodies can be large and constitute the bulk of the total resources of the deposit. Grades range from 0.06 (cutoff grade) to 0.6% U and average 0.11–0.2% U. Veinlike to stockwork

ore bodies are lower in grade and smaller in tonnage. Ore contains up to 0.6% carbonate and 2% fluorite.

The *Central sector* is 4.3 km long, 1.7–2.7 km wide, covers about 9 km², and accounts for 78% of total deposit resources. It includes three ore zones, # 1, 2, and 4, with tabular ore bodies located at depths from 40 to 500 m along and in the flat to shallow dipping Gurvanbulag fault, and two zones, # 3 and 5, with stockwork ore bodies extending to depths of 750 m controlled by high-angle faults.

60% of the deposit resources are contained in the large # 2 *Ore Zone*. This zone stretches for 3 100 m along NW-SE strike and 500–1 600 m down dip; inclination is 5–10° SE. Grades range from 0.06 (cutoff grade) to more than 0.3% U and average 0.17% U. 17 tabular ore bodies hosted by a tuff horizon are delineated over a vertical interval from 40 to 500 m below surface. Individual ore bodies are 0.8–5.3 m, locally to 13.5 m thick, and 4 000–500 000 m² in size. Grades of ore bodies average from 0.11 to 0.2% U. Low-grade mineralization up to 100 m wide ground intervenes between the ore bodies.

Located 2.5 km south of the Central sector, the *Intermediate sector* contains tabular, flat to shallow dipping ore bodies in four ore zones, and stockwork ore in one zone. Tabular ore zones are from 450 to 1 000 m long, 150–400 m wide down dip, 1–9 m thick, and have grades between 0.1 and 0.7% U. The stockwork ore zone is 1 200 m in NE-SW length, varies between 0.7 and 6.8 m in thickness, and persists from 40 to 120 m down dip at an inclination of 75–85° SE. Grades range from 0.06–0.3% U.

The *Southwest sector* is located 4.5 km SSW of the Central sector. It contains two ore zones with tabular ore bodies at grades from 0.1 to 0.16% U and dimensions similar to those of the Intermediate sector.

8.1.1.3 Mardaingol Deposit

Mardaingol is located some 95 km north of Choibalsan and ca. 5 km NNW of the Dornod deposit (Fig. 8.3). The volcanic-type deposit encompasses two sectors with seven mineralized zones composed of tabular and vein-stockwork ore bodies. Mineralization is monometallic. Ore bodies are of small size, low grade, and situated far apart.

Underground exploration had commenced in the late 1980s but was abandoned in 1992. One shaft, 180 m deep, was sunk and investigations conducted on two levels, 550 m and 700 m a.s.l. Resources amount to about 1 100 t U at 0.12% U.

Sources of information. IAEA 1995, 2007; Mironov 2003; Mironov and Rogov 1992, 1993; Mironov et al. 1993, 1995; pers. commun. by Chuluun O, staff of Uran Company Ltd. of Mongolia, and ERDES Mining Enterprise.

Geological Setting of Mineralization

Mardaingol is situated in the northern part of the Dornod Volcanic-Tectonic Structure. Early Paleozoic biotite granite-gneiss and granodiorite intruded by Late Paleozoic leucocratic biotite granite, aplite and microdiorite dikes constitute the *basement*. Separated by an unconformity, Late Jurassic-Early Cretaceous

sedimentary and volcanogenic facies of the *Dornod Formation* overly the basement. The strata dip 10–20° NE.

The *Dornod Formation* is represented by only the Middle and Lower members (700–800 m thick). The *Middle Member* is 300–450 m thick and consists of sheets of polyfacies felsic volcanic outflows and their tuffs.

The *Lower Member* is composed of a 100–300 m thick unit of sheets of andesite-basalt, trachydacite, and trachyrhyolite interbedded with clastic sediments and tuffs, and a basal unit of conglomerate, up to 200 m thick, in paleodepressions.

Subvolcanic bodies of felsic porphyry and a variety of dikes and sills, the youngest being trachydacite dikes, were intruded into the older rocks. A large felsite body separates the western and eastern mineralized sectors.

The *structural pattern* is dominated by steeply dipping NW-SE-, N-S-, E-W-, and NE-SW-oriented fault systems, and strata-peneconcordant, shallow, 5–30° dipping fracture zones at the contact of beds and within sedimentary and tuffaceous strata.

NW-SE faults dip 65–85° SW and NE. They include the prominent, 15 km long and ca. 1.5 km wide Dagai fault zone, which controls the uranium mineralization. The Dagai fault zone is composed of three main faults, numbered 1, 2, and 3, and branching and intersecting subsidiary faults with associated, up to 70 m wide cataclastic zones. About N-S-oriented major faults dip 60–85°, trend subparallel 200–400 m apart, and can be traced for up to 4 km.

Host Rock Alteration

Ore-related alteration is reflected by hydromica-montmorillonite, kaolinite, chlorite (chamosite), carbonate, quartz, fluorite, and hematite. Extension of the alteration aureole can be as much as double that of the related ore body.

A primary geochemical halo of U and associated elements such as Pb, As, Ag and Mo is developed around ore bodies. The halo is controlled by, and commonly confined to permeable cataclastic lithologies and/or faults, which also host the ore. Dimensions of uranium halos can be twice as much as that of related ore bodies.

Mineralization

Coffinite and pitchblende are the principal U minerals. U⁶⁺ minerals (uranophane, β -uranotile, and curite) occur in oxidized intervals. Associated ore minerals include arsenopyrite, galena, marcasite, pyrite, and rare molybdenite and chalcopyrite. Gangue is mainly composed of quartz, hydromica, and montmorillonite, with minor calcite, fluorite, K-feldspar, plagioclase, and rare anatase, titanomagnetite, and zircon. Ore minerals occur mostly as fine- to coarse-grained aggregates, 0.001–0.5 mm, rarely up to 2 mm in size. Ore exhibits impregnation, stringer, reticulate and, in high-grade sections (>0.3% U), breccia and cement textures.

Uranium mineralization is restricted to the *Dornod Formation* within which it occurs on the eastern and western flank of a large subvolcanic felsite body. Ore distribution is controlled by intersections of the Dagai fault zone with N-S

structures. Although uranium occurs at intersections with all rock facies, felsic porphyry dikes, oligophyric rhyolite lava and related tuffs are the most prominent host rocks.

Shape and Dimensions of Deposits/Characteristics of Individual Ore Bodies

The deposit covers approximately 1 km² in which two mineralized sectors occur, *Sector One* to the east and *Sector Two* to the west. The two sectors are in excess of 750 m apart in E-W direction. They contain seven ore zones composed of discontinuous ore bodies distributed over a vertical interval from 80 to 650 m below surface.

Ore bodies are predominantly of vein-stockwork and minor tabular configuration. Stockwork ore bodies are of unpredictable shape and consist of irregularly distributed veins, pockets, and lenses of ore grade material enveloped in weak mineralization. Subparallel, steeply dipping, about N-S- or NW-SE-oriented faults cutting structures of the Dagei fault zone control the position of the lodes.

Sector One is 700 m long in NW-SE direction, 80–180 wide, and contains 360 t U in two ore zones: “NW” and “SE”, which are about 140 m apart. Mineralization is discontinuously distributed over a depth interval from 80 to 280 m. Individual ore lodes are 0.8–5.3 m thick and have grades ranging from 0.06 to 0.6% U, averaging about 0.1% U. Mineralization is located along hanging and footwalls of felsic porphyry dikes where these are broken up by subparallel, steeply dipping N-S faults.

Sector Two is 800 m long in N-S direction, 140–450 m wide, and contains 740 t U in three ore zones with vein-stockwork and two zones with tabular mineralization. Mineralization is distributed over a depth interval from 80 m to 230 m bounded atop by flat-laying faults. High-angle N-S and NW-SE, and flat-laying faults control the ore lodes.

Stockwork ore bodies are up to 100 m long and 25 m thick, and have grades of up to 0.4% U. Lenticular mineralization is bound to flat-laying faults that peneconcordantly transect tuff beds within a tuff-sandstone horizon in the upper part of the stratigraphic sequence and at the bottom of basal clastic sediments. Ore lenses are 0.3–2.1 m in thickness and grade 0.06–0.3% U.

8.1.1.4 Nemer Deposit

Nemer is located some 100 km north of Choibalsan and ca. 10 km NNW of the *Dornod* deposit (Fig. 8.3). The deposit consists of three ore zones with tabular and minor stockwork ore bodies. Mineralization is of monometallic and polymetallic (U, Mo) volcanic type. Resources (EAR-1) amount to some 2 500 t U at 0.15% U and almost 500 t Mo. Potential resources are estimated at 1 500 t U. Polymetallic U-Mo mineralization constitutes some 20% of the total resources.

Sources of information. IAEA 1995, 2007; Mironov 2003; Mironov and Rogov 1992, 1993; Mironov et al. 1993, 1995; pers. commun. by Chuluun O and staff of Uran Company Ltd. of Mongolia, and ERDES Mining Enterprise.

Geological Setting of Mineralization

The Nemer deposit is in the northern part of the Dornod Volcanic-Tectonic Structure. Proterozoic metasediments intruded by Early Paleozoic granite and granodiorite of the Motochudag Complex, and Late Paleozoic K- and Na-metasomatized biotite leucogranite constitute the *basement*. The latter granite is the dominant facies in the deposit area. An uplifted basement block forms the NE flank of Ore Zone 3 and the NW part of Ore Zone 2.

Separated by an unconformity with distinct relief, an up to 800 m thick sequence of Late Jurassic-Early Cretaceous sedimentary and volcanogenic facies of the Middle and Lower members of the *Dornod Formation* overly the basement. The strata dip 10–20° NE. This sequence is reduced to a thickness of some 200 m in the NW part of the deposit. Numerous subvolcanic stocks, dikes, and sills of felsic porphyry were intruded into these older rocks.

The *Middle Dornod Member* is 150–320 m thick and consists of polyfacies felsic volcanic outflows and tuffs with intercalated clastic sediments. The *Lower Member*, 300–500 m thick, is composed, from top to bottom, of

- a unit, 5–10 m and in paleo-depressions up to 60 m thick, of interbedded and interfingering clastic sediments (sandstone, argillaceous sandstone, gravel, conglomerate) with abundant vegetal matter, and tuffaceous horizons
- a unit, 60–160 m thick, of andesite-dacite and rhyolite-dacite lava-breccia and related tuffs
- a volcanic sheet, 100–150 m thick, of andesite-basalt and
- a basal sedimentary unit, up to 90 m thick, composed of coarse fragmental conglomerate-breccia, conglomerate, and sandstone, which is particularly prominent in a NW-SE-trending graben structure

The structural pattern is dominated by steeply dipping, about NW-SE-, N-S-, and E-W-oriented fault systems, and strata peneconcordant, shallow, 5–30° dipping fault-fracture zones.

Most prominent is the Dagai fault zone. It trends NW-SE for 15 km, is 500 m wide, and consists of several major faults (# 8, 10, 10a, and 11), which dip 70–85° NE to SW, and numerous branching and intersecting subsidiary structures and associated cataclastic zones. Fault # 10 with displacements of up to 150 m is one of the main ore controlling structures. A 160–300 m wide cataclastic zone accompanies this complex fault.

Flat to shallow dipping faults occur intraformational and along the contact of beds of different physico-mechanical properties. They constitute important uranium hosts.

Host Rock Alteration

Ore-related alteration products include hydromica-montmorillonite, kaolinite, chlorite (chamosite), carbonate, and quartz. Extension of the alteration aureole is as much as double as that of related ore bodies.

A *primary geochemical halo* of U and associated elements (Pb, As, Mo), controlled by structural elements, surrounds ore bodies. A *secondary dispersion aureole* also exists and is

displaced from the primary halo. The uranium aureole is most extensive extending along strike of permeable zones in excess of 500 m from ore bodies. The halo of associated Pb, As, and Mo is smaller; their tenor is highest near high-grade uranium ore. Uranium and other elements correlate positively in the vicinity of ore bodies.

Alteration by weathering is very limited, essentially restricted to major faults along which it may locally extend to depths of 300 m.

Mineralization

Principal U minerals are coffinite and pitchblende. U⁶⁺ minerals (uranophane, β -uranotile, rare woelsendorfite, kasolite, amorphous U-hydroxides) occur in oxidized zones. Associated ore minerals include galena, molybdenite, pyrite, and rare arsenopyrite and chalcopyrite. Gangue or ore accompanying minerals are biotite, hydromica, montmorillonite, and quartz, with minor ankerite, siderite, baryte, fluorite, K-feldspar, muscovite, and rare anatase, sericite, and tourmaline.

Ore minerals occur mostly as fine- to coarse-grained aggregates, 0.001–0.5 mm, rarely up to 2 mm in size and show colloform, granular, grating, or spherulitic textures. Ore is of the impregnation type showing dispersion, maculose, globular, stringer, and rarely banded or earthy features. Rich ore (>0.3% U) has breccia textures.

Mineralization is found in almost all rock facies including basement rocks where minor, mostly low-grade mineralization occurs. Ore bodies are restricted, however, to the Lower and the Middle Member of the Dornod Formation in which they occur in carbonaceous, coarse clastic sediments at the base of the Dornod Formation, and in intraformational, carbonaceous sedimentary and tuffaceous horizons and cataclastic coarse-grained felsic tuff affected by peneconcordant, flat to shallow dipping faults.

Two varieties of host rock settings and uranium mineral assemblages are noticed: Pitchblende-coffinite-molybdenite in carbonaceous sediments; and pitchblende-coffinite in effusive and pyroclastic volcanics.

Shape and Dimensions of Deposits/Characteristics of Individual Ore Bodies

The Nemer deposit contains three ore zones with tabular and some stockwork ore bodies in a 2 500 m long and 500 m wide area, and at depths from 120 to 320 m. U-Mo mineralization with 0.15% U and 0.13% Mo on average constitutes some 20% of the total resources. This ore prevails at lower levels. Dimensions and characteristics of ore zones and ore bodies are as follows:

Ore Zone I contains two tabular, polymetallic (U, Mo) ore bodies in fractured, interbedded carbonaceous sandstone, mudstone, conglomerate, and tuffaceous sediments, which form the transition from the Lower to the Middle Member of the Dornod Formation. Ore lenses are positioned along margins of strata, which are intensely broken by flat-laying fracture zones and

intersecting, steeply dipping, subparallel NW-SE-oriented faults. Ore lenses are 0.3–3.5 m thick, subhorizontal, elongated, and superjacent stacked, 5–15 m apart. They consist of irregular mineralization with grades ranging from 0.07 to 0.9% U. Flat-laying faults constitute the hanging wall and undisturbed sediments the footwall boundaries of the ore lenses.

Ore Zone II consists of two tabular, monometallic ore bodies in highly fractured tuff of the Upper Dornod Member at depths from 130 to 230 m. Ore is restricted to intersections of a flat-laying fault with high-angle, NW-SE-oriented faults. Sub-ore grade mineralization occurs as small lenses and joint-fracture filling at contacts of various lithologies.

Ore Zone III is located adjacent to the NW of Ore Zone II and contains several tabular to stockwork U-Mo ore lodes immediately above the basement at depths of 200–300 m. Ore lodes are hosted in cataclastic sandstone, conglomerate, and coarse fragmental conglomerate-breccia that form the basal sedimentary unit in a NW-SE graben structure. Main ore-bearing structures within the basal conglomerate-breccia beds are intraformational, strata-peneconcordant, flat to shallow dipping faults and fracture zones located near a high-angle fault. Richest mineralization is in the SE part of Zone III where it occurs in the form of flattened stockworks composed of small, subhorizontal lenses interconnected by steeply dipping mineralized fissures. To the northwest, the shape becomes more and more tabular and mineralization gradually fades out.

Several small vein-like ore bodies, as much as 4 m thick, containing 0.08% U and up to 0.05% Mo were drill intercepted in leucocratic granite of the basement at a depth of 280 m.

8.1.1.5 Additional U Occurrences in the Mardai/Dornod District

In addition to the above-mentioned deposits, several uranium occurrences were identified in the Mardai/Dornod District, some of which are associated with Pb-Zn or fluorite deposits. U resources are commonly several hundred tonnes U at grades between 0.01 and 0.15% U.

The *Davaan*, *Dorozhnoye*, *Muhar*, and *Ulaan* occurrences exist in a geological setting similar to the Gurvanbulag deposit. Their position is controlled by the shallow to flat dipping Gurvanbulag fault. *Davaan* consists of eight ribbon-like uraniumiferous lenses with resources estimated at 500 t U, and a grade of 0.01% U. *Dorozhnoye* contains 420 t U at 0.14% U in a tabular ore body. *Muhar* is situated close to the Muhar Pb-Zn deposit. Small veins and lenses occur in the Gurvanbulag fault at the base of a rhyolite horizon. *Ulaan* coincides spatially with the same named Pb-Zn deposit. Resources amount to 270 t U at 0.11% U. Some 90% of these resources are monometallic and the rest polymetallic (U with Pb-Zn).

The *Ilreh* and *Tsever* occurrences are located in the Mardaingol block. Both the geological setting and mineralization are similar to Mardaingol. *Ilreh* has almost 300 t U at a grade of 0.13% U in a tabular ore body.

Tsagaan-nuur is located 1.5 km E of and occurs in a similar geological setting as the Dornod deposit. Tabular and vein mineralization occurs at depths from 200 to 650 m in zones altered by hematitization, silicification, fluoritization, and pyritization.

8.1.2 Other Uranium Occurrences/Areas in the North Choibalsan Region

Besides the Dornod Volcanic-Tectonic Structure, the North Choibalsan region encompasses the Ugtam, Turgen, and Engershand volcanic-tectonic complexes with uranium occurrences as well as gold, fluorite, tungsten (scheelite), polymetallic (Pb-Zn-Ag), and graphite deposits.

Sources of information. Mironov and Rogov 1992, 1993; Mironov et al. 1993, 1995; pers. commun. by Chuluun O and staff of Uran Company Ltd. of Mongolia, and ERDES Mining Enterprise.

8.1.2.1 Ugtam Area

Ugtam is situated about 50 km NW of the Mardai District. The area coincides with the Ugtam Volcano-Tectonic Structure, a volcano-sedimentary complex similar to the Dornod Volcano-Tectonic Structure. One U occurrence, *Ugtam*, has been investigated. It consists of 0.7–6.5 m wide veins contained in two zones within a 3 km long and 350–800 m wide area. Resources are estimated at 4 200 t U at a grade of 0.02% U. In addition, several deposits of gold (*Ugtam*, *Doos*), fluorite (*Zharaahai*, *Ugtam*), scheelite (*Tenger*), and polymetals/Pb-Zn-Ag (*Bolotinskii*, *Nairin*) occur in the structure.

8.1.2.2 Turgen Area

Turgen is situated about 80 km NW of the Mardai District at the northwestern extremity of the North Choibalsan region. The area coincides with the Turgen Volcano-Tectonic Structure, a 750 km² large volcano-sedimentary complex similar to the Ugtam and Dornod structures but of smaller size. Resources of the Turgen area are estimated at 5 000 t U, at a grade on the order of 0.05% U. In addition, this area has gold (*Hooloi*, *Tsagaan-Chuluut*) and fluorite (*Khalchin*, *Bat*, *Zhargalant*) deposits.

Two U occurrences, *Tsagaan-Chuluut* and *Baruun-Hooloi*, have been explored.

Tsagaan-Chuluut is hosted in the Upper Member (basalt-andesite, tuff, tuffaceous sandstone, and conglomerate) of the Dornod Formation. Mineralization occurs in three configurations, two are structure-bound and one is strata-bound. A 900 m long zone along a N-S fault contains gently dipping lenticular ore bodies within strata-internal cataclastic segments, and a series of contiguous, steeply dipping, 1–6 m wide veins with grades of 0.06–0.08% U. Strata-bound mineralization with

grades of 0.02–0.04% U bound in colophane, occurs in ten phosphatic silt- and mudstone layers, 0.2–10 m thick and up to a few hundred meters long.

Baruun-Hooloi is positioned in the Middle Member (felsite, rhyolite, rhyolitic tuff) of the Dornod Formation. Mineralization consists of uranophane and autunite contained in structurally controlled lenticular bodies along an about E-W-trending fault. The host rock is strongly fractured extrusive felsite porphyry. Ore sections are enveloped in an aureole of intense hydromineralization and fluoritization. Grades average 0.05% U.

8.1.2.3 Engershand Area

This area covers the Engershand Volcanic-Tectonic Structure in the SE part of the North Choibalsan region, some 100 km NE of Choibalsan (Fig. 8.1). A few uranium showings are recorded as well as some polymetallic deposits like the Pb-Zn-Ag deposit Tsav (15–16% Pb + Zn, 200–500 ppm Ag, 2 ppm Au; at depths from surface to more than 270 m).

8.2 Berkh Region, Khentei Aimag

The Berkh region is located some 400 km ENE of Ulaan Baatar in the NE part of Khentei aimag (Fig. 8.1). Four volcanic F-Mo-U type occurrences are reported from the *Batnorov* and *Ulziit-Saikhanuul* volcanic structures, in addition to a vein-type uranium occurrence (*Mizer*) in leucogranite of the basement. This region also includes five fluorite deposits (*Berkh*, *Kovalev*, *Chemindyn*, *Delger-Haan*, *Khavtgai*).

Sources of information. Mironov and Rogov 1992; pers. commun. by staff of Uran Company Ltd. of Mongolia.

Regional Geological Setting of Mineralization

The Berkh region is in the central part of the North Kerulen tectonic zone and within the intracontinental Mongol-Priargun Volcanic Belt. Metamorphic rocks are of Upper Proterozoic to Early Cambrian (schist, marble, amphibolite preserved as xenoliths in granite) and Permian age (Ulziin Formation: slate, quartz-sericite schist).

Depressions are filled with continental sediments and volcanogenic rocks of the Early Cretaceous Zuunbayan Formation. The formation consists, from top to bottom, of an Upper Series composed of sand- and mudstone, a Middle Series of andesite, and a Lower Series of conglomerate, sandstone, carbonaceous mudstone/siltstone, basalt, and trachyte.

Granitoid rocks were intruded during three periods: granite, granodiorite and diorite during Early Paleozoic, leucogranite and granodiorite during Middle Paleozoic, and leucocratic biotite granite, alkaline granite porphyry and granosyenitic porphyry during Middle and Late Jurassic. The latter facies form the Erdenedavaa Intrusive Complex.

Felsic volcanism occurred during Middle and Late Jurassic. It was followed by Late Jurassic to Early Cretaceous mafic volcanism.

Principal Characteristics of Mineralization

Uranium mineralization is of volcanic type, attributed in Russian literature to the U-Mo-F paragenesis. Ore settings are controlled by faults or cataclastic continental sedimentary or volcanic rocks. All uranium occurrences show an affinity to rhyolitic facies.

8.2.1 Batnorov Area

This area lies in the southwestern part of the Berkh region. Two larger volcanic-type uranium occurrences hosted by mafic to intermediate volcanics interbedded with continental sediments are established: *Ikh-bulag* and *Tanai*.

Ikh-bulag occurs in a depression filled with sandstone, conglomerate, quartz dacite tuff, andesite, quartz porphyry, and felsic lava. Felsic volcanics form two small necks. One of these necks contains uranium (uranophane, autunite, and metatorbernite) associated with Cu, Mo, Pb, and Zn in the form of low-grade mineralization that envelopes two parallel, 170 m long and 0.5–5 m thick lenses composed of stockwork and tabular mineralization with grades of 0.06 and 0.16% U, respectively. The tenor of Cu, Mo, Pb, and Zn is several hundredths of a percent, and that of As and F is several tenths of a percent. U resources are estimated at 2 000–3 000 t.

Tanai is hosted by an arkosic grus horizon that is covered by an andesite-basalt sheet of the Lower Series of the Zuunbayan Formation. Host rocks are enriched in carbonaceous detritus, kaolinite, hydromica, and fluorite. Autunite and black products (sooty pitchblende) are the principal U minerals. Associated elements include Ag, As, Ge, Mo, Pb, and Zn. Mineralization is of tabular shape and was traced over a length of 230 m. Ore bodies are about 2 m thick and grade 0.05–0.08% U.

8.2.2 Ulziit-Saikhan-Uul Area

This area corresponds to the Ulziit-Saikhan-Uul Volcano-Tectonic Complex in the NE Berkh region. This complex is a semi-ring structure, 2.4 km² in size, composed primarily of felsic effusives and subvolcanic stocks. Early to Middle Paleozoic granites form the basement. A volcanic-type uranium occurrence, *Tumen-Haan*, has been investigated. The geological setting of this occurrence is similar to deposits in the Dornod District. Mineralization is hosted by a quartz-feldspar porphyry sheet 250–600 m thick in which it is controlled by the intersection of E-W fracture zones with a NW-SE-trending fault zone. U minerals (coffinite, uranophane, and uranospinite) occur in irregular distribution in up to 2 m thick veins and lenses. Associated elements include As, Cu, Pb, and Zn. Grades range from few hundredths to 0.4% U.

8.3 Dornogovi (Eastern Gobi) Region

A number of uranium occurrences of sandstone, volcanic, lignite, phosphorite, vein?, and surficial? type are recorded from the Dornogovi region in SE Mongolia. They are grouped in several areas (► Fig. 8.1). One sandstone-type deposit is delineated, Kharaat in the Cretaceous Choir Basin.

Sources of information. IAEA 1995, 2007; Mironov 2003; Mironov and Rogov 1993; Mironov et al. 1995; pers. commun. by staff of Uran Company Ltd. of Mongolia.

Regional Geology of the Dornogovi Region

The Dornogovi region is within the Caledonian Central Mongolian fold belt and covers in part the western section of the Late Jurassic-Early Cretaceous Mongol-Argun volcanogenic metallogenic belt, which is part of the Mongol-Transbaykal metallogenic province. Precambrian and Paleozoic metasediments, Precambrian to Mesozoic granites, and Paleozoic to Mesozoic volcanic complexes of mafic to felsic composition constitute the basement. Regional faulting generated a basin and range geomorphology. Archlike uplifts of Precambrian to Late Mesozoic lithologies are separated by downfaulted, intermontane basins filled with Early Cretaceous terrestrial sediments with intercalated lignite seams. Alluvial sediments of Late Cretaceous-Paleogene age cover the older basin infill. Prominent faults and lineaments trend E-W, NW-SE, and NE-SW.

Basement rocks below Cretaceous basins and exposed in uplifts include

- *Early Cretaceous to Late Jurassic* continental rhyolite to trachybasalt
- *Late to Middle Jurassic* leucocratic, K-feldspar granite in the southwest and northeast part of the region
- *Triassic-Permian* felsic volcanics and subalkaline alaskite (with REE and polymetals enrichments e.g. in Bor-Undur Complex) prevailing in the NW and central part of the region
- *Permian-Carboniferous* biotite granite
- *Carboniferous* andesite-dacite
- *Early Paleozoic* gabbro-diorite-granite plutons present as cores in dome structures in the central part of the region
- *Early Cambrian* metasediments
- *Precambrian* gneiss, granite-gneiss, schist, amphibolite, quartzite, and marble, prominent in the SW part of the region

Regional Characteristics of Mineralization

A variety of mineralization is noticed in the Dornogovi region including

- *volcanic-type* F-Mo-U-bearing veins, stockworks, and tabular ore bodies controlled by hydrothermally altered fault-fracture zones within volcano-tectonic complexes. Two mineral assemblages are reported: pitchblende-coffinite-sulfide-quartz (examples: *Bor-Undur*, *Hongor*, *Zurkhin* occurrences), and

fluorite-pitchblende-coffinite-quartz-fluorine-apatite (examples: *Khara-Tolgoi*, *Ikh-Khet*, *Ulaan-Nuur-2* occurrences)

- *sandstone- and lignite-type* U-rare metals-REE mineralization in non or weakly lithified Late Mesozoic and Cenozoic sediments in intermontane basins. Two parageneses are distinguished: U-rare metals-minor REE associated with near-surface oxidation zones (example: *Kharaat* deposit and a number of occurrences), and rare metals-REE-minor U related to diagenetically altered zones (example: *Jargalant-Nuur* occurrence)

Other mineralization includes volcanic-related epithermal fluorite deposits. Differentiated granites and alkaline complexes contain Mo, Sn, W, and REE mineralization. Iron ore is present in metasediments, contact-metamorphic skarn, and veins.

8.3.1 Choir Cretaceous Basin, Dornogovi (East Gobi) Aimag

Located some 250 km SSE of Ulaan Bataar in central-southeastern Mongolia, the Choir Basin is a submeridional, 150 km long and 10–25 km wide, curvilinear depression (► Fig. 8.7). Uranium showings are found in a 110 km long and 2–8 km wide stretch. One sandstone U deposit, *Kharaat*, was delineated along with a number of sandstone- and lignite-type uranium occurrences.

Total uranium resources in the Choir Basin are estimated at 90 000 t U, some 10 000 t U (EAR-1) of which are estimated for the *Kharaat* deposit while the rest are speculative resources (references see above).

Regional Geological Setting of Mineralization

A sequence of continental, weakly to non-lithified sediments of Paleogene and Cretaceous age, up to 1 500 m thick, fill the Choir Basin. The sediments are subhorizontally bedded with a monoclinical dip increase to 10° at the flanks of the basin. Basin lithologies include, from top to bottom

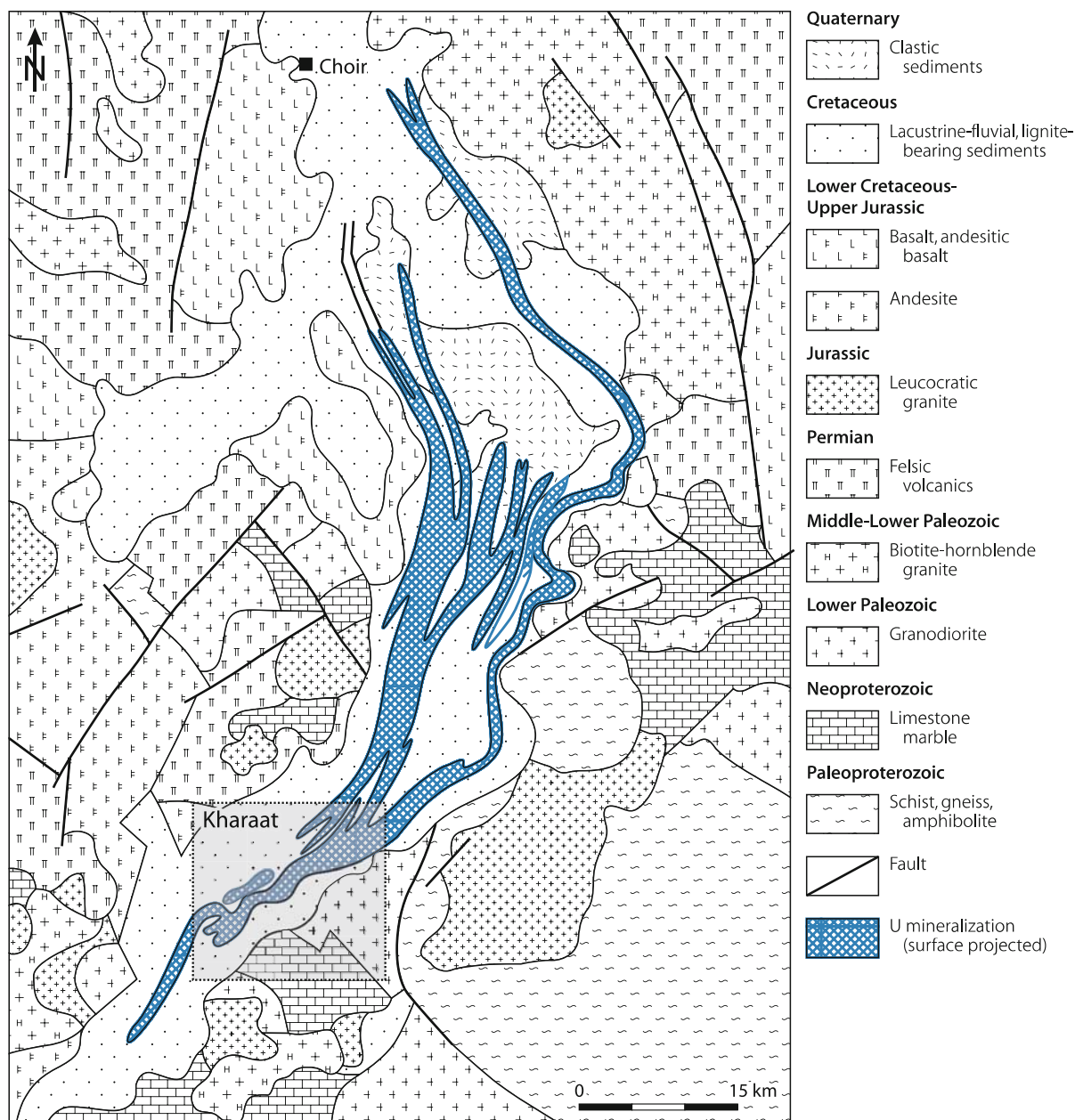
- *Quaternary*: Clastic sediments (only locally developed)
- *Upper Cretaceous* Sainshand Formation: Alternating, discontinuous beds of weakly cemented, variegated (red, green etc.) alluvial sand, gravel, and conglomerate
- >Unconformity<
- *Lower Cretaceous* Zuunbayan Formation: Fluvial, lacustrine, and paludal sediments composed of grey, unconsolidated, carbonaceous, and sulfidic clays, argillaceous, partly limy sands, silts, and sands, which contain abundant vegetal matter and iron sulfides and are intercalated with lignite seams

Basement

- *Lower Cretaceous-Upper Jurassic* mafic volcanics (basalt, andesite)
- *Jurassic* leucocratic granite
- *Permian* felsic volcanics (rhyolite)
- *Middle-Lower Paleozoic* biotite-hornblende granite
- *Lower Paleozoic* granodiorite and pegmatite

Fig. 8.7.

Choir Basin, schematic map of the geological setting of the intracratonic basin with distribution of U mineralization and location of the Kharaat deposit (after Mironov and Rogov 1993)



- Neoproterozoic marble
- Paleoproterozoic metamorphics (schist, gneiss, amphibolite)

Faults exposed in the basement trend about NE-SW, NW-SE, and E-W. Major structures include the Khar Airag-Choir fault system, which tends to control the position of paleovalleys in the Choir Basin.

Principal Host Rock Alteration

Common host rock alteration apparently includes weathering-related surface-bound oxidation as reflected by limonitization,

which persists to depths of 30 m, and, at depth, kaolinitization, hydromicazation, carbonatization, silicification, and sulfidization. Sulfides are restricted to zones containing organic carbon.

Principal Characteristics of Mineralization

Two principal types of U mineralization are reported, sandstone- and lignite-hosted uranium. Sandstone-type mineralization occurs in two settings: (a) along the footwall boundary of the surface-related oxidation interval and (b) at depth in grey,

reduced sediments in the vicinity of oxidized zones. Preferential host environments are carbonaceous and sulfide-bearing sand lenses and their contacts with argillaceous intercalations in paleochannels.

U oxide phases (pitchblende, black products) are the principal U minerals in reduced environments while U^{6+} minerals (mainly autunite) are prevalent in oxidized environments. Associated minerals/elements include Fe- and Mo-sulfides and a variety of rare and rare earth elements (details see Kharaat deposit).

General Shape and Dimensions of Deposits

Uranium mineralization is ubiquitous in the Choir Basin as indicated by the numerous occurrences and showings. Most of the occurrences have low grades, however, on the order of 100–300 ppm U while better grade bodies with grades in excess of 0.05% U tend to be limited in size and tonnage, at least as far as established to date.

Mineralized bodies exhibit pod and lenticular configurations and are arranged peneconcordant to strata. They occur individually or superjacent stacked. Common dimensions are on the order of up to a few hundred meters long, up to a few tens of meters wide and from less than a half to a few meters thick.

Principal Aspects of Metallogenesis

Two genetic modes of U concentration are noticed:

- *Diagenetic* U concentration is reflected by low-grade (few hundred ppm U) lenses and bands, up to a few meters thick along the contact of grey sands and mottled clastic sediments, or at the contact of grey clays with organic matter and lacustrine sands. This mode is known from several occurrences but is only of potential interest.
- *Epigenetic* U concentration is controlled by surface-bound oxidation zones in the Cretaceous sands. The Kharaat deposit and most occurrences belong to this mode. Isotope dating yields a time range from 20 to 30 Ma (Neogene) for this mode of mineralization in the Kharaat deposit.

Felsic volcanics and intrusives of the basement such as sub-alkaline alaskite of the Bor-Undur Complex are considered the source of uranium and associated elements. Fixing of uranium occurred by reducing substances such as carbonaceous matter and sulfides particularly along surface-bound oxidation boundaries and intraformational redox interfaces, and by adsorption on organic and inorganic material (plant remains, clay particles, Fe-oxides etc.).

8.3.1.1 Kharaat Deposit

The Kharaat deposit was discovered in 1988 in Dornogovi aimag, some 250 km SSE of Ulaan Bataar and about 70 km SSW of the railroad settlement Choir also referred to as Sumber. The deposit contains polymetallic sandstone-type uranium mineralization.

Resources amount to some 10 000 t U (RAR + EAR-I) at a grade of 0.03% U including almost 4 000 t U grading in excess of 0.07% U (status 1995). (Note: The calculation is based on a cutoff grade of 0.01% U, a minimum thickness of 0.5 m, and a maximum thickness of 2 m for barren rock.)

Sources of information. IAEA 1995, 2007; Mironov 2003; Mironov and Rogov 1993; Mironov et al. 1995; pers. commun. by staff of Uran Company Ltd. of Mongolia.

Geological Setting of Mineralization

Mineralization occurs along the southeastern flank of the Choir Basin in upper horizons of the Early Cretaceous Zuunbayan Formation (► Fig. 8.8). These horizons consist of alternating, discontinuous, 0.2–20 m thick lenses and beds of grey carbonaceous sandy gravel, sand, silt, argillaceous sand and silt, and mud that fill a paleovalley. Sands with high contents of vegetal remains and sulfides (pyrite, marcasite) provide the most favorable host rocks.

Host Rock Alteration

Host rock alteration is twofold. Weathering-related oxidation reflected by limonitization penetrates from surface to depths from 1 to 30 m. It is overprinted at depth by kaolinitization, hydromicazation, carbonatization, silicification, and sulfidization (mainly pyrite). Sulfide distribution is restricted to zones containing organic carbon.

Mineralization

U-oxide phases (pitchblende, black products) occur disseminated and as dispersed globular aggregates associated with carbonaceous matter in reduced environments. Autunite, torbernite, schroëckerite, and earthy aggregates of bergerite and phosphuranylite are typical for oxidized zones in which they fill cracks and occur as matrix constituent in sand.

Associated minerals/elements include marcasite, pyrite, colloidal MoS_2 , rare galena, and REE and rare metals (Ce, Ge, La, Re, Sc, Yb, Y). Tenors of molybdenum and selenium are up to 0.15% and 0.05%, respectively.

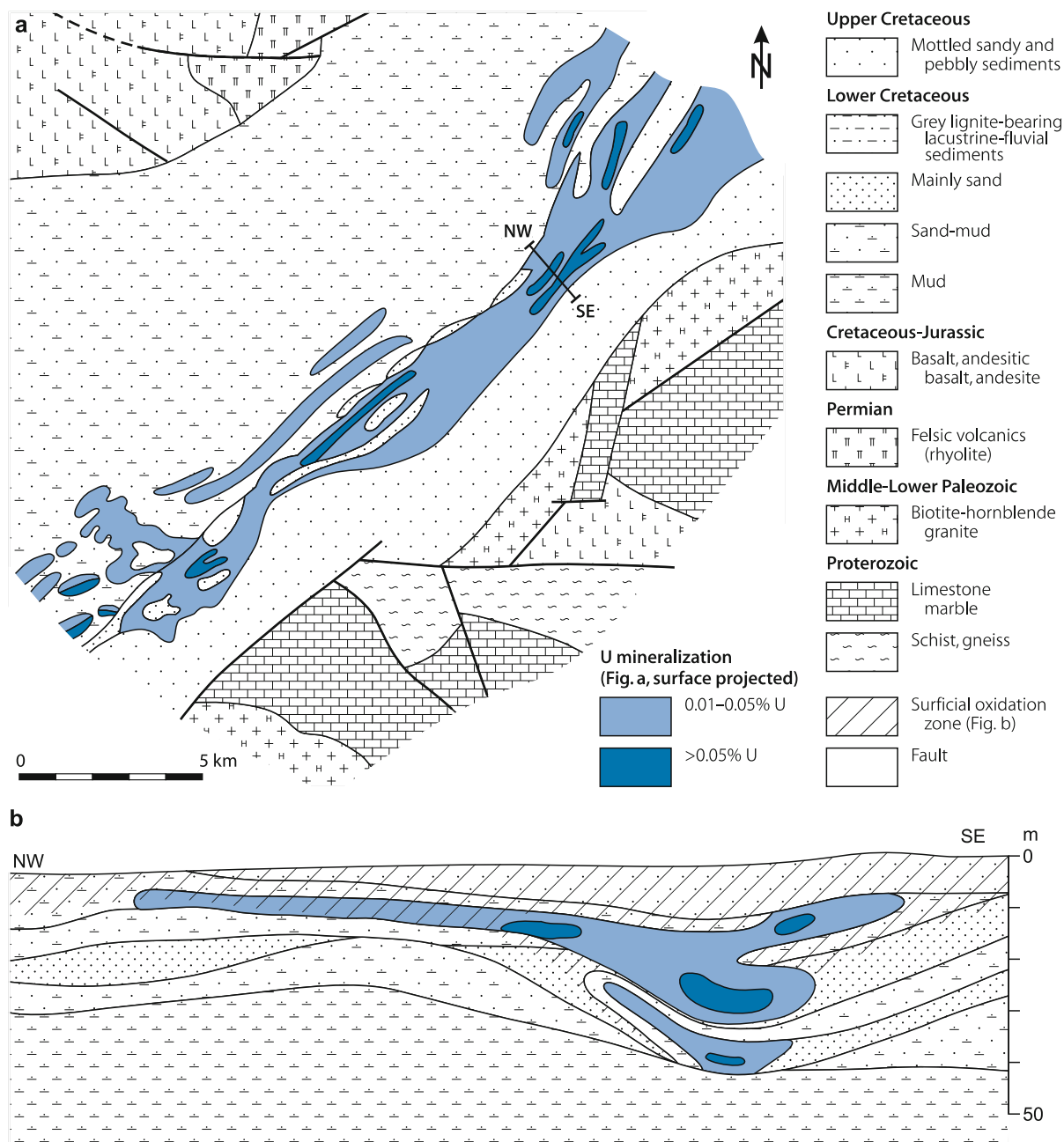
Mineralization occurs along the footwall boundary of the surface-related oxidation interval and further below in grey, reduced sediments in the vicinity of oxidized zones. Preferential host environments are paleochannels in which carbonaceous and sulfide-bearing sand lenses and the contacts of these sands with argillaceous intercalations are favored sites for uranium concentrations.

Shape and Dimensions of Deposits/Characteristics of Individual Ore Bodies

Mineralization of the Kharaat deposit is spread in the form of a ribbon some 20 km in NE-SW length and 0.5–2.5 km in width.

Fig. 8.8.

Choir Basin, Kharaat deposit, **a** schematic geological map and **b** NW-SE section illustrating the distribution of U mineralization in grey, lignite-bearing lacustrine-fluvial sediments and concentration of better grade mineralization associated with channels (after Mironov et al. 1995)



Mineralized material (0.02% U or more) is distributed in peneconcordant lenses and pods, which occur individually or stacked superjacently.

Five principal lens-shaped ore bodies are delineated. They have dimensions of 300–600 m long, 50–60 m wide, and 0.5–17 m thick. Ore bodies are enveloped in subhorizontal, irregularly shaped, ribbon-like zones of low-grade mineralization, which follow paleovalleys. These low grade zones are 400–2 500 m long, 50–300 m wide and 1–33 m thick, and occur at depths from 0.5 to 45 m. Ore grades range from 0.02 to 0.07% U or

more in small lenses and pods positioned in the bottoms of paleovalleys, but grades of as much as 5% U may be encountered locally.

The mode and distribution of ore bodies differs in the northern and southern portion of the Kharaat deposit.

Northern Part: Lenticular and ribbon-shaped ore bodies (<15 m in thickness, <0.1% U or more) occur predominately within the surface-bound oxidation zone hosted by sand and clay enriched in organic material. Dispersed U oxides represent

primary U mineralization whereas oxidation zones contain disseminated autunite, bergerite, and phosphuranylite. Two varieties of uranium-bearing clays are distinguished: (a) grey or light tan, 10–50 cm thick silty clay beds with autunite in fissures and U oxides in clay substrate; and (b) black, unoxidized uraniferous clay with high concentrations of organic material (<8%) and uranium (>0.1% U) in the form of U oxides.

Southern Part: Mineralization occurs on two levels. Tabular ore bodies on the upper level are 0.5–6 m thick and grade 0.02–0.05% U; they are hosted in oxidized clay and sand rich in organic matter. Neogene yellow gravel beds rest upon the mineralized unit. Ore lenses of the lower level are 2–12 m thick and grade 0.1% U or more. These lenses are positioned at the lower boundary of the surface-bound oxidation zone. Mineralization consists of dispersed pitchblende. High U concentrations associate with carbon detritus. Radioactive disequilibrium decreases from the upper levels to the lower levels, which is thought to reflect oxidative solution and redistribution of primary U mineralization.

Ore Control and Recognition Criteria

Ore bodies of the Kharaat deposit are predominantly lens-shaped and composed of polymetallic, low-grade mineralization controlled by lithology and redox interfaces as reflected by the following criteria:

Host environment

- Intermontane basin
- Paleovalleys
- Essentially unconsolidated, carbonaceous and sulfidic sand lenses and argillaceous beds

Alteration

- Weathering-related near-surface oxidation
- Oxidation zones at depth overprinted by reducing processes as reflected by sulfidization

Mineralization

- Polymetallic U-REE-rare metals assemblage
- Control of U, Mo, Se, Re by redox interfaces and of Sc, Y, REE by neutralization zones
- Ore minerals occur disseminated within ore lenses and pods
- Ore is concentrated at interfaces of sand lenses/beds with argillaceous intercalations, and
- At and below the footwall boundary of a surface-related oxidation zone

8.4 Gobi-Tamtsag Region, Dornogovi-Omnogovi-Suhbaatar-Dornod Aimags

The Gobi-Tamtsag region stretches as an ESE-WSW-oriented belt 100–400 km wide and 2 000 km long from the Tamtsag area in the east to the Gobi Altai mountains in the south of Mongolia.

The region covers part of the Caledonian South Mongolian and southerly adjacent South Gobian fold belts and accounts for a number of sandstone-, vein-, and volcanic-type uranium occurrences (Fig. 8.1) including the sandstone-type Nars deposit in the Sainshand Basin.

8.4.1 Sainshand Cretaceous Basin, Dornogovi (East Gobi) Aimag

This basin is some 500 km SSE of Ulaan Bataar in SE Mongolia. The railroad town Sainshand is in the center of the basin (Fig. 8.1). Systematic exploration for uranium begun in 1977 and resulted in the discovery of a number of sandstone- and lignite-type uranium occurrences including the sandstone-type Nars deposit and several noteworthy occurrences, such as *Durbulja*, *Nars 2*, and *Yant*.

Sources of information. IAEA 1993; Mironov 2003; Mironov and Rogov 1993; pers. commun. by staff of Uran Company Ltd. of Mongolia.

Regional Geological Setting of Mineralization

A basement of Proterozoic to Jurassic sediments and igneous rocks, predominantly granites, underlies the Sainshand region. The Caledonian Orogeny affected the older rocks. Basins were downfaulted during Cretaceous time. They are filled with Early to Late Cretaceous continental alluvial, fluvial, lacustrine, and limnic sediments, which are covered by Paleogene to Quaternary alluvium. Oil and gas deposits occur in the Sainshand Basin. Lithologies include, from top to bottom:

Basin fill (up to 1 500 m thick)

- *Quaternary-Paleogene* (<50 m thick, only locally developed): reddish-tan and variegated, lacustrine and alluvial sediments;
- *Santonian-Turonian* Bayanshiree Formation (350–400 m thick): pink-variegated clay, sand, and rare gravel

>Minor unconformity<

- *Cenomanian* Sainshand Formation (100–350 m thick): three cycles of variegated, lacustrine and alluvial sediments (conglomerate, sand, silt, mud/clay) grading downwards into
- *Albian-Hauterivian* Zuunbayan Formation (<1 500 m thick): grey clastic, lacustrine and limnic sediments (clay, shale, silt, sand, conglomerate, partly containing dispersed vegetal matter and minor lignite seams, and intercalated lenses of marl and limestone)

>Unconformity<

Basement

- *Lower Cretaceous-Upper Jurassic* Tsagaant Formation and volcanogenic Dornod Complex: limnic and continental volcanogenic sequence (basalt, andesite, rhyolite, sandstone, tuffaceous sandstone)

- *Upper Jurassic* Sharlin Formation: clastic sediments (variegated conglomerate, sandstone, siltstone)
- *Upper to Middle Permian*: felsic and intermediate volcanics (rhyolite, rhyodacite, clastic and tuffaceous sediments)
- *Upper to Middle Carboniferous* Dusinobin Formation: intermediate to felsic volcanics (andesite, andesite-dacite, rhyolite)
- *Lower Carboniferous* Gunbayan Formation: clastic sediments and mafic to felsic volcanics (sandstone, tuffaceous sandstone, siliceous tuffite, basalt)
- *Upper-Middle Devonian* Gurvansaihan Formation: clastic sediments, limestone, felsic to mafic volcanics and tuffs
- *Middle-Lower Devonian* Undurud Formation: clastic sediments and mafic volcanics
- *Silurian*: continental volcanogenic and carbonatic molasse sediments
- *Cambrian*: clastic sediments and limestone
- *Proterozoic*: geosynclinal sequence of spilite-diorite, quartzite, schist, gneiss, and marble

Magmatic intrusions

- *Lower Cretaceous-Upper Jurassic* subvolcanic intrusives of quartz porphyry and microgranite porphyry
- *Upper-Middle Jurassic, Triassic, and Permian* leucocratic and alkaline granites
- *Devonian* subalkaline and alkaline granites and grano-syenites
- *Upper-Middle Carboniferous* granite, granosyenite, granodiorite, and gabbro-diorite

Major faults are oriented about NE-SW and NW-SE. Block faulting along these structures resulted in horst and graben structures.

Principal Host Rock Alteration

Host sediments are altered by weathering-related, surface-bound limonitization, and, at depths, by kaolinitization, hydromicazation, sulfidization (pyrite, marcasite, galena), patchy and banded hematitization, and bitumen formation. Reduction is particularly prominent along faults.

Principal Characteristics of Mineralization

Coffinite, pitchblende, and black products/sooty pitchblende are the principal U minerals. They are partly intergrown with bitumen. Autunite, uranophane, and schroëckingerite are typical for oxidized environments. Associated minerals include galena, marcasite, pyrite, rare colloidal MoS₂, quartz, and minor carbonates. The ore contains minor amounts of lanthanum, scandium, selenium, and yttrium.

Uranium mineralization is hosted in carbonaceous clastic sediments of the Zuunbayan and Sainshand Formations. Three ore settings, which are often overlapping are noticed:

- stack-type mineralization related to reduction zones along faults (example: *Ingin sector* of Nars deposit)

- tabular mineralization associated with boundaries of strata-bound oxidation zones (example: *Durbulja* occurrence, *Mys (Miso) sector* of Nars deposit)
- tabular mineralization bound to basal contacts of surface-related oxidation zones (e.g.: *Nars-2* and *Yant*)

General Shape and Dimensions of Deposits/ Characteristics of Individual Ore Bodies

Ore bodies exhibit peneconcordant lens and blanket shapes as well as stack and roll morphologies. In more detail, the earlier mentioned three varieties of ore settings show the following characteristics:

Stack- and roll-type mineralization of the *first variety* is typical for the *Ingin sector of the Nars deposit* (for grades and tonnage see Nars deposit) and many other occurrences. Ore is distributed within a 30–120 m thick section of variegated green and grey colored, alternating clayey and sandy lithologies. This unit is overlain by 40–50 m thick pink colored and underlain by 40–60 m thick variegated argillaceous horizons of the Sainshand Formation. Mineralization is confined to intervals intersected by fault zones. Uranium is concentrated in lenses, blankets, rolls and fractures at the margins of sulfidized and hydromica altered, grey and light green sands in which U minerals fill interstices, joints, and microfractures.

Tabular mineralization of the *second variety*, as exemplified by the *Durbulja occurrence*, is confined to the contact of interbedded, reduced grey siltstone with oxidized yellow sandy gravel beds of the Zuunbayan Formation. The deposition site is controlled by edges of stratiform oxidation, which developed in highly permeable clastic sediments. Mineralization at *Durbulja* occurs at a depth of 350 m. Ore thickness is 0.4–1.9 m. Grades average 0.017–0.026% U. The highest drill intercept is 0.112% U.

Tabular mineralization of the *third variety* resembles that of the Kharaat deposit in the Choir Basin. Uranium is near surface concentrated in ribbon-like bodies in grey sandy-clayey layers rich in organic matter of the Zuunbayan Formation, immediately below oxidized, variegated, coarse-grained sediments of the Sainshand Formation. Apparent control of the mineralization is the lower boundary of the weathering-related oxidation zone. The type example is the *Nars-2* occurrence. Mineralization of *Nars-2* can be traced intermittently over a length of 11 km and is hosted by narrow, 50–250 m long and 0.2–1.5 m thick lenses of grey siltstone containing abundant vegetal matter. Ore grades vary between 0.01 and 0.34% U. Uranium minerals are autunite, uranophane, and schroëckingerite. Associated elements are selenium, yttrium, lanthanum, and scandium. The *Yant* occurrence has an identical geological setting as *Nars-2*.

Principal Ore Control and Recognition Criteria

Mineralization occurs in tabular and roll-shaped configurations controlled by lithology, structure and redox interfaces as reflected by the following criteria:

Host environment

- Intermontane basin
- Unconsolidated, carbonaceous and sulfide-bearing sand and gravel beds interbedded with argillaceous horizons
- Steeply dipping fault zones

Alteration

- Oxidation and reduction are reflected by hematitization, carbonatization, hydromicization, and sulfidization
- Reducing processes have overprinted oxidized strata along faults as documented by sulfidization
- Sulfidization may have resulted from an influx of hydrocarbons

Mineralization

- U-REE-rare metals assemblage
- U associates with hydrocarbons (kerite)
- Ore minerals occur disseminated in lenses, blankets, stacks, and rolls, and as fracture filling
- Lenses and blankets occur at interfaces of permeable and impermeable beds, and
- Stacks and rolls at redox fronts associated with faults
- Radioactive disequilibrium is in favor of uranium

Principal Aspects of Metallogenesis

Mineralization is thought to have formed during Neogene to Quaternary time by epigenetic processes. Permeable sediment horizons as well as permeable fault zones apparently acted as important conduits for mineralizing solutions as indicated by the position of better grade ore bodies along major faults. These faults may also have been pathways for migrating hydrocarbons. Fixing of uranium occurred by reduction and adsorption of uranium and associated elements along fault-bound and intraformational redox interfaces, and at surface-bound oxidation boundaries. Potential reducing substances include carbonaceous matter, sulfides, and perhaps hydrocarbons derived from oil and gas reservoirs. Adsorbing agents include plant remains, clay particles, Fe-oxides, etc. Felsic volcanics and intrusives of the basement are considered to be the source of uranium and associated elements.

Fault-related mineralization, as found in the Ingin sector of the Nars deposit, exhibits to some extent similarities with uranium deposits in South Texas, USA, where hydrocarbons played a critical role in generating reducing conditions and as such provided a favorable environment for forming rollfront uranium ore bodies.

8.4.1.1 Nars Deposit

This sandstone-type deposit was discovered in 1978 in Dornogovi aimag, some 500 km SSE of Ulaan Bataar and about 65 km NE of the railroad town Sainshand. The deposit consists of two separated sectors, Mys (or Miso) and Ingin. Ingin contains approximately 1 000 t U (references see above).

Geological Setting of Mineralization

The Nars deposit is positioned at the NE margin of the Tugrikiin horst near the southern rim of the Sainshand Basin. The stratigraphic column of Tertiary and Cretaceous sediments at the deposit includes, from top to bottom:

- *Neogene-Paleogene* sediments of minor thickness
- *Santonian-Turonian Bayanshiree Formation* (350–400 m thick): pink silt, grey sand, resting upon variegated, grey, massive and horizontally bedded silt
- *>Minor unconformity<*
- *Cenomanian Sainshand Formation* (100–350 m thick): pink and variegated clay and silt overlying grey, fine- to medium-grained sand and gravel;
- *Albian-Hauterivian Zuunbayan Formation*: weakly to unconsolidated, grey, partly carbonaceous limnic sediments, in the upper section predominantly composed of rhythmically alternating grey silt, sand, and gravel beds underlain by black and greenish-grey, foliated clay, argillaceous and bituminous shale with intercalated lenses of marl and limestone. This suite rests unconformably upon the basement

Mineralization is hosted by a 30–110 m thick sequence of the Sainshand Formation, which is composed of weakly to non-lithified, variably grained sand and gravel beds interbedded with impermeable horizons of pink and mottled clay and argillaceous silt. Ore-bearing sands vary in length from 800 m to few kilometers and are from 100 to 400 m wide. Within this stratigraphic sequence, mineralization is restricted to segments intersected by the NW-SE-trending Sainshand fault, a 1–1.5 km wide zone of intense faulting, fracturing, shearing, dragging of strata, and interspersed carbonate veinlets.

Host Rock Alteration

Alteration features include oxidation of permeable strata as documented by patchy to banded hematitization associated with kaolinitization, and reduction along fault zones. The latter extends tongue-like into permeable horizons and is reflected by sulfidization (pyrite, marcasite, galena), hydromica, and bitumen formation.

Mineralization

Pitchblende, partly associated with bitumen, black products (sooty pitchblende), and coffinite are the principal U minerals. Associated minerals include pyrite, marcasite, galena, rare colloidal MoS₂, quartz, and minor carbonate. Additional elements include various enrichments of As, Ba, Cr, Cu, Ge, La, Sr, V, W, Y, and Zn.

Three mineral assemblages are distinguished: pitchblende-kerite, pitchblende-black U products, and pitchblende-coffinite. Pitchblende-kerite is the prevailing assemblage. It is characterized by a close intergrowth of pitchblende with the carbon phase.

Mineralization exhibits predominantly disseminated and rarely veined textures. U minerals fill interstices, joints, and microfractures, form pseudomorphs after vegetal detritus in sulfidized, grey and light green sands, and occur along interfaces of lithologies of different permeability.

Shape and Dimensions of Deposits/Characteristics of Individual Ore Bodies

Two mineralized sectors exist at the Nars deposit, Ingin and Mys.

Resources (EAR-II) of the Ingin sector are estimated at 1 000 t U at a grade averaging 0.04% U (calculated on an average thickness of 3 m, and a cutoff grade of 0.02% U. The Mys sector is considered to be of no economic potential.

Mineralization at Ingin occurs at depths from 180 to 480 m. It occupies a zone 100–400 m in width and 4.5 km in length along the Sainshand fault. The zone is composed of contiguous, en echelon arranged, subhorizontally dipping ore bodies positioned on several stratigraphic levels. Ore grades range from 0.016 to 0.7% U.

Ore bodies in the Ingin sector are predominantly of strata-discordant stack- or roll-type and occur along the contact of

grey, sulfidized and hydromica altered sands. Mineralization in the Mys sector occurs as peneconcordant, lenses and blankets in permeable strata.

Dimensions of individual ore bodies are as follows:

- Blanket ore bodies: 200–300 m long, 100–200 m wide, 0.5–3 m thick
- Lenticular ore bodies: 800–1 200 m long, 100–200 m wide, 0.3–3 m thick
- Stack- or roll-shaped ore bodies: 80–150 m long, 100–200 m wide, 3–7 m thick

References and Further Reading for Chapter 8 • Mongolia

For details of publications see Bibliography.

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