Chapter 6
Kazakhstan

Uranium deposits and major occurrences have been reported in nine regions and some isolated locations (Fig. 6.1). Deposits with resource estimates and mining potential are known from six regions: *Kokshetau* (Kokchetav), N Kazakhstan, *Pricaspian*, SW Kazakhstan, *Chu-Sarysu Basin*, south-central Kazakhstan, *Syr-Darya Basin*, S Kazakhstan, *Pribalkhash* or *Kendyktas-Chuily-Betpak Dala* region, SE Kazakhstan, and *Ily Basin*, SE Kazakhstan. Deposits of limited economic interest are known from the *Turga-Priyrtish* region, N Kazakhstan, and the *Granitnoye* and *Zhalanshiksky* regions in central Kazakhstan.

Principal types of uranium deposits include sandstone, vein-stockwork, volcanic stockwork, lignite/coal and a special variety of organic phosphorite-type, viz. clay-hosted phosphatized fossil fish bone.

Remaining resources (RAR + EAR-I, status January 1, 2005) amount to 817 000 t U (OECD-NEA/IAEA 2005). More than 400 000 t U recoverable at less than $130 per kg U are contained in sandstone-type deposits, about 120 000 t U in vein-stockwork, almost 100 000 t U in lignite/coal, in excess of 70 000 t U in volcanic and 64 000 t U in organic phosphorite deposits (OECD-NEA/IAEA 1999).

Cumulative production from 1953 to 2005 is estimated at about 100 000 t U. Conventional mining yielded until 1998 when it was interupted 60 300 t U (38 700 t U of which by underground the remainder by open pit mines). ISL operations produced about 40 000 t U between 1969 and 2005. Uranium was produced from about 20 deposits in the first five regions mentioned above, and partly also during development work at other deposits.

In 2004 nine ISL sites in the Chu-Sarysu and Syr-Darya Basins with a capacity of 4 700 t U yr^{-1} produced 3 412 t U and the Vostok underground mine, Kokshetau region, 317 t U. Operator of ISL operations is NAC Kazatomprom through its local subsidiaries except for three joint ventures with foreign companies. The Vostok deposit is mined by LLP Szepnogorski Mining and Chemical Corporation.

Two mills operated formerly in Kazakhstan, at *Stepnogorsk*, Kokshetau region, from 1958 to 1995 (nominal capacity 2 500 t U yr^{-1}) and *Aktau*, Pricaspian region, from 1959 to 1993 (2 000 t U yr^{-1}). Tselinny Mining and Chemical Combinate was the operator of mining and milling facilities in the Kokshetau region while Pricaspiski Mining and Metallurgical Combinate (PMMC, renamed to KASKOR Joint Stock Company) was the operator in the Pricaspian region. Ore from the Pribalkhash region was treated in the *Kara Balta* mill (nominal capacity 1.5 million tonnes of ore or 3 600 t U yr^{-1}) located 60 km W of Bishkek (formerly Frunze) in Kyrgyzstan. Mining and milling operator for this district was the Kyrgyz Combinate, later renamed Yuzhpolymetal Production Company, headquartered in Bishkek, Kyrgyzstan.

Uranium exploration is in the responsibility of two subsidiary institutions of the Ministry of Geology of Kazakhstan, "Stepgeology" for northern and "Volkovgeology" for southern Kazakhstan.

Sources of information. Abakumov (1995), Boitsov AV pers. commun., Boitsov AV et al. (1995), Boitsov VE (1989, 1996), Fyodorov (2001, 2002, 2005), Fyodorov et al. (1997), IAEA (1995), Laverov et al. (1992a–c), OECD-NEA/IAEA (1993–2005), Petrov et al. (1995, 2000), Poluarshinov and Pigulski (1995), Yazikov (2002), Zhelnov (1994), amended by data of other authors cited in the sections of the various uranium regions.

The interested reader is in particular referred to the books of petrov et al. (1995 and 2000), which document in comprehensive and specific manner charecteristic features of "exogenous" and "endogenous" uranium deposits, respectively, in Kazakhstan.

Historical Review

Exploration for uranium commenced in Kazakhstan in 1943 when the country was part of the former USSR. First discoveries were southwesterly of Lake Balkhash in volcanic rocks of the Caledonian *Kendyktas* or *Pribalkhash* region where the Kurday deposit was found in 1951, followed by Botaburum in 1953 and Kyzylsay (or Kyzyltas) in 1957.

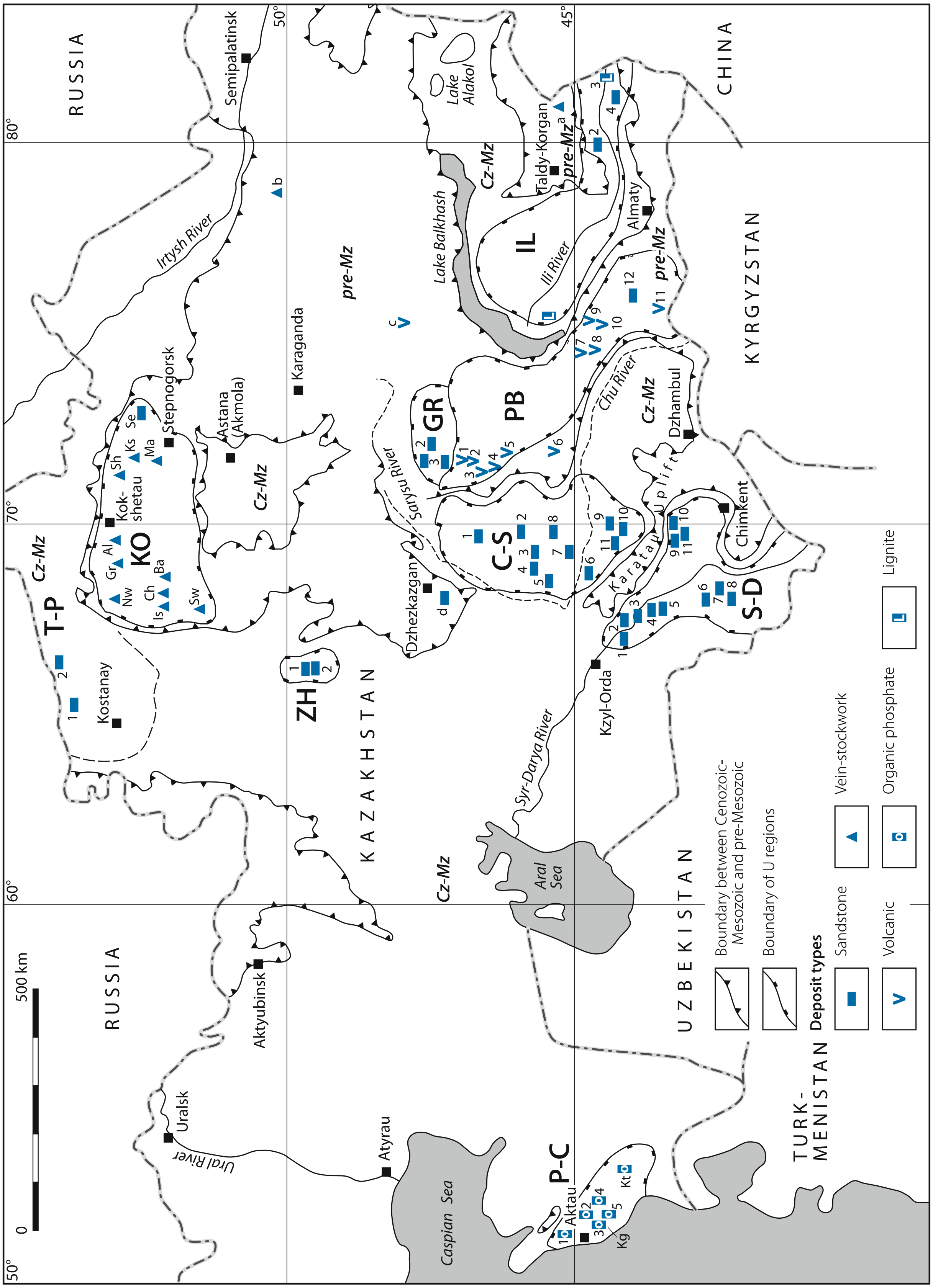
Exploration by the Stepnoi Expedition in the Caledonian *Kokshetau Massif*, northern Kazakhstan, resulted in the discovery of vein-stockwork-type deposits, Kubasadyrskoye, Balkashinskoye and Shatskoye in 1953, and Manybayskoye, Ishimskoye, Tastykol and Zaozernoye in 1954–1955. Later on more than fifty deposits were found including the large Vostok (1964) and Grachevskoye (1967) deposits.

From 1954 to 1962, search by the Stepnoi Expedition for sandstone- and surficial-type deposits in Mesozoic-Cenozoic sediments at the southern margin of the Westsiberian Platform revealed a number of uranium occurrences such as Aurtav in Quaternary clays, Torfjanoye in Oligocene lignite, and Koitass and Pjatigorsk in Jurassic-Cretaceous clastic sediments in northern Kazakhstan but no minable deposits. Reassessment of data during the early 1970s and, in consequence, resumed exploration resulted in the discovery in 1973 of the sandstone-type Semizbay deposit at the inner margin of the Kokshetau Massif, and similar deposits in western Siberia such as Dalmatovskoye in the Transurals (see Russia).

The discovery of uraniferous fossil fish bones in Tertiary sediments near Shevchenko, now Aktau, on the northeastern shore of the Caspian Sea in 1954 (Melovoye deposit) established the *Pricaspian* uranium region.

During the period from 1957 to 1968 uraniferous coal deposits (Koldzhat 1957) were found in the *Ily Basin* but did not prove worthwhile mining. Also between 1957 and 1968, the sandstone-type deposits Uvanas and Zhalpak were discovered in the *Chu-Sarysu Basin*, and the volcanic-type Djidely in the *Pribalkhash* region.

Fig. 6.1.
Kazakhstan. Uranium regions and deposits (after Abakumov 1995; OECD-NEA/IAEA 1995, 1997; Petrov et al. 1995, 2000; Poluarshinov and Pigulski 1995; Yazikov 2002) (*Type of deposit: lig* lignite, *org* organic, *phosp* phosphate, *ss* sandstone (*tab* tabular/lenticular/stratiform,



b-ch **basal channel,** ***roll*** **rollfront),** ***struc*** **structure bound,** ***stw*** **stockwork,** ***surf*** **surficial,** ***ve*** **vein,** ***volc*** **volcanic).**

Region, ore field (OF),

KO Kokshetau Region (Proterozoic-Paleozoic, ve-stw)

(deposits/occurrences in brackets):

Is **Ishimsky OF (Ishimskoye, Kamyshevoye, Shokhpak)**

Ch **Chistopolsky OF (Molodezhnoye, Dubrovskoye, Victorovskoye, Akkan-Burluk, Burlukskoye)**

Ba **Balkashinsky OF (Balkashinskoye, Vostok, Promeshutochnoye, Zvezdnoye, Tushinskoye, Olginskoye, Dergechevskoye)**

Nw **NW Kokshetau Area (Voskhed)**

Gr **Grachevsky OF (Grachevskoye, Sartubekskoye, Kosachinoye, Bolotnoye, Fevralskoye, Dukonskoye)**

Al **Altybaysky OF (Slavyanskoye, Chaglinskoye, Abaiskoye, Kominsko-Krasnoyarskoye, Novogodnee)**

Sh **Shatsky OF (Glubbinnoye, Shatskoye 1+2, Agashskoye)**

Ks **Koksengirsky (or Zaozernoye) OF (Belagashkoye, Gvardaiskoye, Borovskoye, Koksorskoye, Koksorskoye South, Zaozernoye, Mezhozernoye, Tastykolskoye, Vostochno Tastykolskoye, Murzambetskoye)**

Ma **Manybaysky OF (Kerbayskoye, Manybayskoye, Yuzhno Manybayskoe, Bezymiannoye, Krugloye, Aksu)**

Se **Semizbay OF (Semizbay, Yuzhno Semizbay, Selentinsk, Kiziltuk)**

Sw **SW Kokshetau Area (Kubasadyr)**

P-C Pricaspian/Mangyshlak Region (Oligocene)

Kg **Karagiin OF**

1 **Tomak (org. phosph.)**
2 **Melovoye (org. phosph.)**
3 **Tasmurun (org. phosph.)**
4 **Taybagar (org. phosph.)**
5 **Sadyrnyn (org. phosph.)**

Kt **Karyntarskoye OF (org. phosph.)**

C-S Chu-Sarysu Basin (Cretaceous-Tertiary)

1 **Karakoyn (ss-roll)**
2 **Zhalpak (ss-roll)**
3 **Akdala (ss-roll)**
4 **Mynkuduk (ss-roll)**
5 **Inkay (ss-roll)**
6 **Budenovskoye (ss-roll)**
7 **Sholak Espe (ss-roll)**
8 **Uvanas (ss-roll)**
9 **Moynkum (ss-roll)**
10 **Kanzhugan-Tortkuduk (ss-roll)**
11 **Bars (surf?)**

S-D Syr-Darya Basin (Cretaceous-Tertiary)

1 **Irkol (ss-roll)**
2 **North Karamurun (ss-roll)**
3 **South Karamurun (ss-roll)**
4 **North Kharasan (ss-roll)**
5 **South Kharasan (ss-roll)**
6 **Zarechnoe (ss-roll)**
7 **Zhautkan (ss-roll)**
8 **Assarchik (ss-roll)**
9 **Kyzylkol (ss-roll)**
10 **Chayan (ss-roll)**
11 **Lunnoye (ss-roll)**

P-B Pribalkhash Region (Silurian-Devonian)

1 **Bezymyannoye (volc-struc)**
2 **Dzhideli (volc-struc),**
3 **Shorly (volc-struc)**
4 **Kostobe (volc-struc)**
5 **Daba (volc-struc)**
6 **Kurmanchite (volc-struc)**
7 **Kyzylsay (# I to VIII) (volc-struc)**
8 **Kyzyltas (volc-struc)**
9 **Botaburum (volc-struc)**
10 **Dzhusandalinskoye (volc-struc)**
11 **Kurday (volc-struc)**
12 **Kopalysayskoye (ss-tab)**

GR Granitnoye Area (Cenozoic)

1 **Talas (ss, b-ch)**
2 **Granitnoye (ss, b-ch)**

IL Ily Basin (Jurassic-Tertiary)

1 **Nizhne Ilyskoye (lig)**
2 **Suluchekinskoye (ss-roll)**
3 **Koldzhat (lig, ss-tab)**
4 **Kalkan + Aktau (ss-roll)**

ZH Zhilanshiksky Region (Cenozoic)

1 **Lazarevskoye (lig/ss, b-ch)**
2 **Lunnoye (Torgai) (lig/ss, b-ch)**

T-P Turgai-Priyrtish Region

1 **Tobolskoye (ss, b-ch, Up Jur.-L Cret)**
2 **Sensharskoye (ss, b-ch, Up Jur.-L Cret)**
Koitass, Pjatigorsk (ss?, Up Jur.-L Cret)
Torfjanoye (lig/ss, b-ch, Olig)
Aurtav (surf?, Quat)

Isolated U Deposits/Occurrences

a **Panfilovskoye, SE Kazakhstan (ve)**
b **Ulken Akzhal, E Kazakhstan (ve)**
c **Kyzyl, E Kazakhstan (volc-struc)**
d **Kuray, central Kazakstan (ss, b-ch)**

Successful testing of ISL uranium exploitation at Uvanas in 1969/1970 gave rise to intensified exploration for sandstone-type deposits, which was rewarded by the discovery of Kandjugan (1972), Moynkum (1976) and Mynkuduk (1976) in the *Chu-Sarysu Basin;* North and South Karamurun, and Irkol (1970–1975), and Zarechnoye (1977) in the southerly adjacent *Syr-Darya Basin*. More deposits were then detected in both basins in the late 1970s and 1980s.

Conventional uranium mining started in the *Pribalkhash* region in 1953. Underground operations produced uranium until 1990. Ore was shipped to the Kara Balta mill in Kyrgyzstan. In the *Kokshetau* region, exploitation commenced with the Manybayskoye open pit operation in 1957 followed by a number of underground mines, and lasted until 1995; it revived for a short while in 1997–1998 but was then again abandoned. A mill for the region operated at Stepnogorsk from 1958 to 1995. In the

Pricaspian region, mining (open pit) lasted from 1959 to 1993 and was served by the *Aktau* mill which started operation in 1959 and closed in 1993.

In situ leaching operations on a commercial basis began in the *Chu-Sarysu Basin* at Uvanas in 1977, followed at Kanzhugan and Mynkuduk in 1988 after several years of testing. Subsequently, ISL production was commissioned at Moynkum 1, and, in 2001, at Moynkum 2 and 3, Inkay, and Akdala. In the *Syr-Darya Basin,* ISL operations started at the North Karamurun deposit in 1985 followed by South Karamurun.

Annual production reached a peak of approximately 4 000 t U in the 1980s. In 1992, 2 802 t U were recovered from 14 deposits, decreasing to 1 090 t U in 1997. In that year, exploitation was confined to an underground operation in the *Kokshetau* region, one ISL operation in the *Syr-Darya Basin* and three ISL operations in the *Chu-Sarysu Basin*. In 2005 nine ISL sites in the two basins and the Vostok underground mine, Kokshetau region, were active.

6.1 Kokshetau Region, Northern Kazakhstan

The Kokshetau uranium region (Fig. 6.2) is situated in the Akmola region and coincides with the Kokshetau (Kokchetav) Median Massif at the southern margin of the West Siberian Plain, between the middle Irtysh river and its western tributary, the Ishim river. Major towns are Kokshetau in the northern and Stepnogorsk in the eastern part of the region.

Some forty uranium deposits have been delineated and a number of major occurrences have been identified. They are grouped in eight ore fields in crystalline rocks, and one ore field in sedimentary terrane. Some isolated deposits/occurrences are known in the northwestern and southwestern Kokshetau region. Table 6.1 provides the names and selected characteristics of significant deposits and occurrences.

Two types of U deposits are noticed in the Kokshetau region. Most deposits consist of structurally controlled mineralization classified as vein-stockwork-type deposits (in Russian literature referred to as vein-stockwork in folded complexes). Some deposits are hosted in paleovalleys incised into the pre-Upper Jurassic surface. They are classified as basal-channel, tabular sandstone-type deposits (stratiform – ground infiltration-type in Russian literature). The latter are restricted to the northeastern margin of the massif.

Vein-stockwork mineralization is partly monometallic and partly polymetallic. By-products include Mo, Sc, Y, REE, and phosphorous.

Remaining in situ resources in the up to $130 per kg U cost category are about 200 000 t U, including 139 000 t U in the RAR + EAR-I category. 81 600 t U of these resources are attributed to the less than $80 per kg U category. In situ ore grades average 0.1–0.2% U (OECD-NEA/IAEA 1993, 1995). These resources include at the Mine Management Unit # 1, 3, 4, and 5 of the Tselinny Combinate measured and indicated resources (A, B, C1 categories) of 34 million t at an average grade of 0.129% U or 43 900 t U, 24 million t of inferred resources (C2) at an average grade of 0.114% U or 27 400 t U, and 17 million t of prognostic (P) resources at an average grade of 0.108% U or 18 400 t U. The prognostic resources are generally based on an extrapolation of the ore-bearing structures beyond the measured, indicated, and inferred resource outlines. (Note: Discrepencies in resource figures are partly based on a change of the cutoff grade; calculations were based on a 0.03% U cutoff grade until 1991 and on 0.05% U thereafter.) (Pool T, pers. commun.).

The first deposits were discovered in the Kokshetau region in 1953. Mining started in 1957. Eleven vein-stockwork deposits have been exploited mainly by underground mines since, five of which are depleted and five operations are closed; one (Vostok) is again in operation. ISL methods were used at one sandstone-type deposit (Table 6.1).

A mill with a nominal capacity of 2 500 t U yr^{-1} operated at *Stepnogorsk*. Total production through 1998 is speculated to be on the order of 30 000–35 000 t U. All mining and processing activities ceased in 1998 but the Vostok Mine was reopened again in 2003.

Sources of information. The subsequent description is largely based on Petrov et al. (2000), who provided a comprehensive documentation of U deposits in the Kokshetau region amended by data from Abakumov (1995), Birka et al. (2003), Boitsov AV et al. (1995), Boitsov VE (1989, 1996), Fyodorov et al. (1997), Laverov et al. (1992), Naumov et al. (1996), OECD (NEA)/IAEA (1993–2005), Omelyanenko et al. (1993), Petrov et al. (1995), Polyarshinov et al. (1994), Poluarshinov and Pigulski (1995), Yazikov et al. (1994), Zhelnov (1994), Boitsov AV, Pool TC, and staff of Kazatomprom pers. commun., unless otherwise noted.

Regional Geological Setting of Mineralization

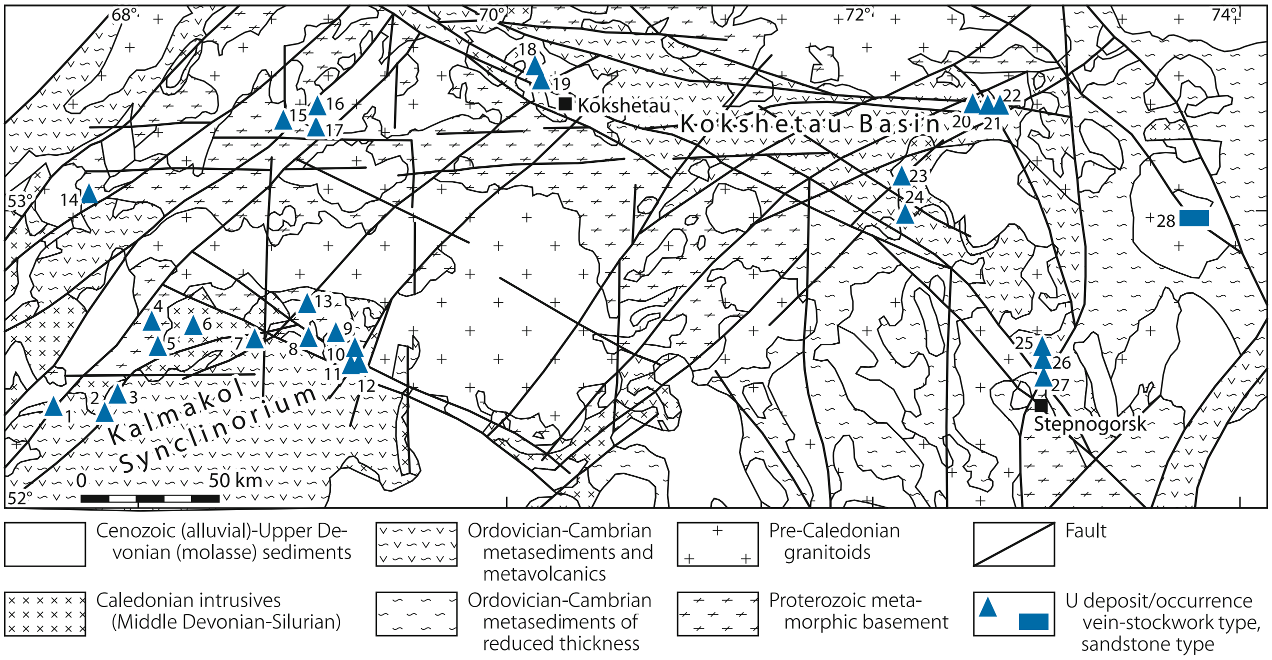
The Kokshetau uranium region is within the Kokshetau Massif, which is a segment of the Caledonian North Tien Shan Fold Belt of the Ural-Mongolian orogenic system. The massif is presumably a fragment of a Precambrian platform that was markedly reworked during the Caledonian geosynclinal and orogenic stages.

Proterozoic metamorphics (gneiss, amphibolite, schist, slate, quartzite, marble) constitute the oldest unit of the Kokshetau Massif. During the *Cambrian-Ordovician* most of the massif was a positive morphological feature but depressions within and marginal to the block, for example, the Kalmakol Synclinorium in the SW and the East Kokshetau Basin in the eastern part of the block, were filled with *Cambrian-Ordovician* volcanogenic and sedimentary deposits and *Middle to Upper Ordovician* flysch. These strata were tightly folded and weakly metamorphosed during the *Caledonian Orogeny*. The main folding phase was during the Silurian. Caledonian multiphase intrusions ranging from early gabbro, diorite, granodiorite, and granite to late leucogranites invaded the older complex during the Ordovician-Silurian and Early Devonian. Mafic to felsic subvolcanic bodies and sheets as well as syn- and post-orogenic dikes are abundant. The latter often group in swarms.

Middle to Upper Devonian volcanics overlain by redbed molasse sediments occur in late orogenic volcanic-tectonic depressions where they rest with a distinct unconformity on the crystalline basement. Some depressions contain predominantly quartz porphyries while andesite porphyry, andesite-basalt, and

Fig 6.2.

Kokshetau region. Geological map of part of the Caledonian Kokshetau Massif with location of uranium deposits. #1–27 are vein-stockwork-type and #28 basal channel sandstone-type deposits (after Boitsov AV pers. commun., Laverov et al. 1992c, Petrov et al. 2000; Poluarshinov and Pigulski 1995)



Ishimsky Ore Field
1 Ishimskoye
2 Kamyshevoye
3 Shokhpak

Chistopolsky OF
4 Molodezhnoye
5 Dubrovskoye
6 Victorovskoye
7 Akkan-Burluk

Balkashinsky OF
8 Balkashinskoye
9 Vostok
10 Promeshutochnoye
11 Zvezdnoye
12 Tushinskoye
13 Olginskoye, Dergechevskoye

NW Kokshetau area
14 Voskhed

Grachevsky OF
15 Kosachinoye
16 Grachevskoye
17 Fevralskoye

Altybaysky OF
18 Slavyanskoye
19 Chaglinskoye

Shatsky OF
20 Glubbinnoye
21 Shatskoye, Shatskoye-1
22 Agashskoye

Koksengirsky (or Zaozernoe) OF
23 Zaozernoye
24 Tastykolskoye

Manybaysky OF
25 Manybayskoe
26 Yuzhno Manybayskoe
27 Aksu

Semizbay OF
28 Semizbay

related tuffs prevail in others as in the Olenty-Seletensk area in the eastern Kokshetau Massif.

Jurassic-Cretaceous alluvial-fluvial sediments occupy paleovalleys incised into the pre-Upper Jurassic peneplain. Valleys are up to few kilometers wide, up to 100 m and more deep and stretch for tens of kilometers from peripheral basins like the Pri-Irtish Syncline into the massif. Unconsolidated platform sediments of *Cretaceous to Cenozoic* age cover much of the Kokshetau Massif.

The following litho-stratigraphic profile provides, in more detail, the rock facies as found in the Central Kokshetau Anticlinorium (after Omelyanenko et al. 1993; based on Rozen et al. 1971 and Abdulkabirova 1987).

Cenozoic to Cretaceous: several 10s of meters and locally over 100 m thick, unconsolidated platform sediments.

Cretaceous-Jurassic: up to 100 m and more thick, alluvial-fluvial sediments in paleovalleys.

Devonian: grabens with redbed molasse (pink conglomerate, sandstone) topping volcanics (rhyolite to andesite-basalt sub-volcanic bodies, lavas, and related tuffs); dikes of quartz diorite porphyry, plagiogranite porphyry cutting Lower Devonian sediments.

Caledonian Orogeny: early orogenic (Silurian) diorite, granodiorite, granite; widespread skarnitization with Fe, Au, and polymetallic mineralization including propylitization with Fe and beresitization with Au mineralization; main orogenic (Silurian-Early Devonian) leucocratic granite intrusions associated with greisenization and Sn, W, and some Mo mineralization; syn- and post-orogenic mafic to felsic dikes.

Silurian-Ordovician: weakly metamorphosed flysch sediments in Ordovician geosynclinal troughs

Ordovician-Cambrian: weakly metamorphosed volcanogenic and sedimentary deposits in early geosynclinal Cambrian troughs with small intrusions of early gabbro, peridotite, pyroxenite

Table 6.1.
Kokshetau region. Geological characteristics and dimensions of deposits (references see text)

Region/deposit	Type of deposit	Ore mode/alteration	Lithology/host rock	Stratigraphy	Length (m)	Width (m)	Depth (m b.s.)	Resource (t U)	Grade (% U)	Remarks/status
Kokshetau Region			Metased, ign rocks	Prot-Pal				230 000[a]	0.1–0.2	[a]Estimated original
(1) Ishimsky OF										
1 Ishimskoye	ve-stw	U-Mo/beres	Metased, dio, spess	Ord-Sil	2 000	1 000	<1 000	20 700	0.204	Depl., UG
2 Kamyshevoye	ve-stw	U-Ti+U-ox/albit	Metased, ss, cgl, volc	Ord, Dev	1 500	1 000	<1 000	20 700	0.114	Closed, UG
3 Shokpak	ve-stw	U-ox/albit	Metased, cgl, ss	Ord, Dev	700	500	<500	3 200	0.135	Closed, UG
(2) Chistopolsky OF										
4 Victorovskoye	ve-stw	U-ox/albit+ U-Ti/beres	Cgl, ss	Dev	1 900	15	50–250	3 000	0.133	Dev.
5 Molodezhnoye	ve-stw		Metased, (cgl, sl, slt)	Ord			<250	Small	0.113	Dev.
6 Dubrovskoye	ve-stw	U-ox/albit	Gneiss, schist; dikes	Pt	1 000		90–300		0.064[b]	[b]+0.12% P_2O_5
7 Akkan-Burlukskoye	ve-stw		Schist	Pt				280	0.138	Dev.
8 Burlukskoye	ve-stw		Marb	Pt?				1 720	0.184	Dev.
(3) Balkashinsky OF										
9 Balkashinskoye	ve-stw	U-ox/beres	Qu-porph, ss, cgl	Dev				3 000	0.123	Partly depl., OP 1959–1966
10 Vostok	ve-stw	U-Mo/beres U-Mo	Metased (mds, slt, ss)	Ord	1 000	500	50–2 000	20 000	0.17	UG 1966–1995, 2003 active
11 Promeshutochnoye	ve-stw	/beres	Metased	Ord						
12 Zvezdnoye	ve-stw	U-Mo/beres U-Mo	Metased, volc/pyrocl	Ord	1 000	50	60–1 400	8 630	0.166	Closed, UG, 1978–1992
13 Tushinskoye	ve-stw	/beres	Metased, volc	Ord, Dev			<460	5 400[c]	0.105	[c]Incl. prognost res.
14 Olginskoye	ve-stw	U^{6+}/beres	Metavolc	Camb-Ord	100	35	30–100	55	0.145	Depl., 1968–1970
15 Dergechevskoye	ve-stw		Schist	Pt			<100	320	0.21	Depl., 1964–1969
(4) Grachevsky OF										
17 Grachevskoye	ve-stw	U-Si/albit,	Qtz;gab, porph, grt	Pt; L Pz	400	200	1 000	18 000	0.128[d]	Closed 1996, UG,[d]+2.5% P_2O_5
18 Kosachinoye	ve-stw	U-ox, U-Si, U-Ti/albit	Cabs sl, dolr	L Pz	8 000	5 000	1 500	95 700	0.109	Dev.
19 Fevralskoye	ve-stw	U-Si, U-Ti	Marb, schist	Pt	1 400[*]	20[*]	650[e]	4 600	0.097	Dev.,[e] dim.of ore bodies
20 Bolotnoye	ve-stw									
21 Sartubekskoye	ve-stw									

Kokshetau Region *continued*										
22 Dukonskoye	ve-stw									
(5) Altybaysky OF										
23 Slavyanskoye	ve-stw	U-ox, U-S/albit	Gneiss, amph	Pt	1 200		650	5 300	0.075[f]	Expl.,[f]+0.042% Mo
24 Chaglinskoye	ve-stw	U-Si, U-Ti/albit	Metased, –volc	Camb-Ord	4 000		700	14 000	0.069	Dev.
25 Abaiskoye	ve-stw	U-Si/albit+beres	ss (molasse)	Mid-Up Dev	2 200	800			0.058	Expl.
26 Kominsko-Krasnoyarskoye	ve-stw		ss (molasse)	Mid-Up Dev						
27 Novogodnee	ve-stw									
(6) Shatsky OF										
28 Glubbinnoye	ve-stw	U-Mo, U-Si/albit	Volc/pyrocl	Up Ord	1 000	50	1 000	6 600	0.104[g]	Dev.,[g]+0.021% Mo, 0.169% Zr
29 Shatskoye-2	ve-stw	U-Mo, U-Si/albit	Volc/pyrocl	Up Ord				600	0.056	Dev.
30 Shatskoye-1	ve-stw	U-Mo, U-Ti, U-ox/albit	Volc/pyrocl	Up Ord	2 500		600		0.083[h]	Dev.,[h]+0.127% Mo
31 Agashskoye	ve-stw	U-Si/albit	Grt	Sil	970		750	6 170	0.146[i]	Dev.,[i]+0.038% Zr
(7) Koksengirsky OF										
32 Belagashkoye	ve-stw									
33 Gvardaiskoye	ve-stw									
34 Borovskoye	ve-stw									
35 Koksorskoye	ve	U-ox, U-P	Metased (ls, ss, slt)	Pt-Ord	1 000	180	250	760	0.088[j]	Dev.,[j]+5% P_2O_5, 0.2% Zr, 0.18% Sr
36 Koksorskoye South										
37 Zaozernoye	ve-stw	U-P-REE/albit	Metased (ls, mds, tuff)	Up Ord	2 000	1 000	1 200	~20 000	<0.2[k]	Clos., ´61-´92, UG,[k] 5% P_2O_5, 0.16% REE
38 Mezhozernoye	ve-stw							2 000		
39 Tastykolskoye	ve-stw	U-P-REE/albit	Metased (ls, slt)	Up Ord			400	~3 000	<0.2	Depl.1981, UG+OP
40 Tastykols East	ve-stw	U-P-REE/albit								
41 Murzambetskoye	ve-stw									
(8) Manybaysky OF										
42 Kerbayskoye	ve-stw	U-Mo/alb								
43 Manybayskoye	ve-stw	U-P?/alb	Pyrocl, sed	Mid Ord				~20 000	0.68[l]	Depl. 1981, UG+OP,[l]+0.04% Mo
44 Manybayskoye South	ve-stw	U-Mo/alb	Pyrocl, sed	Mid Ord			250	~2 000	0.08[m]	[m]+0.02% Mo
45 Bezymiannoye	ve-stw									
46 Krugloye	ve-stw									

Table 6.1. (Continued)

Region/deposit	Type of deposit	Ore mode/alteration	Lithology/host rock	Stratigraphy	Length (m)	Width (m)	Depth (m b.s.)	Resource (t U)	Grade (% U)	Remarks/status
Kokshetau Region *continued*										
47 Aksu	ve-stw	U/alb	Pyrocl, sed	Mid Ord					0.102^{n}	Depl.,^{n}+0.05 Mo, 0.02% Zr, 0.085% Sr
(9) Semizbay OF										
48 Semizbay	ss, b-ch		ss, cgl, mds	Jur				17 000	0.057	Inactive, ISL
49 Semizbay South	ss, b-ch		ss, cgl, mds	Jur				Small	<0.1	Expl.
50 Selentinsk	ss, b-ch		ss, cgl, mds	Jur				Small	<0.1	
51 Kiziltuk	ss, b-ch		ss, cgl, mds	Jur				Small	<0.1	Expl.
NW Kokshetau area										
52 Voskhed	ve-stw		Amph, grd	L-Mid Camb						
SW Kokshetau area										
53 Kubasadyr	ve-stw?									

Type of deposit: stw stockwork, ***ve*** **vein,** ***ss, b-ch*** basal channel sandstone. ***Ore mode/alteration:*** principal U-ore constituents and associated type of alteration (***U-ox*** pitchblende or uraninite, ***U-Mo*** U-oxides+Mo-sulfides, ***U-Si*** coffinite, ***U-Ti*** brannerite and other U-Ti phases, ***albit*** albitization, ***beres*** beresitization).

Lithology: amph amphibolite, ***cabs*** carbonaceous, ***cgl*** conglomerate, ***dio*** diorite, ***dolr*** dolerite, diabase, ***gab*** gabbro, ***grd*** granodiorite, ***grt*** granite, ***igs*** igneous, ***ls*** limestone, ***marb*** marble, ***mds*** mudstone, argillite, ***metased*** metasediments, ***metavolc*** metavolcanics, ***porph*** porphyry, porphyrite, ***pyrocl*** pyroclastic, ***sl*** slate, ***slt*** silt, ***spess*** spessartite, ***ss*** sandstone.

Stratigraphy: L Lower, ***Up*** Upper, ***Camb*** Cambrian, ***Dev*** Devonian, ***Jur*** Jurassic, ***Ord*** Ordovician, ***Pz*** Paleozoic, ***Pt*** Proterozoic, ***Sil*** Silurian.

Dimensions: max. extensions of deposits but values are only approximate due to hivghly irregular shape of deposits. ***Depths: m b.s.*** meter below surface.

Resources of regions: original in situ RAR + EARI <$130 per kg U. ***Resources of deposits:*** not specified, unclear whether original or remaining resources, may or may not include prognostic (P1) resources. ***Grade:*** in situ.

Status: depl depleted, ***dev*** developed prospect, ***expl*** explored, ***ISL*** in situ leaching, ***OP*** open pit, ***UG*** underground.

and related apatite, antophyllite-asbestos, Co, Ni, Cu, Au, Ag, Pt mineralization.

Proterozoic: Vendian Kokshetau Formation subdivided into: (thicknesses are approximate and refer to Grachevskoye area)

- *Andreevskaya Member* (V_{an}): 650 m thick psephitic-pelitic, weakly metamophosed sediments (sandstones consist essentially of quartz with little sericitic cement, siltstone of poorly rounded quartz grains in hydromica-chlorite matrix, and mudstone with hydromica-chlorite and minute quartz grains). Three units are distinguished:
  - upper unit: 300 m thick, alternating 10–65 m thick medium- and fine-grained sandstone and mudstone-siltstone beds with local limestone lenses
  - middle unit: 200 m thick, medium-grained quartz-sandstone, overlying 100 m thick intercalated siltstone-mudstone, fine- and medium-grained sandstone
  - lower unit: 50 m thick, medium-grained, quartzose sandstone
- *Sharykskaya Member* (V_{sh}): 1 000 m thick, pelitic-calcareous, weakly metamophosed sediments divided into two units, at exocontact of granite transformed into skarn with Sn-W mineralization:
  - upper unit: carbonaceous and/or sericitic shale, dolomite, limestone often enriched with carbonaceous matter, mudstone, siltstone
  - lower unit: sericitic shale locally with <5 m thick intercalations of limestone that often contain organic substances

Riphean

- *Borovsk Formation*: porphyroids; actinolite, chlorite-actinolite and quartz-sericite-chlorite schists; and
- *Zerendin Formation*: eclogite, gneiss, amphibolite, mica schist, a.o.

Numerous faults cut the massif including deep rooted structures-which were repeatedly reactivated. Principal fault systems trend NW-SE, NE-SW, N-S and E-W (Fig. 6.2). Deep-rooted faults divide the massif into uplifted blocks and downthrown grabens. The latter are filled with the afore mentioned Early-Middle Paleozoic geosynclinal lithologies or post-Caledonian continental rocks.

Principal Characteristics of Vein-Stockwork Deposits of the Kokshetau Region

(For description of characteristics of sandstone-type deposits of the Kokshetau region see Sect. 6.1.9: *Shokay Zone, Olenty-Seletinsk Area, Eastern Kokshetau Region.*)

Principal Host Rock Alterations

Principal alteration features in rocks surrounding uranium deposits include two *pre-uranium stages* one of alkali metasomatism essentially reflected by albitization with hematitization that affected all lithologies, and another of beresitization (i.e. quartz-sericite-ankerite-pyrite alteration), which extends from mineralized structures for as much as 100 m into wall rocks. The pre-uranium beresitization process generated a marked porosity of the affected rocks that provided a favorable host environment for ore deposition. *Syn-uranium* beresitization associated with chloritization and hydromicazation is locally developed at some deposits. *Late- to post-uranium stage* carbonatization (mainly dolomitization) overprinted the former alteration facies for up to 100 m from mineralized structures.

Albitization and beresitization occur at most deposits, but in variable intensity. Both are typical for the Altybaysky and Chistopolsky ore fields whereas beresitization prevails at deposits of the Ishimsky and Balkashinsky ore fields; and albitization associated with chloritization and carbonatization in the other ore fields.

Principal Characteristics of Mineralization

Three marked minero-chemical varieties of mineralization are distinguished each dominated by either a uranium-apatite assemblage, e.g. in the *Tastykolskoye, Zaozernoye,* and *Vostok* deposits or a uranium-molybdenum mineral assemblage as found in the *Balkashinskoye, Grachevskoye, Ishimskoye,* and *Manybayskoye* deposits. The former predates the latter. The third variety consists of deposits with simple U mineralization (also referred to as uranium-albite mineralization) such as *Kosachinoye, Shokpak*, and *Kamyshevoye*. Overprinting of the various mineral assemblages often generated complex mineral associations.

Uranium-apatite mineralization may include uraniferous fluorine-apatite with minor pitchblende, coffinite, pyrite, marcasite, galena, chalcopyrite, arsenopyrite, zircon, thorite, and REE-bearing minerals. Gangue minerals are chlorite, hydromica, albite, and commonly large quantities of calcite and dolomite. Some deposits have high uranium contents bound in arshinovite. U-P mineralization occurs preferentially in highly broken intervals of Na-metasomatized Proterozoic and Lower Paleozoic rocks at and adjacent to Caledonian hypabyssal stocks and dike swarms.

U-Mo mineralization (0.02–0.5% Mo) consists of U oxide and U silicate (pitchblende, uraninite, coffinite) associated with sulfides of Mo (molybdenite, jordisite), Fe (mainly pyrite), Pb, Cu, and As. Gangue minerals are represented by carbonate (commonly ankerite, minor dolomite), sericite, chlorite, and some apatite. Zirconium (in arshinovite) occurs in significant amounts. Post-uranium carbonates (mainly calcite) can be present in large amounts and occur as veins and veinlets, and fill voids in ore. The carbonate fraction of U-Mo ore varies between 0.1 and 50% CO_3. Ore minerals reflect a certain vertical zoning: Pitchblende with pyrite and galena prevail on upper levels, and pitchblende with molybdenite and coffinite at lower levels. U-Mo deposits typically occur in terrane of marked post-orogenic volcanism. Ore bodies are controlled by faults and highly cataclastic intervals within and at the exocontact of subvolcanic intrusions, volcanic structures, and complicated volcanic sheets of Paleozoic depressions. Wall rocks are commonly altered by beresitization.

Simple U mineralization may consist of U-oxide, U-Ti-, and/or late U-silicate phases (pitchblende, uraninite, brannerite, coffinite) associated mainly with carbonate and chlorite. Ore lodes occur in fracture zones on both sides of the Middle Paleozoic unconformity. Wall rocks may be altered by albitization, and/or carbonatization (mostly dolomite), silicification (quartz), chloritization, hematitization, goethitization, or pyritization. CO_3 content can exceed 10%.

Based on studies of deposits in the Ishimsky and Grachevsky ore fields, Boitsov et al. (1995) distinguish three principal *lithostratigraphic settings of U mineralization* and several lithology-related mineral assemblages. Although they are most typical for the Ishimsky and Grachevsky ore fields, they are partially or with variations also recognized in other ore fields:

1 Mineralization in Proterozoic crystalline basement rocks and intrusive Caledonian granites:
  1.1 Albitized granite and quartzite (type example: *Grachevskoye*): apatite-coffinite-REE paragenesis with yttrium and thorium; U grades are variable and can be up to >1%. Phosphorus ranges between 0.3 and 10% P_2O_5.
  1.2 Siliceous and argillic carbonaceous schist and diabase distant from granite (type example: *Kosachinoye*):
    a coffinite-chlorite in albitized rocks,
    b brannerite or brannerite-uraninite in carbonate-chlorite or quartz-goethite altered rocks, and
    c late coffinite-pyrite in dolomitized rocks overprinting the former assemblages.
    U grades of Type 1.2 ores are commonly low; carbonate content is in excess of 6% CO_3.
2 Mineralization in weakly metamorphosed *Lower Paleozoic* rocks cut by Caledonian igneous dikes and sills (type example: *Ishimskoye*): jordisite-coffinite and molybdenite-pitchblende in hydromica and carbonate altered rocks.
3 Mineralization in weakly metamorphosed Lower Paleozoic lithologies and unmetamorphosed Devonian redbeds at and immediately below and above the *Middle Paleozoic unconformity*. (type example: *Shokpak* in basement, *Kamyshevoye* in basement and redbeds):
  a brannerite in quartz-goethite-carbonate altered albitized terrestrial rocks including conglomerate at upper levels of *Kamyshevoye*, (in excess of 10% CO_3)
  b pitchblende-chlorite overprinting the brannerite phase resulting in a brannerite-pitchblende association at lower levels of *Kamyshevoye*
  c uraninite-chlorite in hematitized, silicified quartzite unaffected by albitization (*Shokpak*)

Poluarshinov and Pigulski (1995) note that certain elemental ratios in uranium showings may be used for the determination of the erosional level of a deposit, i.e. for the potential of ore presence at depth. High As/U ratios may suggest limited erosion and as such a preserved blind ore body while high Mo/U and Pb/U ratios indicate most likely a deep erosion level with only the roots of an ore body preserved.

General Shape and Dimensions of Vein-Stockwork Deposits

Individual deposits range in size from few hundred tonnes to 95 000 t U and in grade from 0.05 to 0.18% U.

Deposits may consist of a number of ore bodies distributed over a depth interval from near surface to more than 1 000 m. Ore control is primarily by structure. Consequently, shapes and dimensions of deposits and ore bodies are highly variable and are governed by the local structural situation. U-P, U-Mo, and simple U mineralization occur in complexly-arranged and irregularly-mineralized stringers, veinlets, disseminations, and breccia matrix, which group to complex veins, linear, flattened lenticular or pipe-shaped or compact and almost isometric bodies with stockwork structure located often, but not necessarily, at the exocontact of or within hypabyssal intrusions of variable leucocratic to mafic composition. Linear ore bodies can persist for several kilometers along fault zones as at the Kosachinoye deposit. Ore distribution is irregular and discontinuous. This results in highly variable ore grades ranging from some 100s of ppm to several percent U. Details of dimensions, grades, and resources of individual deposits as far as known are provided in later chapters and summarized in Table 6.1.

Regional Geochronology

Caledonian granites of the Orlinogorskii complex yield K-Ar ages between 420 and 360 Ma with a grouping of 390–380 Ma (Omelyanenko et al. 1993).

The main stage of uranium mineralization in vein-stockwork deposits of the Kokshetau region is dated at 380–360 Ma (Table 6.2), which corresponds to the Late Devonian. This is supported

Table 6.2.
Northern Kazakhstan, Kokshetau region. Isotope ages of U mineralization and redistribution in endogenic deposits. (Petrov et al. 2000) (*italic:* principal ages of ore formation)

Mineralization type	Age (Ma)	Deposits example
Th-U in quartz-feldspar metasomatite	1 400–1 250, 600–510	East Dybrovskoye
P-U and U in Na metasomatite	490–460, 420–405, *380–360*, 330–310, 270–250	Grachevskoye, Kosachinoye, Fevralskoye, Chaglinskoye, Zaozernoye, Tastykolskoye
Mo-U, U in Na metasomatite and beresite zones	470–450, 420–405, *380–360*, 330–310, 280–250	Agashskoye, Shatskoye, Glubinnoye, Manybai, Aksu, Shokpak, Kamyshovoye, Viktorovskoye
Mo-U, U in beresitization, argillization and feldspathization zones	480–450, 420–405, *380–360*, 330–310, 280–265	Ishimskoye, Centralnoye, Vostok, Zvezdnoye, Balkashinskoye, Dergachevskoye

by geological relationships; uranium mineralization occurs in Caledonian and pre-Caledonian rocks and in the overlying Middle to Late Devonian sediments but is absent in Carboniferous sediments. The ore forming event is attributed to a general uplift of the Kokshetau region during the waning episode of the Caledonian Orogeny.

Potential Sources of Uranium

Two principal lithologic units are considered as potential U sources, uraniferous crystalline rocks and black shale. Both may have contributed individually or in combination to ore formation in the Kokshetau region. The first group includes Precambrian and Lower Paleozoic lithologies with 3.2–7.2 ppm U, Middle to Upper Paleozoic leucogranites with 10–70 ppm U, and rhyolite with up to 10 ppm U. The igneous rocks are considered to be the product of granitization of crustal material, which may also have produced magmatic ore-forming solutions. The Paleozoic black shale contains 100–200 ppm U and formed in a geosynclinal regime at the margins of median massifs and geoanticlinal uplifts composed of the afore mentioned rocks.

Principal Ore Controls and Recognition Criteria of Vein-Stockwork Deposits

Vein-stockwork-type deposits in the Kokshetau region are primarily controlled by structures and secondly by lithologies altered by Nametasomatism/albitization and/or beresitization. Typically, U-P ore is preferentially confined to Na-metasomatized, and U-Mo ore to beresitized, environments. Significant ore controlling parameters or recognition criteria of major deposits include:

Host Environment

Proterozoic crystalline basement overlain and surrounded by

- Lower Paleozoic, weakly metamorphosed, tightly folded geosynclinal facies of terrigenous and volcanic origin
- Caledonian intrusions ranging from gabbro to leucocratic granite
- orogenic and post-orogenic mafic to felsic dikes forming swarms
- Devonian unmetamorphosed molasse redbeds and mafic to felsic effusives and pyroclastics filling grabens
- Upper Jurassic to Lower Cretaceous alluvial sediments filling paleovalleys
- Mesozoic to Cenozoic unconsolidated cover deposits including impermeable horizons
- elevated U background values in Precambrian and Lower Paleozoic metamorphics, Caledonian leucogranite and rhyolite, and Paleozoic black shale
- deep reaching lineaments and major fault systems trending NW-SE, NE-SW, E-W, and N-S, vertical displacements along which provoked horsts and grabens
- intense fracturing and cataclasis along prominent faults and at faults intersections
- distinct unconformities between Lower Paleozoic and Middle Devonian, and Paleozoic and Upper Jurassic units
- host rocks include
  - Devonian molasse-type redbed sandstone, conglomerate with intercalated effusive and pyroclastic volcanics,
  - Caledonian igneous rocks: granite, gabbro, quartz porphyry,
  - Lower Paleozoic weakly metamorphosed geosynclinal and flysch facies: shale/mudstone, sandstone, siltstone, and
  - Proterozoic high-grade metamorphics: gneiss, amphibolite, schist, slate, quartzite, marble

Alteration

- pre-uranium Nametasomatism (albitization associated with hematite, chlorite, carbonate alteration) of all Precambrian and Paleozoic rocks
- pre-uranium beresitization (sericite, carbonate [ankerite, minor dolomite], silica [quartz], pyrite alteration)
- minor syn-uranium beresitization with hydromica and chlorite alteration
- late to post-uranium carbonatization (dolomite, calcite)

Mineralization

General features:

- restriction of deposits to areas of Caledonian magmatism
- geotectonic position of deposits and ore bodies controlled by
  - deep reaching, long-lived and repeatedly reactivated prominent fault zones
  - intersections or junctions of such fault zones
  - highly fractured and/or cataclased intervals along faults or their intersections
  - dip- or strike-angle variation of faults
  - 2nd and 3rd order faults and their intersection sites with boundaries of Caledonian grabens
- restriction of ore lodes to rock facies of favorable physical-mechanical (brittle) and locally chemical (carbonaceous/graphitic) properties (heterogenous lithologies with variable rockmechanical properties)
- restriction of mineralization to markedly altered rocks (albitization and/or beresitization etc.)
- several phases of mineralization reflected by two prominent polymetallic (U-P succeeded by U-Mo) parageneses, and simple U mineralization
- Mo/U, Pb/U, As/U ratios can be used for indication of erosion levels
- characteristics of *U-P mineralization* include
  - complex P-U-REE assemblage composed of uraniferous F-apatite and pitchblende associated with Cu-, Fe-, Pb-, As-sulfides, Th, Y, and REE-bearing minerals
  - prevailing associated gangue minerals are calcite, dolomite
  - deposits consist of intermittent ore bodies
  - ore bodies are commonly of columnar and lenticular shape with internal stockwork structure
  - geotectonic position of ore bodies at intersection, lacing and/or branching of faults, particularly at interformational deformation zones with a high degree of jointing/fracturing

  - lithologic-tectonic position of ore bodies in albitized pre-Caledonian rocks at and adjacent to Caledonian hypabyssal intrusions (granite stocks, dike swarms)
  - best U grades are in highly silicic rocks with low apatite contents
  - U ore with high P contents are usually confined to carbonate rocks (marble, limestone)
- characteristics of *U-Mo mineralization* include
  - U-oxides and U-silicate (pitchblende, coffinite) associated with sulfides of Mo (molybdenite, jordisite), Fe, Pb, Cu
  - gangue minerals include carbonates, sericite, chlorite, some apatite
  - locally complex mineral assemblages due to overprinting of U-P by U-Mo parageneses
  - ore bodies consist of veins and flattened linear or lenticular bodies with internal stockwork structure composed of stringers, veinlets, disseminations, breccia fillings
  - ore bodies are related to faults and highly cataclastic intervals within and at exocontacts of subvolcanic intrusions, volcano-tectonic structures, and complicated volcanic sheets in Paleozoic depressions
  - spatial (and genetic) association with Caledonian andesite-diorite, granite, and rhyolite of late orogenic volcanism within folded Lower Paleozoic geosynclinal facies
  - restriction to host rocks altered by beresitization
- characteristics of simple *U mineralization* include
  - U-Ti, U-oxide, and U-silicate phases (brannerite, pitchblende, uraninite, coffinite) with sulfides of Cu, Fe, Pb
  - gangue minerals include carbonates, chlorite, sericite, some apatite
  - geotectonic position of ore in fracture zones at, above and below the Middle Paleozoic unconformity: U-silicate mineralization on upper levels in Devonian redbeds, replaced downward by U associated with carbonate in albitized metamorphic rocks of the Lower Paleozoic geosynclinal sequence
  - wall rocks may be altered by albitization, and/or carbonatization (mostly dolomite), silicification (quartz), chloritization, hematitization, goethitization, or pyritization

Metallogenetic Concepts

Several metallogenetic hypothesis are forwarded for the vein-stockwork uranium deposits of the Kokshetau region. Although U is hosted by Caledonian granite in some deposits, Laverov et al. (1992c) reject a genetic correlation of U mineralization with granite. Omelyanenko et al. (1993) also do not see a convincing relation of uranium deposits to the magmatic intrusions. They point out that the main uranium stage occurred during the Late Devonian as evidenced by the restriction of primary uranium mineralization to Devonian and older rocks and isotope ages of U minerals grouping at 370–350 Ma. The authors attribute the principal ore-forming event to a general uplift of the Kokshetau region during the waning episode of the Caledonian Orogeny in Late Devonian time.

A common model for the primary uranium event favors hypogene uraniferous fluids that evolved from late magmatic differentiation or uranium derived by leaching of uraniferous country rocks, or from both sources. All younger mineralization stages, as dated for the Upper Triassic-Jurassic, Paleogene and Neogene, are considered but redistribution processes. The Triassic-Jurassic ages are attributed to a major paleoweathering episode that resulted in an upgrading of the U content in deposits such as Kosachinoye and Grachevskoye (Skoros-pelkin 1981).

Boitsov et al. (1995) suggest a uniform hydrothermal system for ore formation. This system generated the various mineral parageneses during several phases, apparently in a series of pulsations, first the U-P phase (pitchblende, F-apatite), followed by the U-Mo phase, and finally, a U phase associated with carbonate, which derived by rejuvenation of earlier uranium mineralization.

Omelyanenko et al. (1993), based on their studies of the Grachevskoye deposit, conclude that the highly variable composition of altered rocks, and extent and intensity of alteration are a function of the chemistry of hydrothermal fluids, lithology of the parent rock, and the scope and grade of tectonic deformation preceding the various hydrothermal events (see also Sect. 6.1.4.1: *Grachevskoye*). The authors propose that alkaline, phosphorous-rich solutions have formed the ore-bearing metasomatites at Grachevskoye. As indicated by fluid inclusions and decrepitation tests, the alteration occurred at a temperature between 220 and 280°C. The metallogenetic and related precursor processes began with Nametasomatism (mainly albite), succeeded by apatitization that overlapped and postdated albitization, and were continued with coffinite crystallization, which was coeval with and after apatite. Pitchblende deposition postdated the former processes. Narrow veinlets of albite, and rare apatite, quartz, chlorite and sericite/hydromica, and pockets of carbonate formed last. The bulk of coffinite, apatite, chlorite, and other minerals precipitated during the terminal stage of the hydrothermal event and typically occur in zones of post-albite microfracturing. Repeated brittle deformation preceded the various alteration and mineralizing processes.

In contrast to Grachevskoye, at Kosachinoye and adjacent deposits situated some 20 km S of Grachevskoye, uraniferous albitized rocks, although containing a high calcium content, are not anomalous in phosphorous, which implies that two autonomous solutions were involved in the formation of these deposits.

The vein-stockwork deposits of the Kokshetau region are considered by the Russian authors to be fairly similar to the Beaverlodge veins in Canada but for the high apatite content in some deposits; hence, only deposits with simple U(-albite) may be considered comparable. In addition, the Kokshetau deposits have been compared with the vein U deposits hosted in albitites of the Ukrainian Shield, but the latter have formed at far higher temperatures of 300–450°C (Omelyanenko 1978).

6.1.1 Ishimsky Ore Field, Southwestern Kokshetau Region

This ore field is in the western part of the Ishimsk-Balkashinsk metallogenetic zone and includes the large *Ishimskoye* and

Kamyshevoye deposits, and the *Shokpak* deposit (Fig. 6.2, Table 6.1).

Sources of information. Boitsov et al. 1995; Petrov et al. 2000; Poluarshinov and Pigulski 1995; amended by data from other sources.

General Geological Features of the Ishimsk-Balkashinsk Metallogenetic Zone

According to Poluarshinov and Pigulski (1995), the Ishimsk-Balkashinsk metallogenic zone includes the Ishimsky and Balkashinsky ore fields. This zone is situated at the boundary of two structural units, the Kokshetau Block to the north and northeast and the Kalmakol Synclinorium to the south. Rocks of the Kokshetau Block include Precambrian gneiss, amphibolite and schists intruded by Caledonian granitoids, gabbro, and gabbro-diorite. The block was a positive element continuously during the Lower Paleozoic interval while the Kalmakal Synclinorium was a trough during the Caledonian geosynclinal stage. The synclinorium is filled with folded and weakly metamorphosed Cambrian to Ordovician volcanics and sediments and Middle-Upper Ordovician flysch. Late to post-orogenic grabens contain Middle to Upper Devonian pink molasse, which rests with a distinct unconformity on the crystalline basement. Some of the Devonian depressions contain mafic to felsic effusives and pyroclastics. The area is covered by a 40–60 m thick blanket of loose platform deposits, which increase in thickness to more than 100 m at some locations. Major structures trend mainly about NE-SW and E-W.

6.1.1.1 Ishimskoye

This deposit was discovered some 200 km SW of Kokshetau in 1957. Ore is of U-Mo vein type hosted in beresitized rocks. Original resources were in excess of 20 000 t U and averaged 0.204% U and 0.066% Mo. The deposit was mined underground and is depleted.

Ishimskoye ore bodies occur within the Ishim syncline composed of weakly metamorphosed Ordovician sandstone, siltstone, mudstone, which are overlain by Mid-Upper Devonian pink conglomerate and sandstone. Two groups of Silurian dikes cut the Ordovician sediments: shallow, 20–30°NW inclined lamprophyre and gabbro-syenite sills, and NNE-SSW-oriented, 60–70°SE dipping granodiorite-porphyry and diorite dikes.

The conformably to the Ordovician sediments NNE-SSW-trending, 35–40°NW dipping Carbonatny fault is the main structure at the deposit. It consists of 2–5 adjacent faults, 3–10 m thick each.

Pre-uranium beresitization (quartz, sericite, carbonate, pyrite alteration) is the principal alteration that altered all rocks along gently, strata-peneconcordant and steeply dipping structures but in a litho-differential mode. Carbonatization prevails in rocks of intermediate composition (spessartite and diorite dikes), whereas a combination of silicification and sericitization is typical for silicic facies, as well as for sandstone and shale.

Ore consists of the U-Mo paragenesis composed of pitchblende, coffinite and molybdenite/jordisite with sulfides of Cu, Fe, Pb, Zn, and As, and, locally, anthraxolite. Pitchblende constitutes 99% of the resources. Gangue is reflected by post-uranium stringers and veinlets of ankerite, and quartz-carbonate.

Ishimskoye consists of 15 ore bodies contained in a 2 km long and 1 km wide area. Three ore bodies occur in the Vesely sector and provided 66% of the resources, 7 in the Zmeiny and 5 in the Pryishimsky sector, which accounted for 27% and 7% of the resources, respectively.

Structural criteria exerted the principal ore control. Most favorable structural settings and high-grade ore are controlled by the intersection of steep faults with interformational, strata-peneconcordant, shallow-dipping, intensely-shattered fracture zones. High-grade ore also occurs in breccia zones, which developed at sites where steep faults cut dikes.

Ore bodies consist of veins but mainly of elongated, subhorizontal lens- or pipe-like shaped bodies with an internal stockwork structure. Ore bodies are 1–6 m, rarely up to 10 m thick, from 20 m to 1 000 m long, from 10 m to 500 m wide, and extend for 750 m downdip. Ore persists from depths of 50 m to 1 000 m below surface.

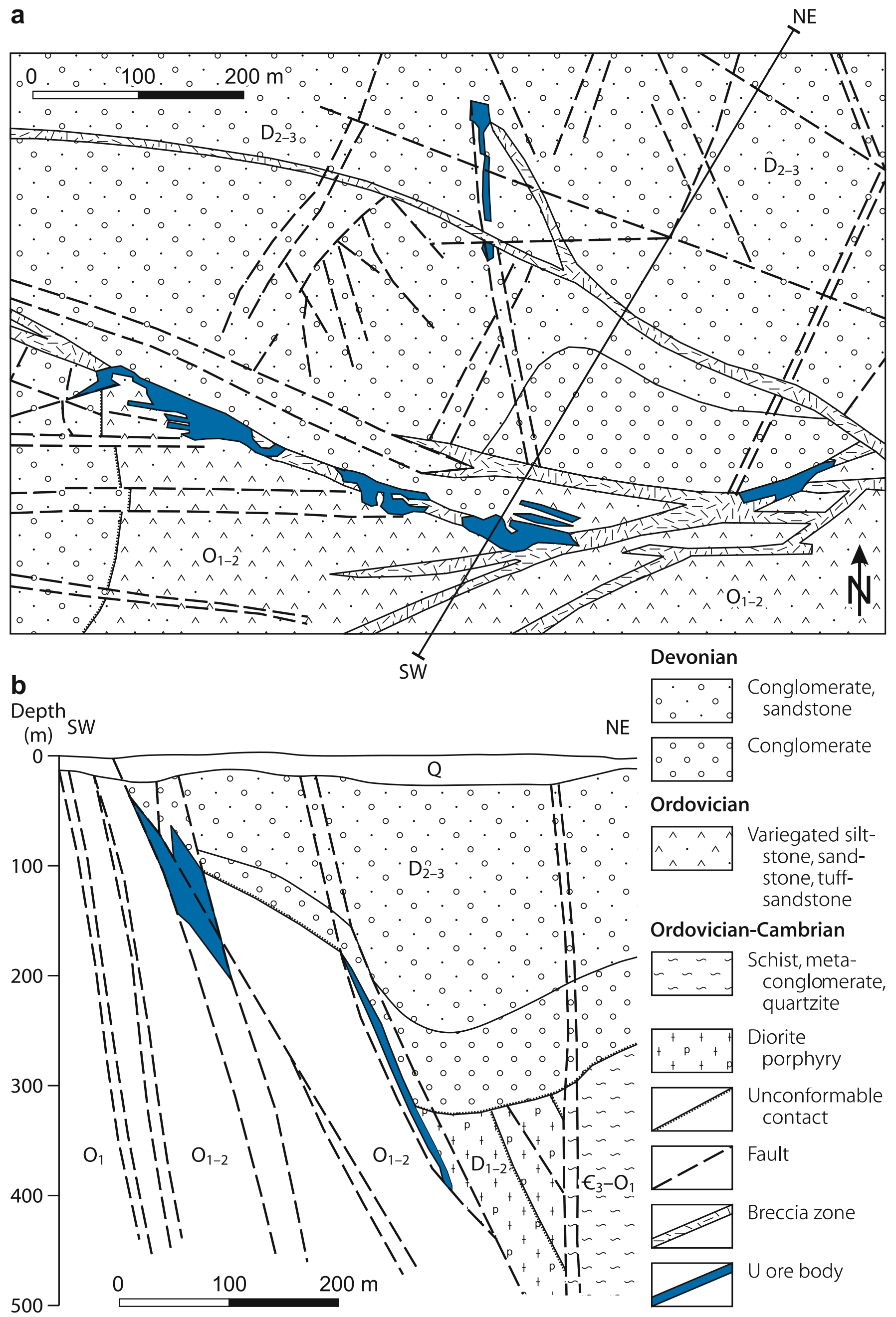
6.1.1.2 Kamyshevoye

This partly exploited deposit is located about 2 km SW of the Shokpak deposit and 170 km SW of Kokshetau. It was discovered in 1977 and explored by two shafts. Ore is of U-Ti and U-oxide vein-type and occurs in two ore zones. Original in situ resources totalled 20 700 t U at an average grade of 0.114% U (OECD-NEA/IAEA 1995); ore zone # 2 accounted for 87% of these resources. Remaining(?) inferred resources (C2 category) contained within ore zones # 1 and # 2 amount to 7 800 t U at an average grade of 0.12% U. The # 2 ore body contains additionally 5 000 t U prognostic resources (P) at an average grade of 0.082% U. (Basis for calculation: 0.03% cutoff grade and minimum thickness of 1 m.)

Kamyshevoye is situated at the SE edge of the Shokpak graben-syncline. Uranium occurs largely in a sequence of 80–300 m thick Devonian redbed molasse conglomerate and sandstone, which rests unconformably on a basement of slightly, metamorphosed Middle-Upper Ordovician terrigenous rocks (siliceous shale, siltstone, sandstone, and conglomerate) and andesite-basalt. These rocks are transected by N-S- and E-W-trending older faults which are cut by structures oriented about NW-SE (Figs. 6.3a,b).

Two ore zones composed of discontinuous vein and stockwork ore bodies occur at depths from 70 to 1 000 m. Steeply-dipping, SE to ESE and N-S-trending fault-breccia zones controll the ore zones and the setting of ore bodies. Ore bodies are of linear shape with lateral bulging at fault intersections. Ore bodies are from 50 m to 450 m long, and extend for as much as 700 m downdip (Fig. 6.3b). At the upper levels, U mineralization consists of brannerite and is hosted in albitized silt- and sandstone affected by quartz-goethite-carbonate alteration similar to that on upper levels of the Kosachinoye deposit. This assemblage

Fig. 6.3.
Kokshetau region, Kamyshevoye, a geological map and b SW-NE section showing the position of vein-stockwork ore bodies immediately at the Devonian/Ordovician unconformity (after Petrov et al. 2000)



was replaced immediately at and from the un-conformity downwards by a pitchblende-chlorite association. Where at depth brannerite ore in albitized lithologies were overprinted by the pitchblende paragenesis, a brannerite-pitchblende assemblage associated with carbonate has developed. Both the brannerite and pitchblende ores are considered to be of primary origin.

6.1.1.3 Shokpak

This deposit is located 165 km SW of Kokshetau and 2 km NE of Kamyshovoye. It was discovered in 1968 and is depleted. Original resources averaged 0.135% U and amounted to 3 200 t U contained in three ore zones: *Northern, Southern* and *Shirotnaya*; the Southern zone accounted for 62% of the resources.

The ore zones occur in an about 700 m long and up to 500 m wide strip along the curvilinear NE-SW-trending suboutcrop of the Lower/Middle Paleozoic unconformity, which separates Ordovician metasediments from Middle to Upper Devonian redbed molasse. Older faults trend about N-S and NW-SE. They are displaced by E-W- and NW-SE-oriented faults. Faults of all systems offset the unconformity.

Ore consists of U-oxide mineralization, essentially pitchblende associated with chlorite, that forms irregularly distributed vein-stockwork ore bodies in beresitized rocks. Host rocks are Devonian hematitic, quartzose redbed sediments and mainly Ordovician weakly metamorphosed sand- and siltstone (silicified quartzite). Wall rock alteration includes beresitization (sericitization, carbonatization, pyritization, chloritization) and hematitization. Albitization is absent.

Ore lodes occur discontinuously along about WNW, NE, and NW-trending faults at and immediately below the unconformity and are distributed from 50 m to 500 m below surface. Ore bodies are mainly of linear-isometric shape with dimensions from 60 m to 350 m long, from 6 m to 25 m thick, and persist over depth intervals from 90 to 200 m.

6.1.2 Chistopolsky Ore Field, Southwestern Kokshetau Region

The Chistopolsky ore field is some 140 km SW of Kokshetau and includes the small *Victorovskoye, Molodezhnoye, Dubrovskoye, Akkan-Burlukskoye,* and *Burlukskoye* vein-stockwork deposits. Host rocks are partly albitized and partly beresitized Precambrian and Paleozoic lithologies. Deposits range in size from a few 100 to a few 1 000 t U and exhibit average grades from 0.1 to 0.2% U (Fig. 6.2, Table 6.1).

Sources of information. Petrov et al. 2000.

Most deposits occur in or adjacent to the western part of the Chistopol Basin, except Akkan-Burlukskoye that is in the eastern part. The basin is filled with Middle-Upper Devonian pink molasse (conglomerate, sandstone, siltstone). These sediments rest unconformably upon a basement composed of Precambrian metamorphites (amphibole-biotite gneiss, migmatite, amphibolite, schist), Lower Paleozoic effusive-sedimentary lithologies (conglomerate, tuff, gravel, sandstone, andesite porphyry), and Lower-Middle Ordovician siliceous-terrigenous sediments (siltstone, argillite, jasper, sandstone, conglomerate). Dikes occur in the western part and at the SW edge of the Chistopol Basin. Mineralization occurs in all rock types. The abyssal Ishim-Balkashin fault zone is a prominent regional structure, which trends adjacent to the Chistopol Basin.

6.1.2.1 Victorovskoye

This deposit is located within the SW margin of the Chistopol Basin. It was discovered in 1979 and explored by underground workings but not mined. In situ resources amount reportedly to 3 000 t U and average 0.107% U.

Ore bodies are hosted in Devonian sandstones with interbedded gravel and conglomerate, which were intruded by granite porphyry and dacite dikes. The dikes are up to 30 m thick and 1–1.5 km long, and occur in a belt, 300–400 m wide and 8 km long, situated 200–800 m from the S edge of the basin. Ordovician conglomerate, sandstone, and Cambrian spilite -diabase occur to the south of the Devonian sequence. Principal host rock alteration includes beresitization, albitization, and carbonatization.

Brannerite and uraninite are the principal U minerals. Brannerite mineralization is hosted in beresite altered, and uraninite mineralization in albite-carbonate altered pink Devonian sediments. Mineralization occurs in a 1.9 km long and 15 m wide zone controlled by the Northern fault zone, an up to 50 m wide structure with 2 steeply dipping faults. The ore zone includes 3 ore bodies with vein- and lens-like lodes, 25–250 m long, 0.7–40 m wide, and 50–250 m deep. 39% of the Victorovskoye resources occur in ore body # 1 and 53% in ore body # 3.

6.1.2.2 Molodezhnoye

This small deposit was discovered 1.5–2 km to the SW from the edge of the Chistopol Basin in 1963. The ore averages 0.113% U. Mineralization occurs to a depth of 250 m in NW-SE- and NE-SW-oriented fault zones that cut Lower–Middle Ordovician, slightly metamorphosed shale, conglomerate, and siltstone intruded by Devonian plagioclase porphyry and diabase. Five vein-type ore bodies are delineated, which are from 50 to 130 m long and persist over depths intervals from 50 to 110 m.

6.1.2.3 Dubrovskoye

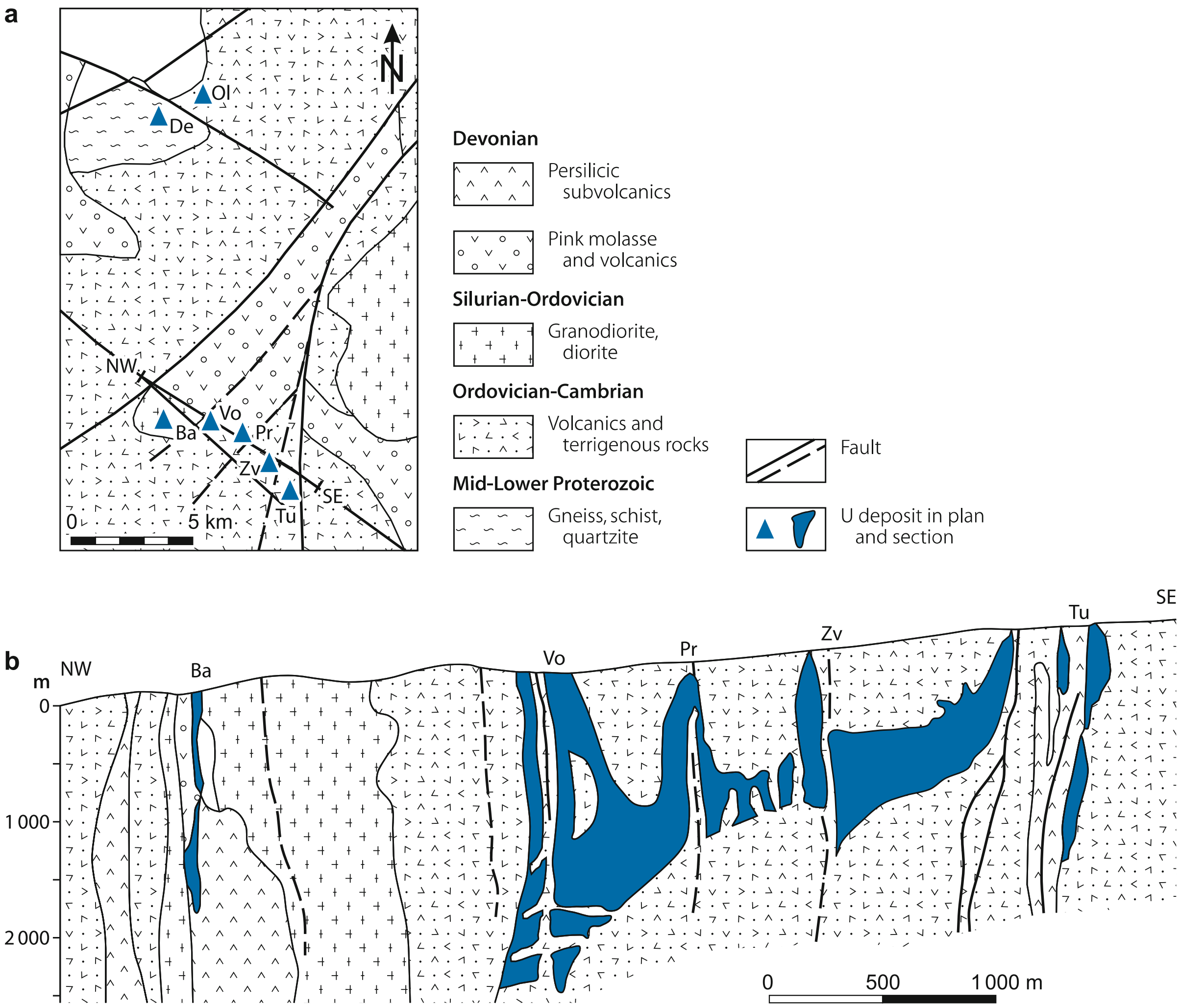
Discovered in 1969, Dubrovskoye is located in the northern Chistopolsky ore field, 1.5–5 km off the NW edge of the Chistopol Basin. Two ore sectors are recorded: the *Southeastern* with 8 ore bodies and 90% of the resources, and the *Northwestern* with 4 ore bodies. The ore averages 0.064% U, and 0.12% P_2O_5.

Mineralization occurs at the SW edge of a granite-gneiss dome within two Precambrian metamorphic units: Proterozoic gneiss of the Zerendin Series (amphibole, quartz and pyroxene paragneiss) and Vendian schist (coaly-siliceous phyllite, schist, quartzite) of the Sharyk Suite. Intrusions include spessartite, kersantite, and gabbro-diabase dikes, which occur predominantly in gneiss. Ore bodies consist of veins ranging from 100 to 730 m long, 3.5–4 m thick, and depths persistence from 90 to 300 m. Wall rocks are transformed by carbonate-albite alteration.

6.1.3 Balkashinsky Ore Field, Southwestern Kokshetau Region

This ore field (operated by Mine Management Unit # 1) is 40 km W of Balkashino and about 130 km SW of Kokshetau and contains the *Balkashinskoye, Zvezdnoye*, and the large *Vostok* deposits, which were mined prior to 1996. Additional deposits include *Promeshutochnoye* and *Tushinskoye*. Except for Balkashinskoye, the other four deposits may actually be regarded as a continuous single deposit controlled by a major NW-SE fault cut by N-S and NE-SW faults near the margin of the Kokshetau Uplift and the southwesterly adjacent Kalmykol Synclinorium. Ore is of U-Mo vein-stockwork type hosted in beresitized rocks of Ordovician terrestrial-pyroclastic provenance except for Balkashinskoye, which is in Devonian volcanics. Two additional deposits occur 15 km to the north of Balkashinskoye, *Dergachevskoye* in Lower Proterozoic gneiss and schist, and *Olginskoye* in Cambrian-Ordovician metamorphics (Figs. 6.2, 6.4a,b, Table 6.1).

Fig. 6.4.
Kokshetau region, Balkashinsky ore field, a geological map, b NW-SE longitudinal section (courtesy of Boitsov AV based on Russian literature). U deposits: *Ba* Balkashinskoye, *De* Dergechevskoye, *Ol* Olginskoye, *Pr* Promeshutochnoye, *Tu* Tushinskoye, *Vo* Vostok, *Zv* Zvezdnoye



Historical production of the Balkashinskoye ore field totals about 17 000 t U for the period from 1959 to 1995. The present geological inventory includes over 14 000 t U reserves (A, B, C1) and over 13 000 t U prognostic resources (P1) (based on a cutoff grade of 0.05% U).

Sources of information. Petrov et al. 2000; Poluarshinov and Pigulski 1995; unless otherwise cited.

6.1.3.1 Balkashinskoye

The Balkashinskoye U-Mo deposit is located 130 km SW of Kokshetau and was discovered in 1953. The deposit encompasses two sectors, *Central* and *Northern*. The bulk of the U resources are contained in the *Severnoye* (North) and *Glavnoye* (Main) ore bodies in the Central sector. Four small ore bodies are located in the Northern sector. Original resources totalled some 3 000 t U at a grade averaging 0.123% U. This figure includes 1 640 t U proven resources contained in the Main and the North ore bodies. The depleted Main ore body was mined by open pit methods to a depth of 100 m from 1959 to 1966 and yielded 900 t U at a grade of 0.1% U. Remaining reserves of 740 t U at an average grade of 0.078% U (0.05% U cutoff grade) are contained in the North ore body. Prognostic resources (P1) of the two ore bodies total 4 300 t U and average between 0.06 and 0.08% U (Pool T, pers. commun.).

Mineralization occurs within a small depression, 2.5 × 1 km in size, filled with Middle-Upper Devonian sediments and volcanites (conglomerate, sandstone, tuff, with intercalated felsic and quartz porphyry layers). The basin is downfaulted into a basement of Ordovician gabbro and gabbro-diorite of the Shantobe Massif, which is cut by spessartite and diorite porphyry dikes. A regional, N-S-oriented and 60–85° inclined fault, 15–20 m wide, is the principal structure at the deposit; it trends along a conglomerate-quartz porphyry contact.

Ore occurs in ± vertically dipping vein-shaped bodies, controlled by the intersection of N-S and NE-SW faults. Pitchblende and associated Mo-sulfides are the essential ore minerals. Devonian felsic subvolcanics (quartz porphyry), sandstone and conglomerate constitute the principal host rocks. Wall rock alteration is of beresitic nature, dominated by sericitization and silicification. Weathering persists to a depth of 30 m. Ore lodes are from 100 to 250 m long, and persist over depths intervals from 100 to 140 m. The bulk of the ore is distributed over a depth from 10 to 160 m below surface, but mineralization extends from subsurface to depths in excess of 1 500 m.

6.1.3.2 Vostok

Discovered in 1964, the Vostok deposit is some 130 km SW of Kokshetau. Ore is of the U-Mo vein-stockwork type and hosted in beresitized rocks. Original in situ resources were on the order of 20 000 t U at a grade averaging 0.17% U and 0.038% Mo contained in the *Severo-Zapadnoye* (Northwest) and *Glavnoye* (Main) ore bodies.

The deposit was mined from 1966 to 1995 and opened again in 2003. Production amounts to about 15 000 t U. The mined ore averaged 0.146% U. Mo was recovered as a by-product. The mine was serviced by three shafts as much as 780 m deep but working levels reach only 430 m below the surface. Remaining reserves total some 5 000 t U at grades that vary between 0.06 and 0.4% U and average 0.12% U at a cutoff grade of 0.03% U (Pool T, pers. commun.).

Vostok is situated in the central part of the Glavny (Main) fault, a NW-SE-oriented, about 7 km long and up to 2 km wide structural zone, which also contains the southeasterly adjacent interconnected Promeshutochnoye, Zvezdnoye, and Tushinskoye deposits. The zone follows a large, deep rooted, NW-SE fault, which is offset by NE and NNE faults and which widens to more than 4 km at its NW end where the Balkashinskoye deposit is located. Characteristically, numerous anomalies of uranium and indicator elements (Mo, Pb, As) are found in this zone.

Host rocks are Ordovician, slightly metamorphosed, continental argillaceous and arenaceous sediments, 1 100–1 400 m thick. The sediments were intruded by Ordovician granodiorite, diorite, and gabbro. Devonian sediments (largely conglomerate with intercalated sandstone beds) and volcanics (felsite, felsite porphyry, quartz porphyry, andesite porphyry), from 200 to 700 m thick, occur adjacent to the NE; they include a lower conglomerate and an upper tuff unit. Approximately 70 m thick unconsolidated overburden covers the Ordovician rocks.

Wall rock alteration is reflected by pre-ore beresitization (sericitization, silicification, chloritization, pyritization) and post-ore carbonatization.

Ore bodies occur from 50 m to more than 2 000 m below surface in highly fractured intervals of the Glavny fault zone. On upper levels of the deposit, ore bodies consist of multiple, steeply inclined, lenticular and columnar lodes composed of veined and disseminated U-Mo mineralization; these lodes converge at a depth of approximately 1 000 m to form a single, shallow dipping body. Dimensions of ore bodies are on the order from 10 m to over 500 m long, from 2 m to 10 m, rarely to 30 m, wide, and extend for over 1 500 m downdip. Prominent ore accumulations are found at sites of strike and dip angle variations of the main fault plane (and not at fault intersections as in other deposits).

Two major ore bodies are identified: Glavnoye (Main) and Cevero Zapadnoye (Northwestern). The Glavnoye ore body has a lenticular shape, and is from 100 to 530 m long, and from 28 to 31 m thick. The Northwestern ore body has a columnar shape with a length from 150 to 200 m; its position is controlled by a flexure of the Glavny fault, where the strike turns from NW-SE to E-W (Fig. 6.5).

6.1.3.3 Zvezdnoye

This depost is located about 2 km SE of the Vostok deposit. Original reserves at Zvezdnoye amounted to 8 630 t U contained in two major ore bodies, *Main* or *Glavnoye* (also referred to as Zvezdnoye), discovered in 1964, and *Eastern* or *Vostochnoye Zaleshi* (Zaleh), discovered some 700 m to the east in 1986. The Glavnoye ore body was mined from 1978 to 1992; it produced 995 t U at an average grade of 0.085% U and has remaining reserves of 1 600 t U at 0.124% U. The Eastern ore body accounts for 6 000 t U reserves (B, C category) at 0.21% U and prognostic resources (P1) of 3 350 t U at 0.19% U (Pool T, pers. commun.).

Zvezdnoye is controlled by the Glavny fault zone, and is of similar mineralization and geological setting as Vostok. The two ore bodies mentioned above have the following dimensions: The Glavnoye ore body is as much as 200 m long, up to 50 m thick, and extends for 660 m downdip at a 70–75°NW inclination. The Eastern ore body is from 60 m (at the depth of 60 m) to 650 m (at the depth of 850 m) long, and contains mineralization from 60 to 1 375 m below surface.

6.1.3.4 Tushinskoye

Discovered in 1973, *Tushinskoye* is situated in the SE part of the Balkashinsky ore field, about 2 km to the SW of Zvezdnoye. Three ore sectors are delineated: *North, Central* and *South*. Reserves of the North sector amount to almost 900 t U at 0.105% U and prognostic resources to 4 400 t U at 0.15% U (Pool T, pers. commun.).

Mineralization occurs at intersections of N-S, NW-SE and NE-SW faults. Mineralization in the Central and Southern sectors is controlled by these structures within a Devonian subvolcanic body. Host rocks are felsite, lava-breccia and tuffaceous lava. Mineralization occurs at the contact of felsite with explosive breccia and in fault zones. The host rocks are altered by beresitization. A vein-like and two columnar ore bodies are identified in the Central sector. The largest ore body measures from 20 × 25 m to 30 × 45 m in planview and persists to a depth of 230 m. The Southern sector consists of veins and ore nests, up to 20 m long and up to 3 m thick, which occur at depths from 230 to 290 m. The Northern sector contains ore in Ordovician argillite. Its main ore body is of complex shape and located at depths from 220 to 460 m.

6.1.3.5 Olginskoye

Olginskoye is located 10 km E of Dergachevskoye. It was discovered in 1962, exploited from 1968 to 1970, yielding 55 t U, and is depleted. The mining grade averaged 0.145% U as compared to an in situ grade of 0.182% U.

The deposit occurs in the eastern effusives of the Cambrian-Ordovician Yakshin volcanic structure composed of weakly metamorphosed rhyolite porphyry, quartz porphyry, felsite, and other rocks. The basement consists of chlorite schist. Mineralization is hosted in quartz porphyry altered by beresitization and forms a complex lens-like ore body, 100 m long, 30–35 m thick, that persists over a depth interval of 30 m to the depth of 100 m. Uranium occurs as U^{6+} minerals, mainly autunite, torbernite, and other U micas.

6.1.3.6 Dergachevskoye

This depleted deposit is situated in the NW part of the Balkashinsky ore field, 15 km to the north of Balkashinskoye and to the east of the Yakshin volcanic structure. *Dergachevskoye* was discovered in 1962, mined (underground) from 1964 to 1969

Fig. 6.5.
Kokshetau region, Vostok, a geological map, b NW-SE longitudinal section, c SW-NE cross-section through the NW part of the Cevero Zapadnoye ore body. As shown, U-Mo ore bodies occur structurally controlled along the Devonian-Ordovician contact (after a Petrov et al. 2000; b, c Pool T. pers. commun. 1996)

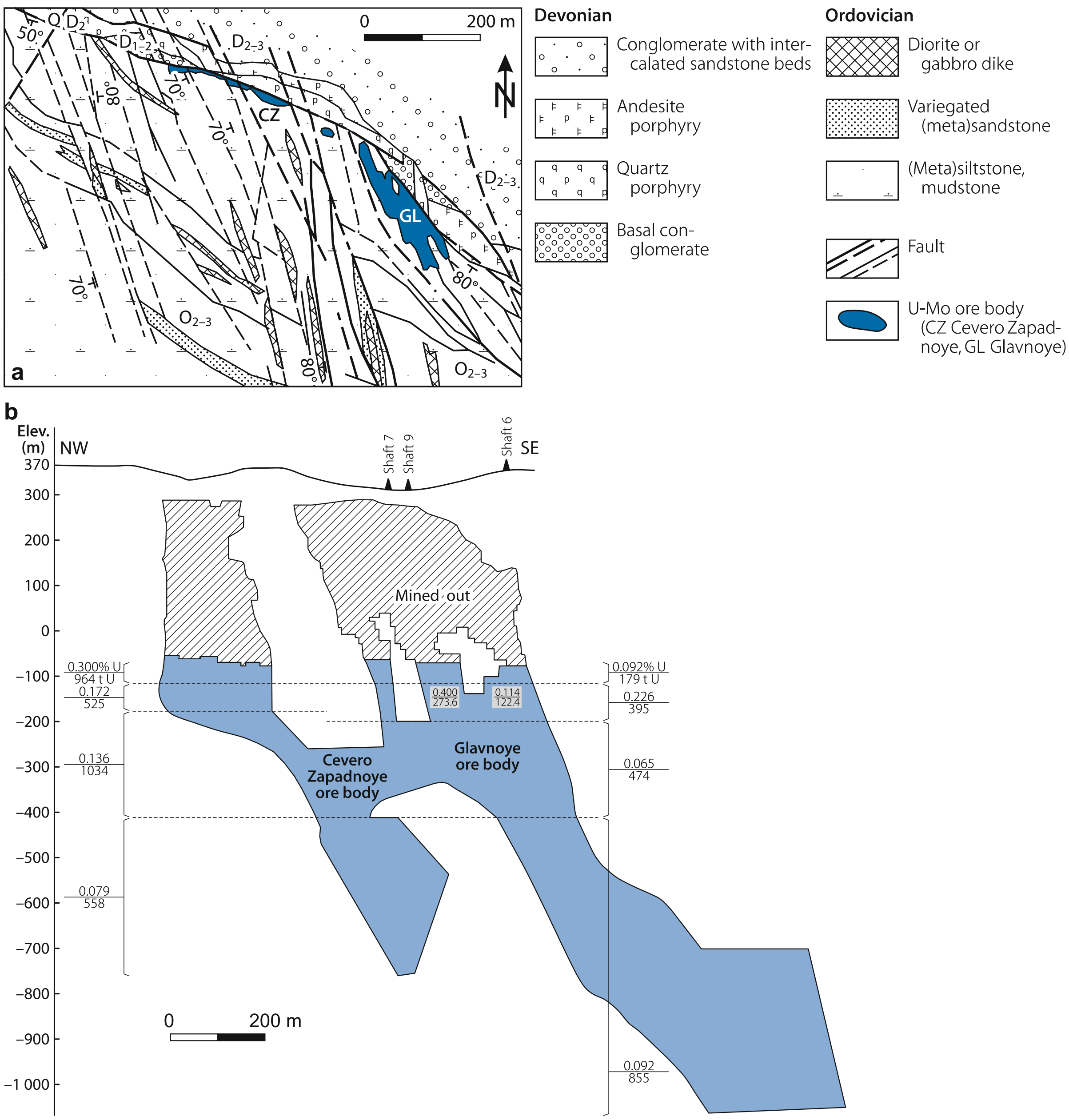
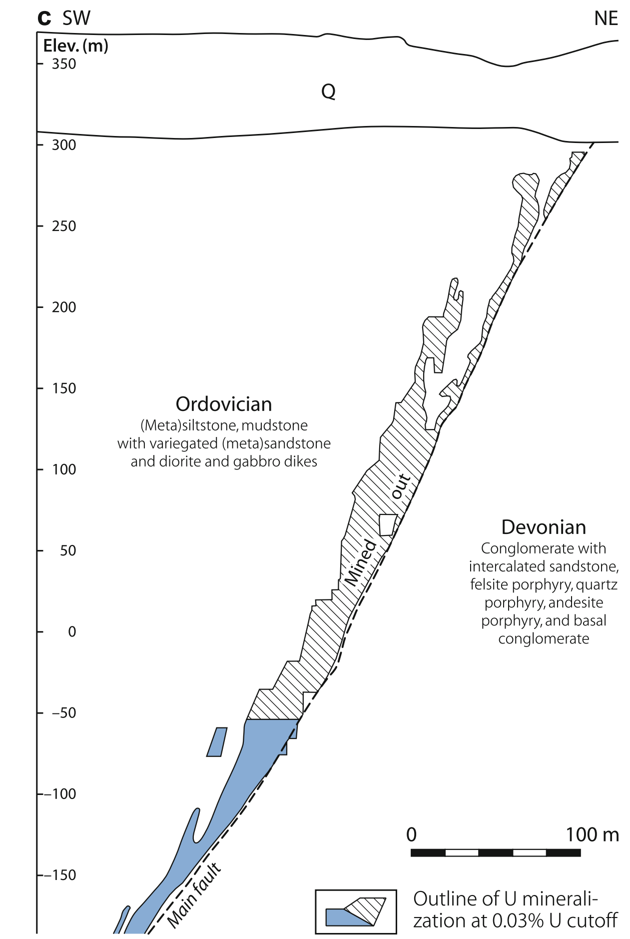


Fig. 6.5. (Continued)



and produced 320 t U at a mining grade of 0.21% U. The in situ grade averages 0.260% but 65% of the resources are in the grade class of 0.5–3.5% U. Two ore bodies are delineated: *Main* or *Glavnoye*, and *# 2*.

The host environment consists of Riphean crystalline schists and quartzite intruded by diabase dikes and cut by NW-SE-oriented and 40–80° NE dipping faults. The two ore bodies are confined to crystalline schists at a flexure of the NW-SE Savelevsky fault. Numerous, fault-controlled, small lenses form the Glavnoye ore body that is 170 m long, 25–30 m thick, and persists over depths intervals from 75 to 90 m. Ore body # 2 has an irregular shape, is 10–15 m wide in section, and 30 m long. Age datings yield 420±10 Ma and 380–330 Ma for the mineralization.

6.1.4 Grachevsky Ore Field, Northwestern Kokshetau Region

The Grachevsky ore field is, by resources, the largest in the Kokshetau region. It includes *Kosachinoye*, (>95 000 t U) the largest single deposit of the region. Another large deposit is the partly exploited *Grachevskoye* deposit. Additional deposits are *Fevralskoye, Sartubekskoye, Bolotnoye*, and *Dukonskoye* (Fig. 6.2, Table 6.1). Ore is of the vein-stockwork type with U-P and/or simple U mineralization hosted in albitized rocks.

Sources of information. Petrov et al. 2000; and others as cited.

6.1.4.1 Grachevskoye

Grachevskoye was disvovered 100 km W of Kokshetau in 1967 and has been developed for underground mining to a depth of 700 m by two vertical shafts. At a 0.03% U cutoff grade, the original in situ resources amounted to almost 18 000 t U at an average grade of 0.128% U and 2.5% P_2O_5. Mining started in 1985 and produced 2 650 t U until the closure of the mine in 1995. Remaining resources (A, B, C categories) total about 14 000 t U at an average grade of 0.18% U and a 0.05% U cutoff grade.

Sources of information. The subsequent description is largely derived from Omelyanenko et al. (1993) amended by data from Boitsov AV et al. (1995).

Geological Setting of Mineralization

The Grachevskoye deposit occurs in Proterozoic-Cambrian metasediments at the southwestern intrusive contact of a Silurian-Devonian, medium- and coarse-grained leucogranite of the Legaevskii Massif (Fig. 6.6). Three granite facies of the Caledonian Orlinogorskii complex are distinguished in the Legaevskii Massif. The leucogranite is peraluminous (according to the chemical composition given by Omelyanenko et al. 1993) and is the earliest and most abundant facies; second is a porphyritic granite, and the latest is fine-grained aplitic granite and aplite, which occur within the previous granites and in rocks adjacent to the massif. The granites have elevated tenors of F, Li, Rb, Sn, Th, and U. Uranium background values of the first two facies both average 19 ppm U, while the aplitic granite averages 39 ppm U.

The granites were intruded into and imposed an up to 100 m wide contact-metamorphic aureole of hornfels upon folded sediments of the Upper Proterozoic (Vendian) Kokshetau Formation and overlying effusive-terrigenous Cambrian rocks, which fill a graben. Riphean porphyroids and schists form, with fault contact, the western boundary of the graben. The metasediments are cut by a stock (~200 m in diameter), and up to 15 m thick, NE-SW-trending dikes of Ordovician gabbro, retrograde metamorphosed to greenschist grade facies, and Silurian-Devonian porphyritic and aplitic granite dikes partly altered by greisenization. The quantity and thickness of the granite dikes increase markedly with depth. Quartz veins dissect both granites and metasediments. Unconsolidated, 10–120 m thick overburden covers the deposit.

The Kokshetau Formation consists of weakly metamorphosed sediments separated into two conformable members: the ore-hosting upper, arenaceous-pelitic Andreevskaya Member (650 m thick, sandstone, siltstone-mudstone), and the lower, pelitic-carbonatic Sharykskaya Member (limestone, dolomite, carbonaceous shale, and/or sericitic shale).

The deposit is positioned at the intersection of two deep rooted, repeatedly reactivated fault zones: the NE-SW-oriented, vertically dipping Volodarskaya and the 15–20 km wide, over

100 km long, E-W-trending Central Kokshetau fault zones. Both structures consist of a number of faults and related fractured, sheared and brecciated intervals.

Grachevskoye is confined to a 2 km long in E-W direction and up to 900 m wide tectonic wedge bordered to the N, SW, and SE by three major faults and internally deformed by numerous locally developed faults of various orientations. The western and southern segment of the wedge is occupied by highly distorted sediments of the Andreevskaya Member and the eastern segment is occupied by the earlier-mentioned gabbro stock and leucogranite. Adjacent to larger faults, strata are unpredictably folded into flexures associated with pronounced fracturing. The most prominent flexure is at the western flank of the deposit; it is bend along a 10 m wide zone of shearing and faulting along which displacement of sediments exceeds 100 m (Fig. 6.6).

Host Rock Alteration

Pre-uranium metasomatism/alteration includes ubiquitous albitization succeeded and partially overlapped by apatitization. Subordinate alteration includes chloritization, carbonatization, sericitization/hydromicazation, and hematitization. The latter imposed, by finely dispersed hematite, a distinctive pink hue upon the altered rocks. Where late chloritization overprinted the earlier metasomatites, the rocks attained a dark green-grey color.

At upper levels of the Grachevskoye deposit, alteration overprinted predominantly sandstone and siltstone of the Andreevskaya Member whereas porphyritic and aplitic granite dikes were mainly affected at lower levels.

Alteration extent, intensity and nature are a function of the scope and grade of preceding tectonic deformation exerted by numerous strata-concordant and discordant faults, fractured and cataclastic zones, as well as the mineralogy of the parent rock. As a result, altered rocks are of highly variable composition. Extreme facies may be almost monomineralic albitite or they may consist predominantly of apatite, with gradual transitions between the two. The most-typical metasomatites consist of 60–80% albite, 5–10% apatite, 5–10% relictic quartz, with the remainder of carbonate and hematite, and late stage chlorite, quartz, sericite, and carbonate. The amount of apatite varies between fractions of a percent and 60% as a function of the calcium content in the parent rock. Highest apatite contents are confined to limestone and gabbro (see also the following Sect. *Mineralization*).

Mineralization

The principal U mineral is coffinite associated and partly intergrown with chlorite and/or apatite, which form simple U(-albite)-type mineralization with transitions into a U-P type due to the intergrowth of coffinite with apatite. Some pitchblende occurs locally. Th and Zr are common but not everywhere are they constituents of the Grachevskoye ore. Inclusions and stringers of reddish-brown, amorphous material locally interspersed in high-grade U ore were identified by Omelyanenko et al. (1993) as a mixture of zirtolite (zircon containing admixtures of Th, U and Hf) and ferrithorite.

The crystallisation sequence of principal ore constituents begins with albite, succeeded by apatite, which overlaps and postdates albite, and continues with coffinite that crystallized coeval with and after apatite. Pitchblende postdates the former minerals. Narrow veinlets of albite, and rare apatite, quartz, chlorite, and sericite/hydromica, and pockets of carbonate are the latest product. Most of the coffinite, apatite, chlorite, and other minerals precipitated during the terminal stage of the hydrothermal event and typically occur in zones of post-albite microfracturing.

Ore is restricted to albitized and phosphatized rocks of the Andreevskaya Member and to porphyritic granite dikes where it is controlled by profoundly deformed sections along numerous strata-concordant and discordant faults, fractured and cataclastic intervals. Brittle rocks adjacent to the gabbro stock suffered the most intense fracturing due to the heterogenous physical properties of the various lithologies and the rigid behavior of the gabbro during tectonic deformation; consequently, ore-bearing metasomatites are markedly developed around the gabbro stock.

Ore hosted in metasomatite derived from interbedded sandstone-siltstone laminae has preferentially a disseminated or a banded to streaky, and that after granite dikes a brecciated-disseminated, texture. Disseminated ore prevails except for high-grade intersections where a streaky-disseminated texture is most typical due to coffinite accumulation in microcracks. Such rich ore is contained in dark-greenish-brown to reddish-brown, albite-apatite rich, dense rocks cut by stringers of albite, quartz, chlorite, and sericite. Regardless of the parent lithology, ore-bearing metasomatites are compact rocks with high strength due to intensive healing.

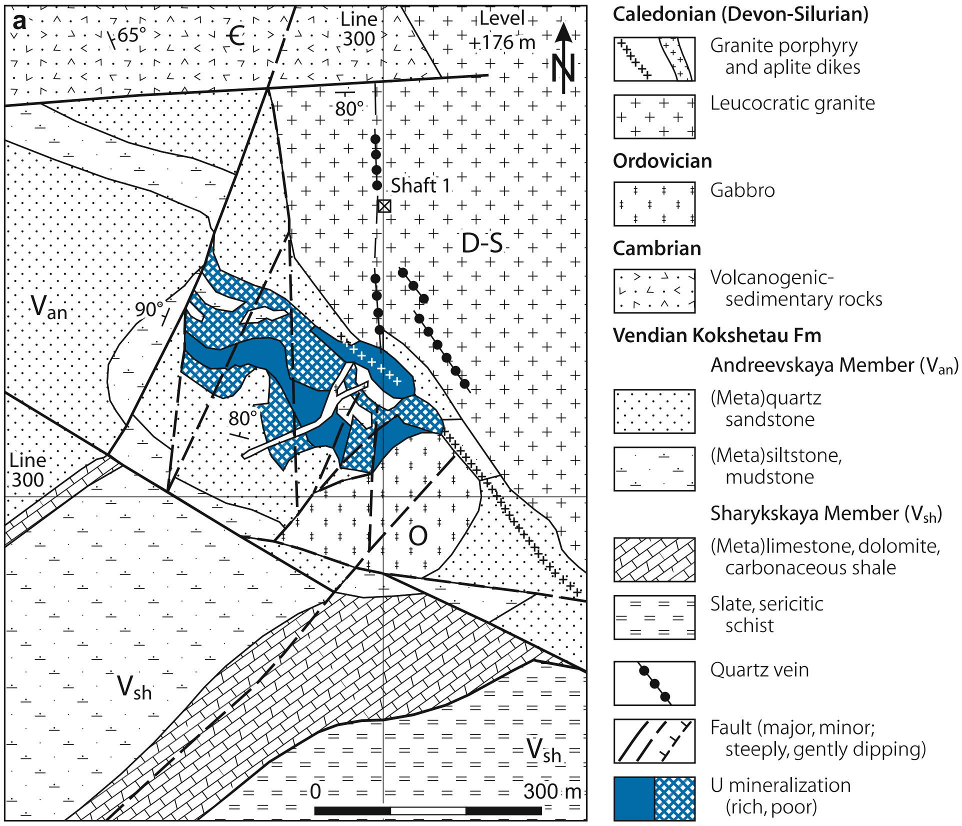
Most-essential structures, particularly for highly enriched ore as found e.g. to the N of the gabbro stock, correspond to narrow, rarely up to 2 m wide "zones of three-dimensional cataclasis", i.e. lithologic intervals intensely broken by a dense and complex network of microcracks. Hydraulic fracturing in response to high pressure generated by ascending hydrotherms or, alternatively, tectonic movements along faults are thought to be reasons for their formation. This variety of brittle deformation is not found in unmineralized ground but is restricted to ore lodes; hence this type of cataclasis is considered a critical prerequisite for the localization of ore (and related alteration development), which is further supported by the fact that the morphology of ore bodies is not defined to any significant degree by prominent faults.

Shape and Dimensions of Deposits

Grachevskoye covers a 400 m long and 200 m wide area in which U mineralization occurs in a more or less vertically plunging pipelike lode from 100 m to over 1 000 m below surface. The lode is of unpredictable morphology; it has a core with offbranching apophyses, and is partly split by gabbro into two branches. On upper levels, from a depth of some 350 m upwards, where ore is hosted by sediments of the Andreevskaya Member, the main branch is up to 300 m long and 150 m wide. At lower levels where ore is in steeply dipping porphyritic and aplitic granite dikes, the

Fig. 6.6.

Kokshetau region, Grachevskoye, a geological plan at level +176 m, b N-S section, and c planviews of selected levels. Planes and section illustrate the structural configuration of the vein-stockwork ore body at the contact of Proterozoic (meta)sediments and Caledonian leucogranite and intervening Ordovician gabbro. Host rocks are altered by early albitization and, locally, apatitization as well as various younger alteration products (after a, c Omelyanenko et al. 1993; b Laverov et al. 1992b)



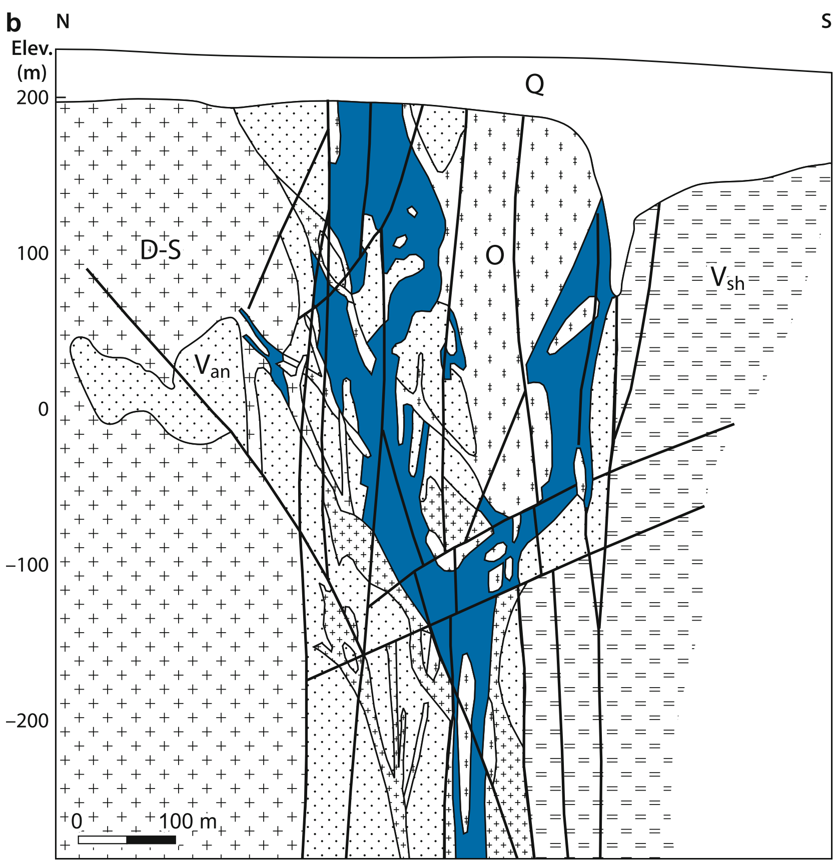
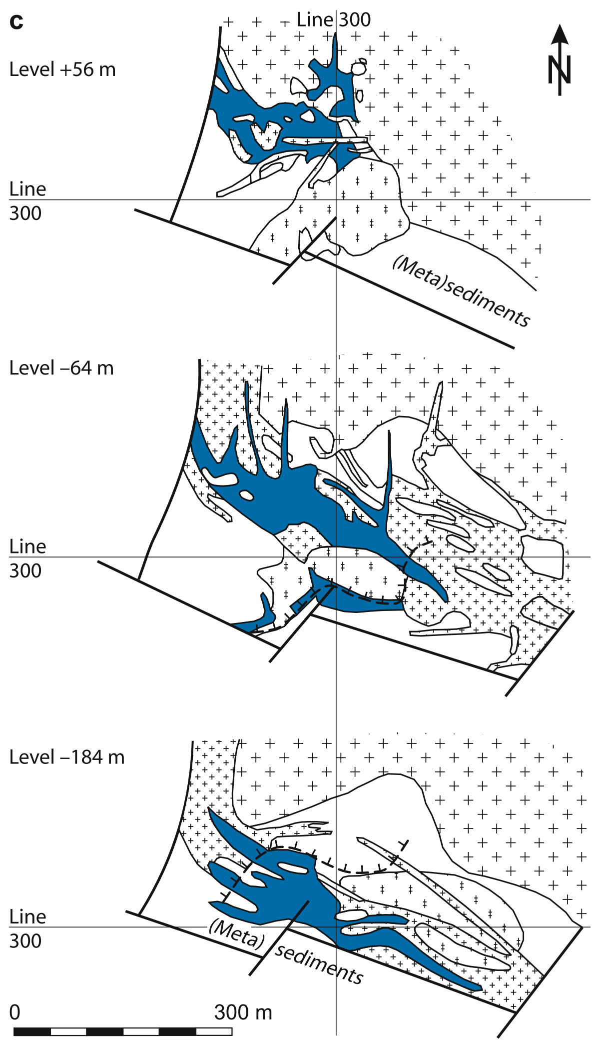


Fig. 6.6. (Continued)



lode narrows to a width of some 50 m and becomes about 400 m long in a NW-SE direction. At higher levels, the dikes are as much as 10 m thick, but merge at a depth of 400 m into a 80–100 m thick single body. A steeply dipping NE-SW fault determines the NW limit of the lode, and the gabbro stock determines the SE border (Figs. 6.6b,c).

The lode has a heterogenous internal structure reflected by an erratic U tenor of ore and intervening barren and weakly mineralized ground. U mineralization is ubiquitously distributed, although in a highly erratic manner, throughout the albite-apatite altered rocks. This is in contrast to most other deposits of the Kokshetau region where ore bodies are commonly confined to central sections of alteration zones.

U contents correlate with the intensity of cataclasis and degree of alteration of host rocks. The bulk of mineralization has grades ranging from hundredths to tenths weight percent U but small intervals can, exceptionally, be as high as 1% U or more (mining blocks are defined as ordinary ore with 0.05–0.1% U and rich ore with over 0.1% U) Phosphorus ranges between 0.3 and 20% and averages about 2.5% P_2O_5. Most of the ore contains from hundredths to tenths weight percent thorium.

Ore consists overwhelmingly of disseminated, minute grains and to a lesser extent of irregularly shaped aggregates and tiny stringers of coffinite. Stringers are most commonly fractions of a mm thick and up to several cm long; only exceptionally do they attain a thickness of a few mm and a length of 1 m. Pitchblende occurs locally in small stringers within high-grade coffinite ore.

6.1.4.2 Kosachinoye

Discovered in 1973, Kosachinoye is located some 110 km W of Kokshetau (Fig. 6.2) and encompasses several isolated sectors: *Central, Sartubek, Kutuzovsky, Bolotny, Dorozhny, Shakhtny, Vostochny (Eastern), Glukhariny, Lyubotinsky,* and *Zapadny (Western)*, which can be regarded as individual deposits. In situ resources total 95 700 t U (OECD-NEA/IAEA 1995). Ore grades average 0.109% U. About 70–80% of the resources occur in the Central, Sartubek, and Kutuzovsky sectors. Resources (outlined down to the 650 m level) are estimated to be 23 000 t U; they include 14 300 t U measured and indicated resources at an average grade of 0.106% U, and 9 000 t U inferred resources (based on a 0.05% cutoff grade) (Pool T, pers. commun.). The deposit is explored but not mined except for some parts in weathered rock that have been mined from an open pit.

Sources of information. Boitsov et al. 1995; Omelyanenko et al. 1993; Petrov et al. 2000.

The above mentioned individual sectors occur within an 8 km long and 4–5 km wide zone (Fig. 6.7a), which is controlled by the interjunction of the large NE-SW-striking Volodarskaya and the E-W-oriented, steeply south dipping Central Kokshetau fault zone. Country rocks include predominantly

- *Lower Silurian-Upper Ordovician* andesite-dacite and basalt (diabase) porphyries, lava breccia, felsic tuff, conglomerate, limestone,
- *Middle-Lower Cambrian* (Lubotinskaya Suite) cherty and carbonaceous/graphitic argillite/slate, quartzite, metasiltstone, limestone/marble, diabase/basalt and other volcanic rocks, and
- *Proterozoic* (Vendian Andreevskaya and Lubotinskaya series) graphitic slate and quartzite, limestone/marble, quartzite, and gabbroic lava breccia.

Carbonaceous/graphitic slate and diabase are the favored host rocks. They are altered by ubiquitous albitization, which is overprinted along faults by deep-reaching (>1 400 m deep) carbonatization and chloritization, and, additionally, on upper levels by silicification (quartz) and hematitization to depths of as much as 600 m (Fig. 6.7d).

Mineralization consists of pitchblende, coffinite, and U-Ti phases associated with a variety of gangue and Fe minerals, which occur in three ore parageneses: *(a)* brannerite or brannerite-pitchblende associated with carbonate-chlorite or quartz-goethite, *(b)* coffinite-chlorite, and *(c)* late coffinite-pyrite associated with dolomite. Carbonate content is in excess of 6%. Lower and intermediate levels of ore bodies are mineralized with coffinite-chlorite in albitized rocks. Some brannerite and pitchblende both contained in carbonate-chlorite or quartz-hematite/goethite altered rocks are typical for upper levels. The zoning is camouflaged, however, by late dolomitization and pyrite-coffinite formation, which overprints the former two parageneses (Boitsov AV et al. 1995).

Uranium occurs in vein-stockwork ore bodies of variable shape and size. The main ore body is 800–1 000 m long, about 50 m thick, and persists to a depth of almost 1 500 m. It includes a better grade zone within a subvertical pipe-like body, which is confined to a brecciated and altered Cambrian carbonaceous limestone unit in contact with Lower Cambrian porphyritic diabase/basalt.

Ore bodies cumulate in the afore mentioned sectors. The two significant Central and Kutuzovsky sectors exhibit the following dimensions: The *Central* sector is 2,6 km long, from 100 to 400 m wide, from 350 to 400 m deep in the S and to 1 500 m deep in the N. Ore lodes occur along the Central fault, a N-S-oriented structure that trends along the contact of calcareous schists of the Sharyk suite to the west and Cambrian subvolcanic basalts to the east. The *Kutuzovsky* sector extends over a length of several kilometers, a width of at least 1 500 m, and to a depth from about 100 m to about 1 000 m with sub-ore grade mineralization continuing in excess of 1 400 m deep.

6.1.4.3 Fevralskoye

This deposit is situated 5 km SE of Kosachinoye. It was discovered in 1971 and contains reportedly 4 600 t U at a grade of 0.097% U, and as high as 5% P_2O_5. Mineralization occurs within the southern margin of the Sumalkol syncline and is hosted by Vendian carbonate/marble and schist, which were intruded by Silurian granite of the Zarendine Complex. The medium steeply dipping Rechnaya fault zone, 150–250 m wide, is the principal structure at the deposit. Three lenticular ore bodies are delineated controlled by steeply and shallowly dipping faults.

Fig. 6.7.

Kokshetau region, Kosachinoye, a generalized geological plan with position of ore sectors, b W-E cross-section and c longitudinal SW-NE section with ore grade distribution, d vertical projection of mineralization with allocation of uranium and alteration phases. Host rocks are albitized slate and diabase (after a–c Pool T. pers. commun. 1996; d Boitsov et al. 1995). Ore sectors: *Bo* Bolotny, *Ce* Central, *Do* Dorozhny, *Gl* Glukhariny, *Ku* Kutuzovsky, *Ly* Lyubotinsky, *Sa* Sartubek, *Sh* Shakhtny, *Vo* Vostochny, *Za* Zapadny

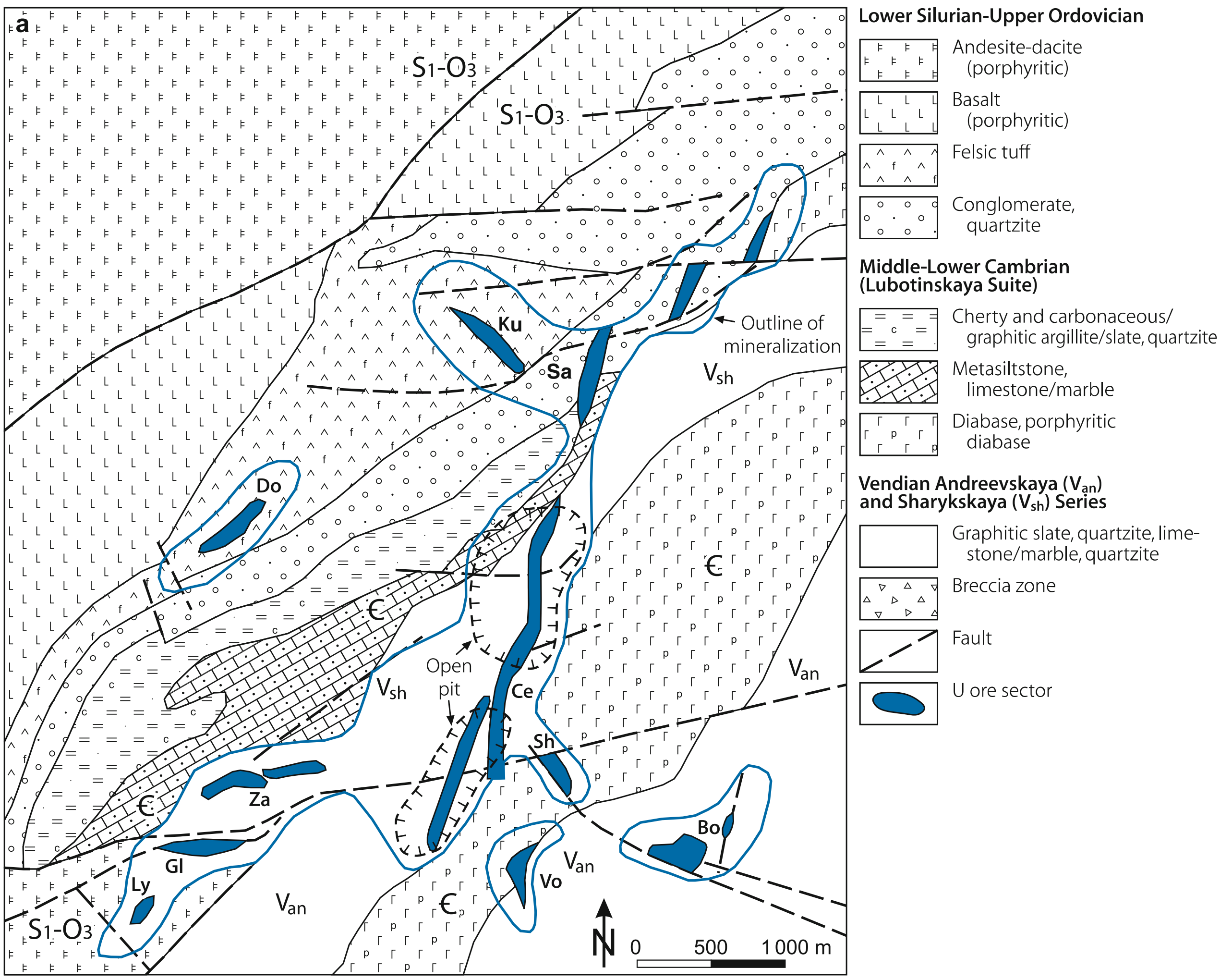
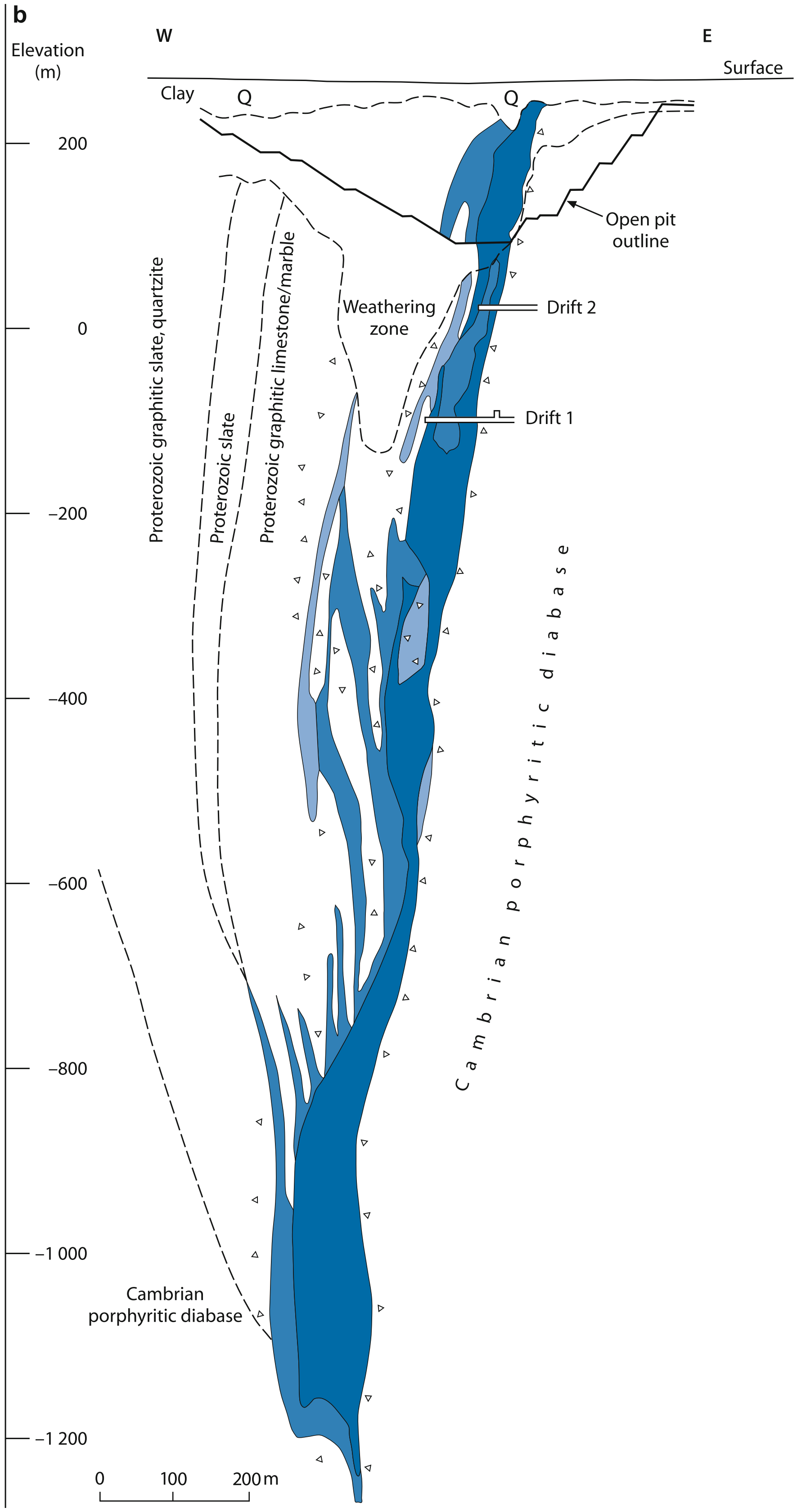
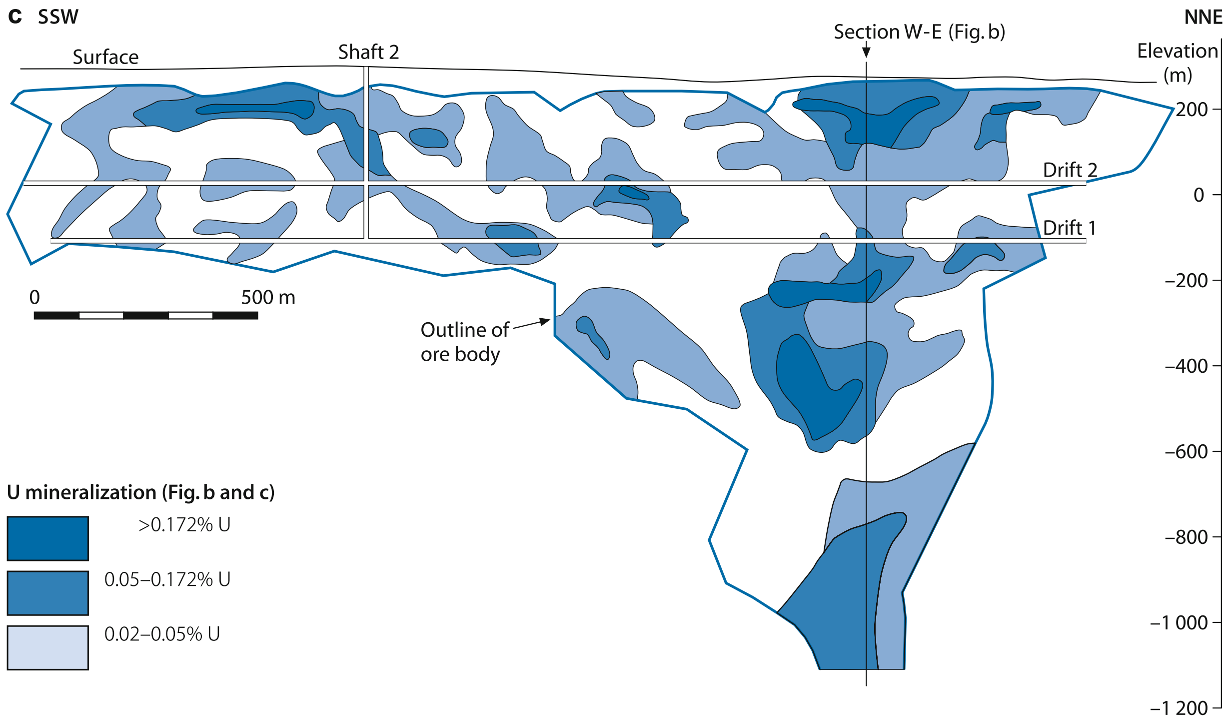
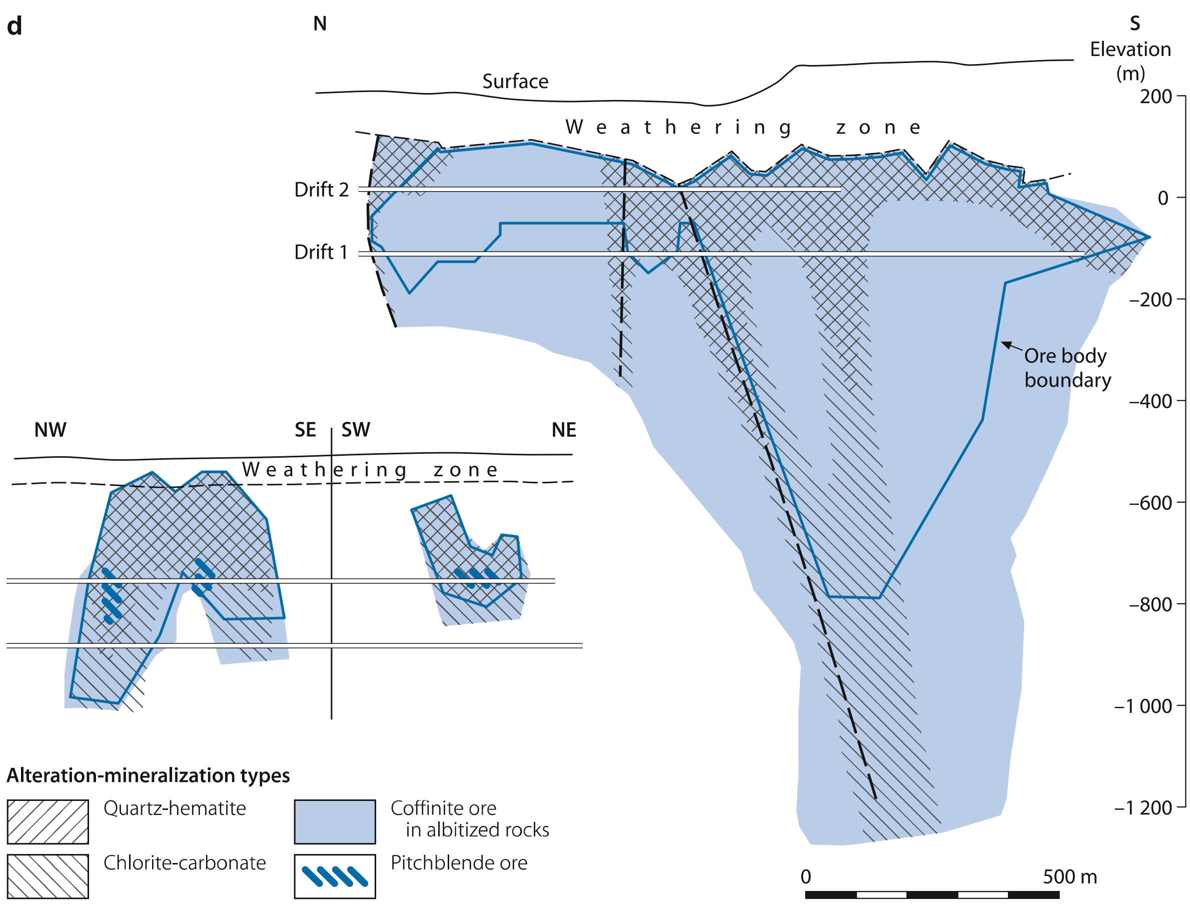


Fig. 6.7. (Continued)




c SSW
NNE
Section W-E (Fig. b)
Surface
Shaft 2
Elevation (m)
200
Drift 2
0
Drift 1
−200
0
500 m
Outline of ore body
−400
−600
U mineralization (Fig. b and c)
>0.172% U
0.05–0.172% U
0.02–0.05% U
−800
−1 000
−1 200


d
N
S
Elevation (m)
Surface
200
Weathering zone
Drift 2
0
Drift 1
−200
Ore body boundary
−400
NW
SE
SW
NE
Weathering zone
−600
−800
−1 000
Alteration-mineralization types
Quartz-hematite
Coffinite ore in albitized rocks
−1 200
Chlorite-carbonate
Pitchblende ore
0
500 m

The ore bodies are from 250 to 1 400 m long, from 0.2 to 20 m thick, and extend for 60–650 m downdip. Brannerite and coffinite are the principal U minerals.

6.1.5 Altybaysky Ore Field

This ore field is situated in the Altbaysky block of the Kokshetau Massif and includes the *Slavyanskoye, Chaglinskoye*, and *Abayskoye* U deposits (and also the Vasilkovskoye gold deposit) (Fig. 6.2, Table 6.1). U deposits are of the vein-stockwork type, some hosted in albitized, and others in beresitized rocks. None of the deposits were mined due to low grades of less than 0.1% U.

Source of information. Petrov et al. 2000.

6.1.5.1 Slavyanskoye

Slavyanskoye is located 35 km NW of Kokshetau and 20 km NW of Chaglinskoye. It was discovered in 1973 and accounts for in situ resources of 5 300 t U at an average grade of 0.075% U contained in three ore zones, *Eastern, Central*, and *Western*. The deposit occurs in a granite-gneiss dome composed of granite, gneiss, amphibolite and schist of the Zarendine Complex, which was intruded by granite porphyry. Several large E-W faults and numerous N-S fractures control the mineralization at sites where they intersect granite-gneiss and schist. The three ore zones are 600–1 200 m long, 3–70 m wide, and extend to depths from 350 to 650 m. These ore zones contain small ore lenses from 50 to 650 m below surface composed of pitchblende, coffinite, molybdenite, and femolite. The ore grade averages 0.075% U but some intersections yield 0.3% U. Molybdenum averages 0.042%.

6.1.5.2 Chaglinskoye

This deposit was discovered 20 km SE of Slavyanskoye and 10 km W of Kokshetau in 1977. In situ resources amount to 14 000 t U with an average grade of 0.069% U contained in 5 vein-type ore bodies. Ore body # 1 contains 30% of the U resources. In addition to U, it contains an average of 0.024% Mo and 0.6–0.8 ppm Au. Ore body # 2 accounts for 60% of the resources of Chaglinskoye.

Chaglinskoye occurs in an area divided into two blocks by the regional, NW-SE-trending, about 70° dipping Dongulash fault. The NE block includes Precambrian diorite and granodiorite of the Zarendin Complex and Vendian metasediments; and the SW block Ordovician-Silurian effusive-sedimentary rocks. Host rocks are Vendian and Lower Paleozoic, weakly-metamorphosed, terrigenous and volcanic sediments altered by albitization and carbonatization. Ore controlling faults trend NW-SE and N-S. Three ore bodies are controlled by the NW-SE-trending contact fault and two ore bodies by N-S-oriented faults. The prevailing U minerals are coffinite and U-Ti phases (brannerite). Pitchblende and uraniferous F-apatite are rare. Ore bodies consist of veins and some small lenses; they have lengths from 500 to 4 000 m, widths from 1 to 24 m, and extend to 500–700 m deep.

6.1.5.3 Abayskoye

Abayskoye is located 2–3 km to the south of and may be considered an appendix of Chaglinskoye. The small deposit was discovered in 1979. The ore averages 0.058% U. Three ore zones are identified: *Northwest, Central*, and *South*; the latter contains the bulk of the resources.

The deposit is situated in Middle-Upper Devonian redbed molasse near the SE margin of the Kokshetau Graben. Host rocks are grey-green conglomerate and sandstone beds, 10–20 m thick, which are weakly altered by albitization and beresitization. Host sediments are folded into a brachy-fold. Beds trend NW-SE and dip steeply near NW-SE-oriented branches of the Kokshetau fault zone.

The ore zones are from 1.8 to 2.2 km long and from 100 to 800 m wide. Each zone contains as much as six tabular- to lens-shaped ore bodies that range from 700 m to 1 500 m long, 100 m to 600 m wide, and 1 m to 4 m, locally up to 15 m, thick. Pitchblende and sooty pitcblende are the principal U minerals, and locally coffinite. Associated minerals include sulfides and/or selenides of Fe, Cu, Pb, and Zn. Carbonate content of the ore is less than 5%.

6.1.6 Shatsky Ore Field, Northeastern Kokshetau Region

The Shatsky ore field is 140–170 km E of Kokshetau in the Lower Paleozoic East Kokshetau Basin at the boundary with the Precambrian Shatsky. Uplift. Four small deposits, *Shatskoye-1, Shatskoye-2, Glubbinnoye*, and *Agashskoye* (from W to E), are delineated along the sublatitudinal Shatsky fault (Fig. 6.2, Table 6.1). Ore is of the U-Mo vein-stockwork type hosted in albite-carbonate altered rocks. The first three deposits occur in Upper Ordovician volcanics while Agashskoye is within Caledonian granite. All deposits are explored in detail but have not been mined.

Source of information. Petrov et al. 2000.

6.1.6.1 Shatskoye-1

Discovered in 1953, Shatskoye-1 is located some 145 km E of Kokshetau. It contains ore that averages 0.083% U and 0.127% Mo.

The deposit is controlled by the regional WNW-ESE-oriented Shatsky fault zone and consists of an ore zone that occupies intensely brecciated ground between the southern branch of the Shatsky fault and a NW-SE-trending fault. The southern branch separates the area into two blocks; the southern block is characterized by Ordovician andesite-basalt and porphyry, and the northern block by dacite and andesite intruded by Devonian granite.

The ore zone is 2.5 km long and encompasses seven stockwork ore bodies that range in lengths from 200 to 600 m, in thickness from 1 to 17 m, and persist for 100–600 m downdip. Pitchblende and brannerite are the principal U minerals. Wall rocks are altered by albitization and carbonatization, essentially ankerite.

6.1.6.2 Shatskoye-2 and Glubbinnoye

These two deposits are commonly considered as one deposit controlled by the WNW-ESE-oriented Shatsky fault zone as is Shatskoye-1. Glubbinnoye is located adjacent to the east of Shatskoye-2. The latter is separated from Shatskoye-1 by a barren interval of ca. 3 km. Resources amount to 600 t U at an average grade of 0.056% U at Shatskoye-2 and to 6 600 t U at an average grade of 0.104% U at Glubbinnoye. Shatskoye-2 also contains higher grade U mineralization at a depth of some 1 000 m. Associated Mo and Zr occurs in grades averaging 0.021% and 0.169%, respectively.

These two deposits occur in a tectonic-stratigraphically tripartioned terrane: a northern block consists of Devonian volcanics, a southern block of Middle Ordovician porphyrite and tuff, and a central block of Ordovician(?) sediments and volcanics. Seven ore zones are identified, which occupy breccia zones, six of which occur in the Central block. These ore zones contain stockwork and lenticular ore lodes that range in lengths from 50 to 1 300 m, in widths from 2 to 40 m, and persist for 30–300 m downdip. Coffinite is the principal uranium mineral.

Glubbinnoye occupies an approximately 1 000 m long and 50 m wide stretch elongated along the sublatitudinal Shatsky fault. Host rocks are Upper Ordovician tuffs altered by albitization and carbonatization. Ore occurs in linear stockwork bodies, about 3–5 m thick. Ore persists over a depth interval from 300 m to more than 1 000 m below surface.

6.1.6.3 Agashskoye

Agashskoye is located 2 km NE of Shatskoye-1 and about 170 km E of Kokshetau. The 1974 discovered deposit has in situ resources of 6 170 t U with an average grade of 0.146% U. Associated zirconium grades 0.038%.

Mineralization occurs intragranitic at the periphery of the Agashky granitic massif. The host rock is Caledonian (Silurian) leucogranite with xenoliths of porphyrite and some diabase dikes altered by albitization, carbonatization (ankerite, calcite), and chloritization. The deposit is as much as 970 m long and contains 23 steeply dipping vein- and lens-like ore lodes over a depths interval from 30 to 750 m below surface. The lodes are 0.2–20 m, in average 3 m, thick and 200–300 m long emplaced at the intersection of the E-W-trending Shatsky fault and the NE-SW-oriented Koksorsky fault. Ore bodies are controlled by fracture/breccia zones and faults at the contact of granite with porphyrite xenolith. Mineralization consists of coffinite with minor pitchblende and U-Ti phases (brannerite). Molybdenite is present in small amounts. Ore lode 1, 2, 6, and 14 contain 85% of the above mentioned resources.

6.1.7 Koksengirsky (or Zaozernoye) Ore Field, Central-Eastern Kokshetau Region

This ore field is 130–140 km ESE of Kokshetau, in the eastern segment of the Koksengirsky Trough and includes the partly mined *Zaozernoye,* depleted *Tastykolskoye,* and the explored *East Tastykolskoye*, *Koksorskoye*, *South Koksorskoye*, *and Boroskoye,* and *Mezhozernoye* deposits, as well as a number of scattered U occurrences (Figs. 6.2, 6.8a, Table 6.1). All deposits have been discovered between 1954 and 1956.

Source of information. Petrov et al. 2000.

Mineralization is of the U-P vein-stockwork type and consists of uraniferous F-apatite, U-arshinovite, pitchblende, and U-Ti-phases (brannerite). Deposits are controlled by intersections of NW-SE with N to NE-oriented faults. Host rocks include Na-metasomatized rocks of the entire litho-stratigraphic section.

The area is underlain by weakly metamorphosed Middle Ordovician intermediate to mafic volcanics/pyroclastics (interlayered tuff, andesite, basalt with minor limestone), Upper Ordovician siltstone, sandstone, and hematitic limestone, and unconconformably overlying, unmetamorphosed Mid-Upper Devonian molasse redbeds. A number of small stocks (500 m by 1–2 km) of Ordovician granodiorite and monzonite porphyry are also present.

6.1.7.1 Zaozernoye

Zaozernoye is 130 km ESE of Kokshetau. With original reserves of about 20 000 t U, a large part thereof contained in ore body N-3, it is the largest deposit of the ore field. In situ grades average 0.1–0.3% U, up to over 20% P_2O_5, and up to 1 600 ppm REE including 5–10 ppm Sc. Zaozernoye is partly exploited. Mining commenced in 1961 and was suspended in 1992; it reached to a depth of 500 m. Remaining measured and indicated resources (between the −350 m and −1 010 m level) are reported to be 7 500 t U at an average grade of 0.123% U and 19.5% P_2O_5.

The deposit is positioned at the sinuous N to NE-trending Tastykolsky fault (Fig. 6.8a). Impure Upper Ordovician limestones with tuffaceous and argillaceous intercalations (Tastykol Horizon) are the predominant host rocks. Two intercalated intermediate tuff horizons, up to 50 m thick, serve as marker horizons. Beds strike NNE-SSW and dip at 80–85°E in the central part and at less than 45°E in the northern part of the deposit. These rocks underlie Upper Ordovician arkose, sand- and siltstone with intercalated diorite sills (Karamolin Horizon) and overlie Middle Ordovician intermediate to mafic volcanics. Some ore occurs in granite porphyry dikes. Silicate-bearing beds and igneous dikes are albitized.

Uraniferous F-apatite is the predominant ore mineral; coffinite and U oxides are subordinate. Associated minerals/elements include carbonate, chlorite, hydromica, albite, and P, Th, Zr, and F respectively. Two ages of U-P mineralization are recorded. A 420 Ma age is believed to represent syngenetic mineralization that formed along bedding planes in a reef environment at a temperature in the range of 180–220°C. The younger age of 320–280 Ma is thought to reflect secondary enrichment of uranium and phosphate minerals by lateral migration of solutions along crosscutting fractures orthogonal to the bedding planes of the carbonate layers.

Main ore bodies are of a tabular, peneconcordant shape from which conjugate apophyses branch off (Figs. 6.8b,c). The distribution and size of ore bodies are controlled by strata-peneconcordant and -discordant cataclastic intervals adjacent to prominent faults.

The deposit extends for 2 000 m in length and 1 000 m in width. The largest ore body, N-3, spreads over 2 000 m long and 50–400 m wide, and persists from 100 to 1 200 m in depth. Ore lodes are about 40 m thick.

6.1.7.2 Tastykolskoye and East Tastykolskoye

Discovered in 1954, these two deposits include three ore-bearing sectors in the southern Koksengirsky ore field: *Central, Northern*, and *Eastern*. The Central sector accounts for 80% of the resources with grades averaging 0.105% U, 18.3% P_2O_5, 0.8% Zr, and 0.23% Sr. Tastykolskoye (or Central sector?) was mined by open pit and underground methods until 1981; it produced on the order of 3 000 t U and is depleted.

Mineralization occurs in the eastern and western wings of the Tastykol horst-anticline. Ordovician volcanics constitute the core while limestone overlain by sandstone/siltstone forms the wings of the anticline. Plagiogranite and diorite porphyry dikes are abundant. The steep Tastikolsky fault intervenes between the effusive and the limestone horizons.

Mineralization consists of an P-Zr-U assemblage composed of two mineral associations: arshinovite-uraninite-apatite and apatite-arshinovite-ankerite. These assemblages form lenticular ore bodies that range in lengths from 20 to 500 m, in thickness from 0.5 to 30 m, and persist from 40 to 400 m in depth. The ore lodes occur stratabound in limestone and siltstone adjacent to the contact of these two lithologies.

6.1.7.3 Koksorskoye

Koksorskoye was discovered in the northern Koksengirsky ore field in 1954. Six ore bodies are delineated; ore body 1 contains 70% of the resources, which amount reportedly to 760 t U. Grades average 0.088% U, 4–5% P_2O_5, 0.2% Zr, and 0.18% Sr. U-oxides contain 70% of the U endowment; the remainder is incorporated in Ca-phophate.

The deposit occurs in the Koksor anticline, composed of Proterozoic(?)-Ordovician volcanics and (meta-)sediments. Tuff and porphyry form the core, and siltstone, limestone, sandstone, conglomerate, and tuff the wings of the anticline. Intrusions include diorite and granosyenite dikes and stocks. The anticline is dissected by the NE-SW-oriented Koksor fault zone and NW-SE-trending, 60–90° dipping faults. The latter controll the ore where they cut calcareous sandstone and siltstone of the Tastykol Horizon.

The Koksorskoye ore zone, 1 km long, 120–180 m wide and 250 m deep, includes vein- and/or lens-shaped ore bodies that range from 50 to 700 m long, and persist from 50 to 150 m downdip.

6.1.8 Manybaysky Ore Field, Southeastern Kokshetau Region

The Manybaysky ore field is 210–220 km SE of Kokshetau, at the southeastern margin of the Cambrian-Ordovician *East Kokshetau Basin* adjacent to the Eshkrolmessky block (Fig. 6.2, Table 6.1). It includes the depleted *Manybayskoye* and *Aksu* deposits and the explored *Kerbayskoye, Yuzhno (south)-Manybayskoye, Bezymannoye*, and *Krugloye* deposits. Ore is hosted by albite-carbonate altered rocks. Three uraniferous

Fig. 6.8.
Kokshetau region, Koksengirsky ore field, a schematic geological map documenting the control of U-P deposits by major faults, b geological plan of the −190 m level and c NW-SE cross-section of the Zaozernoye deposit showing the structure-controlled position of ore bodies in impure Ordovician limestone (after a Boitsov VE 1989; b, c Petrov et al. 2000) *U-P deposits*: *Bo* Borovskoye, *Me* Mezhozernoye, *Ko* Koksorskoye, *Ko-S* Koksorskoye South, *Ta* Tastykolskoye, *Ta-E* Tastykolskoye East, *Za* Zaozernoye

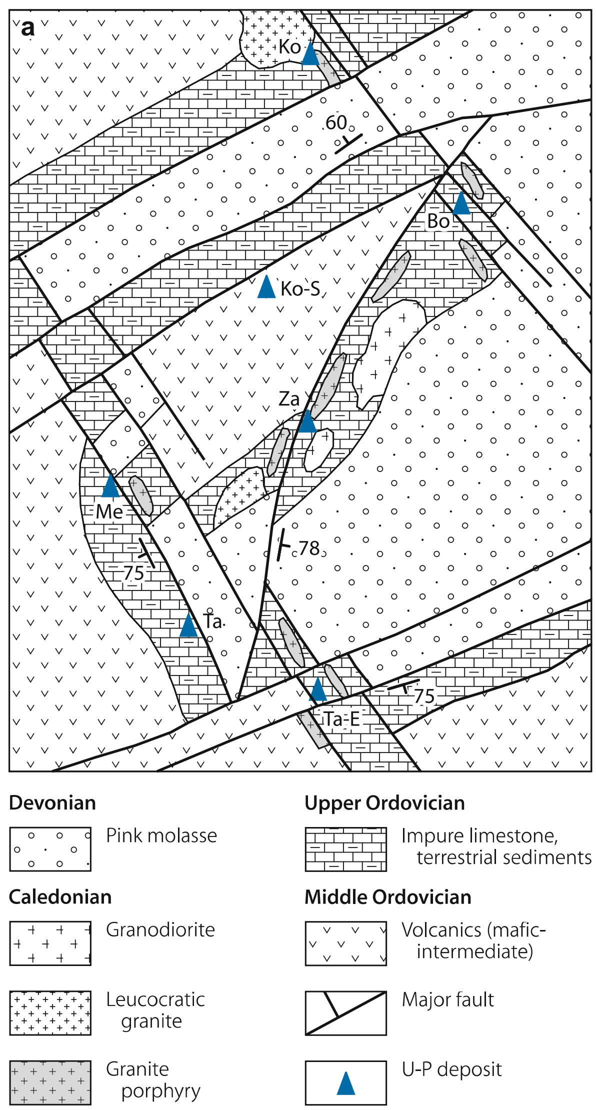
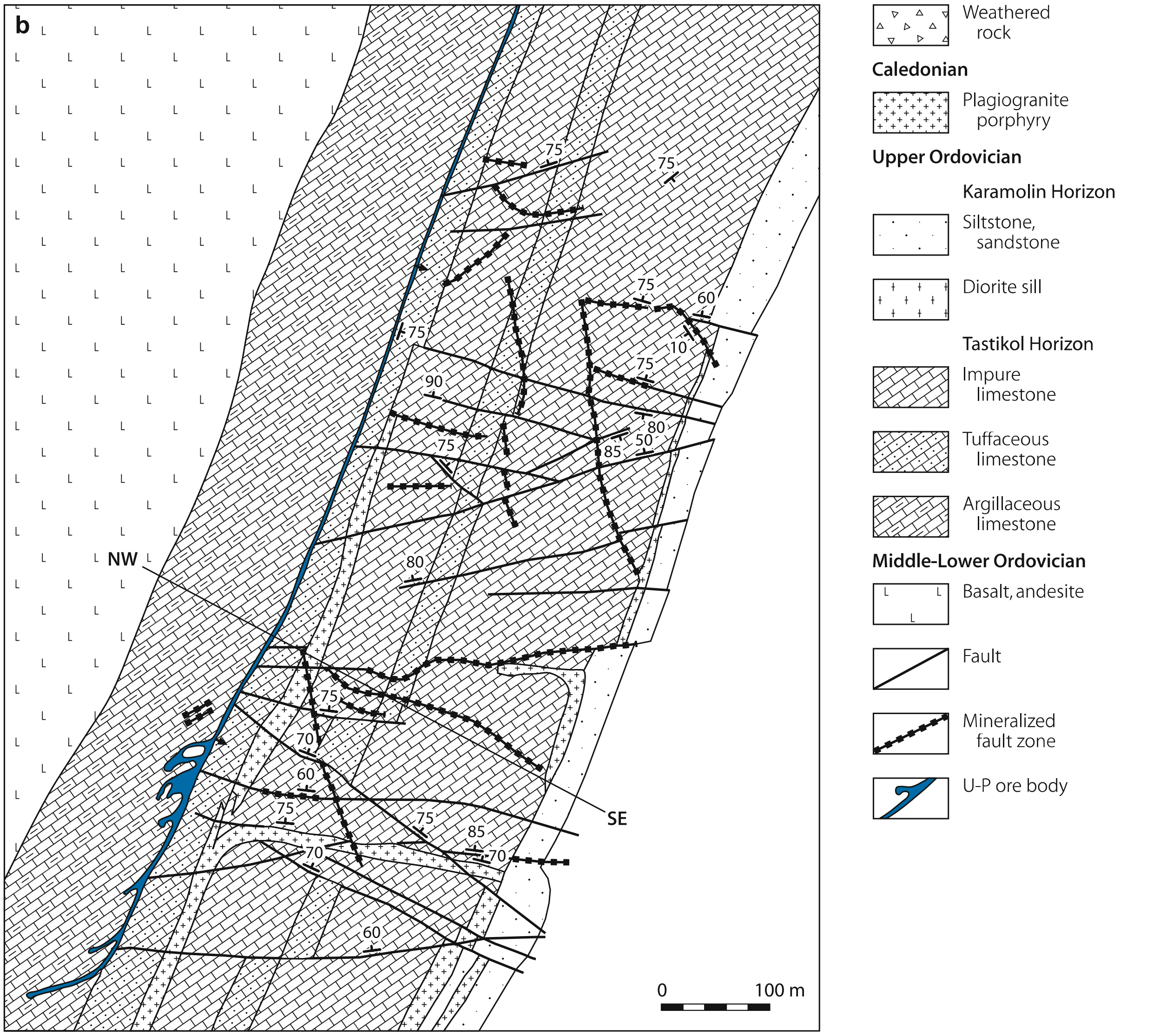


Fig. 6.8. (Continued)



mineral assemblages are differentiated: P-Zr-U (apatite-arshinovite with chlorite-brannerite-coffinite), Mo-U (molybdenite-coffinite-pitchblende), and simple U (pitchblende-coffinite). *Manybayskoye* is an example of the Mo-U type (see below) and *Aksu* of the latter type. Mineralization at Aksu consisted of pitchblende veinlets in albitized Ordovician pyroclastic and terrigenous sediments.

Source of information. Petrov et al. 2000.

6.1.8.1 Manybayskoye

This deposit is located 15 km N of Stepnogorsk. Original reserves amounted to some 20 000 t U. The ore grade was 0.086% U and 0.044 Mo. Mining by open pit methods commenced in 1957 and ceased with the depletion of the deposit in 1981.

Host rocks are Middle Ordovician pyroclastic and terrestrial sediments with strata-peneconcordant lamprophyre or diabase sills folded around a NE-SW-oriented axis. The deposit occurs in the core of the fold where it is cut by intersecting NNE-SSW- and NE-SW-trending faults. Wall rock alteration includes albitization, carbonatization, chloritization, and hematitization.

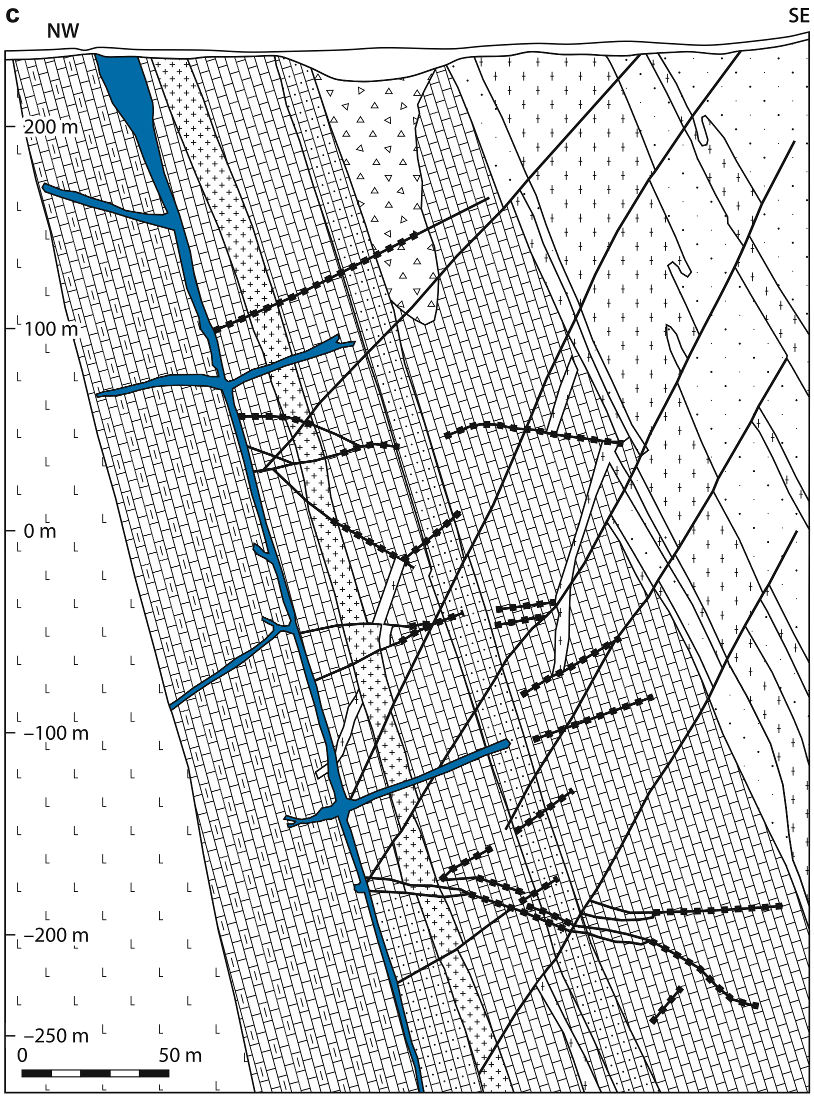
U-Mo minerals constitute the bulk of the ore. One ore body had a more refractory mineralization with uraniferous zircon. Associated minerals include sulfides of Cu, Fe, Pb, Zn, and As. Hydrocarbons occur locally.

Manybayskoye included seven ore lodes within a mineralized column-like body that persists to depths of 1 000 m, and to a length of 500 m in the upper part and to 100 m at depths below 700 m. Ore lodes NW, Glavnoye, and SE occur to depths of 200 m, lodes # 1 and # 2 between 200 and 400 m, and lodes # 3 and # 4 below 400 m. The lodes are of stockwork or column-like shape. Siltstone and silt-sandstone are the preferential host rocks.

6.1.8.2 South Manybayskoye

This small deposit, discovered 2 km S of Manybayskoye in 1954, consists of four ore bodies with grades averaging 0.08% U and

Fig. 6.8. (Continued)



0.02% Mo. The deposit area is underlain by Middle Ordovician sandstone, siltstone, mudstone with interbedded tuff and limestone, which are folded into a syncline. Diorite was intruded into the west wing of the syncline. The country rocks are cut by a regional NE-SW fault and NW-SE as well as N-S faults. Ore bodies are of lenticular shape and occur in tuff and sediments along NW-SE, N-S, and interstratified faults to depths of 250 m. The lodes range in length from 50 to 300 m, in thickness from 0.2 to 3 m, and extend for 100–200 m downdip.

6.1.8.3 Aksu

This small, depleted deposit is located in the southern Manybayskoye ore field. It consisted of vein and lenticular ore bodies that ranged from 15 to 170 m long and from 7 to 9 m thick, extended from 10 to 350 m deep, and averaged 0.102% U, 0.05% Mo, 0.02% Zr, and 0.08% Sr. The NE-SW-trending Aksu fault controls the position of the lodes in folded Ordovician carbonaceous-siliceous sediments close to the contact with porphyry dikes.

6.1.9 Shokay Zone, Olenty-Seletinsk Area, Eastern Kokshetau Region

The Olenty-Seletinsk area is within the Shokay metallotectonic zone in the eastern Kokshetau Massif near the margin of the Pri-Irtysh Basin (Fig. 6.2, Table 6.1). A number of basal-channel sandstone-type deposits are reported including *Semizbay, Selentinsk*, and *Kiziltuk*. Mineralization occurs in paleovalleys filled with Lower Cretaceous-Upper Jurassic alluvial-fluvial sediments and buried under as much as 100 m thick Cretaceous and younger sediments.

6.1.9.1 Semizbay

Semizbay is a basal-channel sandstone-type deposit located some 250 km ESE of Kokshetau and 60 km E of Stepnogorsk. Original resources are reported to total 17 000 t U at an average grade of 0.057% U (based on a minimum grade of 0.01% U and a minimum grade-thickness product of 0.04 m-%), almost two thirds of which are thought to be recoverable by in situ leaching methods. The deposit was discovered in 1973 and partly exploited by ISL techniques from 1982 to 1990.

Sources of information. The following description is primarily based on Poluarshinov and Pigulski (1995).

Geological Setting of Mineralization

U deposits occur in a complexly branched paleochannel system, which was incised into the Proterozoic-Paleozoic basement of the eastern Kokshetau Massif and which dewatered eastwards to the Pri-Irtysh Basin (now the West Siberian Lowlands) during Late Jurassic and Early Cretaceous time. Channels extent for tens of kilometers from the basin into the massif. A regolithic profile of the crystalline rocks attests to intense weathering prior to the deposition of the Late Jurassic and younger sediments.

Semizbay is in the upstream (apex) part of the Semizbay paleovalley, about 25 km inland from the eastern edge of the Kokshetau Massif. At the site of the deposit, the channel trends curvilinear E-W and is incised for up to 150 m into granites of the Zhaman-Kotass Massif (Figs. 6.9a–c).

Basement rocks at and around the deposit are dominated by Middle to Upper Devonian alaskitic granite and granite porphyry dike swarms, which were intruded into Silurian to Lower Devonian biotite granite and Upper Ordovician to Lower Silurian diorite and granodiorite. Andesite porphyry, andesite basalt and related tuffs, and some Lower Paleozoic metasediments occur locally.

Valley fill consists of the up to 100 m thick Lower Cretaceous-Upper Jurassic Semizbay Formation (Sm) of fluvial-alluvial origin. Five horizons are distinguished. They are, from top to bottom (Fig. 6.9c):

- mottled argillaceous conglomerate and sand with interbedded clay-sand lenses ("slope facies", Sm_2^2),
- grey clay-silt flood plain facies with intercalated sand and mud-silt lenses (Sm_2^1),
- grey clay-silt flood plain facies with some sandy intercalations (Sm_1^3),
- grey sand with intercalated mud-silt lenses (Sm_1^2), and
- grey gravel beds with interbedded sand lenses (Sm_1^1).

A conterminous clayey layer of the Lower Cretaceous Kijalin Formation had originally covered the sediments of the Semizbay Formation but it is now, to a large extent, eroded. It provided a regional aquiclude additional to upper Campanian argillaceous beds.

Host Rock Alteratiozns and Mineralization

Besides pre-Upper Jurassic weathering of the basement, the basal part of the Semizbay Formation exhibits early oxidation documented by Fe-hydroxides and bleaching associated with destruction of organic debris. Subsequent reduction is reflected by Fe-sulfides (pyrite). Post-ore alteration features include carbonatization and chloritization. The temperature of carbonate formation is given as 150–200°C by Poluarshinov and Pigulski (1995).

The principal *uranium minerals* are coffinite, pitchblende, and sooty pitchblende. *Associated elements* include Se, Ge and substantial amounts of scandium. Carbonate and chlorite are the main *gangue minerals*. Ore texture is of a disseminated nature with U primarily contained in the matrix of sandy facies. Isotope dating of pitchblende yields ages of 120–110 Ma, which is considered the principal ore-forming period.

Shape and Dimensions of Deposits

Semizbay consists of a number of ore bodies distributed over a 15 km long and 500 m wide channel section. The ore bodies occur intermittently in two horizons (Sm_1^2 and Sm_2^1) separated by a 10–15 m thick argillaceous horizon (Sm_1^3). The upper horizon is 30–35 m thick and carries ore in basal grey sand lenses. The lower horizon is 15–20 m thick and contains several superimposed ore bodies in grey sand beds (Figs. 6.9a,b).

Mineralization forms ore bodies of discontinuous, almost horizontal, stratiform ribbons, elongated lenses, or tabular and roll- or pocket-like bodies. Thicknesses of ore bodies range from tens of centimeters to 7.5 m and average 2.1 m. Ore bodies are from about 500 m to 5 km long, 20–80 m rarely up to 200 m wide and occur at depths from 50 to 150 m below surface. Grades are highly variable ranging from several tens of ppm to 0.5% and locally up to 8% U; the average is about 0.05–0.07% U.

Sources of Uranium

Alaskitic granite and granite porphyry contain background values of 3–10 ppm U and localized concentrations of syngenetic uranium. Other elements like Sc, Be, Sn, Mo, and Y are present in anomalous amounts. At least some of the uranium is present as uraninite, i.e. in leachable form. As such these rocks are thought to be a viable source of uranium for the formation of the deposit.

Ore Controls and Recognition Criteria

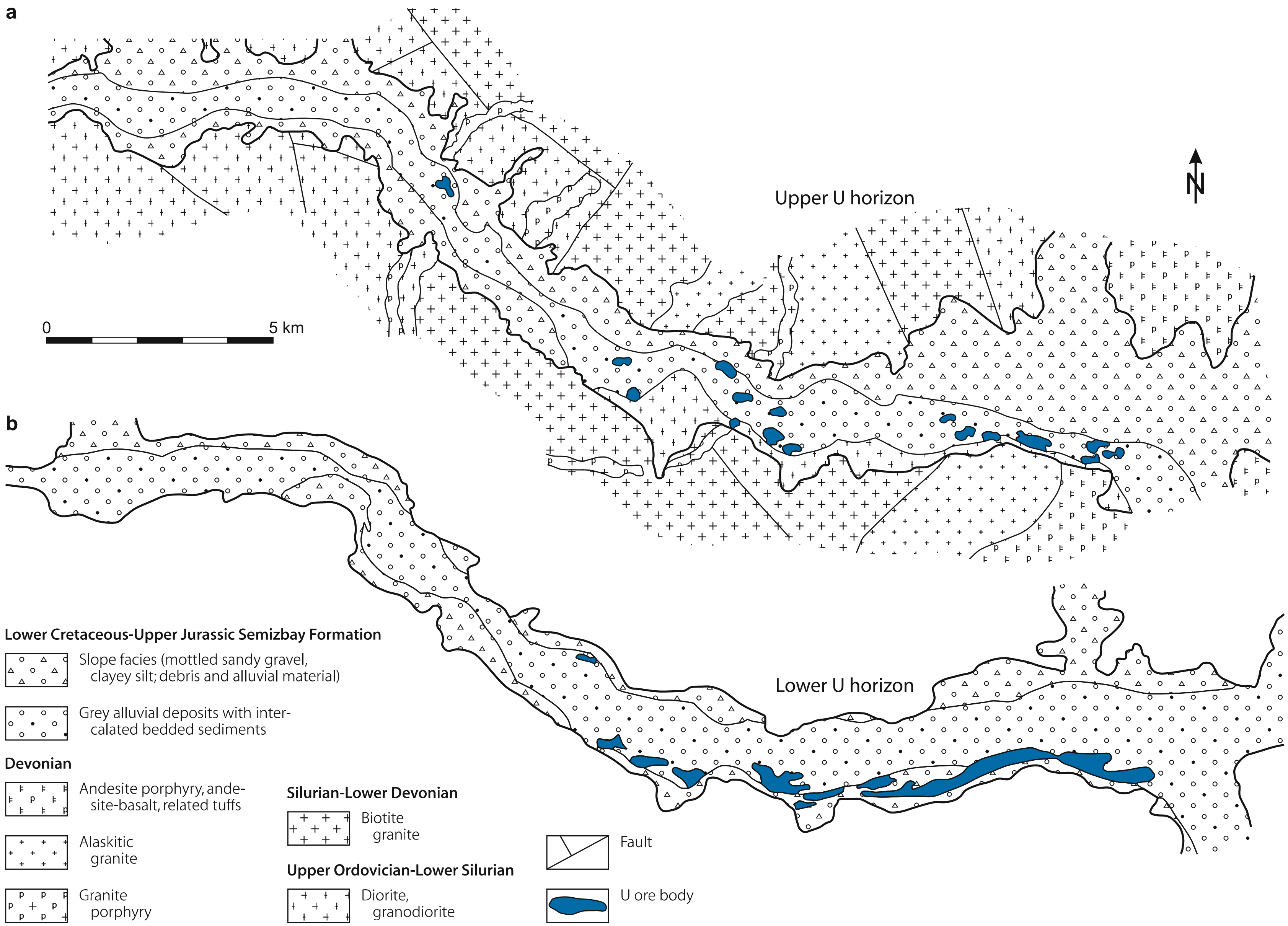
Significant ore controlling and recognition criteria of the basal sandstone-type Semizbay ore bodies are as follows:

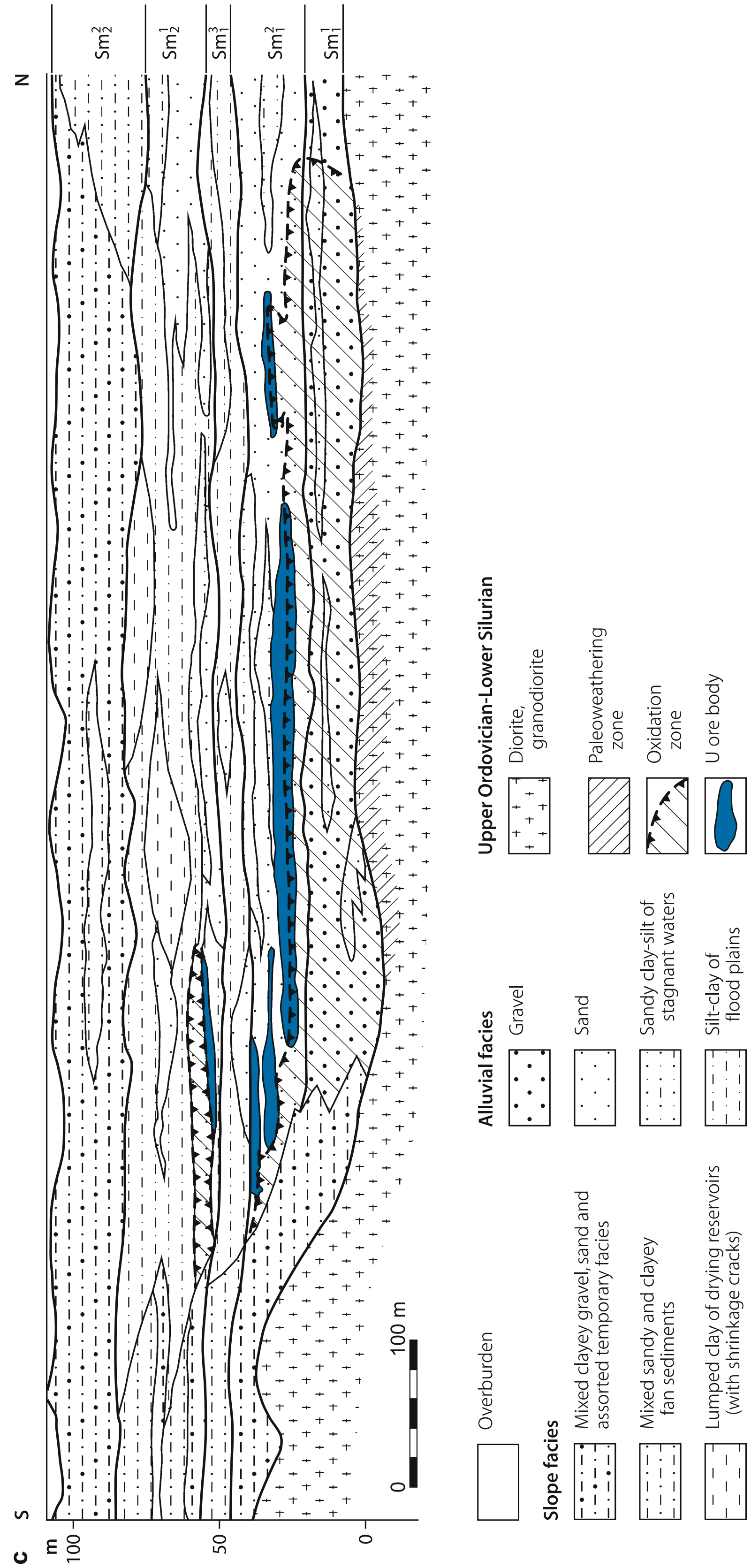
Host Environment

- paleovalleys predominantly incised into leucocratic granitic basement
- alternating permeable and more or less impermeable fluvial beds in paleovalleys
- intraformational hiatuses
- valley fill covered by impermeable clay blanket
- host rocks consist of carbonaceous, reduced sandy facies
- reductants in form of carbonaceous matter and sulfides

Fig. 6.9.

Kokshetau region, Semizbay, geological maps of two levels of the U mineralized Lower Cretaceous-Upper Jurassic paleovalley. The Semizbay Valley is incised into Lower Paleozoic slightly metamorphosed clastic sediments cut by Caledonian intrusions. U ore lenses are of basal-channel sandstone type and occur at two levels preferentially in the lateral basal part of the channel as documented in a (upper) and b (lower level), and along intraformational oxidation zones, as shown in section c (after Poluarshinov and Pigulski 1995)




C
S
N
m
100
50
0
Sm_2^2
Sm_2^1
Sm_1^3
Sm_1^2
Sm_1^1
0
100 m
Overburden
Slope facies
Mixed clayey gravel, sand and assorted temporary facies
Mixed sandy and clayey fan sediments
Lumped clay of drying reservoirs (with shrinkage cracks)
Alluvial facies
Gravel
Sand
Sandy clay-silt of stagnant waters
Silt-clay of flood plains
Upper Ordovician-Lower Silurian
Diorite, granodiorite
Paleoweathering zone
Oxidation zone
U ore body

- arid climate episodes permitting liberation and transport of U into valley sediments

Alteration

- early oxidation of valley fill reflected by oxidation zones in basal channel facies
- subsequent reduction of alluvial sediments reflected by bleaching associated with destruction of organic matter
- ore-related sulfidization
- post-ore carbonatization (calcite)

Mineralization

- coffinite, pitchblende, sooty pitchblende
- associated elements include Se, Ge, Re, Sc and Y-bearing minerals
- gangue minerals are mainly carbonates and chlorite

Metallogenetic Aspects

As may be deduced from the works of Poluarshinov and Pigulski (1995) and others, the metallogenesis of the Semizbay and other basal-channel sandstone-type deposits in the Kokshetau Massif may have occurred as follows:

During periods of Mesozoic tectonic activation and arid climate, uranium was liberated from granitic basement rocks. Quiet interludes between tectonic activities permitted a steady infiltration of oxygenated, uranium-bearing waters into depressions. Favorable geologic-structural and paleohydrological conditions for ore formation existed in smaller artesian depressions, which contained: (1) permeable sandy horizons permitting the percolation of fertile solutions and (2) reducing agents in the sedimentary sequence such as organic material for uranium reduction and deposition. So-called "ancient" zones of stratiform oxidation as they are retained in the basal part of the Semizbay Formation were generated in pre-Cretaceous time. Uranium was deposited in form of coffinite (and black products?) at the geochemical interface of the "ancient" oxidation zones. Subsequently some uranium was redistributed by a high temperature carbonatization event of 150–200 °C.

An alternative model assumes a polygenetic origin of the Semizbay ore. Fluid inclusions/homogenization and decrepitation analyses indicate a high crystallization temperature of about 150 °C for post-uranium calcite, which is thought to suggest the involvement of hydrothermal fluids. Such solutions presumably migrated along faults and permeable beds and introduced the bulk of the uranium. A later exogenetic process generated stratiform oxidation and redistributed some of the preexisting uranium.

6.1.10 Other Uranium Occurrences in the Kokshetau Region

6.1.10.1 Voskhod, NW Kokshetau Region

This small deposit was discovered at the western margin of the Voladar metallogentetic zone in the NW Kokshetau Massif at the end of the 1950s. The area is underlain by Lower-Middle Cambrian schist, gneiss, and amphibolite intruded by porphyry, lamprophyre, and granodiorite dikes of the Baksan Massif. Vein-stockwork ore bodies occur at the intersection of E-W with NW-SE faults. Amphibolite and granodiorite altered by beresitization (quartz-chlorite-sericite) are the preferential host rocks (Petrov et al. 2000).

6.2 Pricaspian (or Mangyshlak) Uranium Region, West Kazakhstan

The Pricaspian uranium region is located to the east of the town of Aktau (formerly Shevchenko) on the Mangyshlak Peninsula at the northeastern coast of the Caspian Sea, western Kazakhstan (Fig. 6.1). Within this region, two ore fields are established. The *Karagiin* ore field contains the partly mined deposits *Melovoye, Tasmurun-Ashisai, Taybagar, Tomak*, and *Sadyrnyn* (Fig. 6.10), and the *Karynzharyk* ore field with three subeconomic occurrences, located some 80 km to the southeast of the Karagiin field.

Ore deposits of the Pricaspian region consist of uraniferous mineralization associated with fossil fish bones hosted in pyritic clays. These deposits are classified as organic phosphorous type, a unique type of U deposits recorded only near the northern Caspian Sea in western Kazakhstan and in the Ergeninsky region, Kalmyk Autonomous Republic in Russia.

Remaining resources of the Pricaspian region (status 1995) are 64 400 t U in the $80–130 per kg U RAR category, 43 800 t U of which are contained in Melovoye. Other deposits in the Kara-giin ore field have resources varying between 4 000 and 9 000 t U.

Ore grade averages 0.04–0.06% U and although this grade is very low, the bone detritus is easily separated from the matrix and yields a concentrate with a U content 2–3 times higher and a phosphate content of about 30% P_2O_5. In addition to the uranium and phosphorus, rare earth elements and scandium were recovered from the detritus.

Uranium was discovered in 1954. Mining started in 1959 and lasted until 1993 when economic reasons forced the shut down of operations. Exploitation was by open pit methods with a total production of about 15 000 t U. Uranium recovery was by means of ion exchange in a mill near Aktau situated 20 km W of the Melovoye deposit. The "Pricaspiski Mining-Metallurgical Combinate" was the operator until the early 1990s when it was reorganized into the "Joint Stock Company KASKOR" (OECD-NEA/IAEA 1993, 1995).

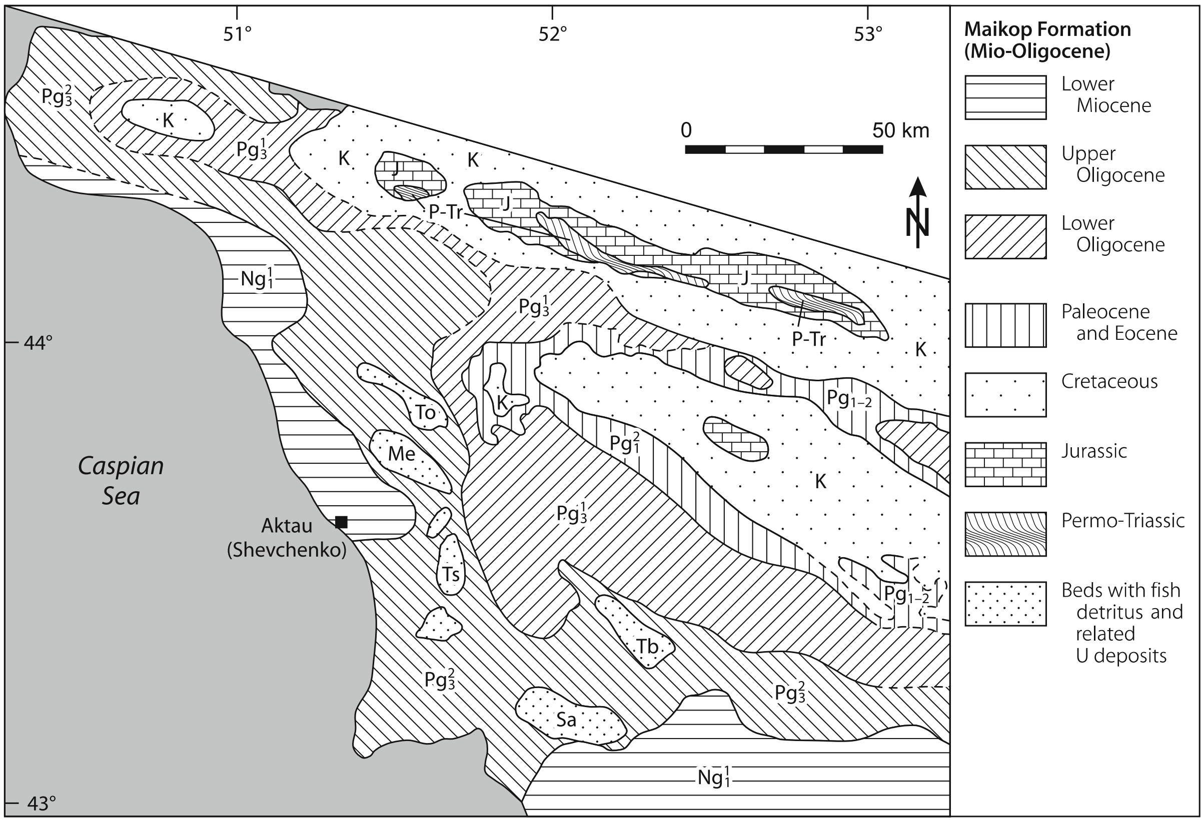
Sources of information. Abakumov (1995), Laverov et al. (1992b, c), OECD-NEA/IAEA (1993, 1995, 1997), Petrov et al. (1995), Stolyarov and Ivleva (1995).

Regional Geology and Mineralization

The litho-stratigraphic profile of the Karagiin ore field comprises Neogene to Cretaceous marine sediments resting upon a

Fig. 6.10.

Pricaspian region, Karagiin ore field. Geological map with location of U deposits (Neogene-Quaternary cover not shown). Mineralization consists of stratiform accumulations of uraniferous, phosphatized fish bone detritus in pyritic clay horizons of Oligocene age (after Stolyarov and Ivleva 1995) U deposits: *Me* Melovoye, *Sa* Sadyrnyn, *Ta* Taybagar, *To* Tomak, *Ts* Tasmurun



basement of folded Jurassic and Permo-Triassic sediments. The cover sequence includes, from top to bottom:

- *Neogene-Quaternary*, 10–90 m thick clay strata with interbedded marl
- *Lower Miocene to Lower Oligocene* Maikop Formation, over 800 m thick, divided into
  - Lower Miocene Kashkaratin Member, up to 100 m thick (mud, clay)
  - Upper Oligocene Karagiin Member, up to 400 m thick (U)
  - Middle Oligocene Kenjalin Member
  - Lower Oligocene Uzunbas and Kuyules Members
- Paleocene-Eocene and Cretaceous sediments

The mineralized Karagiin Member is subdivided into three units with the following characteristics:

- upper unit: up to 80 m thick, greenish-grey clay with disseminated pyrite concretions and intercalated mud beds
- middle (or fish) unit: 40–150 m thick, dark clay with beds enriched in pyrite and melnicovite concretions (0.01–0.05 mm in diameter), fish bones, and fish scales (mainly herring relics)
- lower unit: up to 90 m thick, greenish-grey, partly carbonatic clay with rare shell and "mud eater" fossils

Minable U mineralization is restricted to the middle (fish) unit of the Karagiin Member. It contains between one and four superjacently-stacked, uraniferous, phosphatic fish bone horizons which, in some deposits, feather out into several beds to form a horse-tail pattern (Figs. 6.11a–c).

Uraniferous beds are from 0.1 m to 11 m thick and extend laterally for up to 18 km in length and several kilometers in width (details see at individual deposits). Mineralization is found from surface (Tasmurun, Sadyrnyn) to 240 m deep (Taybagar).

Individual fish beds contain from few percent to 75% fish detritus, 1–25% P_2O_5, 10–60% sulfides (5–30% S_{py}), and concentrations of U, La, Sc, Y, lanthanides (except promethium), Co, Ni, and Mo. Total REE content varies between 0.5 and 2.1%. Scandium ranges from 13 to 77 ppm and uranium from 1 ppm to a few percent averaging 0.02–0.06% U. Average values for deposits are given in Table 6.3. Phosphate is present in fossil fish bones and as a rock constituent. Uranium, scandium, and REE are primarily incorporated in phosphatized fish bone detritus.

The uranium-bearing unit extends southeastward beyond the Pricaspian mining district, but occurs at greater depth. It is also found to the northwest of the Caspian Sea where U occurrences are reported from the Kalmyk Autonomous Republic.

Principal Ore Controls and Recognition Criteria

Significant ore-controlling parameters or recognition criteria of the major deposits in the region, include:

Table 6.3.
Pricaspian region, Karagiin ore field. Average mining grades of deposits (Stolyarov and Ivleva 1995)

Deposit	Average content											
	U (%)	RE_2O_3 (%)	Mo (%)	Ni (%)	Co (%)	Sc (ppm)	Re (ppm)	P_2O_5 (%)	S_{py} (%)	Al_2O_3 (%)	U/P_2O_5	RE_2O_3/P_2O_5	RE_2O_3/U
Melovoye	0.042	0.18	0.022	0.060	0.015	27	1.0–2.0	4.32	11.1	12.5	0.010	0.042	4.28
Tomak	0.062	0.26	0.014	0.067	0.017	22	0.3–0.6	8.50	11.2	11.5	0.007	0.031	4.19
Taybagar	0.043	0.21	0.015	0.057	0.013	–	–	8.00	9.3	10.0	0.005	0.026	4.88
Tasmurun	0.040	0.15	0.042	0.075	0.026	15	–	5.16	15.3	7.0	0.007	0.026	3.75
Sadyrnyn	0.022	0.10	0.035	0.050	0.017	13	–	3.14	9.5	12.0	0.007	0.032	4.54

Host Environment/Host Rocks

- Argillaceous marine sediments of Tertiary age filling gentle basins
- Host formation of 20–60 m thick pyritic clay unit containing intercalated beds with abundant fish remains

Mineralization

- U associated with Sc and REE incorporated in phosphatized fossil fish bones and scales
- Low U ore grades (<0.06% U)
- Variable phosphate content ranging from 1 to 25% P_2O_5 averaging 3–8.5% P_2O_5
- High sulfide content ranging from 5 to 30% S_{py} averaging 9–15% S_{py} in various deposits
- REE, phosphate, and pyrite recoverable as byproducts to uranium
- Large lateral extension of mineralized beds, up to 70 km² in size
- 0.1–11 m thick argillaceous, uraniferous fish bone beds alternating with clay beds
- Feathering out of fish bone horizons in horse-tail pattern

Metallogenetic Concepts

A diagenetic concentration of uranium and other metals by sorption on phosphate or phophatized fish bone detritus is generally accepted as the ore-forming mechanism. Sea water is thought to be the source of the ore-forming elements. The enormous accumulation of fish bone debris is attributed to a marked increase in hydrogen sulfide in seawater resulting in a catastrophic impact on the fish population.

6.2.1 Karagiin Ore Field

This ore field encompasses five U deposits: *Melovoye, Tomak, Taybagar, Tasmuran,* and *Sadyrnyn*. Melovoye differs from the other deposits by its large size and ore characteristics. Sediments were deposited in a deep sea environment, which was obviously more favorable for U, REE, and Sc accumulation in bone phosphate, and for Re incorporation in sulfides than in the Tomak and Taybagar deposits. Sedimentation forming the latter two deposits occurred coeval with that at Melovoye but under shallow marine conditions. This resulted in a doubling of the content of fish bone debris in ore beds as reflected by the phosphate content, and locally in a higher carbonate component. But the U tenor did not rise in proportion as illustrated by the U/P_2O_5 ratio decreasing by 30–50%, from 0.01 at Melovoye to 0.007 at Tomak and to 0.005 at Taybagar. Horse-tail patterns of ore beds are typical for each of the three deposits.

Tasmurun and Sadyrnyn in the southeastern part of the ore field consist of the most recent fish bone-bearing sediments. The ore bed configuration in these deposits is commonly of a simple tabular or lenticular nature. Grades of ore-forming elements are lower than in the afore-mentioned deposits.

6.2.1.1 Melovoye

Melovoye is located some 10 km NE of Aktau. Mining was by open pit methods and lasted from 1959 to 1993. Remaining reserves are 43 800 t U (grades are given in Table 6.3). Fish bone concentrate contains 0.185% U.

Melovoye is 18.5 km long, up to 7 km wide, and covers an area of 88.6 km². Uranium occurs in four horizons with abundant fish bones within a 20–60 m thick pyritic clay unit of the middle Karagiin Member. The horizons join to the south and east and feather out in horse-tail fashion in opposite directions (Fig. 6.11). A 10–60 m thick clay horizon overlies, whereas clayey sediments with rare fish bones and other fossils underlie, the uranium bearing unit. The sequence rests on silty and carbonatic clays of the Middle Oligocene Kenjalin Member.

Dimensions of the ore beds are as follows:

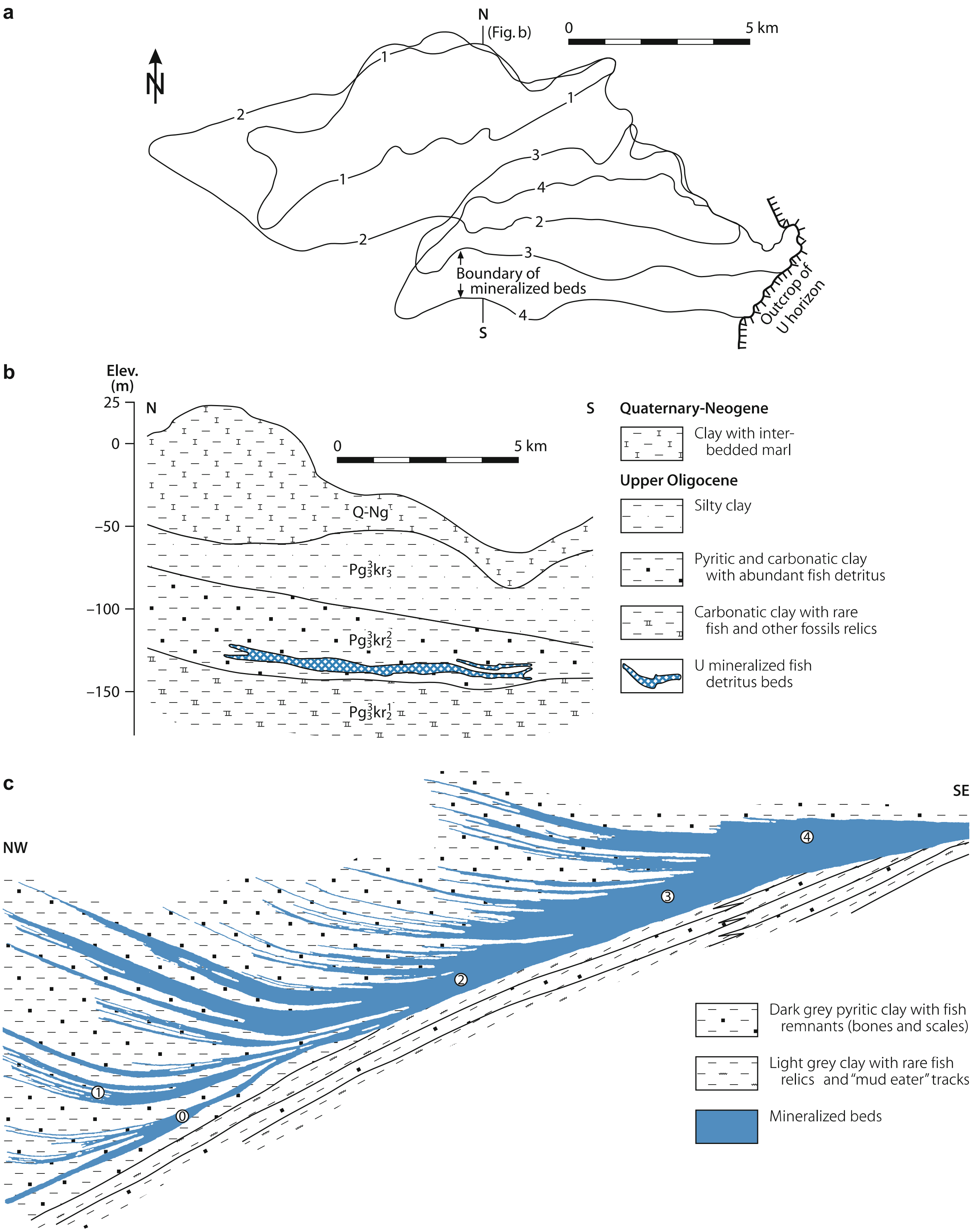
- *Ore bed 1,* situated in the NW part of the deposit, is 0.2–0.6 m (av. 0.5 m) thick, 11 km long, up to 3 km wide, and covers an area of about 20 km². Mineralization occurs in up to 10 cm thick laminae. Reserves are insignificant.
- *Ore bed 2* is from less than 1 m to several meters thick, 17 km long, up to 6 km wide, and covers 70 km². It contains the principal U and REE reserves.
- *Ore bed 3* (in SE part of the deposit) is 0.3–2.5 m thick, 11 km long, up to 4 km wide, and covers 25 km².
- *Ore bed 4* (in SE part of the deposit) is 0.5–1.5 m thick, 12 km long, up to 4 km wide, and covers 33 km².

6.2.1.2 Tomak

Tomak is situated some 20 km NE of Aktau and was mined by open pit methods until 1993. Remaining resources are less than

Fig. 6.11.

Pricaspian region, Melovoye deposit. a Distribution and size of the four U mineralized clay beds with fish detritus in the Upper Oligocene Karagiin Member, Maikop Formation; b litho-stratigraphic N-S section, and c schematic longitudinal NW-SE section documenting the horse-tail structure of mineralized beds (after Stolyarov and Ivleva 1995)



7 000 t U (grades are given in Table 6.3). Tomak covers an area about 20 km long and 1 km wide in which four ore horizons occur. The sediments were deposited in a more shallow marine environment than at Melovoye and a different ore composition resulted. U and REE contents of bone detritus are comparably higher, and clay beds are partly dolomitic.

6.2.1.3 Tasmurun

Tasmurun (also Tasmurun-Ashisai) is located about 13 km ESE of Aktau. Resources are less than 5 000 t U (grades are given in Table 6.3). The deposit consists of several ore bodies. The main ore body is 8 km long, 0.6–2.5 km wide and covers an area of 24.4 km^2. It is of tabular morphology, 0.7–1.5 m thick in the central part but thinning to 0.3–0.4 m in peripheral segments. Fish bones are evenly distributed. Ore composition differs from that of Melovoye by a 30% lower U/P_2O_5 ratio and a 40% higher sulfide content.

6.2.1.4 Taybagar

Taybagar is situated about 35 km ESE of Aktau. Resources are less than 7 000 t U (grades are given in Table 6.3). Fish bone concentrate contains 0.11% U.

Taybagar covers an almost 20 km long and 1–7 km wide area in which four ore horizons occur. They finger out in a SE direction associated with a thinning of mineralized beds from 7–8 m down to 0.25 m. Mineralized beds are always separated by a clay horizon a few meters thick. The carbonate content in lower beds is low but increases upward to between 16 and 39% CO_2 in the upper bed whereas the sulfide content is reduced to 3.7% S (in pyrite).

6.2.1.5 Sadyrnyn

Sadyrnyn is located about 35 km SE of Aktau. Resources are between 4 000 and 9 000 t U (grades are given in Table 6.3). Sadyrnyn contains several tabular or lenticular ore beds, which are spread over an area more than 20 km long in a NW-SE direction. Thicknesses of the ore beds average 0.8 m but vary between 0.2–0.3 m in the central part and 1.5–1.8 m in the SE sector where they feather out.

6.3 Chu-Sarysu Basin, South-Central Kazakhstan

The Chu-Sarysu Basin is located in south-central Kazakhstan (Fig. 6.1). It is as much as 250 km wide and extends for more than 600 km from the foothills of the Tien Shan mountains to the south and southeast, and merges into the flats of the Aral Sea depression to the northwest. The northern and western boundary coincides roughly with the course of the Sarysu River while the Chu river flows across the southern part of the basin. The basin is bounded to the SW by the NW-SE-trending Karatau mountain range, which separates the Chu-Sarysu Basin from the southwesterly located Syr-Darya Basin (see next chapter). These two basins originally formed a single basin before they were separated by periodical uplifts of the Karatau Range. The separation took place after the formation of the U deposits.

Yazikov (2002) reports a total inventory of 973 000 t U for the basin. According to Abakumov (1995) (remaining?) resources amount to 221 000 t U in the RAR + EAR-I <$80 per kg U cost category, 74 000 t U of EAR-II, and 20 000 t U of prognosticated resources. Ore grades average from 0.02 to 0.07% U.

Most deposits are grouped in two districts: the *Kenze-Budenovskaya District* in the central-western basin, and the *Uvanas-Kanzhugan District* in the central-southern basin. Isolated occurrences include *Karakoyn* in the northern, *Sholak Espe* in the central, and *Bars* in the southern basin (Figs. 6.1, 6.12).

U mineralization is controlled by dynamic redox fronts in arenite strata. Deposits are therefore classified as sandstone-rollfront type. Some ore bodies are of the tabular sandstone type.

Uranium was discovered in the Chu-Sarysu Basin in the 1960s, first at Uvanas and Zhalpak. When conventional mining proved unfeasible, ISL techniques were tested at the Uvanas deposit in 1969–1971. Positive results triggered more intensive exploration that led to additional discoveries: Kanzhugan in 1972, Mynkuduk in 1973, and, later in the 1980s, Inkay, Budenovskoye, Akdala, Sholak Espe, and Karakoyn (see Sect. *Historical Review*).

Exploitation has been only by ISL techniques to-date. In 2004, six deposits were in production. Uvanas was the first operation; it started in 1977 and was followed by Mynkuduk in 1978, Kanzhugan in 1982, Inkay, Moynkum, and Akdala in 2001. Total production was some 27 000 t U through 2005.

Operators of these production facilities are the Kazatomprom (formerly KATEP) subsidiaries: Mining Company Stepnoye (Uvanas and Mynkuduk-Vostochny/East) and Centralnoye (Kanzhugan and Moynkum south or site 1), and three joint ventures of Kazatomprom with Cogema (Katko Co.; Moynkum Central and North or sites 2 and 3), and Cameco (Inkay), and the Betpak Dala J.V. at Akdala. Nominal total production capacity is 4 100 t U yr^{-1} (OECD-NEA/IAEA 2005).

Sources of information. The description presented hereafter is based largely on Aba-kumov (1995), Fyodorov (1997, 2002, 2005), IAEA (1995), Kislyakov and Shchetochkin (2000), OECD-NEA/IAEA (1995–2005), Petrov et al. (1995), Shakhverdov (2003), Shchetochkin and Kislyakov (1993), Shor and Kharlamov (2003), Yazikov (2002), Zinchenko and Stoliarenko (2002), as well as pers. commun. by Yazikov, Petrov, staff of Central Mining Co./Kazatomprom 2003, and Boitsov VA and Catchpole 2005, unless otherwise stated.

Regional Geological Setting of Mineralization

The Chu-Sarysu Basin is located at the eastern margin of the Turan Platform. The basin is bounded to the southwest by the NW-SE-trending Big Karatau Uplift, a mountain range composed of Proterozoic to Ordovician crystalline schists unconformably overlain by Carboniferous and Devonian limestone and sandstone. The Chuily-Kendyktas Uplift forms the northeastern, the Kirgizian Range (a branch of the Tien Shan mountains) the southern, and the Ulutau Massif the northern limit. The basement and surroundings are part of the Caledonian Orogen.

The basin is filled with up to 2 000 m thick Quaternary to Cretaceous, mainly continental and minor shallow marine sediments, which are divided by a major unconformity into two stratigraphic-structural units. The *upper unit* consists of Quaternary-Neogene sediments up to several hundreds of meters thick. The uranium-bearing, up to 500 m thick *lower unit* includes Eocene to Upper Cretaceous, largely unconsolidated alluvial/fluvial, deltaic, and lacustrine sediments deposited on a large alluvial plain at the margin of the huge Turan Platform. During the waning period of the Eocene, the region was flooded and shallow marine, grey-green, argillaceous sediments as much as 150 m thick were laid down. Subsequent orogenic activity, which was strongest during the Oligocene, caused uplift of basement blocks such as the Tien-Shan mountains located to the south of the basin. Associated erosion led to the deposition of pink-colored continental facies of the upper unit upon the Paleogene unconformity. It was during this period that the basin became artesian.

The following *litho-stratigraphic profile* provides a synopsis of the sedimentary facies in the central basin based on Petrov at al. (1995) (from surface downwards):

Upper Unit

- *Quaternary-Pliocene*: few meters to 200 m thick, sand and clay-silt
- *Pliocene-Miocene* Todusken Formation: 20–300 m thick, limy clay overlying sand beds with minor clay-silt lenses
- *Oligocene-Miocene* Betpak dala Fm: 10–50 m thick, sand and limy clay (pink series)

Fig. 6.12.
Chu-Sarysu and Syr Darya Basins, a generalized geological map and b SW-NE cross-section with location of redox fronts and related U deposits (after a Fyodorov 2002; b Petrov et al. 1995)

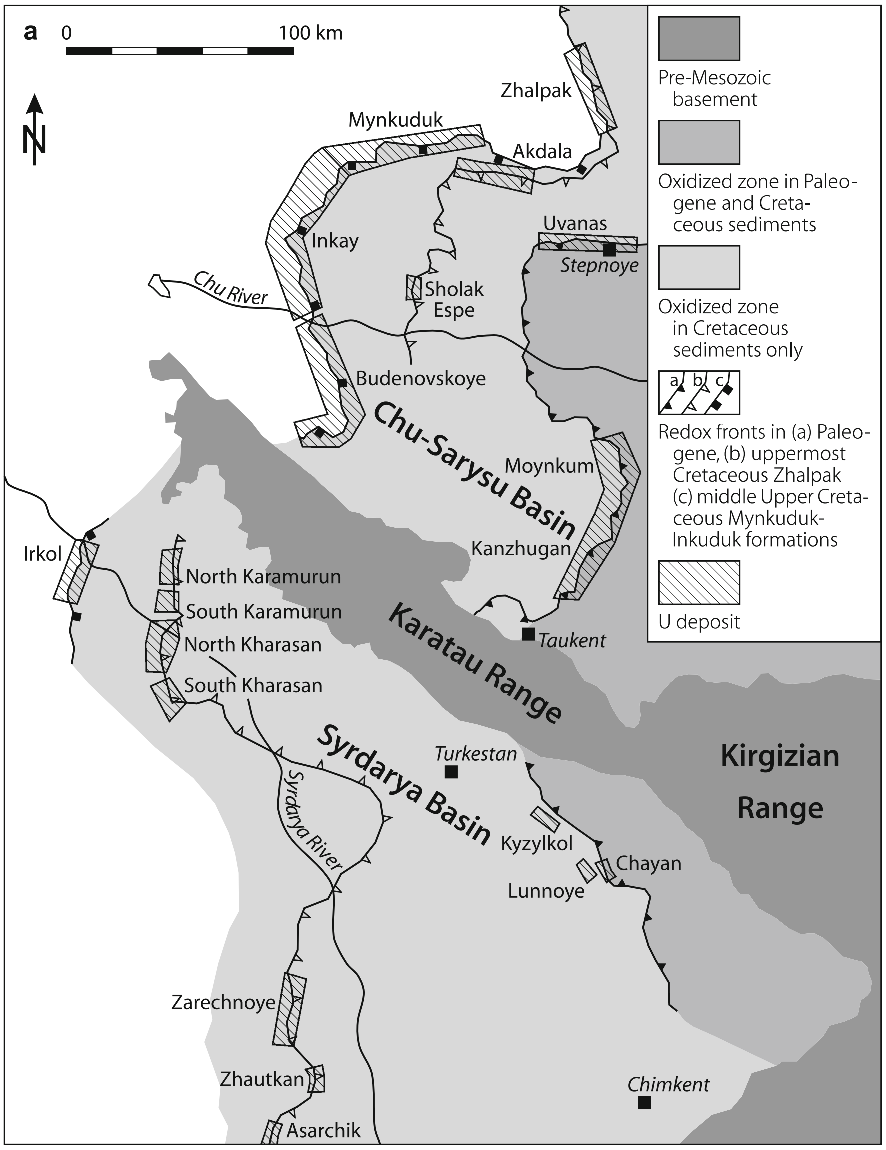
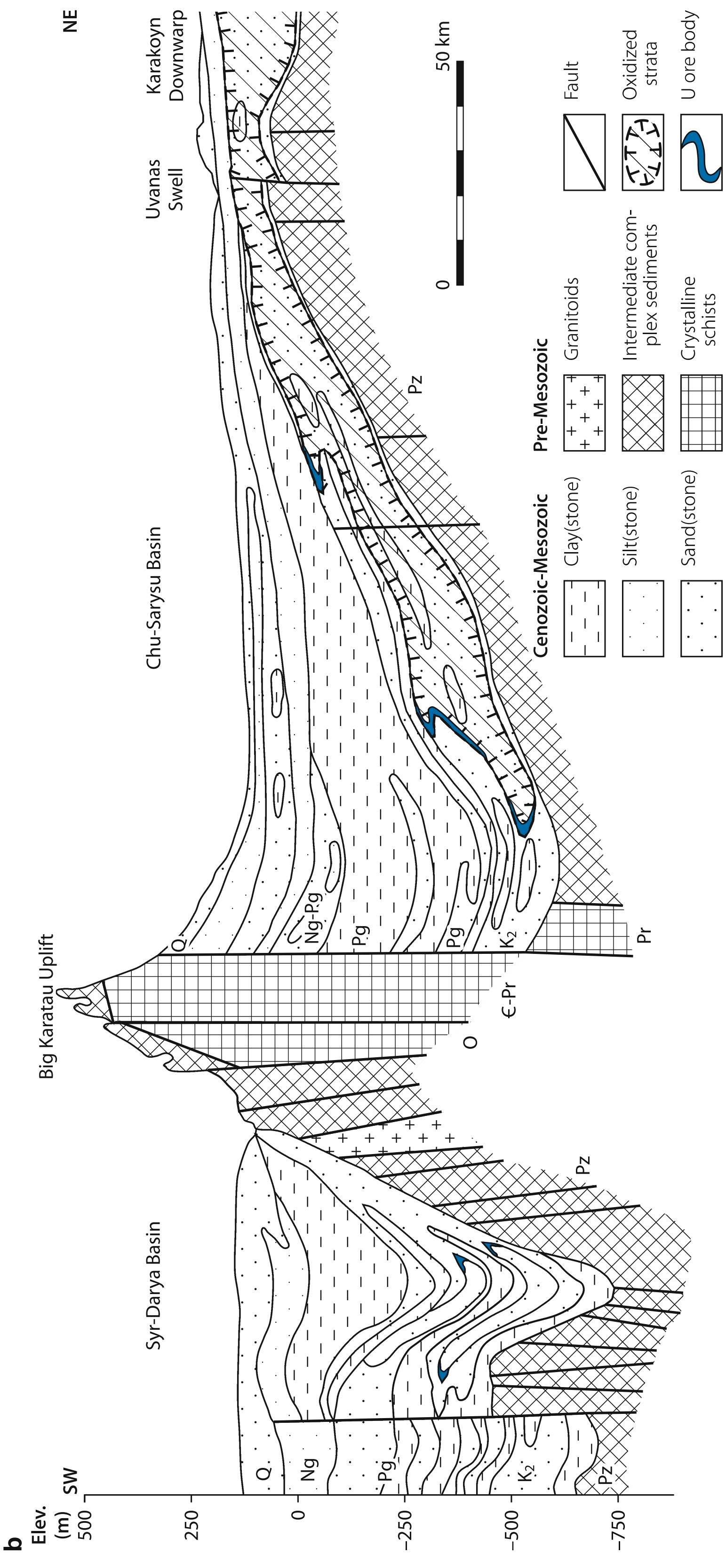


Fig. 6.12. (Continued)



>Major unconformity<

Lower Unit

- *Paleogene*: three U-bearing formations separated by unconformities
  - *Upper Eocene* Intymak Fm: regional, 20–150 m thick, grey-green clay-silt horizon with minor sandy lenses at base
  - *Middle Eocene* Ikan Fm: 5–60 m thick, clay and sand of deltaic origin, U-mineralized
  - *Lower Eocene* Uyuk Fm: 5–65 m thick, clay and sand of deltaic origin, U-mineralized
  - *Paleocene* Uvanas/Kanzhugan Fm: 5–70 m thick, alternating sand, sandy gravel, and clay-silt of fluvial/alluvial and lacustrine provenance, U-mineralized
- *Upper Cretaceous*: three U-bearing formations separated by unconformities, cumulatively 250–300 m thick, of cyclic depositions of mainly gravel and sand with minor intercalated clay-silt lenses of fluvial and lacustrine origin
  - *Maastrichtian-Campanian* Zhalpak Fm: 30–90 m thick, contains more organic debris than Inkuduk and Mynkuduk Fms
  - *Santonian-Turonian* Inkuduk Fm: 40–120 m thick, separated into 3 horizons/cycles, U in lower and middle parts
  - *Lower Turonian* Mynkuduk Fm: 20–80 m thick, U mainly in lower part
- *Cenomanian*: 10–30 m thick, argillaceous sands
- *Lower Cretaceous/Albian* Tantei Fm: 0–140 m thick, sandstone overlain by sandy mudstone

- >Major unconformity<

- *Lower-Middle Jurassic:* 0–400 m thick, sandstone-mudstone
- *Permian-Carboniferous:* consolidated siltstone, sandstone, and limestone

- >Major unconformity<

- Proterozoic-Cambrian-Ordovician: crystalline schists

The marine Upper Eocene clays constitute the upper confinement and Paleozoic, locally Jurassic, rocks the basal regional confinement for hydraulic systems in the Cretaceous to Eocene stratigraphic-structural unit of the Chu-Sarysu Basin.

Uranium is hosted in six continental, 20–150 m thick, stratigraphic formations (termed "horizons" in Kazakh-Russian literature) of Paleogene (Uvanas-Kanzhugan zone) and Late Cretaceous age (Kenze-Budenovskaya zone). Deposition of these formations occurred in macrocycles which, in turn, are composed of a great number of microcycles with different permeabilities. As indicated in the litho-stratigraphic column above, the three *Paleogene* uraniferous formations are in Paleocene and Lower-Middle Eocene sediments of mainly medium- to fine-grained, weakly carbonaceous sands separated by continuous argillaceous beds. The three mineralized formations in *Turonian to Maastrichtian* strata consist of several, 10–40 m thick horizons each starting with an up to some 10 m thick basal gravel bed grading upward into variably sized, mostly coarse-grained sands. 80–90% of these arenites are of permeable nature. Discontinuous argillaceous and silty lenses overly and intervene between the horizons (see Sect. *Principal Characteristics of Mineralization* for host rock composition).

The *structure* of the basin is dominated by a large monocline in the central-western segment while the eastern basin is more complex with a major basement rise of NW-SE orientation (Uvanas swell), local brachyanticlines, and subbasins like the Karakoyn trough. Sediments of the monocline dip gently southwestward from the Uvanas swell toward the Karatau Range in front of which they warp upward and transition into a medium steep NE inclination (Fig. 6.12b).

Regional faults trend predominantly NW-SE and to a minor degree N-S and E-W. Their manifestation decreases in the Mesozoic-Cenozoic cover from bottom to top. Synsedimentary, pre- to syn-Oligocene faulting caused major displacements in the lower unit of the basin. The Proterozoic-Paleozoic basement is block faulted.

Groundwater influx into the Chu-Sarysu Basin is from the northern Tien Shan. The groundwater migration is directed towards northwesterly discharge areas at the Aral Sea. Annual flow rates average 1–4 m depending on the permeabilities of the various sand horizons. Groundwater in Paleogene sediments has drinkwater quality whereas that in the Cretaceous sediments contains from 1 to 6 g l^{-1} dissolved salts.

Principal Host Rock Alterations

A regional oxidation zone (referred to as "stratum oxidation zone" in Russian terminology) is the prominent alteration feature in the artesian lower stratigraphic-structural unit of the Chu-Sarysu Basin. A still active hydrodynamic system of oxygenated groundwater, which commenced in Late Oligocene time migrated northwestwards, downdip the regional trend of aquifers, and multilevel redox fronts, up to 300 km long, were established within aquifers of six superjacent litho-stratigraphic units. Permeable grey arenitic horizons reduced by diagenetic processes became oxidized and mostly speckled-colored. Due to variable permeabilities of the aquifers, the redox fronts advanced differentially. Oxidation fronts in the Upper Cretaceous sediments of the Kenze-Budenovskaya zone progressed for a distance of as much as 500 km whereas those in the Paleogene sediments of the Uvanas-Kanzhugan zone migrated for some 350 km from the recharge area in the Tien Shan mountains. The Inkuduk Formation has the highest permeability and therefore contains the farthest advanced redox front, which is 10–18 km ahead of that in the Mynkuduk aquifers.

In response to the oxidation process, organic debris decayed associated with generation of hydrocarbons and hydrogen. The water-dissolved gases are concentrated in the redox zone at the head of the regional oxidation tongue where their concentration is 6–8 times higher than normal and, as such, provided the reducing agents required for uranium deposition.

Principal Characteristics of Mineralization

Uranium ore in the Chu Sarysu Basin is mostly monometallic but, locally, also polymetallic at sites where Re and/or Se are concentrated to recoverable grades. Pitchblende, coffinite, and black products (sooty pitchblende) are the principal *uranium minerals. Associated minerals/elements* include marcasite, pyrite, sphalerite, goethite, hydrogoethite, pyrolusite, calcite, siderite, and radiobaryte, which are present in limited quantities, and minor to trace amounts of As, Ge, Mo, Re, Se, V, Y, REE, and others. Se, V, and As typically occur in oxidized sands at the rear of a roll while Mo is present in the reduced front part. Re is distributed throughout an ore body and extends into non-uraniferous, grey facies. Table 6.4 provides a summary of selected trace elements.

Mineralization has a disseminated texture. Uranium phases occur finely dispersed in the clayey-silty matrix of arenites, fill voids and microfissures in rock fragments, coat sand grains, and pseudomorph plant remains.

U mineralization is contained in at least nine arenaceous horizons within six stratigraphic formations. Two prominent regional redox fronts control deposits of the Uvanas-Moynkum-Kanzhugan zone in the Paleogene Uvanas/Kanzhugan Formation, and deposits of the Kenze-Mynkuduk-Inkay-Budenovskaya zone in the Late Cretaceous Zhalpak, Inkuduk, and Mynkuduk Formations. A third redox front positioned between these two zones controls the Sholak Espe deposit in the Zhalpak Formation.

Some deposits (Inkay, Mynkuduk, Uvanas) occur in fluvial sediments of large rivers while others (Moynkum, Kanzhugan) are hosted by delta sediments. Mineralized fluvial channel facies consist of grey sands and gravel, which are generally composed of 60–80% quartz, 10–15% feldspar, 2–15% clay particles, 1–5% heavy minerals, and 0.01–0.1% organic matter; in ore zones these channel facies also contain <0.1% pyrite and 0.01–0.2% calcite.

General Shape and Dimensions of Deposits

Uranium occurs in at least nine arenaceous horizons at depth intervals from 80 m to more than 500 m along highly extensive, up to several hundreds of kilometers long, almost continuous mineralized zones along sinuous redox fronts, individual sections of which are arbitrarily defined as deposits. Deposits consist of a number of individual ore bodies separated by barren or weakly mineralized ground. In situ ore has a wide range of grades, from <0.01 to 0.4% U and locally more, and exhibits average deposit grades between 0.02 and 0.07% U.

Ore bodies linked to redox fronts are predominantly of roll shape while lenticular or tabular ore bodies occur at variable distances behind the redox fronts. In planview, roll-type ore bodies appear as continuous, winding ribbons, a few kilometers to as much as 30 km long and from 20 to 1 000 m wide; in cross-section, they predominantly display an asymmetric crescent, 1–30 m thick, with tails of variable length. Multilevel ore zones contain superjacently stacked ore bodies with a cumulative thickness in excess of 30 m.

Ore body position, configuration, and dimension tend to be primarily a function of the simple nature of sedimentary cycles,

Table 6.4.
Chu Sarysu Basin. Selected trace elements in ore and sand horizons. Zone of U loss refers to strata intervals from which U was removed (Maksimova et al. 1995)

Deposit/ –Formation	Environment	Sc (ppm)		Y (ppm)		Yb (ppm)		La (ppm)		Ce (ppm)		Nd (ppm)	
		Ø	Max	Ø	Max	Ø	Max	Ø	Max	Ø	Max	Ø	Max
Kainar[a] –Kanzhugan Fm	High grade ore	2.6	6.4	–	150	6.6	16.0	–	–	–	–	–	–
	Zone of U loss	2.5	3.0	45	126	2.3	3.2	–	–	–	–	–	–
Budenovskoye –Zhalpak Fm	Oxidized sed.	2.7	2.7	36	77	3.0	4.5	–	–	–	–	–	–
	Unaltered sed.	2.2	2.6	–	–	1.9	1.4	–	–	–	–	–	–
	High grade ore	5.0	12.4	91	276	2.3	5.0	71	226	39	135	38	122
	Zone of U loss	3.3	4.1	15	17	1.6	3.0	17	25	11	15	13	15
Inkay –Inkuduk Fm	Oxidized sed.	3.2	13.0	15	28	1.9	3.7	19	21	<20	<20	13	16
	Unaltered sed.	3.2	6.0	13	26	–	–	–	–	–	–	–	–
	High grade ore	6.3	19.0	28	53	3.0	5.0	–	–	–	–	–	–
	Zone of U loss	6.0	15.0	16	31	2.4	3.0	–	–	–	–	–	–
–Mynkuduk Fm	Oxidized sed.	3.7	5.8	15	28	2.0	4.0	–	–	–	–	–	–
	Unaltered sed.	–	5.8	–	30	–	1.4	–	–	–	–	–	–
	High grade ore	10.0	23.0	67	1208	4.0	1.8	17	29	49	76	10	22
	Zone of U loss	–	3.3	11.8	11.8	–	1.4	–	12	–	49	–	10

[a]Kainar is at SW end of the Kanzhugan deposit.

degree of permeability, and confinement of mineralized strata by aquicludes as evidenced by ore transecting the host lithologies independent of their texture. Textural parameters of host beds such as grain size, crossbedding, or clay content in the matrix of arenites exerted, however, a certain although subordinate impact as reflected by a more complex internal structure of the ore bodies.

Regional Geochronology

U/Pb ages of U minerals vary within a wide range. Most reliable ages group in the time interval from 35 to 22 Ma and from 250 000 to 100 000 years ago. This indicates that ore formation commenced in Oligocene time contemporaneously with the uplift of the Tien Shan ranges. The younger ages indicate uranium redistribution processes, which are still active as documented by younger ages of mineralization at the front of ore rolls compared to ages obtained from the rear part of rolls (Fyodorov 2002).

Potential Sources of Uranium

Circumstantial evidence suggests that the Tien Shan mountains, which abut the Chu-Sarysu Basin to the S and SE not only furnished sediments to the basin, but also provided U and other ore-associated elements. Ordovician and Silurian granites, which intruded coeval with granodiorite into crystalline schists and slates of the Tien Shan are considered a viable source of these elements. Another potential source for uranium and other elements found in the uranium deposits may be seen in felsic volcanics exposed to the east of the basin in the Kendyktas-Chuily-Betpak Dala uranium region.

Principal Ore Controls and Recognition Criteria

Significant ore controlling parameters or recognition criteria of the major deposits in the Chu-Sarysu Basin include:

Host Environment

- Artesian basin situated at the margin of a large platform and partly fringed by mountain ranges
- Basin containment of two stratigraphic-structural units separated by a major unconformity
- Upper unit of Quaternary-Neogene marine and continental sediments
- Uranium-bearing lower unit is composed of Paleogene-Upper Cretaceous continental fluvial/alluvial and lacustrine facies deposited in megacycles, and minor shallow marine sediments
- Host rocks are mainly fluvial/alluvial, grey, slightly carbonaceous, partly arkosic sand and gravel beds mostly of the middle and basal parts of sedimentary cycles
- Host rocks have interbedded mottled or green argillaceous and/or silty beds continuous in Upper Cretaceous and discontinuous in Paleogene strata
- The uranium-hosting lower unit is vertically confined by a regional argillaceous horizon of Upper Oligocene age on top, and Paleozoic rocks at the base
- The western part of the basin is characterized by a large monocline whereas the eastern basin has a more complex structure caused by swells and brachyanticlines
- Major displacements are bound to synsedimentary, pre- and syn-Oligocene faults

Alteration

- Diagenesis-related reduction of lower unit reflected by grey arenites and green or mottled clay-silt
- Regional epigenetic oxidation zone documented by pink arenites terminating at front-end redox interfaces
- Decay of vegetal remains by thermo-oxidative, aerobic and anaerobic bacterial destruction associated with generation of hydrocarbons and hydrogen providing the principal reductants
- Abnormal concentration of water-dissolved hydrocarbons and hydrogen gases restricted to redox front

Mineralization

- Predominantly monometallic ore characterized by U-oxides and U-silicate
- Locally minor polymetallic Se, Re and/or Sc mineralization with or without U
- Accessory minerals represented by limited quantities of Fe- and Zn-sulfides, Fe-hydroxides, carbonates, radiobaryte
- Large number of accessorial elements in minor to trace quantities
- Disseminated texture of mineralization
- Predominantly roll-type and minor tabular or lenticular ore bodies
- Strata transgressive distribution of mineralization and simple structural characteristics of ore bodies primarily due to relative uniform permeability of host lithologies in response to a simple nature of cyclic sedimentation and confinement of mineralized strata by aquicludes
- Limited complexity of internal structure of ore bodies caused by texture of host beds such as grain size, crossbedding, and/or clay content in the matrix of sands
- Deposits are of large size but composed of more or less interconnected ore bodies
- Low ore grades

Metallogenetic Concepts

As may be deduced from descriptions of the various geoscientists reporting on uranium deposits in the Chu-Sarysu Basin (see Bibliography), the metallogenetic evolution of the Chu Sarysu Basin may be summarized as follows.

Basic ingredients for ore formation include an initial diagenetic reduction of Upper Cretaceous and Paleogene sediments of the lower stratigraphic-structural unit of the artesian basin followed, from Oligocene-Miocene to date, by an oxidation overprint of the reduced sediments (strata oxidation) reflected by a regional oxidation tongue. The influx of oxygenated waters was triggered by the uplift of the Tien Shan and continued subsidence of the axial segment of the Turan Plate. The oxidation front advanced differentially in the various aquifers from the Tien Shan downdip to the NW. Oxygenated waters transported uranium and other metals to the site of precipitation. Sufficiently reducing conditions were and are provided at the redox front at the downdip head of the oxidation zone by water-dissolved reductants-which had evolved by thermo-oxidative and bacterial destruction of vegetal material. As documented for the Kanzhugan-Tortkuduk deposit, this kind of decay of carbonaceous matter resulted in an epigenetic zoning formed by six thermal groups that occupy distinct positions across the redox profile and correlate with the spatial distribution of distinct bacterial populations. Six bacteria species are distinguished (going from oxidized rock across the ore roll into reduced rock): (1) sulfate forming, (2) cellulose decomposing aerobic, (3) hydrogen forming, (4) sulfate reducing/hydrogen sulfide forming, (5) methane forming, and (6) cellulose forming anaerobic bacteria (Shchetochkin and Kislyakov 1993 based on data from Maksimova MF, Shugina GA, and Urmanova AM).

The confinement of aquifers by hanging and footwall aquicludes allowed the formation of roll-type ore bodies. Due to the regional nature of the oxidation front and the simplicity of the lithology of host rocks, laterally extensive ore bodies of a relatively simple crescent shape evolved.

Ore formation began during Oligocene time. Redistribution processes are still active as evidenced by younger ages of mineralization at the head of rolls as compared to rear parts of rolls, tails, and tabular ore.

6.3.1 Kenze-Budenovskaya District

The Kenze-Budenovskaya District correlates with a winding, S-forming redox front, some 400 km long, in the northern and central-western Chu-Sarysu Basin. The redox front constitutes the northwestern limit of a regional, NW to W migrating oxidation tongue in Upper Cretaceous sediments. Deposits of this zone include from north to south: *Zhalpak, Akdala, Mynkuduk, Inkay,* and *Budenovskoye*. The *Kenze* and *Karakoyn* occurrences are at the northern extension of the redox front zone. A small U deposit, *Sholok Espe*, occurs at a slower-moving redox front southeasterly behind the major deposits of the Kenze-Budenovskaya zone (Figs. 6.1, 6.12a).

6.3.1.1 Zhalpak

Zhalpak is located 50 km NE of Akdala and was discovered in 1964 as the first deposit of the Kenze-Budenovskaya zone. Three ore zones are identified, *North*, *Central*, and *South*. Resources are reportedly almost 15 000 t U at a grade averaging 0.035% U.

Sources of information. Fyodorov 2005; Petrov et al. 1995; Yazikov 2002.

The mineralized, alluvial, Upper Cretaceous *Zhalpak Formation* is 45–75 m thick and is subdivided into an upper member, 25–35 m thick, composed of pale sands with clay and limy sandstone beds, and a lower member, 15–30 m thick, of grey, carbonaceous, hetero-granular quartz-feldspar sands and light green sands with intercalated clay laminae. The lower member is the principal ore host.

The Eocene Intymak Horizon, a 40–45 m thick sequence of – from top to bottom – grey-green sandstone, sand, silt, and clay, unconformably overlies the Zhalpak Formation except in the southern part of the deposit where up to 10 m thick relics of sand lenses of the Uvanas Horizon rest upon the Zhalpak Formation. Fluvial psephitic sediments, 40–60 m thick, of the Inkuduk and Mynkuduk Formations underlie the Zhalpak Formation and rest upon Paleozoic siltstone and mudstone of the Zhidelisai, and sandstone of the Kengir Formations.

Uranium mineralization is of a disseminated texture and is dominated by coffinite. (Sooty) pitchblende occurs subordinately. Associated minerals and elements include pyrite, marcasite, bravoite, up to 200 ppm Se (av. 12 ppm), up to 13 ppm Y, up to 62.5 ppm Re, 1.9–4.7 ppm Sc, and REE averaging 106 ppm.

Three modes of ore are distinguished: dark grey sandy ore with relatively high U and organic matter contents, pyrite enriched grey and greenish-grey sandy ore barren of organic material, and bleached, light grey sediments with low U grades.

The Zhalpak deposit extends over a N-S length of some 45 km. Eight ore bodies are delineated at a depth from 125 to 145 m in the northern and central segments, and as much as 200 m deep in the southern part. Four of the ore bodies account for 75% of the total resources, and 30% are contained in ore body # 2.

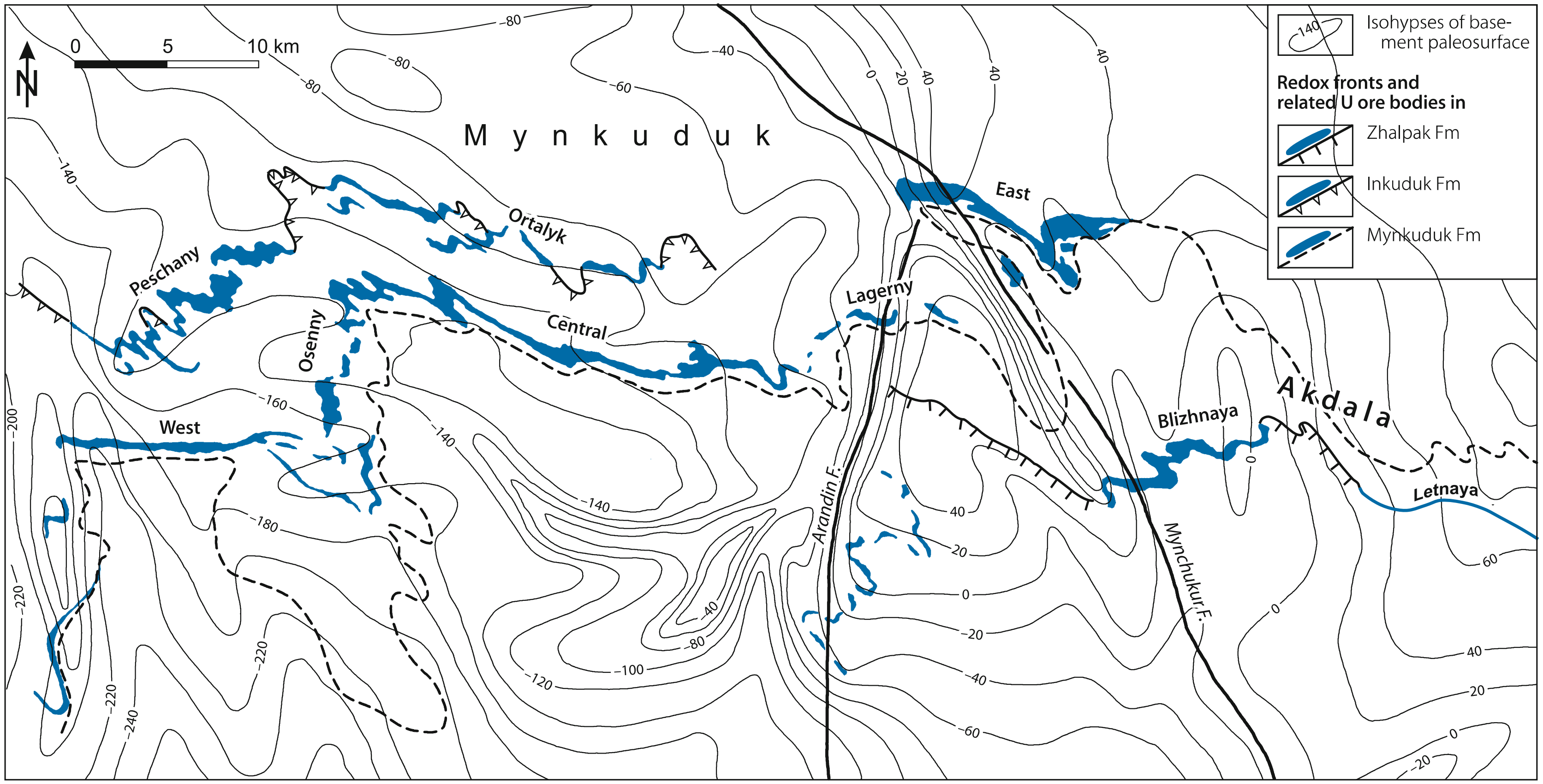
Ore bodies are of tabular to lenticular and semi-roll configuration. They are from 25 to 850 m wide, from 0.5 to 15 m thick, and extend from 3 to 7 km in length except for ore body # 2, which is 22 km long. Ore grades vary between 0.01 and 0.4% U with local peaks of 0.85% U.

6.3.1.2 Akdala

Akdala is located in the northwestern part of the Chu-Sarysu Basin, adjacent to the eastern portion of Mynkuduk. Akdala may be considered an eastern extension of the latter, but separated from the bulk of the Mynkuduk ore bodies by a major NNW-SSE-trending fault. Akdala has reserves of 14 250 t U at an average grade of 0.059% U (OECD-NEA/IAEA 2005); about 40% of these reserves are of higher grades. This deposit is exploited by ISL techniques since end of 2001.

The rollfront-type deposit includes two ore zones, *Blizhnaya* and *Letnaya*, within an E-W-trending, about 30 km long strip. These ore zones are controlled by a curvilinear, E-W-oriented redox front in the 50–70 m thick Upper Cretaceous *Zhalpak Formation*. Sediments are dominated by alluvial sandy facies with intercalated, 1–2 m thick, feldspar-quartz sands. Coffinite is the dominant U mineral. It constitutes 65%, and sooty pitchblende 35%, of the U minerals. Ore bodies occur at depths from 135 to 195 m, av. 6.6 m in thickness, 0.057% U, 0.5% Fe-sulfide, 0.1% carbonate, and 0.09% organic carbon (Fyodorov 2005). Ore bodies # 19 to # 21 contain increased amounts of rhenium (>0.2 ppm Re), which correlate with the uranium contents.

Fig. 6.13.
Chu-Sarysu Basin, Mynkuduk-Akdala ore field, geological map exhibiting the course of redox fronts and related U ore bodies in the Upper Cretaceous Zhalpak, Inkuduk, and Mynkuduk Horizons (after Fyodorov 2005; Petrov et al. 1995)



Scandium amounts to 2.8 ppm in ore body # 19. REE averages 91 ppm, and Y 19.3%. Selenium occurs locally, and also outside U ore bodies, in concentrations of more than 0.01% Se (Petrov et al. 1995). The ore interval exploited first (since 2001) consists of an up to 14 m thick coarse- to medium-grained sandstone poor in clay and carbonate, higher in U grade than other portions of the deposit, and yields a productivity of 12–14 kg U m^{-1}.

6.3.1.3 Mynkuduk

Mynkuduk is located in the northwestern part of the Chu-Sarysu Basin. The deposit encompasses seven ore zones: *Peschany* (Sandy) and *Ortalyk* are in the Inkuduk Formation; *West, Osenni, Central, Lagerny*, and *East* are in the Mynkuduk Formation. Mynkuduk contains a total of 127 000 t U in situ resources. These resources include 48 000 t U at 0.047% U in the Central and 24 000 t U at 0.042% U in the East zone. (Other sources report original reserves for the Central zone as C1 = 42 528 t U, and C2 = 5 125 t U, at 0.047% U over a thickness of 7.23 m; and for the East zone as C1 = 23 245 t U, and C2 = 4 707 t U, at 0.025–0.040% U). Exploitation is by ISL techniques but only in the East zone. A pilot plant began operation in 1977 and full production was achieved in 1988.

Sources of information. Catchpole 1997; Fyodorov 2005; Petrov et al. 1995; Yazikov 2002.

Geology and Mineralization

U mineralization at Mynkuduk occurs in an Upper Cretaceous sequence, which is overlain by Late Oligocene to Quaternary sediments and underlain by Permian to Upper Devonian strata. The Late Paleozoic unconformity is at a depth of 220 m in the eastern and 450 m in the western section of the deposit. The lowermost basement complex consists of folded continental Cambrian and Ordovician formations the top of which is at a depth of 2–3 km.

Ore zones of the Mynkuduk deposit are controlled by regional redox fronts within three Upper Cretaceous formations (Figs. 6.13, 6.14a,b).

The *Zhalpak Formation,* which rests conformably upon the Inkuduk Formation, is a common sedimentary cycle, 40–75 m thick, dominated by alluvial sandy facies with intercalated, 1–2 m thick, feldspar-quartz sands. Quartz and siliceous debris constitute some 81% of the Zhalpak facies; feldspar, muscovite, biotite, kaolinite, montmorillonite and limonite 18%; and calcite, siderite, pyrite and marcasite 1%. Increased values of organic matter occur in the lower section of the formation. Ore zones within the Zhalpak Horizon occur only to the east of Mynkuduk, in the adjacent Akdala deposit.

The *Inkuduk Formation* is 40–130 m thick and consists of three sedimentary cycles of greenish-white arenites, silts and clays. Hetero-grained sands with gravel prevail. Quartz and siliceous debris constitute 84.5% of the Inkuduk facies; feldspar, muscovite, biotite, kaolinite, montmorillonite and limonite 15%; and calcite, siderite, pyrite and marcasite 0.5%. Bleached sands are confined to the Ortalyk sector. Sand thickness increases from 50 m in the east to 100 m in the west. The Inkuduk Formation was unconformably laid down upon the Mynkuduk Formation after an erosional hiatus. Inkuduk-hosted ore bodies are confined to the Peschany (Sandy) and Ortalyk sectors in the western and central part of the deposit, respectively.

The *Mynkuduk Formation,* the main ore-hosting unit, is 30–90 m thick and is derived from SW- and almost S-flowing rivers, which deposited clastic sediments in two cycles. The lower cycle is 15–20 m thick at the eastern margin of the deposit and increases to 35–40 m in the central and western segments. Each cycle is characterized by a gradual transition from coarse- to medium- and to fine-grained sands and then to clays. Fine- and medium-grained sands predominate. Quartz and siliceous debris constitute 79% of the Mynkuduk facies; feldspar, muscovite, biotite, kaolinite, montmorillonite and limonite 20%; and calcite, siderite, pyrite and marcasite <1%. The Mynkuduk Formation is 30–40 m thick in the East and Lagerny, and up to 70 m in the Central, Osenni, and West ore zones.

Sand horizons in the three formations have high horizontal permeabilities. Filtration coefficients range from 9 m d^{-1} in the Zhalpak to 12 and 13 m d^{-1} in the Mynkuduk and Inkuduk aquifers, respectively.

Mineralization consists of coffinite and (sooty) pitchblende, and has a disseminated texture. Pitchblende occurs as micron-sized globules and spherical aggregates, and coffinite as tiny crystals. Coffinite prevails in ore of the Inkuduk Formation whereas pitchblende is dominant in that of the Mynkuduk Formation.

Sulfide and carbonate contents are low; ore in the Inkuduk and Mynkuduk Horizons contain an average of 0.26% and 0.73%, respectively, of combined pyrite and marcasite, 0.19% and 0.23% of calcite and siderite, and 0.04% and 0.07% of vegetal matter. Selenium contents commonly range from 0.01 to 0.06% but can be as high as 0.2%. Maximum Se grades are confined to the frontal segment of the ferruginous oxidation tongue. In the West and Osenni sectors, 75% of sampled intervals contain in excess of 0.01% Se. Selenium also occurs independent of uranium, in lenses as much as 200 m long and 10 cm thick. Scandium can be as high as 4.8 ppm as in ore body # 14 in the Mynkuduk Formation of the Osenni zone. Maximum Sc values of up to 21.1 ppm (av. 13.8 ppm) occur in impermeable clays. Yttrium amounts to 22.5 ppm and REE to 100 ppm in U ores of the Mynkuduk Formation (Petrov et al. 1995).

Shape and Dimensions of Deposits

Ore zones of the Mynkuduk deposit occur within an E-W-trending, 65 km long and up to 10 km wide strip in which roll-shaped ore bodies are controlled by twisted, globally E-W-trending redox fronts (Fig. 6.13).

The redox fronts have a cumulative strike length of 90 km along which some 30 ore bodies have been delineated, 16 of which are hosted by the Mynkuduk Formation at depths of 205–430 m and the remainder by the Inkuduk Formation at depths of 225–325 m.

The Ortalyk and Peschany ore zones are hosted in the Inkuduk Formation and contain 11% of the total reserves of

Fig. 6.14.
Chu-Sarysu Basin, Mynkuduk and Inkay deposits, a litho-stratigraphic column and b schematic cross-section of the Paleogene-Cretaceous sequence indicating the position of U-bearing horizons, c examples of ore bodies morphology at Mynkuduk. (After a, b Fyodorov 2005; c Yazikov 2002)

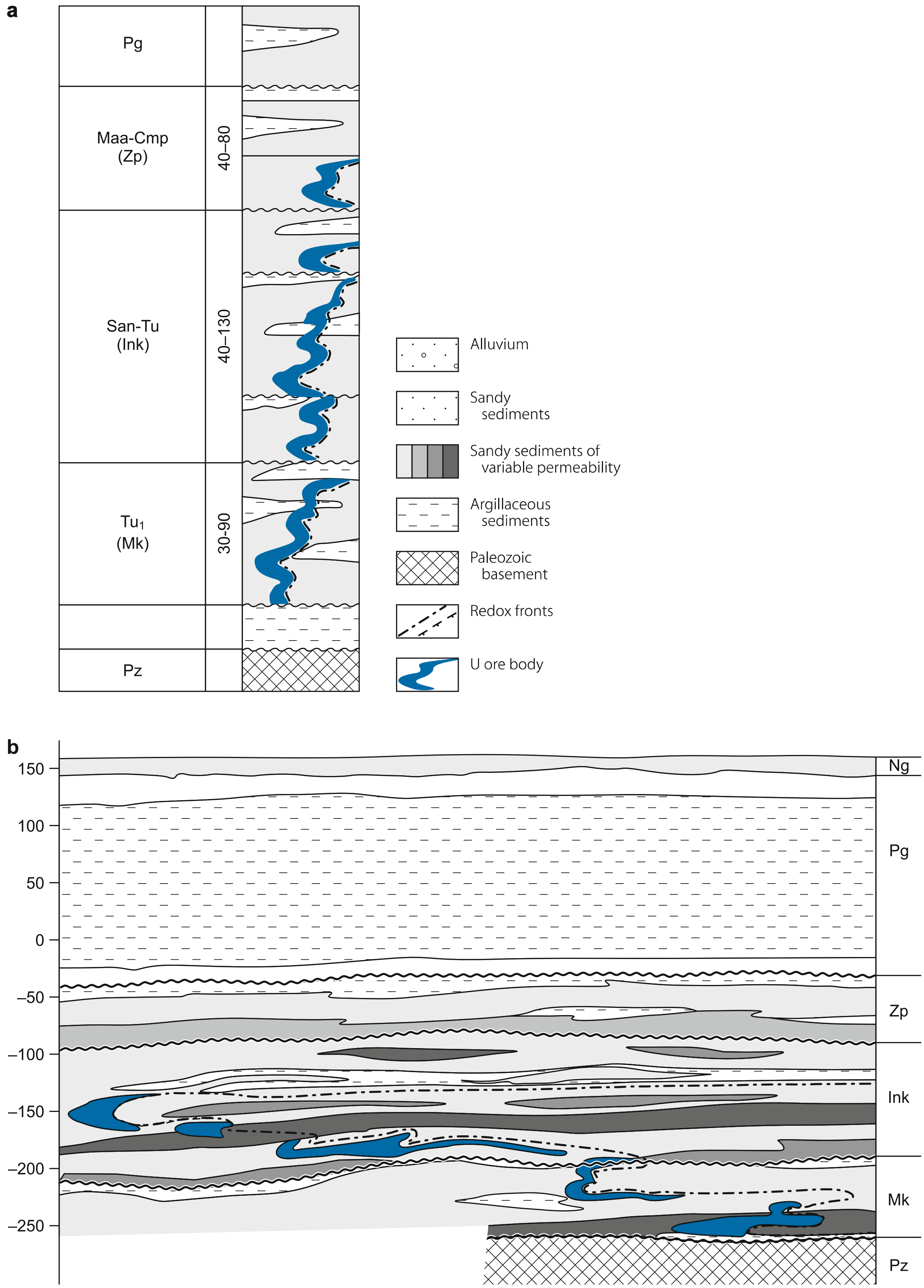
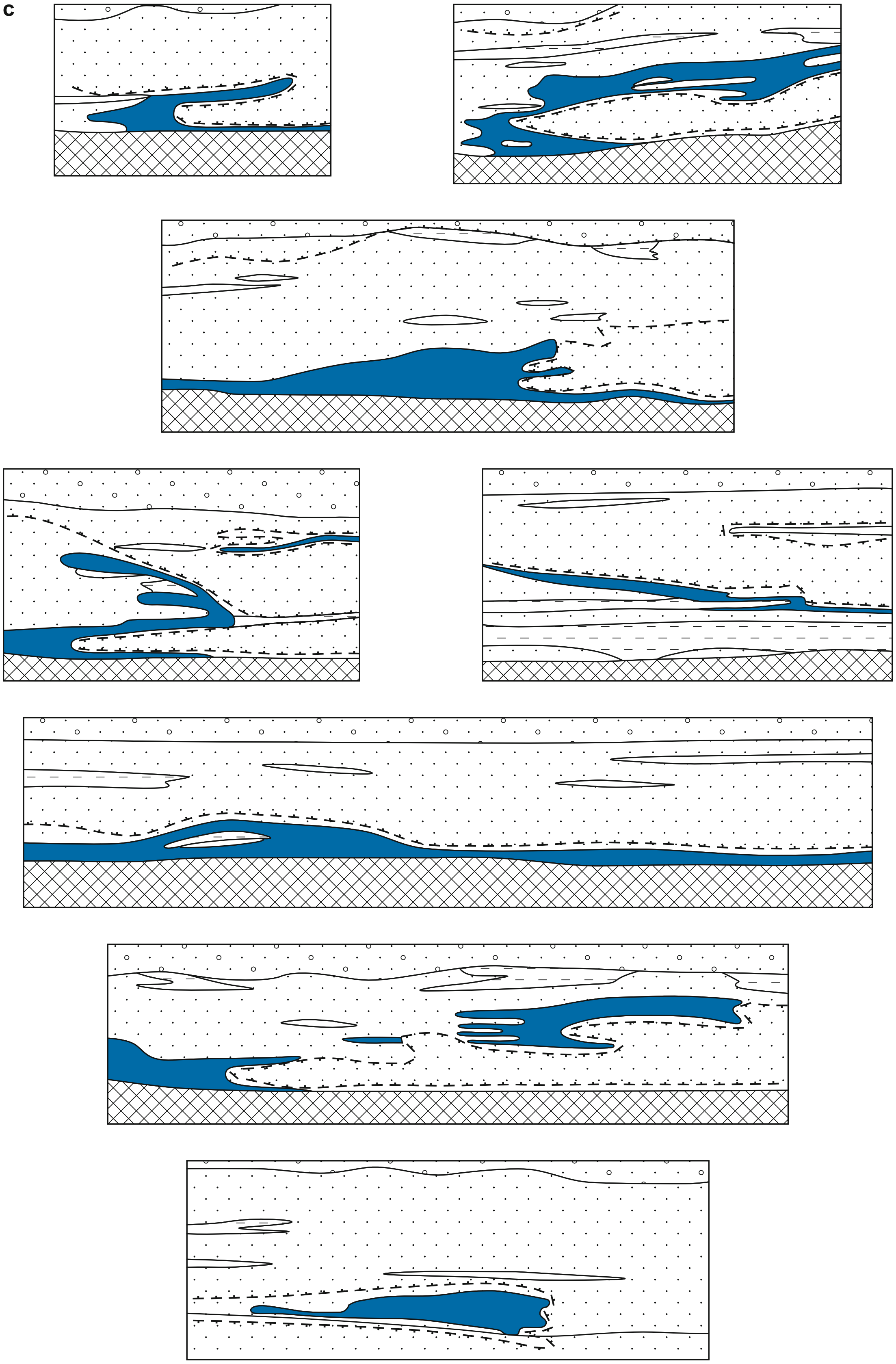


Fig. 6.14. (Continued)

c



the Mynkuduk-Akdala ore field at an ore grade averaging 0.028% U. Respective figures for ore zones hosted in the Mynkuduk Formation are as follows (percent share of reserves/average U grade). West: 2.3%/0.038% U; Osenni: 7.5%/0.037% U; Central: 36.9%/0.047% U; Lagerny: 2.3%/0.025% U; and East: 21.8%/0.030% U.

Ore bodies appear in plan view as continuous, sinuous ribbons, up to 20 km long (without accounting for corrugation) and 50–500 m, locally up to 1 700 m wide as in ore body # 1. Barren intervals between individual ore bodies range laterally, i.e. on the same stratigraphic level, from few hundred meters to several kilometers. In cross-section, ore bodies commonly consist of one major, although variably shaped, up to 25 m thick roll in a given horizon. Ore rolls may have one or several, 2–10 m thick tails and isolated ore bodies some distance behind the major lode separated from it by barren ground (Figs. 6.14b,c). U grades vary in a wide range, from 0.015–0.15% U and may locally be in excess of 0.4% U.

6.3.1.4 Inkay

Inkay was discovered in 1976 in the western Chu-Sarysu Basin, 160 km ENE of the town of Kzyl-Orda. Inkay is one of the largest U deposits in the basin. The sandstone rollfront-type deposit includes three segments, *North*, *Central*, and *South*. Global resources are estimated at 330 000 t U including 55 000 t U RAR + EAR-I at an ore grade averaging 0.06% U (Catchpole 1997); OECD-NEA/IAEA (2005) reports reserves of 42 500 t U at 0.063% U for Inkay-sites 1 and 2 operated by the Inkay joint venture. An ISL pilot plant commenced operation in late 2001.

Sources of information. Abakumov and Zhelnov 1997; Catchpole 1997; Fyodorov 2005; Petrov et al. 1995; Yazikov 2002.

Geology and Mineralization

The general geology of the area corresponds to that of the northeasterly adjacent Mynkuduk deposit (see above). U mineralization is restricted to the Upper Cretaceous Inkuduk and Mynkuduk Formations. An intraformational unconformity separates the two horizons. The *Inkuduk Formation* consists predominantly of medium- to coarse-grained, weakly sorted sands. The subjacent *Mynkuduk Formation* is composed of several, one to several meters thick sedimentary cycles each starting with coarse-grained facies grading upward into fine-grained sediments. Medium- to fine-grained sands predominate. Impermeable pelite beds constitute 10% and 20% of the Inkuduk and Mynkuduk Formations, respectively. Unoxidized facies are grey or grey-green in color. The various sands have high horizontal permeabilities. Filtration coefficients range from 7 to 19 m d^{-1} in the Mynkuduk and from 7 to 20 m d^{-1} in the Inkuduk aquifers.

Multilevel oxidation tongues have developed in response to the multicycle structure of the sedimentary sequence. Sinuous, highly twisted redox interfaces at the head of the tongues are regionally NE-SW oriented in the northern part of the deposit; they turn, in the central part, to a NNW-SSE direction. Due to the indented nature of the redox fronts, the cumulative length of all the fronts in subhorizons of the Inkuduk Formation is 726 km, while that in the Mynkuduk Formation is 427 km.

Uranium mineralization consists of (sooty) pitchblende and coffinite; the former constitutes about 80% of the uranium fraction. Associated minerals include marcasite, pyrite, calcite, and siderite. Several trace elements are present but in uneconomic amounts. Tenors of Re are less than 0.1 ppm, Sc 2.8–4.5 ppm, and REE 89–120 ppm (see also Table 6.4). U mineralization occurs in all lithologies, but preferentially in sands where it exhibits a finely-disseminated texture.

Shape and Dimensions of Deposits

The Inkay deposit covers a 55 km long and from 7 to 17 km wide stretch partitioned into a North zone of general NE-SW trend, a Central zone occupying the hinge joint, and a South zone of NNW-SSE orientation (Fig. 6.15). The Central zone is further divided into Section # 1 and # 2.

Uranium occurs in nine permeable beds in the Inkuduk and Mynkuduk Formations. Inkuduk sands contain 65% and Mynkuduk horizons 35% of the total RAR and EAR-I of Inkay. A breakdown of reserve percentage distribution and other ore-related parameters by the four zones are shown in Table 6.5.

Ore bodies are predominantly of a roll shape controlled by redox fronts, but lenticular and tabular lodes also occur. Eight major ore bodies are delineated, five in Inkuduk and three in Mynkuduk strata.

Ore bodies appear in planview as continuous, winding and highly twisted ribbons, from 9 to 31 km long and from 100 to 400 m wide, and are situated at a depth interval from 260 to 525 m. Barren intervals between individual ore bodies range from a few hundred meters to several kilometers. In cross-section, ore bodies commonly consist of a main, variably shaped roll, on average 4.2–7.4 m thick. Ore rolls may have one or several tails; some isolated ore bodies also occur some distance behind the principal ore lode and separated from it by barren ground (Figs. 6.14b,c).

Ore bodies have highly variable U grades, which average 0.045–0.063% U. Carbonate contents in ore average 0.1–0.2% CO_3 in the Inkuduk, and 0.2–0.3% CO_3 in the Mynkuduk horizons.

6.3.1.5 Budenovskoye

Budenovskoye was discovered in 1979 on the SSE extension of the redox front that controls the Inkay deposit. A barren or weakly mineralized interval, some 20 km long, separates the two deposits. Total in situ resources are speculated at 300 000 t U including 41 000 t U at an in situ grade of 0.09% U in the EAR-I category. Trace elements are given in Table 6.4. The redox front exceeds 90 km in length, including 50 km in the southern sector. Mineralization occurs in Zhalpak, 40–80 m thick, Inkuduk, 30–100 m thick, and Mynkuduk, up to 30 m thick horizons at depths between 550 and 700 m. Ore bodies average a thickness of 5 m.

Fig. 6.15.
Chu-Sarysu Basin, Inkay, planview of redox fronts and related U ore bodies in the Mynkuduk Horizons (after Fyodorov 2005)

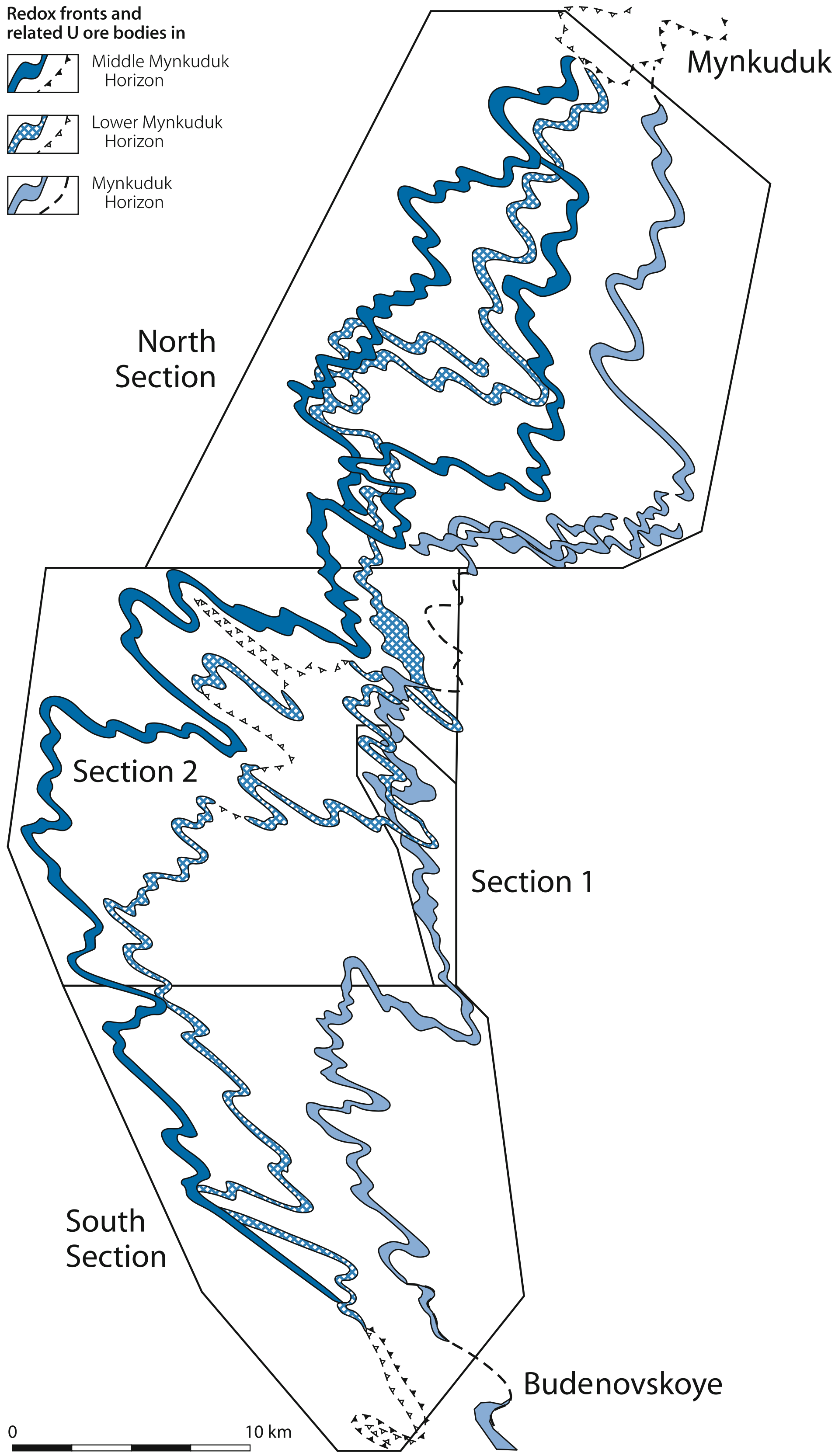


Table 6.5.
Inkay deposit. Selected characteristics of ore zones (Fyodorov 2005)

Parameter	Zone			
	North	Central #1	Central #2	South
Inkuduk Formation				
Reserves (% share)[a]	19.1	0.6	28.9	16.4
Average grade (%)	0.051	0.047	0.037	0.057
Average carbonate content (% CO_3)	0.1	0.1	0.2	0.2
Average thickness of ore bodies (m)	5.2	4.9	7.4	4.2
Average width of ore bodies (m)	200	100	250	200
Depth of ore bodies (m)	290–370	430	330–380	350–420
Mynkuduk Formation				
Reserves (% share)[a]	7.6	12.3	3.6	11.5
Average grade (% U)	0.054	0.072	0.050	0.041
Average carbonate content (% CO_3)	0.2	0.3	0.3	0.3
Average thickness of ore bodies (m)	3.50	6.08	5.83	6.28
Average width of ore bodies (m)	100	400	350	150
Depth of ore bodies (m)	430	515	480	510

[a] Reserves refer to share of total RAR + EAR-I of the deposit.

6.3.1.6 Sholak Espe

This deposit is located some 50 km to the east and southeast of the Kenze-Budenovskaya zone. Roll-type U mineralization occurs in the Zhalpak Formation. The ore controlling redox front in this formation did not advance as far as those in the underlying Inkuduk and Mynkuduk horizons but stayed behind for approximately 40–60 km (Fig. 6.12). Resources are reportedly in excess of 5 000 t U. Ore grades vary between 0.01 and 0.04% U.

6.3.2 Uvanas-Kanzhugan District

The Uvanas-Kanzhugan District corresponds to an irregularly submeridional-trending redox front at the head of a regional oxidation tongue in Paleogene sediments in the south-central Chu-Sarysu Basin (Fig. 6.16). Rollfront-type deposits associated with this front include, from N to S: *Uvanas* (N of Chu River), and to the south of the Chu River *Moynkum* and *Kanzhugan(-Kainar)*. Moynkum is offset approximately 50 km to the ESE from Uvanas by a regional WNW-ESE fault whereas Moynkum and Kanzhugan are continuous and actually form a large ore zone. A small sandstone, basal-channel-type U deposit, *Bars*, is also found in this area.

6.3.2.1 Uvanas

Uvanas is located in the central part of the Chu-Sarysu Basin, 350 km N of the town of Chymkent. Original in situ resources amounted to 20 000 t U (Abakumov 1995) with an average ore grade of 0.02–0.04% U. This sandstone rollfront-type deposit was discovered in 1963 and has been exploited by ISL techniques since 1977. Stepnoye Mining Company is the operator.

The deposit is partitioned into four sectors. The *East*, *Central* (with ore bodies # 2 and # 4) and *West* (with ore body # 1) sectors are controlled by a generally E-W-trending redox front whereas the *Koskuduk* sector is a NE-SW-trending ore zone situated to the SW of the main zone and offset for 2–3 km to the south by a NW-SE-striking fault. The East sector includes ore body *# 5*, *East Flank*, and *Kyzemchek East*. The latter is a NE-oriented, curved zone with subeconomic ore situated to the N of the East sector (Fig. 6.17a).

Source of information. Petrov et al. 1995; amended by information from staff of Central Mining Co./Kazatomprom pers. commun. 2003.

Geology and Mineralization

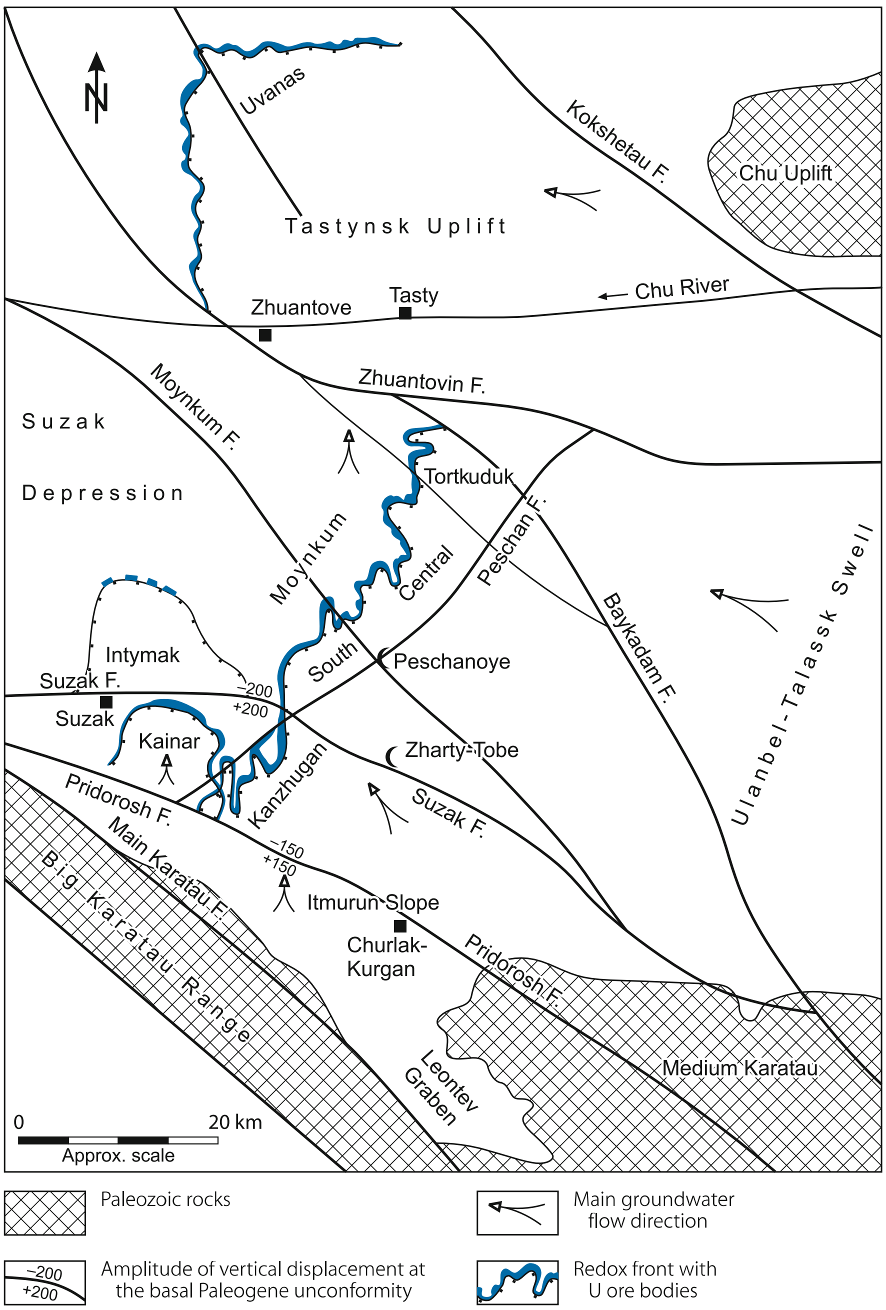
Uranium is hosted by the Paleocene Uvanas Formation (equivalent to Kanzhugan Formation at Moyinkum), which is overlain by more or less impermeable horizons of Eocene to Quaternary age and underlain by Upper Cretaceous and Paleozoic sediments (Fig. 6.17b). The Eocene section is reduced in the Uvanas area due to an erosional interval during the early-middle Oligocene. In more detail, the litho-stratigraphic profile of the Uvanas area may be summarized after Petrov at al. (1995) as follows:

- *Quaternary-Pliocene*: 20–50 m thick, pink and brown clay-silt, and sand
- *Upper Eocene* Intymak Fm: 40–60 m thick:
  - Upper bed, 2–5 m thick, dark grey clay with dispersed vegetal debris
  - Middle bed, 3–15 m thick, sand and blue-grey clay
  - Lower bed, 15–30 m thick (up to 47 m in Koskuduk sector), grey-green clay

  - Basal bed, 1–4 m thick, green clay, mud, sand with phosphorite pebbles and detrital fish bones
- *Lower Eocene* Uyuk Fm: 5–8 m thick, grey sand with clay and calcareous beds (only developed in Koskuduk sector)
- *Paleocene* Uvanas Fm: 1–8 m thick in E increasing to 20–30 m in the Central and to 45–50 m in the Koskuduk sector; main U-hosting formation separated into
  - Upper unit (cycle): <20 m thick, pink and green argillaceous sand and pelite with lignite seams,
  - Middle unit (cycle): <15 m thick, bleached sand with low silt-clay fraction,
  - Lower unit (cycle): <15 m thick, carbonaceous, sulfidic sand with lignite seams and 3–6 m thick clay-silt lenses
- Upper Cretaceous:
  - *Maastrichtian-Santonian* Zhalpak Fm: increasing from 25 m thick in E to 75 m in W sector, sand with minor gravel and mud lenses

Fig. 6.16.

Chu-Sarysu Basin, Uvanas-Kanzhugan District, geological map with course of redox fronts and related U deposits. U ore bodies occur preferentially in the Paleocene upper Kanzhugan Horizon and to a minor degree in the middle horizon of the Eocene Uyuk Formation (after Petrov et al. 1995)



- *Santonian-Coniacian-Turonian* Inkuduk Fm: 25 m thick in E sector, increasing to 60 m in W and Central sectors, gravel and gravel-sands with bleached clay intercalations
- *Turonian* Mynkuduk Fm: up to 30 m thick, sand with gravel and mud lenses
- *Cenomanian*: 2–25 m thick, sandy clay

• *Mid-Late Paleozoic:* consolidated siltstone, sandstone and mudstone, upper limit commonly 160–300 m deep

Uranium occurs, in planview, along a wedge-shaped redox front at the head of a regional oxidation tongue that migrates in a WNW direction between two regional faults, some 30 km apart and striking NW-SE. The northern wing of the front trends from E to W for some 15 km, turns southwards for about 15 km, and then terminates at a NW-SE fault near the Chu River. NW-SE-oriented faults also cut the deposit (Fig. 6.17a).

Coffinite is the principal U mineral. Associated carbonates and Fe-sulfides occur in small amounts.

Shape and Dimensions of Deposits

The Uvanas deposit is partitioned into several sectors, which encompass 26 ore bodies. Three sectors, East, Central, and West, combined also referred to as the "main ore zone", contain the principal ore bodies # 1 to # 5, which account for 70% of the Uvanas resources. These ore bodies occupy a 10 km long stretch controlled by a sinuous but generally E-W-oriented redox front in the Paleogene Uvanas Formation. Ore occurs at a depth interval from 82 to 126 m in the main zone to as much as 175 m deep in the Koskuduk sector.

Ore bodies consist of irregularly shaped rolls in section (Fig. 6.17c) and persist, in plan, as a ribbon for up to 3 km along the redox front. Ore bodies are 2–7 m and locally up to 12 m thick. Uranium grades are commonly 0.02–0.04% U but can be as high as a few percent in lignite.

6.3.2.2 Moynkum(-Tortkuduk)

Moynkum was discovered in 1976 to the north of Kanzhugan in the southern Chu-Sarysu Basin, 250 km N of the town of Chymkent. Three sectors are outlined, from N to S, *Tortkuduk*, *Central*, and *South*. Ore bodies are of sandstone roll-front type. Two U occurrences, *Peschanoye* and *Zharty-Tobe* occur some 10 km to the SE, at the rear of the main deposits (Fig. 6.16).

Fig. 6.17.

Chu-Sarysu Basin, Uvanas, a geological map with redox front and related U ore bodies in the Paleocene Uvanas Formation, b litho-stratigraphic N-S cross-section, c cross-sections documenting the irregular shape of ore bodies (after Petrov et al. 1995)

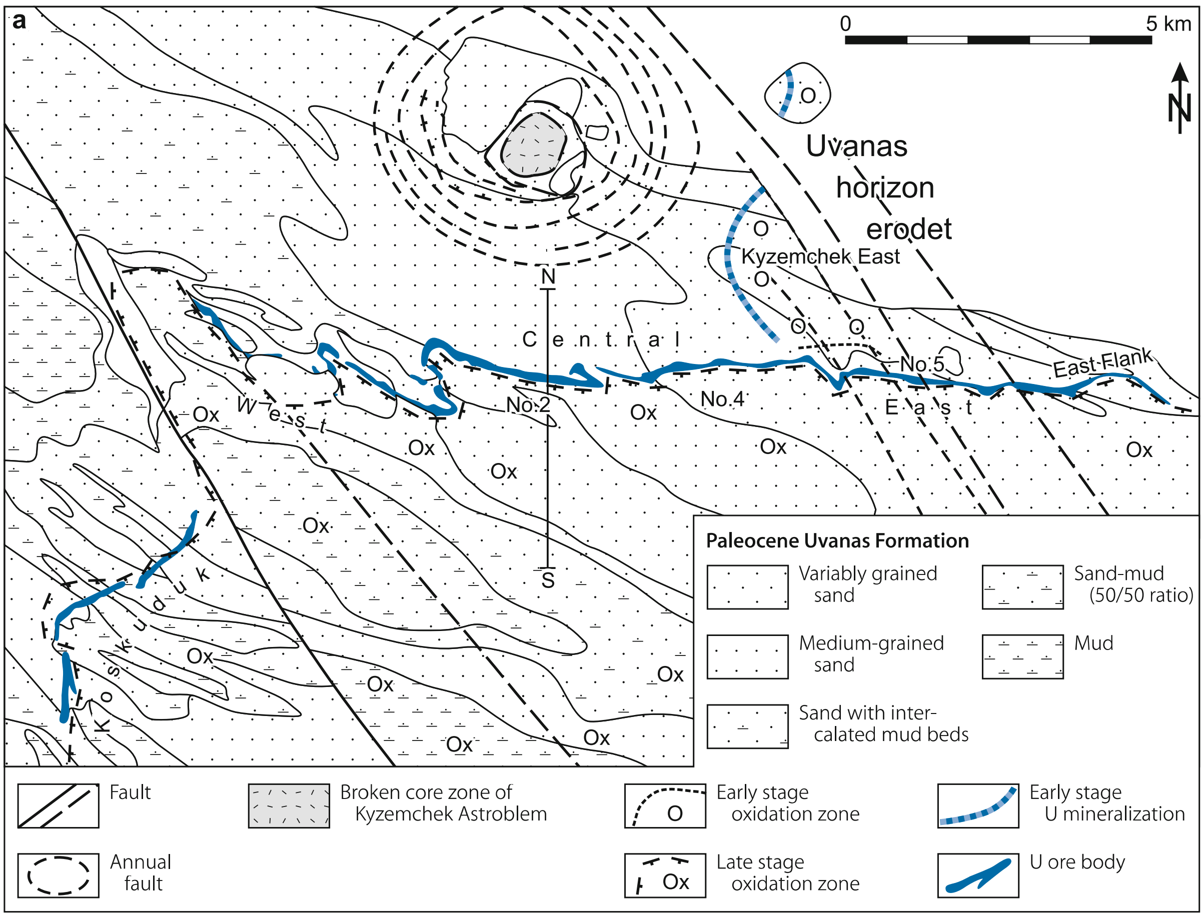
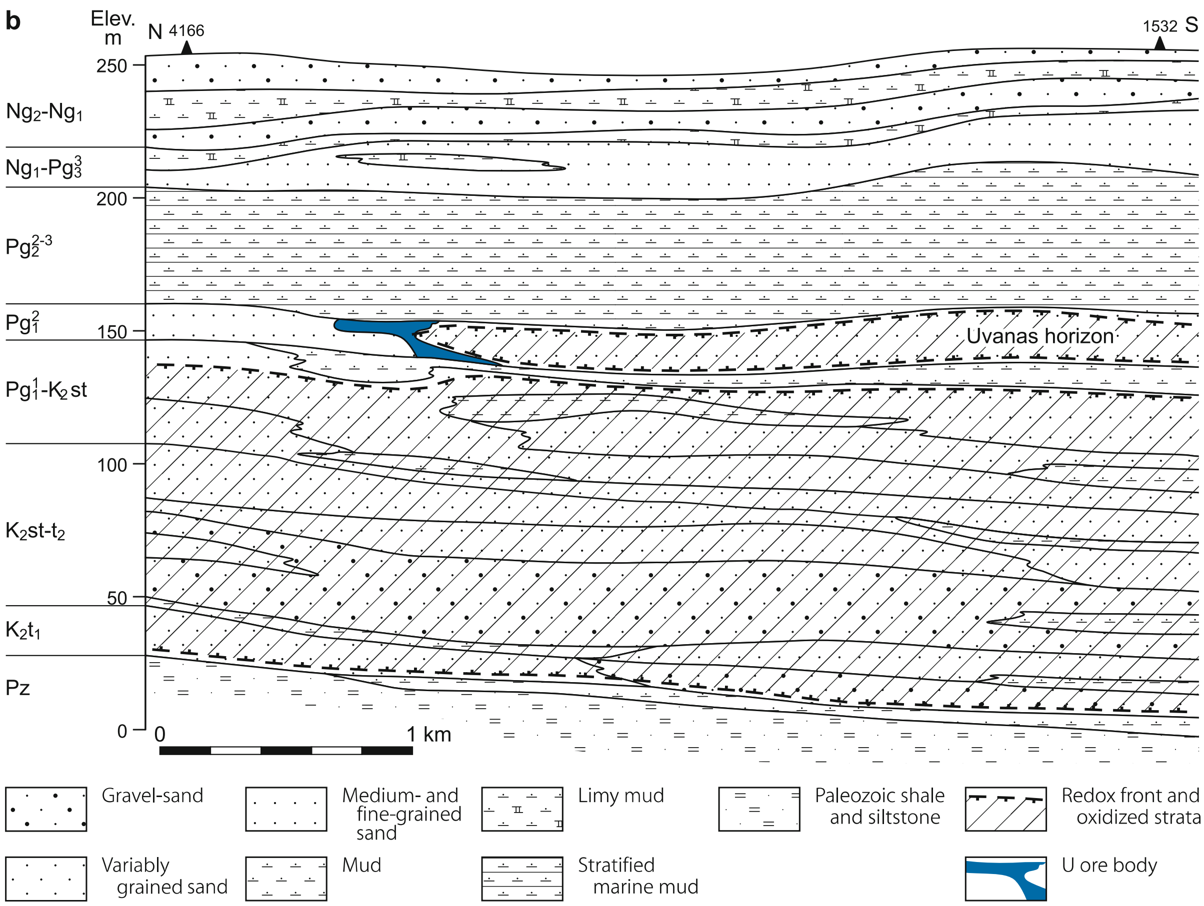


Fig. 6.17. (Continued)



Exploitation is by ISL techniques and started in 2001; the South sector by the Central Mining Company of Kazatomprom and the Central sector by KATCO, a joint venture of Cogema and Kazatomprom. Original in situ resources totalled 82 500 t U (Abakumov 1995) at a grade of 0.01–0.04% U. OECD-NEA/IAEA (2005) reports reserves of 67 360 t U at a grade of 0.064% U for the Central sector (Moynkum 2 and 3) operated by KATCO.

Sources of information. Petrov et al. (1995) amended by information from staff of Central Mining Co./Kazatomprom pers. commun. (2003).

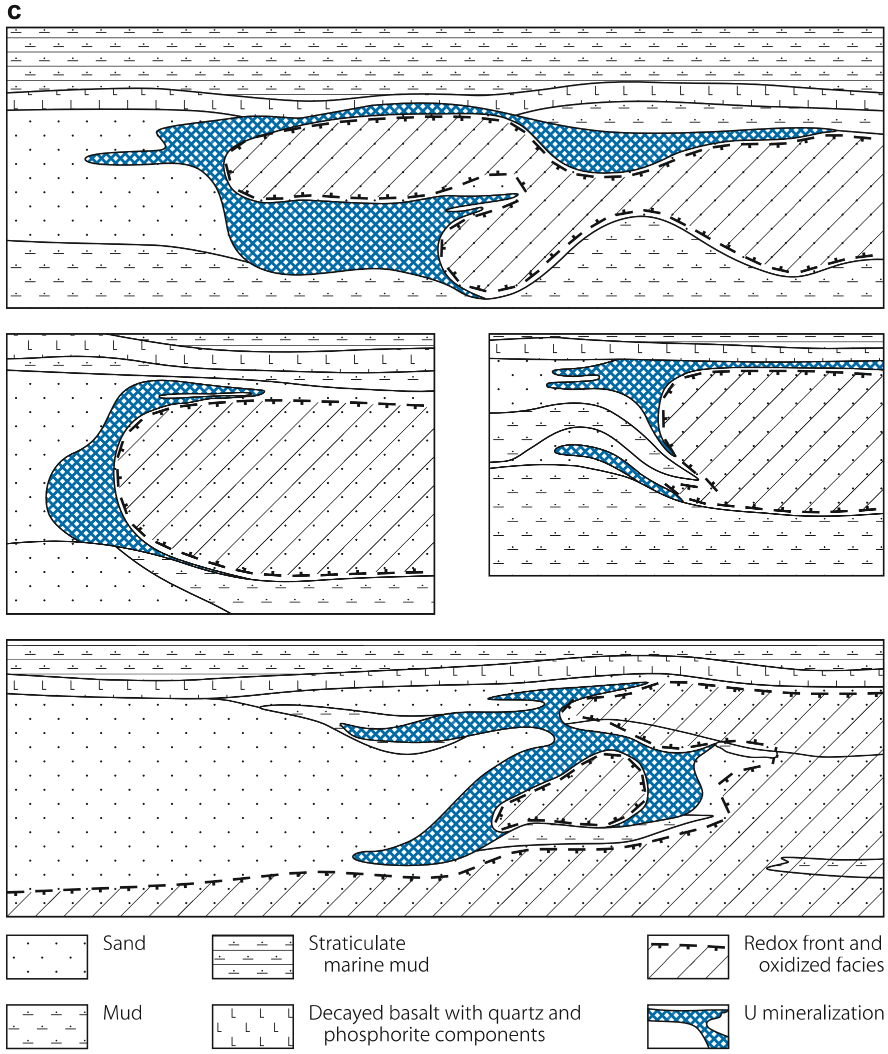
Geology and Mineralization

Moynkum is situated within the Suzak depression, the most submerged part of the Chu-Sarysu Basin. Moynkum is 30–40 km long and is conterminous with the southwesterly adjacent Kanzhugan deposit. As such, these two deposits actually form one large ore zone along a sinuous redox front in Paleogene aquifers. The boundary of the two deposits is given by the Suzak fault, a major WNW-ESE-trending fault zone that uplifted for up to 200 m the Kanzhugan side.

A synopsis of the litho-stratigraphic section of the Moynkum-Kanzhugan zone, drawn from Petrov et al. (1995), displays the following characteristics:

- *Pliocene-Miocene* Todusken Formation: 5–250 m thick, yellow-brown and red-brown limy clay and sand
- *Oligocene-Miocene* Betpak Dala Fm: 5–200 m thick, red-brown clay and sandy clay
- *Upper Eocene* Intymak Fm: 70–120 thick, occurs between surface and 480 m deep, grey-green and grey marine clay, mud and silt, resting upon basal clayey sand with gravel and remnants of gastropods and fish bones
- >Unconformity<
- *Middle Eocene* Ikan Fm: 5–60 m thick, roof in uplifted blocks at 70–260 m and in downfaulted blocks at 380–500 m below surface, sand constitutes 60% of the formation. Two horizons are recognized separated by a 0.5–5 m thick bed of black and grey clay:
  – Upper horizon: quartz sand with intercalated clay and mud lenses
  – Lower horizon: littoral to marine, fine- and medium-grained feldspar-quartz sands
- *Lower Eocene* Uyuk Fm: 50–55 m thick, includes three horizons:
  – Upper impermeable horizon: 13–50 m thick, clay, mud, argillaceous sand, in lower section lignite and black clay beds, up to 1 m thick
  – Middle horizon (U-bearing): <50 m thick, medium- and fine-grained quartz sand with low clay component, about

Fig. 6.17. (Continued)



10% composed of interbedded mud and clay lenses, up to 10 m thick

– >Unconformity<
– Lower Kyzylchin horizon: <20 m thick, mainly clayey sediments

- >Unconformity<
- *Paleocene* Kanzhugan Fm (equivalent to Uvanas Fm): mainly delta and shallow marine sediments subdivided into two horizons
  – Upper Kanzhugan horizon (main U horizon): 60–80 m thick, fluvial sediments including channel sand, argillaceous sand, mud, black clay (alternating variegated clay and sand), roof in uplifted block at 130–390 m and in downfaulted block at 440–550 m below surface
  – Lower Kanzhugan horizon: 10–15 m thick, fine-grained quartz-feldspar sand, clay, mud, depth 520–550 m
- *Paleocene* Variegated Fm: 20–70 m thick, alluvial sediments, variegated marl, silt, quartz-feldspar sand, overlying unconformably Mesozoic or older rocks including:
- *Upper Cretaceous*: <100 m thick and locally more, yellow, bleached alluvial sands with pink clay laminae
- *Jurassic:* <400 m thick, lithified, coarse-grained arenites with lignite lenses
- *Paleozoic:* <2 000 m thick, consolidated terrestrial sediments and limestone
- *Precambrian:* gneiss, crystalline schists, metaconglomerate

Uranium ore bodies are controlled by a redox front at the head of a regional oxidation tongue in permeable arenite beds sandwiched between impermeable silt-clay layers, all of Eocene and Paleocene age. The redox front developed initially by waters derived from the Kirgizian range. At a later stage, infiltration from the Big Karatau range became more significant due to the uplift of this range. Present-day groundwaters percolate northwards in the Moynkum-Kanzhugan ore zone, at a sharp angle to the general strike of the zone.

Quartz sand with a 6–7% clay fraction is the preferential host rock. Sands on the rear side of the redox front are altered by limonitization. Micazation, reflected by a 4–5% fraction of muscovite/sericite in the host rock, is a typical alteration feature near ore.

Uranium is essentially represented by coffinite except for the Tortkuduk sector where coffinite and (sooty) pitchblende occur in a 65–35% ratio. U minerals fill interstices and coat sand grains giving a finely disseminated texture to the ore. Associated minerals include pyrite, hematite, and goethite. Carbonate content is less than 0.5%. U is accompanied by a wide range of trace elements including Ge, Mo, Re, Se, Y, and REE as outlined further below.

Shape and Dimensions of Deposits

Moynkum and the adjacent Kanzhugan deposit consist of numerous U ore bodies that occur in highly erratic and discontinuous fashion associated with the redox fronts within aquifers of the Uyuk and Kanzhugan Formations at a depth interval of 50–500 m. Small relic ore bodies are found within oxidized ground at the rear of the redox fronts. U-hosting sand beds are highly variable in thickness ranging from 0.2 to 15 m.

Ore bodies are primarily of the roll-type but tabular- or lenticular-shaped lodes also occur. U grades are variable ranging from <0.04 to 0.2% U; and they are lower in the main part of rolls than in tails or in lenticular ore bodies. Large roll ore bodies are from 100 to 1 000 m wide and extend as ribbons for 3–30 km along redox fronts. Stratiform ore occurs in medium size lodes, which form elongated lenses, 1–3 km long and 50–200 m wide, or tabular blankets, 1.5–2.5 km wide. Small ore bodies are from 100 to 1 000 m long and 50–100 m wide. The South sector U ore body mined by Central Mining Co. is 10–15 m thick, 440–460 m deep, and has a productivity of 4–8 kg U m^{-2}.

Selenium commonly amounts to 240 ppm in the Kanzhugan, 60 ppm in the Uyuk, and 40 ppm in the Ikan Formation. In the South sector of Moynkum, the Se tenor increases to 0.447% in the Uyuk, and to 0.353% in the Kanzhugan Formation. Selenium mineralized lenses with more than 100 ppm Se also occur separated from U ore lodes. Such Se lenses are as much as 400 m long, up to 150 m wide, and 0.2–5 m thick. *Rhenium* tenors generally range from 0.08 to 0.38 ppm. Maximum values are 3.85 ppm Re in the Uyuk, and 4.8 ppm Re in the Kanzhugan Formation in the Tortkuduk sector and in the southern part of Kanzhugan. Re-bearing lenses containing in excess of 0.5 ppm Re are as much as 50 m wide and 0.1–10 m thick. *Scandium* averages 2.3–3.2 ppm in U ore. Markedly increased Sc values of 3–10 times that in sands are identified in clay where Sc can augment to 21 ppm.

Tortkuduk Sector of the Moynkum Deposit

The Tortkuduk sector is situated at the northern extremity of the Moynkum deposit. It is separated from the Central sector by a NW-SE-striking fault (Fig. 6.16), and displays the following features (Shchetochkin and Kislyakov (1993): Tortkuduk is, in plan-view, a roughly N-S-elongated zone with converging, winding redox fronts. Roll-type U mineralization is contained in an arenite horizon, about 40 m thick, sandwiched between clay-silt horizons and intercalated with dark grey clay and silt lenses up to a few meters thick. An extensive clay lens splits the arenite horizon into two subunits and results in the development of two superjacent oxidation tongues. Host rocks are irregular lenses of grey, carbonaceous, medium- and fine-grained sands deposited in a deltaic environment. Sands on the convex side of ore rolls are altered by limonitization. Filtration coefficients of the sands range from 5–10 m d^{-1}. Vegetal debris has been decomposed by thermo-oxidation and bacterial activity as described earlier (Sect. *Metallogenetic Concepts*).

U mineralization persists for about 10 km along a winding redox front. Due to the litho-geochemical splitting, uranium occurs in a complexly-shaped double roll at the redox front. The forward section of the roll is almost 20 m thick; tails are up to several meters thick and more than 400 m long. A rhenium halo (>0.1 ppm Re) coincides with the uranium distribution and surrounds the frontal section of the roll where it persists for up to 60 m or more into the grey facies. A selenium zone with >50 ppm Se prevails in the rear part of the roll (Fig. 6.18).

6.3.2.3 Kanzhugan

This deposit is located on the same redox front as, and immediately to the south of, Moynkum. The WNW-ESE-striking Suzak fault separates the two deposits. The production centers of Kanzhugan and the South sector of Moynkum are 18 km apart. Kanzhugan includes two sections, *Central* or *Kanzhugan* proper, and *Kainar*. A U occurrence, *Intymak*, occurs on a separate redox front to the north of Kainar (Fig. 6.16). Original in situ resources of the roll-type deposit totalled 50 000 t U (Abakumov 1997). (Remaining proven resources in 2002 were reportedly 15 000 t at a grade of 0.033% U). Kanzhugan was discovered in 1972. ISL tests commenced in the Central section in 1982 and commercial production by ISL techniques started in 1988. Centralnoye Mining Company is the operator.

Sources of information. Petrov et al. 1995; Zinchenko and Stoliarenko 2002.

Mesozoic-Cenozoic sediments attain a thickness of 350 m. The upper 120–200 m thereof represent the upper stratigraphic-structural unit, which is composed of Neogene and Quaternary, mainly argillaceous and silty, sediments. Uranium is hosted in Eocene strata of the lower stratigraphic-structural unit. The Eocene sequence is 80–150 m thick and includes five sandy horizons separated by clay-silt layers 3.5–30 m thick. Two of the sandy horizons, Kanzhugan and Uyuk, host U ore bodies (Figs. 6.19a,b). Medium- and fine-grained quartz (63–69%) and feldspar (10–15%) are the main host rock constituents. Ore-bearing horizons are up to 20 m thick. The lower horizon is at a depth of 220–290 m.

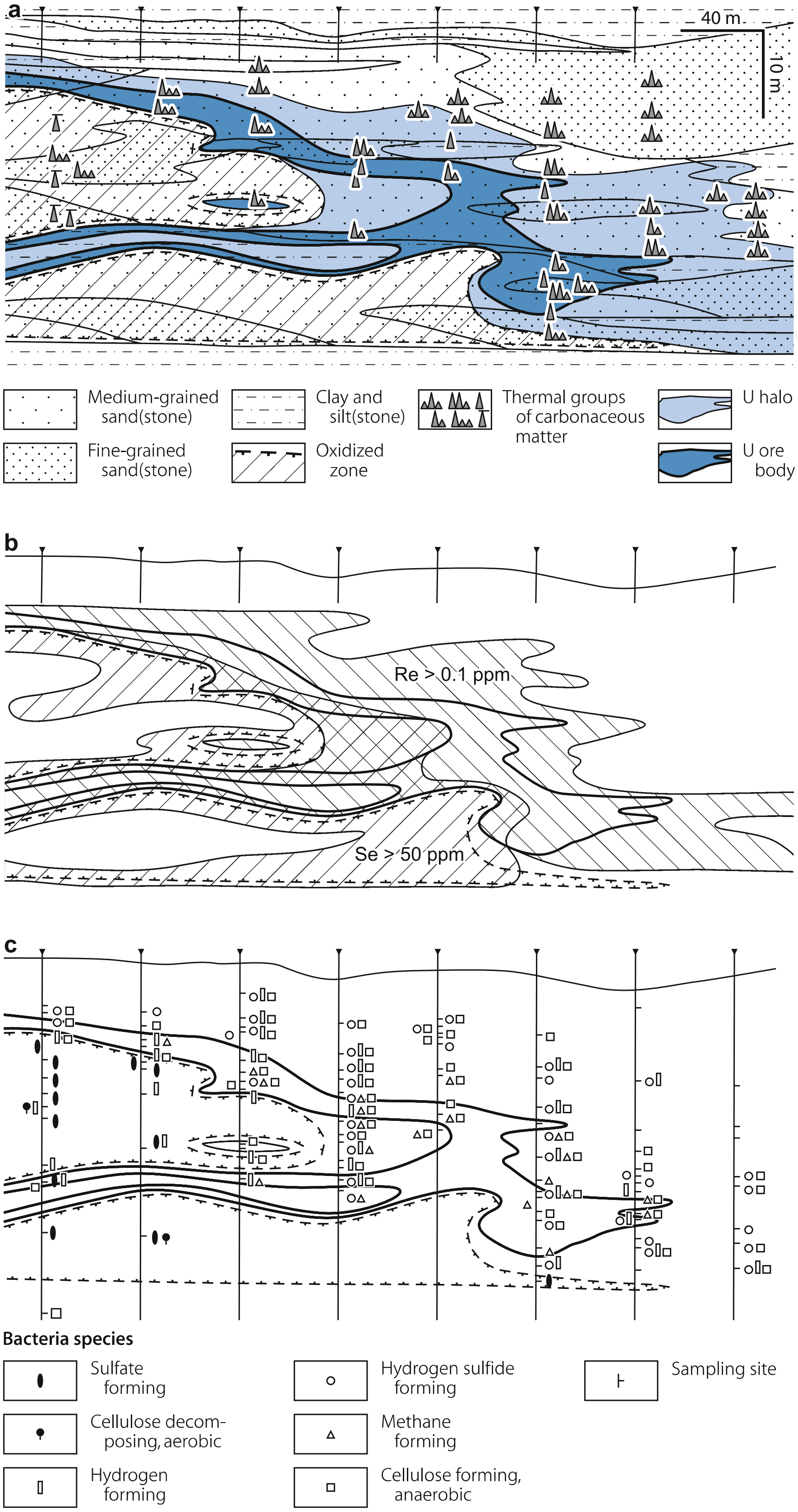
The Central or Kanzhugan sector occupies a generally NNE-SSW-trending, but highly sinuous, redox front some 20 km long, which switchbacks northward at a NW-SE fault at its south end to form the Kainar sector.

The Kanzhugan deposit exhibits a comparable ore body distribution as Moynkum (see above). Ore bodies are related to sinuous redox fronts that extend for a length of as much as about 10 km. Ore bodies have roll and tabular morphologies. Their width is 40–800 m. Thicknesses vary between 1 and 20 m and average 5.3 m. Ore grades range widely and average 0.038% U. Values of trace elements in the Kainar sector are provided in Table 6.4).

6.3.2.4 Bars

Bars is a small basal-channel-type sandstone U deposit situated between the Uvanas and Moynkum deposits. U lenses occur in

Fig. 6.18.
Chu-Sarysu Basin, Moynkum-Tortkuduk sector, litho-geochemical profile illustrating the distribution of a U, b Se and Re, and c bacteria species (after Shchetochkin and Kislyakov 1993 including data from Maksimova, Urmanova, and Shugina)



a Cenozoic channel filled with sand, mud, and lignite. Resources are reportedly a few 1 000 t U at an ore grade on the order of several 100 ppm U. Vanadium is an associated element (Petrov et al. 1995).

6.4 Syr-Darya Basin, S Kazakhstan

The Syr-Darya Basin is located in southern Kazakhstan. It is bounded to the NE by the NW-SE-trending Big Karatau range and to the south by the Chatkal-Kuramin range/Tien Shan mountains at the Uzbekistan and Kyrgyzstan border. The Karatau range separates the Syr-Darya from the Chu-Sarysu Basin with which it was originally united.

Uranium deposits in the Syr-Darya Basin are hosted in arenites controlled by dynamic redox fronts. They are therefore classified as sandstone-rollfront type. Mineralization consists either of a U-Se or a U-V(-Se) paragenesis. Original in situ resources were 143 000 t U and included 77 300 t U proven reserves (RAR + EAR-I) in the <$80 per kg U cost category, 10 700 t U estimated additional (EAR-II) and 55 000 t U prognostic resources (Abakumov 1995). Average grades range from 0.03 to 0.08% U.

Deposits are found in three districts; the *Karamurun District* in the northwestern, the *Karaktau District* in the central western, and the *Kyzylkol-Chayan District* in the eastern part of the basin (Fig. 6.12a). Uranium was discovered first at North Karamurun in 1972, at Irkol in 1976, and at Zarechnoye in 1977. More discoveries were made in the 1980s. Commercial exploitation by ISL methods started in 1985 at North Karamurun, followed by South Karamurun (see further below).

Fig. 6.19.

Chu-Sarysu Basin, Kanzhugan, a simplified plan of the central part of the deposit (ore bodies 1k–4k in Kanzhugan and 2u–6u in Uyuk Horizon), b WNW-ESE section demonstrating the structural complex situation of ore lodes (after Petrov et al. 1995)

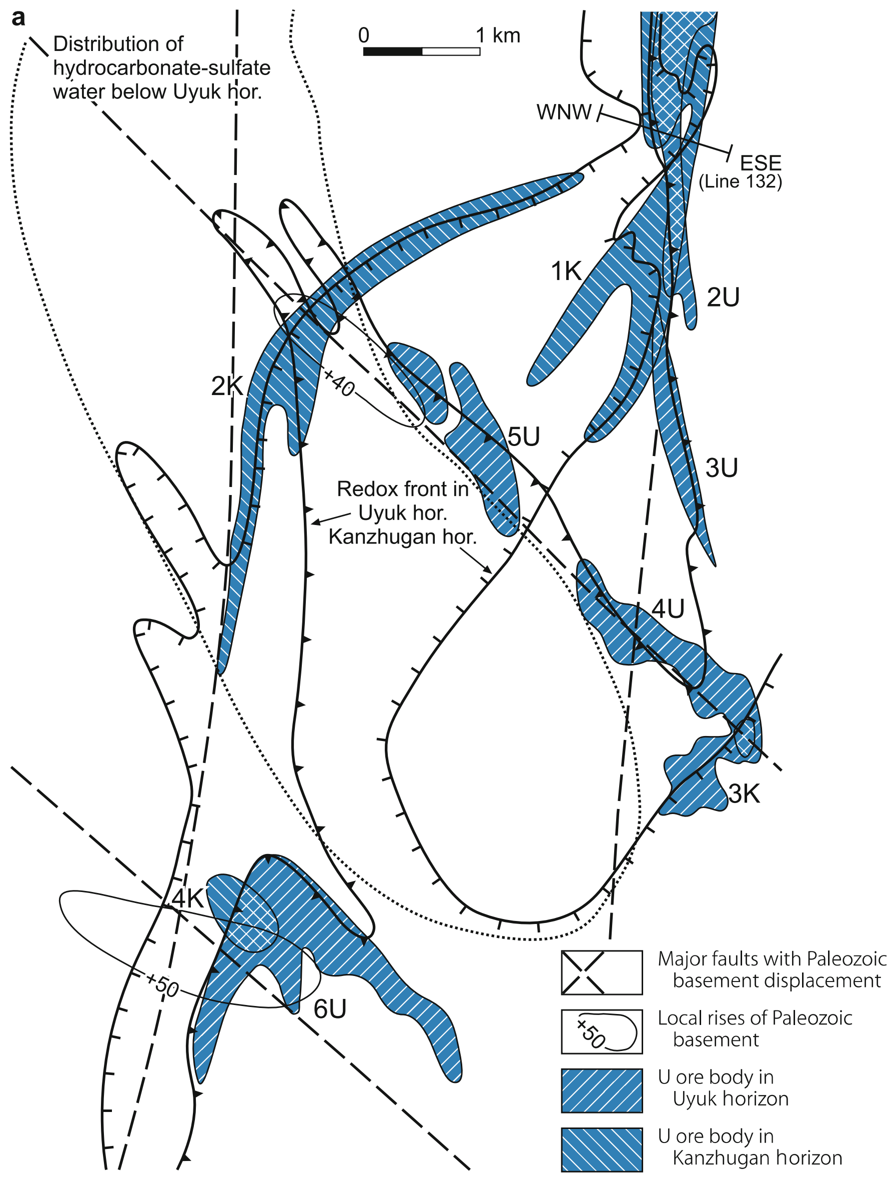
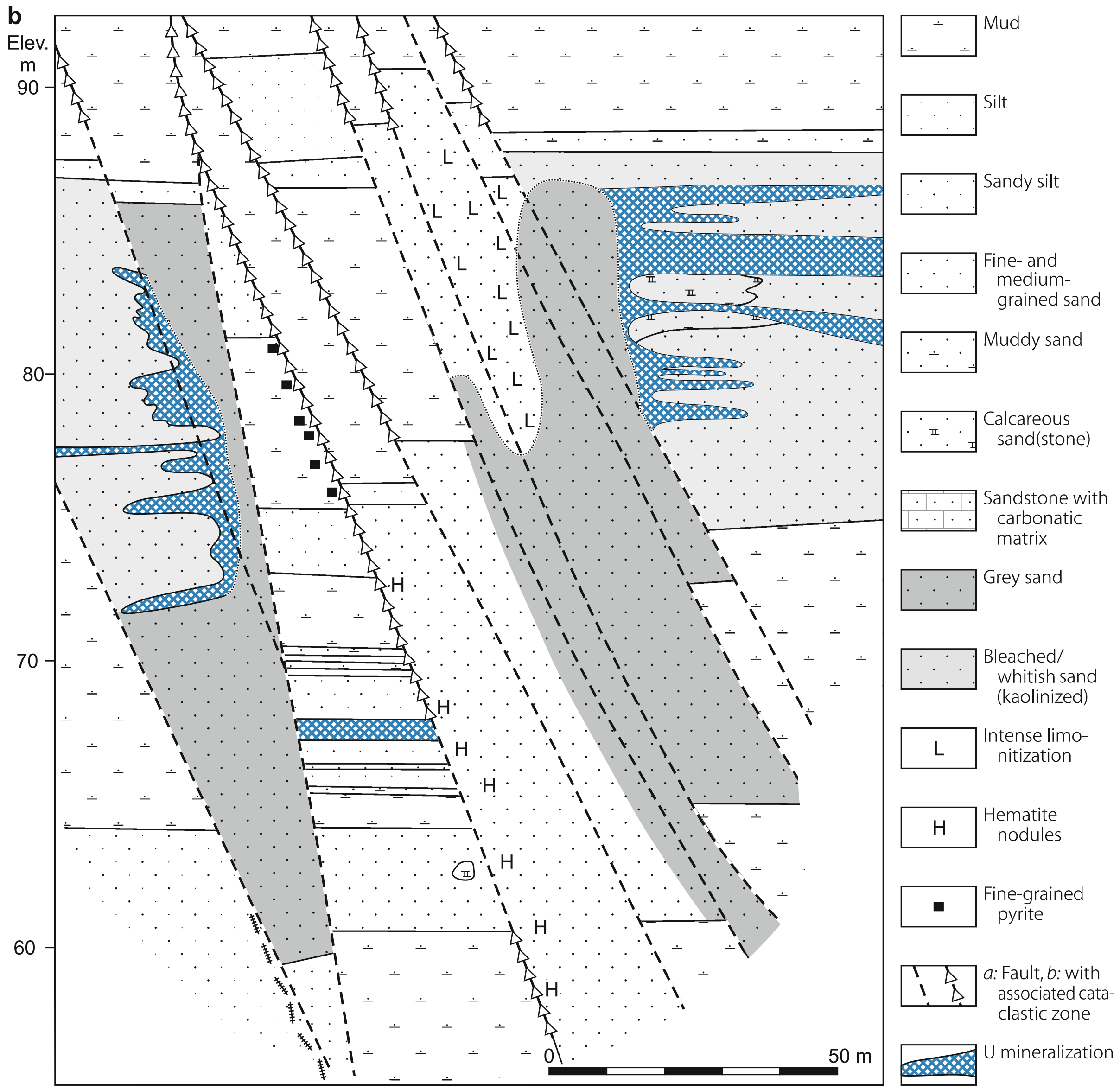


Fig. 6.19. (Continued)



Sources of information. Abakumov (1995), Fyodorov (1997), OECD-NEA/IAEA (1995–2005), Petrov et al. (1995), Yazikov (2002), Zabaznov (2002), and pers. commun. by Petrov and staff of Mining Co. # 6 (2003).

Regional Geological Features of the Syr-Darya Basin

The artesian Syr-Darya Basin is bounded to the NE by the NW-SE-trending Big Karatau Uplift, a mountain range composed of Proterozoic to Ordovician crystalline schists upon which Carboniferous and Devonian limestone and sandstone rest uncomformably. The southern margin is the Chatkal-Kuramin Uplift, which is composed of Proterozoic and Paleozoic limestone, crystalline schists, granite, and mafic to felsic volcanics, and the southwestern limit by the Central Kyzylkum Uplift, which separates the Syr-Darya Basin from the SW situated Kyzylkum U region and the Amu-Darya Basin in Uzbeskistan (Fig. 7.1).

The Syr-Darya Basin is a complex depression filled mainly with continental (including pyroclastic) and minor marine sediments, as much as 3 000 m thick. An upper stratigraphic-structural unit of Quaternary-Neogene sediments rests unconformably upon a lower stratigraphic-structural unit of Paleogene-Upper Cretaceous sediments up to 500 m thick.

The Cenozoic-Mesozoic strata dip and increase in thickness from the Karatau Uplift in a SW direction for about 50–80 km. Further southwestwards, they warp upwards coupled with a decreasing thickness of the Neogene sediments. Pre-Neogene synsedimentary vertical faults caused displacements of up to 250 m or more associated with a thickening of the sedimentary sequence in the western part of the basin. Regional faults trend NW-SE and NE-SW.

The Mesozoic sequence rests unconformably upon a *basement* affected by the Hercynian Orogeny and composed of Carboniferous limestone and dolomite as well as Devonian continental sediments, which overly Proterozoic to Ordovician crystalline schists. Igneous rocks include Upper Paleozoic granitoids, felsic intrusives, and dacite-andesite sheets. The basement is block faulted with major displacements. Locally downthrusted grabens are filled with Jurassic-Lower Cretaceous terrestrial sediments. Basement relief is in excess of 300 m (Fig. 6.12b).

Uranium deposits are restricted to the artesian lower stratigraphic-structural unit where they are contained in Eocene and Upper Cretaceous strata. Host rocks are sand and gravel-sand beds with high permeabilities (1–12 m d^{-1} filtration coefficient). Contents of carbonaceous matter are generally low but can be as high as 5% in U deposits. Argillaceous aquicludes separate the arenitic horizons. An Upper Eocene clay horizon constitutes the upper regional confinement and Paleozoic and Early-Middle Mesozoic lithified rocks along the pre-Cretaceous unconformity are the lower limit for all hydraulic systems in the lower stratigraphic-structural unit.

The most characteristic ***alteration*** features are associated with multilevel regional oxidation tongues in Cenomanian to Eocene aquifers in the western and eastern half of the basin. Three redox fronts have been delineated. The westernmost redox front trends sinuously about N-S, is hosted by Upper Cretaceous sediments, and controls the Irkol deposit. Some 30–50 km to the east of this front, another curvilinear N-S-oriented redox interface also occurs in Upper Cretaceous strata. This front extends from the Tien Shan mountains for 350 km or more northwards and controls deposits of the Karamurun District in the north and those of the Karaktau District about 140 km to the south. The third redox front is located in the eastern Syr-Darya Basin, approximately 120 km to the east of the afore mentioned redox front; it controls deposits of the Kyzylkol-Chayan District. Alteration features of the redox fronts compare to those of the Chu Sarysu Basin.

Uranium deposits in the Syr-Darya Basin are very similar to those in the Chu-Sarysu Basin. Ore grades for deposits average 0.05–0.08% U while those of individual ore bodies range from 0.01 to 0.6% U. Several deposits contain significant amounts of selenium and/or vanadium as well as other trace elements such as Ge and Re. Ore occurs at depths of 100–700 m. Deposits may consist of up to 9 stacked ore zones. The largest deposits occur in Upper Cretaceous strata.

Regional geochronology, potential U sources, ore controls, recognition criteria, and metallogenetic considerations are practically identical with those of the Chu-Sarysu Basin except that potential U sources may also be seen in the Chatkal-Kuramin uranium region at the border to Uzbekistan and Kyrgyzstan.

6.4.1 Karamurun District

The Karamurun District is spread over both sides of the Syr-Darya river near the mining town of Shieli (or Chiili) in the northwestern Syr-Darya Basin. The district includes the *Karamurun-Kharasan* and *Irkol ore fields*. Irkol occurs offset from the Karamurun-Kharasan deposits some 30 km to the W-NW and is controlled by a further advanced redox interface. All deposits are hosted by Upper Cretaceous sediments (Figs. 6.12a, 6.20a,b). Original in situ resources of this district amount to about 80 000 t U RAR + EAR-I (including production of some 11 000 t U from 1973 through 2003) and an additional 50 000 t U of potential resources according to IAEA (2002b/Annex II).

Sources of information. Petrov et al. 1995; amended by data from IAEA 2002b/Annex II, and pers. commun. by staff of Mining Company # 6.

General Geology and Mineralization

Geology of the Karamurun District includes Quaternary to Oligocene suborogenic sediments deposited upon Paleogene and Cretaceous platform sediments. This sequence is as much as 3 000 m thick. Paleozoic rocks constitute the basement. A synopsis of the litho-stratigraphic section of the district, drawn from Petrov et al. (1995), includes the following units:

- *Quaternary-Oligocene*: suborogenic sediments
- *Upper Eocene*: <220 m thick, grey-green silt and clay
- *Middle Eocene*: ~50 m thick, marl and clay
- *Lower Eocene*: ~35 m thick, sand and grey clay
- *Paleocene*: 20–40 m thick, dolomitic sandstone, siltstone, dolomite, limestone
- >Unconformity<
- *Maastrichtian*: ~40 m thick, alluvial-deluvial sand, partly marine grey sand (principal U host at N and S Karamurun)
- *Campanian*: ~20 m thick, alluvial clay and sand (contains U at N and S Karamurun and Irkol)
- *Santonian*: ~80 m thick, pink clay and minor sand; U in grey alluvial facies
- *Coniacian*: ~60 m thick, alternating beds of grey gravel and fine-grained sand (principal U host at Irkol)
- *Turonian*: 40–50 m thick: including:
  - Upper Turonian: predominantly green-grey, fine-grained alluvial sand interbedded with grey lacustrine clay, silt, and sand (contains 10% of the resources of Irkol)
  - Lower Turonian: red-brown clay and silt
- *Cenomanian*: <50 m thick, gravel
- >Unconformity<
- *Pre-Mesozoic* basement: Middle Devonian terrestrial sediments and Lower Carboniferous limestone and dolomite, intruded by Upper Paleozoic granite

6.4.1.1 Karamurun-Kharasan Ore Field

This ore field is situated some 170 km SE of the town of Kyzyl-Orda and actually consists of a single large deposit that is arbitraliy subdivided, from N to S, into the *North Karamurun* Se-U deposit, the *South Karamurun* U deposit, and the *Kharasan* deposit [formerly separated into North and South Kharasan, and several isolated, small (some 100 t U) deposits]. The Karamurun deposits occur on the north and the Kharasan deposits on the south banks of the Syr-Darya river.

OECD-NEA/IAEA (2005) reports for the Karamurun North and South deposits combined remaining reserves of 33.860 t U at a grade of 0.086% U as per January 1, 2005. The nominal ISL production capacity of these two operations is 600 t U yr^{-1}. Total production through 2003 was approximately 7 000 t U. The operator was formerly Vostochny (Eastern) Mining and Chemical Combine and is now the # 6 Mining Company, a Kazatomprom (formerly KATEP) subsidiary.

Ore bodies occur at depths from some 400 m in the north to 800 m in the south controlled by a generally N-S-trending but sinuous redox front, approximately 60 km long, in Upper Cretaceous aquifers. The redox front migrates westwards from the Karatau Uplift.

Coffinite and (sooty) pitchblende are the principal U minerals. Associated minerals/elements include selenium in the form of native Se and ferriselite, vanadium (locally up to 4% V_2O_5) as tyuyamunite and häggite, <0.3% Ge, <0.2% As, and <19 ppm Re.

Deposits consist principally of roll-shaped ore but there exist also lenticular ore bodies due to highly erratic interrelationships of arenaceous and pelitic facies. Ore bodies are from 750 to 5 500 m long, 25–450 m wide, 6–24 m thick, and average 0.07–0.08% U. Ore with grades in excess of 0.01% U are confined to grey facies. Footwall boundaries of deposits vary in depth between 300 and 700 m.

North Karamurun had reportedly original in situ resources of some 28 000 t U at a grade of 0.07–0.08% U and approximately 17 000 t Se. Ore bodies occur at depths from 400 to 550 m. Testing of ISL techniques at this deposit began in 1976 and commercial production in 1984.

South Karamurun continues southwards from the North Karamurun deposit for about 15 km to the Syr-Darya river. Original in situ resources totalled 12 000 t U at grades averaging 0.06–0.09% U. The deposit was tested by ISL techniques in the 1970s and is in production since 1979. The cutoff for recoverable

Fig. 6.20.
Syr-Darya Basin, Irkol and Karamurun-Kharasan ore fields, a generalized map indicating the distribution of U ore bodies in Upper Cretaceous strata below younger strata (Quaternary and Upper Pliocene cover not shown) and b the position of ore lodes in the Irkol *(Ir)* and Karamurun North *(KN)* and South *(KS)* deposits (after Petrov et al. 1995 based on VV Kazarinov)

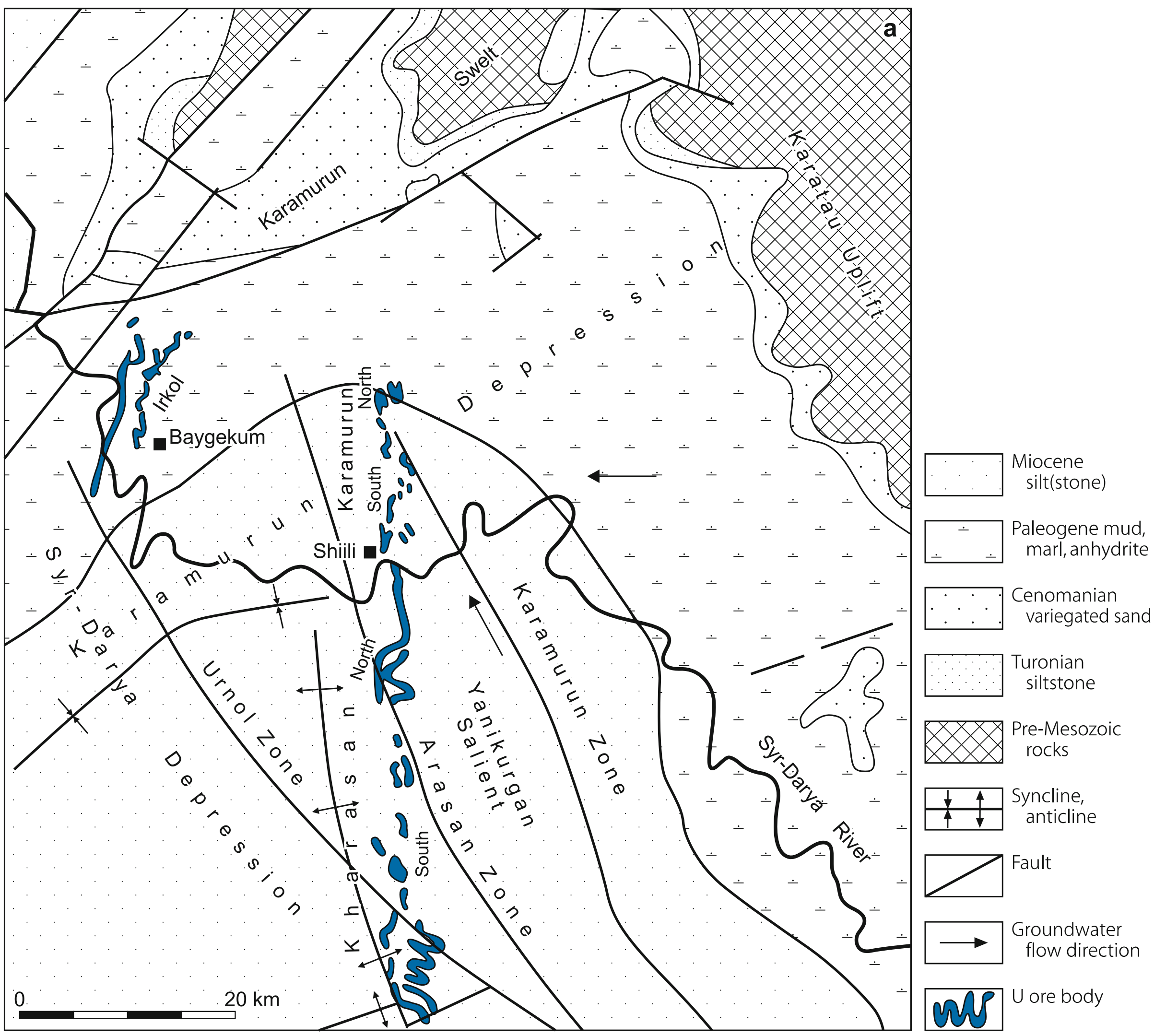
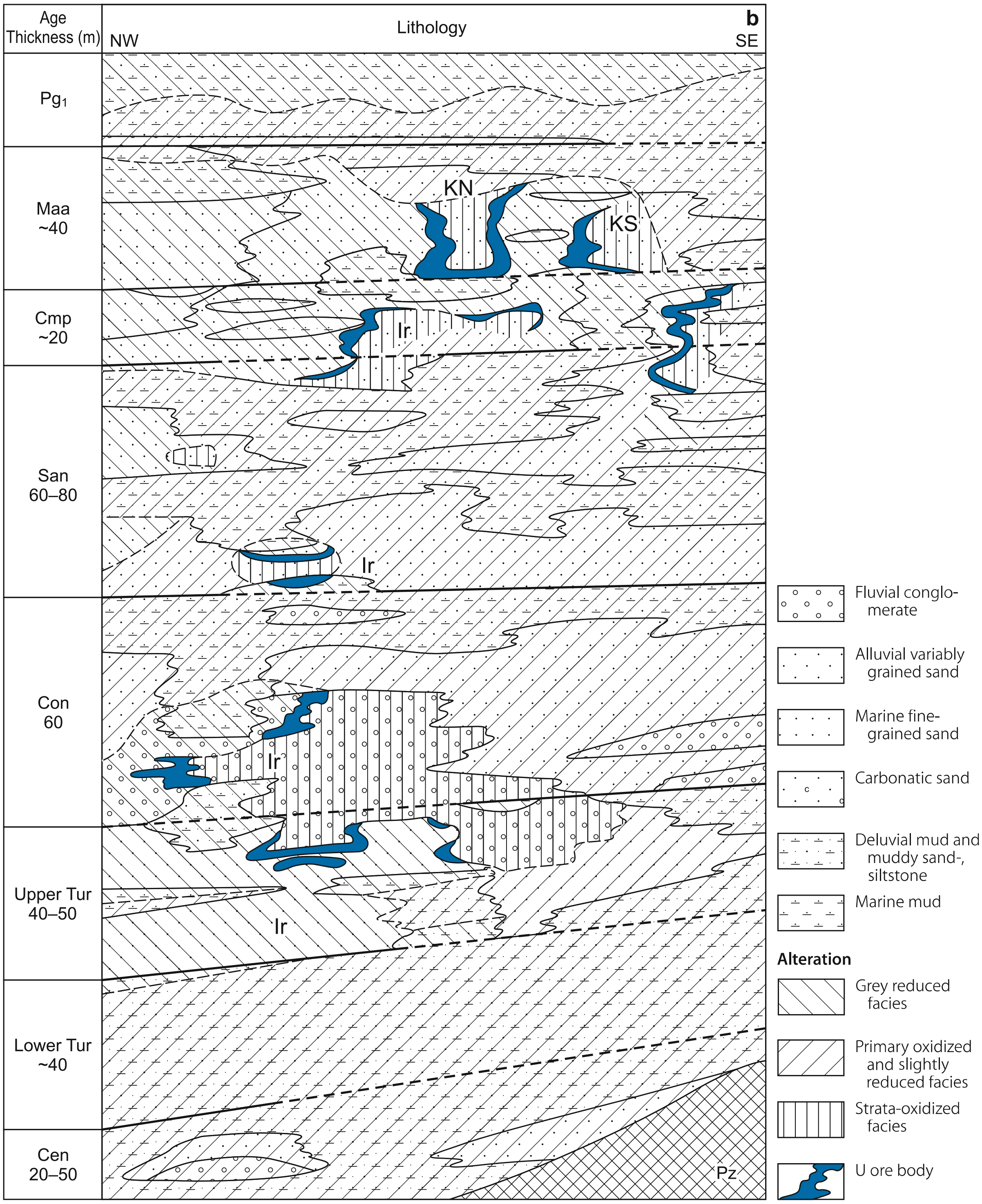


Fig. 6.20. (Continued)



reserves is 2 kg U m^{-2} while much of the ISL-mined ore bodies (status 1996) have reportedly grade coefficients from 5 to 15 kg U m^{-2} (IAEA 2002b/Annex II). Host rocks are Campanian and Maastrichtian fluvial, fine-grained, feldspathic quartz sands (80–90% quartz, ca. 10% feldspar) characterized by low contents of carbonate (0.5% $CaCO_3$) and carbonaceous debris, high permeability (15–20 m d^{-1} infiltration coefficient) and an increased temperature of 40–42 °C. Three major ore bodies are outlined; they are 25–450 m wide, 6–24 m thick, and spread over a length of about 5 km at depths of 450–670 m. The ISL-exploited ore-bearing aquifer occurs at depths from 550 to 670 m and is overlain by a 360 m thick aquiclude of massive clay upon which 100–120 m thick Pliocene and Quaternary sediments rest.

North Kharasan extends southwards from the Syr-Darya river for almost 15 km. It consists of several ore bodies at depths from 590 to 680 m. *South Kharasan* continues from North Kharasan for almost 30 km further southwards and includes ore bodies as deep as 800 m. Resources of the two deposits combined are reportedly 42 000 t U at a grade of about 0.1% U.

6.4.1.2 Irkol Ore Field

Irkol is located on the NE banks of the Syr-Darya river in the northwestern Syr-Darya Basin, 140 km SE of the town of Kyzyl-Orda. Ore is controlled by a redox front some 30 km to the west of the redox front, which controls the Karamurun and Kharasan deposits (Figs. 6.12a, 6.20a). Reported in situ resources amount to 38 000 t U including 21 100 t U proven reserves at an average grade of 0.042% U. Carbonat content is 0.2%. Ore bodies occur at depths from 390 to 700 m with the bulk of the ore at depths between 400 and 450 m (Yazikov and Zabaznov 2002).

Ore bodies are of rollfront configuration, have a thickness between 1 and 20 m (av. 5 m) and range in grade from 0.01 to 0.07% U. Uranium is hosted by sand horizons, from 20 to 80 m thick, of Campanian to Turonian age. Compared with Karamurun, the ore-bearing sand horizons are thicker and the Se content lower. The deposit was tested by ISL techniques in 1985 but did not go in operation.

6.4.2 Karaktau District

The Karaktau District is located in the central western part of the Syr-Darya Basin, about 150 km to the west of the town of Chimkent. The district includes the Se-U deposits *Zarechnoye* and, some 50 km to the south, *Zhautkan* (<5 000 t U), and the U-V deposit *Assarchik* (>5 000 t U), located about 40 km to SE of Zarechnoye (Fig. 6.12a). All deposis are hosted in Upper Cretaceous sediments.

Source of information. Petrov et al. 1995.

General Geology and Mineralization

A litho-stratigraphic profile of the Karaktau District shows a sequence of Paleogene and Cretaceous platform sediments more than 1 300 m thick covered by Quaternary sediments. Deposits occur along bending, generally NNW-SSE-trending redox fronts in Upper Cretaceous aquifers. The Paleogene-Cretaceous sequence includes (from top to bottom) Paleogene sands; Maastrichtian, 40–120 m thick, sand-clay and limy clay; Campanian, 40–100 m thick, grey sands with interbedded silt-clay; and Lower Cretaceous, approximately 560 m thick, variegated siltstone with intercalated clay, marl, and limestone beds. This suite rests unconformably upon a basement of Paleozoic terrestrial sediments, which overlie Devonian-Silurian metamorphics.

6.4.2.1 Zarechnoye

Zarechnoye is an explored U-Se deposit that was discovered in 1977 and exhibits a geological setting and composition similar to U deposits in the Karamurun ore field. In situ resources total an estimated 40 000 t U including almost 20 000 t U of proven reserves at a grade averaging 0.056% U.

Geology and Mineralization

Cenozoic-Mesozoic platform sediments in excess of 1 300 m thick rest unconformably upon Silurian-Devonian metasediments intruded by Late Paleozoic granite. The stratigraphic column includes (from top to bottom):

- *Quaternary*: up to 250 m thick, brown and reddish alluvial sand and clay
- Eocene-Paleocene sediments
- *Upper Cretaceous*: up to 800 m thick, marine and continental sandy and clayey sediments
- *Lower Cretaceous*: up to 560 m thick, variegated siltstone with clay, marl, and limestone beds

Campanian and Maastrichtian sediments host the U mineralization. The Campanian includes three rhythms, 15–30 m thick each, of fine-grained, grey sands with clay, sandstone, and siltstone beds; and the Maastrichtian includes 2 rhythms of 40–120 m thick deltaic and inshore marine sediments, the lower rhythm consists of sandy-clay and the upper of clay-carbonate. Within these units, 3 Campanian and 2 Maastrichtian permeable sand horizons contain mineralization at depths from 400 to 700 m. U is confined to grey, reduced facies while Se mineralization occurs in yellow, oxidized sandy intervals. Ore is controlled by redox fronts that are from 10 to 30 km long and spread over widths of as much as 5 km.

Ore consists of disseminated U and Se minerals. Coffinite constitutes 70–90% of the U endowment and pitchblende the rest. Native Se and minor ferroselite represent selenium. Carbonates comprise less than 1%.

U and Se commonly form individual ore bodies. Selenium ore bodies coincide to 70% with the contour of uranium mineralization but also occur between U ore lodes. U ore bodies are of roll shape and average a thickness of 5 m with a maximum of 12 m. Individual Se ore bodies exhibit the same dimensions. Combined U-Se lodes range in thickness from 2 to 20 m and average 8–12 m. Lodes contain from 0.01 to 0.6% U and from 0.04 to 0.055% Se.

6.4.3 Kyzylkol-Chayan District

This district is situated in the eastern part of the Syr-Darya Basin, near the Karatau range, about 100 km to the north of the town of Chimkent. Discovered in 1961–1963, this district includes the small *Kyzylkol, Lunnoye,* and *Chayan* deposits, as well as the *Dzedykuduk, Buyun*, and *Glinkovo* occurrences hosted in Eocene sediments of the Kyzylkol-Prytashkent zone (Fig. 6.12a).

Sources of information. Petrov et al. 1995; Petrov pers. commun. 2003.

Geology and Mineralization

A litho-stratigraphic profile of the Kyzylkol-Chayan District shows Oligocene to Quaternary suborogenic sediments resting on Paleogene and Cretaceous platform sediments. Paleozoic terrigenous clastic and carbonatic sediments constitute the basement. The Tertiary-Cretaceous suite includes the following lithologies:

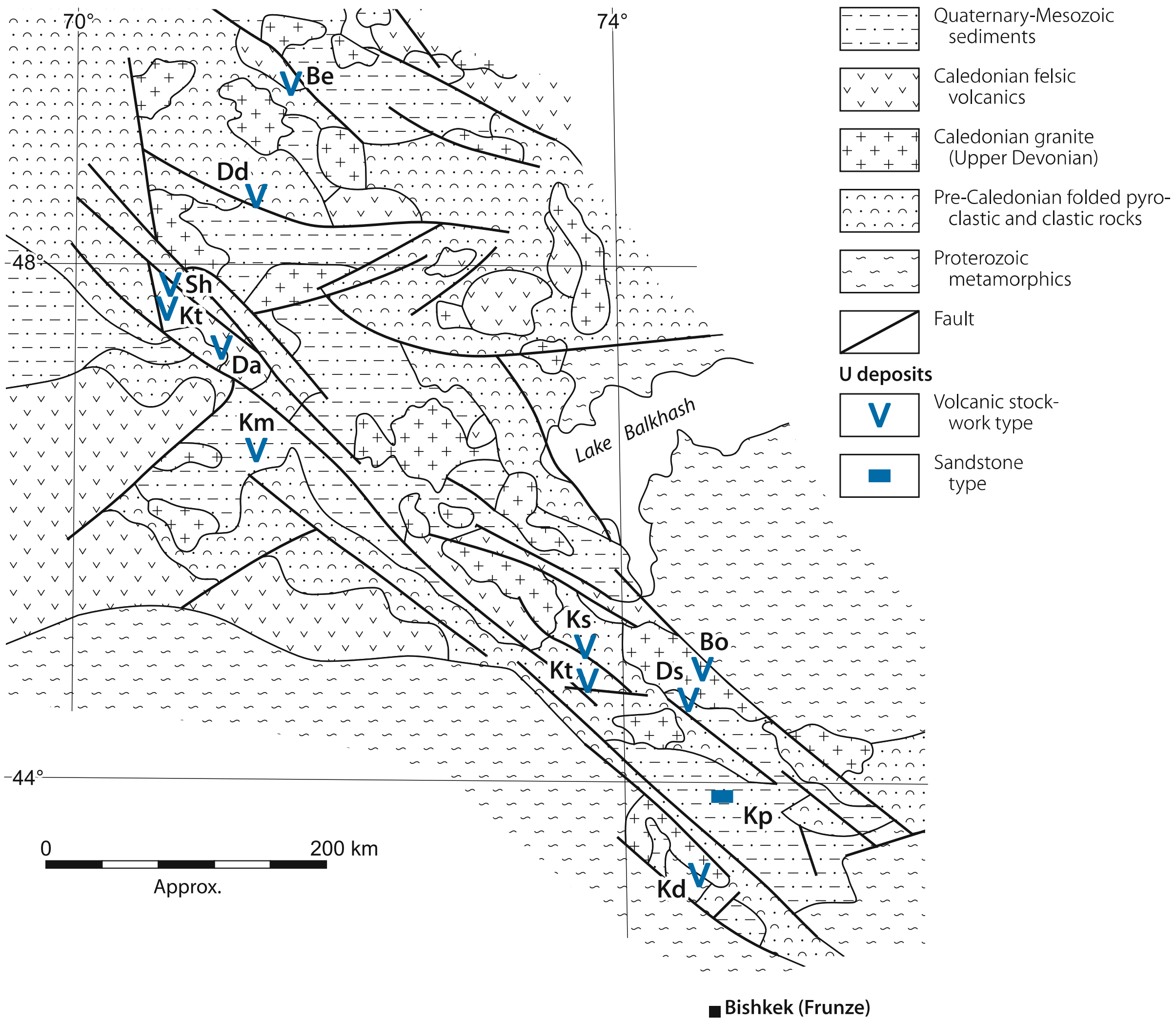
- *Miocene-Oligocene*: <250 m thick, clay
- *Upper Eocene*: 200–250 m thick, green-grey clay
- *Middle Eocene* Ikan Formation: 30–40 m thick, quartz-feldspar sand with interbedded sandstone and dolomite beds, including an up to several meters thick ore-bearing horizon
- *Lower Eocene* Uyuk Formation: 50–60 m thick, with a U-bearing 15–25 m thick sand bed between two clay layers
- *Eocene-Paleocene*: 100–130 m thick sediments
- *Cenomanian-Albian*: variegated and pink continental sediments
- *Turonian*: marine grey clay

Deposits of the Kyzylkol-Chayan District occur along a NNW-SSE-trending redox front in Tertiary aquifers that contain carbonate lenses. Ore bodies are of roll shape and consist of finely dispersed coffinite and (sooty) pitchblende. Rolls are a few meters thick, range from 100 m to few kilometers long, and from 10 to 300 m wide. Ore at Kyzylkol occurs at depths from 130 to 200 m, and at Lunnoye from 310 to 530 m.

6.5 Pribalkhash (Lake Balkhash)/ Kendyktas-Chuily-Betpak Dala Region, SE Kazakhstan

The Pribalkhash uranium region stretches from the Kyrgyzstan border in the Kirgizian range (north of the town of Bishkek in NW Kyrgyzstan) to the area west of Lake Balkhash and further north and northwestwards into the Betpak Dala (Hunger Steppe) in central-south Kazakhstan. Deposits group primarily in the

Fig. 6.21.
Pribalkhash uranium region, simplified geological map of the Caledonian Chuili-Kandyktas Uplift and associated volcanic- and sandstone-type U deposits (after Laverov et al. 1992c). *U deposits:* Be Bezymyannoye, Dd Dzhideli, Sh Shorly, Kt Kostobe, Da Daba, Km Kurmanchite, Ks Kyzylsay (# I to VIII), Kt Kyzyltas, Bo Botaburum, Ds Dzhusandalinskoye, Kd Kurday, Kp Kopalysay



northern *Betpak Dala* and the central *Chuily* (also spelled Chu-Ily) area. Additionally, some small deposits are known such as *Kurday* in the southern *Kendyktas* and *Karatal* in the *Shuisky* area (Figs. 6.1, 6.21). The northwestern part encloses the *Granitnoye ore field*, a small sedimentary basin with a few basal-channel sandstone-type deposits. Most other deposits, except *Kopalysay*, which is of the sandstone rollfront type, are associated with volcanics and consist of structurally controlled stockwork mineralization. They are therefore classified as volcanic stockwork type (in Russian literature referred to as vein-stockwork deposits in continental volcanic complexes or as hydrothermal Mo-U deposits associated with the rhyolite-granite association in subvolcanic massifs or in exploration pipes and necks, respectively).

Original(?) in situ resources of the Pribalkhash region amount to 71 900 t U RAR + EAR-I. They include 21 900 t U RAR (Abukumov 1995; OECD-NEA/IAEA 1993). Resources in volcanic-type deposits amount to more than 65 000 t U, and in sandstone-type to less than 7 000 t U. Ore grades range from ca. 0.1–0.3% U.

The first deposit, Kurday, was discovered in 1951. Mining started in 1953 and lasted until 1990. Exploration was performed by Stepgeology while the Kyrgyz Mining Combinate, later renamed Yuzhpolymetal Production Enterprise, based in Bishkek, was the mining operator during these years. About 15–20 mostly small U deposits have been exploited. Total production is speculated to be on the order of 10 000 t U. Ore was treated in a mill at Kara Balta (Kyrgyzstan), ca. 60 km W of Bishkek, that had a nominal capacity of 1.5 million t ore yr^{-1} and an estimated U production capacity on the order of 3 600 t U yr^{-1}.

Sources of information. Petrov et al. (1995, 2000) amended by data from Abukumov (1995), Laverov et al. (1992a–c), OECD-NEA/IAEA (1993, 1995).

Regional Geological Setting of Mineralization

The Pribalkhash uranium region is within the Chuily-Kendyktas Uplift, a fragment of the Ural-Mongolian fold belt of Caledonian age. Precambrian gneiss and schist and Late Silurian-Early Devonian continental felsic to mafic volcanics constitute the basement. Devonian granites and felsic volcanics were intruded and extruded, respectively, during the Caledonian Orogeny. Most of the uranium deposits are located within the margin of this Devonian igneous belt. Mesozoic-Cenozoic sediments rest on the crystalline rocks.

The Silurian-Devonian continental volcanic suite consists of folded alternating layers of rhyolite to andesite lavas intercalated with pyroclastic and clastic rocks. Caledonian subvolcanic stocks of rhyolitic composition and small hypabyssal batholiths of granite were intruded into this suite in a linear belt oriented NW-SE. The belt is a horst and graben structure up to several hundreds of kilometers wide controlled by NW-SE-trending, deep seated lineaments with NW-SE-oriented first order structures of large vertical and horizontal displacements in the pre-Caledonian basement. These structures are expressed by wide zones of brecciation and/or intense fracturing and jointing, tens to hundreds of meters wide, and by subvolcanic intrusions and dike belts in the overlying volcanic suite. Younger fault systems of variable orientation imposed additional deformation on the magmatic belt.

Principal Host Rock Alterations

Principal alterations associated with structurally controlled U deposits include propylitization, beresitization, and argillization. *Propylitization* is reflected by calcite and chlorite after muscovite and biotite; *beresitization* by pyrite-sericite, hydromica-carbonate and chlorite-hematite associations; and *argillization* by kaolinite, quartz, and hydromica. The transformation process occurred during the Upper Devonian to Lower Carboniferous and typically affected the various deformed lithologies within U-hosting regional fault zones but also occur along the contacts of Devonian granitic massifs. The alteration facies are distributed in a centripetal zoning around U deposits grading from propylitization at the periphery to beresitization, and argillization. At some deposits, e.g. at Dzhusandalinskoye, the country rocks are Na metasomatized reflected by albitization.

Principal Characteristics of Mineralization/General Shape and Dimensions of Volcanic-Type Deposits

Volcanic-type mineralization is polymetallic composed of a uranium-molybdenum paragenesis. Pitchblende and locally coffinite are the principal uranium minerals. Associated minerals are jordisite, molybdenite, marcasite, pyrite, and other sulfides in minor amounts. Gangue minerals include quartz, sericite, carbonates, and fluorite.

Deposits consist of structurally controlled ore bodies of highly irregular configuration, size and grade with uranium tenors ranging from 0.03 to as much as 10% U or more as in some ore shoots at Dzhideli. Ore bodies are composed of a complex system of interlinked veins, lenses, and/or stockworks in which the ore occurs in disseminated, streaky and, more rarely, massive texture. Most deposits mined had original reserves between 1 000 and 2 000 t U except Botaburum which contained some 10 000 t U. Felsic effusive sheets, pyroclastics, and volcanic dikes and necks composed of felsite, quartz-porphyry, and rhyolitic lava, breccia, and tuff provide the prevailing host rocks except at Kurday where the ore is hosted by granodiorite porphyry but in immediate contact to a steeply dipping felsite body (Figs. 6.22a–c). Structural and lithologic elements, which control the position and configuration of ore bodies are listed further down.

Regional Geochronology

The main stage of structurally controlled uranium mineralization in the Pribalkhash region is dated at 370–350 Ma, which corresponds to the Late Devonian. Additional episodes of U introduction or redistribution yield 330–310 and 285–265 Ma

Fig. 6.22.
Pribalkhash region, Shorly deposit, a map and b W-E cross-section, c Kurday deposit, SW-NE cross-section, illustrating the litho-structural setting of stockwork-type U mineralization (after a, b Petrov et al. 2000; c courtesy of Boitsov AV based on Russian literature)

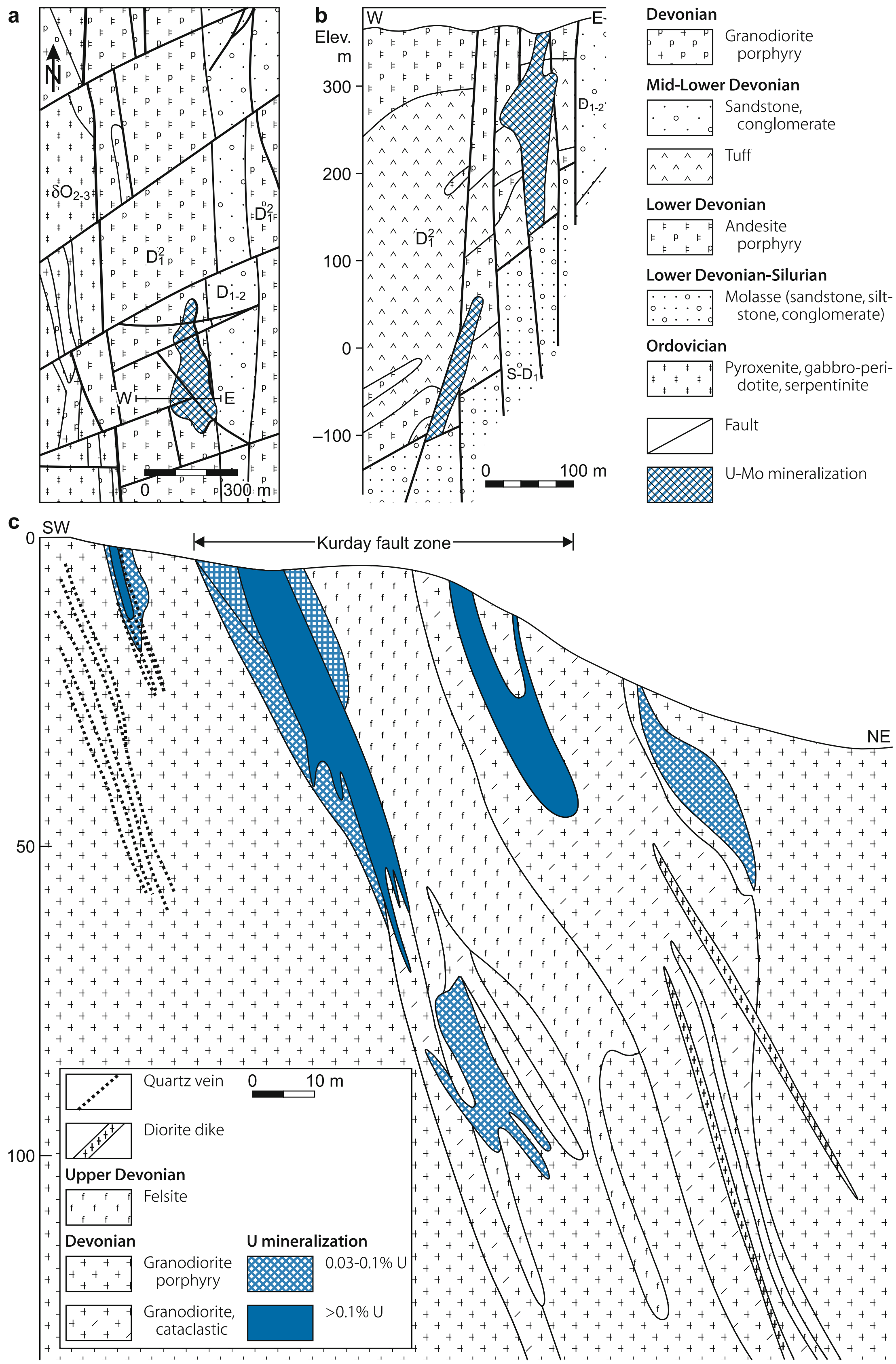


Table 6.6.
Chuily-Betpak Dala region, Isotope ages of U mineralization and redistribution in endogenic deposits (Petrov et al. 2000). *In italic:* **principal age of ore formation**

Mineralization type	Age (Ma)	Deposits example
P-U, U in Na metasomatite and beresitization zones	486–450, *370–350*, 330–310, 285–265	Kostobe, Daba, Dzhusandalinskoye
Mo-U, U in beresitization, argillization, and feldspathization zones	*370–350*, 330–310, 285–265	Botaburum, Kyzylsai, Dzhideli, Shorly, Kurday

while an early P-U mineralization, dated at 486–450 Ma, is identified at some deposits (Petrov et al. 2000) (Table 6.6).

Principal Ore Controls and Recognition Criteria of Volcanic-type Deposits

Significant ore controlling parameters or recognition criteria of the major volcanic-type deposits in the Pribalkhash region, include:

Host Environment

- Large volcanic belt dominated by felsic facies of Caledonian age controlled by deep reaching regional faults
- Association of U deposits essentially with felsic/rhyolitic volcanics
- Regional faults associated with extensive cataclastic zones along which the position of ore bodies is controlled by one or several of the following parameters:
  - intersections of faults along axial trend over basement highs
  - intersection of transverse fractures with dikes
  - axial faults following steeply-dipping contacts between extrusive volcanics and hypabyssal granite
  - sharp changes in dip of facies contacts cut by a fault
  - volcanic necks and granite porphyry dikes in annular fault zones
  - contacts of volcanic lithofacies

Alteration

- Predominantly propylitization, beresitization, and argillization
- Na metasomatism/albitization at some deposits

Mineralization

- Polymetallic U-Mo assemblages primarily composed of pitchblende, minor coffinite, molybdenite, jordisite
- Associated metallic minerals are dominated by sulfides (mainly Fe-sulfides)
- Gangue of quartz, sericite, carbonates, and/or fluorite
- Ore textures range from disseminated, to streaky and locally massive
- Deposits commonly consist of a number of ore bodies
- Ore bodies are characterized by
  - a complex system of interlinked veins, lenses, and stockworks
  - low to high average grades (0.046–0.6% U)
  - commonly small to medium tonnage (few tens to rarely a thousand t U)

Metallogenetic Concepts of Volcanic-Type Deposits in the Pribalkhash Region

As far as known, the metallogenesis of the volcanic-type U deposits in the Pribalkhash region was only dealt with in a larger scope, together with this type of deposits particular in the Streltsovsk District, Russia, and the Karamazar region, Uzbekistan, from where more specific, substantiated descriptions are published. The reader is therefore advised to find information provided in the respective chapters on metallogenetic aspects of these two areas.

6.5.1 Northern Betpak Dala Area

The northern Betpak Dala area includes four uranium ore fields: *Dzhideli, Koskarin, Shorly-Kostobe,* and *Daba*. Exploration started in the 1950s. Mining began in the 1960s following the discovery of the Dzhideli deposit and lasted until the mid 1980s. The area is located in the western part of an intrusive-volcanic belt. Two geological structures dominate the terrane, the Buruntay anticlinorium, a linear, NW-SE-oriented structure, 300 km long and 60–180 km wide, and the westerly adjacent Zhalair-Naiman synclinorium, 250 km long and 20–90 km wide. Mesozoic-Cenozoic sediments of the Chu-Sarysu Basin cover the latter.

Source of information. Petrov et al. 2000.

6.5.1.1 Dzhideli Ore Field (Dzhideli and Sarytas Deposits)

This ore field is centered 110 km south of the town of Karashal in the Dzhezkazgan region of central Kazakhstan. It is located in the Sasyrlyk volcanic basin, a western fragment dominated by andesite-dacite and rhyolite facies of the Devonian intrusive-volcanic belt. The basin is 200 km long in NW-SE direction and 100 km wide, and bordered by the large Shabdar fault to the SW, the Akdala fault to the SE, and the Atasui fault to the NE. The ore field contains the medium size *Dzhideli* deposit, the small *Sarytas* deposit, and the *Kostakyr, Proktasskoye, Gravitacionnoye*, and *Kuntau* occurrences. The ore lodes are classified as structurally controlled volcanic type, which relate in Russian classification to the molybdenum-uranium type in the zones of beresitization, argillization, and feldspathization.

The Dzhideli deposit was discovered in the southern part of the same named volcanic structure in 1961 and contained resources in the 1 500–5 000 t U resource category. Grades averaged about 0.4% U but some ore shoots had grades in excess of 10% U. Mining was by open pit and underground methods but has ceased in the mid 1970s.

Three suites of Middle to Upper Devonian volcanics contain U mineralization (from top to bottom): *(a)* plagioclase porphyry, tuff-sandstone, and volcanic breccia; *(b)* two horizons of welded felsite tuff, up to 170 m thick (principal host rocks); and *(c)* plagioclase-quartz porphyry, tuff, ignimbrite, and lava-breccia, up to 350 m thick. NW-SE- and W-E-striking diabase and diabase porphyry dikes dissect this volcanic suite. Principal structures are the NW-SE- and NE-SW-trending Northern, Southern, and Dzhideli faults. Host rock alteration phenomena include pre-ore chlorite-albite, ore-related pyrite-ankerite, and post ore quartz-calcite-sulfide.

Mineralization is of polymetallic nature dominated by uranium-molybdenum associated with As, Bi, Co, Ga, Pb, Sb, and Zn. Two ore types are distinguished: femolite-pitchblende and pitchblende-sooty pitchblende. Uranophane, beta-uranotile, autunite, etc are typical for the oxidation zone, which extends to a depth of 100 m. Primary mineralization is dated at 360 ± 8 Ma, and redistributed mineralization at 210–100 Ma.

Ore bodies # 1, 2, 5, 6, and 8 have a lenticular shape and occur in fault zones within welded felsite tuff at depths from 30 to 180 m. Ore bodies # 1, 2, and 5 contain 95% of the Dzhideli resources. Ore body # 1 is 400 m long, 0.5–35 m (av. 10 m) thick, persists from 30 to 80 m deep, and has a grade of 0.228% U. Ore body # 2 is 1 000 m long, from 2 to 18 m (in average 6 m) thick, occurs at depths from 70 to 140 m, and averages 0.213% U. Ore body # 5 contains high-grade ore with an average of 2,42% U. It is 160 m long, from 2 to 25 m (av. 7.5 m) thick, and occurs at a depth interval from 30 to 70 m.

Sarytas is a small deposit with an average grade of 0.077% U. It was discovered in 1965 almost 100 km to the SW of the town of Karazhal in the southern part of a volcanic dome. Country rocks are a Devonian andesite porphyry, up to 400 m thick; a volcanic-terrestrial horizon, 40–95 m thick; a felsite horizon, about 120 m thick; and a volcanic sandstone, 200 m thick. Lenticular ore bodies, 2.3–7 m thick, are restricted to the lower felsite horizon in which they are controlled by the intersection of the N-S Glavnaya with the NW-SE Anomalnaya fault zone. Wall rocks are altered by pyritization, chloritization, sericitization, and carbonatization. Pitchblende and sooty pitchblende are the principal U minerals. Associated minerals include molybdenite, arsenopyrite, and galena.

6.5.1.2 Koskarin Ore Field (Bezymyannoye Deposit)

This ore field includes the explored *Bezymyannoye* deposit located 70 km N of the Dzhidely deposit in the NW part of the Sasyrlyk volcanic basin. Resources of Bezymyannoye are less than 1 500 t U and average 0.15% U. Country rocks include Devonian ignimbrite with sandstone intercalations that rest upon quartz porphyry tuff and lava. Mineralization is hosted by breccia zones in ignimbrite close to the contact with a subvolcanic felsite body. The wall rocks are altered by sericitization, silicification, and chloritization. Pitchblende and molybdenite are the principal ore minerals. Associated elements include Be, Sn, Zr, and F. Ore bodies are of vein and lenticular configuration. They are up to 300 m long and up to 20 m thick, and occur in a 300–500 m wide zone close to the N-S-trending Bezymyanny fault.

6.5.1.3 Shorly-Kostobe Ore Field (Kostobe and Shorly Deposits)

Shorly is located 50 km SW of the Dzhideli deposit and forms with the about 10 km to the south situated Kostobe deposit the Shorly-Kostobe ore field.

Shorly was discovered in 1980. In situ resources amount to 1 300 t U at a grade of 0.125% U. The deposit occurs in a tectonic block, which is limited by N-S and NE-SW faults. Host rocks are Lower Devonian sedimentary and volcanic rocks, as much as 500 m thick, composed of lithoclastic tuff, breccia, tuff-sandstone, and andesite porphyry. Devonian granodiorite dikes cut this sequence. Silurian to Lower Devonian pink molasse underlies unconformably this unit. The steeply inclined, NNW-SSE-oriented Western Ulkensor fault exerts the principal ore control.

Mineralization is of polymetallic U-Mo composition. Coffinite is the prevailing uranium mineral, pitchblende is of minor abundance; molybdenum occurs as molybdenite and femolite. Ore consists of three mineral associations: femolite-anatase-pyrite-arsenopyrite, coffinite-pyrite, and femolite-pyrite. The ore contains elevated concentrations of up to 1% (in average 0.22%) Cu, up to 0.7%, (av. 0.28%) As, and up to 0.07% (av. 0.01%) Pb.

Two ore bodies are identified. The upper *ore body # 1* is of lenticular shape with an internal stockwork structure. It is 500 m long, up to 40 m thick, occurs at the depth interval from 25 to 260 m, and contains 70% of the resources at a grade of 0.131% U. The lower *ore body # 2* is a steep lens, 250 m long, up to 40 m (in average 10 m) thick, and persists from 250 to 500 m downdip (Figs. 6.22a,b).

Kostobe was discovered in 1977 and mined by open pit methods. Original resources were less than 1 500 t U at a grade of 0.201% U. Country rocks consist of Lower to Middle Devonian volcanic-sedimentary rocks bi-partitioned into an upper unit, as much as 110 m thick, of andesite-porphyry, tuff, tuff-conglomerate, and porphyry; and a lower unit, 500–650 m thick, of volcanic conglomerate, sandstone, and gravel. NW-SE and E-W fault systems dissect the area. Shallow to intermediate steeply dipping faults, most of them occur interstratified in the upper horizons, control the uranium mineralization. Ore bodies are composed of veinlets and finely disseminated uranium minerals and are distributed at depths from 20 to 200 m. Two main ore bodies are identified. Ore body # 1 consists of some lenses hosted by beresite-altered porphyry. It is 250 m long, from 1 to 23 m (av. 13 m) thick, persists at depths from 17 to 125 m, and contains 80% of the Kostobe resources at an average grade of 0.216% U. Ore body 2 occurs 80–100 m below ore body # 1 in tectonic breccia within gravel and sandstone of the lower unit. The lens-shaped lode is from 35 to 40 m long, up to 15 m (av. 9 m) thick, extends to depths from 140 to 200 m, and averages 0.2% U.

6.5.1.4 Daba

Daba is an explored U deposit situated ca. 50 km SE of the Kostobe deposit. It was discovered in 1979 and contains resources in excess of 5 000 t U in the two *sectors # 1* and *# 2*.

Daba is located at the NE contact of the Ordovician Keepchakbai hyperbasite massif with Upper Ordovician continental rocks. The latter host the ore in a volcanic-sedimentary sequence, up to 700 m thick, composed of (from top to bottom) a flysch-type sedimentary-volcanic formation, 300 m thick, with conglomerate, gravel, sandstone, tuff, and andesite porphyry; massive aphanitic limestone 100–200 m thick; and black carbonaceous-silica siltstone with interbedded sandstone. Devonian tuff with sandstone layers and andesite porphyry lenses rest unconformably upon the Ordovician. The Devonian is overlain by Mesozoic-Cenozoic sediments, 1–25 m thick, composed of Triassic to Jurassic eluvial material, Paleogene conglomerate, and Quaternary clay-sand. Intrusions are represented by Ordovician ultrabasite (dunite, pyroxenite) and gabbro bodies to the W of the deposit and a complex of Middle Devonian diorite and diabase porphyry dikes. Some dikes are 200–700 m long and 10–20 m thick. The rocks are folded to a monocline of NW-SE strike and 20–40° to 60–80° NE dip. NW-SE faults offset by ENE-WSW faults are the predominant brittle structures. Host rock alteration is reflected by carbonatization, propylitization, and bleaching.

Ore lodes occur in two sectors, which contain mineralization of two different mineral associations and ages. An early Paleozoic metamorphic stage, dated at 500–430 Ma, is reflected by low-grade, stratiform pitchblende-apatite ores, whereas late Paleozoic orogenic tectonic-magmatic activity, dated at 350 Ma, generated vein pitchblende-sulfide ores.

Sector # 1 covers a 3.7 km long zone in the southern part of the deposit in which ore lodes occur at depths from 0 to 250 m, distributed over vertical intervals that average a thickness of 36 m. Host rocks are preferentially brecciated, carbonaceous sandstone but also carbonaceous siltstone, sandstone, gravel, and andesite. Mineralization consists of a pitchblende-apatite (frankolite) association. Apatite contains up to 0.3% U, 3% Zr, and 0.6% Sr. Ore lodes average 0.043% U and have elevated concentrations of up to 11% P_2O_5, 0.7% F, 0.33% Sr, and 0.22% Zr. Separate lenticular ore bodies occur strata-concordant within the litho-stratigraphic profile.

Sector # 2 is an 850 m long zone situated in the northern part of the deposit, at the contact of the Upper Ordovician volcanic-sedimentary sequence with hyperbasite. Mineralization consists of a pitchblende-sulfide (chalcopyrite, pyrite, sphalerite) association, which forms vein or stockwork ore bodies with a thickness from 12 to 15 m and an average grade of 0.064% U (max. 0.174% U). The ore lodes are controlled by intersections of ENE-WSW and NW-SE faults.

6.5.2 Central Chuily Area

This area is located in the Chuily Uplift to the south of the western end of Lake Balkhash and the Kyrgyzstan border. It includes three ore fields: *Kyzylsay*, *Botaburum,* and *Mynaral*. Principal deposits occur within the first two ore fields. A Devonian volcanic-intrusive belt and abyssal fault zones control these fields. Exploitation started in the late 1950s following the discovery of the Botaburum and Kyzylsay deposits. Some isolated deposits/occurrences are also reported such as the stockwork-type *Kurmanchite* deposit that is located at the western margin of the Chuily area about 420 km NW of Almaty.

Source of information. Petrov et al. 2000.

6.5.2.1 Kyzylsay Ore Field

This ore field was discovered 340 km NW of Almaty in 1957 and coincides with the same named caldera. *Kyakhtinskoye, sector 2, Blishnee, sectors 4, 7, 8,* and *Zhamantas* are deposits within the Kyzylsay Caldera while the small *Kyzyltas* deposit occurs at the southern margin of the caldera. Original resources were reportedly in excess of 5 000 t U at a grade of about 0.1% U. Most deposits were mined underground and are depleted.

The Kyzylsay Caldera is a circular structure, 20–30 km in diameter, composed of Devonian volcanic (rhyolite, ignimbrite, dacite porphyry) and terrigenous rocks intruded by Late Devonian stocks and dikes. Ore lodes are controlled by E-W structures. Preferential host rocks are Devonian felsic porphyry and lava breccia affected by propylitic-beresitic and feldspar-argillic alteration. Ore mineral associations comprise uraninite-molybdenite-magnetite, pitchblende-molybdenite, and pitchblende-femolite-pyrite. The *Kyakhtinskoye* and *sector 2* deposits occur in the central block of the ore field. *Sector 2* mineralization consists of lenses and veinlets, which form several stockwork ore lodes within a fracture zone that cut rhyolite. Stockworks range from 30 to 150 m long, up to 20 m wide, and persist to 300 m deep. Grades average 0.12% U and 0.06% Mo.

6.5.2.2 Botaburum Ore Field

This ore field was discovered about 260 km NW of Almaty in 1953. Original resources were reportedly some 10 000 t U at an average grade of 0.157% U contained in several separate ore bodies. Mining was by underground methods and has ceased. Molybdenum was recovered as a by-product to uranium.

Botaburum is located within the homonymous volcanic caldera, which is characterized by rhyolite, eruptive breccia, and rhyolite porphyry tuff-breccia. Country rocks include rhyolitic and andesitic volcanics and clastic sediments of the Upper to Mid Devonian Karasay Formation (or suite) and the Lower Devonian Koktaus Formation. Upper Devonian leucogranite of the Dzhusandaly Massif occurs as cupolas. Intrusive stocks, dikes, and/or sills consist of quartz-, granite-, diabase-, diorite-, and gabbro-porphyry, and andesite-basalt. Wall rocks are altered mainly by beresitization.

Mineralization consists of coffinite, uraninite, and brannerite associated with Mo and other sulfides that form stockwork-type ore bodies. Most ore lodes occur in subvolcanic rhyolite bodies close to the contact with granite controlled by the intersection of steep, NE-SW-oriented fracture zones with the NNW-SSE-trending, 65° W dipping contact fault. Some ore bodies also locate in fracture zones at the contact of extrusive and intrusive volcanics. Ore bodies range from 50 to 220 m long and deep, from 3.5 to 40 m thick, and have grades from 0.08 to 0.5% U. Ore persists to depths of 1 200 m.

6.5.2.3 Dzhusandalinskoye

Dzhusandalinskoye is a developed prospect situated 12 km SW of Botaburum. It was discovered in 1981 and consists of the *Northern* and *Southern sectors*. Resources are in excess of 5 000 t U and average 0.239% U.

Host rocks consist of Upper Devonian leucogranite and microcline granite of the Dzhusandaly Massif, which are cut by diorite, diabase porphyry, and quartz porphyry dikes. Three structural elements dominate the deposit terrane: the NNE-SSW-trending Daike zone, 600 m wide, with 7 fracture and cataclastic zones, each 10–50 m wide; ENE-WNW fracture zones; and the N-S-oriented Dzhusandalin structure with eight, from 8 to 20 m wide faults. Mineralization consists of coffinite and pitchblende contained in stockwork or column-like ore bodies that are embedded in wall rocks altered by quartz-carbonate-albite and hydromica-calcite facies. Ore bodies group in the Northern and Southern sector in which they are controlled by the intersection of the Daike and Dzhusandalin zones with quartz porphyry dikes. Each sector consists of isolated ore bodies distributed to depths of 1 000 m. Ore bodies are from 300 to 400 m long, 12–120 m thick, persist for 140–160 m downdip, and grade from 0.03 to 1.4% U.

6.5.3 Southern Pribalkash Region

The southern Pribalkash region includes the *Kurday* and *Kopalysay* U deposits. The latter is a small sandstone rollfront-type U deposit in Lower Silurian sandstone with resources of less than 5 000 t U at a grade of <0.1% U.

6.5.3.1 Kurday, Kendyktas Area

Kurday is a volcanic stockwork deposit located in the Kendyktas area, about 200 km W of Almaty and 40 km E of Georgievka. It was discovered in 1951 and had original resources of about 3 500 t U at an average grade of 0.6% U. The deposit was mined by open pit and underground methods and is depleted.

Kurday is hosted in Devonian porphyritic granodiorite of the Kurday Complex, which was intruded into Upper Proterozoic-Lower Cambrian metamorphites. Upper Devonian-Carboniferous dioritic dikes and stocks, felsite dikes, and quartz-sulfide veins dissect the country rocks. The regional Kurday fault zone is a major, NW-SE-trending, steeply NE-dipping structure in the area and exerts the primary control on the position of the Kurday ore lodes. Ore lodes occur within this fault zone at the intersection with other structures, but likewise along blastomylonite sutures, felsite dike contacts, and fracture zones (Fig. 6.22c). The ore hosting lithologies are altered by albitization, beresitization, and carbonatization.

Mineralization occurs in discontinuous lenticular stockwork and vein lodes, which are from 1 to 300 m long, from 1 to 50 m thick, and persist over vertical intervals from 30 to 210 m. Grades range from 0.03 to 1.5% U. Major lodes occur on both sides of a steeply NE-dipping, up to 20 m wide felsite dike. Rocks are heavily brecciated and altered for up to 30 m wide on the NE side and for up to 10 m wide on the SW side of the felsite. Each of these two cataclastic zones contain a stockwork-type U-Mo ore body composed of an up to 8 m wide core with grades in excess of 0.1% U. The core in the NE zone extends to a depth of ca. 30 m and that in the SW zone to about 65 m. Both ore zones are surrounded by lower grade aureoles ranging from 0.03 to 0.1% U. The lower grade NE zone is up to 35 m wide and persists to a depth in excess of 130 m. The SW zone is about 15 m wide near surface, narrows down at depth and extends, with barren intervals, to about 100 m deep. Several narrow ore bodies with variable depths extensions occur discontinuously on both extremities but particularly on the NE side of the main ore zones to depths of 500 m.

6.5.4 Granitnoye Ore Field

The Granitnoye ore field is located in a Cenozoic depression at the northern margin of the Betpak Dala area (Fig. 6.1). Two basal-channel sandstone-type U deposits, *Talas* and *Granitnoye*, each containing a few hundred tonnes of uranium at ore grades of less than 0.1% U, occur in Miocene paleochannels filled with carbonaceous, clayey, and gravelly sands overlain by mud and gravel sand.

At *Talas*, mineralization occurs as lenses in basal sediments of the Aral-Pavlodar complex. Lenses are some tens of meters wide, up to 1 m thick, and range in length from some tens to several hundreds of meters elongated along the channel axes. Uranium is preferentially concentrated in grey, carbonaceous, argillaceous sediments close to the contact with sands while sands tend to contain only minor mineralization. At *Granitnoye*, the ore setting is similar to Talas but U mineralization occurs additionally in the weathered crust of the underlying pre-Mesozoic granite basement (Petrov et al. 1995).

6.6 Ily Region, SE Kazakhstan

The Ily uranium region is situated in southeastern Kazakhstan. It stretches along the Ily River from Lake Balkhash to the Chinese border and into NW China. The Ily region occupies parts of two basins, to the north a western segment of the Balkhash Basin referred to as Nizhne-Ily Subbasin, and the southerly adjacent Ily Basin.

Resources of the Ily region are about 130 000 t U in the <$130 per kg U cost category. They include 92 900 t U RAR + EAR-I and 37 000 t U EAR-II. 28 900 t U of the RAR are attributed to the <$80 per kg U cost category (Abakumov 1995). The given uranium resources are contained in three major deposits, the lignite-type *Nishne-Ilyskoye* and *Koldzhat* and the sandstone-type *Suluchekinskoye* deposits, which were developed but never mined. In addition, a number of small sandstone-type U deposits also occur, such as *Kalkan* and *Aktau* (Fig. 6.1).

6.6.1 Western Balkhash Basin/Nizhny-Ily Subbasin

The large Balkhash Basin extends from Lake Balkhash for hundreds of kilometers eastwards into the Xinjiang region in NW China and southwards to about Almaty. The basin includes in its northwestern section the Nizhne-Ily Subbasin, which hosts the Nizhne Ilyskoye lignite-uranium deposit.

Sources of information. Abakumov (1995), Kislyakov and Shchetochkin (2000), Petrov et al. (1995), and Shchetochkin and Kislyakov (1993) unless otherwise cited.

Regional Geological Features of the Nishny-Ily Subbasin

The Nizhny (Lower)-Ily Subbasin is characterized by and resulted from block faulting along NW-SE- and about N-S-oriented deep faults. Grabens are downfaulted into Paleozoic rocks and filled with Jurassic sediments including a 125–260 m thick unit of Lower to Middle Jurassic lignite-bearing facies. The lignite facies lies at a depth of 100–500 m. Upper Tertiary and Quaternary sediments up to several hundred meters thick cover the pre-Tertiary lithologies.

The grabens are relics of Mesozoic intermontane depressions within a large central Asian orogenic belt. Tectonic reactivation in pre-Oligocene time generated sublongitudinal faults, which now define the geometry of the grabens. Rocks of uplifted blocks were strongly eroded leaving only thin remnants of Jurassic strata.

6.6.1.1 Nizhne Ilyskoye

The Nizhne Ilyskoye lignite-U deposit was discovered approximately 300 km NW of Almaty near the western margin of the Nizhny-Ily Subbasin in 1973 and was explored from 1978 to 1980. In situ resources are 60 000 t U at a grade on the order of 0.1% U. The deposit is developed but mining has been postponed due to unfavorable economics.

Geological Setting of Mineralization

The Nizhne Ilyskoye deposit occurs in a buried NW-SE-oriented, 100 km long and 15–20 km wide graben. The graben is downfaulted into a basement composed predominantly of Devonian porphyry (Figs. 6.23a,b). A bauxite-bearing paleoregolith zone, as much as 40 m thick, is developed on the basement.

Jurassic continental sediments fill the graben. A single sequence of Lower to Middle Jurassic alternating alluvial, lacustrine, and paludal sediments up to 200 m thick forms the basal unit. Medium-grained, polymict sandstone is the prevalent lithology. It encloses discontinuous, partly carbonaceous gritstone and pelite beds from a few meters to 25 m thick, and in the upper section a lignite seam up to 56 m thick. On the NE side of the graben, the seam is of massive nature and abuts against the paleovalley slope. The seam splits up and pinches out to the southwest. Upper Jurassic arenite, 20–100 m thick, rests on the older Jurassic suite. A blanket of 100–120 m thick Neogene (Ng_2) mud-silt overlain by 80–100 m thick Quaternary sand buries the Jurassic rocks (Figs. 6.23b,c).

The Jurassic sediments are almost horizontally bedded while the overlying Cenozoic sediments are distinctly inclined to the east attesting to a complex tectonic history of the region.

Host Rock Alteration

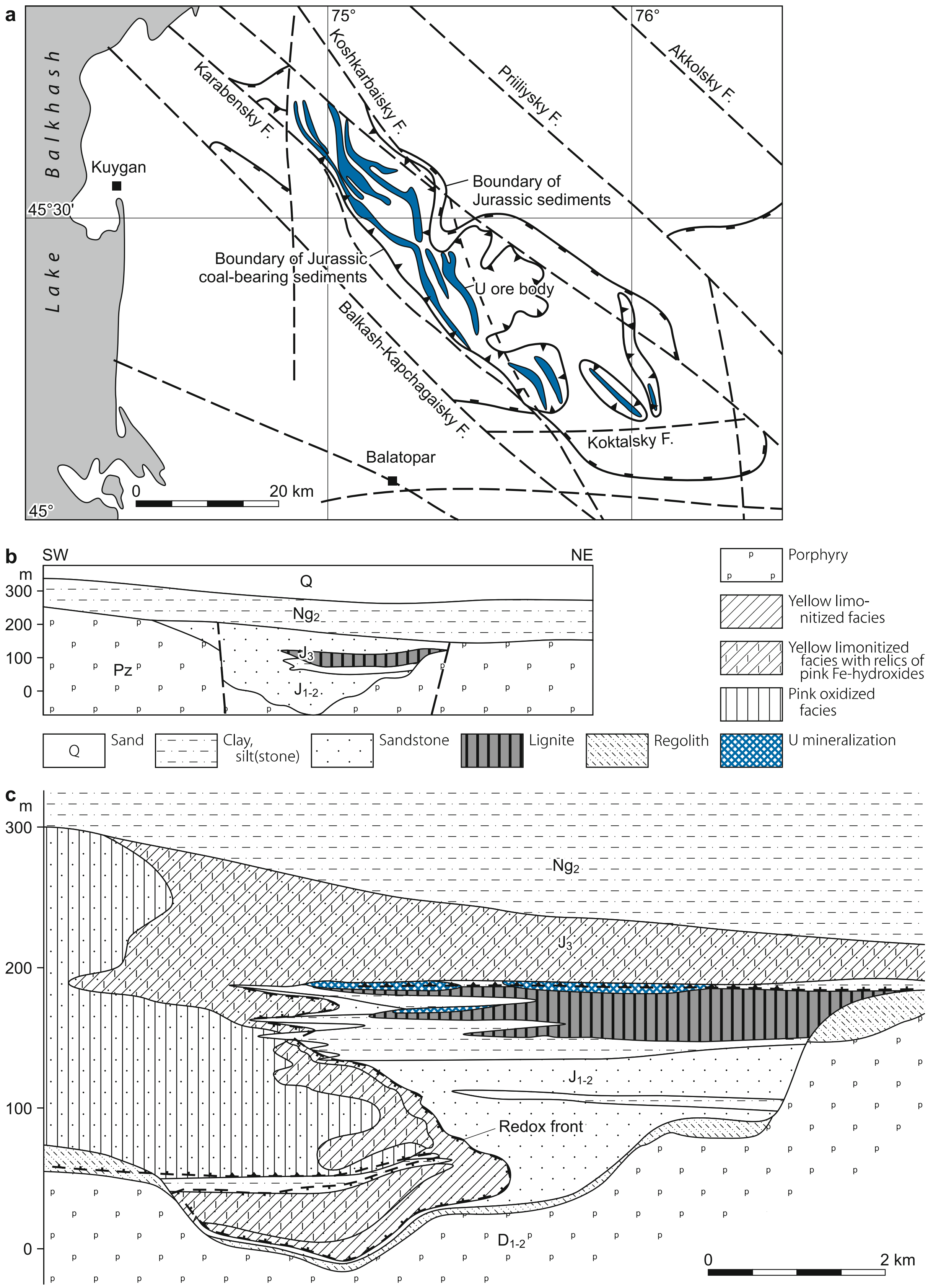
Prominent regional alteration features in Jurassic rocks include oxidation and reduction effects reflected by grey, pink, and yellow-colored facies. They derived by three prominent alteration stages (Fig. 6.23c):

1. An early epigenetic oxidation stage has transformed originally grey facies into pink (hematitic) facies prior to their burial under an aquiclude of Neogene clay and gypsiferous sand. The process affected the whole of the Upper Jurassic sediments overlying the lignite seam and, in sections where the seam wedges out, the complete Jurassic sequence down to and into the basement. Remnants of this oxidation phase are also found in re-reduced facies. Circumstantial evidence deduced from other parts of central Asia suggests that the oxidation period occurred during Late Jurassic time.
2. Re-reduction followed the oxidation period and affected parts of the sedimentary accumulation. Reducing agents supposedly evolved by oxidation of organic matter that generated organic acids and associated reductants such as hydrogen sulfide, hydrogen, and methane, which migrated through and reduced parts of the formerly oxidized sediments.
3. Late oxidation reflected by yellow colored, limonitized rocks overprinted predominantly re-reduced facies. It extends only slightly into the zone of early oxidation.

Mineralization

Mineralization is polymetallic composed primarily of U-Mo accompanied by trace amounts of other elements. *Uranium minerals* include pitchblende and sooty pitchblende (black products), which constitute approximately 80% of the U minerals fraction while coffinite accounts for about 20%. Additional U minerals include rare ianthinite, mourite, fourmarierite, U-selenide, and studtite. A major fraction of the uranium is adsorbed by carbonaceous matter in limonitized lignite. The principal *Mo-minerals* are ilsemannite, jordisite, and less common molydenite and

Fig. 6.23.
Ily Regin, Balkhash Basin, Nizhne-Ilyskoye, a map of the northwestern Balkhash Basin showing the graben structure hosting uraniferous lignite seams. U is concentrated in the roof section of the seams. b Litho-stratigraphic SW-NE section, c litho-geochemical section illustrating the style and distribution of alteration features, (after a Petrov et al. 1995; b, c Shchetochk in and Kislyakov 1993)



molybdite. *Associated minerals* include mainly ferroselite, marcasite, pyrite, and minor to rare, arsenolite, chloantite, galena, orpiment, radiobaryte, realgar, skutterudite, sphalerite, tennantite, and native lead and selenium.

A number of *trace elements* occur in the deposit. Two elemental groups are distinguished: Uranium ore zones contain Ag, Cd, Co, Ga, Ge, Mo, Ni, Re, Tl, and Zn, while limonitized lignite contains Be, Cu, Pb, Sc, Se, V, Y, Zr, and REE.

Shchetochkin and Kislyakov (1993) report an oxidation-related vertical zoning of ore grade. From top to bottom:

1. oxidized clastic sediments subdivided into a subzone of pink facies (due to pink Fe-hydroxides) and a subzone of yellow facies (due to yellow Fe-hydroxides);
2. strongly oxidized limonitized lignite with appreciable high residual concentrations of up to 0.03% U;
3. weakly altered mineralized lignite subdivided into disintegrating ore, high-grade ore (>0.1% U), average ore (>0.05% U), and marginal U concentrations; and
4. unaltered barren lignite.

Ore minerals occur in a finely dispersed distribution concentrated in lenses in the hanging wall part of the lignite seam. The position of ore lenses is controlled by the permeability of overlying clastic sediments. U grades are highest below fluvial gritstone and coarse-grained sandstone channels located at the base of the Upper Jurassic suite. The uranium content drops sharply where argillaceous beds, even of thin thickness, overlie the lignite seam.

The bulk of the uranium ore is confined to lignite. Carbonaceous clays have poor U tenors. No uranium is found at the boundary of oxidation zones with grey sandstone.

Shape and Dimensions of Deposits

The Nizhne Ilyskoye deposit consists of 48 ore bodies contained in a zone about 40 km long and 100–2 000 m wide positioned in a NW-SE-oriented graben structure. Ore occurs at depths from 100 to 500 m. Ore bodies are of lenticular configuration and are largely restricted to the upper two meters of the lignite seam. Lenses are from less than 1 m to 4 m thick, range in size from 0.1 to 3.2 km^2, and contain from less than 0.05 to 2% U averaging 0.1% U, 0.03% Mo, <30–60 ppm Ag, and <2–5 ppm Re. Barren or weakly mineralized ground interlinks the ore bodies.

Ore Controls and Recognition Criteria

Host Environment

- Intermontane, narrow but long graben structure
- Graben downfaulted along NW-SE-trending regional faults cut by younger N-S faults
- Basin fill of Jurassic continental, lignite-bearing sediments of various provenance
- Overburden of Neogene and Quaternary ± impermeable sediments
- Basement largely composed of porphyry
- A lignite seam is host for mineralization

Alteration

- Oxidation during two events, a late synsedimentary and a postsedimentary
- Re-reduction intervening between the two oxidation events

Mineralization

- Polymetallic U-Mo mineralization associated with a great number of trace elements
- Lenticular ore bodies composed of adsorbed U and dispersed ore minerals
- Highly variable U grades
- Discontinuous distribution of ore bodies
- Location of ore bodies almost exclusively within top part of a thick lignite seam

Geochemistry

- Reducing environment provided by organic material and gaseous reductants
- Gaseous reductants (H_2S, methane) generated by oxidative destruction of organic matter
- Presumable involvement of appreciable amounts of organic acids in metallogenesis
- Probably only low U tenors in mineralizing groundwater
- Mineralizing solutions presumably identical with waters that generated secondary oxidation
- Deposition of mineralization at a secondary oxidation front (yellow facies) within altered lignite

Metallogenetic Aspects

Following Shchetochkin and Kislyakov (1993), the Nizhny-Ily Subbasin evolved through and experienced a number of geological, climate-related geochemical and geohydrological processes, which finally led to the formation of the Nizhne Ilyskoye U-Mo deposit. The following sequence of events is recorded:

1. Downthrust of a deep graben in an area of rugged morphology with high relief.
2. Intense and deep weathering of the Paleozoic rocks not later than Early Jurassic.
3. Filling of the graben by various carbonaceous clastic sediments of continental provenance during Jurassic time.
4. Development of a hydrodynamic system by more or less vertically percolating, oxygenated waters (ground infiltration) during the waning episode of sedimentation and the structural completion of the graben. Contemporaneous change of climate to semiarid conditions of about savanna type during the Late Jurassic.
5. Mobilization and transport of uranium by oxygenated groundwater but uranium transport probably in very minor concentrations as may be deduced from the Late Jurassic climate and sites of uranium deposition. The climate was characterized by considerable annual rainfall, which supposedly controlled the irrigation regime of groundwater and prevented, due to its quantity, any appreciable concentration of uranium in the groundwater. A complete lack of U

concentration at redox boundaries between pink and grey sandstones is considered indicative for low U contents in groundwater.
6. Substantial amounts of U only accumulated only at interfaces with a distinct reduction-oxidation contrast, which only existed in highly carbonaceous sediments like lignite.

The development of an early, more or less vertically progressing oxidation process by unconfined oxygenated waters is the critical element in the formation of the U-Mo mineralization. This event oxidized parts of the grey Jurassic sediments and turned them into a pink facies. This early oxidation stage must have been active prior to the burial of the Jurassic sequence under a Neogene argillaceous aquiclude as indicated by the distribution of the pink facies. Circumstantial evidence from similar continental basins in central Asia suggest that the most likely time of this oxidation event was during the Late Jurassic.

A favorable, strongly reducing environment was presumably achieved by the decomposition of carbonaceous matter by oxidation, which generated organic acids and reductants such as hydrogen sulfide, hydrogen, and methane. Migration of the reductants re-reduced the earlier formed pink facies and also acted as reductants for the U^{6+} in solution.

The presence of a large variety of trace elements in mineralized lignite including those of low migration capacity in a supergene environment (Zr, Be, Y, REE, SC etc.) suggests the involvement of considerable amounts of organic acids in the metallogenesis. The formation of the acids in response to oxidative disintegration of organic substances is supported by the presence of carboxyl (COOH) compounds in limonitized lignite.

Precipitation of uranium (and other elements?) occurred preferentially in the upper part of the main lignite seam but substantial ore grade accumulation developed almost exclusively at sites where the seam was overlain by permeable channel facies. Mineralization starts about 0.2–0.4 m below the hanging wall contact. This interval coincides with the interface of unoxidized lignite and yellow colored, secondarily oxidized facies with remnants of the pink facies. These lithologic-geochemical relationships and the kind of ore distribution suggest that the ore-forming processes took place in late or post-Jurassic time and were associated with the yellow coloring oxidation event.

6.6.2 Ily Basin

The Ily Basin is an E-W-elongated depression extending from west of Almaty eastwards to the Chinese border and into Xinjiang in NW China where the basin has the largest expansion. A number of U deposits/occurrences of lignite type, such as *Koldzhat*, and of sandstone type are reported. The latter include the large *Suluchekinskoye* and several small deposits such as *Kalkan, Aktau*, and *Malai-Sary* (Fig. 6.1).

Sources of information. Abukumov 1995; Kislyakov and Shchetochkin 2000; Petrov et al. 1995; Shchetochkin and Kislyakov 1993; Petrov and Yazikov pers. commun. 2003.

Regional Geological Setting of Mineralization

The Ily Basin is an E-W-oriented depression, up to 100 km wide, filled with Mesozoic-Cenozoic sediments. Paleozoic rocks constitute the basement. The litho-stratigraphy section consists of continental clastic sediments separated into a Tertiary-Cretaceous and a subjacent Middle to Lower Jurassic suite. Both units contain lignite seams. Lignite-bearing Jurassic sediments occur in the Kazakh part of the basin over a length of 30 km along regional strike and 30 km downdip. The lignite-bearing sequence crops out in the southern part of the basin and dips at 5–7° N. It reaches a depth of 1 500 m or more in the axial zone of the basin.

6.6.2.1 Koldzhat

The Koldzhat deposit (also spelled Koldjat) is located approximately 300 km E of Almaty and extends from the Chinese border in the SE toward the NW. Koldzhat is considered a U-Mo-lignite deposit. Coal was discovered in 1957 and two years later (1959) two uraniferous coal seams were intersected by drilling. Underground exploration to a depth of 600 m took place from 1969 to 1978. In situ resources of Koldzhat amount to 37 000 t U. Grades average about 0.1% U. The subsequent synopsis is largely based on Petrov et al. (1995).

Geological Setting of Mineralization

Koldzhat is situated at the southwestern flank of the Ily coal basin. Basin fill consists of Cenozoic-Mesozoic continental sediments, up to 1 000 m thick, which rest unconformably upon Upper Paleozoic sediments and volcanics. The litho-stratigraphic sequence includes:

- *Quaternary*: up to 150 m thick, boulder-pebble sediments
- *Pliocene*: up to 140 m thick, yellow sandstone
- *Miocene-Oligocene*: 30–35 m thick, pink mudstone
- Late Cretaceous:
  - *upper unit,* 120–200 m thick, alluvial and lacustrine sandstone with pelite lenses
  - *lower unit,* 30–50 m thick, red-brown conglomerate, gravel, sand-, silt-, mudstone
- >Unconformity<
- *Middle-Lower Jurassic*: 50–220 m thick, grey, pink or yellow-brown oxidized lacustrine, alluvial, and peat sediments. This suite is 50–100 m thick in the southern, and thickens to 180–220 m in the northern part of the deposit; it occurs within a depth interval from 25 to 450 m in the S and from 550 to 700 m in the N part of the deposit. Five sedimentary cycles are recognized each consisting of conglomerate (partly with carbonate cement), gravel, sand-, silt-, mudstone beds with interbedded lignite seams. Cycle thicknesses are: cycle 1: 20–25 m, cycle 2: 15–17 m, cycle 3: 25–65 m, cycle 4: 25–35 m, and cycle 5: 40–120 m
- *Upper Triassic*: grey and yellow-brown mud-, silt-, sandstone, 180–210 m thick; and conglomerate, 65–85 m thick
- >Unconformity<

- *Middle-Upper Permian*: 200–250 m thick, tuff
- *Lower Permian*: andesite and diabase porphyrite and their tuffs

Host Rock Alteration

Prominent regional alteration features in Jurassic rocks include oxidation and reduction effects reflected by grey, pink (ground oxidation), and yellow-brown-colored (bed oxidation) facies.

Mineralization

Pitchblende, sooty pitchblende, and coffinite are the principal uranium minerals; they constitute 76%, 14%, and 10%, respectively, of the total U present. Molybdenum minerals include ilsemannite, jordisite, and molybdenite. Associated Fe-sulfides include pyrite and marcasite. Mineralization has a disseminated texture and occurs in variably shaped ore bodies within Jurassic lignite-bearing clastic sediments. Uranium is concentrated in lignite seams as well as in sand-conglomerate beds (see below) while molybdenum enrichment is restricted to U ore bodies in lignite.

Shape and Dimensions of Deposits

The Koldzhat deposit covers an arcuate, NW-SE-elongated area, some 16 km long and as much as 7 km wide, in which several lignite seams exist including two major seams: # IV and # V. *Seam # IV* is 11 km long, 7 km wide, covers 62.6 km^2 and occurs at depths from 120 to 190 m; it is 2.5–3 m, locally as much as 5.6 m thick and averages a thickness of 2.77 m. *Seam # V* is 20–23 m thick, 7 km long, 5 km wide, covers 32.5 km^2, and occurs within a depth interval of 300–600 m.

Uranium occurs in 7 horizons, 3 lignite and 4 sandstone, within two curved, NW-SE-trending belts (in planview). The *southern belt* is 12 km long, up to 1.5 km wide, with depths of 30–50 m in the eastern, 120–300 m in the central, and 1 000–2 000 m in the northwestern section; it contains uranium in the # III and # IV lignite horizons, and in the # IV sandstone horizon. The *northern belt* is 16 km long, 1–2 km wide, and 300–600 m deep; it contains uranium in lignite horizon # V, and sandstone horizons # II, # III and # V.

Lignite contains 58.5% and sandstone 41.5% of the uranium resources of Koldzhat. The resources are distributed in the various horizons as follows: lignite horizon # III contains 6%, # V 51%, and # VI 2%; sandstone horizon # II contains 6%, # III 26%, # IV 6%, and # V 3%.

Uranium ore bodies have roll, tabular, and lenticular shapes. Roll-type lodes are typical for sandstone hosted ore while tabular and lenticular ore occurs preferentially in lignite. Ore bodies are from 0.5 to 14.5 km long, 20–2 000 m wide, and as much as 2 m thick. The uranium content is irregular but ranges commonly from 0.05 to >0.1% U.

Ore Controls and Recognition Criteria

Host Environment

- Intermontane, narrow but long basin of graben structure
- NW-SE-trending regional faults control the graben
- Younger N-S faults cut the graben fill
- Basin is filled with Cretaceous and Jurassic continental, lignite-bearing sediments
- Overburden consists of Neogene and Quaternary sediments
- Basement is largely composed of mafic to intermediate volcanics
- Host rocks include lignite and sandstone-conglomerate

Alteration

- Oxidation during two events, a late synsedimentary and a postsedimentary
- Re-reduction intervened between the two oxidation events

Mineralization

- Polymetallic U-Mo mineralization in lignite, simple U mineralization in sandstone and conglomerate
- Disseminated texture of ore
- Lenticular and tabular ore bodies in lignite, roll-type ore bodies in sandstone beds
- Location of lignite-hosted ore almost exclusively within top part of lignite seams
- Variable U grades
- Discontinuous distribution of ore bodies

Metallogenetic Aspects

The evolution of the Ily Basin and the formation of the Kolzhak deposit are thought to be similar to that of the Nizhny-Ily Subbasin and of the Nizhne Ilyskoye U-Mo deposit, respectively, described in the previous chapter.

6.6.2.2 Suluchekinskoye

Suluchekinskoye is located 5 km N of the Ily river in the northeastern Ily Basin, close to the Chinese border and some 200 km NE of Almaty. It was discovered in 1978 and contains 33 000 t U at grades ranging from 0.07–0.13% U. The rollfront-type sandstone deposit was developed for ISL operation but did not reach production.

Ore bodies of the Suluchekinskoye deposit occur at the East Kalkanskaya anticline, which is composed of Middle Cretaceous to Neogene sediments. Host rocks are fine- and middle-grained quartz-feldspar sandstones with some interbedded clay, silt, and gravel lenses of the 60–120 m thick Lower Paleogene-Middle Cretaceous Ily Formation. They are overlain by pink or mottled sandstone and green-grey clay of the Eocene Aktau Formation upon which limy and silty clays rest. Neogene sediments form the uppermost layer and include the 60–90 m thick Pavlodar Clay Suite and the 50–330 m thick Ily Suite. The latter is composed of silt, sand, and clay. Paleozoic tuff and tuffaceous sandstone form the basement and outcrop to the northeast and west of the deposit.

Alteration includes epigenetic reducing processes with intense pyritization of the host rocks. Subsequently, an oxidation tongue penetrated the Ily Formation from the east. Rollfront-type ore bodies occur at the redox interface and display a zonal distribution of elements. Rhenium penetrates furthest into reduced ground followed by a U-Re zone. Selenium forms the rear of a roll in oxidized ground. Ore grades vary between 0.07 and 0.13% U, 1 and 24 ppm (av. 1–2 ppm) Re, and 10 and 30 ppm Se. Se can increase to more than 100 ppm in limonitized intervals. Uranium is present as pitchblende and coffinite. The former constitutes 82% of the ore. Selenium occurs as native selenium and ferriselite.

Ore bodies are spread over an area 24 km long in an E-W direction and 150–8 000 m wide. Depths range up to 700 m. Individual ore bodies are 2–6 km long, 150–2 000 m wide, and 2–3 m thick.

The metallogensis is attributed to strata-infiltrational processes that took place during the Late Oligocene-Miocene; but the ore formation was apparently hampered and complicated by the injection of abyssal reducing solutions, which entered the aquifers along deep faults.

6.6.2.3 Kalkan, Aktau, Malai Sary

Kalkan (or Kalkanskoye) and Aktau occur some 5 km W and 10 km SE of Suluchekinskoye, respectively, and Malai-Sary and other small deposits about 50 km NE of Almaty. These deposits belong to a group of small sandstone-type U deposits hosted by Tertiary-Cretaceous continental clastic sediments. Most of these deposits are controlled by small islands of relic grey, reduced facies in the basal part of Campanian and Maastrichtian strata that rest upon Permian, mostly volcanic strata.

6.7 Zhalanshiksky Region, Central Kazakhstan

Two sandstone-type U occurrences are known in this region, *Lazarevskoye* and *Lunnoye* (in Torgae) (Fig. 6.1). U mineralization associated with disseminated vegetal debris occurs as lenses, as much as several hundred meters long, in Paleogene argillaceous sand- and siltstone. The mineralized strata are sandwiched between clay beds and contain up to 0.4% U. Organic carbon ranges from 10 to 27%. Pitchblende and coffinite are identified with organic matter in high-grade ore (Petrov et al. 1995).

6.8 Turgai-Priyrtish Region, Northern Kazakhstan

Several U occurrences are known in the Turgai-Priyrtish region in northern Kazakhstan in the southern extension of the Transural region, Russia. They tend to belong to the same basal-channel sandstone-type deposits as those in the Transural region. Reported occurrences include *Tobolskoye, Sensharskoye, Koitass, Pjatigorsk, Torfjanoye*, and *Aurtav* (Fig. 6.1).

6.9 Isolated Uranium Deposits/Occurrences in Kazakhstan (Fig. 6.1)

6.9.0.1 Panfilovskoye, SE Kazakhstan

This deposit is located 270 km ENE of Almaty within the South Dzhungar Basin. Permian felsite-porphyry forms the core of a syncline, which is cut by steeply inclined tectonic zones intruded by diabase-porphyry dikes and stocks that control the mineralization. Seven steep ore zones, 800–1 500 m long and from 50 to 150 m apart, are identified; four zones are of simple configuration associated with one dike, and three are of complex configuration associated with several dikes. Simple zones are up to 2 m and complex zones up to 60 m thick. Wall rocks are altered by carbonatization, hematitization, and chloritization.

Mineralization occurs in veins with pitchblende and uraninite as the principal U minerals; in stockworks which typically contain uranophane, sooty pitchblende, and uranospinite; and in small lenses composed of thin carbonate-pitchblende veinlets as much as 5 cm thick. Four stockwork ore bodies occur in the central part of the deposit, they are from 22 to 70 m long, 2–17 m wide, and persist to depths of 400 m. Grades average 0.061–0.086% U (Petrov et al. 2000).

6.9.0.2 Ulken Akzhal, E Kazakhstan

Ulken Akzhal is situated in the central part of the Chingiz-Zaisan area, some 300 km W of Semipalatinsk in eastern Kazakhstan. Resources amount reportedly to about 2 000 t U and average 0.172% U. The deposit is explored but not yet mined (status 2004).

The area is underlain by Carboniferous to Permian granitoids and Permian volcanics. A caldera filled with felsic volcanics, 1 200–1 700 m thick, includes, from top to bottom, trachyrhyolite-porphyry, felsite, dacite, and andesite-porphyry, and contains U mineralization in the hanging and footwall of a brecciated dacite horizon, 400 m thick, which occurs in the intermediate part of the volcanic sequence. Several ore sectors are identified with principal resources contained in the Central sector. Mineralization occurs in steep NE-SW fault zones along the contact of lithified rhyolite-dacite and felsite breccia. Wall rocks are altered by argillization, beresitization, and hematitization. Oxidation penetrates from surface to depths of as much as 40 m and to 250 m along faults. Primary ore consists of pitchblende associated with sulfides that form lens, vein, stockwork, or column-like ore bodies with dimensions of up to 100 m long, up to 9 m thick, and up to 140 m deep (Petrov et al. 2000; Petrov pers. commun. 2003).

6.9.0.3 Kyzyl, E Kazakhstan

This deposit is located 115 km N of Lake Balkhash in central-eastern Kazakhstan. Resources are less than 5 000 t U. Country rocks consist of volcanics of the basal Upper Carboniferous Keregetas Formation composed of dacite porphyry and rhyolite, and the Upper Carboniferous–Lower Permian Arkharlin Formation. Intrusions include felsic subvolcanic stocks, sills, necks, and dikes. The deposit occurs at the intersection of the NW-SE-oriented Ulken-Karaobin and the NE-SW Keregeshal-Symbyl abyssal zones.

Five lenticular ore bodies with pitchblende as the principal U mineral occur to depths of 175 m in fracture zones in the hanging and footwall of the NW-SE Rudny fault. Host is rhyolite porphyry tuff altered by argillization, hematitization, and silicification. Ore bodies are 80–220 m long, 1–10 m thick, and persist from 30–50 m downdip. Ore grade is as much as 0.6% U and averages 0.226% U in the largest ore body # 4 (Petrov et al. 2000).

6.9.0.4 Kuray, Central Kazakhstan

Kuray is a basal-channel sandstone-type U deposit located S of the town of Dzhezkazgan in central Kazakhstan. Uranium occurs in a 4–7 km wide channel incised into a pre-Mesozoic basement. The channel is filled with Senonian-Paleocene argillaceous sands, which are oxidized in the marginal zones and reduced in the axial part of the channel. Several elongated ore bodies, up to several kilometers long, are delineated in the reduced sediments. Mineralization consists of U associated with Mo and Se; the latter two range from 0.01 to 0.1% (Petrov et al. 2000).

References and Further Reading for Chapter 6 · Kazakhstan

For details of publications see Bibliography.

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