TAMARA DUDAR
GEORGII LYSYCHENKO
MARHARYTA BUHERA

URANIUM RESOURCES OF UKRAINE:
GEOLOGY, MINERALOGY, AND SOME MINING ASPECTS

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T. Dudar, G. Lysychenko, M. Buhera
Uranium Resources of Ukraine: Geology, Mineralogy, and some Mining Aspects

We present the characteristics of raw uranium resources and the main uranium bearing minerals of commercial deposits in Ukraine. Particular attention is paid to operating, dormant and depleted deposits and geological and mineralogical peculiarities of their resources.

This volume was written for specialists working for nuclear industry and related sectors, including teachers and students of corresponding specialties

ISBN

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INTRODUCTION

The world's demand for energy will continue to increase as a result of economic development and population growth. In this respect the availability of adequate energy supplies at reasonable prices has long been a concern of many countries. One reason for such concerns is that oil and gas resources and production are concentrated in a relatively small number of global regions and alternative energy sources – wind and solar – will not be able to cover energy demands in the near future. In the longer term, there are concerns that as low-cost fossil fuel resources are depleted, extraction will become more costly and potentially more environmentally damaging.

On the other hand, even if for the last years over 90% of the world's uranium output is produced by eight-nine countries, global resources are widespread across the world. Furthermore, the nature of the nuclear fuel cycle means that nuclear plants are not dependent on continuous deliveries of large quantities of fuel. Nuclear fuel has its advantages and disadvantages. One of the main advantages is that it is a very concentrated energy source, and is easy to stockpile. About 25 tons of fabricated fuel will provide a year's supply for a typical nuclear plant, while a coal-fired plant of similar output requires some three million tons of fuel annually.

As to Ukraine, it is considered as a uranium-mining country with Europe's largest resources. Unfortunately, in the nearest future the country is supposed to stay heavily dependent on nuclear energy. In this respect, the capacity of uranium production might be considered through improving the existing production potential. "In Ukraine, ambitious plans are in place to start supplying electricity to the European Union by 2019 via its planned 'energy bridge', was mentioned in the World Nuclear Performance Report 2017 produced by the World Nuclear Association, 2017.

Ukraine is in the top ten countries on proven uranium reserves in the world. More than 45% of the territory of Ukraine settles down on the Ukrainian Shield where the total uranium reserves are mainly found and exploited. Existence of significant proven and projected reserves of natural uranium makes it possible to provide economic independence from the price of external uranium suppliers. Taking into account mentioned above, the topic of this publication is of high interest to policy-makers worldwide as they need to be informed regarding the investment in the power sector.

The Eastern Mining and Ore Dressing Enterprise (VostGOK) is the biggest in Europe and the only enterprise in Ukraine that extracts and processes uranium ore, and produces uranium concentrate. It is located in the town of Zhovti Vody in the Dnipropetrovska Oblast, Central Ukraine. The enterprise currently operates tree mines: Smolinska, Ingulska and Novokostyantynivska. Smolinska mine develops the Vatutinske deposit; Ingulska mine – the Michurinske and Tsentralne deposits, and Novokostyantynivska mine currently operates the Novokostyantynivske deposit. Severynivske deposit is ready for development and put in reserve, while other deposits were evaluated and prepared for a detailed prospecting. The mentioned deposits are the focus of given publication.

Since the experts from the Institute of Environmental Geochemistry, IEG (former Department of Metallogeny of the Institute of Geochemistry, Mineralogy and Ore Formation, National Academy of Sciences of Ukraine) have been involved into scientific research on uranium geology for a very long time and accumulated a lot of experience and archival materials, especially on uranium and its daughter products geology, geochemistry, and the environment [1-3], the authors of this publication set a goal to process available data on geology and mineralogy of uranium deposits based on the STCU Project P-464 [4] results, open published materials, and the authors' research, with a particular focus on commercial uranium deposits and ore mineralization of the Ukrainian Shield.

The environmental impacts of uranium mining and milling activities in Ukraine are severe. These impacts range from connected radon emanations, the creation of massive stockpiles of radioactive and toxic waste rocks and sand-like tailings to serious contamination of surface and underground waters with radioactive and toxic pollutants, and releases of conventional, toxic and radioactive air pollutants [5-7]. Underground uranium mining highly contributes to exit to the surface of huge reserves of radon that was accumulated for millions of years at a depth. Additional cracks appeared in the rock massifs from explosions and from the movement of underground transport, serve as easy pathways for radon emanations coming uplift to the surface. Released cavities are filled in with new gas, which is continuously formed in the decay of radioactive elements. The most hazardous are zones where intensively fractured rocks are located relatively close to the surface. The maximum amount of radon was established in the geodynamically active zones of the sedimentary cover associated with fractured sites in parent rocks. A clear correlation between the detected local sites of high radon emanation level and newest tectonic activation zones was recently confirmed by our research within the Kremenchukske uranium deposits.

In the following we present the basic geological characteristics of the Ukrainian uranium deposits, of these, the Pervomaiske deposit is already depleted, and development of the Zhovtorichenske deposit was stopped despite the associated iron, because of the depth of extraction made the operation unprofitable. The other deposits discussed are either under operation or prepared for development. The deposits are presented according to the World Distribution of Uranium Deposits (UDEPO) database approach (depleted, operating, and dormant deposits), presented on the IAEA website [8]. Their primary characteristics are covered in detail in two fundamental monographs edited by Ya. Belevtsev (1968), and V. Koval (1995) [9, 10], and in a large number of Russian-Ukrainian language publications issued in limited access in the second part of the previous century. During that time, information about the geological structure, genesis, mineralogy, and geochemistry of Ukrainian uranium deposits was not publicly accessible, and lack of English-language literature on this topic was obvious. In this publication the authors included the actual data from mining and scientific organizations, the access to which was severely restricted up till 2008. The deposits passports, compiled according to the IAEA requirements, and the Ukrainian-English uranium geology and mineralogy vocabulary developed in the frame of STCU project P-464 (IEG, 2012) [4] are also included.

I URANIUM ORE DEPOSITS IN UKRAINE

1.1 General Overview and Classifications

Although uranium deposits in Ukraine generally have a low uranium content, the deposits are comparatively large, with thick strata, relatively low water content in the mining tunnels, and only require simple radiation protection. An example of this is the endogenous albitites of the Ingulskyi megablock of the Ukrainian Shield. But in spite of the relatively low U content, the development of mining infrastructure and uranium concentrate production have remained competitive in the market.

A typical example of Ukainian uranium resources is seen in the deposits of the Kirovogradskyi ore region. This ore region is situated in the central part of the Ukrainian Shield within the Central axial uplift of the Korsun-Novoukrainska anticline (Fig. 1.1, based on [2]). The region is elongated latitudinally with meridional granite-gneissic plicated structures and uranium ore fields. It is bounded in the north by the Subbotinsko-Koshorinskyi latitudinal fault and in the east and west by the Kirovogradska and Zvenigorodsko-Annovska tectono-metasomatic zones, respectively; the south has no distinct structural boundary. Seismic studies showed that this ore region is in a latitudinal-strike crustal block with a distinct northern boundary along the Subbotinsko-Moshorinskyi fault, and characterized by a thick crust (45 km) and the occurrence of palingenetic granitoids at 20 km depth.

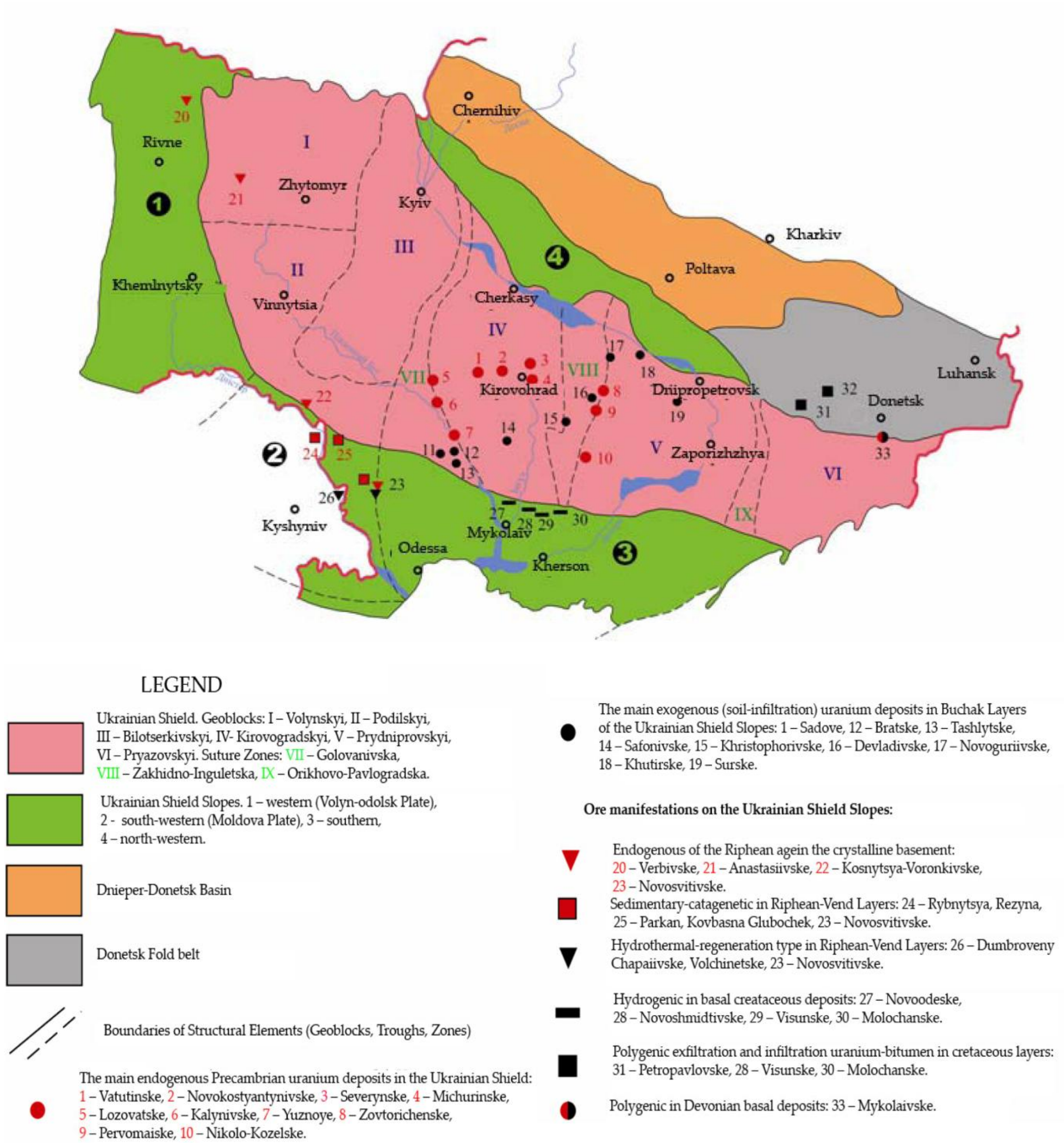

Fig. 1.1 Localization of the major uranium deposits and manifestations on the territory of the Ukrainian Shield and its slopes (according to E.G. Sushchuk, [2])

In Ukraine uranium ore reserves are estimated according to “Application Instruction of Classification of reserves and resources of mineral deposits of State Fund of the earth interior to uranium ores” [11]. According to this classification, deposits are divided into the following groups, based on uranium content, geological complexity, and recognized mineral accumulations with high uranium concentrations: uranium found in findings; uranium found in beds with non-commercial or uncertain characteristics; uranium deposits.

Uranium deposits are divided into four groups according to their reserves:

- small deposits with reserves of hundreds of tons;
- medium deposits with reserves of thousands of tons;
- large deposits with reserves of tens of thousands of tons;
- unique deposits with reserves of hundreds of thousands of tons.

According to uranium content, the ores are divided into:

- lean ores with uranium content less than 0,05%;
- low-grade ores with uranium content 0,05 – 0,10%;
- mine-run ores with uranium content 0,10 – 0,20%;
- high-grade third-class ores with uranium content 0,20 – 0,50%;
- high-grade second-class ores with uranium content 0,50 – 1,00%;
- high-grade first-class ores with uranium content more than 1.00%.

In compliance with item 20 of the Classification of Reserves and Resources of Mineral Deposits of State Fund of the Earth interior, approved by the Resolution of the Cabinet of Ministers of Ukraine dated 5 March 1997, № 432 (432-97-п), ore deposits are divided into four groups based on their size, shape, thickness, internal structure and distribution of useful components in the ores or their sites (considered a raw mineral source for certain enterprises). The four groups are:

- deposits (sites) of simple geological structure with unbroken or weakly broken bedding, stable quantitative and qualitative parameters for the main minerals, and uniform distribution of useful and useless components;

- deposits (sites) of complicated geological structure with variable quantitative and qualitative parameters for the primary minerals, and nonuniform distribution of useful or useless components;
- deposits (sites) of very complicated geological structure with variable quantitative and qualitative parameters for the primary minerals and variable distribution of useful and useless components;
- deposits (sites) of extremely complicated geological structure with highly variable quantitative and qualitative parameters for the primary minerals, and highly variable distribution of useful and useless components.

Variability indexes of the biggest mineral deposits parameters (contained not less than 70% of mineral reserves) are used for determination of complexity of mineral deposit (site) geological structure.

Exploration of uranium ores in Ukraine began in 1944. At that time, military exploration was a high priority and by 1945, the Pervomaiske and Zhovtorichenske deposits were discovered. Later, uranium became a needed raw material for domestic nuclear power plants (NPP) and several large-scale deposits and many more ore manifestations were discovered. Ukrainian uranium resources were estimated at as – 221,000 tU according to the IAEA 'Red Book' 2016, 59,000 tU of these recoverable at under $80/kgU. Reasonably assured resources are 139,400 tU, nearly all in metasomatite deposits in the Kirovogradskyi block of the Ukrainian Shield [12]. According to total resources and proven reserves Ukraine is among the top ten countries in the world and is considered a key producer in Europe (Fig. 1.2).

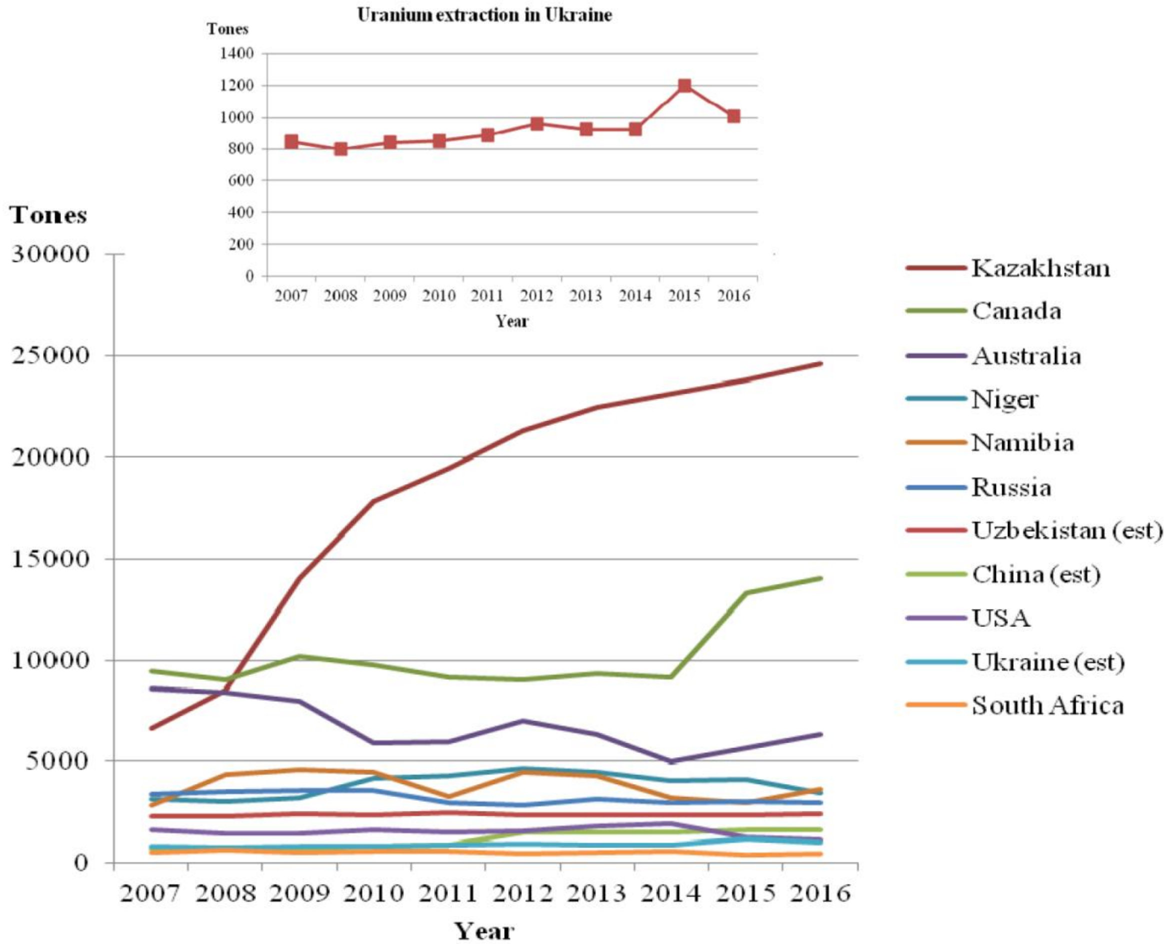

Fig. 1.2 Uranium extraction in the world and in Ukraine

Most Ukrainian deposits are referred to as small to average in size, with the majority of them characterized by insignificant uranium reserves of 1,000 to 5,000 tons. However, the Novokostyantynivske deposit deserves a special mention. According to explored reserves, this is the largest deposit in Europe. The sheer size of this deposit prompted the Ukranian government to start building a new dressing enterprise. However the construction was frozen later on for uncertain time. More details of the geological characteristics of the Novokostyantynivske deposit are discussed below.

Commercial uranium deposits in Ukraine are typically found as endogenous deposits in albitites and exogenous deposits in basic sediments of the Ukrainian Shield. There are 12 endogenous uranium deposits with total reserves capable of providing currently operating domestic NPP with fuel for almost 100 years. The largest of the endogenous deposits are located within the Kirovogradskyi ore region (Fig. 1.3. from [1]).

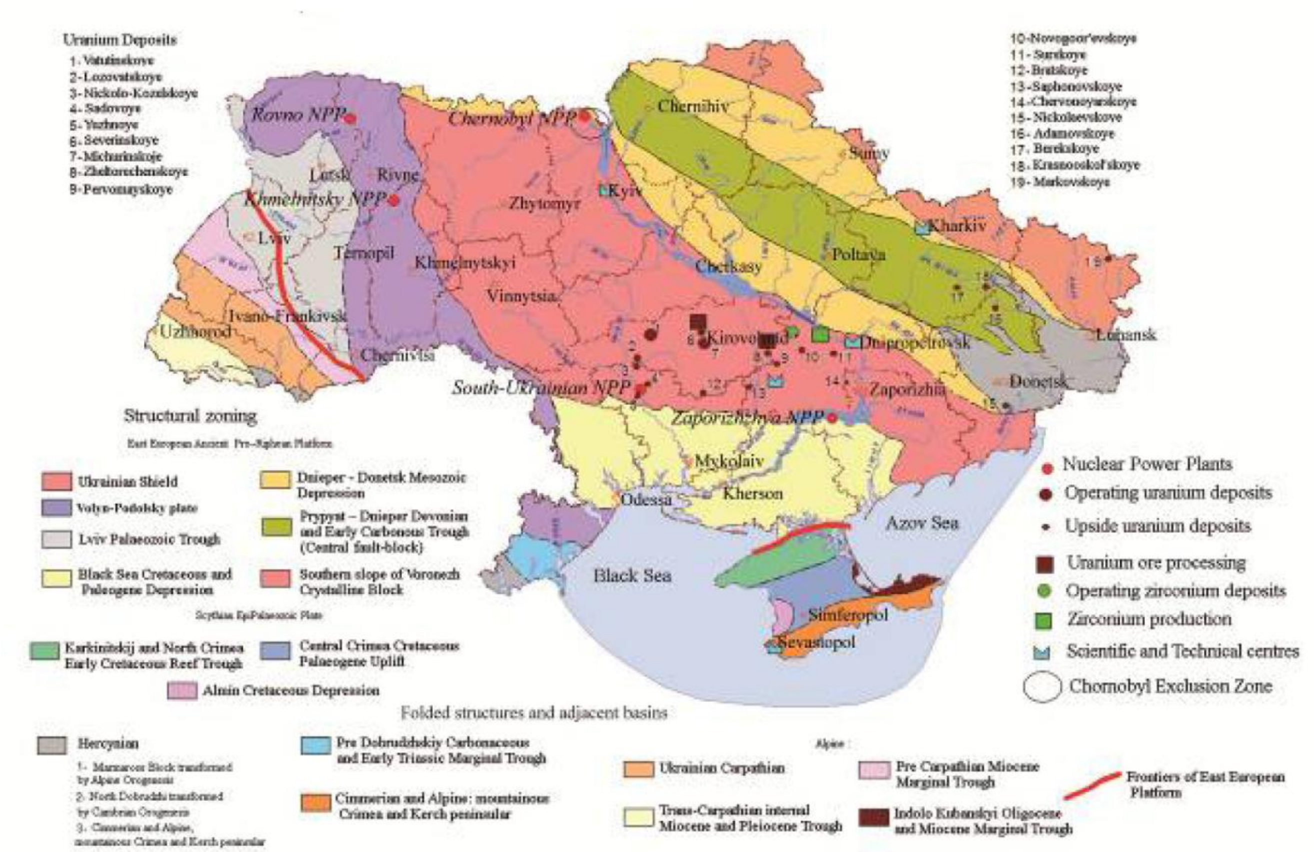

Fig. 1.3. Uranium deposits, mining and processing facilities in Ukraine

Uranium prospecting is complicated because of geochemical mobility and nonuniformity in uranium content both horizontally and vertiacally. In general, the following features are known for the uranium deposits of the Ukrainian Shield: structural and morphological complexity, distribution of “windows” of barren rocks, and whether the uranium is mainly connected with hydrothermal metasomatic processes, faults, or different exogenous (syngenetic), diagenetic or epigenetic veins. Many deposits are genetically unique, and very often prospecting their analogs has been unsuccessful.

Uranium production is provided by metasomatite deposits of the alkaline albitite type developed within zones of deep faults of the Ukrainian Shield. The origin of uranium mineralization is associated with sodium metasomatism superimposed on granite-gneiss basement within an area of tectono-magmatic protoactivization occurred at the end of the Ukrainian Shield orogenesis. Three main types of uranium ores are distinguished: alumino-silicate, iron-carbonate, and carbonate. Aluminosilicate uranium ores consist of 70–90% of albite, amphiboles, egyrine, hydronicas, and chlorite: hematite, magnetite, and accessory minerals account for 10-20%. Uranium minerals are presented by oxides (uraninite, nasturan), silicates (uranophane, boltwoodite, betauranotile, coffinite), titanates (brannerite, davidite). Furthermore, albitite always contains hematite, magnetite, apatite, malacone, rutile. Besides deposits in albitites, exogenic epigenetic deposits in Paleogene sand-coal sedimentary cover of the Ukrainian Shield were discovered and described in particular in [13, 14]. These deposits are suitable for the uranium extraction using the most advanced method of underground leaching. This method differs from traditional mining methods and has high levels of resource efficiency. As it is proved in other parts of the world, it allows reducing environmental problems to a certain degree because it does not leave heaps and abandoned mines. Moreover, accompanying elements like selenium, molybdaenum, rhenium, vanadium, and scandium make these deposits even more reasonable for exploration.

The deposits of hydrothermal and metasomatic type of sodium-uranium formation are genetically associated with the final stage of ultra-metamorphism of uranium-containing rocks. The uranium ores are considered to be complicated for technological processing because of their matter and chemical composition and wide range of ore mineralization. Brannerite along with iron hydroxides and their thin intergrowth of uranium and dark-colored minerals make it complicated when ore processing through autoclave sulphuric leaching.

When demands for raw uranium were highest in the 1940s, the former USSR government made a decision to conduct radiometric research on all possible uranium sources, including museum specimens, mines, adits, and open pits. This prospecting program led to the chain of uranium discoveries in Ukraine, the most important of which are discussed below (Table 1.1, Fig. 1.4).

Table 1.1

Commercial uranium deposits

Deposits	Discovery	First Ore	Development
Pervomaiske	1945	1957	Depleted (underground mining)
Zovtorichenske	1946	1956	Depleted (underground mining)
Devladivske	1955	1965	Depleted (in-situ leaching)
Bratske	1962	1970	Depleted (in-situ leaching)
Michurinske	**1965**	**1969**	**Operating (underground mining)**
Vatutinske	**1968**	**1975**	**Operating (underground mining)**
Tsentralne	**1973**	**1989**	**Operating (underground mining)**
Novokostyantynivske	**1975**	**2011**	**Operating (underground mining)**
Pivdenne	**1963**		**Dormant**
Adamivske	**1960**		**Dormant**
Severynivske	**1968**		**Dormant**

Fig. 1.4 Fragment of the Kirovogradskyi region map with discussed deposits location

1. 2 Depleted Deposits

Pervomaiske Iron-Uranium Deposit

The uranium deposit in the Pervomaiske iron mine was discovered in 1945 after detection of high radioactivity in some chlorite-sericite shales, and amphibole-carbonate-magnetite ores were later found. Further research confirmed discovery of the first high-grade uranium deposit not only in Ukraine, but in the former USSR as well. The trust "Krivbasruda" began developing the deposit, and in 1951, the Ore-Dressing and Processing Enterprise was founded to continue production. This uranium deposit operated until 1968 but the iron operation lasted longer due to the rich iron ores.

The Pervomaiske deposit is a block structure located in the northern part of the Kryvorizhska fold and fault structure, where the Pervomayska syncline is defined somewhat artificially. The Pervomaiskyi block is characterized by a high level of metamorphism, active metasomatism, and numerous faults in a complicated stratigraphy (Fig. 1.5) [15]. Formation of high-grade iron and uranium ores is connected with metasomatism, and in these volcanogenic-sedimentary rocks, the chemical and mineral composition of ores greatly depends on the type of primary metamorphic rocks, and the shape of the ore bodies is defined by the fold and fault geometries. The ores in this deposit are of carbonate-hematite-magnetite composition with impregnations of uranium minerals that appears to be completely localized in the commercial iron ores, resulting in dual classification as both iron and uranium ores. The ores are comprised of iron minerals (30-75%), carbonates (mainly dolomite, sideroplesite – 20-70%), silicates (alkaline amphibole, aegirine, mica); rarely chlorite, biotite, albite; and isolated grains of pyrite, chalcopyrite, sphene, apatite, and zircon. The main uranium minerals are uraninite, pitchblende, and coffinite.

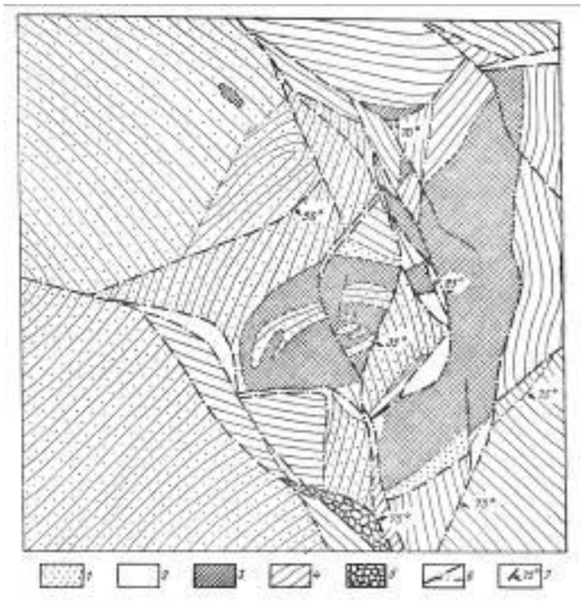

Fig 1.5. Geological structure of Pervomaiske iron-uranium deposit:

1 – hornfel amphibole-magnetite; 2- shales; 3 - chamosite and iron-uranium ores; 4 – direction of hornfel and slate occurrence; 5- breccia zone; 6- faults; 7 – attitude [10]

Performing a detailed study of the mineralogical composition, structure, morphology, and ontogeny is very important to develop technological schemes for uranium ore dressing and further hydrometallurgical processing. Unfortunately, the geology of this deposit was not sufficiently studied due to information restrictions and security concerns at the uranium facilities. The geological survey for this deposit was not published and the information is segmented amongst many different confidential reports.

Zhovtorichenske deposit *(Appendix 1, the deposit passport p. 86)*

The Zhovtorichenske deposit is located in the outskirts of the town of Zovti Vody, Dnipropetrovsk oblast. Similar to the Pervomaiske deposit, the ores here are of complex, iron-uranium content. Development of these iron ores has been carried out since the end of 19th century, and the radioactivity of these ores was first discovered in core samples in 1945. In 1946 the deposit was estimated as a high-grade uranium deposit and commercial development began in the early 1950s. In the 1990s the uranium ores were almost exhausted to a depth of 1.5 km, but complex rare metal and rare earth ores were discovered and explored in the upper horizons. However, the extraction of the rare earth ores was halted when the shafts flooded.

Structural and other controlling factors of mineralization. The Zovtorichenske uranium deposit is associated with the Zovtorichenska ribbon of metamorphic rocks of the Kryvorizhska series that form a syncline among the Archean granitoids (Fig. 1.6) [4]. By analogy with the central part of the Kryvorizhskyi Basin, metamorphic rocks are divided into four suites, the Saksaganska (middle), the Grantsivska (upper) suites, the Skelevatska and the Novokryvorizhska. The uranium mineralization is directly associated with these suites and mainly controlled by sodium metasomatism found in tectonic dislocations, not only by high-grade iron ores. Primary rocks for metasomatites are quartz-biotite shales, dolomites, and quartzites of the upper suite, and also aureoles of the middle suite rocks. The main deposit structure is a narrow isocline fold of almost vertical inclination. [15, 16]

Host rocks and wallrock alteration. The primary rock composition in tectonic dislocations is significantly altered by alkaline metasomatism. Primary shale-dolomite-quartzite and biotite-chlorite associations are altered with metasomatites. The main rock forming minerals of metasomatites are albite, aegirine, alkaline amphiboles (riebeckite, arfvedsonite, roduzite, calcium silicates (diopside, actinolite, garnet, talc), carbonates (dolomite, calcite, ankerite, siderite), rarely apatite, malacon, and grothite. In similar metasomatites of the Saksaganska suite, the main set of alkaline minerals are found as well as relict magnetite, hematite, and sometimes quartz.

Ore mineralization. Uranium mineralization is localized in bedded, columnar, lens-shaped bodies and diverse veins. The main commercial types are embedded tabular deposits from several hundred meters to one kilometer in length, especially zones where tectonic structures intersect.

The main rock forming minerals in ore zones are the same silicates and aluminum silicates (85-90% by weight) as in the host metasomatites: albite is predominant, and less commonly, amphiboles, aegirine, and chlorite; while in ferruginous rocks, hematite and magnetite are also present (10-15%).

Uranium minerals include brannerite, uraninite, and sometimes pitchblende; accessory minerals are malacon, sphene, and apatite, although these accessory minerals are not of commercial value. Uranium minerals likely form the end-products of metasomatic processes, forming scattered impregnations, striped and spotted accumulations, or constitute the cement, fractures and intergrain spaces in tectonic breccia. [18, 19]

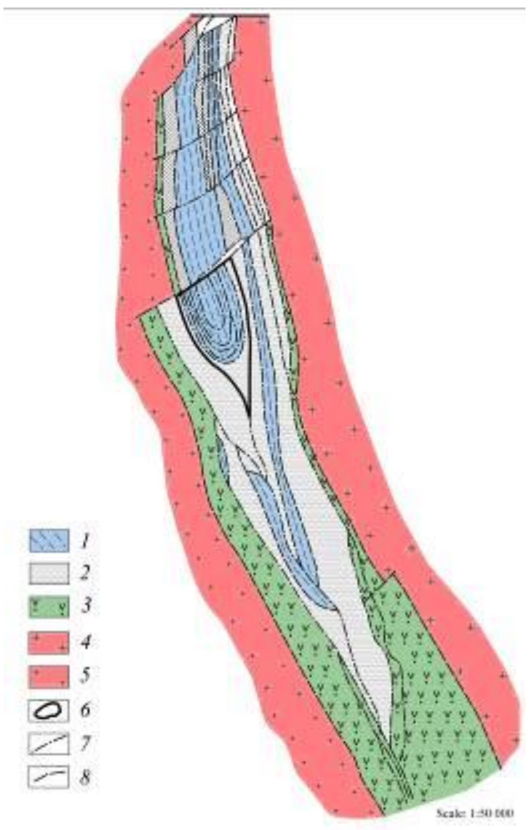

Fig. 1.6. – Schematic map of the Zhovtorichenske deposit:
1 – Grantsevska suite (K_3); 2 – Saksaganska suite (K_2); 3 – Skelevatska and Novokryvorizhska suites; host Archaean granitoids: 4 – bifieldsdpathic; 5 – plagioclase; 6 – outline of uranium-containing metasomatite; 7 – tectonic dislocations; 8 – lithologic boundaries (mapped using materials from the SE “Kirovgeologiya”) [4]

A new mineralization type was discovered in this deposit: multimetal ores of scandium and vanadium. These ores are also associated with zones of alkaline metasomatites. Scandium content in aegirine-acmite is up to 0.1%, while vanadium is up to 9%. As mentioned above, however, the extraction of these ores was not successful.

Commercial uranium extraction in the Zovtorichenske deposit was discontinued and geological and mineralogical analogues of this deposit were not discovered either in Kryvorizzya or elsewhere in Ukraine.

Devladivske and Bratske deposits

The Devladivske and Bratske deposits were discovered in 1955 by the Pivdennoukrainska geological party when prospecting nickel ores in Eocene lignite strata. It is located in Serednye Prydniproviya, in the Saksaganska basin. Uranium ores are found in the coalificated sand and clay strata of the Buchakska suite and are overlain by the Kyivski clays, which forms an artesian aquifer in the production horizon.[10, 13]

Technological studies showed that uranium was easily dissolved even in weak solution (3-5%) of sulfuric acid, and in 1957 researchers from the Kirovska geological party proposed using an underground leaching (UL) technique, the first in the former USSR. This method later turned out to be both effective and economically sound. Over the period from 1965 to 1977, the main reserves of the Devladivske (1961-1984) and the very similar Bratske (1966-1989) deposits were extracted (Fig. 1.7 *a*, *b*).

a *b*

Fig. 1.7 Bratske deposit (ISL) 1970, geotechnological field *(a)*; after recultivation 2010 *(b)*

In these deposits, the uranium is contained mainly in carbonaceous matter (35%), argillaceous matter (~25%), and also in sooty uranium (17%). Sooty uranium, found only in rich ores, forms accumulations or thin films around grains of pyrite, marcasite, and ilmenite. Around 5% of uranium is contained in leucoxene, and around 3% in iron hydroxides.

1.3. Commercial Uranium Deposits Currently Operating

Michurinske deposit*(Appendix 1, the deposit passport p. 87)*

As with many other uranium deposits, the Michurinske deposit was discovered by accident. In 1964 while hydrogeology prospecting, high radioactivity was detected at great depth with gamma-ray logging. Yu.B. Bass, a lead geologist with the Pivdenno-Ukrainian party, ordered additional boreholes to be drilled, and the presence of uranium ores was confirmed.

A large section of the migmatite that extends to the west from the Kryvorizhska fold was considered unlikely to produce uranium, and the first borehole study did not attract special attention, containing the typical weathered rocks, mainly kaolinites, with black strings of ore mineral. Only later was this found to be mixtures of black uranium (Fig. 1.8).

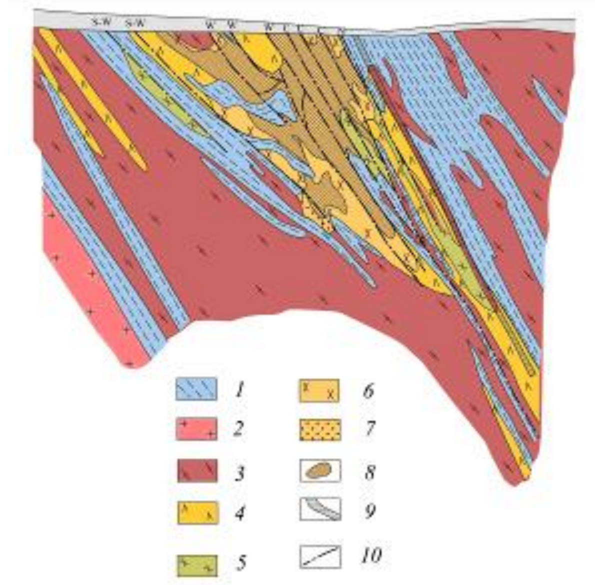

Fig. 1.8. Geological section of the Michurinske deposit:

1 – gneisses; 2 – granites; 3 – migmatites; 4 – desilicated syenite-like apogranite and apomigmatite rocks; 5 – desilicated and albitited gneisses (epidote albitite and chlorite albitite); 6 – apogranite and apomigmatite albitites; 7 – apogneiss albitites; 8 – ore bodies; 9 – Michurinskyi fault; 10 – fault dislocation: E – Eastern Zone, C – Central Zone, W – Western Zone, S-W – Southern and Western dislocation zones (mapped by O. Kramar using the information from SE “Kirovgeologiya” [4])

Similar mineral associations are often found in weathering crusts without any visual connection with primary uranium deposits. However, Ya. Belevtsev was sure that a large-scale uranium deposit had to be here, and as a result of saturation prospecting up to 400-450 m depth, large-scale uranium ore beds were discovered. On the basis of this deposit the Ingulske Mining Enterprise was founded. Further geological surveys within the Kirovogradska fault zone found uranium ores at great depth, with a vertical mineralization range associated with sodium metasomatites reaching about 1800 m, and the metasomatites themselves reaching up to 3500 m. In the late 1970s, SE Kirovgeologiya found the fringe zone of sub-ore metasomatites at a depth of 3000 m in the Lelekivske ore field, a site connected with the deep Kirovogradskyi fault. Metasomatites are represented by barren often albitized and desilicated syenite-like diafluorides with rare singular impregnations of uranium mineralization. According to the content of dark-colored minerals, albitites are divided into chlorite, phlogopite, riebeckite, aegirine, riebeckite-chlorite, and aegirine-riebekite [20, 21].

As opposed to the Kryvorizzya deposits, which are associated with iron-siliceous formations, the Michurinske deposit is located in the core of the Kirovograska brachyanticline. It is found within a massif of porphyritic granites, migmatites, and biotite gneisses (Fig. 1.9).

Fig 1.9. Map of the ore bodies connected with the fold and fault dislocations in the Michurinske deposit:

1 – ore bodies; 2 – Michurinskyi fault; 3 – other dislocations with a break of continuty; 4 – direction of strike within flexure bends (mapped by O. Kramar [4])

Uranium mineralization is spatially and genetically connected with different tectonites (milonite, cataclasite, breccia) that are in some places altered by metasomatism forming syenites, albitized gneisses, apogranite and apomigmatite, as well as apogneiss albitites. They are distinguished by quartz content, with both quartz-containing and quartz-less types. Chlorite, phlogopite, aegirine, riebeckite with impregnations and strings of uranium mineralization are included in the albitite content. Uranium mineralization is present as oxides (uraninite (~10%) and pitchblende), silicate (coffinite and nenadecvite (~30%), and occasionally as titanates (brannerite, davidite) (Fig. 1.10-1.13). The ores are oxidized in different ways, and primary uranium minerals are often altered with secondary minerals. From these processes, both enrichment and depletion of primary ores are possible. The questions of interrelations of these minerals and geochemical peculiarities of the processes are further considered in detail below.

Fig. 1.10 Ore from the Michurinske deposit (from the collection of O. Kramar and B. Melnichenko).

The ore is an apogranite mesocratic aegirine albitite, with major ore minerals of brannerite and davidite; minor minerals are uraninite and sooty uranium.

Fig. 1. 11 Ore from the Michurinske deposit (from the collection of O. Kramar and B. Melnichenko).

This sample is a breccia of aegirine - riebeckite apogranite albitite. High-grade uranium mineralization is localized in the breccia. The major ore mineral is brannerite, while sooty uranium, pitchblende, coffinite and fourmarierite are also found.

Commercial ore bodies and zones According to the borehole exploration data there are 49 ore bodies in the deposit with seven bodies comprising 80,5% of the reserves. According to the operational exploration data, there are 26 ore shoots, including those with the basic reserves (74.7%). The ore shoots range in size from 30 to 73 m along strike, and from 30 to 400 m along pitch. The area of ore shoots is 3,100-163,100 m^2. The average content across the ore body is 8,300 g/t.

Ore bodies are concentrated in four ore zones: the biggest one according to its scale and reserve is in the Central zone, the second largest is in the Southeast zone, and two zones are found in the Northeast. Ore zones are characterized by a very complicated and irregular structure, and ore shoots are of isometric and lens-like forms. In the western part of the deposit the ore bodies course is not that steep (40-50°) as in its eastern part close to the Michurinskyi fault (up to 75). Within the four ore zones, 49 ore shoots of commercial value are outlined with uranium content of greater than 300 g/t.

Fig.1. 12 Sample from the Michurinske deposit (a - piece of ore, b – radiography, c - piece of ore (color photography) (from the collection of O. Kramar and B. Melnichenko).

This ore sample is apogranite with greatly cataclastic aegirine-riebeckite albitite. Ore mineralization is represented by uraninite, pitchblende, coffinite and sooty uranium.

Fig. 1. 13 Sample from the Michurinske deposit (a - piece of ore, b – radiography) (from the collection of O. Kramar and B. Melnichenko).

High-grade uranium mineralization is localized in the highly brecciated blastomylonite. Ore mineralization is represented by brannerite, uraninite, coffinite and pitchblende

Structural localization of commercial ore bodies The commercial ore bodies are associated with faults (confirmed by the brecciation of the rock substrata) and zones of cataclasis and milonitization as well as with zones of cataclasis and minor fracturing within the flexure folds. The northwest bodies are located within the north flexure, the northeast bodies are located within the east flexure, the central bodies are within the steep central flexure, and the southeast bodies are within the south flexure. Ore bodies of lens-like form predominate, although columnar, bedded and complicated isometric forms also occur.

Inter-mineral and post-mineral tectonics of ore bodies Inter-mineral tectonics is found in the forms of breccia, blastomylonite joints, zones of tectonic schistosity, volumetric cataclasites and minor fracturing and feathering in the main structures. Ruptures are predominant, and shear cracks are met within joining limbs of flexure folds. Minor folds are also found. Post-mineral tectonics are represented by minor fracturing, shear cracks with attrition clay, and zones of fracturing in ore albitites. As a result, the ores are transformed into polychromatic mylonites and breccia-like tectonites. Deformed ores contain secondary mineralizations of sericite and chlorite, veinlet quartz and carbonate. However, the majority of cracks remain open.

Near-surface alteration of ore bodies The main uranium oxide ore mineral (brannerite) is partially or completely altered with leucoxene-like products under conditions of hypergenesis. Ores are highly fractured. Secondary sodium silicates that are yellow in color are found along numerous fractures.

Mineral composition of ores The ores are mainly oxidized. The major ore minerals are sooty uranium and uranophane (53%); primary silicates are a mixture of boltwoodite and uraninite (called nenadkevite; 32%);primary oxides are pitchblende and uraninite (up to 11%); and uranium titanates are brannerite and davidite at approximately 4%. There are two generations of uraninite and pitchblende in the form of microveins and impregnations. The first generation of pitchblende is found along with the second generation of uraninite. The second generation of pitchblende is post-uraninite. Hydrated pitchblende and urgit are products of pitchblende oxidation and are mainly found in small amounts in the near-surface area of the deposit. The major non-metallic minerals are albite (up to 75-90%), chlorite, phlogopite, riebeckite, aegirine, and epidote. The minor non-metallic non-uranium minerals formed in the process of ore formation are carbonate and hematite.

Characteristics of commercial minerals The major ore minerals uranium and uranophane are found together in fine impregnations, veinlets and net-like aggregations. Their sizes range from 10^{-3} to 0,5 mm. Veinlets are mainly filled with uraninite, and less often with pitchblende and uranium silicates, which more typically form fine colloform spots of 0,02 to 0,1 mm with aggregations up to 3,0 mm. Uranium mineralization is mainly localized in dark-colored minerals (chlorite, aegirine, riebeckite) and accompanied by hematitization. The uranium ores have impregnated, net-impregnated, veinlet, and breccia textures, with the impregnated and net-impregnated types most prevalent. The ore structures are idiomorphic and impregnated, zonal, or cemented. Ores also occasionally contain coffinite, davidite, hydrated pitchblende, beta-uranotile, and sooty uranium..

Chemical composition of ores The ores within the Kirovogradskyi fault are characterized with high Fe_2O_3, Na_2O, CaO, and CO_2 contents in all types (apogneiss hematite-carbonate-chlorite, apomigmatite hematite-carbonate-chlorite, apogranite hematite- riebeckite-aegirine-chlorite), Table 1.2 [4].

Table 1.2

Average chemical composition of ores

TiO_2	Al_2O_3	Fe_2O_3	FeO	Fe_2O_3 FeO	CaO	Mg	MnO	Na_2O	K_2O	Na_2O K_2O	P_2O_5	SO_2	SiO_2	H_2O	CO_2
03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
034	17,10	2,52	1,83	4,35	2,82	1,50	0,06	8,51	0,78	9,29	0,21	0,21	0,13	0.11	0,71

Tsentralne deposit*(Appendix 1, the deposit passport p. 88)*

The Tsentralne depost is located within the Kirovogradska deep fault zone in the southern suburb of the Kropyvnytskyi (former Kirovograd) city. It is currently operated by the Ingulska mine along with the Michurinske deposit.

Structural control of mineralization The Tsentralne deposit is associated with a throw shift fault between its eastern (Kuchivskyi) and western limbs connected with echelon faults at higher levels. The ore-containing tectonic and metasomatic zone was formed on the eastern limb of the Sokolivskyi granite dome intersected by the Lelekivska and Kirovogradska brachyaxial fold. The ore bodies are associated with faults and localization of uranium mineralization is directly linked to permeable areas of cataclastic and fractured albitites. The syn-fault flexure folds result from the shift of echelon-like fault dislocations and also play an important role in the location of uranium ore. The major faults (Kuchivskyi and Western) were ore-forming and ore-shielding (especially Kuchivskyi) although they also contain ore mineralization. They are represented with multievent tectonites and apoblastomilonite breccia, micro breccia, foliated rocks, and boudinage (Fig. 1.14).

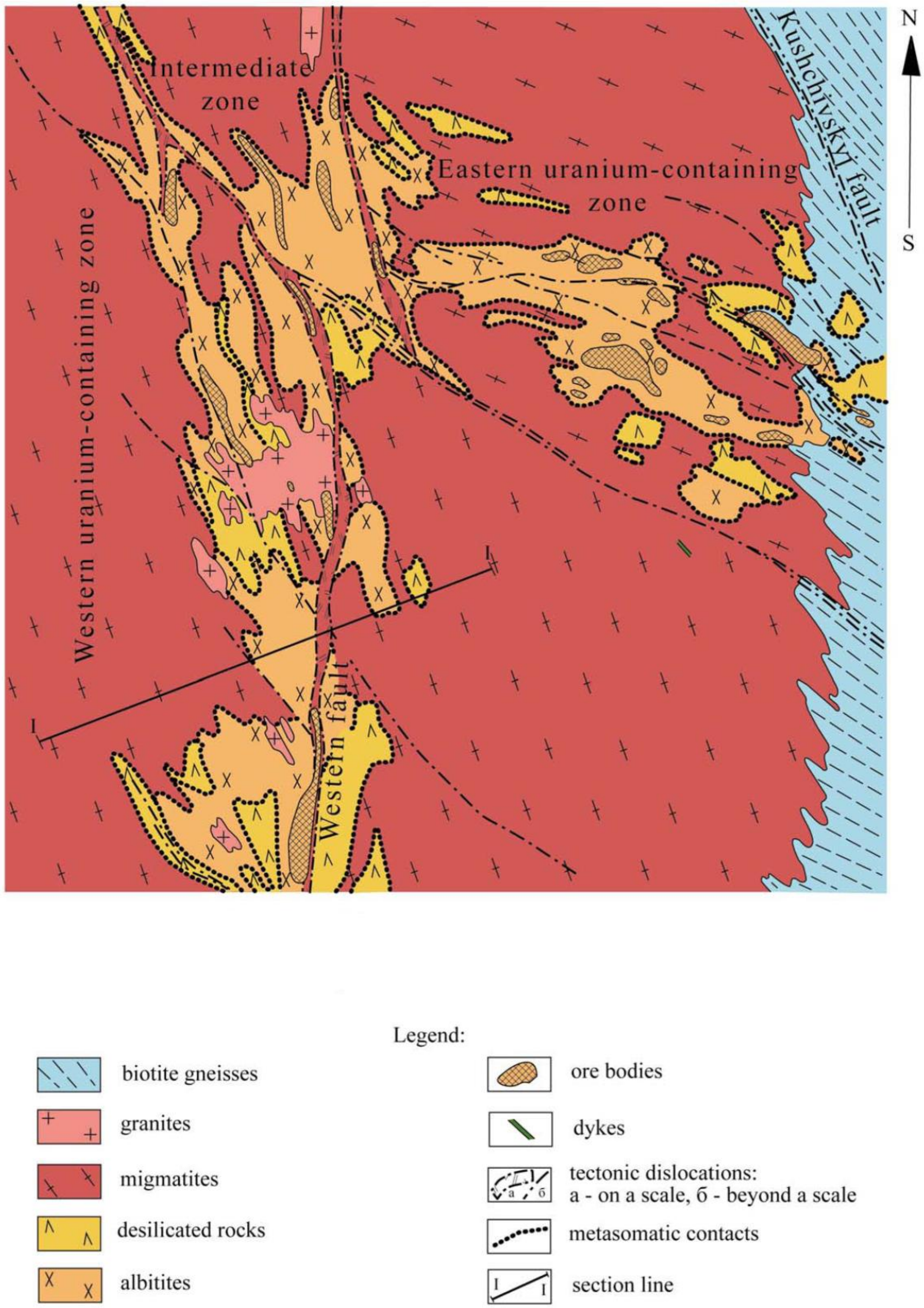

Fig. 1.14. Geological scheme of the Tsentralne deposit

Ore controlling factors *Petrological* control is shown by the localization of commercial ore exclusively in the central part of albitites and sufficient content of dark colored minerals and minimal quartz. _Geochemical_ control is revealed in high Fe^{3+} content (iron is a uranium precipitator). _Physical-mechanical_ control is characterized by the porosity and permeability of albitite, while thermobaric control determines the depth and vertical spread of uranium mineralization formed at average temperatures.

Source of mineralization The deposit is hydrothermal and metasomatic in origin, leading to sodium-uranium formation. It is genetically connected with the processes of ultra metamorphism. Post ultra-metamorphic solutions penetrated along the fault zones and led to sodium metasomatism and follow on formation of apogranite, apomigmatite and in the east close to the Kumivskyi fault, partial apogneiss albitites. Diaphthorites (syenite-like desilicated rocks) also formed as a product of incomplete sodium metasomatism but these do not contain commercial ore mineralization.

Weathering crust The kaolin weathering crust is an areal type. Primary rocks are gneisses, migmatites, granites, and metasomatites. Ore bodies are mainly blind, located in basement rocks at hundreds of meters depth so ore weathering crust was not found. Linear weathering crust (zones of hypergenesis) is found along the permeable zones along pitch.

Host rocks Ore is found in the apomigmatite, apogranite, and apogneiss albitites of Paleoproterozoic age. Albitization, hematitization, chloritization, carbonatization, desilication, epidotization, and silicification is found in the upper part of the vertical metasomatic columnar shoots located over the ore bodies. Within selvages of sodium metasomatite bodies, sericitization, phlogopitization, riebeckitization, and aegirinization display syn-mineral stages of tectonic deformations. Tectonites of a different age comprise fault dislocations and minor and micro folding are found in dislocations representing different stages of the deposit formation. The following types have been identified: 1) micro-curved and eye-foliated rocks of amphibolite facies found in the form of relicts; 2) pre-albitite blasto-milonites, blasto-breccias, micro-breccias and blasto-cataclasites of epidote-amphibolite facies; 3) pre-mineral and syn-mineral milonites and cataclasites of greenschist facies; 4) post-mineral tectonites represented by fracturing zones, kakirites, and attrition clay. Ore-forming primary minerals and ore-containing rocks were altered during tectonic and magmatic stages. Aureoles spread over 2500 m along pitch and around 1500 m along strike, with a depth of many hundreds of meters.

The *unaltered rocks* are gneisses, migmatites, and granites. Tectonites, diaphtorites, and sodium metasomatites of different mineral compositions and structural and tectonic peculiarities are formed in narrow fractured cataclastic zones. Gneisses are the most widespread in the eastern part of the deposit, close to the Kuchivskyi fault. Gneisses are of biotite, and to a lesser extent, amphibole-biotite content. Medium-grained porphyroblastic migmatite are found throughout the deposit. According to the content they are related to the tonalites and granodiorites. Medium-grained trachytoid granites are found in the central part of the Western fault and extend along strike for a distance of 1 km. Their content indicates that they correspond to the adamellites. Fine to medium grained gneiss-like (Lelekivskyi type), pegmatoid and aplite-like granites are found in veins. Diaphtorite (syenite-like rocks) of greenschist facies form wide aureoles along tectonic joints and are considered as transition zones between unaltered rocks and ore-containing albitites. These are mainly epidote and chlorite rocks. Crystalline basement is covered with sedimentary strata, and the areal kaolin weathering crust is found extensively on the crystalline basement.

Commercial ore bodies and zones The deposit consists of four ore zones: Western, Intermediate, Central, and Eastern. The Western is the main zone and is where the major ore bodies are located. The metasomatite here is almost 100 m thick and at the boundary of the Western and Eastern zones it reaches some hundreds of meters. Uranium-containing albitites of the Western zone are of columnar-like shape, with a steep pitch (Fig. 1.15, 1.16). They reach their maximum thickness within the ore-controlling tectonic joints.

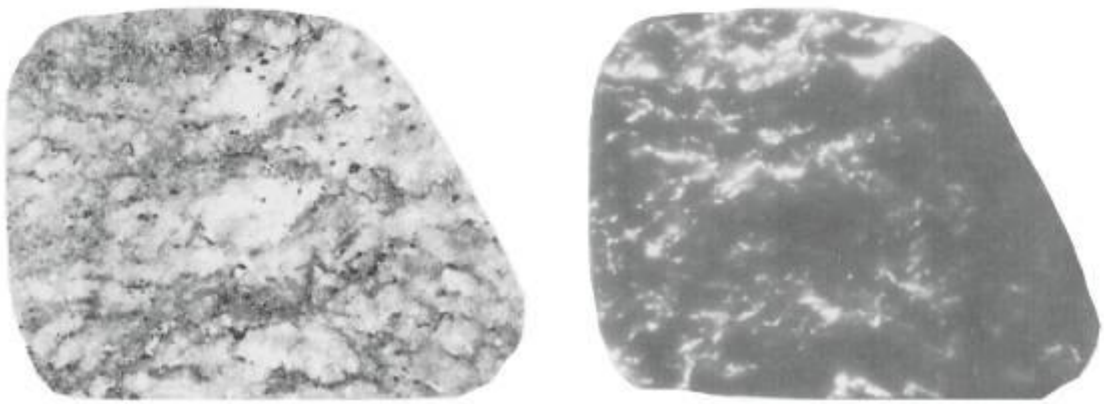

Fig. 1.15. Sample from the Tsentralne deposit (a - piece of ore, b – radiography). High-grade uranium mineralization is associated with greatly cataclasized apogranite phlogopite albitite. Uranium minerals include brannerite, uraninite, nenadecvite, pitchblende and coffinite.

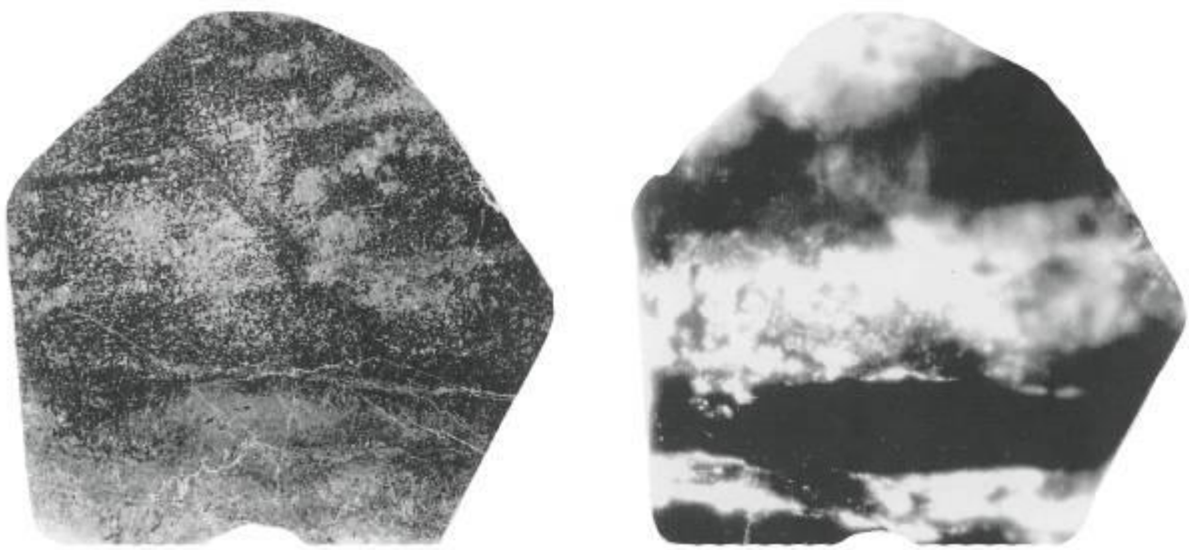

Fig. 1.16 Samples from the Tsentralne deposit (a - piece of ore, b – radiography). High-grade uranium mineralization is localized in cataclastic zones in fine-grained apogneiss aegirine-riebeckite albitite. Major uranium minerals include brannerite and uraninite, with minor minerals represented by yellow secondary silicates, pitchblende and coffinite.

The Intermediate zone is located between the tectonic joints of the Western fault. It is similar to the Western zone in its morphology but is significantly smaller in size. Ore bodies within the Western and Intermediate zones strike at 330-360^0, with a pitch of 55-85^0 East and North-East.

The Central zone is the second greatest (after Western) in size and uranium reserves. It is controlled by the tectonic joints of the Central fault. Uranium-containing albitites form extensive echelon-like bodies that are gradually trend out along strike toward the gneisses.

The Eastern sub-latitudinal ore zone extends up to 1 km along strike. It extends to a depth of hundreds of meters from the basement surface. Ore bodies have a strike of $270\text{-}300^0$, with a pitch of $60\text{-}70^0$ North and North-East.

There are 15 ore bodies altogether. They have diverse morphologies but are generally isometric along a clear horizontal strike. Commercial ore bodies are divided into two types according to their geometry: 1) tabular (Eastern zone); and 2) lens-like (the major type) with bulges and wedging-out. The ore bodies' length along strike varies from meters to hundreds of meters in scale, and hundreds of meters along pitch.

The ore texture and structure is determined by peculiarities of ore-containing albitites inherited from primary rocks, the intensity of syn-mineral tectonic deformations, and the form and character of dissemination of the dark colored minerals (riebeckite, aegirine, chlorite, and phlogopite). The ore texture types include fine impregnation, fine net-like impregnation, fine veinlet impregnation.

The Obgonnyi ore body of complex bismuth-uranium content is found within the northern flank of the deposit at a depth of 800 m. It is located in attrition clays of the activated Obgonnyj fault (a component tectonic element of the deposit rupture structure). The fault consists of silicificated micro breccia formed on blastomilonites, and contains the rich complex mineralization. The age of bismuth-uranium veinlet mineralization is around 350 million years. The horizon that contained this mineralization was flooded.

<u>Inter-mineral and post-mineral tectonics of ore bodies</u> Inter-mineral deformations are found in the form of milonites, breccias, tectonic schistosity, minor flexure folding, and cataclasis that are considered ore-containing within the Eastern ore zone. Post-mineral tectonics are represented with late fracturing zones and cataclasis, open shears with attrition clay and cracks filled in with secondary carbonate, quartz, sericite, and iron oxides.

Mineral composition of ores The major ore minerals are brannerite, oxidized brannerite and lesser amounts of pitchblende and coffinite (Fig. 1.17). Hydrated pitchblende, yellow secondary silicates, and sooty uranium are more rarely found. The major non-metallic minerals are albite, phlogopite, chlorite, and carbonate, and more rarely, aegirine, riebeckite, epidote, and hematite. The mineral composition of the Obgonnyi ore body includes chlorite (45-55%), coffinite+uraninite (up to 30-50%), bismuthine, syn-mineral galena and siderite, calcite, and pyrite. Uranium content reaches 15,5%, bismuth 0,8-1,3%, lead 2%, and beryllium 0,01%. Commercial minerals include brannerite, oxidized brannerite, completely altered brannerite with leucoxene-like products, and uraninite.

Fig. 1.17 Ore sample from the Central deposit. This sample is a greatly cataclasized and fractured apogneiss chlorite-phlogopite albitite with carbonate. Uranium ore minerals include brannerite, oxidized brannerite and uraninite, along with coffinite, pitchblende and sooty uranium.

Chemical composition of ores Chemical compositions of the ore samples is given in the table below (SE "VostGOK" laboratory data, Table 1.3). They were sampled three times during January-March 2012 at the Michurinske (12 samples), Tsentralne (12 samples) and Vatutinske (16 samples) deposits. There are 40 samples altogether representing the major ore types according to their mineral composition and host rock content. Data of some of them on Tsentralne deposit are presented in the table below.

Table 1.3

Chemical compositions of the ore samples

Name	$Ra^{226} 10^{-7}$	$Th^{230} 10^{-7}$	$Pb^{210} 10^{-7}$	$Po^{210} 10^{-7}$	U	
Sample	Uranium ore from Central deposits Ci/kg				$U \cdot 10^{-3}$%	activity 10^{-7} Ci/kg
Tsentralne deposit						
Sample №1 block $1^{б}$-1-2 horizon -335	3,86	2,10	4,23	2,24	75,8	5,12
Sample №2 block $1^{б}$-1- 2 horizon -335	3,84	2,16	4,20	2,29	62,3	4,20
Sample №3 $1^{б}$-1- 2 horizon -335	1,07	0,84	1,21	0,95	23,2	1,57
Sample №4 block $1^{б}$-1- 2 horizon -335	4,13	2,37	4,17	2,70	91,0	6,14
Sample №5 block $1^{б}$-1- 2 horizon -335	4,44	2,55	4,57	2,81	79,6	5,37
Sample №6 block $1^{б}$-1- 2 horizon -335	2,63	2,38	2,76	2,83	52,5	3,54
Sample №7 block $1^{б}$-1- 2 horizon -335	1,78	1,1	1,87	2,01	34,0	2,30
Sample №8 block $1^{б}$-1- 2 horizon -335	1,98	1,23	2,36	1,85	44,0	2,97

The Michurinske deposit ores consist of apogranite, apomigmatite and apogneiss albitites. Apogneiss albitites are different from the first two types by higher (up to 25-35%) dark mineral content. The Tsentralne deposit ores are represented by the only apogranitoid albitites including albitites formed on fine-grained leucocratic and melanocratic aplite-like granites of the Lelekivska suite. Aegirine, riebeckite, chlorite, and epidote are widespread among the dark colored minerals from the Michurinske deposit while phlogopite is more typical for the ore albitites from the Tsentralne deposit. Uranium oxides and nenadkevite are typical for the ores from the Michurinske deposit. They are rarely found in the Tsentralne deposit where brannerite (uranium titanate) is more commonly found.

Technological characteristics of ores. The method of autoclave sulfuric leaching is the most interesting for ore processing and is used for other deposits of this genetic type at the Ingulskyi mega block (and the Michrinske ore field).

Mining conditions According to geological structure, hydrological and hydro technical conditions, this deposit is suitable for mining. The ores and rocks are quite hard with the exclusion of tectonic dislocations of low thickness and length with failure zones. Correspondant timbering is required within these zones.

Hydrological mining conditions The Tsentralne deposit is located under the suburb of Kropynitskyi (former Kirovograd) city. It is connected to the Michurinske deposit through the six-kilometer main drift. The small tributary of the Ingul and Bianka Rivers flows across the deposit site. Numerous deep drillings and roadheadings at the stage of prospecting works and also mine water pumping led to a significant drawdown of the groundwater in both the sedimentary and crystalline horizons, resulting in a large sinkhole. The depression extends north-south up to 8 km, and reaches 2 km in width near the deposit. Waters have a low mineralization rate and are not corrosive to metal or concrete. The water supply for the “Tsentralna” mine is shared with the Ingulskyi water intake.

Vatutinske deposit *(Appendix 1, the deposit passport p. 89)*

The Vatutinske deposit was discovered in 1965–1966, with a detailed survey started in 1968 and finished in 1972. The deposit is currently under operation by the Smolinske mining enterprise. It is located in the southern suburb of settlement Smoline. Its geological structure is similar to the Michurinske deposit and is located in the central part of the Ukrainian Shield (80 km from Kropyvnitskyi (former Kirovograd) city on the western arm of the Kirovogradska anticline within the Zvenigorosko-Gannivska fault zone. Primary rocks are blocks of biotite-garnet-amphibole gneisses, migmatites, and granites of different types. Mineralization is also connected with alkaline metasomatites where microcline (30-80%), albite (20-60%, and in albitites, up to 90%), and dark-colored minerals (up to 40%) predominate; sometimes quartz (up to 35%) is also present.

Structural control of mineralization The deposit is associated with the Vatutinska tectonic and metasomatic zone that was formed in the lying (eastern) limb of the western Kurnykivskyi fault – a large branch of the Zvenigorodska and Gannivska deep fault zone within the ore field (Fig. 1.17). Pitching at angle of 75-80°, the main fault was formed at a contact of granitoid (from the west) and heterogenous granite-migmatite strata. Separate gneiss bodies partially remained after granitization. The tectonic and metasomatic zone of sub-meridian extension that contains the uranium bodies is found in the feathering of the main fault with fracturing structures that strike northeast-southwest. These smaller structures are characterized by flexures on plan and in section. They are joined to the main structure at acute angles in the south.[22, 23]

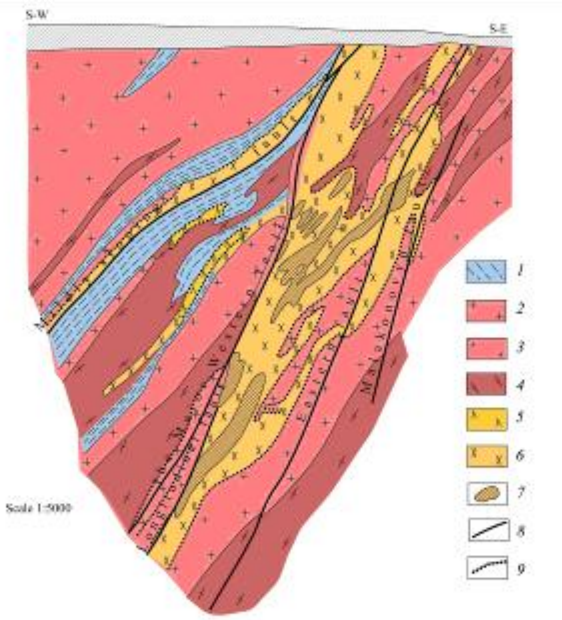

Fig. 1.17 Geological map of the Vatutinske deposit (using materials from SE "Kirovgeologia"):

1 – biotite gneisses; 2 – medium-grained granites; 3 – fine-grained granites; 4 – migmatites; 5 – syenite-like rocks; 6 – albitites; 7 – ore bodies; 8 –tectonic dislocations; 9 – metasomatic contacts

The geometry of the ore controlling structure determines the wedge-like morphology and its flare to the south. To the east, the deposit is bordered by the Eastern fault, which is considered a feathering fault in relation to the Major Western fault.

The Major Western fault has a local name of Western-Kurnykivskyi fault. It consists of cataclastic, foliated, brecciated primary (unaltered) and metasomatically altered rocks. Tectonites of different types are superimposed, implying a long multi-event fault formation. Three main tectonic stages can be identified: syn-metasomatic, syn-mineral and post-mineral. Blastomilonites and mylonites, blastocataclazites and cataclazites, fine fracturing, tectonically foliated rocks and boudinage, and also breccia, micro breccia and kakirite are formed as products of dislocation metamorphism. Tectonites on metasomatites consist of albite, aegerite, riebeckite, carbonate, chlorite, sphene. Quartz-free cataclastic albitites contain uranium mineralization and commercial uranium concentrations. The small flexure folding accompanied formation of ore-controlling shift-type fault zones and influenced the location of metasomatites and ore bodies. The ore impregnation and micro veinlets are localized in small fractures and rocks in dark colored minerals as well as in zones of high volume cataclasis and fracturing. Dark colored minerals containing divalent iron as a uranium precipitator are considered ore controlling in zones of fracture, cataclasis, and mineralization. Uranium mineralization is accompanied with light and dark brown aureoles of hydroxides.

<u>Genesis of mineralization</u> The deposit originated from hydrothermal processes and sodium metasomatism. It is genetically connected with ultra metamorphism of uranium-containing rocks. Post ultra-metamorphic solutions penetrated along long-lived fault zones and led to sodium metasomatism and the follow on ore formation in albitites. Uranium was transferred in hydrothermal solutions as uranyl-sodium-carbonate or uranyl-potassium-carbonate ion complexes. Diaphthorites (syenite-like desilicated rocks) formed as a product of incomplete sodium metasomatism, quartz (in syn-mineral time), and tectonically immature albitites of poor permeability are contaminated with uranium and do not contain commercial ore mineralization.

<u>Weathering crust</u> The kaolin forms an areal weathering crust. Primary rocks are granites, migmatites, gneisses, granites, and uranium ores. The crust thickness together with sedimentary cover is 60-70 m thick on average.

<u>Wall rock alteration of host rocks</u> Albitization, hematitization, chloritization, epidotization, desilication, carbonatization, saussuritization, desilication, and silicification occur in the upper part of the vertical metasomatic columnar shoot. Within selvages of sodium metasomatite bodies, sericitization, phlogopitization, riebeckitization, aegirinization, and incomplete manifestation of syn-mineral dynamic metamorphism occur. All of the rock-forming minerals in primary rocks are altered. The transition zone between mineral-free and ore albitites is on the order of tens of meters. The tectonic and metasomatic zone extends over 3 km, with a width of 0.6 km. The depth after erosion is over 1.2 km.

The majority of the ore bodies do not emerge on the basement surface and instead extend out at a depth of hundreds of meters. This distribution has allowed research into the hypogene zonality in the upper-ore, ore, and sub-ore parts of the vertical cross-section of the deposit.

Zonality types Metasomatic zonality is seen in the gradual change of metasomatite mineral composition as a result of formation of external zone (slightly altered primary rocks) – diaphtorite – intermediate zone (syenite-like rocks) – internal zone (albitites and commercial mineralization in albitites). Mineral compositions in the intermediate zone include albite (20-60%) and microcline (30-80%), along with chlorite, epidote, actinolite, alkaline amphibole, aegirine, quartz (10-15%), carbonate, sphene (up to 1-3%), and accessory minerals (apatite, zircon, monazite, allanite, magnetite, and hematite). The internal zone contains albitites with albite (up to 60-80%) and dark colored minerals including aegerine, alkaline amphibole, rarely actinolite, chlorite, epidote, phlogopite, and hydrated mica (1-40%). Carbonate and sphene are common in ores. Uranium minerals include oxides, silicates, and titanates. Metasomatic zonality is mainly connected with changes in the thermobarogeochemical conditions resonsible for the formation of albitite and ore mineralization.

Geochemical zonality is connected with metasomatic zonality. The Na_2O content is predominant over K_2O in albitites. The total amount of alkaline elements as well as carbon dioxide and Fe^{3+} content is significantly higher than in primary rocks. The content of U, Pb, V as well as Li, Rb, Ti, Ba, Sr, Zr, Y, Yb, and Th is higher in ores. But the content of Cu and Mn is not higher in ores in comparison to primary rocks. Vertical zonality is especially noticeable in the increased (1.5-2x) concentrations of Y and Zr.

Commercial ore bodies and zones Uranium ores form three main ore zones: Eastern, Central, and Northern-western. They consist of the chain of ore bodies of different sizes and morphologies, both lens-like and complicated isometric. Bedding in the ore bodies is associated with ore controlling structures, and mineralization extends hundreds of meters along strike.

Inter-mineral and post-mineral tectonics of ore bodies Inter-mineral tectonics is seen in the form of zones of brecciation, milotinization, foliation and boudinage, volumetric cataclasis and minor fracturing. Post-mineral tectonics is represented by minor fracturing, late cataclasis, attrition clay, and sometimes kakirite, breccia and blastomylonitejointing, zones of tectonic schistosity, cataclasites and fracturing zones. Some ore bodies are blocked due to the displacement.

Near-surface alteration of ore bodies During hypergenesis the ore minerals are oxidized along post-mineral fault structures and form aureoles that are yellow in color. Sooty uranium, secondary yellow silicates, and late generation oxides are also formed.

Mineral composition of ores (Fig. 1.18, 1.19) The main ore minerals are uraninite, beta-uranotile, sooty uranium, and nenadkevite. Secondary ore minerals: hydro pitchblende, secondary silicates of yellow color, uranium titanate. Rare minerals: coffinite, brannerite, carnotite. The main non-metallic mineral is albite. Secondary non-metallic minerals: chlorite, riebeckite, aegirine, hematite, carbonate, epidote. The main commercial minerals are uraninite, beta-uranotile, and a mixture of sooty uranium and nenadkevite.

Fig. 1.18. Ore from the Vatutinske deposit that is apogranite riebeckite-aegirine albitite. Major ore minerals are uraninite, beta-uranotyl, sooty uranium, and nenadecvite

Fig. 1.19. Ore from the Vatutinske deposit that is apogranite phlogopite albitite. Uraninite mineralization is in veinlets in the brecciation zone.

Characteristics of commercial minerals (Fig. 1.20) Uraninite, beta-uranotile, sooty uranium and nenadkevite form fine scattered impregnations in the dark colored minerals, in zones of fracture and cataclasis, and in fine-grained rock cement. They are also found in the form of minor veinlets or net-like aggregations from 10^{-3} mm up to mm in size. The ore mineralization is surrounded with brown iron hydroxide aureoles and uranium-containing grains and aggregations in rock-forming minerals (both dark colored and albite) are surrounded with radial grids of micro fractures because of the influence of radioactive emission.

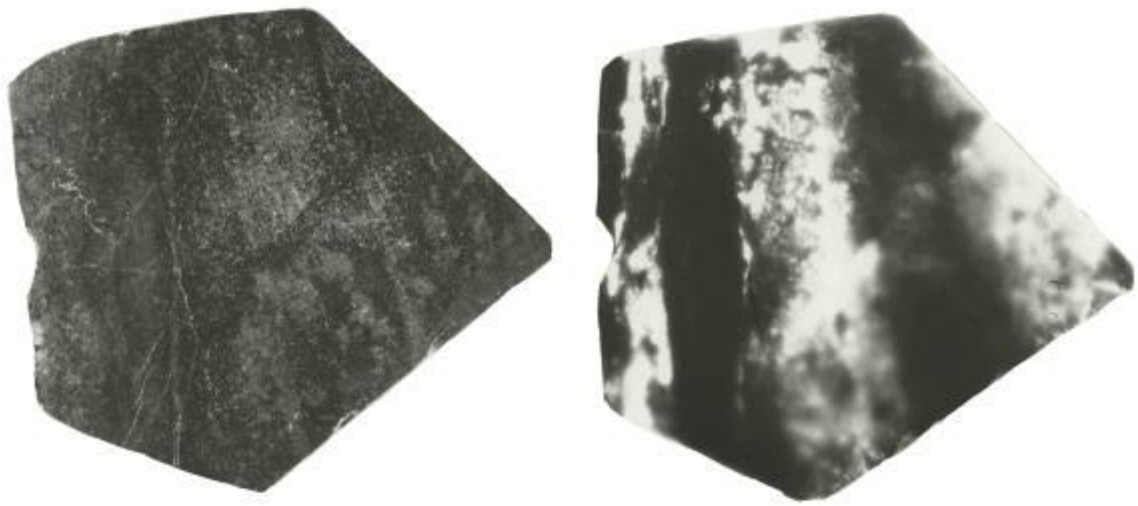

Fig. 1.20. Sample from the Vatutinske deposit (a - piece of ore, b – radiography) that is apogneiss epidote-chlorite albitite. Major ore minerals are uraninite, beta-uranotyl, sooty uranium, boltwoodite and hydrated pitchblende.

Chemical composition of ores The chemical composition of ore that was sampled at the deposit is given in Table 1.4 (according to data from laboratory analyses at the SE "Vostgok" [4]). The average content (weight %) of alkaline elements in primary rocks, mineral-less and ore-containing metasomatites is shown in Table 1.5, while the average content of micro elements in primary rocks and metasomatites is found in Table 1.6.

Albitization of granites is accompanied by the removal of K_2O and SiO_2 and addition of Na_2O, Al_2O_3, CO_2 and MnO; a significant decrease of FeO and increase of Fe_2O_3 is also observed. The follow on removal of SiO_2 and addition of primarily Na_2O and CO_2 occurred during the process of uranium mineralization in apogranite albitites. Albitization of migmatites is accompanied with removal of K_2O and SiO_2 and addition of Na_2O, CO_2 and Al_2O_3; a significant decrease of Fe and increase of Fe_2O_3 content is also observed. During this process, mineralization led to further removal of SiO_2 and addition of Na_2O and CO_2.

Table 1.4

Characteristics of uranium ore

Name	$Ra^{226} 10^{-7}$	$Th^{230} 10^{-7}$	$Pb^{210} 10^{-7}$	$Po^{210} 10^{-7}$	U	
Sample	Uranium ore from the Vatutinske deposits (Ci/kg)				$U \cdot 10^{-3}$%	activity 10^{-7}Ci/kg
Sample №17 Block 1.1 – В/Г-Д Horizon 550-640	8,24	7,26	8,60	7,91	150	10,13
Sample №18 Block 1.1 – А/З Horizon 610	12,7	10,19	13,48	10,84	300	20,25

Table 1.5

Average content (weight %) of alkaline elements in primary rocks and metasomatites

Rock	K_2O	Na_2O	K_2O+Na_2O
Granite	5,35	3,25	8,58
Diaphtorited granite	5,18	3,53	8,69
Syenite-like apogranite	6,75	4,71	11,47
Apogranite albitite:			
non-metallic	0,45	8,66	9,11
ore-containing	0,26	8,71	8,98
Migmatite	3,37	3,52	6,91
Syenit-like apogranite	5,63	5,22	11,16
Apomigmatite albitite			
non-metallic	0,51	8,04	8,60
ore-containing	0,52	8,99	9,56

Table 1.6

Average content (g/t) of trace elements in primary granites and metasomatites

Element	Granite	Diaphtorite of external zone	Syenite-like rocks of intermediate zone	Albitite of internal zone	
				non-metallic	ore-containing
Li	14,4	7,2	3,4	11,5	12,9
Rb	90	66	115	4	7
Cu	17	19	18	19	20
Pb	42	42	45	30	122
Ti	1340	1360	1620	1500	1740
V	13	14	19	46	219
Mn	236	235	220	250	257
Ba	493	455	480	235	265
Sr	208	183	178	175	227
Zr	126	122	124	135	145
Y	8,8	8,4	9,1	8,2	12,8
Yb	0,9	0,9	0,9	1.1	1,5
Th	11,6	10,7	16,0	13,0	16,0
U	8,2	10,8	10,0	19,0	50

Aluminosilicate uranium ores are of low iron content (content of FeO and Fe_2O_3 varies from 1 to 2% and from 2 to 3%, respectively). Uranium ores are often monometallic and lack thorium. Microstructure of uranium minerals is colloform-impregnated. The ore structure is scattered-impregnated and veinlet-impregnated.

Technological characteristics of ores The ores are technologically homogenous and divided into blocks of different technological properties because of interbedding and superimposition of mineral paragenesis of different acid consumption and rock release capacity. The method of autoclave sulfuric leaching is the most interesting for ore processing the same as for other deposits of this genetic type at the Ingulskyi mega block.

Mining conditions The deposit is operated using blasting explosive mining methods, although underground block leaching is also used. Uranium is extracted from low-metal content rock tails on the surface using a heap leaching method.

Hydrogeological mining conditions Hydrogeological conditions are suitable for mining the deposit. There are two water bearing horizons at the deposit (groundwater and fracture waters). Horizons of underground water in Cenozoic sedimentary rocks are 10 m thick and the weathering crust serves as a confining layer. The maximum thickness of sedimentary cover is 60 m; the minimum is found in deep ravines and the Kilten' River valley. The fracture water horizon in crystalline rocks is the main water bearing horizon. Its depth varies from 2 to 280 m. The fracture water reserve within the deposit is stable and dynamic inflow has been shown to be unimportant during the complete dewatering from mine exploration (from 200 to 400 m^3/ year).

Novokostyantynivske deposit

The Novokonstantinivske uranium deposit was opened in 1975 and is found in a farming region near Alexeevka village. The field is located in the central part of the crystalline Ukrainian shield, and coincides with the timing of the tectonic and metasomatic node formed by the intersection of the East and oblique faults, which control not only formation of albitites, but also the location of uranium mineralization. The crystalline basement is covered by sedimentary platform deposits, dominated by loams and sands, ranging from meters to several tens of meters thick. Sediments overlie the weathering crust of crystalline rocks, the thickness of which varies from one to tens of meters. The Novokonstantinovskiy deposit has large reserves and the total length of mineralization along strike is 1500 m, 1200 m along dip, and the ore zone varies from tens of meters up to 250 meters.

The host rocks are granite porphyry, fine-grained granite, pegmatoid granites, and migmatites. They form a series of lenticular bodies oriented north and north-east at an angle of 30–50°, ranging from a few to 200 m. The field has three ore zones with an angle of incidence of the ore bodies from 30° to 60°. Along dip, the ore zones can be traced at 650 m depth for 1200 m along strike. Ore deposits are not continuous ore bodies, and here they are a series of ore intervals with a variable ore content.

Dimensions of ore deposits vary widely and the length along strike and dip varies from a few tens of meters up to 700 m.

The deposit is also located within the Central Ukrainian metallogenic region and it consists of several ore bodies (Fig. 1.21, [1]). The Novokostyantynivske ore field is of meridional strike, and extends to a distance of about 7 km. The width of faulting is from several hundreds of meters to 2 km. Uranium mineralization is associated with complicated zones of volumetric cataclasis in place of strata folds and secondary tectonic dislocations where intensive alkaline metasomatism is spread. Mineral associations of host rocks and ores are not principally different from uranium-bearing interlayers of this type. As mentioned above, the deposit development started in 2008. The recent detailed survey significantly broadened perspectives of this deposit and according to informal data published by some mass media, annual uranium output can reach 900 t with the possibility of increasing up to 3000 t.

It has to be mentioned that faults of the Novokostyantynivska ore zone of up to 10 km width (similar to Kirovogradska and Zvenigorod-Gannivska) extend in the sub-meridional direction to a distance of up to 250 km. The availability of uranium ores in these tectonic dislocations requires further study, especially taking into account the specific distribution of metasomatism and connected mineralization.

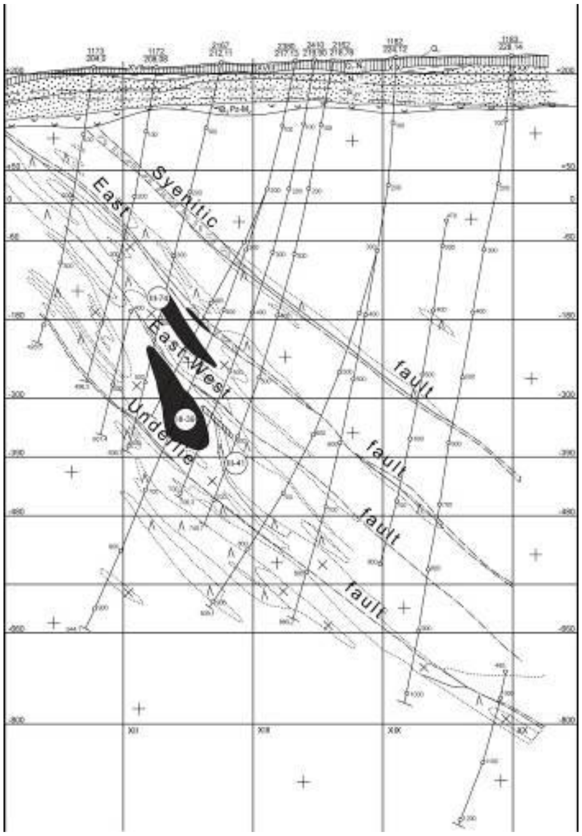

Fig.1.21. Geological map of the Novokostyantynivske uranium deposit:
1 – granites; 2 – desilicated rocks; 3 – albitites; 4 – tectonic dislocations; 5 – uranium-containing ore deposits and their numbers

1. 4. Dormant Deposits

Pivdenne deposit

The Pivdenne deposit is associated with thin pegmatite veins that have a high uranium content, up to 0,1-0,5%. Low-grade ores (0,03–0,05%) are connected with sub-meridional zones 10-30 m thick that extend to a distance of up to 7 km among Proterozoic gneisses, migmatites, and granites (Fig. 1.22). The impregnated ores contain uraninite, sooty uranium, uranium-containing cyrtolite, and monazite as the primary uranium minerals; pitchblende and coffinite are also found. Ore concentrate contains 56% uranium and 3.5% thorium.

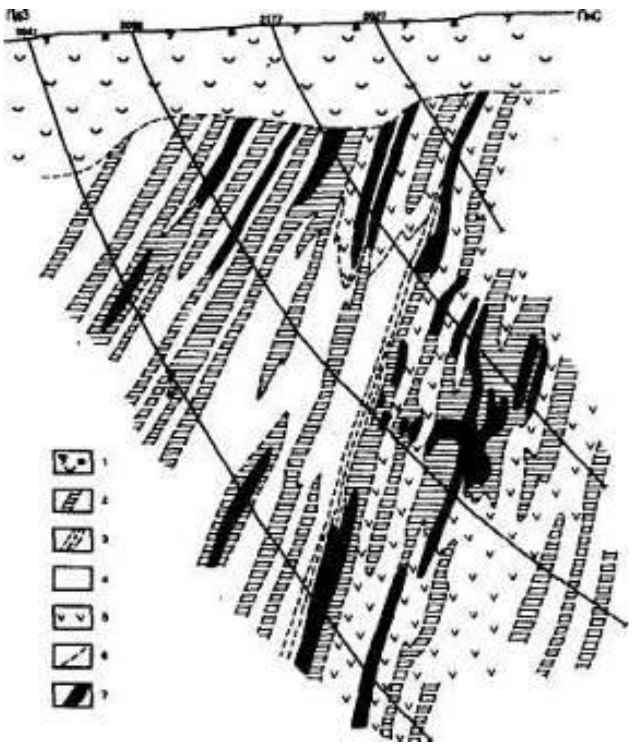

Fig. 1.22. Geological section of the Pivdenne deposit:

1 – Mesozoic and Cenozoic strata; 2 – aplite and pegmatite granites and microclines; 3 – graphite and biotite-graphite gneisses; 4 – garnet-pyroxene-biotite gneisses; 5 – pyroxene-biotite gneisses; 6 – tectonic dislocations; 7 – uranium-containing microclines [1, 10]

The Kalynivske and Lozovatske deposits are of similar structure and content, and according to mineralization scales, all three deposits are small – medium sized deposits. They are not developed yet.

Mykolo-Kozelske deposit

The Mykolo-Kozelske deposit is associated with a horizon of quartz conglomerates 0,3–3,5 m. Uranium mineralization is connected with the sandy cement of the conglomerates and is found in thin uneven impregnations of pitchblende, uraninite, coffinite, brannerite, and uranium-containing bitumen (Fig. 1.23.). Sulfides of copper, lead, and zinc, as well as monazite are found. Uranium content is up to 12%.

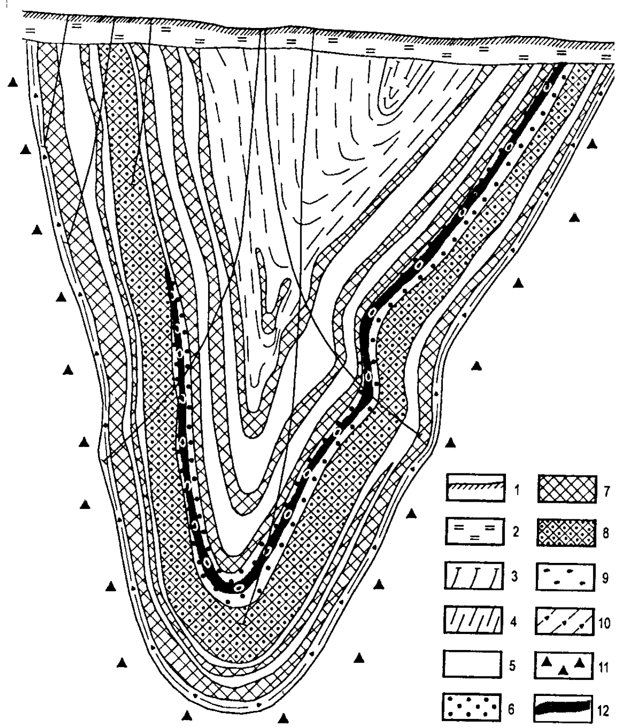

Fig. 1.23. Geological section of the Mykolo-Kozelske ore body:

1 – soil-vegetative layer; 2 – Cenozoic strata; 3 – talc shales; 4 – phyllitic carbonaceous – silica – sericitic shales; 5 – aleurite, quartz – sericitic shales; 6 – sandstones; 7 – quartzites; 8 – quartzite – sandstones; 9 – conglomerates; 10 – corniferous – plagioclase – quartz – biotite shales, quartz – plagioclase – biotite shales; 11 – amphibolites; 12 – uranium mineralization [1, 10]

Adamivske deposit

The Adamivske deposit is located in the sandstones of the Dronivska suite. It is associated with paleochannels that round the Adamivskyi salt dome (Figs. 1.24, 1.25). Mineralization age is Early-Middle Triassic. Ore bodies are 100-200 m thick, and contain layers of impregnated or massive black (oxianthraxolite) and dark-brown (kerite) bitumen. Impregnated non-uranium-containing bitumen (asphaltite and asphalt) are also found. Shelf-type ore bodies are found close to fault dislocations. The U content of the bitumen varies from a few to 85%. Besides U, the bitumen also contains V and Mo (up to 1%) as well as Cr (up to 0.1%). Cinnabarite, molybdenite, jordisite, sphalerite, barite, fluorite, celestine, and rarely, gold, are also found.

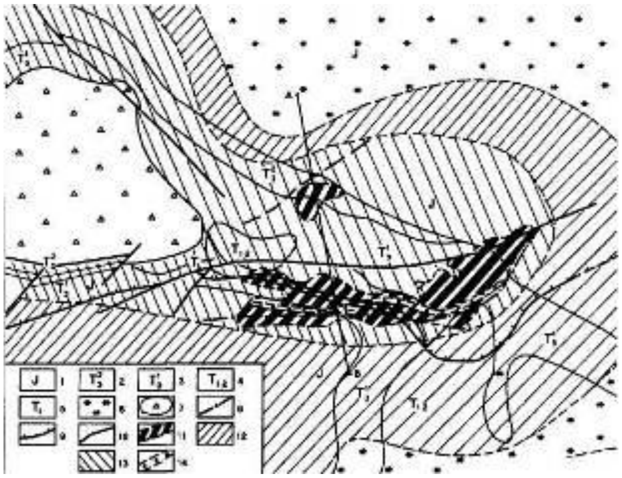

Fig. 1.24. The geological structure of the Adamivske deposit.

1 – Jurassic strata; 2-5 – Triassic strata). Suites: 2 - Novorayska, 3 – Protopivska, 4 –Sriblyanska; 5 – Dronivska; 6 - unaltered rocks; 7 - diapiric breccia; 8 - ore control faults; 9 – Pivdennyj overthrust; 10 - post-ore faults; 11 - outline of uranium-rich bituminbeds; 12 – contact zone of red colored and epigenetically renewed rocks; 13 - epigenetically renewed rocks; 14 – area of silicification [1, 13]

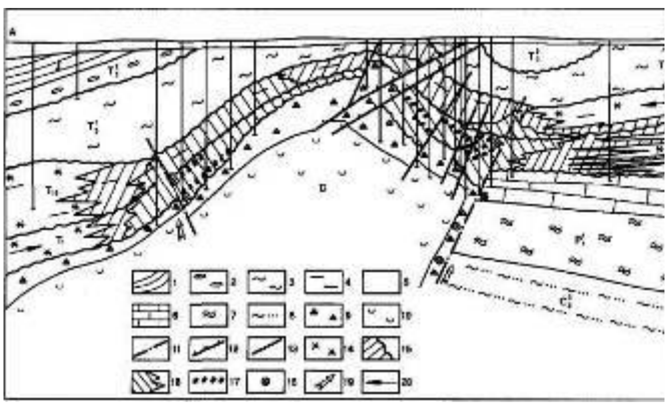

Fig. 1.25. Geological section of the Adamivske deposit:
1 – Lias; 2 – Novorayska suite; 3 – Protopivska suite; 4 – Sriblyanska suite; 5 – Dronivska suite; 6 – Slovyanska and Kramatorska suites; 7 – Kartamyska suite; 8 – Upper Carbonic; 9 – diapiric breccia; 10 – halite; 11 – pre-ore faults; 12 – overthrusts; 13 – post-ore faults; 14 –unaltered oxidized rocks of the Dronivska and Sriblyanska suites; 15 – greenish clays and rocks of the Dronivska and Sriblyanska suites; 16 – grey rocks of sulfide reduction area; 17 – bituminous uranium ore bodies; 18 – polymetallic mercury mineralization; 19 – direction of reduced fluid movement; 20 – direction of groundwater movement [1, 13]

Severynivske deposit

The Severynivske deposit is presented here in more details as its forecasted reserves estimated up to 50 000 t of U. It is located in the Kirovogradska zone north of the Michurinske deposit. It was discovered in 1968 while saturation prospecting the Lelekivske ore field. The Severynivske deposit is characterized by its areal extent and depth of mineralization (Fig. 1.26). Ores were found to a depth of 1450 m, and the uranium ore appeared to extend beyond that. Other boreholes reached albitites with uranium mineralization at a depth of more than 2000 m and barren albitites even deeper.

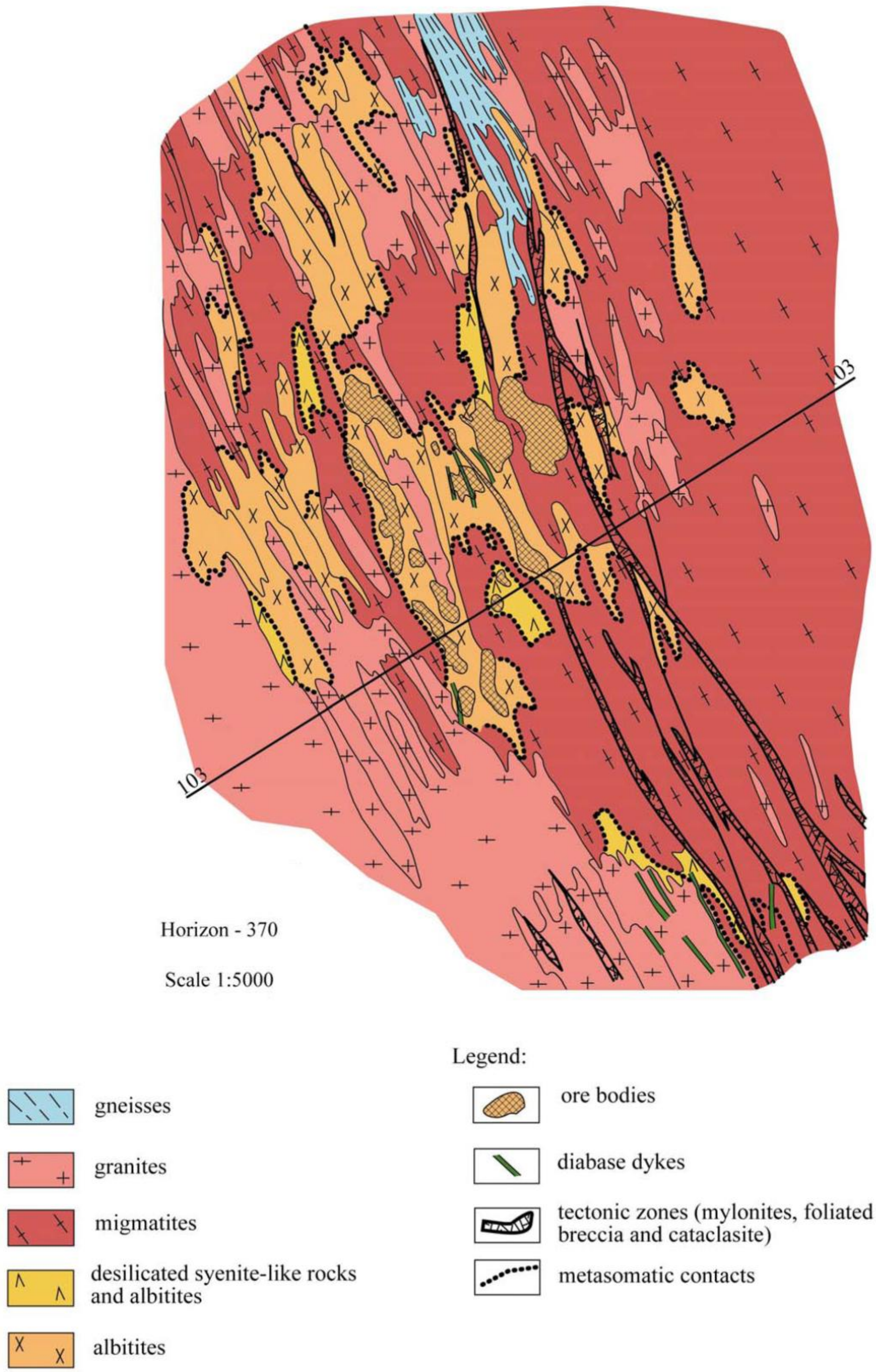

Fig. 1.26. Geological scheme of the Severynivske deposit

The deposit structure is defined by a system of diagonal and meridional faults. Rock associations are analogous to those of the Michurinske deposit, with biotite gneisses, migmatites, and granites present. Mineralization is controlled by the location of the ores in the zone of sodium metasomatism, albitites of hematite-carbonate-chlorite and hematite-carbonate-riebeckite-aegirine content. The uranium ores consist of typical primary (uraninite, brannerite, pitchblende) and secondary ore minerals that are oxidation products. Ores are characterized by the presence of hematite and more intensive carbonatization

The discovery and detailed survey of the Severynivske deposit significantly broadened perspectives of the Kirovogradskyi ore region. This deposit is currently dormant.

Structural control of mineralization (location in ore-containing structure, folded and breach faults, mineralization control). The deposit is associated with the Severynivska tectonic and metasomatic zone which is considered as a component part of the Kirovogradskyi fault of the throw-shift type. It is formed at the contact of the Lelekivskyi massif (the Kirovograd-type medium-grained granites and fine-grained gneiss-like granites) with the Severynivskyi massif of migmatites at the site of sub-confirmed fault structures of fan-like ramification (Figs. 1.26, 1.27). By structural control of mineralization we mean association of ore bodies with fault zones that are surrounded with cataclasites and fractures and also with flexures of sub-shift type. Ore mineralization in the form of impregnated accumulation is associated with zones of volumetric cataclasis, minor fracturing. Mineralized micro veinlets are associated with fractures. Mineralized plots are found in syn-mineral milonites and breccia and also in tectonically foliated rocks. The last ones prove the fact that the main tectonic structures served as ore channel ways, and feathering them tectonites and small structures – as ore distributing and ore containing.

An echelon location of mylonites and cataclasites joints, numerous tectonic dislocations of low thickness (developed in parallel with the main joints) directly influenced mineralization formation and morphology of ore bodies. It favored the formation of ore bodies and metasomatites of columnar shape; intensive post-albitite feeding of tectonic zones and formation of wide aureole of cataclastic rocks and superimposed uranium mineralization. The ore bodies of complicated isometric form are localized in zones of faults intersection.

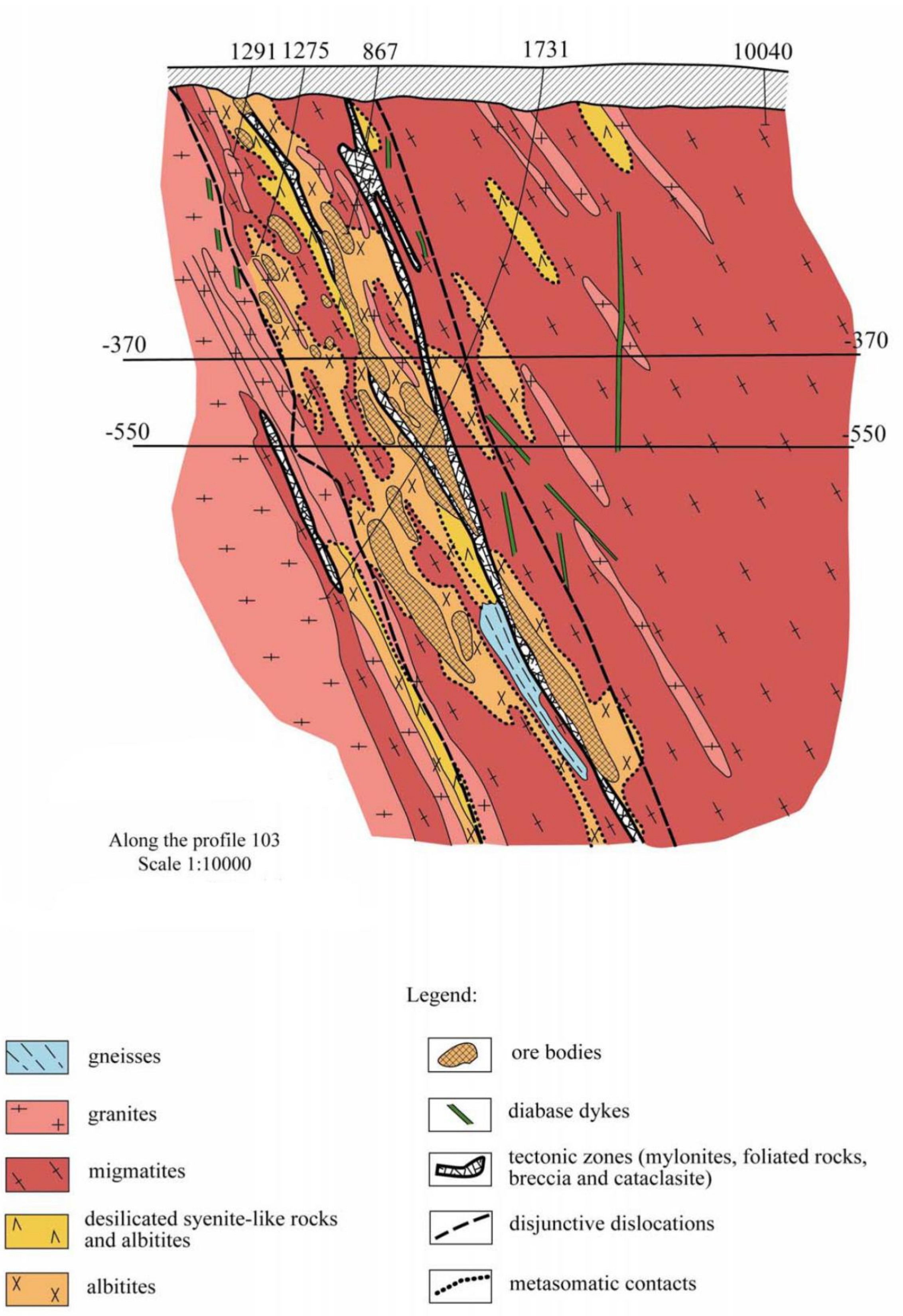

Fig. 1.27 Geological section of the Severynivske deposit

Geomorphological control (forms and elements of relief, mineralization control, etc.). Geomorphological factors of control of mineralization, ore zones and bodies as well as distribution of ore mineralization inside ore bodies are absent. However geomorphological peculiarities of the present-day surface (ravines, gullies, river valleys) reflect Pre-Cambrian ore-controlling fault zones. [24]

Genesis of mineralization . The deposit is of hydrothermal and metasomatic type of sodium-uranium formation. It is genetically connected with the processes of ultra metamorphism of uranium-containing rocks. Post ultra-metamorphic solutions penetrated along long-lived fault zones and led to sodium metasomatism and the following on ore formation in albitites. Diaphthorites (syenite-like desilicated rocks) as a product of incomplete phase of sodium metasomatism are mainly contaminated with uranium and do not contain commercial ore mineralization. ***Kaolin weathering crust*** is of areal type. Primary rocks are gneisses, migmatites, granites.

Wallrock alteration of host rocks (type, intensity, width of aureole, etc.). Albitization, hematitization, chloritization, carbonatization, desilication, epidotization, silicification in the upper part of the vertical metasomatic columnar shoot and also within selvages of sodium metasomatite bodies sericitization, phlogopitization, riebeckitization, aegirinization along the tectonic zones. All the rock-forming minerals of primary rocks are altered. The aureoles spread is more than 2600 m on pitch, around 1400 m on strike while the width is many hundreds meters.

Other data on host rocks (formation, facies, complex, rock strata, thickness, tectonics, etc.). The unaltered rocks are migmatites, granites of the Kirovogradskyi complex, gneisses of the Checheliivska suite, Ingul-Inguletska series of Paleoproterozoic age. The rocks strike is north-west 320-340°, the pitch - north-east 55-65°. Crystalline rocks of the basement are covered with sedimentary rocks of 30 t0 60 m thickness. The areal weathering crust of 10-50 m thickness is extended on crystalline rocks.

Commercial ore bodies and zones of the deposit (number, names, reserves, form and character of ore shoots, thickness, etc.). Thirty two (32) commercial ore bodies are prospected at the deposit. They are localized in two extensive ore zones (steady on strike and pitch). The biggest two ore zones 36-I and 66-II contain 33,1% and 32,5% of total uranium reserves correspondently. And five big ore zones contain 84,3% of total uranium reserves. The ore bodies are of seam-like, lens-like, and complicated isometric morphological form. Ore bodies pitch is very steep. Their average horizontal thickness varies from 1.4 to 27.2 m. The biggest seven ore bodies are of 15 m thickness. The average horizontal thickness of the deposit is 27.1 m.

Inter-mineral and post-mineral tectonics of ore bodies' (plicative and disjunctive dislocations; continuity of ore bodies on extension and thickness, etc.). Inter-mineral tectonics is shown up in the form of breccias', blastomylonites' joints, zones of tectonic schistosity, cataclazites and fracturing zones feathering the main tectonic dislocations and also in the form of volumetric cataclasis associated with tectonic dislocations.

Post-mineral tectonics is shown up within the zone №3 in the form of wide aureole of quartz-sericite rocks and attrition clay imposed on mineralization without displacement of ore bodies along these zones. It is also fixed with numerous sites of cataclasis, minor fracturing and clevage cracks of low thickness.

Near-surface alteration of ore bodies (form, thickness, characteristics of oxidation, secondary enrichment zones, etc.). Under condition of hypergenesis the main ore mineral brannerite is partially or completely altered with leucoxene-like products containing residual quantity of uranium.

Noncommercial ore bodies are represented with unconditioned (4 blocks) or insufficiently researched 37 blocks.

Mineral composition of ores. The major ore minerals are brannerite and brannerite oxidated. Minor minerals: pitchblende is a secondary ore mineral here. Trace ore minerals: sooty uranium, uraninite, secondary silicates of yellow color. The major non-metallic minerals are albite, chlorite, phlogopite, riebeckite, aegirine, epidote. Minor non-metallic non-uranium minerals formed in the process of ore formation are carbonate, magnetite, hematite.

Major commercial minerals: brannerite, brannerite oxidated, pitchblende, sooty uranium, uraninite, secondary silicates of yellow color.

Characteristics of commercial minerals (content, habitus, sizes, etc.). Brannerite and uraninite are met in the form of even impregnation, veinlets or net-like aggregations. Their sizes are from hundredth and thousandth parts of a millimeter to 0.2-0.4 mm. Pitchblended and uranium silicates associated with it form fine colloform spots. The size of spots is from 0.02 up to 0.1 mm, of aggregations – up to 2.0-3.0 mm. The veinlets' thickness reaches 5.0 mm. Ore aggregations, separate impregnations, and also some veinlets are localized in dark-colored minerals (chlorite, phlogopite, aegirine, riebeckite) contained an element – uranium precipitator Fe^{+2}, that is transformed into trivalent form. As a result one can observe light brown aureoles around uranium mineralization. Uranium inclusions in rock-forming minerals (both in dark colored and in albite) are surrounded with radial grid of micro fractures because of influence of radioactive emission.

Chemical composition of ores, %. The ores within the Kirovogradskyi fault are characterized with increased content of Fe_2O_3, Na_2O,CaO, CO_2 in all their types (apogneiss hematite-carbonate-chlorite, apomigmatite hematite-carbonate-chlorite, apogranite hematite- riebeckite-aegirine chlorite) see table below (according to data from the SE "Kirovgeologiya"). The following elements are usually found in higher amount: zirconium (0,015-1,020% when average content is 0,122%); vanadium - 0,036-0,154%; lead – mainly of radiogenic origin in average 0.021%; aurum (from traces to 0.03 g/t). The ores are considered to be monometallic uranium.

Aluminosilicate uranium ores are of low iron content (content of FeO and Fe_2O_3 varies from 1 to 2% and from 2 to 3,6%). Content of CO_2 in ores is 1-3,5%, phosphorus pentaoxide – 3,7%, sulfuric anhydride – 3,07%, magnesium and calcium oxides – 3-7%. Uranium ores are often thorium-less. Ore structures and textures are determined by peculiarities of host albitites, intensity of syn-mineral cataclasis, form and character of dark colored and uranium minerals distribution. Dissemination of fine-impregnated ores is conditioned by pre-mineral volumetric cataclasis. Apomigmatite, apogranite and apogneiss ore albitite are spread. Apomigmatite of fine- and medium-grained blastocement cataclastic structure are predominant. Uranium minerals are of colloform-impregnated, idiomorphic-impregnated, pseudomorphic-impregnated micro structure. Ores are of fine-impregnated (predominant) and veinlet-impregnated structural types.

Other data about ore mineralization. According to classification of solid commercial mineral reserve, the deposit is referred to the II group (taking into account geological structure and character of mineralization. Reserve calculation is as of 1 July 1981 (party № 37, SE “Kirovgeologiya). The calculation was done using method of geological blocks on vertical projection. After determination of reserves of C_1 and C_2 categories, speculated resources of P_1 category were calculated – 426 t of uranium content 0,078%.

The Severynivske and Novokostyantynivske deposits are partially eroded. That is why they are characterized by the highest vertical spread of mineralization remained after erosion on the Ingulskyi mega block (correspondently 1500 i 1300 m). So, in post-mineral time 200-400 m of primary vertical ore column were removed as a result of tectonic processes, erosion, and peneplanation of the Ukrainian Shield. To the contrary, the Michurinske deposit was deeply eroded and just 400-500 m of ore deposit was preserved (the deposit root part). According to scientific calculation (taking into account vertical spread of ore-containing albitites, vertical mineralogical, geochemical, and thermobarometric zonality of metasomatites and uranium ores) the maximum vertical spread of mineralization at the Severynivske deposit was ~ 1800м.

Technological characteristic of ores (technological testing and its results). The study of technological characteristics of ores was performed on the basis of a number of separate and group samples. It proved that the ores are technologically homogenous and divided into blocks of different technological properties because of interbedding and superimposition of mineral paragenesis of different acid consumption and rocks release capacity. The ore from 36-II group is exclusion. Acid consumption for obtaining final cakes here is significantly lower than on average for the deposit. The method of autoclave sulfuric leaching is the most interesting one for laboratory ore sample processing at t = 150°C and P = 5 atm. It leads to high leaching of uranium into solution (94-95%) at sulfuric acid consumption of 110-120 kg/t. The study of mini plant technological samples №№ 67-T and 69-T of 123 t weight proved the laboratory results. At t = 130-140°C and P=14-16 atm the uranium extraction reached 92-93% when H_2SO_4 consumption 11-13%. Taking into account the ores granulometric composition and contrast range they were accepted for radiometric separation. 26.6% of tales contained 0.015% of uranium is separated from ores contained 0.03-0.10% uranium using separators of "Vikr" type. The concentration rate of ore dressing is 1.26 when uranium extraction - 93,4%.

Mining conditions (mining properties of ores and rocks, mining conditions, etc.). According to geological structure, hydrological and hydro technical conditions the deposit is suitable for mining. The ores and rocks are quite hard and referred to the I-III category of the Protodiakonov's hardness scale (f =14+20); their fracturing ratio is of low or average level (15 fractures per m). Prognosis assessment of mining pressure in the course of time carried out using ultrasonic logging on the basis of workings research and different parameters of fracturing zones around workings allowed making the following conclusion. The tense massif state relating the rock hardness is less than 10%

in the PE-3 mine. The formation of balmstones is an effect of mining pressure here. It fades after an opening mine and rocks airing. Exploratory workings are not timbered excluding those in mine roadways, zones of fracture and chambers of underground drilling. The Central deposit is located 8 km south of the Severynivske deposit, and the Michurinske deposit – 14 km. They are currently under operation and joined with the main drift. Genetically they are referred to the same sodium-uranium formation. So, the mining conditions were turned out to be favorable for operation and it was proved when the deposit development.

Hydrogeological mining conditions (complexity of lithological conditions and other characteristics of water-bearing horizons, extension and level of workings flooding, water inflow, etc.). Hydrogeological conditions are suitable for the deposit mining. The deposit watering is low and decreases with depth as areal fracturing fades at depths of 175-300 m and lineal zones of intensive fracturing are filled in with clayey, carbonate and quartz cement at depth of 500-700 m. Total water inflow from two mine horizons located lower than zone of intensive fracturing did not exceed 20.7 cubic m/year. However prognostic water inflows (expected when operation of upper watered horizons) are made up 200-250 cubic m/year. They were calculated on the basis of experimental filtration research and by analogy with average annual water inflow into upper horizons of the Michurinske and Vatutinske deposits. Significant damage for the Lelekivskyi water intake of Kirovograd city (located at a distance of 2 km) from unwatering of operating workings is not expected because of its separation from the deposit according to feeding conditions, low filtration properties of host rocks and complicated hydraulic connection of water-bearing horizons.

Water supply (sources, equipment, coverage, demand on service and portable water, etc.). The Kandaurskyi water intake is expected to be the source of water supply for the mine at the Severynivske deposit. The average capacity of this water intake is 5.5

thousand cubic m/day. Its prospected reserve is 14,8 thousand cubic m/day. It may also be considered to use the Ingulskyi water intake of 9.3 thousand cubic m/day capacity.

2. ORE MINERALOGY OF COMMERCIAL URANIUM DEPOSITS

Uranium minerals are characterized by complicated and unstable chemical compositions that reflect the variable physical properties and conditions of their formation. Many of these minerals have similar outward appearance and optical properties. They are often metamict and X-ray amorphous, metastable and easily altered. Thin intergrowths of uranium and rock-forming minerals, and diverse morphological forms including isometric grains, plates, globules, and amorphous masses of different configurations are the most typical found in uranium ores.

Around two hundred different uranium and uranium-containing minerals are currently recognized, although just a small subset are of commercial importance. The minerals are mainly compounds of U^{4+} and U^{6+} ions, and while some researchers mention that U^{5+} complexes can also be found, this valence form is not stable and is more often reduced or oxidized to the more stable U^{4+} or U^{6+} in the mineral structure. As a result, complex multiphase mineral aggregates are formed. Relatively light mutual conversion of uranium ions of different valence under oxidation-reduction conditions leads to the trapping of different accessory ions in the crystal lattice, creating complex polymineral formations. The predominant structural component of these are complex uranyl ions of UO_2^{2+}.

Uranium minerals are often classified as either minerals of tetravalent uranium (that are traditionally considered primary minerals) or hexavalent uranium (secondary minerals). According to their origin, tetravalent minerals belong to hypogene, while hexavalent minerals belong to hypergene minerals. Among minerals of (U^{4+}) and (U^{4+} + U^{6+}) there are three classes of chemical compounds: oxides, orthosilicates, and titanates. Uraninite, pitchblende, and uranium black are oxides; coffinite and nenadkevite are orthosilicates; and brannerite and davidite are titanates. All of these groups are widespread in the prime uranium ores (unoxidized and unhydrated) in Ukraine. The secondary and exogenous minerals are also widespread in these deposits, and while they have been studied less extensively, the following minerals have been found: hydroxides (schoepit, urgite), phosphates (otenite), silicates (uranophane, beta-uranotile, boltwoodite), and vanadates (carnotite, tyuyamunite, senzierite). Complex aggregates of relict primary minerals and products of their alteration due to oxidation, hydration, and interaction with circulating solutions in the weathering crust are also considered secondary minerals. In general, they are not identified as individual minerals but as mixtures of certain phases, the components of which are determined through radiography, roentgenography, and electron microscopy.

This chapter discusses the characteristics of uranium mineral data that were officially published or presented in [government?] reports. Results of authors' research conducted at the IEG NASU are also presented here.

Taking into account the details mentioned above, it is reasonable to discriminate mineral aggregates as associations of mineral species and idealized compounds that are chemically and electronically balanced with fixed compositions. Physical and chemical constants given in the literature are mainly applied to "pure" compounds under standard conditions. They are widely used for thermodynamic calculations of natural geochemical processes (including those with petrological and ore applications). The term "mineral species" here is conditionally replaced with a simplified chemical formula or general name. Double-terms like "chemical" and "stoichiometric formula" composition are widely used, and the shortened term "minal" can be found in petrological literature (D. Skarzinskii, V. Zharikov). Wide variations in chemical composition, isomorphic and mechanical impurities, and uncertainties in structure make it difficult to definitively identify and compare minerals. As chemical composition is of high importance when processing ore, it is reasonable to express mineral composition through constituent oxides taking into account the presence or absence of lead impurities than can be of heterogenic (including radiogenic) origin.

2.1. Prime (hypogene) minerals

2.1.1 Uraninite (pitchblende). The mineral is of $mUO_2 \cdot nUO_3 \cdot pPbO$ composition, with a complete formula of $(U^{4+}, U^{6+}, Th, TR, Pb, Ca)O_{2+x}$; correlation between basic component oxides varies and depends on the amount of oxidation of the uranium. The formula U_3O_8 or $UO_{2,67}$ (for mole parts of component oxides $m : n = 1 : 2$) is considered to be the most stable species. This is also confirmed by research of phase correlations in the system UO_2 – UO_3. Isomorphic impurities in unaltered prime minerals - Th (broggerite)б TR and Th (cleveite). In altered oxides (sooty uranium) $m : n < 1 : 2$; microscopic mineral impurities of uranyl and sulfides are often found and Fe, Si, Ca, Zr, and heavy metals have been found to be fixed in many studies. They are rarely found in the oxide. Lead is generally of radiogenic origin and its content basically correlates with uranium. This dependence is disturbed during recrystallization with selective carryover of lead or uranium and in the case of polyphasicity of these processes.

One of the most well-known and widely found ore minerals is pitchblende (uranit, pechblende). It predominates in uranium-bearing alkaline metasomatites among ferrous rocks of the Northern Kryvorizzya whereas it is less common in albitites compared to uraninite and brannerite. Spherulitic, reniform, concentric, and zonal-striated structures and their variation are typical for this species (Fig. 2.1, 2.2).

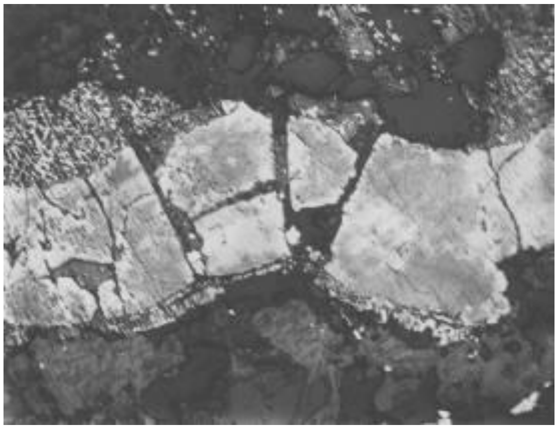

Fig. 2.1. Uraninite (white) propagated on coffinite (grey) (section, magnification 160x)

Fig. 2.2. Columnar crystals of uraninite of late generation growth on the walls in solution cavities (section, magnification 160x)

Spherulite growth is often observed on aggregates of smaller grains with formation of so called colloform (metacolloidal) structures (Fig. 2.1). According to thermodynamic calculations, it is thought that these structures form as a consequence of solidification of viscous gel-like masses. Assuming insignificant variation of ΔG, uranium precipitation occurs in ionic-colloidal systems across a wide range of pH, mU, and Eh values. It has to be also mentioned that spherulite and similar structures do not always indicate the presence of colloids as the intermediate step during mineral formation. However, the reverse process, of transformation of the fully crystalline phase into an amorphous phase is much less probable. These structures (textures) of pitchblende are not exclusive to this mineral and are widespread in others, specifically, in calcite, hematite, and malachite. At the Zhovtorichenske deposit, where oxides are the most widespread among uranium ores, different crystallization conditions led to simultaneous formation of uraninite cubic crystals and pitchblende (colloform aggragate) spherulites. As a result, morphologically complex structures reflecting the evolution of mineral formation were formed (Figs. 2.3, 2.4). Transformation from cubic, clearly shaped forms to aggregates of crystals overgrown with spherulites, are most often observed. The reverse of this transformation is occasionally observed (sometimes in one polished thin section) with spherulite included into clearly faceted crystals of uraninite.

Fig. 2.3. Uraninite (black) replaces hornblende (white). Calcite has expanded onto amphibole (in the center of the image) with a crosscut veinlet of biotite (section, magnification 160x)

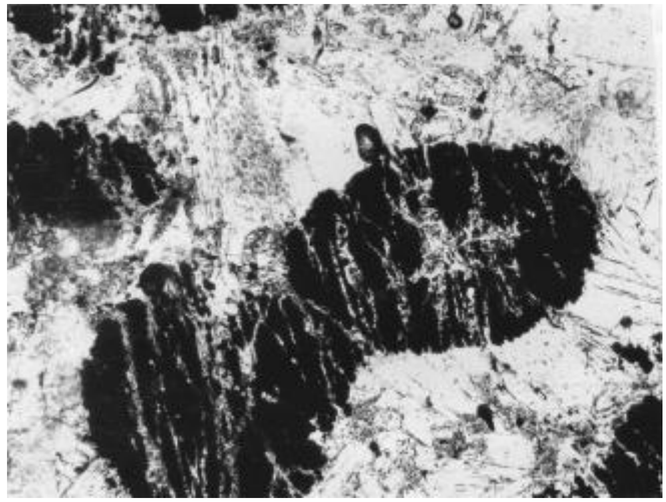

Fig. 2.4. Uraninite (black) in biotite shale (section, magnification 160x)

There are few complete chemical analyses for monomineral fractions of uraninite and pitchblende from Ukrainian deposits in the scientific literature. Those found are mainly microroentgen-spectral analyses that do not include light component content – (CO_2, H_2O); the correlation between UO_2 : UO_3 and FeO : Fe_2O_3 are not completely reliable or absent; and some components, specifically, Fe_2O_3, SiO_2, Na_2O, and MgO are possibly due to impurities. Only the total uranium content (in the form of UO_2 or U_3O_8) and iron content (in the form of Fe_2O_3) are included. The probable chemical compositions of the main uranium deposits of Ukraine, recalculated in molar parts, taking into account penetration of lead into the crystalline lattice of uraninite or other phases (galenite, metallic lead, and possibly $PbUO_4$) are given below.

Zhovtorichenske deposit

$$0{,}66UO_2 \cdot 0{,}21PbO \cdot 0{,}07CaO \cdot 0{,}03TiO_2 \cdot 0{,}02ZrO_2 \cdot 0{,}01Fe_2O_3 \qquad (2.1)$$

m<0,01 – Y_2O_3, ThO_2, SiO_2; UO_2 : UO_3 =?; Pb : U = 0,32.

Uraninite (prime ?).

$0{,}65UO_2 \cdot 0{,}23PbO \cdot 0{,}08CaO \cdot 0{,}02ZrO_2 \cdot 0{,}01TiO_2 \cdot 0{,}01Fe_2O_3$ (2.2)

$m<0{,}01$ – Y_2O_3, SiO_2; $UO_2 : UO_3$ =?; Pb : U = 0,35.

Uraninite (prime ?).

$0{,}64UO_2 \cdot 0{,}23PbO \cdot 0{,}09CaO \cdot 0{,}02Fe_2O_3 \cdot 0{,}01TiO_2 \cdot 0{,}01ZrO_2$ (2.3)

$m<0{,}01$ – Y_2O_3, SiO_2. $UO_2 : UO_3$ =?; Pb : U = 0,36.

Uraninite (prime ?).

$0{,}67\ UO_2 \cdot 0{,}12CaO \cdot 0{,}11\ PbO \cdot 0{,}08\ ZrO_2 \cdot 0{,}01\ TiO_2 \cdot 0{,}01\ Fe_2O_3$ (2.4)

$UO_2 : UO_3$ =?; Pb : U = 0,16.

Pitchblende.

Michurinske deposit

$0{,}32UO_2 \cdot 0{,}30UO_3 \cdot 0{,}20Pb \cdot 0{,}07CaO \cdot 0{,}03ZrO_2$ (2.5)

$UO_2 : UO_3$ = 1,07; Pb : U = 0,32.

Uraninite (prime ?).

$0{,}35UO_2 \cdot 0{,}32UO_3 \cdot 0{,}21PbO \cdot 0{,}08CaO \cdot 0{,}04ZrO_2$ (2.6)

$UO_2 : UO_3$ = 1,09; Pb : U = 0,31.

Uraninite, analog (2.5).

$0{,}88UO_{2,67} \cdot 0{,}07PbO \cdot 0{,}03CaO \cdot 0{,}02ZrO_2$ (2.7)

$UO_2 : UO_3$ = 2,0 (?); Pb : U = 0,08. Pitchblende.

Severynivske deposit

$0{,}52UO_{2,67} \cdot 0{,}37CaO \cdot 0{,}08SiO_2 \cdot 0{,}02PbO \cdot 0{,}01Th_2O_3$ (2.8)

$UO_2 : UO_3$ = 1 : 2 (?).

Calcium uraninite (pitchblende ?) with 11,5% by mass CaO and anomalously low PbO content (2,2 mass %).

$$0{,}51UO_{2,67} \cdot 0{,}37CaO \cdot 0{,}10SiO_2 \cdot 0{,}01PbO \cdot 0{,}01Th_2O_3 \quad (2.9)$$

$UO_2 : UO_3 = 1 : 2$ (?). Analog (2.8).

$$0{,}48UO_{2,67} \cdot 0{,}36CaO \cdot 0{,}13SiO_2 \cdot 0{,}02PbO \cdot 0{,}01Th_2O_3 \quad (2.10)$$

$UO_2 : UO_3 = 1 : 2$ (?). Analog (2.8).

Vatutinske deposit

$$0{,}23UO_2 \cdot 0{,}47UO_3 \cdot 0{,}21PbO \cdot 0{,}09CaO \quad (2.11)$$

$UO_2 : UO_3 = 2{,}04$; $Pb : U = 0{,}30$.

Uraninite (nearly corresponds to stable phase of U_3O_8, calcium species).

$$0{,}23UO_2 \cdot 0{,}46UO_3 \cdot 0{,}23PbO \cdot 0{,}09CaO \quad (2.12)$$

$UO_2 : UO_3 = 1 : 2{,}0$; $Pb : U = 0{,}33$

Uraninite (stable phase of U_3O_8, calcium species).

$$0{,}22UO_2 \cdot 0{,}45UO_3 \cdot 0{,}20PbO \cdot 0{,}13CaO; \quad (2.13)$$

$UO_2 : UO_3 = 1 : 2{,}0$; $Pb : U = 0{,}30$.

Uraninite (stable phase of U_3O_8, calcium species).

From the molar contents of uranium oxides given above, it is obvious that only those from the Vatutinske deposit correspond to minerals that contain significant (up to 15%) CaO impurities, called “calcium uraninite” elsewhere. This species is found at a depth of 1000 m in the form of fine crystals or xenomorphic grains with hematite. According to roentgenographic research by Ye. Kopchenova, calcium is included in the mineral structure. In general, impurities of different valence (TR^{3+}, Th^{4+}, Fe^{2+}, Pb^{2+}) are often fixed in uraninites but their structural location and effects (isomorphism, influence of internal radiation, micro impurities of other minerals) remain uncertain.

A somewhat different situation is observed with lead impurities. According to mineralogical and geological data it has a radiogenic origin in primary unaltered oxides. The stable end product of ^{238}U decay is ^{206}Pb, and the product of ^{235}U is ^{207}Pb. An isotopic uranium-lead method for determination of geological formation age was developed by E. Sobotovich, and is based on correlation analysis between the isotopes in each chain. Zirconium with low uranium content (0,0*n* – 0,*n*%) is mainly used for geochronology. Correlation between $^{206}Pb/^{238}U$ is of high significance for genetic conclusions. In uraninites from Zhovtorichenske deposit it equals 0,28 – 0,32 (data from D. Shcherbak). That corresponds to 1.8 billion years, which is consistent with isotopic dating results. Taking into account other lead nuclides (^{207}Pb, ^{208}Pb) this number could be higher. However mineralization "rejuvenation" could make it lower. Lead recrystallization and mobilization (secondary migration) can also cause significant uncertainty in these correlations when making genetic conclusions. Recalculation of the chemical analyses data mentioned above (2.11 – 2.13) show that $Pb_{заг} : U \approx 0,30$ when $UO_2 : UO_3 = 1 : 2$ (thermodynamically stable phase of U_3O_8) for unaltered uraninites from Vatutinske deposit. The close correlation of Pb : U is obtained for uraninites from Zhovtorichenske deposit (analyses 2.1 – 2.3) though correlation of $UO_2 : UO_3$ was not calculated here. Uraninites from Michurinske deposit (analyses 2.5 – 2.6) are characterized by high reduction conditions ($UO_2 : UO_3 \approx 1,08$) when there is a regular lead-uranium correlation. It can be stipulated either by physical and chemical conditions or analytical methods. Some research suggests that oxides of UO_2 type are the first to precipitate from hydrothermal solutions, then oxidation compounds of variable UO_{2+x} content form. This process procedes in consequence of oxygen diffusion into the crystalline lattice of the oxide. Other authors consider oxides of penta- and hexavalent uranium as the primary oxides which are then further reduced. In our opinion, it is more likely that the primary stable oxide should be U_3O_8, as confirmed by thermodynamic calculations and U – O system phase diagrams.

Available microroentgenspectral analyses of uranium oxides from the Severynivske deposit (2.8 - 2.10) may not be balanced under the "normal" condition of UO_2 : UO_3 = 1 : 2 attributed to primary uraninites; the lead content and Pb : U ratio are underestimated, and confirm significant oxidation and polyphasicity of mineral formation.

In any case, these secondary processes (if they were not accompanied by uranium carryover) were positively reflected upon further hydrometallurgical ore processing. The content of other ore elements in uraninites (Th, Zr, TR, Ti) rarely exceeds a background content, and they are not of commercial value.

2.1.2. Coffinite. Coffinite has a composition of $U(SiO_4)_{1-x}(OH)_{4x}$ or $USiO_4$, although the variant is doubtful because the presence of a hydroxide group has not been confirmed. Infrared spectrometry data indicates that the hydroxide group is present (as zircons and thorites), but roentgenographic data shows that water removal during calcination does not affect the elementary lattice parameters. It is likely that hydrated species exist (2-14%) due to metamict decay. In its unaltered form, this mineral is tetragonal, black in color, mainly opaque, fragile, and similar to uraninite. It is often mistaken for the latter. Coffinite forms fine impregnations, thin veinlets, lenses, and intergrowths with colloform aggregates of pitchblende that complicate its macroscopic diagnostics.

Coffinite is widespread in ores of the Kirovogradskyi block, specifically, in the Novoukrainskyi region, and less widespread in Ktyvorizzya. However, quantitative correlations of ore minerals were not only hindered by diagnostic problems. Primary minerals in uranium-containing albitites remained in very small quantities as relicts among secondary polymineral masses of hydrothermal and hypergene genesis. So the chemical composition of coffinites varies over a wide range. Theoretically the weight per cent of UO_2 in $USiO_4$ is 81,8% and of SiO_2 is 18,2%. In natural coffinites the weight per cent varies from 46 to 68% and 10 to 16%, respectively. In addition, up to 45% UO_3

and 1,5–5,0% H_2O also do not correspond to the theoretical mineral composition. It should be mentioned also that even in synthetic coffinites, a certain amount of U^{6+} is fixed, caused by oxidation of U^{6+} under experimental conditions.

There is sufficient mineralographic data to indicate that the majority of published results refer to mixtures of idealized coffinites $m\text{USiO}_4 \cdot n\text{U}_3\text{O}_8$ of silicate and stable oxide composition without taking into account water and radiogenic lead content. A simple calculation shows that the average content of 65% UO_2, 23% UO_3, and 12% SiO_2 will yield $0{,}77\text{USiO}_4 \cdot 0{,}23\text{U}_3\text{O}_8$, or $USiO_4$ with excess UO_3 that could be included in the crystalline lattice of coffinite or into micro impurities (clusters) of other minerals. The set of other ore elements is usual for all uranium oxides and silicates, and their content exceeds by several times the clarkes for host albitites, shales, and gneisses.

2.1.3. Brannerite. Brannerite has a composition of UTi_2O_6, with a complete formula of $(\text{U, Ca, Th, Y})\,[(\text{Ti, Fe})_2\text{O}_6]\cdot n\text{H}_2\text{O}$. It usually has radiogenic lead impurities, along with Al, Zn, and Mg among others. Infrared spectrometry has indicated significant hydration in metamict minerals. Brannerites are brownish-black, dark and light brown, to yellow or pale yellow in color. The coloring appears to depend on the crystallinity and level of uranium oxidation. In ore, this mineral looks fragile with a strong pitch-black luster, while in polished thin sections it is grey, isotopic, and electromagnetic.

Before discovery of the Kirovogradske deposits, the brannerite group was considered to be a regularly found, but minor ore mineral. Unaltered dark-colored brannerites with high uranium content were often considered to be oxides, specifically pitchblende, especially in widespread aggregates, colloform associations, and pseudomorphs.

When sampling uranium ores from the Kryvorizzya mine ore piles, hand specimen metasomatites were found. Fractures, caverns and breccia cement in these metasomatites were filled with yellow and light brown masses of pure brannerite. Almost monomineral ductile flowable masses appeared to enter under pressure into tectonically weakened zones. However, this still does not fully explain the physical and chemical phenomena outside of the existence of “metasomatic magma”, a dispersed, amorphous movable ore mass, created with micro particles of minerals or oxide compounds with limited light phase content.

In published papers the chemical composition of brannerites are cited based on microroentgenspectral analyses. These data are not complete without light components content (H_2O, CO_2) and correlation of higher and lower oxides of uranium, iron, and titanium. The uranium content is often specified only in the form of UO_2, U_3O_8 or even U_3O_2. If at all possible, we recalculated analytical data to UO_2 form.

For chemical (hydrometallurgical) processing of uranium ores it is important to know the level of mineral decomposition including the metamict level. Besides the optical and roentgengraphic methods, chemical analyses can determine the $U^{4+} : U^{6+}$ and Pb : U ratios as well as the correspondence of the brannerite mineral (Br) to the following ratio:

$$Br = \Sigma\,(Ti, Si\ldots) : \Sigma\,(U, Pb, Ca, Th\ldots), \qquad (2.14)$$

where Br ideally equals 2.00, and deviation is conditioned by certain impurities in the crystalline (mineral inclusions, clusters) or amorphous (atomic, molecular) mineral state. The sum of the last components in the formula equals one, taking into account excess of oxides. The maximum molar part CaO in the calcium brannerite structure is conditionally taken as 10%, which corresponds to ~5% by weight.

Zhovtorichenske deposit

$$(0{,}15UO_2 \cdot 0{,}02PbO \cdot 0{,}02ThO_2 \cdot 0{,}09\,CaO)_{0{,}28}\,(0{,}52TiO_2 \cdot 0{,}02SiO_2 \cdot 0{,}02FeO)_{0{,}56} \quad (2.15)$$

Pb : U = 0,13; Br = 2,00.

Excess of CaO = 0,16. Calcium brannerite, with impurities.

$$(0{,}16UO_2 \cdot 0{,}06PbO \cdot 0{,}04CaO)_{0{,}26}(0{,}45TiO_2 \cdot 0{,}06SiO_2 \cdot 0{,}01FeO)_{0{,}52} \qquad (2.16)$$

Pb : U = 0,37; Br = 2,00.

Excess of CaO = 0,21. Brannerite with impurities.

$(0{,}18UO_2 \cdot 0{,}04PbO \cdot 0{,}04CaO)_{0,26}\ (0{,}50TiO_2 \cdot 0{,}03SiO_2 \cdot 0{,}03FeO)_{0,56}$ (2.17)

Pb : U = 0,22; Br = 2,15.

Excess of TiO_2 = 0,18. Brannerite with impurities.

$(0{,}18UO_2 \cdot 0{,}04PbO \cdot 0{,}06CaO)_{0,28}\ (0{,}55\ TiO_2 \cdot 0{,}01\ FeO)_{0,56}$ (2.18)

Pb : U = 0,22; Br = 2,00.

Excess of TiO_2 = 0,08; SiO_2 = 0,08. Calcium brannerite with grothite (?) or silicate impurities.

$(0{,}19UO_2 \cdot 0{,}06PbO \cdot 0{,}05CaO)_{0,30}\ (0{,}50TiO_2 \cdot 0{,}07SiO_2 \cdot 0{,}02FeO)_{0,59}$ (2.19)

Pb : U = 0,32; Br = 1,97.

Excess of TiO_2 CaO = 0,11. Calcium brannerite, with impurities.

Severynivske deposit

$(0{,}20UO_2 \cdot 0{,}05PbO \cdot 0{,}07CaO)_{0,32}\ (0{,}57TiO_2 \cdot 0{,}08SiO_2 \cdot 0{,}03FeO)_{0,68}$ (2.20)

Pb : U = 0,25; Br = 2,12.

Calcium brannerite.

$(0{,}22UO_2 \cdot 0{,}01PbO \cdot 0{,}09CaO)_{0,32}\ (0{,}55TiO_2 \cdot 0{,}06SiO_2 \cdot 0{,}07FeO)_{0,68}$ (2.21)

Pb : U = 0,05; Br = 2,12.

Calcium brannerite.

Vatutinske deposit

$(0{,}21UO_2 \cdot 0{,}06PbO \cdot 0{,}04CaO)_{0,31}\ (0{,}52TiO_2 \cdot 0{,}05SiO_2 \cdot 0{,}04FeO)_{0,61}$ (2.22)

Pb : U = 0,29; Br = 1,97.

Brannerite.

$(0{,}25UO_2 \cdot 0{,}04PbO)_{0,29}\ (0{,}47TiO_2 \cdot 0{,}06SiO_2 \cdot 0{,}04FeO)_{0,57}$ (2.23)

Pb : U = 0,16; Br = 1,97.

Excess of CaO = 0,14. Calcium (?) brannerite.

Given this recalculation of the chemical analyses, typical natural brannerites appear to be characterized primarily by their diversity across uranium deposits. The majority of samples do not have clearly defined crystallographic forms, but occurred in colloform aggregates. Even micro crystals undergo pseudometamorphosis although they do not correspond to a classical meaning of this term (formation of a new crystalline phase in situ of the previous one while maintaining the geometric forms of the first phase). In fact, they are considered to be a mixture of amorphous particles and crystal clusters of primary titanate (UTi_2O_6), oxide components (TiO_2), isomorphic impurities (CaO, SiO_2), and their compounds. The only mentioned analysis that corresponds to this mineral is 2.21 (but with excess CaO in the structure), or possibly carbonates (analyses 2.15, 2.19-2.21, 2.23). Excess SiO_2 usually correlates with coffinite. In some samples (2.16, 2.18) above standard SiO_2 excess can be explained with quartz impurities or decomposed silicates. Direct determinations of CO_2 content are not cited, which is why carbonate content, especially typical for the Zhovtorichenske deposit, remains uncertain. The Pb : U ratio is considered to be one piece of of evidence for low-temperature hydrothermal and hypergene alteration of brannerite. Mostly this is shown as deviation from equilibrium, but some analyses (2.16, 2.19, 2.22) seem to be an exception, where $UO_2 : UO_3 > 1,0$.

Brannerite and byproducts of its decomposition are known to be the main source of uranium from the western group of deposits and numerous ore manifestations of the Ukrainian Shield. According to theoretical and experimental data, the chemical composition, aggregate state, and structure of minerals from this group are of great significance for further hydrothermal processing.

Primary (hypogene) unaltered brannerite is very stable. It is not completely broken down by hydrofluoric acid steam and concentrated sulfuric acid, nor dissolved in other acids. A protective film of titanium dioxide often forms on the surface of the mineral. But altered (amorphous) oxidized brannerite is easily dissolved in concentrated acids. Under conditions of alkaline metasomatosis, titanate is also decomposed with carryover and reprecipitation of substantial uranium in different mineral forms (oxides and hydroxides, coffinite, and uranyl). Relict rutile, grothite, and quartz are also included in the pseudometamorphosis content.

2.1.4. Davidite. The complete formula of davidite is $(Fe^{2+}, Fe^{3+}, U^{4+}, TR)_2\ (Ti, Fe^{3+}, Cr, V)_5O_{12}$. Composition of natural davidite (Dv) minerals is very changeable. The above formula is not electronically balanced, specifically concerning the ions of different valences (Fe, U, Ti ?, V ?). Chemical characteristics of crystals have to also be specified, especially for Precambrian titanates. These are always found in the form of mitamict, microcrystalline aggregates and inclusions in albite, grothite, and brannerite. Distinct and more or less homogeneous regions are found within single grains. Data of some micro roentgen spectral analyses recalculated to molar fractions of oxides according to extended formula and Dv coefficient are given below:

$$Dv = \Sigma\ (Ti, V) : \Sigma\ (U, Fe, TR). \qquad (2.24)$$

It is not reasonable to calculate a correlation between uranium and lead because of low lead content.

Michurinske deposit

$$(0{,}04UO_2 \cdot 0{,}21Fe_2O_3 \cdot 0{,}02PbO \cdot 0{,}04SrO)_{0{,}31}\ (0{,}69TiO_2)_{0{,}69} \qquad (2.25)$$

Dv = 2,23.

$$(0{,}04UO_2 \cdot 0{,}19Fe_2O_3 \cdot 0{,}02PbO \cdot 0{,}04SrO)_{0{,}29}\ (0{,}71TiO_2)_{0{,}71} \qquad (2.26)$$

Dv = 2,45.

$$(0{,}05UO_2 \cdot 0{,}19Fe_2O_3 \cdot 0{,}02PbO)_{0{,}26}\ (0{,}74TiO_2)_{0{,}74} \qquad (2.27)$$

Dv = 2,85.

Vatutinske deposit

$$(0{,}03UO_2 \cdot 0{,}21Fe_2O_3 \cdot 0{,}03PbO)_{0{,}27}\ (0{,}69TiO_2 \cdot 0{,}04V_2O_5)_{0{,}73} \qquad (2.28)$$

Dv = 2,70.

Chemical analysis has not been systematic. However the available data mainly corresponds to the extended formula and is close to the ideal value of Dv = 2,5. In two samples (analyses 2.27, 2.28) excess titanium is found. Mineral forms can rarely be determined from amorphous or crystalline TiO_2 to grothite and pseudo brookite. In the sample (2.25) titanium is in deficit, however, as in sample (2.26) an excess of strontium is fixed at 3.8% by weight, the usual isomorphic compound of carbonates. Crystalline davidite is quite stable; it is not dissolved in hydrochloric acid and a mixture of hydrochloric and nitric acids partially leaches iron and uranium. Metamict amorphized species are less stable and the majority of ore components is dissolved in acid solutions, with excess titanium, silica and trivalent iron forming a gel-like sediment.

2.2. Secondary (relict) minerals and aggregates

Rating these minerals as a separate group is conditional but some mineralogists-practitioners use it in publications and reports. Uranium minerals from the Precambrian deposits of Ukraine are 1.8 billion years old, some of the oldest of their type in the world. Around 35% of the initial uranium has decayed and a correspondent amount of radiogenic ^{206}Pb (with insignificant ^{207}Pb impurity) has formed over that period. This irradiation has resulted in a decay of the crystalline structures of uranium-containing minerals and their amorphization (metamict state). So-called pleochroic haloes have formed around some of the micron-scale inclusions of radioactive rock-forming minerals (chlorites, amphiboles, biotites) as a result of radiochemical oxidation of iron, manganese and other unstable valences. Minerals of this group are considered to be products of in-situ hydrogenous or hypergene decomposition, and redeposition with or without carryover of elements from the main uranium minerals described above.

2.2.1. Hydrous pitchblende and sooty uranium. Determination of hydrous pitchblende as a mineral species is based on mineralographic research of hydration and oxidation of pitchblende with formation of almost complete pseudomorphs consisting of uranium hydroxides with different tints of brown. It is considered that such globular and colloform aggregates are a mixture amorphous oxide – relicts of UO_2 - U_3O_8 with hydroxides and silicates. Nevertheless, uranium black does not form specific pseudomorphs. Mostly it is contained in powdery earthy masses and breccia cement that fill in fractions in parent rocks. The ideal formula corresponds to uraninite with $UO_2 < UO_3$ and significant water content. Detailed research has shown that these formations can contain crystallites of oxides and other hypogene uranium minerals (coffinite, brannerite) that are hard to diagnose with roentgen structural analysis. However, in-depth study of relict inclusions is of great importance in the survey criteria for deep ore deposits located in weathering crust.

2.2.2. Nenadkevite.The complete formula of nenadkevite is $(U^{4+}$, Y, Ce, Th...)U^{6+}(Ca, Mg, Pb)$(SiO_4)_2$ $(OH)_4 \cdot nH_2O$. This corresponds to uncertainty in nenadkevite as a mineral species, as has been discussed at length. The only microroentgenspectral analysis does not support accurate mineral identification. Correlation of $UO_2 : UO_3$ was not determined, and the sum only accounted for 82.9%. Recalculation on the basis of molar ratios gave:

$$(0{,}35UO_2 \cdot 0{,}07PbO \cdot 0{,}15CaO \cdot 0{,}01Fe_2O_3)_{0{,}58}\ (0{,}42SiO_2)_{0{,}42} \qquad (2.29)$$

$UO_2:UO_3$ = ?; PbO:U = 0,20; excess CaO = 0,07; PbO = 0,07. Coffinite.

If the excess CaO that is, possibly, included in carbonate composition is not taken into account (the shortage of 17%), then the analyzed sample fully corresponds to partially oxidized coffinite with small Ca, Zr, Y, Th, Ti impurities that were not included in the sample (2.29). So, the more reasonable conclusion made by Ye. Kopchenova, is that nenadkevite is a mixture of mineral phases formed as a result of decomposition of a primary uranium mineral while keeping its primary shape (pseudocrystals). Uranium hydroxides, uranyl silicates (cozolite, boltwoodite), and uranium oxides of high dispersity associated with hematite and iron hydroxides are found in the pseudocrystals. A lengthened prismatic zircon-like shape of pseudomorphs indicates that coffinite was possibly a primary mineral. The main components of nenadkevite are dissolved in concentrated acids and excess silica creates gel-like sediment.

2.2.3. Ningyoite. Ningyoite has a composition of $U^{4+}Ca\ (PO_4)_2 \cdot nH_2O$. The complete formula is similar and availability of Fe^{2+}, Th and (OH) in the structure is recognized.

More often ningyoite is considered a mineral of downward enrichment in the form of fine masses, small needles, columnar crystals, and stars in caverns and fractures. Placing ningyoite in a group of primary hydrothermal minerals is conditional because it is connected not with genetic position, but with uranium valence (tetravalent uranium) in contrast to the exogenous uranium minerals UO_2^{2+} .

Recalculation of from only a few microroentgenspectral analyses of ningyoite gave the following correlation of component oxides:

$$(0{,}31UO_2 \cdot 0{,}29CaO \cdot 0{,}03Ce_2O_3 \cdot 0{,}02La_2O_3)_{0{,}65}\ [(0{,}35P_2O_5)_{0{,}35}]_{0{,}70}, \qquad (2.30)$$

where mP : mCa = 2,41; taking into account UO_2 and Th this ratio is 1,08. The imbalance in the formula may be due to a mixture of phosphate, oxide, and carbonate.

Ningyoite is easily dissolved in acids and is straightforward to process.

2.3 Hypergene minerals

More than 20 uranium minerals are found in weathering crusts, zones of deep-earth oxidation and sedimentary rocks. However, only some of them are of independent commercial value. They are described in detail.

Hexavalent uranium forms and extremely resistant complex cation of $(UO)_2^{2+}$ uranyl and is the basis of the hypergene mineral structure. Availability of U^{4+} is an exception reflecting specific, highly reducing conditions during their formation. Presence of certain anions (phosphates, molybdates, arsenates) is also needed. However, minerals are not monophase, but composites, i.e., mixtures with the remains of primary mineral relicts.

Hypergene minerals have a stratified structure where uranyl-anionic neutral or charged strata are the basis of the structure. Cations, hydroxyl, and zeolite or hygroscopic water are located between strata. For this reason, formulas for these compounds remains under debate. Roentgenographic or optical data are not enough for diagnosis.

2.3.1. Hydroxides. In natural minerals of $UO_3 \cdot nH_2O$ composition, *n* is not a stable value and varies within 1-8. That is why designation according to this parameter in species such as schoepite, paraschoepite or urgite is considered to be conditional. The most widespread and stable phase is schoepitr ($UO_3 \cdot 2H_2O$ or $UO_2(OH)_2 \cdot H_2O$) and is confirmed by our thermodynamic experiments. Golden-yellow fine crystals and earthy aggregates of schoepite in association with other hypergene minerals are located at the top of the oxidation zone. As compensators of negative anions charge, the following cations can be included into hydroxides: Cu^{2+} (vandenbrandeite), Ca (becquerelite), Pb^{2+} (fourmarierite, curite)[1]. All of these are easily dissolved in acids, especially with heating. This is important in uranium extraction by underground leaching.

2.3.2. Silicates. In minerals with a composition of Ca $[(UO_2) \cdot SiO_4]$, replacement of Ca^{2+} cations with Mg^{2+} (sklodowskite), Pb^{2+} (kasolite), or replacing the anionic with $(SiO_3OH)^{3-}$ is possible. In oxidized ores of the Ukrainian deposits, especially in the Kirovogradska group, beta-uranotil and calcium boltwoodite are the most widespread. Calcium boltwoodite has been synthesized and studied using the roentgengraphic method. The compounds appear to be very changeable (even without taking into account water content):

[1] *vandenbrandeite $CuO_4.2H_2O$; becquerelite $CaU_6O_{19}.11H_2O$; fourmarierite $PbU_4O_{13}.4H_2O$*

$$(0{,}18CaO \cdot 0{,}29UO_3 \cdot 0{,}31SiO_2)_{0{,}78}. \qquad (2.31)$$

Excess of hexavalent uranium hydroxides and xonotlite or silica is possible.

$$0{,}34CaO \cdot 0{,}32UO_3 \cdot 0{,}34SiO_2. \qquad (2.32)$$

This ideally corresponds to the conditional mineral. The water (9.66% by weight) is not included in the structure.

The content of natural silica is somewhat different. For example, for boltwoodite aggregate from an oxidation zone at a depth of 80 m, the correlation between oxides is the following:

$$0{,}14CaO \cdot 0{,}07Al_2O_3 \cdot 0{,}04MgO \cdot 0{,}29UO_3 \cdot 0{,}45SiO_2 \cdot 0{,}01ThO_2. \qquad (2.33)$$

Even Al_2O_3 (5,24% by weight), MgO and ThO_2 are possibly connected with impurities of montmorillonite and thorite. If these impurities are included, the formula will be:

$$0{,}19CaO \cdot 0{,}38\ UO_3 \cdot 0{,}43\ SiO_2\ . \qquad (2.34)$$

The ratio Ca : U : Si is approximately 1 : 2 : 2 and the formula is $Ca[(UO_2)(SiO_3OH]_2$.

The chemical composition of other calcium silica of uranyl, specifically beta-uranophane, varies over a wide range according to Ca and U content, as well as water. This is why identification of separate species is conditional:

$$0{,}21CaO \cdot 0{,}06Al_2O_3 \cdot 0{,}30UO_2 \cdot 0{,}42SiO_2 \cdot 0{,}01ThO_2\ . \qquad (2.35)$$

After the exclusion of impurities we obtain a formula similar to (2.34) with some deficit of cations and uncertain water content. Recalculation from other analysis of the same mineral gives:

$$0{,}17CaO \cdot 0{,}08Al_2O_3 \cdot 0{,}32UO_3 \cdot 0{,}42SiO_2 \cdot 0{,}01ThO_2 \,. \qquad (2.36)$$

Taking into account kaoline (Al_2O_3 + SiO_2) is a probable impurity, we will get a Ca : U : Si ratio almost identical to boltwoodite (2.34).

Uranyl-silicates are the most widespread ore minerals of the deep oxidation zones that are connected to the extended fault tectonic structures. They are found at depths of more than 3000 m in association with products of primary brannerite, coffinite, and pitchblende decomposition. They are represented by accumulations of microcrystals with tints of yellow and separate transparent fine crystals. All of them are easily dissolved in acids, sometimes with formation of gel-like sediment of silica and aluminum hydroxide. Presence of silica in the weathering crust can be one of the criteria for primary deposit prospecting.

2.3.3. Phosphates. Autunite $Ca(UO_2)_2\ (PO_4)_2 \cdot 6H_2O$ is known as the most widespread among phosphates. It is traditionally related to a group of uranites (autunites) where rare species are also included: Mg (saleite), Ba (uranocirtite), and Cu (torbernite). Autunite is the only mineral that is reliably diagnosed in hypergene altered ores of albitite type. This phosphate is found in different rocks and ores, from migmatites to carbonaceous shale and sandstones with bone remains of fossil fish and reptiles. The authors have found radial autunite druses of greenish-yellow color at brooks banks at a distance of some kilometers from the uranium ore manifestation. The source of phosphorus is not known, but could be from dissolved mineral fertilizers from nearby agricultural lands.

Aytunite as well as other uranyl-hydroxyl minerals is not stable; its content, especially the water content, changes during separation of the monomineral fraction.

Diagnostic characteristics also change: color, index of refraction, Debye powder pattern, and thermogram.

Uranyl phosphates are not of commercial value, however, they are found in Neogene-Quaternary oxidation zones and stratiform ore manifestations.

2.3.4. Vanadates. This group of minerals is considered to be quite exotic in its structure and content. Tyuyamunite is widespread with a formula of CaO $[(UO_2)_2(V_2O_8)] \cdot 8H_2O$. Other species include K (carnotite) and Cu (senzierite) and are salts of ortho-vanadic acid. All of them are found in sedimentary rocks (sandstones, conglomerates) where they sometimes form commercial deposits (for examples, carnotite on the Colorado Plateau, USA). Unfortunately, deposits of this type are not found in Ukraine. Single samples are sometimes found in weathering crust, and more specifically, in uranium-containing albitites where all species of this group are present.

2.4. Sequence and zonality of mineral formation

The questions of sodium-uranium (albitites) and ferruginous-siliceous formation are covered in detail by I. Mineyeva and others [1, 10]. We have considered only the characteristics of uranium minerals. However, the sequence of mineral formation processes and their secondary alterations are insufficiently studied. Superimposition of primary hypogene (hydrothermal) ore mineralization into previously formed paragenesis of rock-forming minerals is clear. However, the mechanisms behind this process vary widely, from metasomatic replacement to filling of cracks, slip zones, and sites of pressure gradients. Uranium sedimentation has not occurred as a result of classical metasomatosis, but through exchange reactions of ore-bearing solutions with rock forming minerals that served as acid and acid-base barriers.

Sometimes certain alternations are fixed. This is shown by the existence of several mineral generations (up to four generations for uraninite), and as a result, specific spatial zonality in uranium mineral distribution is formed. The example of this is shown in Fig. 2.5.

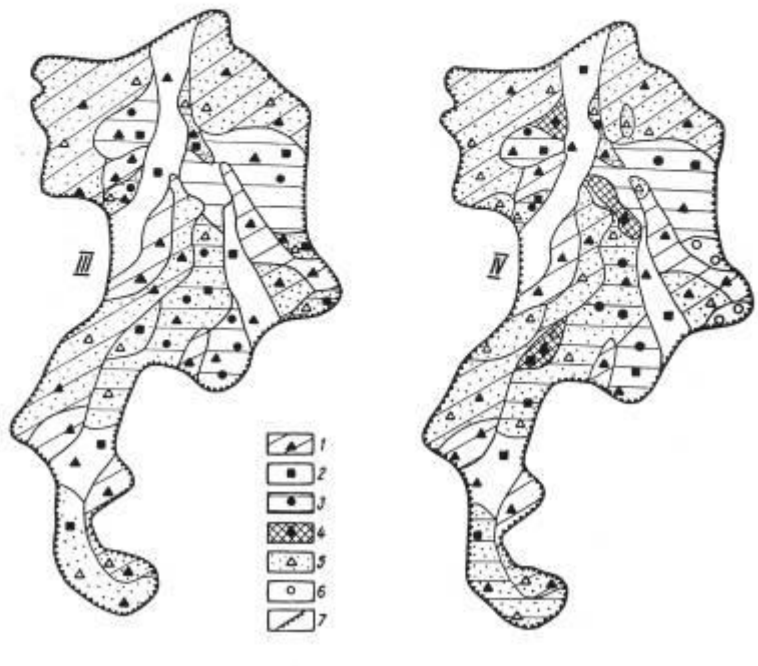

Fig. 2.5. Schematic of uranium mineral zonality in albitite ore body. Horizontal planes from two separate depths: *1 – brannerite; 2 – uraninite; 3 – pitchblende; 4 – coffinite; 5 – oxidated brannerite; 6 – uranyl – silicates; 7 – contour of ore deposit*

Imposed post-Cambrian hypergene processes made zonality more complicated with secondary (or more) redistributions of geochemically mobile uranium forms. As a result of surface and internal oxidation, primary and relict minerals and diverse newly formed uranyl compounds were deposited.

Uranium minerals in deep borehole section

Depth, m	Mineral association
812	Uraninite + oxidated brannerite
864	Uraninite+coffinite
1012	Coffinite+ uranophane
1042	Uranium oxides
1700	Uranyl silicates
1938	Coffinite+ beta-uranotile
2002	Uranium hydroxides – decomposition products of brannerite, pitchblende
2078	Uranium hydroxied

2350	Uranophane
2766	The same
2910	Boltwoodite
3159	Coffinite
3297 – 3400	Uranophane+ beta-uranotile+boltwoodite
3416	The same
3478	Boltwoodite

In such a case, the depth is not crucial– oxides and titanates of tetravalent uranium predominate in the intervals of 800-1100 m, while hypergene hydroxides of hexavalent uranium and relict mixtures predominate at ~2000-3000 and 3300-3500 m, respectively. –The main reason for heterogeneous distribution is tectonics, that is, zones of deep faults with accompanying secondary structures, high fracturing, and breccia formation.

On the whole, internal oxidation zones in the Precambrian tectonic base are of great interest in terms of general theory for ore formation. In such zones of internal oxidation the famous deposits of high-grade martite ores in Kryvorizzya (prospected to a depth of 3000-3500 m) are located; at a depth of 900 m deposits of pure magnetite of more than 70 m thickness are found. The unique copper-uranium Chervonoshakhtarske deposit is located close by. A detailed survey was not carried out here. In this context, the Kirovogradska fault structure is considered to be the most important and needs to be surveyed and studied in more depth.

2.5 Comparative analysis of Uranium Ores from three deposits *(Michurinske, Tsentralne, and Vatutinske)*

Uranium ores from three operating deposits, Michurinske, Tsentralne, and Vatutinske, were studied to identify specific characteristics relating uranium ore concentrates to their place of origin. Ore samples contain specific characteristics of uranium ore concentrates that can link the concentrates to their place of origin. This information is an important component of the Ukrainian database on uranium materials.

The deposits are genetically connected with the processes of ultra metamorphism of uranium containing rocks. Post ultra-metamorphic solutions penetrated along long-lived fault zones and led to sodium metasomatism and ore formation in albitites. Uranium was transferred in hydrothermal solutions in the form of uranyl-sodium-carbonate or uranylpotassium-carbonate ions (complexes). Diaphthorites (syenite-like desilicated rocks) were formed as a product of incomplete sodium metasomatism and are mainly contaminated with uranium and do not contain commercial ore mineralization [25-29].

The primary rocks are different for each deposit. The ore-containing metasomatites that formed on the source rocks inherited their structural and textural peculiarities, percentage of dark colored minerals, etc. The ores from the Michurinske and Vatutinske deposits consist of apogranite, apomigmatite, and apogneiss albitites of Paleoproterozoic age. Apogneiss albitites are different from the first two types by higher content (up to 25-35%) of dark colored minerals. The ores from the Tsentralne deposit are represented by the only apogranitoid albitites, including albitites formed on fine-grained leucocratic and melanocratic aplite-like granites of the Lelekivska suite.

Structural control of mineralization is obvious for each deposit and connected with correspondent faults in the tectonic and metasomatic zones [26-28].

The primary differences in composition between the three ore deposits included the sooty uranium content (a mixture of black microaggregate minerals), uranophane and primary U-silicates (coffinite and nenadkevite), as well as the occurrence of brannerite, a U-titanate mineral. The major commercial phases observed in the Michurinske deposit ores were sooty uranium and uranophane. The primary silicate mineral was nenadkevite, a mixture of boltwoodite and uraninite. The primary oxide mineral was uraninite. Uranium titanites, including brannerite and davidite, made up approximately 4% of the ore. Major non-metallic minerals included albite (up to 75-90%), aegirine, chlorite, phlogopite, riebeckite, and epidote. The major commercial minerals of the Tsentralne deposit were brannerite, oxidized or completely altered brannerite with leucoxene-like products, and uraninite. The major non-metallic minerals were albite, phlogopite, chlorite, and carbonate. More rarely, aegirine, riebeckite, epidote, and sometimes hematite were observed. The major commercial phases of the Vatutinske deposit were uraninite, beta-uranophane, and a mixture of sooty uranium and nenadkevite. The major non-metallic mineral was albite. Secondary non-metallic minerals included chlorite, riebeckite, aegirine, hematite, carbonate, and epidote. Our observations and those found in [25-29] confirmed that aegirine, riebeckite, chlorite, and epidote were widespread among the dark colored minerals from the Michurinske deposit, while phlogopite was more typical for the ore albitites from the Tsentral deposit. Uranium oxides and nenadkevite were typical for the ores from the Michurinske deposit. These minerals rarely appeared in the Tsentral,ne deposit where brannerite was commonly found. In contrast, the Vatutinske deposit ores were fine-grained albitites formed on metasomatic orthogneisses.

Appendix 1

Deposits Passports (on IAEA requirements)

Deposit ***Country***	*Zhovtorichenske* *Ukraine*
General information	
Metallogenic Region	*Ukrainian crystalline shield. Central-Ukrainian uranium-containing region (oblast). Kryvorizhskyi and Kremenchutskyi ore region. Zhovtorichenske ore field.*
Owner	*State Enterprise "Vostgok", Ministry of Energy and Coal Industry of Ukraine*
Prospecting Organization	*State Enterprise "Kirovgeologiya"**,** expedition № 10. Discovered in 1946.*
Administrative Location	*Dnipropetrovska oblast, Pyatikhatky rayon (region).*
Economic Region	*Agricultural and Industrial*
Nomenclature of Map-Sheets	*M-36-XXXIY (scale - 1 : 200 000)*
Geographic Location	*Longitude - 33^0 32^I east. Latitude - 48^0 20^I north*
Other Data on the Region	*Location –suburb of town Zovti Vody, 13 km SW of town Pyatikhatky.* *Distance to Kryvyi Rig - 69 km by railway.*
Structural Location of Region	*Ukrainian shield, Ingulskyi mega block*
Technical information	
Tonnage range (t U)	*10.000-25000*
Grade range (% U)	
Deposit Status	*Depleted up to horizons 1200-1500 m*
Current Processing Plant	-
Reserves (t U)	*Reserves below 1200-1500 m were not evaluated*
Grade (% U)	-
Production Period	-
Production Grade (% U)	-
Geological information	
Ore-containing Structure	*Kryvorizhskyi and Kremenchutskyi synclinorium*
Structural Control of Mineralization	*Zhovtorichenska stripe of metamorphic rocks of Kryvorizhska series; axial part of sinclinorim*
Other Ore Controlling Factors	*Saksaganska and Gdantsevska suites*
Genesis of Mineralization	*Hydrothermal and metasomatic type of sodium-uranium formation in ferruginous rocks*
Geological Age	*Paleoproterozoic*
Absolute age	*1800±20 mln. years*
Host Rocks	*Albitites and amphibole – magnetite, albitite shales*
Wallrock Alteration	*Sodium and sodium-carbonate metasomatism is developed on zones of tectonic dislocations. Primary shale-dolomite-quartzite and biotite-chlorite associations were altered with metasomatites. The main rock forming minerals of metasomatites are: albite, aegirine, alkaline amphiboles (riebeckite, arfvedsonite, roduzite, calcium silicates (diopside, actinolite, garnet, talc), carbonates (dolomite, calcite, ankerite, siderite), rarely apatite, malacon, grothite. In similar metasomatites of the Saksaganska suite besides the main set of alkaline minerals, relict magnetite, hematite, sometimes quartz are found.*
Commercial Ore Bodies and Zones	*Western zone is of columnar morphology, Eastern – stripe-like. Ore bodies thickness – 5/13 m. Depth of formation roof occurrence – from 70 to 115 m.*
Mineral Composition of Ores	*Major minerals: uraninite, pitchblende, silicates of yellow color. Minor minerals: malacon, acmite (Sc-containing mineral). Major non-metallic minerals: albite, biotite, amphibole. Minor non-metallic minerals: hematite, calcite, magnetite, quartz,.*
Other Data about Chemical Composition of Ores.	Content of P_2O_5 in albitite varies from 0,02 to 0,14%. Thorium is almost absent.
Mining	*The mine was worked out till the depth of 1500 m (in 1990-s).*

Deposit **Country**	Michurinske Ukraine
General information	
Metallogenic Region	Ukrainian crystalline shield. Central-Ukrainian uranium-containing region (oblast). Kirovogradskyi ore region. Michurinske ore field.
Owner	State Enterprise "Vostgok", Ministry of Energy and Coal Industry of Ukraine
Prospecting Organization	State Enterprise "Kirovgeologiya", expedition № 37. Discovered in 1964.
Administrative Location	Kirovogradska oblast, Kirovogradskyi rayon (region).
Economic Region	Industrial
Nomenclature of Map-Sheets	M-36-125-XXXIII (of 1 : 200 000 scale)
Geographic Location	Longitude - 32^0 18^I east. Latitude - 48^0 27^I north
Other Data on the Region	Location – south-east suburb of Kirovograd city. Nearby railway stations: Kirovograd (10 km), Lelekivka (12 km), Kanatove (24 km). Distance to Zovti Vody – 135 km, Dniprodzerzhinsk – 180 km.
Structural Location of Region	Ukrainian shield, Ingulskyi mega block
Technical information	
Tonnage range (t U)	10,000–25,000
Grade range (% U)	0.01-0.10
Deposit Status	Operating
Current Processing Plant	SE "Vostgok"
Reserves (t U)	$C_1 + C_2$ 18492
Grade (% U)	0.081
Production Period	
Production Grade (% U)	94-95%
Technological Characteristics of Ores	Technologically homogenous, divided into blocks of different technological properties. Processing method: autoclave sulfuric leaching. Radiometric separation.
Geological information	
Ore-containing Structure	Kirovogradska deep fault zone
Structural Control of Mineralization	Major Michurincskyi fault; fault structures and zones of volumetric cataclasis; four big flexures (Northern, Eastern, Central, and Southern).
Other Ore Controlling Factors	Dark-colored minerals (riebeckite, aegirine etc.).
Genesis of Mineralization	Hydrothermal and metasomatic type of sodium-uranium formation. Genetically connected with processes of ultra metamorphism of uranium-containing rocks.
Geological Age	Paleoproterozoic.
Absolute age	1750 ± 50 mln. years
Host Rocks	Apomigmatite, apogranite, apogneiss albitites.
Wallrock Alteration	In the upper part of the vertical metasomatic columnar shoot: albitization, hematitization, carbonatization, desilication, epidotization, silicification. Within selvages of sodium metasomatite bodies: phlogopitization, riebeckitization, aegirinization.
Other Data on Host Rocks	Unaltered rocks: migmatites, granites (Kirovogradskyi complex), gneissess (Checheliivska suite). Sedimentary cover: 30-60 m.
Commercial Ore Bodies and Zones	49 ore bodies (borehole exploration data); major 26 (operational exploration data). Ore shoots sizes: from 30 to 73 m on strike, and from 30 up to 400 m on pitch. Four ore zones: Central, South-East, two North-East zones.
Inter-mineral and Post-mineral Tectonics of Ore Bodies'	Inter-mineral tectonics: breccias', blastomylonites' joints, zones of tectonic schistosity, volumetric catalasis and minor fracturing feathering the main structures. Post-mineral tectonics: minor fracturing, shear cracks with attrition clay, zones of fracture in ore albitites.
Mineral Composition of Ores	Major ore minerals: brannerite, brannerite oxidated and uraninite. Other ore minerals -: uraninite, pitchblende, sooty uranium, coffinite, davidite, hydro-pitchblende, and urgit. Major non-metallic minerals: albite (up to 75-90%), chlorite, phlogopite, riebeckite, aegirine, epidote. Minor non-metallic minerals: carbonate, hematite.
Chemical Composition of Ores	High content of Fe_2O_3, Na_2O,CaO, CO_2
Mining	Mining using blasting explosive.
Hydgeological Mining Conditions	Suitable for mining (even though located under the river Ingul channel). Watering rate is low. Maximum water inflow into mine workings - 180 м^3/year.

Deposit ***Country***	*Tsentralne* *Ukraine*
General information	
Metallogenic Region	*Ukrainian crystalline shield. Central-Ukrainian uranium-containing region (oblast). Kirovogradskyi ore region. Michurinske ore field.*
Owner	*State Enterprise "Vostgok", Ministry of Energy and Coal Industry of Ukraine*
Prospecting Organization	*State Enterprise "Kirovgeologiya"***,** *expedition № 37. Discovered in 1964.*
Administrative Location	*Kirovogradska oblast, Kirovogradskyi rayon (region).*
Economic Region	*Industrial*
Nomenclature of Map-Sheets	*M-36-125-XXXIII (of 1 : 200 000 scale)*
Geographic Location	*Longitude - 32^0 18^l east. Latitude - 48^0 27^l north*
Other Data on the Region	*Location – south-east suburb of Kirovograd city. Nearby railway stations: Kirovograd (10 km), Lelekivka (12 km), Kanatove (24 km). Distance to Zovti Vody – 135 km, Dniprodzerzhinsk – 180 km.*
Structural Location of Region	*Ukrainian shield, Ingulskyi mega block*
Technical information	
Tonnage range (t U)	*10,000–25,000*
Grade range (% U)	*0.01-0.10*
Deposit Status	*Operating*
Current Processing Plant	*SE "Vostgok"*
Reserves (t U)	*$C_1 + C_2$ 18492*
Grade (% U)	*0.081*
Production Period	
Production Grade (% U)	*94-95%*
Technological Characteristics of Ores	*Technologically homogenous, divided into blocks of different technological properties. Processing method: autoclave sulfuric leaching. Radiometric separation.*
Geological information	
Ore-containing Structure	*Kirovogradska deep fault zone*
Structural Control of Mineralization	*Major Michurincskyi fault; fault structures and zones of volumetric cataclasis; four big flexures (Northern, Eastern, Central, and Southern).*
Other Ore Controlling Factors	*Dark-colored minerals (riebeckite, aegirine etc.).*
Genesis of Mineralization	*Hydrothermal and metasomatic type of sodium-uranium formation. Genetically connected with processes of ultra metamorphism of uranium-containing rocks.*
Geological Age	*Paleoproterozoic.*
Absolute age	*1750 ± 50 mln. years*
Host Rocks	*Apomigmatite, apogranite, apogneiss albitites.*
Wallrock Alteration	*In the upper part of the vertical metasomatic columnar shoot: albitization, hematitization, carbonatization, desilication, epidotization, silicification. Within selvages of sodium metasomatite bodies: phlogopitization, riebeckitization, aegirinization.*
Other Data on Host Rocks	*Unaltered rocks: migmatites, granites (Kirovogradskyi complex), gneissess (Checheliivska suite). Sedimentary cover: 30-60 m.*
Commercial Ore Bodies and Zones	*49 ore bodies (borehole exploration data); major 26 (operational exploration data). Ore shoots sizes: from 30 to 73 m on strike, and from 30 up to 400 m on pitch.* *Four ore zones: Central, South-East, two North-East zones.*
Inter-mineral and Post-mineral Tectonics of Ore Bodies'	*Inter-mineral tectonics: breccias', blastomylonites' joints, zones of tectonic schistosity, volumetric catalasis and minor fracturing feathering the main structures. Post-mineral tectonics: minor fracturing, shear cracks with attrition clay, zones of fracture in ore albitites.*
Mineral Composition of Ores	*Major ore minerals: brannerite, brannerite oxidated and uraninite. Other ore minerals -: uraninite, pitchblende, sooty uranium, coffinite, davidite, hydro-pitchblende, and urgit. Major non-metallic minerals: albite (up to 75-90%), chlorite, phlogopite, riebeckite, aegirine, epidote. Minor non-metallic minerals: carbonate, hematite.*
Chemical Composition of Ores	*High content of Fe_2O_3, Na_2O,CaO, CO_2*
Mining	*Mining using blasting explosive.*
Hydgeological Mining Conditions	*Suitable for mining (even though located under the river Ingul channel). Watering rate is low. Maximum water inflow into mine workings - 180 $м^3$/year.*

Deposit ***Country***	*Vatutinske* *Ukraine*
General information	
Metallogenic Region	*Ukrainian crystalline shield. Central-Ukrainian uranium-containing region (oblast). Kirovogradskyi ore region. Vatutinske ore field*
Owner	*State Enterprise "Vostgok", Ministry of Energy and Coal Industry of Ukraine*
Prospecting Organization	*SE"Kirovgeologiya"*, *expeditions №47 and № 37. Discovered in 1970.*
Administrative Location	*Kirovogradska oblast, Malovyskivskyi rayon (region).*
Economic Region	*Agricultural*
Nomenclature of Map-Sheets	*M-36-XXXIII (scale - 1 : 200 000)*
Geographic Location	*Longitude - 31^0 16^l east. Latitude - 48^0 36^l north*
Other Data on the Region	*Location – south suburb of town Smoline. Nearest railway station – Zlynka (25 km). Distance to Zovti Vody – 165 km.*
Structural Location of Region	*Ukrainian shield, Ingulskyi mega block*
Technical information	
Tonnage range (t U)	*25 000-50 000*
Grade range (% U)	*0.10-0.20*
Deposit Status	*Operating*
Current Processing Plant	*SE "Vostgok"*
Reserves (t U)	*C_1+C_2 25383*
Grade (% U)	*0.132*
Production Period	
Production Grade (% U)	
Technological Characteristics of Ores	*Technologically homogenous, divided into blocks of different technological properties. Processing method: autoclave sulfuric leaching. Radiometric separation.*
Geological information	
Ore-containing Structure	*Zvenigorodska and Gannivska deep fault zone*
Structural Control of Mineralization	*Vatutinska tectonic and metasomatic zone of sub-meridian extension. Ore-controlling fault zones of shift type. Wedge-like morphology. Flexure folding.*
Other Ore Controlling Factors	*Dark-colored minerals (riebeckite, aegirine), etc.*
Genesis of Mineralization	*Hydrothermal and metasomatic type of sodium-uranium formation. Genetically connected with processes of ultra metamorphism of uranium-containing rocks.*
Geological Age	*Paleoproterozoic.*
Absolute age	*1750 ± 50 mln. years*
Host Rocks	*Apomigmatite, apogranite, apogneiss albitites. Pre-metasomatic rocks: migmatite (up to 45%), granite (up to 50-55%), pegmatoid and orthogneiss (up to 10%).*
Wallrock Alteration	*In the upper part of the vertical metasomatic columnar shoot: albitization, hematitization, chloritization, epidotization, desilication, carbonatization, saussuritization, desilication silicification. Within selvages of sodium metasomatite bodies: sericitization, phlogopitization, riebeckitization, aegirinization.*
Other Data on Host Rocks	*Metasomatic zonality: external zone (low altered primary rocks) – diaphtorite rocks – intermediate zone (syenite-like rocks) – internal zone (albitites and commercial mineralization). Geochemical zonality: Na_2O is predominant over K_2O in albitites; high content of U, Pb, V and also Li, Rb, Ti, Ba, Sr, Zr, Y, Yb i Th in ores.*
Commercial Ore Bodies and Zones	*Three main ore zones – Eastern, Central, and Northern-Western; chain of ore bodies of lens-like and complicated isometric forms.*
Inter-mineral and Post-mineral Tectonics of Ore Bodies'	*Inter-mineral tectonics: brecciation, milotinization, foliation and boudinage; volumetric cataclasis and minor fracturing. Post-mineral tectonics minor fracturing, late cataclasis, attrition clay, sometimes – kakirite. breccias', blastomylonites' joints, zones of tectonic schistosity, cataclazites and fracturing zones feathering the main one.*
Mineral Composition of Ores	*Major minerals: uraninite, beta-uranotile, sooty uranium, mixture of pitchblende and boltwoodite (nenadkevite). Minor minerals: hydro pitchblende, secondary silicates of yellow color, uranium titanate. Trace minerals: coffinite, brannerite, carnotite. Major non-metallic mineral: albite. Minor non-metallic minerals: chlorite, riebeckite, aegirine, hematite, carbonate, epidote.*
Mining	*Mining using blasting explosive. Underground block leaching. Heap leaching.*
Hydgeological Mining Conditions	*Suitable for mining. Watering rate is low. Two water bearing horizons: underground water horizon in Cainozoic sedimentary rocks (10 m thickness) and fracture water horizon in crystalline rocks (up to 280 m depth).*
Deposit	*Severynivske*

Country	*Ukraine*
General information	
Metallogenic Region	*Ukrainian crystalline shield. Central-Ukrainian uranium-containing region (oblast). Kirovogradskyi ore region. Severynivske(Lelekivske) ore field*
Owner	*State Enterprise "Vostgok", Ministry of Energy and Coal Industry of Ukraine*
Prospecting Organization	*State Enterprise "Kirovgeologiya"*, *expedition № 37. Discovered in 1968.*
Administrative Location	*Kirovogradska oblast, Kirovogradskyi rayon (region).*
Economic Region	*Industrial*
Nomenclature of Map-Sheets	*M-36-125-XXXIII (scale - 1 : 200 000)*
Geographic Location	*Longitude - 32^0 15^I east. Latitude - 48^0 35^I north*
Other Data on the Region	*Location – northern suburb of Kirovograd city. Nearby railway stations: Kirovograd (10 km), Lelekivka (12 km).* *Distance to Zovti Vody – 135 km; Dniprodzerzhinsk – 180 km.*
Structural Location of Region	*Ukrainian shield, Ingulskyi mega block*
Technical information	
Tonnage range (t U)	*25 000-50 000*
Grade range (% U)	*0.01-0.10*
Deposit Status	*Dormant*
Current Processing Plant	-
Reserves (t U)	*C_1+C_2 38353*
Grade (% U)	*0.087*
Production Period	-
Production Grade (% U)	-
Technological Characteristics of Ores	*Technologically homogenous, divided into blocks of different technological properties. Processing method: autoclave sulfuric leaching. Radiometric separation.*
Geological information	
Ore-containing Structure	*Kirovogradska deep fault zone.*
Structural Control of Mineralization	*Severynivska tectonic and metasomatic zone surrounded with cataclasites, fractures and flexures of sub-shift type.*
Other Ore Controlling Factors	*En echelon location of mylonites and cataclasites joints, numerous tectonic dislocations of low thickness. Dark-colored minerals.*
Genesis of Mineralization	*Hydrothermal and metasomatic type of sodium-uranium formation. Genetically connected with processes of ultra metamorphism of uranium-containing rocks.*
Geological Age	*Paleoproterozoic.*
Absolute age	*1750 ± 50 mln. years*
Host Rocks	*Apomigmatite, apogranite, apogneiss albitites.*
Wallrock Alteration	*In the upper part of the vertical metasomatic columnar shoot: albitization, hematitization, chloritization, carbonatization, desilication, epidotization, silicification. Within selvages of sodium metasomatite bodies: sericitization, phlogopitization, riebeckitization, aegirinization.*
Other Data on Host Rocks	*Unaltered rocks: migmatites, granites (Kirovogradskyi complex), gneisses (Checheliivska suite). Rocks strike - north-west 320-340°, pitch - north-east 55-65°.*
Commercial Ore Bodies and Zones	*32 commercial ore bodies (prospecting data). Two extensive ore zones - 36-I and 66-II - 33,1% and 32,5% of total uranium reserves. Ore bodies average horizontal thickness: from 1.4 to 27.2 m.*
Inter-mineral and Post-mineral Tectonics of Ore Bodies'	*Inter-mineral tectonics: breccias', blastomylonites' joints, zones of tectonic schistosity, cataclazites and fracturing zones feathering the main tectonic dislocations.* *Post-mineral tectonics: wide aureole of quartz-sericite rocks and attrition clay; numerous sites of cataclasis, minor fracturing and clevage cracks of low thickness..*
Mineral Composition of Ores	*Major minerals: brannerite and brannerite oxidated . Minor minerals: pitchblende. Trace minerals: sooty uranium, uraninite, secondary silicates of yellow color. Major non-metallic minerals: albite, chlorite, phlogopite, riebeckite, aegirine, epidote. Minor non-metallic minerals: carbonate, magnetite, hematite.*
Other Data about Chemical Composition of Ores.	*Zr - 0,015-1,020% (average content 0,122%); V - 0,036-0,154%; Pb – mainly of radiogenic origin in average 0.021%; Au (from traces to 0.03 g/t).*
Other Data about Ore Composition and Properties	*Content of FeO and Fe_2O_3 - from 1 to 2% and from 2 to 3,6%); CO_2 - 1-3,5%, phosphorus pentaoxide – 3,7%, sulfuric anhydride – 3,07%, Mn and Ca oxides – 3-7%.*
Mining	*Mining using blasting explosive.*
Hydgeological Mining Conditions	*Suitable for mining. Watering rate is low.*

Appendix 2

Ukrainian-English vocabulary

General geological vocabulary

альпійський	Alpine
антикліналь	anticlinal , anticline
аншліф	polished thin section
архейський	Archean
архейський фундамент	Archean basement
безводный (хім.)	anhydrous
бітум	bitumen
~ твердий бітум	hard bitumen
брекчія	breccia
~ складна брекчія	complex breccia
брекчіювання	brecciation
вапняк	limestone
Велике Ведмеже озеро	Great Bear Lake
виклинювання	fringe
відвали	tailings
вкрапленість	impregnation
~ розсіяна вкрапленість	scatted impregnation
~ дрібна вкрапленість	fine impregnation
вуглефікація	carbonization coalification
вулканізм	volcanism
~ андезитовий вулканізм	andesite volcanism
~ базальтовий вулканізм	basalt volcanism
~ ліпаритовий вулканізм	liparite volcanism
геологорозвідувальний	geological prospecting / exploration / survey; geological surveyance
герцинський	Hercynian
гірнича виробка	mine working; mine tunnel
грунтово-рослинний шар	soil-vegetative layer
дебаєграма	Debye powder pattern
діапір	diapir
енергетична мінеральна сировина	energy minerals
енергоносій	energy carrier
еоцен	Eocene
жила	vein
~ діагенетична жила	diagenetic vein
~ епігенетична жила	epigenetic vein
~ сингенетична жила	syngenetic vein
залягання	occurrence; bedding
~ порушене залягання (гірських порід)	broken bedding
~ непорушене залягання (гірських порід)	unbroken bedding
залягати	occur
запас/ мн. запаси	reserve/ pl. reserves
~ вірогідно розвідані запаси	reasonably assured resources
~ забалансові запаси	non
~ запаси уранових руд	uranium ore reserves
~ нерозвідані запаси	undiscovered reserves
~ перспективні запаси	challenging resources

~ підтверджені запаси	proven reserves
~ попередньо оцінені запаси	inferred reserves; estimated additional resources
~ прогнозні запаси	expected reserves; speculated resources; probable reserves
~ розвідані запаси	explored reserves
~ сумарні (загальні) запаси	total reserves
захоронення	disposal
збагачена руда	beneficiated uranium ore
зерно (мінералу)	grain
~ ксеноморфне зерно	xenomorphic grain
зона неузгоджень	unconformity zone
зона пластового окислення	zone of bedded oxidation
ізоклінальна складка	isocline fold
капітальні витрати	capital outlays
карст	karst
карстова порожнина	cavern
катаклаз	cataclasis
коефіцієнт	index; ratio; factor
~ коефіцієнт вилучення	extraction ratio
~ коефіцієнт рентабельності	profitability index
коломорфний	colloform
країни СНД	CIS countries
кремінь	flint
кристал	crystal
~ дрібний кристал	fine crystal
~ огранений кристал	faceted crystal
~ стовпчастий кристал	columnar crystal
лігніт (буре кам'яне вугілля)	lignite
метасоматит	metasomatite
~ вмісний метасоматит	host metasomatite
~ лужний метасоматит	alkaline metasomatite
~ натрієвий метасоматит	sodium metasomatite
~ підрудний метасоматит	sub-ore metasomatite
метасоматичний	metasomatic
метасоматоз	metasomatism
~ лужний метасоматоз	alkaline metasomatism
мінерал	mineral
~ акцесорний мінерал	accessory mineral
~ другорядний мінерал	minor mineral
~ корисний мінерал	commercial mineral
~ супутній мінерал	associated mineral
молярний	molar
~ молярне співвідношення	molar ratio
на місці залягання	- in situ
надра Землі	the bowels of the earth, earth interior
насув	overthrust
науково-тенічний центр	Scientific and Technical Centre
невелика глибина	shallow depth
неконденційна (бідна) руда	halvans; low grade ore
неоген	Neogene
окварцювання	silicification
ордовік	Ordovician (Period)
осклування	vitrescence
очисний блок	mine face

палеозойський	pal(a)eozoic
палеозойська ера	pal(a)eozoic era / period
палеоген	Palaeogene
параметр/ мн. параметри	parameter / pl. parameters
~ витримані параметри	stable parameters
~ кількісні параметри	quantitative parameters
~ мінливі параметри	variable parameters
~ невитримані параметри	unstable parameters
~ якісні параметри	qualitative parameters
перешаровуватись	interstratify
перекриваючий (про пласт)	overlying
пермська система	Permian formation
перспективні родовища урану	Upside uranium deposits
підвищена концентрація	enhanced concentration
підняття	uplift
підтверджені запаси	proven reserves
піритизований	pyritized
пласт	bed; stratum (pl. strata)
пластове родовище	bedded deposit
пластовий	bedded
поводження з РАВ	Radioactive Waste Management
показник мінливості	variability index
поклад	bed, deposit
поліфазність	polyphasicity
порода	rock
~ безрудна порода	barren rock
~ первинна порода	primary rock
~ пуста порода	waste rock; brood
~ рихла порода	mouldy rock
~ середньозерниста порода	medium-grained rock
пошук, пошуковий	reconnaissance
приповерхневий	near-surface
прогин	trough
прожилок	veinlet
~ поперечний прожилок	crosscut veinlet
радій	radium
Рамкова класифікація ООН для запасів і ресурсів родовищ твердих горючих корисних копалин, урану та вуглеводної сировини	United Nations Framework Classification (UNFC) for Solid Fuels and Mineral Commodities
розвідка	prospecting; survey
~ детальна розвідка	detailed survey; saturation prospecting
родовище	deposit
~ бідне родовище	low-grade deposit
~ богате родовище	high-grade deposit
~ велике родовище	large-scale deposit, major deposit
~ в резерві (родовище)	for spares
~ діюче родовище урану	operating uranium deposit
~ діюче родовище цирконію	operating zirconium deposit
~ жильне родовище	vein deposit
~ корінне родовище	primary deposit
~ перспективне родовище	promising deposit
~ пластоподібне родовище	tabular
~ промислове родовище	commercial (mineable) deposit

~ родовищт Вітватерсранд	deposit Witwatersrand
~ убоге родовище	lean deposit
розлом	fault
~ глибинний розлом	deep-seated fault
розподіл (корисних компонентів)	distribution (useful components)
~ рівномірний розподіл	uniform distribution
~ нерівномірний розподіл	nonuniform distribution
розробка родовища	field development; mining
рослинного походження	phytogenous
руда	ore
~ золотоносна руда	gold-bearing ore
~ малорентабельна руда	low profit ore
~ некондеційна (бідна) руда	halvans; low grade ore
~ руда I сорту	first-class ore
~ руда II сорту	second-class ore
~ руда III сорту	third-class ore
~ рядова руда	mine-run ore
~ тантало-ніобієва руда	tantalum- niobium ore
~ фосфоритова руда	phosphorite ore
рудоносна порода	ore-bearing rock
свердловина	borehole; drill-hole
світа	suite
січний	counter
~ січна жила	counter vein
~ січне тіло	counter body
силур	the Silurian period
сингонія	system
~ тетрагональна сингонія	tetragonal system
синкліналь	syncline
скальна порода	hard rock
Скіфська епіпалеозойська плита	Scythian EpiPalaeozoic Plate
собівартість	prime cost
структура	structure
~ блокова структура	block structure
~ кубічна структура	cubic structure
~ ниркоподібна структура	reniform structure
~ розломна структура	fault structure
~ складчаста структура	folded structure
~ складчасто-розломна структура	folded and fault structure
~ смугаста структура	striate structure
~ стовпчаста структура (кристалів)	columnar structure
~ сферолітова структура	spherulite structure
~ тонкозерниста структура	fine-grained structure
~ шарувата структура	stratified structure
структурне районування	structural zoning
схема розміщення	layout
схематична карта	schematic map
тектоніка	tectonics
~ розривна тектоніка	fault tectonics
тектонічне порушення	tectonic dislocation
торий	thorium
Український щит	Ukrainian Shield
Українські Карпати	Ukrainian Carpathian
умови залягання	position
уран містячий	uranium-containing

формула	formula
~ розширена формула	complete formula
штольня	adit
четвертинний	Quaternary
Чорнобильська зона	Chornobyl Exclusion Zone

Minerals vocabulary

альбіт	albite
акміт	acmite
актиноліт	actinolite
амфібол лужний амфібол	amphibole alkaline amphibole
анкерит	ankerite
антраксоліт	anthraxolite (graphitic coal)
апатіт	apatite
апліт	aplite
арфведсоніт	arfvedsonite (Na amphibole)
біотіт	biotite
бітум	bitumen
бекереліт	becquerelite $CaU_6O_{19}.11H_2O$
бетауранотіл	beta-uranotile
бранерит	brannerite
бреггерит	broggerite
болтвудіт	boltwoodite
вандербрендеїт	vandenbrandeite $CuO_4.2H_2O$
гідрослюда	hydromica
гематит	hematite
гранат	garnet
давідит	davidite
двоуранат натрію	sodium diuranite
діопсид	diopside
доломіт	dolomite
егірин	aegirine
ільменіт	ilmenite
йордизит	jordisite
казоліт	kasolite
кальцит	calcite
карбонат	carbonate
карнотит	carnotite
кварц	quartz
кіновар	cinnabar
клевеїт	cleveite
кофініт	coffinite
ксонотліт	xonotlite
лейкоксен	leucoxene (altered Fe- Ti minerals)
магнетіт	magnetite
малакон (*радіоактивна різновидність циркона*)	“malacon” (altered or metamict zircon)
малахит	malachite
марказит	marcasite
мікроклін	microcline
монацит	monazite
молібденіт	molybdenite
настуран	pitchblende

нінгіоїт	ningyoite
ортит	allanite (orthite)
отеніт	autunite
пірит	pyrite
пірохлор	chalcolamprite
рибекіт	riebeckite (Na amphibole)
родузит	roduzite
рутил	rutile
салеїт	saleite
самарскіт	samarskite
сенж'єрит	senzierite
серицитовий сланець	sericite (micaceous) shale (rock type)
сидероплезит	sideroplesite ($Fe,MgCO_3$) – member of isomorphic line siderite – magnesite
сидерит	siderite – $FeCO_3$
склодовскіт	sklodowskite
скупіт	schoepite
слюда	mica
сфен	sphene
тальк	talc
торберніт	torbernite
торіаніт	thorianite
тюямуніт	tyuyamunite
ураніл	uranyl
ураніт	uranite
уранініт	uraninite
уранові слюдки	uranites, autunites
уранова чернь	uranium black; sooty uranium
уранофан	uranophane
флогопіт	phlogopite
фумар'єрит	fourmarierite $PbU_4O_{13}.4H_2O$
халькопірит	chalcopyrite
хлорит	chlorite
хальколамприт *(пірохлор)*	chalcolamprite
целестин (*сульфат стронцію*)	celestine (celestite)
цейнерит	zeunerite
циркон	zircon
циртоліт	"cyrtolite" (altered or metamict zircon)

Rocks vocabulary

альбітит ~ апогнейсовий альбітит ~ апогранітний альбітит ~ апомігматитовий альбітит	albitite apo-gneiss albitite apogranite albitite apomigmatite albitite
амфіболіт	amphibolite
базальт	basalt
брекчія ~ піритизована брекчія ~ складна брекчія	breccia pyritized breccias complex breccia
вапняк	limestone
вулканіт ~ метавулканіт	vulcanite metavulcanite
вулканогенно-осадова порода	volcanogenic-sedimentary rock
галька	pebble

глина	clay
гнейс ~ біотитовий гнейс ~ графітовий гнейс	gneiss biotites gneiss graphitic gneiss
граніт ~ порфіроподібний граніт ~ апліт-пегматоїдний граніт	granite porphyry-like granite aplite and pegmatoid granite
гранітоїд ~ архейський гранітоїд ~ лейкократовий гранітоїд	granitoid Archean granitoid leucocratic granitoid
діабаз	diabase
діафторит	diafluoride
залізиста порода	ferruginous rock
каолініт	kaolinite
катаклазит	cataclasite
кварцит	quartzite
конгломерат ~ кварцовий конгломерат ~ кварцово-гальковий конгломерат	conglomerate quartz conglomerates quartz-pebble conglomerate
мігматит	migmatite
мікрокLініт	microclinite
мілоніт	mylonite
пеліт *(тонкозерниста осадова порода)*	pelite
пісковик	sandstone
порфір	porphyry
роговик	hornstone
сланець ~ вуглецево-силіцієвий сланець ~ вуглистий сланець ~ кварц-біотитовий сланець ~ тальковий сланець ~ хлорит-гідрослюдистий сланець ~ хлорит-серицитовий сланець ~ ураноносний сланець	shale, slate carbonic-silicium slate carbonaceous shale quartz-biotite shale chlorite-hydromica slate chlorite-sericite shale uranium-bearing shale
торф	peat
туф	tuff
фосфорит *(осадова порода)*	phosphorite

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