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THE PERIODIC TABLE OF THE ELEMENTS AND THE ASSOCIATED MINERALS: URANIUM

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ABSTRACT

Uranium is silvery-white metal of the actinide series. It is the heaviest of naturally occurring elements and it is found in low concentrations in soil, water and rocks. Uranium is relatively reactive and combines with oxygen, sulfur, chlorine, fluorine, phosphorus, bromine and other elements. This article describes some of the properties and uses of uranium and presents a synopsis of the two hundred and four (204) uranium minerals known at the present time.

KEY WORDS: Uranium, Mineralogy of Uranium, Properties of Uranium, Uses of Uranium

RESUMO

O urânio é um metal branco-prateado da série dos actinídeos. É o mais pesado dos elementos que estão presentes na natureza e encontra-se em concentrações baixa no solo, na água e nas rochas. O urânio é relativamente reativo e combina com oxigênio, enxofre, cloro, flúor, fósforo, bromo e outros elementos. Este trabalho descreve algumas das propriedades e usos do urânio e apresenta uma rápida sinopse dos duzentos e quatro (204) minerais nos quais o urânio encontra-se presente, conhecidos até o momento..

PALAVRAS-CHAVE: Urânio, Mineralogia do Urânio, Propriedades do Urânio, Usos do Urânio

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INTRODUCTION

Uranium is a silvery, shiny metal and is both ductile and malleable, slightly paramagnetic and poor electrical conductor. It is a member of the actinide series and the heaviest naturally occurring element. Uranium metal has a very high density and approximately 70% denser than lead and slightly less dense than gold.

Uranium is a relatively rare element and is present in water, soil and rocks with an estimated abundance of approximately 1 to 2 parts per million.The most common ore of uranium is pitchblende. Other common minerals are uraninite, carnotite, uranophane and coffinite. [1,179-190]

The most common way of mining uranium is similar to iron. The ore is treated with nitric acid to form uranyl nitrate ($UO_2(NO_3)_2$) that is converted to uranium dioxide (UO_2). Treatment with hydrogen leads to uranium metal. The metal reacts with almost all nonmetallic elements. Acids like HCl and HNO_3 dissolve uranium and nonoxidizing acids attack the metal very slowly. Finely divided uranium can react with cold water and the uranium metal becomes coated with a dark layer of uranium oxide.[181-190]

The discovery of uranium is usually credited to Martin Heinrich Klaproth in 1789. He actually isolated a powder of uranium oxide. The first sample of uranium metal was obtained by Eugène Melchior Peligot in 1841 by heating uranium tetrachloride with potassium. The Romans used uranium oxide to obtain the yellow color of glasses and ceramic glazes, a practice continued during the Middle Ages with oxide obtained from pitchblende from the silver mines of Joachimstahl, Bohemia (Jáchymow, Czech Republic).[180]

All three naturally occurring isotopes of uranium, U-234 (0.0056%), U-235 (0.711%) and U-238 (99.284%) are radioactive. The radioactive properties of uranium were discovered by A.H. Becquerel in 1896 and Enrico Fermi and his collaborators were mainly responsible for the use of the element as a fuel in the nuclear power industry and in nuclear weapons. Uranium-238 has a half-life of approximately 4.47 billion years and uranium-235 of about 704 million years and both are used in dating the age of the Earth.[182-186]

Some properties of uranium are given in Table I.

Uranium has 15 isotopes, three of them, as mentioned above, occur in nature and the others are synthetic. Table II describes some of the most stable isotopes.[185-190]

Table I. Some Properties of Uranium.

Atomic weight	**238.0289 g/mol**
Electronic configuration	**(Rn) $5f^3 6d^1 7s^2$**
Density	**19.1 g/cm^3**
Melting point	**1132.3 °C**
Boiling point	**4131°C**
Heat of vaporization	**417.1 kJ/mol**
Heat of fusion	**9.14 kJ/mol**
Oxidation states	**6,5,4,3**
Van de Waals radius	**186 pm**
Electrical resistivity	**0.280 microOhm-m**

Table II. Most Stable Isotopes of Uranium

Isotope	Nat. abund.	Half-life	Decay Modes	DE (Mev)	DP
^{232}U	synthetic	68.9 y	α, SF	5.414	^{228}Th
^{233}U	synthetic	159,200 y	SF, α	4.909	^{229}Th
^{234}U	0.0054%	245,500 y	SF, α	4.859	^{230}Th
^{235}U	0,7204%	7.038×10^8 y	SF, α	4.679	^{231}Th
^{236}U	synthetic	2.342×10^7 y	SF, α	4.572	^{232}Th
^{238}U	99,2742%	4.468×10^9 y	SF, α	4.270	^{234}Th

Uranium compounds are still used today to color glass and ceramics. The tones of color produced range from orange-red to lemon yellow. Uranium has been used for tinting and shading in photography and as a mordant in dyeing operations of textile. Mordants are compounds that help dyes stick to cloth. Uranium oxide has a limited use as an attachment to filaments in light bulbs. It reduces the speed at which an electric current enters the bulb and the possibility of the filament heating too fast and breaking.

The most important application of uranium today is in nuclear weapons and nuclear power plants.

Uranium -235 is the only naturally occurring fissile isotope.Uranium-238 is both fissionable by fast neutrons and fertile. In a nuclear rector it can be converted to fissile ^{238}Pu. The artificial fissile isotope ^{233}U can be produced from thorium in high power breeder reactors and is important in nuclear technology. Uranium-238 has a small possibility to undergo fission spontaneously when bombarded with fast neutrons.[179]

On the other hand, ^{235}U and also ^{233}U undergo fission relatively easy when bombarded with slow neutrons. The heat generated is used in nuclear reactors as a source of power and the fissile material for the production of nuclear weapons. Both of these uses depend on the ability of uranium to produce a sustained nuclear reaction. Depleted uranium (^{238}U) is used in armor plating and kinetic energy penetrators.

Most nuclear weapons produced between 1945 and 1991 employed enriched uranium or uranium derived plutonium. They are both fission bombs. A more powerful fusion bomb (hydrogen bomb), developed later uses plutonium in an uranium casing to produce fusion between a mixture of tritium and deuterium.

There are approximately five hundred (500) commercial nuclear power plants in the world and they produce about 20% of the electrical energy. Most reactors use enriched uranium as a fuel (approximately 3% of ^{235}U). The only commercial reactor capable of using un-enriched uranium is the CANDU reactor. Military nuclear reactors used for propulsion and other purposes employ highly enriched ^{235}U. The use of uranium as a nuclear fuel produces a large amount of nuclear residue and the disposal of nuclear waste is still a major problem today.

Depleted uranium (DU) is employed widely for high density penetrators. The ammunition consists of depleted uranium alloyed with other metals. At high impact velocity, the projectile leads to the destruction of heavily armored targets because of its hardness, density and flammability. Depleted uranium is also used to make tank armor, removable armor plates on combat vehicles, shielding material for missile re-entry vehicles, special containers and counterweight for aircraft control surfaces. Depleted uranium ammunition was widely used in the Persian Gulf and Yugoslavia in the recent past.

Most uranium compounds are poisonous if ingested. Being a radioactive element, exposure to uranium compounds for a prolonged period of time leads to serious health problems with most organ systems. In addition, uranium metal in powdered form is pyrophoric and tends to catch fire spontaneously.[179-190]

Uranium ingested via dust into the lungs tends to accumulate in bone because of uranium's affinity for phosphates. Uranium has a deleterious effect on the reproductive system and uranyl ions (UO2+) from uranyl nitrate, uranium trioxide and other hexavalent compounds cause defects and damage to the immune system.

URANIUM MINERALS

Of the 4271 mineralogical species validated by IMA (International Mineralogical Association) until 2008, two hundred and four (204) contain uranium. Of these, there are 50 phosphates, 44 oxides, 25 arsenates , 24 carbonates, 20 silicates, 13 sulfates, 10 vanadates, 7 molybdates, 5 selenites, 3 tellurites and one species of arsenites, tungstates and vanadium oxysalts, respectively. The only mineral discovered after 2008 is uramarsite ($(NH_4,H_3O)_2(UO_2)_2[(AsO_4,PO_4)_2]_2.6H_2O$), a arsenate complex , found as encrustations on a fracture surface in sub-betuminous coal and uranium coal deposits[178]. A synopsis of the minerals follows.

a) Arsenids

a_1) Acid and normal arsenides

1. Chadwickite $H(UO_2)(AsO_3)$ – Tetragonal system; 60.42% U. A secondary mineral found in dump material from granite rocks of the uranium mines[1,30].

b) Arsenates

b_1) Anhydrous arsenates

1. Hallimondite $Pb_2(UO_2)(ASO_4)_2$ – Triclinic system; 24.74% U. Secondary mineral of Pb-Zn veins[1,62].

b_2) Halogenarsenates

1. Chistyakovaite $Al(UO_2)_2(AsO_4)_2F.6.5H_2O$ – Monoclinic system; 48.53% U. Hidrothermalism in uranium deposits[1,32].

b_3) Hydrated arsenates

1. Abernathyite $K_2(UO)_2(AsO_4)_2.8H_2O$ – Tetragonal system; 45.77% U. Rare secondary mineral in the uraniferous sandstones deposits[1,2].

2. Arsenuranospathite $HAl(UO_2)_4(AsO_4)_{4\cdot40}H_2O$ – Tetragonal system; 39.93% U. A very rare secondary mineral in uraniferous deposits[1,8].

3. Arsenuranylite $Ca(UO_2)_4(AsO_4)_2(OH)_4.6H_2O$ – Orthorhombic system; 60.48% U. Occurs in oxidation zone of sulfide deposits rich in As[1,9].

4. Asselbornite $(PbBa)(UO_2)_6(BiO)_4(AsO_4)_2.(OH)_{12}.3H_2O$ – Cubic system; 44.24% U. Occurs in quartz gangue from an uranium mines[1,10].

5. Arsenovanmeersscheite $U(UO_2)_3(AsO_4)_2(OH)_6.4H_2O$ – Orthorhombic system; 63.47% U. Secondary mineral in the uraniferous deposits[1,14].

6. Heinrichite $Ba(UO_2)_2(AsO_4)_2.10\text{-}12H_2O$ – Tetragonal system – 41.27% U. Secondary mineral present in uraniferous deposits on silicified rhyolite tuffs[1,63].

7. Hügelite $Pb_2(UO_2)_3(AsO_4)_2.(OH)_4.3H_2O$ – Monoclinic system; 43.96% U. Secondary mineral of Pb-U deposits[1,65].

8. Kahlerite $Fe^{2+}(UO_2)_2(AsO_4)_2.10\text{-}12H_2O$ – Tetragonal system; 44.41% U. Rare secondary mineral in the oxized zone in hydrothermal uraniferous deposits [1,69].

9. Metaheinrichite $Ba(UO_2)_2(AsO_4)_2.8H_2O$ – Tetragonal system – 43.30% U. Mineral formed by alteration of heirichite[1,63].

10. Metakahlerite $Fe^{2+}(UO_2)_2(AsO_4)_2.8H_2O$ – Tetragonal system; 46.77% U. Rare secondary mineral which occurss in the oxized zone from the hydrothermal uraniferous deposits [1,81].

11. Metakirchheimerite $Co(UO_2)_2(AsO_4)_2.8H_2O$ – Tetragonal system; 46.63% U. Rare secondary mineral which occurss in the oxized zone from the hydrothermal uraniferous deposits on pitchblende (uraninite) crystals[1,82].

12. Metanovacekite $Mg(UO_2)_2(AsO_4)_2.4\text{-}8H_2O$ – 50.10% U. Rare secondary mineral which occurss in the oxized zone from the hydrothermal deposits of uranium ores[1,84].

13. Metauranospinite $Ca(UO_2)_2(AsO_4)_2.8H_2O$ – Tetragonal system; 47,50% U. Secondary uranium mineral which occurss in the oxidation zone of U deposits[1,93].

14. Metazeunerite $Cu^{2+}(UO_2)_2(AsO_4)_2.8H_2O$ – Tetragonal system; 46.42% U. Rare secondary mineral in the oxidized zones of As-bearing hydrothermal uranium deposits[1,97].

15. Natrouranospinite $(Na_2,Ca)(UO_2)_2(AsO_4)_2.5H_2O$ – Tetragonal system; 47.89% U. Secondary mineral psudomorphous after metazeunerite[1,104].

16. Novacekite I $Mg(UO_2)_2(AsO_4)_2.12H_2O$ – Triclinic system; 44.98% U. Rare secondary mineral which occurss in the oxized zone from the hydrothermal deposits of uranium ores [1,84].

17. Novacekite II $Mg(UO_2)_2(AsO_4)_2.10H_2O$ – Triclinic system; 46.57% U. Rare secondary mineral which occurss in the oxized zone from the hydrothermal deposits of uranium ores [1,84].

18. Orthowalpurgite $(UO_2)Bi_4O_4(AsO_4)_2.2H_2O$ – Orthorhombic system; 16.04% U. Secondary mineral formed by weathering of Bi-bearing ore minerals[1,110].

19. Seelite $Mg(UO_2)_2(As^{3+}O_3)_{1.4}(As^{5+}O_4)_{0.6}.7H_2O$ – Monoclinic system; 38.34% U. Secondary mineral of oxidization zone of U-bearing ores[1,138].

20. Trogerite $(H_3O)[(UO_2)(AsO_4)](H_2O)_3$ – Tetragonal system; 49.38% U. Secondary mineral found as crusts or aggregates of microscopic crystals and growing with zeunerite[1,157].

21. Uramarsite $NH_4(UO_2)AsO_4.3H_2O$ – Tetragonal system; 20.21% U. Secondary mineral which occurs in fractures of uraniferous igneous rocks associated with meta-autunite [1,161].

22. **Metauranospinite $Ca(UO_2)_2(AsO_4)_2.10H_2O$ – Tetragonal system; 45,86% U. Secondary uranium mineral which occurss in the oxidation zone of U deposits[1,93].**

23. Zeunerite $Cu^{2+}(UO_2)_2(AsO_4)_2.10\text{-}16H_2O$ – Tetragonal system; 44.84% U. Secondary mineral in the oxidized zones of As-bearing hydrothermal uranium deposits[1,97].

c) Carbonates

c_1) Anhydrous carbonates

1. Cejkaite $Na_4(UO_2)(CO_3)_3$ – Triclinic system – 44.87% U. A secondary mineral formed by decomposition of uraninite crystals in dry condictions and alkaline pH[1,29].

2. Rutherfordine $UO_2(CO_3)$ – Orthorhombic system – 76.12% U. Secondary mineral product of alteration from uraninite[1,130].

3. Widenmannite $Pb_2(UO_2)(CO_3)_3$ – Orthorhombic system; 27,54% U. Mineral found in alteration zone of uranium ores [1,174].

c_2) Compound carbonates

1. Lepersonnite-(Gd) $Ca(Gd,Dy)_2(UO_2)_{24}O_{12}(CO_3)_8(SiO_4)_4.60H_2O$ – Orthorhombic system; 66.83% U. Secondary mineral present in basal portion of the oxidation zone of uranium ores[1,74].

2. Schrockingerite $NaCa_3(UO_2)(CO_3)_3(SO_4)F.10H_2O$ – Triclinic system; 26.79% U. Secondary mineral found in uranium-bearing ores on matrix rock[1,136].

c_3) Halogencarbonates

1. Albrechschraufite $Ca_4Mg(UO_2)_2(CO_3)_6F_2.17H_2O$ – Triclinic system; 32.92% U. Secondary mineral in the silver deposit of Jáchimov, Czech Republic[1,5].

c_3) Hydrated carbonates

1. Andersonite - $Na_2Ca(UO_2)(CO_3)_3.6H_2O$ – Trigonal system; 36.95% U. Occurs as efflorescenses in uranium mines[1,7].

2. Bayleyite $Mg_2(UO_2)(CO_3)_3.18H_2O$ – Monoclinic system; 28.92% U. Very rare radioactive mineral; occurs as eflorescenses in uranium mines[1,17].

3. Blatonite $UO_2CO_3.H_2O$ – Hexagonal/trigonal systems; 68.39% U. Typical mineral of sedimentary rocks[1,23].

4. Grimselite $K_3Na(UO_2)(CO_3)_3.H_2O$ – Hexagonal system; 39.13% U. Mineral found in granite-aplites and veins of mineralized zones[1,59].

5. Kamotoite-(Y) $Y_2U^{6+}{}_4(CO_3)_3O_{12}.14.5H_2O$ – Monoclinic system; 53.19% U. Mineral found in the oxidation zone of Cu-Co deposits [1,6].

6. Liebigite $Ca_2(UO_2)(CO_3)_3.11H_2O$ – Orthorhombic system; 32.68% U. Secondary mineral in the oxidized zone of uraniferous deposits associated with carbonates and sulfates[1,75].

7. Metazellerite $Ca(UO_2)(CO_3)_2.3H_2O$ – Orthorhombic system; 49.16% U. Typical mineral which occurss in sediments of the uranium mines in oxidized zones[1,96].

8. Swartzite $CaMg(UO_2)(CO_3)_2.12H_2O$ - Monoclinic system; 32.58% U. Secondary mineral which occurs as efflorescence in wall of mines[1,148].

9. Voglite $Ca_2Cu^{2+}(UO_2)(CO_3)_4.6H_2O$ (?) – Monoclinic system; 31.24% U. Mineral found as alteration product of uraninite[1,172].

c_4) Hydroxylcarbonates

1. Astrocyanite-(Ce) $Cu_2(Ce,Nd,La)_2(UO_2)(CO_3)_5(OH).1.5H_2O$ – Triclinic system; 25.02% U. Mineral found in the oxidation zone of Cu-Co deposits[1,11].

2. Bijvoetite-(Y) $(Y,Dy)_2(UO_2)_4(CO_3)_4(OH)_6.11H_2O$ – Orthorhombic system; 53.88% U. Occurs in the basal zone of the oxidation uranium deposits[1,21].

3. Oswaldpeetersite $(UO_2)_2CO_3(OH)_2.4H_2O$ – Monoclinic system; 67.42% U. Secondary mineral which occurs in sandstone and conglomerate rocks rich in organic matter[1,111].

4. Rabbittite $Ca_3Mg_3(UO_2)_2(CO_3)_6(OH)_4.18H_2O$ – Monoclinic system; 32.05% U. Secondary mineral found as efflorescenses in wall of uranium mines[1,124].

5. Roubaultite $Cu_2(UO_2)_3(CO_3)_2O_2(OH)_2.4H_2O$ – Triclinic system; 59.74% U. Secondary mineral found on uraninite ore[1,129].

6. Shabaite-(Nd) $Ca(Nd,Sm,Y)_2(UO_2)(CO_3)_4(OH)_2.6H_2O$ – Monoclinic system; 24.54% U. Secondary mineral found in Cu-Co deposits[1,140].

7. Sharpite $Ca(UO_2)_6(CO_3)_5(OH)_4.6H_2O$ – Orthorhombic system; 66.85% U. Secondary mineral found in Cu-Co deposits [1,141].

8. Urancalcarite $Ca(UO_2)_3(CO_3)(OH)_6.3H_2O$ – Orthorhombic system; 66.97% U. Secondary mineral found on uraninite crystals[1,163].

9. Wyartite $CaU^{5+}(UO_2)_2(CO_3)O_4(OH).7H_2O$ – Orthorhombic system; 67.77% U. Orthorhombic system; 66.97% U. Secondary mineral found as alteration product of uraninite[1,167].

d) Molybdates

d_1) Anhydrous molybdates

1. Deloryite $Cu^{2+}{}_4(UO_2)(MoO_4)_2(OH)_6$ – Monoclinic system; 25.16% U. A secondary mineral found in oxized zone of U-Mo deposits[1,47].

2. Mourite $U^{4+}Mo^{6+}{}_5O_{12})(OH)_{10}$ – Monoclinic system; 22.04% U. Secondary minerals present in U-Mo deposits[1,101].

3. Sedovite $U^{4+}(MoO_4)_2$ – Orthorhombic system; 42.66% U. Secondary mineral found in suoergene zone of U-Mo deposits.[1,137].

d_2) Hydrated molybdates

1. Calcurmolite $Ca(UO_2)_{3\text{-}4}(MoO_4)_3(OH)_{2\text{-}5}.7\text{-}12H_2O$ – (?); 45.71% U. Secondary mineral found in oxized zone of U-Mo deposits[1,27].

2. Molurarite $H_4U^{4+}(UO_2)_3(MoO_4)_7.18H_2O$ – Amorphous; 38.15% U. Secondary mineral found in the oxidation zone of uranium ores[1,99].

3. Tengchongite $Ca(UO_2)_6(MoO_4)_2O_5.12H_2O$ – Orthorhombic system; 62.74% U. Secondary mineral which occurss in oxidized zone of uranim mineralizations[1,150].

4. Umohoite $[(UO_2)MoO_4(H_2O)](H_2O)$ – Triclinic system; 53.13% U. Secondary mineral found in U-Mo deposits[1,160].

e) Oxides

e_1) Multiple oxides

1. Betafite $U^{4+}(Nb,Ti)_2O_6OH$ – Cubic system; 17.20% U. Common primary mineral in granite pegmatites, and rare in carbonatites. It's a secondary source of U[1,20,40].

2. Bismutopyrochlore $(Bi,U,Ca,Pb)_{1+x}(Nb,Ta)_2O_6(OH).nH_2O$ – Cubic system; 12.69% U. Mineral strongly radioactive formed on lepidolite in cavities of pegmatite veins[1,22].

3. Brannerite $(U,Ca,Y,Ce)(Ti,Fe)_2O_6$ – Monoclinic system; 33.54% U. Secondary mineral found in gold placers[1,108].

4. Davidite-(Ce) $(Ce,La)(Y,U,Fe^{2+})(Ti,Fe^{3+})_{20}(O,OH)_{38}$ – Trigonal system; 3.18% U. Occurs in pegmatites[1,45].

5. Davidite-(La) $(La,Ce)(Y,U,Fe^{2+})(Ti,Fe^{3+})_{20}(O,OH)_{38}$ – Trigonal system; 3.20% U. Occurs in pegmatites[1,45].

6. Dessauite-(Y) $Sr(Y,U,Mn)Fe_2(Ti,Fe^{3+},Cr,V)_{18}(O,OH)_{38}$ – Trigonal system; 3.85% U. Occurs in cavities of calcite veins[1,50].

7. Euxenite-(Y) $(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$ – Orthorhombic system; 16.10% U. Acessory mineral in granite-pegmatites and detrital in black sands[1,53].

8. Orthobrannerite $U^{4+}U^{6+}Ti_4O_{12}(OH)_2$ – Orthorhombic system; 53.28% U. Secondary mineral found in the weathering residue of biotite pyroxene syenites[1,109].

9. Petscheckite $U^{4+}Fe^{2+}(Nb,Ta)_2O_8$ – Trigonal system; 36.52% U. Secondary mineral, product of oxidation zones of U deposits[1,114].

10. Tanteuxenite-(Y) $(Y,Ce,Ca,U)(Ta,Nb,Ti)_2O_6$ – Orthorhombic system; 52.37% U. Mineral component of the tin placers[1,149].

11. Thorutite $(Th,U,Ca)Ti_2(O,OH)_6$ – Monoclinic system; 24.36% U. Acessory mineral of nepheline-syenites normally as veins of microcline[1,152].

12. Uranmicrolite $U_{0.5}Ca_{0.5}Ta_2O_6(OH)$ – Cubic system; 27,37% U. Typical mineral of U oxidized zones[1,165].

13. Uranopolycrase $(U,Y)(Ti,Nb)_2O_6$ – Orthorhombic system; 34.35% U. Mineral found in zoned pegmatite vein near contact with granodirites[1,168].

14. Uranosphaerite $Bi(UO_2)O_2(OH)$ – Orthorhombic system; 45.08% U. Mineral found in alteration zone of uraninite[1,167].

15. Uranpyrochlore $Ca_{0.5}U_{0.5}Nb_2O_6(OH)$ – Cubic system; 17.59% U. Mineral found in calcareous tuffs associated with carbonatites[1,165].

16. Yttrocrasite-(Y) $(Y,Th,Ca,U)(Ti,Fe^{3+})_2(O,OH)_6$ – Orthorhombic system; 7.99% U. Mineral present in granites, pegmatites and metamorphic rocks[1,177].

e$_2$) Simple Oxides

1. Agrinierite $(K_2,Ca,Sr)U_3O_{10}.4H_2O$ – Orthorhombic system; 71.48% U. Typical mineral of oxidation zones in the uraniferous deposits in association with uranophane in small cavities of this rocks[1,3,4].

2. Bauranoite $BaU_2O_7.4\text{-}5H_2O$ – Triclinic system; 59.03% U. Secondary mineral replacing uraninite crystals[1,16].

3. Becquerelite $Ca(UO_2)_6O_4(OH)_6.8H_2O$ – Orthorhombic system; 72.48% U. Secondary mineral which occurss in sedimentary uranium deposits in the oxidization zones[1,18].

4. Billietite $Ba(UO_2)_6O_4(OH)_6.8H_2O$ – Orthorhombic system; 71.57% U. Rare mineral, product of alteration from the uraninite[1,18].

5. Calciouranoite $(Ca,Ba,Pb)U_2O_7.5H_2O$ – Amorphous; 60.58% U. Rare mineral found in felsitic rocks, and oxidation zones of U-Mo deposits[1,25].

6. Clarkeite $(Na,K,Ca,Pb)(UO_2)O(OH).0\text{-}1H_2O$ – Trigonal system; 67.21% U. A secondary mineral occurs as hydrothermal alteration product [1,34].

7. Cleusonite $Pb(U^{4+}U^{6+})(Fe^{2+})_2(TiFe^{2+}Fe^{3+})_{18}(O,OH)_{38}$ – Trigonal system; 7.51% U. A rare mineral present in greenchist facies from gneissic rocks[1,35].

8. Compreignacite $K_2(UO_2)_6O_4(OH)_6.7H_2O$ – Orthorhombic system; 71.11% U. The mineral is a product of oxidation from pitchblende (uraninite) ores[1-41].

9. Curite $Pb_2U^{6+}{}_5O_{17}.4H_2O$ – Orthorhombic system; 63.34% U. Occurs associated with torbernite in the oxidation zone of uranium ores[1,44].

10. Fourmarierite $PbU^{6+}{}_4O_{13}.4H_2O$ – Orthorhombic system; 64.53% U. Secondary Pb-U mineral, product of alteration from uraninite[1,54].

11. Holfertite $(UO_2)_{1.75}[TiO_4[(H_2O)_3Ca_{0.25}]$ – Hexagonal system; 63,31% U. Acessory mineral in rhyolite[1,64].

12. Ianthinite $U^{4+}{}_2(UO_2)_4O_6(OH)_4.9H_2O$ – Orthorhombic system; 78.29% U. Mineral occurss in sedimentary uranium deposits[1,66].

13. Metacalciouranoite $(Ca,Na,Ba)U_2O_7.5H_2O$ – Orthorhombic system; 69.58% U. Rare mineral found in oxidation zones of U-Mo deposits[1,80].

14. Metaschoepite $[(UO_2)_8O_2(OH)_{12}].10H_2O$ – Orthorhombic system; 76.04% U. Secondary mineral which occurss in the oxized zone of U deposits[1,86].

15. Metastudtite $UO_2(OH)_4$ – Orthorhombic system; 70.41% U. Secondary mineral which occurss in uranium deposits associated with uranium-lead oxides[1,87].

16. Metavandendriesscheite $PbU_7O_{22}.nH_2O$ - Orthorhombic system; 69.56% U. Secondary mineral present in gummitic zone of the uranium deposits[1,86,167].

17. Paraschoepite $UO_3.2H_2O$ (?) – Orthorhombic system; 73.91% U. Secondary mineral which occurss on pichblende (uraninite) crystals in uranium mines[1,112].

18. Protasite $Ba(UO_3)O_3.3H_2O$ – Monoclinic system; 61.91% U. Secondary mineral found in copper and uranium deposits[1,121].

19. Rameuauite $K_2CaU^{6+}{}_6O_2.9H_2O$ – Monoclinic system; 70.40% U. Secondary mineral found in uranium mines on uraninite[1,125].

20. Richetite $Pb_9(UO_2)_{36}(OH)_{24}O_{36}$ – Triclinic system; 66.15% U. Secondary mineral which occurss on needles of uranophane[1,128].

21. Sayrite $Pb_2(UO_2)_5O_6(OH)_2.4H_2O$ – Monoclinic system; 60.52% U. Secondary uranium mineral which occurss associated with becquerelite and uranophane[1,133].

22. Schoepite $(UO_2)_8O_2(OH)_{12}.12H_2O$ – Orthorhombic system; 72.89% U. Secondary mineral product of alteration of uraninite[1,135].

23. Spriggite $Pb_3[(UO_2)_6O_8(OH)_2](H_2O)_3$ – Monoclinic system; 59.10% U. Secondary mineral found in alteration zone of hydrothermal hematite-U-Nd-REE[1,143].

24. Studtite $UO_4.4H_2O$ – Monoclinic system; 63.63% U. Secondary mineral found in percolation waters of uranium mines[1,146].

25. Uraninite UO_2 – Cubic system; 88.15% U. Occurs in granite and syenites pegmatites, conglomerates, and colloform crusts in hydrothermal veins of high temperatures[164]. Its a major industrial source of uranium. Also called pitchblende.

26. Vandenbrandeite $Cu^{2+}(UO_2)(OH)_4$ – Triclinic system; 59.27% U. Secondary mineral on pitchblende (uraninite) ores[1,165].

27. Vandendriesscheite $Pb_{1.5}(UO_2)_{10}O_6(OH)_{11}.11H_2O$ – Orthorhombic system; 67.76% U. Secondary mineral of gummite alteration zones[1,86,167].

28. Wolsendorfite $Pb_7(UO_2)_{14}O_{19}(OH)_4.12H_2O$ – Orthorhombic system; 59.99% U. Mineral found in fissures of fluorite veins[1,86,167].

f) Phosphates

f_1) Compound phosphates

1. Coconinoite $Fe^{3+}{}_2Al_2(UO_2)_2(PO_4)_4(SO_4)(OH)_2.20H_2O$ – Monoclinic (?) system; 30.91% U. Typical mineral of the sedimentary rocks (arkosic and sandstones)[1,3].

2. Xiangjiangite $(Fe^{3+},Al)(UO_2)_4(PO_4)_2(SO_4)_2(oh).22H_2O$ – Tetragonal (?) sytem; 49.67% U. Secondary mineral of the oxidized zones of uranium deposits[1,176].

f_2) Hydrated phosphates

1. Autunite $Ca(UO_2)_2(PO_4)_2.10\text{-}12H_2O$ – Tetragonal system; 48.27% U. Secondary mineral in oxidation zone in the pegmatites and uraniferous deposits. It's an important source of U[1,12,40].

2. Bassetite $Fe^{2+}(UO_2)_2(PO_4)_2.8H_2O$ – Monoclinic system; 51.19% U. Rare secondary mineral in the oxized zone in hydrothermal uraniferous deposits[1,15].

3. Bergenite $Ca_2Ba_4[(UO_2)_3O_2(PO_4)_2]_3.16H_2O$ – Monoclinic system; 43.28% U. A secondary uranium mineral[1,19].

4. Chernikovite $(H_3O)_2(UO_2)_2(PO_4)_2.6H_2O$ – Tetragonal system; 54.34% U. Occurs in granite pegmatites[1,31].

5. Dewindtite $Pb_3[(UO_2)_3O(PO_4)_2(OH)]_2.12H_2O$ – Orthorhombic system; 49.18% U. Rare secondary mineral formed by alteration from uraninite[1,51].

6. Dumontite $Pb_2(UO_2)_3O_2(PO_4)_2.5H_2O$ – Monoclinic system; 46.47% U. Secondary mineral of Pb-U deposits[1,52].

7. Fritzscheite $Mn^{2+}(UO_2)_2[(PO_4)_2].10H_2O(?)$ – Tetragonal system; 47.65% U[1].

8. Lehnerite $Mn^{2+}(UO_2)_2(P,V)O_4)_2.8H_2O$ – Monoclinic system; 51.24% U. Secondary mineral formed by decomposition of zwieselite crystals[1,73].

9. Meta-ankoleite $K_2(UO_2)_2(PO_4)_2.6H_2O$ – Tetragonal system; 51.96% U. Mineral found in pegmatites[1,78].

10. Meta-autunite $Ca(UO_2)_2(PO_4)_2.2\text{-}6H_2O$ – Tetragonal system; 56.53% U. Typical mineral which occurss in fractures in uraniferous igneous rocks associated with autunite[1,79].

11. Metanatroautunite $Na_2(UO_2)_2(PO_4)_2.6\text{-}8H_2O$ – Tetragonal system; 48.06% U. Secondary mineral in granite-quarries rich in uranium[1,83].

12. Metasalleite $Mg(UO_2)(PO_4).8H_2O$ – Monoclinic system; 44.62% U. Secondary mineral occursed in silicious rocks associated with uranium ores[1,85].

13. Metatorbernite $Cu^{2+}(UO_2)_2(PO_4)_2.8H_2O$ – Tetragonal system; 50.77% U. Secondary mineral product of weathering and dehydratation of torbernite[1,88].

14. Metauranocircite I $Ba(UO_2)_2(PO_4)_2.6H_2O$ – Tetragonal system; 47.92% U. Secondary mineral derived from phosphatic uraninite deposits[1,90].

15. Metauranocircite II $Ba(UO_2)_2(PO_4)_2.6H_2O$ – Tetragonal system; 47.92% U. Secondary mineral derived from phosphatic uraninite deposits[1,90,91].

16. Metavanmeersscheite $U^{6+}(UO_2)_3(PO_4)_2(OH)_6.2H_2O$ – Orthorhombic system; 69.19% U. Secondary uranium mineral found in pegmatites[1,94].

17. Ningyoite $(U,Ca)_2(PO_4)_2.1\text{-}2H_2O$ – Orthorhombic system; 51.50% U. Seconadary mineral wchich occurss in an unoxidized zone of uranium deposits [1,106].

18. Parsonsite $Pb_2(UO_2)[PO_4]_2.2H_2O$ – Triclinic system; 26.15% U. Secondary mineral of Pb-Zn veins[1,115].

19. Phosphowalpurgite $(UO)_2Bi_4O_4(PO_4)_2.2H_2O$ – Triclinic system; 15.56% U. Secondary mineral formed by the supergene alteration of bismuth sulfides and uraninite[1,116].

20. Phophuranylite $KCa(H_3O)_3(UO_2)_7(PO_4)_4O_4.8H_2O$ – Orthorhombic system; 63.73% U. Secondary mineral typical occursring in weathered zones of granite pegmatites[1,117].

21. Phurcalite $Ca_2(UO_2)_3O_2(PO_4)_2.7H_2O$ – Orthorhombic system; 57.67% U. Secondary mineral of the iron deposits associated with hematite[1,119].

22. Przhevalskite $Pb(UO_2)_2(PO_4)_2.4H_2O$ – Orthorhombic system; 41.17% U. Secondary mineral found in oxidized zone of sulfide and uraninite ore deposits[1,122].

23. Sabugalite $H_{0.5}Al_{0.5}(UO_2)_2(PO_4)_2.8H_2O$ - Monoclinic system; 53.60% U. Secondary mineral found associated with salleite, meta-autunite and phophuranylite[1,131].

24. Saleeite $Mg(UO_2)_2(PO_4)_2.10H_2O$ – Monoclinic system; 50.94% U. Secondary mineral found disseminated in carnotite-bearing sandstones and uranium phosphates[1,132].

25. Torbernite $Cu^{2+}(UO_2)_2(PO_4)_2.8\text{-}12H_2O$ – Tetragonal system; 48,00% U. Secundary mineral of granites in uranium ores[1,154].

26. Triangulite $Al_3(UO_2)_4PO_4)_4(OH)_5.5H_2O$ – Triclinic system; 55.48% U. Secondary mineral found in pegmatites[1,155].

27. Tristramite $(Ca,U^{4+})(PO_4).2H_2O$ – Hexagonal system; 30.74% U. Secondary mineral which occurss in intergrown with goethite in fine fractures in uraninite crystals[1,156].

28. Ulrichite $CaCu^{2+}(UO_2)(PO_4)_2.4H_2O$ – Monoclinic system; 37.45 U. Secondary mineral found in granites[1,159].

29. Uramphite $(NH_4)_2(UO_2)_2(PO_4)_2.6H_2O$ – Orthorhombic system; 54.46% U. Mineral found as encrustions on a fracture surface in sub-betuminous coal and uranium coal deposits[1,162].

30. Uranocircite $Ba(UO_2)_2(PO_4)_2.12H_2O$ – Tetragonal system; 46.82% U. Secondary mineral derived from phosphatic uraninite deposits[1,90,91].

31. Uranospathite $Al_{1-x}\square_x[(UO_2)(PO_4)]_2(H_2O)_{20+3x}F_{1-3x}$ – Orthorhombic system; 43.11% U. A very rare secondary mineral in uranium deposits[1,8].

32. Vanmeersscheite $U^{6+}(UO_2)_3(PO_4)_2(OH)_6.4H_2O$ – Orthorhombic system; 67.42% U. Secondary uranium mineral found in pegmatites[1,94].

33. Vyachelavite $U^{4+}(PO_4)(OH)._nH_2O$ – Orthorhombic system; 60.25% U. Mineral found on quartz crystals associated with pyrite[1,173].

34. Walpurgite $(BiO)_4(UO_2)(AsO_4)_2.2H_2O$ – Triclinic system; 18.20% U. Mineral found in oxidized polymetallic ore deposit[1,167].

35. Yingjiangite $K_2Ca(UO_2)_7(PO_4)_4(OH)_6.6H_2O$ – Orthorhombic system; 63.90% U. Secondary mineral of the oxidation zone of uraninite and uranothorite[1,175].

f_3) Hydrated phosphates containing hydroxyl

1. Althupite $AlTh(UO_2)[(UO_2)_3O(OH)(PO_4)_2]_2(OH)_3.15H_2O$ – Triclinic system; 57.77% U. Secondary mineral in the uraniferous zone of the pegmatites[1,6].

2. Françoisite-(Ce) $Ce(UO_2)_3(PO_4)_2O(OH).6H_2O$ – Monoclinic system; 59.44% U. Rare mineral in uranium deposits[1,56].

3. Françoisite-(Nd) $Nd(UO_2)_3(PO_4)_2O(OH).6H_2O$ – Monoclinic system; 61.26% U. Secondary mineral, product of alteration in Cu-Co sedimentary deposits[1,57].

4. Furongite $Al_2(UO_2)(PO_4)_2(OH)_2.8H_2O$ – Triclinic system; 30.24% U. Secondary mineral found in the oxidation zone of uranium deposits[1,58].

5. Kamitugaite $PbAl(UO_2)_5[(P,As)O_4]_2(OH)_9.9.5H_2O$ – Triclinic system; 56.71% U. Secondary mineral found in pegmatites[1,70].

6. Moreauite $Al_3(UO_2)(PO_4)_3(OH)_2.13H_2O$ – Monoclinic system; 26.33% U. Secondary mineral found in the oxidation zone of uranium deposits[1,100].

7. Mundite $Al(UO_2)_3(PO_4)_2(OH)_3.5.5H_2O$ – Orthorhombic system; 61.13% U. Secondary mineral found in the oxidation zone of uranium deposits[1,102].

8. Phuralumite $Al_2(UO_2)_3(PO_4)_2(OH)_6.10H_2O$ – Monoclinic system; 53.44% U. Secondary mineral found in pegmatites associated with others U-phophates[1,118].

9. Ranunculite $HAl(UO_2)(PO_4)(OH)_3.4H_2O$ – Monoclinic system; 46.12% U. Secondary mineral found in U-rich pegmatites[1,126].

10. Sreinite $Pb_2(UO_2)_{11}(BiO)_8(PO_4)_5(OH)_{19}.6H_2O$ – Cubic system; 25.59% U. Secondary mineral found in fissures of quartz crystals in a bismuth deposit from Krusne Hory Mountais, Czech Republic[1,144].

11. Threadgoldite $Al(UO_2)_2(PO_4)_2(OH).8H_2O$ – Monoclinic system; 51.85% U. Mineral which occurss in pegmatites on uraninite[1,152].

12. Upalite $Al(UO_2)_3O(OH)(PO_4)_2.7H_2O$ – Monoclinic system; 60.20% U. Secondary mineral found in pegmatites[1,153].

13. Vochtenite $(Fe^{2+},Mg)Fe^{3+}(UO_2)_4(PO_4)_4(OH).12\text{-}13H_2O$ – Monoclinic system; 52.72% U. Secondary mineral with occurss in oxidized of the uranium mines[1,171].

g) Selenites

g_1) Anhydrous selenites

1. Derriksite $Cu_4(UO_2)(SeO_3)_2(OH)_6$ – Orthorhombic system; 27.04% U. Mineral found in basal portion of Cu-Co deposits[1,49].

g_2) Hydrated selenites

1. Demesmaekerite $Pb_2Cu^{2+}{}_5(UO_2)_2(Se^{4+}O_3)_6(OH)_6.2H_2O$ – Triclinic system; 21.92% U. Mineral found in basal portion of Cu-Co deposits[1,48].

2. Guilleminite $Ba(UO_2)_3(SeO_3)_2O_2(H_2O)_3$ – Orthorhombic system; 55,47% U. Mineral occurss in the oxidized zone of the Cu-Co deposits[1,60].

3. Larisaite $Na(H_3O)(UO_2)_3(SeO_3)_3O_2.4H_2O$ – Monoclinic system; 59,52% U. Secondary mineral in sedimentary rocks[1,72].

4. Piretite $Ca(UO_2)_3(SeO_3)_2(OH)_4.4H_2O$ – Orthorhombic system; 45,6% U. Secondary mineral in uranium and copper deposits[1,120].

h) Silicates

h_1) Cyclosilicates

1. Arapovite $(U,Th)(Ca,Na)_2(K_{1-x}\square_x)Si_8O_{20}.H_2O$ – Tetragonal system; 16.45% U. Mineral found in rocks of maraines in Tajikistan in association with turkestanite[1,13].

h_2) Inosilicates

1. Ciprianiite $Ca_4[(Th,U)(REE)](Al,\square)_2(Si_4B_4O_{22})(OH,F)_2$ – Monoclinic system; 17.24% U. Mineral found in pyroclastic rocks in miarolitic cavities[1,33].

h_3) Nesosilicates

1. Boltwoodite $HK(UO_2)SiO_4.1.5H_2O$ – Monoclinic system; 55.45% U. Surrouding hydrated uranyl oxides incrusting uraninite crystals[1,24].

2. Calcioursilite $Ca_4(UO_2)_4(Si_2O_5)_5(OH)_6.15H_2O$ – (?); 41.51% U. Rare mineral formed in a granite-porphyry[1,26].

3. Coffinite $USiO_4.nH_2O$ – Tetragonal system; 72.63% U. Typical mineral of the sedimentary rocks. It's an important source of U[1,39,40].

4. Coutinhoite $Th_x(Ba_{1-2x})(H_2O)_y(UO_2)_2Si_5O_{13}.H_2O$ – Orthorhombic system; 67.40% U. Secondary mineral of pegmatites, product from the oxidation of uraninite[1,42].

5. Cuprosklodowskite $Cu(UO_2)_2Si_2O_7.6H_2O$ – Triclinic system; 55.24% U. Secondary mineral formed by alteration from uranium ores[1,24].

6. Haiweeite $Ca(UO_2)_2Si_5O_{12}(OH)_2.4.5H_2O$ – Orthorhombic system; 47.58% U. Secondary mineral formed by alteration from uranium ores.[1,61].

7. Kasolite $Pb(UO_2)SiO_4.H_2O$ – Monoclinic system; 40.53% U. Mineral found in uranium mines, oxidation product of uraninite. A source of U[1,40,71].

8. Metahaiweeite $Ca(UO_2)_2Si_6O_{15}.nH_2O$ – Monoclinic system; 46.05% U. Secondary mineral formed by alteration from uranium ores.[1,61].

9. Natroboltwoodite $(H_3O)(Na,K)(UO_2)SiO_4.H_2O$ – Orthorhombic system; 51.60% U. Secondary mineral occurss in small amounts in soils of arid regions[1,103].

10. Oursinite $Co[(UO)_2)(Si_3OH)].4H_2O$ – Orthorhombic system; 54.61% U. Secondary mineral found in oxidation zones of U ores[1,10].

11. Sklodowskite $Mg(UO_2)_2Si_2O_7.6H_2O$ – Monoclinic system; 55.44% U. Secondary mineral of oxidization zone of uranium ores commonly associated with uraninite[1,142].

12. Soddyite $(UO_2)_2SiO_4.2H_2O$ – Orthorhombic system; 71.25% U. Secondary mineral found in oxidized uranium ores associated with curite[1,142].

13. Swamboite $U^{6+}H_6(UO_2)_6(SiO_4)_6.30H_2O$ – Monoclinic system; 56.34 % U. Secondary mineral which occurs as alteration product of others uranium minerals[1,147].

14. Thorite $(Th,U)SiO_4$ – Tetragonal system; 2.36% U. Mineral acessory of augite-syenites[1,151].

15. Uranophane-alpha $Ca(UO_2)_2[SiO_3(OH)]_2.5H_2O$ – Monoclinic system; 40.59% U. Occurs as alteration product of gummites[1,166].

16. Uranophane-beta $Ca(UO_2)_2[SiO_3(OH)]_2.H_2O$ – Monoclinic system; 60.70% U. Occurs as alteration product of uraninite in oxidized zones and pegmatites[1,166].

17. Uranosilite $U^{6+}CaSi_7O_{17}$ – Orthorhombic system; 33.69% U. Occurs as intergrowth with studtite and uranophane on quartz and hematite[1,169].

18. Weeksite $(K,Na)_2(UO_2)_2(Si_5O_{13}).3H_2O$ – Orthorhombic system; 48.58% U. Mineral with occurs in veins of ryolites, conglomerates, limestones and sandstones[1,167].

i) Sulfates

i_1) Anhydrous sulfates

1. Magnesiumzippeite $Mg(H_2O)_{3.5}[(UO_2)_2(SO_4)(O_2)]$ – Monoclinic system; 63.01% U. Secondary mineral from the oxidation zone of sulfides in the uranium deposits[1,76].

i_2) Hydrated sulfates containing hydroxyl

1. Cobaltzippeite $Co_2(UO_2)_6(SO_4)_3(OH)_{10}.16H_2O$ – Orthorhombic system; 57.86% U. Mineral found in oxidized zone of copper ores.[1,37].
2. Deliensite $Fe^{2+}(UO_2)_2(SO_4)_2(OH)_2.3H_2O$ – Orthorhombic system; 54.34% U. Secondary mineral of oxidization zone from uranium deposits[1,46].
3. Jáchymovite $(UO_2)_8(SO_4)(OH)_{14}.13H_2O$ – 69.79% U. Mineral found in dolomitic veins[1,67].
4. Johannite $Cu(UO_2)_2(SO_4)_2(OH)_2.8H_2O$ – Triclinic system; 48.88% U. Secondary mineral, product from the oxidation of uraninite in gypsiferous deposits[1,68].
5. Metauranopilite $(UO_2)_6(SO_4)(O_2)(OH)_{10}.5H_2O$ – Orthorhombic (?) system; 72.19% U – Secondary mineral from an uranium–bearing hydrothermal ore deposits [1,92].
6. Natrozippeite $Na_5(H_2O)_{12}[(UO_2)_8(SO_4)_4O_5(OH)_3]$ – Orthorhombic system; 63.34% U. Secondary mineral of the uranium deposits[1,105].
7. Nickelzippeite $Ni_2(UO_2)_6(SO_4)_3(OH)_{10}.16H_2O$ – Orthorhombic system; 57.49% U. Secondary mineral of the uranium deposits[1,106].
8. Pseudojohannite $Ni_{6.5}[(UO_2)_4O_4(SO_4)_2]_2(OH)_5.25H_2O$ – Triclinic system; 51.93% U. Secondary mineral found in uranium deposits[1,123].
9. Rabejacite $Ca(UO_2)_4(SO_4)_2(OH)_6.6H_2O$ – Orthorhombic system; 62.54% U. Secondary mineral of uranium deposits associated with gypsum[1,124].
10. Uranopilite $(UO_2)_6(SO_4)(OH)_{10}.12H_2O$ – Monoclinic system; 67.93% U. Secondary mineral found on altering uraninite[1,167].
11. Zinczippeite $Zn_2(UO_2)_2(SO_4)(OH)_3.H_2O$ – Monoclinic system; 59.93% U. Mineral common in underground uranium mines[1,167].
12. Zippeite $K(UO_2)_2(SO_4)(OH)_3.H_2O$ – Monoclinic system; 61.91% U. Mineral common in underground uranium mines[1,167].

j) Tellurites

1. Cliffordite $UTe^{4+}{}_3O_9$ – Cubic system; 31.12% U. Mineral found in oxidized zones of hydrothermal Au-Ag telluride deposits[1,36].

2. Moctezumite $Pb(UO)_2(TeO_3)_2$ – Monoclinic system; 28.73% U. Secondary mineral in uranium-bearing ores[1,98].

3. Schmitterite $(UO_2)TeO_3$ – Orthorhombic system; 53.41% U. Secondary mineral found in the oxidized parts of a telluride-bearing deposit[1,134].

k) Tungstates

k_1) Basic and hydrated tungastates

1. Uranotungstite $(Fe^{2+},Ba,Pb)(UO_2)_2(WO_4)(OH)_4.12H_2O$ – Orthorhombic system; 40.77% U. Mineral found as crusts on quartz, meta-uranocircite and meta-heirichite in uranium deposits[1,170].

l. Vanadates

l_1) Hydrated vanadates

1. Carnotite $K_2(UO_2)_2(VO_4)_2.3H_2O$ – Monoclinic system; 52.77% U. A secondary mineral product from the alteration of uranium minerals (uraninite, davidite or montroseite), occurs principally in sandstones, fossil carbonaceous matter, and calcretes[1,28,40].

2. Curienite $Pb(UO_2)_2(V_2O_8).5H_2O$ – Orthorhombic system; 44.61% U. Secondary mineral in sedimentary rocks (sandstones) rich in U-V[1,43].

3. Francevillite $Ba(UO_2)_2(V_2O_8).5H_2O$ – Orthorhombic system; 48.64% U. Secondary mineral occurss as impregnations in sandstones[1,55].

4. Margaritasite $(Cs,K,H_3O)_2(UO_2)_2V_2O_8.H_2O$ – Monoclinic system; 48.84% U. [1,77].

5. Metatyuyamunite $Ca(UO_2)_2(VO_4)_2.3H_2O$ – Orthorhombic system; 55.10% U. Secondary mineral which occurss as product of dehydration of tyuyamunite[1,89].

6. Strelkinite $Na_2(UO_2)_2V_2O_8.6H_2O$ – Orthorhombic system; 51.52% U. Mineral found in carbonaceous-siliceous shales[1,145].

7. Tyuyamunite $a(UO_2)_2V_2O_8.5\text{-}8H_2O$ – Orthorhombic system; 51.85% U. Secondary mineral found in U-V sandstones deposits[1,158].

l_2) Hydrated vanadates containing hydroxyl

1. Metavanuralite $Al(UO_2)_2(VO_4)_2(OH).3H_2O$ – Triclinic system; 49.69% U. Secondary mineral stable in humidity between 28-47%; the less hydrated form of varuralite[1,95].

2. Sengierite $Cu_2(UO_2)_2(VO_4)_2(OH)_2.6H_2O$ – Monoclinic system; 47.36% U. Secondary mineral found in uranium-bearing copper deposits[1,139].

3. Metavanuralite $Al(UO_2)_2(VO_4)_2(OH).11H_2O$ – Triclinic system; 47.04% U. Secondary mineral stable in humidity between 28-47%; the less hydrated form of varuralite[1,95].

Uranium Minerals

m) Vanadium Oxysalts

1. Rauvite $Ca(UO_2)_2V^{5+}_{10}O_{28}.16H_2O$ – Amorphous; 26.07% U. Secondary mineral found in oxized zone of U-V ores[1,127].

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