

# Annotated Bibliography of the Geology of Selenium, 1958-74

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GEOLOGICAL SURVEY BULLETIN 1419





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By CAROL A. GENT

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# **ANNOTATED BIBLIOGRAPHY OF THE GEOLOGY OF SELENIUM, 1958-74**

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BY CAROL A. GENT

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## **INTRODUCTION**

The average crustal abundance of selenium is poorly known, but it is estimated to be about 0.1 ppm. It is much more highly concentrated, however, in certain geologic settings, such as sandstone-type uranium deposits. Preparation of this bibliography was prompted by interest in the deposition and chemical behavior of trace elements in ore deposits as indicators of the geochemical conditions of mineral formation. It is intended primarily to assist in the research now being done on uranium deposits and their paragenesis.

## **SCOPE OF BIBLIOGRAPHY**

References cited in this bibliography are largely limited to the geological aspects of selenium—its occurrence, geochemical behavior, and mineralogy. Several references are included that provide general information about selenium, including its nutritional effects and industrial uses. However, the large volume of literature pertaining to selenium distribution in soils, accumulation in certain vegetation, and toxic effects on livestock has, with a few exceptions, been excluded. Likewise, reports on industrial applications and analytical procedures for selenium were generally not included.

For the most part, references included herein span the years 1958 through 1974. For earlier studies, the reader is referred to U.S. Geological Survey Bulletin 1019-M, "Annotated Bibliography on the Geology of Selenium," by G. W. Luttrell (1959). This bulletin includes references published before 1958 on the geology, mineralogy, geochemistry, metallurgy, analytical procedures, biologic effects, production, and uses of selenium.

The stratigraphic nomenclature used in this report is from many sources and may not conform with that in use by the U.S. Geological Survey.

## EXPLANATION OF BIBLIOGRAPHY

The bibliographic references are listed alphabetically by the first author's last name. Each reference shows the year of publication, the title of the article, and the publication source.

Titles of articles written in non-English languages are translated into English, and the original language is indicated in brackets. If an English translation of the journal is available (for instance, articles in *Geokhimiya* are translated in *Geochemistry*) the language within the brackets is omitted and a reference to the translation is given.

Titles of journals and other publications written in languages that use the Cyrillic alphabet have been transliterated to the Roman alphabet. Names of serial publications are abbreviated in the bibliography and are listed alphabetically in full in the serials list.

References to abstracting journals are given whenever possible, inasmuch as some publications are not available in all libraries. Annotations taken from the author's abstract or one of the abstracting journals are so indicated at the end of the annotation. Minor editorial changes for clarity or consistency have occasionally been made in annotations taken from the author's abstract or other sources.

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In addition to plumboan guillemite and native selenium already described from Olloix, clausthalite (the only hypogene bearer of selenium), an anhydrous lead selenite(?), and chalcocite (a hydrated copper selenite) have been found. (Authors' abstract.)

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The deposit corresponds to a broken zone, with subvertical dip, intersecting porphyritic granite, and leucogranites. Pitchblende is found in reddish quartz veins. Certain altered regions indicate strong traces of selenium. (*Chem. Abs.*, v. 71, item 52189d, 1969, condensed.)

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A veinlet in the Liauzun-en-Olloix granite, containing altered pitchblende and copper sulfides, also contains small amounts of native selenium associated with a hydrous selenide of uranium, barium, and lead which can be considered to be a lead-bearing variety of guillemite. No primary selenide was observable. (*Mineralog. Abs.*, v. 19, p. 139, 1968.)

Ashton, R., Hill, E. G., and Neville-Jones, D., 1954, *Selenium*: London, Her Majesty's Stationery Office, Department of Scientific and Industrial Research, 28 p.

A technical review of the production and utilization of selenium is presented.

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395 samples were analyzed for selenium.

Babčan, Ján, and Ilavský, Ján, 1966, Geochemistry of selenium from the stratiform pyrite deposit of ferrous sulfide-copper ores in Smolnik [in German]: Sb. Geol. Vied, Zapad. Karpaty, no. 6, p. 85-106.

The selenium content of the various minerals in ppm is: galena 440-1,160, sphalerite 198-940, chalcopyrite 50-512, arsenopyrite 70, pyrite 41.3 (max. 600), pyrrhotite 22, ankerite 6-16, quartz, dolomite, melanterite, and chalcantite 2-4. The study of the selenium content of the minerals of the stratiform deposits in Smolnik shows clearly its genetic difference from the thermal, apomagmatic, and sideritic-sulfidic deposits. (Chem. Abs., v. 68, item 97614t, 1968.)

Badalov, S. T., Belopol'skaya, T. L., Prikhid'ko, P. L., and Turesebekov, A., 1969, Geochemistry of selenium in sulfate-sulfide mineral parageneses: Geokhimiya 1969, no. 8, p. 1007-1010; translated in Geochemistry Internat., v. 6, p. 799-801; abs. in Chem. Abs., v. 71, item 93630j, 1969.

The selenium content has been determined for anhydrite and coexisting pyrite, chalcopyrite, or enargite. The sulfide minerals varied from 30-220 ppm selenium, and the anhydrite ranged from 0.8-3 ppm selenium. Factors affecting the distribution coefficient are discussed.

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Mineral-carriers and mineral-concentrators are listed together with genetic types of deposits for the following rare elements: Be, Cd, Ga, In, Tl, Ge, B, Se, Te, Re, Sc, and elements of Pt group. (Chem. Abs., v. 73, item 68443j, 1970.)

Badalov, S. T., and Ruzmatov, S. R., 1960, Contribution to the geochemistry of selenium and tellurium in the Almalyk ore deposits [in Russian]: Akad. Nauk SSSR, Inst. Mineralogii, Geokhimii i Kristallokhimii Redkikh Elementov, Trudy, no. 4, p. 24-27.

The contents of selenium and tellurium were determined in pyrites, chalcopyrites, galena, sphalerite, and molybdenite deposits of various genetic types. The contents of Se and Te in pyrites depend on the type of deposit and are usually related to Cu-Mo types. The highest Se content is found in pyrite of the medium stage of Cu-Mo mineralization. (Chem. Abs., v. 56, col. 12570e, 1962, condensed.)

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The physicochemical conditions of formation of different types of selenides and uranium minerals and their paragenetic relations as revealed by ore microscopic studies are described. (Chem. Abs., v. 69, item 53563s, 1968, condensed.)

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An experimental study of the compounds in the title series is presented.

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In sedimentary formations, the irregular distribution of selenium in minerals and rocks is directly associated with type and genesis of the deposits.

Benesová-Talandová, Marie, 1965, Find of clausthalite in Moravia (Czechoslovakia) [in Czechoslovakian]: *Čas. Mineralogii a Geologii*, v. 10, p. 83-86; abs. in *Mineralog. Abs.*, v. 17, p. 722; and *Chem. Abs.*, v. 62, col. 12905b, 1965.

Clausthalite was found in a calcite vein near Nové Město in Moravia. Analyses for clausthalite and other minerals are presented.

Berzon, R. O., and Karyshev, Yu. M., 1973, Selenium and tellurium in gold ore deposits of the Urals [in Russian]: *Geokhimiya* 1973, no. 11, p. 1615-1619.

In the ore formation process, selenium and tellurium accumulate in late-stage mineral associations. Accumulation of selenium occurs in crystalline lattices of sulfides, and tellurium accumulates in primary minerals. (*Chem. Abs.*, v. 80, item 62143j, 1974, condensed.)

Bethke, P. M., 1958, The sulfo-selenides of mercury and their occurrence at Marysvale, Utah [abs.]: *Dissert. Abs.*, v. 18, p. 1765-1766.

The distribution of selenium, iron, and zinc between cinnabar and metacinnabar could be related to differences in bond type. The mechanism of transportation and deposition of ore from the Lucky Boy mine is discussed from a thermodynamic point of view. Transportation in vapor phase is a possible explanation of the occurrence.

Bethke, P. M., Barton, P. B., Jr., and Page, N. J., 1958, Preliminary experiments on the distribution of selenium between coexisting sulfides [abs.]: *Geol. Soc. America Bull.*, v. 69, no. 12, pt. 2, p. 1759-1760.

Selenium was used in this study to determine the temperature-pressure conditions of mineral formation because selenides form extensive solid solutions with sulfides.

Bhappu, R. B., 1961, Economic recovery of selenium by flotation from sandstone ores of New Mexico: *New Mexico Bur. Mines and Mineral Resources Circ.* 58, 42 p.; abs. in *Chem. Abs.*, v. 55, col. 13225i, 1961.

Physical and chemical properties of selenium and selenium minerals are given. Details of flotation procedure are noted.

———1962, Recovering selenium from sandstone ores of New Mexico: *Mining Eng.*, v. 14, no. 8, p. 48-50.

Native selenium and selenides occur with some uranium ores in the Morrison formation near Grants, N. Mex.

———1962, Recovering selenium from sandstone ores of New Mexico: *Jour. Metals*, v. 14, p. 429-431; abs. in *Chem. Abs.*, v. 57, col. 4396f, 1962.



The selenium-bearing sandstone ores from the Morrison and Galisteo formations of New Mexico were found to be amenable to simple froth flotation procedures. The technical and economic aspects of the process are discussed. (Mineralog. Abs., v. 16, p. 29, 1963-1964.)

Bilenskii, M. A., 1971, Selenium in Paleozoic rocks and waters in southwestern Uzbekistan [in Russian]: Akad. Nauk Uzbek. SSR, Zapiski Uzbekistan. Otdel. Vses. Mineral. Obshch., no. 24, p. 185-187.

Most of the selenium is confined to the electromagnetic and heavy fractions including pyrite, sphalerite, chalcopyrite, clockmannite, and limonite. Results of the estimation of selenium in subsurface waters are presented. (Chem. Abs., v. 77, item 37515n, 1972, condensed.)

Blokhina, N. A., and Shcheblykina, M. D., 1970, Selenium and tellurium in sulfide ores of the Maikhura tin-tungsten deposit (central Tadzhikistan) [in Russian]: Akad. Nauk Tadzhik. SSR, Doklady, v. 13, no. 6, p. 38-40.

Selenium (7-205 ppm) was found in 19 of 20 analyzed ore samples. The maximum content was detected in pyrrhotite ( $\leq 280$  ppm). No selenium minerals were found in spite of elevated selenium content in ores. Evidently, selenium isomorphously replaced sulfur in sulfides. (Chem. Abs., v. 73, item 68478z, 1970, condensed.)

Bogdasarov, A. A., 1972, New data on the selenium content of mercury deposits in southern Fergana: Geokhimiya 1972, no. 6, p. 743-746; translated in Geochemistry Internat., v. 9, p. 478-480; abs. in Chem. Abs., v. 77, item 77837a, 1972.

The distribution of selenium is irregular and probably occurs as an isomorphous replacement of sulfur.

Boitsov, V. E., 1966, Association of pitchblende and selenides in ore of hydrothermal uranium deposits [in Russian]: Atomnaya Energiya, v. 20, no. 1, p. 46-50; abs. in Chem. Abs., v. 64, col. 13931d, 1966.

Selenium minerals from the flanks of a hydrothermal uranium deposit that formed at medium temperatures and at relatively low depths were studied.

Boitsov, V. E., and Dymkov, Yu. M., 1970, Uranium-selenium-vanadium mineralization of carbonate-pitchblende veins [in Russian] in Surazhskii, D. Ya., ed., Mes-torozhdeniya urana; zonal'nost' i paragenезis: Moscow, Atomizdat, p. 119-155; abs. in Chem. Abs., v. 75, item 79062b, 1971.

Five mineralization stages, mineral associations, and geochemical behavior of selenium and other elements are defined. Tabulated X-ray, optical, and chemical data for selenides are given.

Borodin, L. S., Nazarenko, I. I., and Kislova, I. V., 1972, New data on selenium content in igneous rocks: Akad. Nauk SSSR, Doklady, v. 206, no. 1, p. 207-209; translated in Acad. Sci. U.S.S.R. Doklady, Earth Sci. Sec., v. 206, p. 203-205, 1972; abs. in Internat. Geology Rev., v. 15, no. 3, p. 365, 1973; and Chem. Abs., v. 78, item 114030a, 1973.

Results are presented for quantitative fluorometric estimation of selenium in samples from seven different provinces.

Brimhall, W. H., 1963, Progress report on selenium in the Manning Canyon Shale, central Utah: Brigham Young Univ. Geol. Studies, v. 10, p. 104-120.

Selenium is present in unusual concentrations in shaly strata throughout the 1,600 ft [487 m] thickness of the formation. High concentrations of Se are most common in shale that is dark colored, carbonaceous, calcareous, soft, usually gypsiferous, and often iron oxide stained or pyritic. The association of organic matter, pyrite, and gypsum in some of the most seleniferous beds indicates the possible derivation of selenium from organic matter, its reconstitution in part as a sulfide, and its subsequent oxidation to selenite or selenate. (Author's abstract condensed.)

Bur'yanova, E. Z., 1961, Selenium mineralization of sedimentary rocks of Tuva: *Geokhimiya* 1961, no. 7, p. 623-629; translated in *Geochemistry* 1961, p. 669-678; abs. in *Mineralog. Abs.*, v. 16, p. 165, 1963-1964; and *Chem. Abs.*, v. 57, col. 467c, 1962.

A seleniferous geochemical province exists in Tuva in which sedimentary rocks ranging in age from Middle Devonian to Recent are contaminated with selenium. In the most strongly seleniferous areas, the selenides, ferroselite, clausthalite, cadmoselite, and stilleite, were found, as well as seleniferous sulfides (seleniferous pyrite, chalcopyrite, sphalerite, and galena). Chemical, optical, and X-ray data are given. The S:Se ratio in the seleniferous sandstones is 135, and there is an inverse relation between the content of sulfur and selenium. The selenium minerals evidently formed during the diagenesis of sediments in the alkaline, reducing geochemical facies. (Author's abstract.)

—1969, The thermodynamic aspect of the conditions of production of native selenium and the selenides of Fe, Pb, Zn, and Cd in sediments: *Geokhimiya* 1969, no. 12, p. 1451-1465; abs. of translation in *Geochemistry Internat.*, v. 6, p. 1196; abs. in *Chem. Abs.*, v. 72, item 46197j, 1970.

The stability fields of Fe, Pb, and Zn selenides and sulfides are compared. Selenides are less resistant to oxidation than are sulfides in an acid medium. Native selenium has a wider stability field than either sulfides or selenides. Selenides accumulate in alkaline, reduced environments.

Bur'yanova, E. Z., and Kashenova, A. G., 1962, Selenium content in the Lower Carboniferous sedimentary rocks of the northern and southern Minusinsk Basins [in Russian]: *Akad. Nauk SSSR Sibirsk. Otdeleniye, Geologiya i Geofizika*, no. 5, p. 14-20.

The increased selenium content of rocks is not accompanied by an increased content of sulfur: the S:Se ratio is 3:187. Selenium is localized in horizons that were formed in a weakly alkaline medium under reducing conditions. (*Chem. Abs.*, v. 57, col. 14741g, 1962, condensed.)

Chentsov, I. G., 1959, Selenium in the Paleogene deposits of Central Asia: *Akad. Nauk SSSR, Inst. Geologii Rudnykh Mestorozhdeniy, Petrografii, Mineralogii i Geokhimii, Trudy*, no. 28, p. 83-89; translated by Office of Technical Services, U.S. Dept. Commerce, 1961, p. 125-132; abs. in *Mineralog. Abs.*, v. 15, p. 189, 1961-1962; and *Chem. Abs.*, v. 54, col. 24140g, 1960.

The selenium, which is found mainly in bituminous material and sulfides, reaches 0.01-0.05 percent.

Chitaeva, N. A., 1965, Distribution of selenium and tellurium in the oxidized zones of copper sulfide deposits of the southern Urals: *Geokhimiya* 1965, no. 9, p. 1140-1153; translated in *Geochemistry Internat.*, v. 2, p. 830-842; abs. in *Chem. Abs.*, v. 63, col. 16050c, 1965.

In the oxidized parts of iron-copper sulfide ore bodies in the southern Urals, selenium and tellurium are concentrated in supergene sulfides, quartz-native sulfur "sand," and (selenium only) gossan limonites, but they are depleted in sulfate zones relative to the unoxidized ores. The selenium and tellurium form halos around some deposits in sulfate- and limonite-impregnated wall rocks. (*Mineralog. Abs.*, v. 18, p. 165, 1967, condensed.)

Chizhikov, D. M., and Shchastliviy, V. P., 1968, Selenium and selenides [translated from Russian by E. M. Elkin]: London, Collet's, 403 p.

Reviews the properties and production of selenium and selenides; includes crystallographic and experimental data.

Chung, Chia-Jung, 1962, Selenium distribution in cinnabar from the antimony-mercury deposits of South Fergana: *Geokhimiya* 1962, no. 12, p. 1071-1078; translated in *Geochemistry* 1962, no. 12, p. 1209-1218; abs. in *Chem. Abs.*, v. 58, col. 5381g, 1963.

The selenium concentrations of about 300 samples of cinnabar, stibnite, realgar, kermesite, orpiment, sulfur, and pyrite are lognormally distributed. (*Mineralog. Abs.*, v. 16, p. 629, 1963-1964, condensed.)

———1962, On seleniferous antimony-mercury deposits: *Geokhimiya* 1962, no. 8, p. 681-688; translated in *Geochemistry* 1962, p. 788-796; abs. in *Mineralog. Abs.*, v. 16, p. 518, 1963-1964; and *Chem. Abs.*, v. 60, col. 11762d, 1964.

The results of hundreds of analyses of cinnabar, stibnite, pyrite, and other minerals for selenium are summarized. Most of the specimens were from the mercury-antimony belt of South Fergana. Two major types of deposits were distinguished: intermediate and high temperature tabular deposits containing stibnite, cinnabar, realgar, orpiment, tetrahedrite, pyrite, quartz, fluorite, and minor calcite, and low temperature fracture fillings in limestones or tuffaceous sediments consisting almost entirely of cinnabar and calcite. Cinnabar from deposits of the quartz-fluorite-stibnite-cinnabar type characteristically has the highest Se content, and cinnabar from carbonate-cinnabar deposits is practically free of Se. A definite horizontal zoning was established in the Ishmetau deposits where the Se content of the ores decreased as the distance increased from the fault plane that controlled ore deposition. Some effects of wall-rock composition on the Se content of ore are reported. (Author's abstract.)

———1963, Antimony-mercury formation containing selenium: *Akad. Nauk SSSR, Inst. Mineralogii, Geokhimii i Kristallokhimii Redkikh Elementov, Trudy*, no. 10, p. 158-170.

A study of selenium distribution in ores and minerals of the Gornyi Altai, Eastern Kazakhstan, Transbaikalia, and Caucasus antimony-mercury deposits proved that the cinnabar from complex deposits contains the largest amount of selenium (0.064-0.424 percent). The stibnite of the antimony deposit contains much less selenium (0.0035-0.028 percent). The cinnabar of purely mercury deposit of the cinnabar-carbonate type

contained the smallest amount of selenium. This indicates that selenium is typical of the high-temperature complex antimony-mercury deposits. (Chem. Abs., v. 61, col. 2841d, 1964.)

Clark, J. R., 1973, Selenium anomalies, health hazards, and pyrite deposits in Chambers County, Alabama: *Geol. Soc. America Abs. with Programs*, v. 5, no. 5, p. 387-388.)

A geochemical soil survey found anomalies, as great as 170 ppm selenium, in the core of a gabbroic intrusion, in the contact metamorphic zone around this intrusion, and in hydrothermally altered areas in the country rock. Analysis of a pyrite sample from the area showed 255 ppm selenium.

Coleman, R. G., 1959, New occurrences of ferroselite ( $\text{FeSe}_2$ ): *Geochim. et Cosmochim. Acta*, v. 16, no. 4, p. 296-301; abs. in *Mineralog. Abs.*, v. 16, p. 450, 1963-1964; and *Chem. Abs.*, v. 53, col. 21442f, 1959.

Association of ferroselite with selenium, pyrite, and marcasite within discrete areas of the uranium-vanadium deposits of the Colorado Plateau suggests an unusual environment of formation. The association of ferroselite with apparent low temperature assemblages indicates that its minimum temperature of formation is quite low. (Author's abstract, condensed.)

———1959, The natural occurrence of galena-clausthalite solid solution series: *Am. Mineralogist*, v. 44, p. 166-175; abs. in *Mineralog. Abs.*, v. 14, p. 375, 1959-1960; and *Chem. Abs.*, v. 53, col. 8951f, 1959.

A study of the sulfides associated with the vanadium-uranium deposits of the Colorado Plateau has revealed that a complete natural solid solution series exists between galena and clausthalite. (Author's abstract, condensed.)

Copeland, R. A., 1970, Selenium and mercury distribution in Lake Michigan invertebrates: *Geol. Soc. America Abs. with Programs*, v. 2, no. 7, p. 526.

Zooplankton and phytoplankton, collected in 1969-70 and analyzed for mercury and selenium by neutron activation analysis, show dry weight concentrations of 0.5-6 ppm (Se) and 1-14 ppm (Hg). The geographic distribution of selenium in these organisms indicates that the major mode of entry into Lake Michigan was as fallout of airborne selenium from Chicago polluters.

Collins, A. G., Waters, C. J., and Pearson, C. A., 1964, Methods of analyzing oilfield waters—Selenium and tellurium: *U.S. Bur. Mines Rept. Inv. 6474*, 19 p; abs. in *Chem. Abs.*, v. 61, col. 8099e, 1964.

The chemistry of selenium and tellurium is discussed, along with a method of preparing a synthetic oilfield brine, an oilfield brine sampling method, and methods for determining selenium and tellurium in complex oilfield brines. (Authors' abstract, condensed.)

Crenshaw, G. L., and Lakin, H. W., 1974, A sensitive and rapid method for the determination of trace amounts of selenium in geologic materials: *U.S. Geol. Survey Jour. Research*, v. 2, no. 4, p. 483-487.

A sensitive method for the determination of less than crustal abundance amounts of selenium has been developed that can be useful in the geochemical investigation of selenium. The lower limit that can be determined by this method is 0.04 ppm, using a 0.5 g sample. (Authors' abstract, condensed.)

Davidson, C. F., 1966, Selenium in Witwatersrand bankets: *Inst. Mining and Metallurgy Trans., Earth Sci. Sec.*, v. 75, p. B108.

The selenium contents (15–20 ppm) of pyrite from two localities in the Witwatersrand field are considered not to be too low to be compatible with the derivation of the mineralization from the overlying volcanics. (*Mineralog. Abs.*, v. 18, p. 90, 1967.)

Davidson, D. F., 1960, Selenium in some epithermal deposits of antimony, mercury, and silver and gold: *U.S. Geol. Survey Bull.* 1112–A, 16 p.; abs. in *Chem. Abs.*, v. 55, col. 2370c, 1961.

Epithermal silver and antimony deposits are commonly highly seleniferous, and gold and mercury deposits are only rarely so. Selenium is associated with silver and antimony in ore minerals and is not found in other minerals of the deposits. This relation with ore minerals also occurs in the few gold and mercury deposits that contain selenium. Selenium in silver and antimony deposits may have been liberated from crystallizing magma as a part of the process of crystallization and thus have been made available for deposition with the ore metals. (Author's abstract, condensed.)

———1963, Selenium in some oxidized sandstone-type uranium deposits: *U.S. Geol. Survey Bull.* 1162–C, 33 p.; abs. in *Chem. Abs.*, v. 59, col. 322d, 1963.

Studies of selenium and other trace metals in samples from some oxidized sandstone-type uranium deposits in New Mexico, Oklahoma, Pennsylvania, South Dakota, Texas, and Wyoming demonstrate that concentrations of as much as 0.1 percent selenium are not uncommon in the immediate vicinity of uranium concentrations. The work also has demonstrated that the selenium contents of the uranium ores of these deposits, or of the highly seleniferous material associated with the ores, are not correlatable with the contents of any other constituents of the ores or concentrations for which analyses have been made although many of the metals of the deposits were probably derived from the same source and were concentrated together in the deposits. The lack of relationship of selenium to other constituents of these deposits is undoubtedly a reflection of differential movement and fixation of all constituents during the weathering and oxidation to which the ore deposits have been subjected. (Author's abstract.)

Davidson, D. F., and Granger, H. C., 1965, Selenium and tellurium, in *Mineral and water resources of New Mexico: U.S. Cong., 89th, 1st sess., Senate Comm. Interior and Insular Affairs, Comm. Print* (New Mexico Bur. Mines and Mineral Resources Bull. 87), p. 228–230.

General information on occurrence and use of the two elements.

Davidson, D. F., and Gulbrandsen, R. A., 1957, Selenium in the Phosphoria formation in Idaho, Wyoming, Utah, and Montana [abs.]: *Geol. Soc. America Bull.*, v. 68, no. 12, p. 1714.

The Meade Park phosphatic shale member of the Permian Phosphoria formation in

Idaho, Wyoming, Utah, and Montana contains some of the most seleniferous sedimentary rocks known. Analyses show that the selenium content of the phosphate rock ranges from a few to 300 ppm and of the mudstone from a few to more than 1,500 ppm. (Abs. condensed.)

Davidson, D. F., and Lakin, H. W., 1961, Metal content of some black shales of the western United States, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424-C, p. C329-C331.

Ranges of values for Pb, Mn, Cu, Zn, Ni, U, Mo, Ag, Cr, Fe, and Se in carbonaceous marine shales from six geological formations are presented with mean values in three cases. (Mineralog. Abs., v. 17, p. 588, 1965-1966.)

———1962, Metal content of some black shales of the western conterminous United States—Part 2, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 450-C, p. C74; abs. in Chem. Abs., v. 58, col. 5413b, 1963.

Analyses for selenium are tabulated for nine samples of carbonaceous marine shales from Utah, Nevada, Montana, and Idaho.

Davidson, D. F., and Powers, H. A., 1959, Selenium content of some volcanic rocks from Western United States and Hawaiian Islands: U.S. Geol. Survey Bull. 1084-C, p. C69-C81; abs. in Chem. Abs., v. 54, col. 184i, 1960.

Eighty-one analyses for selenium of volcanic rocks from southern Alaska, the Aleutian Islands, the Hawaiian Islands, and several western states have been made as a part of a study of the geology and geochemistry of selenium. (Authors' abstract, condensed.)

Dunoyer, Jean-Michel, 1948, A transformation of selenium at low temperature [in French]: Acad. Sci. [Paris] Comptes Rendus, v. 226, p. 1524-1525.

Ground vitreous selenium or sublimed selenium powder on cooling below  $-80^{\circ}$  shows a red tint and is distinctly red at the temperature of liquid nitrogen. The original color is restored on warming. The rate of warming shows no anomaly. Powdered gray selenium or larger pieces of vitreous selenium do not show the effect. (Chem. Abs., v. 42, col. 6689b, 1948.)

D'yachkova, I. B., 1962, Selenium in waters from the Ural areas containing pyrite deposits [in Russian], *in* Thachuk, V. G., Reimers, F. E., and Khazanov, E. I., eds., Chetvertaya konferentsiya molodykh nauchnykh sotrudnikov IMGRE, Materialy: Moscow, Inst. Mineralogii, Geokhimii i Kristallokhimii Redkikh Elementov, p. 40-43.

Content of selenium was determined in the natural waters in the Gai pyrite deposit area and in some other areas of the Urals. The largest content of selenium ( $\leq 0.4$  mg/l) was detected in the waters taken directly near ore bodies. An elevated amount of selenium was detected in acid waters, having pH 2.4-3.0, and in weakly alkaline waters with pH 7.4-8.0. Beyond the limits of the deposits the selenium was found only in the acid waters. No selenium was found in natural waters which do not contact the pyrite deposits. This permits one to recommend selenium as a hydrogeochemical indicator of pyrite deposits. (Chem. Abs., v. 63, col. 1581g, 1965.)

- 1965, Experimental study of the oxidation of some selenium and tellurium minerals [in Russian], in Vlasov, K. A., Bezsmertnaya, M. S., and Feklichev, V. G., eds., *Eksperimental'no-metodicheskie issledovaniya rudnykh mineralov*: Moscow, Inst. Mineralogii, Geokhimii i Kristalloghimii Redkikh Elementov, p. 256-267; abs. in Chem. Abs., v. 63, col. 16035d, 1965.

The oxidation experiments were carried out with synthetic altaite (PbTe), clausthalite (PbSe), and seleniferous galena. Oxidation proceeded more readily in alkaline media. In the experiments Te precipitated as oxide compounds and Se formed elemental selenium. The results obtained from the experiments are in good agreement with the form of selenium and tellurium that is found in the oxidation zone of sulfide deposits.

- D'yachkova, I. B., and Khodakovskiy, I. L., 1968, Thermodynamic equilibria in the systems  $S-H_2O$ ,  $Se-H_2O$  and  $Te-H_2O$  in the 25°-300°C temperature range and their geochemical interpretations: *Geokhimiya* 1968, no. 11, p. 1358-1375; translated in *Geochemistry Internat.*, v. 5, p. 1108-1125, 1968; abs. in Chem. Abs., v. 70, item 30901g, 1969.

Eh-pH diagrams of the stability fields of various forms of sulfur, selenium and tellurium were plotted for 25°, 150°, and 300°C. Comparative analysis of the diagrams shows that the separation of sulfur, selenium, and tellurium in processes involving the participation of aqueous solutions may be determined by a change in the oxidation-reduction potential, acidity, and temperature of these solutions. The most significant of these factors is the oxidation-reduction potential of the medium. The maximum separation of sulfur, selenium, and tellurium in hydrothermal processes should be observed under oxidation conditions at low temperatures and weakly alkaline values of the pH. (Authors' abstract.)

- Dzhandzhgava, M. I., 1966, Selenium and tellurium contents of pyrite and the associated melnikovite-pyrite [in Russian]: *Akad. Nauk Gruzin. SSR Soobshch.*, v. 41, no. 3, p. 639-645.

Young pyrite ores formed by the hydrothermal effects of effusive volcanic activity showed some peculiarities in the distributions of selenium and tellurium. Pyrite, the main ore mineral present, was from three distinct generations. X-ray analysis shows that the two earliest pyrites contain submicroscopic inclusions of calaverite. Selenium and tellurium concentrations average three orders higher than in the earth's crust although tellurium was not detected in all samples; when detected, tellurium concentrations were below selenium concentrations. The concentration of selenium in crystal grains of pyrite was 5-6 times higher than in metacolloidal and colloformic pyrites, and selenium was apparently present within the pyrite crystal lattice and not as a separate mineral. (Chem. Abs., v. 65, col. 3564b, 1966.)

- 1966, Selenium and tellurium content in various types of sulfide mineralization in Georgia [U.S.S.R.]: *Geokhimiya* 1966, no. 5, p. 579-585; abs. of translation in *Geochemistry Internat.*, v. 3, p. 452; abs. in Chem. Abs., v. 65, col. 5233e, 1966.

Average selenium and tellurium contents are presented for ores and ore minerals from eight types of deposits. The bulk of the selenium is probably contained in solid solution in galena, chalcopyrite, and sphalerite. In general, low-temperature deposits contain less selenium and tellurium than high temperature ones. (Mineralog. Abs., v. 18, p. 261, 1967.)

- 1968, Correlation of selenium and tellurium with bismuth and thallium in sulfide deposits of the Georgian SSR [in Russian]: Akad. Nauk Gruzin. SSR Soobshch., v. 51, no. 2, p. 357-360.

The bismuth was present almost exclusively in those deposits which contained selenium and tellurium. The barite-polymetallic deposits had insignificant amounts of selenium and tellurium, and no bismuth at all. These elements were absent in lead-zinc low-temperature deposits with widely distributed colloformic mineral aggregates. High concentration of selenium, tellurium, and bismuth are typical of deposits of the same type. The direct correlation in contents of bismuth, selenium, and tellurium and the inverse correlation of thallium, selenium, and tellurium was ascertained for Georgian deposits. (Chem. Abs., v. 70, item 21778v, 1969, condensed.)

- 1968, Selenium and tellurium minerals in sulfide ore of the Georgian SSR [in Russian]: Akad. Nauk Gruzin. SSR Soobshch., v. 51, no. 3, p. 637-640.

Selenium and tellurium are common elements in Georgian sulfide ores, but only a few selenium and tellurium minerals were identified. This situation was attributed to the high affinity of selenium and sulfur; this affinity causes the absence of selenides in sulfide deposits. Where selenides are present, they are not synchronous with sulfides and were formed during the nonsulfide stage of mineralization. Tellurides and possibly selenides are frequently present in the form of submicroscopic segregations. This kind of occurrence probably is a cause of their apparently limited distribution in ore deposits that have relatively high contents of selenium and tellurium. (Chem. Abs., v. 70, item 39698d, 1969, condensed.)

- Efendiev, G. Kh., Novruzov, N. A., and Geidarov, A. S., 1969, Selenium and tellurium distribution in the Filizchai deposit [in Russian], in Sogomonyan, M.S., ed., *Issledovaniya v oblasti neorganicheskoi i fizicheskoi khimii*: Baku, Akad. Nauk Azerbaydzhan. SSR, Inst. Neorganicheskoi i Fizicheskoi Khimii, p. 68-73.

The geochemistry of selenium and tellurium associated with pyrites, sphalerite, chalcopyrites, galena, and magnetite in the Filizchai deposit was studied. The average Se:Te ratio in pyrite is 2:1. Marked differences in the selenium-tellurium content are observed in the massive and disseminated ores. A supergene origin is suggested for the complex mineral assemblages. (Chem. Abs., v. 73, item 57967g, 1970.)

- Egel, L.E., 1962, Exogene deposits of selenium [in Russian]: *Geologiya Mestorozhd. Redkikh Elementov*, no. 11, p. 5-18.

The selenium content in sedimentary rocks is 0.3-0.6 ppm and in igneous rocks is 0.06 ppm. Soluble selenium compounds can exist as selenites and selenates only in high oxidation media because selenic acid is a very strong oxidizing agent. Natural selenium and secondary selenides are the most stable forms under natural conditions. More soluble sulfates migrate farther than the less soluble selenates. In the supergene processes, the accumulation of selenium occurs by concentration of selenium in situ through removal of other elements and by dissolution and transport of selenium in highly alkaline solutions and by its precipitation in the form of natural selenium and selenides at Eh 0.5-0.2 and pH 3-7.5. (Chem. Abs., v. 57, col. 16182g, 1962, condensed.)

- Faiziev, A. R., and Dusmatov, V. D., 1971, Characteristics of galena from central Tadzhikistan [in Russian with English summary]: *Mineralog. Sbornik*, no. 25, pt. 2, p. 164-169; abs. in Chem. Abs., v. 77, item 22800c, 1972.



Hydrothermal deposits contain copper and iron, contact-metasomatic deposits contain bismuth, selenium, and tellurium, and pegmatitic deposits are enriched in tellurium and bismuth. Silver is found in all three genetic types.

Faramazyan, A. S., and Zar'yan, R. N., 1964, Geochemistry of selenium and tellurium in the ores of the Kadzharan deposit: *Geokhimiya* 1964, no. 11, p. 1164-1170; abs. of translation in *Geochemistry Internat.*, v. 1, p. 1103-1105; abs. in *Chem. Abs.*, v. 62, col. 3817f, 1965.

The contents of selenium and tellurium in the ore minerals of various stages are summarized in table form. Selenium occurs only in solid solution with the largest amounts in molybdenite. The ease of migration in the oxidized zone decreases in the series S-Se-Te. (*Mineralog. Abs.*, v. 17, p. 751, 1965-1966, condensed.)

Filimonova, L. E., 1972, Selenium and tellurium in the Boshchekul' copper-molybdenum deposit: *Geokhimiya* 1972, no. 2, p. 241-246; translated in *Geochemistry Internat.*, v. 9, p. 151-156.

Results of quantitative estimation of sulfur, selenium, and tellurium in different rock-types and of selenium and tellurium in ore minerals of the pneumatolytic-hydrothermal and hydrothermal stages are presented. The presence of tellurides and the absence of selenium minerals, the relatively uniform distribution of selenium in various minerals, and the unequal tellurium content in ores indicate the isomorphous entry of selenium in the lattice of sulfides. (*Chem. Abs.*, v. 76, item 115984k, 1972, condensed.)

Finkel'shtein, Yu. V., 1971, Selenium content of the western part of the southern Tien-Shan mercury belt and find of tiemannite in Kyzylkum [in Russian]: *Vses. Mineralog. Obshch., Zapiski*, v. 100, no. 1, p. 93-95; abs. in *Chem. Abs.*, v. 74, item 114510z, 1971.

All samples of cinnabar from the Tien-Shan belt contain selenium in amounts ranging from 0.001 to 1.48 percent. Thin sections of cinnabar from the Karasu deposit revealed inclusions of native selenium and tiemannite.

Finkel'shtein, Yu. V., and Nikolayeva, E. P., 1969, The hardness of cinnabar [in Russian]: *Vses. Mineralog. Obshch., Zapiski*, v. 98, no. 2, p. 224-227; abs. in *Chem. Abs.*, v. 71, item 62902v, 1969.

The Karasu cinnabar had varying amounts of selenium, and small inclusions of native selenium and tiemannite were detected in some thin sections. The high content of selenium but very small number of inclusions in cinnabar suggests that selenium replaced sulfur isomorphically.

Franz, Ernst-Dieter, 1972, X-ray diffraction data on mixed phases in the pyrite ( $\text{FeS}_2$ )-ferroselite ( $\text{FeSe}_2$ )/pyrrhotite ( $\text{FeS}$ )-achavalite ( $\text{FeSe}$ ) system [in German]: *Neues Jahrb. Mineralogie Monatsh.*, p. 276-280; abs. in *Mineralog. Abs.*, v. 24, item 73-377, 1973; and *Chem. Abs.*, v. 77, item 80536g, 1972.

In the system pyrite-ferroselite, the following crystalline phases occur in the temperature range of 220°-800°: pyrite and Se-bearing pyrite, ferroselite and S-bearing ferroselite, and also a continuous series of mixed crystals between pyrrhotite and achavalite. (Author's abstract.)

Garmash, A. A., and Kurbanova, N. Z., 1963, Selenium and tellurium in ores of the Zolotushinsk deposit [in Russian]: Akad. Nauk SSSR, Inst. Mineralogii, Geokhimii i Kristalloghimii Redkikh Elementov, Trudy, no. 10, p. 136-157.

The formation of the Zolotushinsk Pb-Cu-Zn sulfide ores occurred from a single hydrothermal solution that changed spatially and with time. Several paragenetic associations of minerals were separated. They formed in three stages of mineralization: pyritic, copper, and polymetallic. A distinct decrease in the temperature and activity of the solutions, an increase in the number of components, and a sharp increase of the oxidation potential of the medium were observed in the final ore stage. Prior to the crystallization of galena, the selenium and tellurium concentrated in chalcopyrite and pyrite. A redistribution of selenium and tellurium occurred, and most of the selenium and tellurium concentrated in the galena. The galena crystallized under conditions of the hypogene oxidation. (Chem. Abs., v. 61, col. 2841a, 1964, condensed.)

Geering, H. R., Cary, E. E., Jones, L. P. H., and Allaway, W. H., 1968, Solubility and redox criteria for the possible forms of selenium in soils: Soil Sci. Soc. America Proc., v. 32, no. 1, p. 35-40; abs. in Chem. Abs., v. 68, item 97587m, 1968.

The solubility of selenium in seven soils indicate that Se concentration in solution is governed primarily by a ferric oxide-selenite-adsorption complex (Se oxidation state +4). However, under certain conditions Se may also exist in the oxidation states +6, 0, and -2. The proportions of Se in the four oxidation states are treated theoretically as they are affected by the redox potential, soil pH, and ions with which Se combines. (Authors' abstract.)

Goleva, G. A., and Lushnikov, V. V., 1967, Occurrence of selenium in the ground waters of ore deposits and in some types of mineral waters: Geokhimiya 1967, no. 4, p. 438-445; translated in Geochemistry Internat., v. 4, p. 378-385; abs. in Chem. Abs., v. 67, item 24011p, 1967.

Mechanisms by which selenium migrates in various types of natural waters and the characteristics of its spreading in waters to form aureoles around chalcopyrite, polymetallic, molybdenum, mercury, and gold ore deposits are considered. (Mineralog. Abs., v. 20, item 69-434, 1969.)

Goleva, G. A., Vorob'eva, I. N., and Lushnikov, V. V., 1965, Geochemical characteristics of selenium and germanium migration in halo waters of blind sulfide mineralization [in Russian], in Udodov, P. A., and others, eds, Trudy mezhvuzovskoi konferentsiy po gidrogeokhimicheskim i paleogidrogeologicheskim metodam issledovaniy v tselyakh poiskov mestorozhdeniy poleznykh iskopayemykh: Tomsk, U.S.S.R., p. 11-17 [1969]; abs. in Chem. Abs., v. 74, item 44218j, 1971.

The highest selenium content (300  $\mu\text{g/l}$ ) was detected in strongly acid sulfate waters. The halo waters of the chalcopyrite deposits contained about 50  $\mu\text{g Se/l}$ .

Granger, H. C., 1966, Ferroselite in a roll-type uranium deposit, Powder River basin, Wyoming, in Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550-C, p. C133-C137; abs. in Mineralog. Abs., v. 20, item 69-1779, 1969; and Chem. Abs., v. 66, item 4795f, 1967.

Delicate stellate penetration twins of ferroselite occur in sandstone on the concave

side of a roll-type uranium ore body in the Powder River basin, Wyoming. Comparison with occurrences in the Ambrosia Lake uranium district, New Mexico, suggests that the margins of altered rock may contain selenium concentrations irrespective of the presence of uranium. (Author's abstract.)

Gulbrandsen, R. A., 1954, Selenium in the phosphatic members of the Phosphoria formation: U.S. Geol. Survey TEI Rept. 440, p. 147-148.

Analyses for selenium were made on 118 samples of phosphatic and nonphosphatic rock from the phosphatic members of the Phosphoria formation. Selenium content of samples ranged from about 1 ppm to 300 ppm and averaged about 45 ppm. Generally samples of very high phosphate content contained less selenium than those very low in phosphate.

Hackney, E. J., 1953, Note on the determination of selenium in rocks which contain organic matter: U.S. Geol. Survey TEI Rept. 330, p. 235.

A method was found to easily remove organic matter from rock samples that are to be analyzed for selenium.

Halbig, J. B., 1970, Trace element studies in synthetic sulfide systems—The solubility of thallium in sphalerite and the partition of selenium between sphalerite and galena [abs.]: Dissert. Abs. Internat., Sec. B, Sci. and Eng., v. 30, no. 7, p. 3240-B

The studies indicate that the solubility of thallium in sphalerite and galena is not a satisfactory geothermometer. The partitioning of selenium between sphalerite and galena, though dependent on temperature and pressure, seems variable because of nonideal behavior of selenium in these solid solutions. A pressure estimate may be required for the practical use of selenium partitioning in determining the temperature of formation of sphalerite and galena.

Hamada, Shuichi, Sato, Ryuji, and Shirai, Toshiaki, 1968, Distribution of some minor elements in sulfide ores from the Hitachi mine, Ibaraki prefecture, Japan: Chem. Soc. Japan Bull., v. 41, no. 4, p. 850-854.

The selenium content in 46 samples varied from 0.5 to 117 ppm and seemed to be concentrated in the ores rich in chalcopyrite and pyrite. The average value of the atomic ratio of Se:S in the pyrite ores was calculated to be  $3.48 \times 10^{-5}$ . Selenium is apparently concentrated in the pyrite ores of the high-temperature type rather than in those of the low-temperature type. A large content of mercury was observed at the depth where the values of the atomic ratios of Se:S and Co:Ni were at their maximum. (Chem. Abs., v. 69, item 12145p, 1968, condensed.)

Harshman, E. N., 1966, Genetic implications of some elements associated with uranium deposits, Shirley basin, Wyoming, in Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550-C, p. C167-C173; abs. in Mineralog. Abs., v. 20, item 69-1269, 1969; and Chem. Abs., v. 66, item 4821f, 1967.

A systematic distribution of uranium, selenium, ferrous and ferric iron, carbon, beryllium, and sulfate sulfur is shown by analytical data derived from samples of unaltered sandstone, ore, and altered sandstone from a roll-type uranium deposit in the lower Eocene Wind River Formation of the Shirley basin. Transportation of uranium and other elements in a neutral to slightly alkaline oxidizing solution and

deposition by changes in the Eh and pH of that solution are suggested by the geochemistry of these elements at low temperatures and pressures. (Author's abstract.)

Hawley, J. E., and Nichol, Ian, 1959, Selenium in some Canadian sulfides: *Econ. Geology*, v. 54, no. 4, p. 608-628; abs. in *Chem. Abs.*, v. 54, col. 15093h, 1960.

Determinations of selenium contents were made by X-ray spectrography on pyrite, pyrrhotite, pentlandite, and chalcopyrite from a variety of Canadian ores. Richest selenium concentrations (several hundred to 1,000 ppm) were found in some of the Precambrian nonnickeliferous copper ores.

Heavens, O. S., and Griffiths, C. H., 1965, The epitaxial growth of selenium: *Acta Cryst.*, v. 18, p. 532-536; abs. in *Chem. Abs.*, v. 62, col. 11219b, 1965.

A study of epitaxial growth of selenium on certain faces of NaCl, KBr, BaF<sub>2</sub>, CaF<sub>2</sub>, and MgO.

Hingston, F. J., Posner, A. M., and Quirk, J. P., 1968, Adsorption of selenite by goethite, in Gould, R. F., ed., *Adsorption from aqueous solution*: Washington, D.C., Am. Chem. Soc. Pub., Adv. Chemistry Ser., v. 79, p. 82-90.

Specific adsorption of selenite on goethite increases the pH of the suspension and the negative charge on the oxide surface.

Howard, J. H., III, 1969, Geochemistry of selenium in earth-surface environments, in *Abstracts for 1968*: Geol. Soc. America Spec. Paper 121, p. 446.

Selenium geochemical behavior, from the weathering of seleniferous pyrite to its incorporation in sedimentary pyrite, was investigated.

———1969, Selenium in the Upper Cretaceous Niobrara Formation and Pierre Shale of south-central Colorado, in *Abstracts for 1968*: Geol. Soc. America Spec. Paper 121, p. 606.

The stratigraphic variation of selenium content (5-20 ppm) corresponds with the lithologic subdivisions of the Smoky Hill Shale Member of the Niobrara Formation and Pierre Shale at Pueblo. Possible causes of the variations are given.

———1970, Geochemical behavior of selenium in earth-surface environments [abs.]: *Dissert. Abs. Internat.*, Sec. B, Sci. and Eng., v. 30, no. 12, pt. 1, p. 5554B-5555B.

Selenium contents of sedimentary rocks and weathering products of south-central Colorado were determined. The Upper Cretaceous Niobrara Formation and the Pierre Shale are the most highly seleniferous formations in Colorado. Most selenium is adsorbed on hydrous ferric oxides or occurs in the elemental state in the weathered samples. In unweathered shales selenium is within diagenetic pyrite.

———1971, Control of geochemical behavior of selenium in natural waters by adsorption on hydrous ferric oxides, in Hemphill, D. D., ed., *Trace substances in environmental health V*, Columbia, Univ. Missouri, p. 485-495, 1972; abs. in *Chem. Abs.*, v. 77, item 38995f, 1972.

Hydrous ferric oxide, the most effective adsorber of selenium, will adsorb as much as

90-97 percent of the selenium from natural water at pH 7-8.

- 1973, Sources of selenium in sediments of western Great Plains; Late Cretaceous volcanic centers of west-central Montana: *Geol. Soc. America Abs. with Programs*, v. 5, no. 6, p. 485.

The Smoky Hill Shale Member of the Niobrara Formation and the lower members of the Pierre Shale are the most highly seleniferous of the Upper Cretaceous formations in south-central Colorado. The more clastic units, which include abundant volcanic materials, have the higher selenium contents.

- Inin, V. D., 1966, Accessory elements in ores of the Nikolaev copper-zinc deposits of the Altai (bismuth, selenium, tellurium) [in Russian]: *Akad. Nauk Kazakh. SSR, Inst. Geol. Nauk, Trudy*, v. 77, p. 110-124.

High contents of bismuth, selenium, and tellurium were related spatially to the part of the deposit having elevated concentrations of sulfur and copper; the content of bismuth, selenium, and tellurium was higher in genetically earlier ores than in their late varieties. Pyrite and chalcopyrite were the main mineral concentrators of bismuth, selenium, and tellurium in ores of the Nikolaevsk deposit. (*Chem. Abs.*, v. 66, item 78284c, 1967, condensed.)

- Ismailov, M. I., 1964, Distribution of selenium and tellurium in the sulfides of the tungsten-molybdenum deposits of the Zirabulak and Nuratinsk Mts.: *Geokhimiya* 1964, no. 10, p. 1067-1069; translated in *Geochemistry Internat.*, v. 1, p. 1014-1016; abs. in *Chem. Abs.*, v. 61, col. 15850c, 1964.

Selenium and tellurium contents of intermediate hydrothermal sulfides and of early hydrothermal sulfides were determined for the Nuratinsk tungsten-molybdenum deposits and the Zirabulak tungsten ores. Highest concentrations of these elements were found in sphalerite, molybdenite, and pyrrhotite. (*Mineralog. Abs.*, v. 17, p. 583, 1965-1966.)

- Ivanov, V. V., Belevitin, V. V., Panfilov, R. V., and others, 1970, Geochemical-statistical parameters for estimating prospects for ore deposits of rhenium, bismuth, germanium, idium, selenium, tellurium, platinum and palladium [in Russian]: *Geokhim. Issled.*, no. 1, p. 62-69.

Statistical parameters (arithmetic mean, standard deviation) of selenium in pyrite, galena, and other elements in the ores are presented.

- Jung, Wolfgang, Knitzschke, G., and Gerlach, R., 1973, The selenium content in the Kupferschiefer of the southeastern foreland of the Harz Mountains [in German]: *Zeitschr. Angew. Geologie*, v. 19, no. 2, p. 57-67; abs. in *Chem. Abs.*, v. 79, item 68864w, 1973.

The distribution of selenium and its relation to other metals in the deposit are discussed.

- Kahrkar, D. P., Turekian, K. K., and Bertine, K. K., 1968, Stream supply of dissolved silver, molybdenum, antimony, selenium, chromium, cobalt, rubidium and cesium to the oceans: *Geochim. et Cosmochim. Acta*, v. 32, p. 285-298; abs. in *Mineralog. Abs.*, v. 19, p. 204, 1968.

Analyses for selenium and other elements were made of waters from the Amazon, Rhone, and 10 rivers in the United States.

Kanasiewicz, Jerzy, 1966, Geochemical distribution of uranium, selenium and rhenium in the Zechstein layer of Leszczyn deposits [in Polish with English summary]: *Kwart. Geologiczny*, v. 10, no. 2, p. 309-313; abs. in *Chem. Abs.*, v. 69, item 79288f, 1968.

The highest concentrations of uranium, selenium, and rhenium occur in the Lower Zechstein beds. The average content of uranium is 11.3, of selenium 2.31, and of rhenium 1.06 ppm.

Karamyan, K. A., 1962, Correlation between rhenium, selenium and tellurium in the molybdenites of the Kadzharan copper-molybdenum deposit: *Geokhimiya* 1962, no. 2, p. 171-174; translated in *Geochemistry* 1962, no. 2, p. 194-198; abs. in *Chem. Abs.*, v. 57, col. 14741f, 1962.

One hundred seven samples of molybdenite averaged 0.043 percent Re, 0.0335 percent Se, and 0.0033 percent Te. Selenium and tellurium concentrations increase as the rhenium content increases; the selenium increases more rapidly than the tellurium.

Kashirtseva, M. F., 1970, Methods of study of epigenetic alteration of clastic sedimentary rocks; mineralogical-geochemical investigations of molybdenum-selenium-uranium infiltrational deposits [in Russian]: Moscow, Nedra, 1953 p.

A study of mineralization in oxidized zones, introduction of ore elements by infiltration of ground waters, zoning, mineral formation, and genetic relationships.

Kashirtseva, M. F., and Sidel'nikova, V. D., 1971, Selenium, uranium, molybdenum in oxogenous roll-type orebodies, in Tugarinov, A. I., ed., *Internat. Geochemical Cong.*, Moscow 1971, Abs. of Repts., v. 2, p. 890-891.

Roll-type orebodies are formed at a geochemical barrier where the migrating ability of elements is changed. The difference in the migrating ability of elements at the reducing barrier is expressed by zoning. The highest amounts of uranium and molybdenum are concentrated in unoxidized rocks at their contact with oxidized rocks. Selenium is concentrated mainly in the oxidized rocks at the pinching out of the zone of stratal oxidation. Selenium is also concentrated in the unoxidized rocks at their contact with oxidized rocks, overlapping the uranium mineralization and sometimes extending beyond it.

———1973, Distribution of selenium, uranium and molybdenum during infiltration mineralization [in Russian]: *Geologiya Rudn. Mestorozhd.*, v. 15, no. 3, p. 82-92.

The epigenetic infiltration ore deposits are confined to the uplift limbs of artesian basins in the peripheral parts of activated platforms. The ore deposits are formed due to the infiltration of waters through water-permeable arenaceous formations. Ore deposits enriched in uranium and molybdenum are formed along the flow of subsurface waters. Low-grade ores develop along the stratal oxidation zone. Selenium ore mineralization is concentrated in the oxidized rocks of the wedging out zone. The permeable rocks exhibit a distinct zoning: Se (internal)-U (intermediate)-Mo (external zone). Selenium is precipitated from stratal waters in limonitized rocks. The post-ore reducing processes are followed by the deposition of pyrite and iron oxides. (*Chem. Abs.*, v. 80, item 5729f, 1974.)

Kashkay, M. A., Novoruzov, N. A., and Geydarov, A. S., 1969, Geochemistry of rare elements of the Filizchaiskiy deposit: *Geokhimiya* 1969, no. 9, p. 1092–1102; translated in *Geochemistry Internat.*, v. 6, no. 5, p. 1009–1010; abs. in *Chem. Abs.*, v. 71, item 104070e, 1969.

The concentration of selenium is associated with sulfur-pyrite mineralization.

Kholodov, V. N., 1966, Uranium-selenium-vanadium-rhenium deposits [in Russian], in Vlasov, K. A., ed., *Geokhimiya, mineralogiya i geneticheskie tipy mestorozhdeniy redkikh elementov*: Moscow, Nauka, v. 3, p. 755–775, 850–852; translated by Israel Program for Scientific Translations, Jerusalem, 916 p., 1968, abs. in *Chem. Abs.*, v. 68, item 4792m, 1968.

A review is given of sedimentary uranium deposits and their genetic association with concentrations of rare elements including selenium. Detailed descriptions of the uranium-selenium-vanadium-rhenium mineralizations in the Colorado Plateau are included.

Kieft, C., and Oen, I. S., 1973, Ore minerals in the telluride-bearing gold-silver ores of Salida, Indonesia, with special reference to the distribution of selenium: *Mineralium Deposita*, v. 8, no. 4, p. 312–320.

In the telluride-bearing ores, paragenetic relations suggest that galena, altaite, hessite, and  $\chi$ -phase and  $\gamma$ -phase solid solutions originally crystallized at temperatures over 120°; on cooling, this assemblage, which equilibrated into one stable phase below 50°, contained galena, altaite, hessite, hessite-sylvanite intergrowths, and hessite-petzite aggregates. Selenium is concentrated in sulfides of the intermediate diffusion zones. (*Chem. Abs.*, v. 80, item 72714k, 1974, condensed.)

Kirsten, T., and Müller, H. W., 1969, Observation of selenium-82 double-beta decay in selenium ores: *Earth and Planetary Sci. Letters*, v. 6, no. 4, p. 271–274.

The isotopic composition of krypton extracted from six different selenium ores gives clear evidence for the double-beta decay of selenium-82. The preliminary half-life of selenium-82, calculated from one sample, is  $1.4 \times 10^{20}$  years, with an error of about 20 percent. (*Chem. Abs.*, v. 71, item 97055y, 1969.)

Klayman, D. L., and Gunther, W. H. H., eds., 1973, The chemistry of organometallic compounds, a series of monographs—Organic selenium compounds, their chemistry and biology: New York, Wiley-Interscience, 1,188 p.

The book discusses selenium and its organic derivatives; topics include physiochemical properties of organoselenium molecules, analytical methods, and the biology of selenium.

Koljonen, Tapio, 1973, Selenium in certain sedimentary rocks: *Geol. Soc. Finland Bull.*, v. 45, pt. 2, p. 119–123.

Selenium contents of some low-metamorphic sedimentary rock groups were studied. The highest selenium contents are found in clayey sediments and sediments containing organic residues. Tentative average calculated selenium content in sandstone and evaporites is <10 ppb, in shale 500 ppb, and in limestone 30 ppb. In shales, the geochemistry of selenium is similar to that of uranium and of vanadium in exogenic

processes. Sediments containing carbonates are neutral or slightly acidic. Organic compounds that may be enriched in selenium are disintegrated and oxidized by the high calcium content, and selenium is freed in oxidized form and migrates with solution, so rocks formed from sands and evaporites are nearly devoid of selenium. (Chem. Abs., v. 81, item 52669s, 1974.)

———1973, Selenium in certain metamorphic rocks: *Geol. Soc. Finland Bull.*, v. 45, pt. 2, p. 107–117; abs. in *Chem. Abs.*, v. 81, item 52668r, 1974.

The selenium contents of Precambrian metamorphic rocks from Finland were studied. Selenium probably does not enter into the structures of the common silicate minerals, but rather is incorporated in the accessory sulfide phase. The distribution resembles that found in the sediments; the highest contents are found in mica schists, in phyllites, and especially in sulfide-bearing black schists—all metamorphosed clays. In exogenic processes, selenides are oxidized to elemental selenium, which, being colloidal, is electrically charged and adsorbed by clay minerals. Selenium contents are low in silicon-rich rocks and rocks derived from calcium- and magnesium-rich carbonate sediments. (Author's abstract, condensed.)

———1973, Selenium in certain igneous rocks: *Geol. Soc. Finland Bull.*, v. 45, pt. 1, p. 9–22; abs. in *Chem. Abs.*, v. 80, item 50698f, 1974.

The selenium content of the igneous rocks studied shows a tendency to decrease when passing from a basic to a more siliceous rock. Selenium probably does not enter the structures of the rock-forming minerals, but it is contained in the sulfide phase, and the distribution of selenium reflects the abundance of the sulfide phase in the rocks. (Author's abstract, condensed.)

Kovalenker, V. A., Gladyshev, G. D., and Nosik, L. P., 1974, Isotope composition of sulfur from sulfides of the Talnakh ore field and the selenium content of the sulfides [in Russian]: *Akad. Nauk SSSR, Izv., Ser. Geol.*, no. 2, p. 80–91.

The degree of enrichment of  $^{34}\text{S}$  in sulfides of the title ore deposits is similar to other copper-nickel ore deposits in the Noril'sk region. Variations in the  $\delta^{34}\text{S}$  value indicate that most of the isotopes were derived by the assimilation of crustal sulfur. The absence of any significant variations in the isotope composition of sulfur from sulfides of diverse mineralogy confirms a single source of sulfur. The zonal distribution of  $\delta^{34}\text{S}$  is discussed in relation to the depth of ore localization. An inverse correlation exists between sulfur and selenium. Sulfides having a high concentration of  $^{34}\text{S}$  are characterized by a low selenium content. (Chem. Abs., v. 81, item 52416g, 1974.)

Kovalenker, V. A., Laputina, I. P., and Vyal'sov, L. N., 1971, First find of minerals of galena-clausthalite series in copper-nickel sulfide ores [in Russian]: *Geologiya Rudn. Mestorozhd.*, v. 13, no. 2, p. 98–101.

The isomorphous galena( $\text{PbS}$ )-clausthalite( $\text{PbSe}$ ) solid solution series obeys Vegard's law. Minerals of the galena-clausthalite series are reported from the exocontact rocks of the nickel-bearing differentiated Talnakh intrusion, with selenium content  $\leq 16.5$  percent. Paragenetic assemblages suggest that the galena-clausthalite series of minerals was formed from postcrystallization residual solutions. (Chem. Abs., v. 75, item 23735f, 1971, condensed.)

Koval'skiy, V. V., and Yermakov, V. V., 1967, Biogeochemical seleniferous province of



Tuva: Geokhimiya 1967, no. 1, p. 86-97; translated in *Geochemistry Internat.*, v. 4, p. 57; abs. in *Chem. Abs.*, v. 66, item 57928a, 1967.

Content, distribution, and some of the characteristics of behavior of selenium in rocks, soils, waters, plants, and animals have been investigated. A biogeochemical seleniferous province, with high selenium content in rocks, soils, and plants, has been mapped in Tuva. Biological reactions of organisms to excess selenium have been observed and described. (*Mineralog. Abs.*, v. 19, p. 206, 1968.)

Kropacheva, S. K., and Vasilevskaya, A. E., 1973, Selenium in sulfate rocks of sedimentary sulfur deposits: *Geokhimiya* 1973, no. 1, p. 143-146; translated in *Geochemistry Internat.*, v. 10, no. 1, p. 107-110.

Given is the selenium content in samples of gypsums and anhydrites, taken primarily from sulfate horizons of sedimentary sulfur deposits, and in some samples of sulfates not associated with sulfuricity. In all ancient and secondary sulfate samples that were studied, the selenium was found to be  $(1-6.4) \times 10^{-6}$  percent. In the Sivash gypsum samples, the selenium content was  $5 \times 10^{-6}$  to  $2.3 \times 10^{-5}$  percent. (*Chem. Abs.*, v. 78, item 126926k, 1973.)

Krouse, H. R., and Thode, H. G., 1962, Thermodynamic properties and geochemistry of isotopic compounds of selenium: *Canadian Jour. Chemistry*, v. 40, no. 2, p. 367-375.

The selenium-76/selenium-82 ratio was studied to determine the extent to which it might be altered in natural and lab processes. The ratio for 16 natural samples was compared. Variations in this ratio and a kinetic isotope effect found in the reduction of the selenite ion to elemental selenium are discussed. Results are compared with similar results from sulfur isotope studies. (*Chem. Abs.*, v. 56, col. 12588b, 1962, condensed.)

Kulikova, M. F., 1966, Selenium and tellurium distribution patterns in the oxidation zone of lead-zinc ore deposits in Central Asia: *Geokhimiya* 1966, no. 4, p. 423-429; translated in *Geochemistry Internat.*, v. 3, p. 322-328.

Although both selenium and tellurium contents are low (0.000n percent) in the oxidized ores, tellurium concentrations in iron hydroxides may be up to 10 times those of selenium. The greater accumulation of tellurium in the oxidation zone is ascribed primarily to its preferential precipitation by iron hydroxides in the slightly alkaline (pH 6.8-7 to 8-8.5) environment of the deposits. (*Mineralog. Abs.*, v. 18, p. 261, 1967, condensed.)

———1971, Structure of the oxidized zone at the Nikolayevsk copper sulfide deposit and the distribution of elements in it: *Geokhimiya* 1971, no. 5, p. 578-587; translated in *Geochemistry Internat.*, v. 8, p. 358-366; abs. in *Chem. Abs.*, v. 75, item 66161h, 1971.

The oxidized zone exhibits vertical zonation. Each zone—gossan, leached zone, and the zone of secondary enrichment is characterized by a sequence of mineral assemblages. Ore-forming elements and most trace elements migrate readily in the strongly acid environment of the oxidized zone, and some of them become fixed in particular mineral assemblages. The distribution of these elements in the oxidized zone is not uniform. Gossan and the leached zone are strongly impoverished in the

elements compared with the primary ores; the zone of secondary enrichment, carrying the highest copper concentrations, is enriched in both ore-forming and trace elements. (Author's abstract.)

Kullerud, G., and Donnay, G., 1958, Natural and synthetic ferroselite, a roentgenographic mimesis of rammelsbergite: *Geochim. et Cosmochim. Acta*, v. 15, p. 73-79; abs. in *Chem. Abs.*, v. 53, col. 5982f, 1959.

Iron diselenide ( $\text{FeSe}_2$ ) has been synthesized in sealed, evacuated silica-glass tubes at temperatures between  $450^\circ$  and  $550^\circ$  C. Its powder pattern is identical with that of ferroselite described by Buryanova and Komkov (1955). The first 15 lines of the pattern are indistinguishable from those of rammelsbergite ( $\text{NiAs}_2$ ). Single crystals of ferroselite from Temple Mountain, Utah, were studied on the precession camera. Their diffraction patterns were also deceptively similar to those of rammelsbergite. (Authors' abstract.)

Kurbanov, A. S., 1972, Distribution characteristics of selenium and tellurium in the skarn-ore deposits of Rabindzhan (western Uzbekistan) [in Russian]: *Akad. Nauk Uzbek. SSR, Zapiski Uzbekistan. Otdel. Vses. Mineral. Obshch.*, no. 25, p. 191-192; abs. in *Chem. Abs.*, v. 78, item 32561k, 1973.

Most of the selenium and tellurium was found concentrated in copper sulfides—14-19 ppm selenium and 80-600 ppm tellurium.

Kvacek, Milan, and Trdlicka, Zdenk, 1970, Rhenium and selenium contents of Bohemian molybdenites [in German]: *Acta Univ. Carolinae Geol.*, v. 2, p. 105-111; abs. in *Mineralog. Abs.*, v. 24, item 73-762, 1973.

The rhenium and selenium contents of some molybdenite samples from Bohemia vary between  $<0.00008$  and  $0.143$  and between  $0.0066$  and  $0.030$  percent, respectively. The rhenium content increases with the decrease of the formation temperature. Rhenium and selenium occur as isomorphous substitution for molybdenum and sulfur, respectively, in the molybdenite. (*Chem. Abs.*, v. 75, item 120237c, 1971.)

Lakin, H. W., 1961, Geochemistry of selenium in relation to agriculture, in *Selenium in agriculture: U.S. Dept. Agriculture, Agriculture Handb.* 200, p. 3-12.

This report contains information on the source of selenium in sedimentary rocks, its association with sulfur and sulfides, and its transportation. The behavior of selenium in various environments is also discussed.

———1961, Vertical and lateral distribution of selenium in sedimentary rocks of Western United States, in *Selenium in agriculture: U.S. Dept. Agriculture, Agriculture Handb.* 200, p. 12-24.

The selenium content of many samples of sedimentary rocks in the Western United States is presented. The content differs widely, ranging from less than  $0.02$  ppm to more than  $1,500$  ppm.

———1972, Selenium accumulation in soils and its absorption by plants and animals: *Geol. Soc. America Bull.*, v. 83, no. 1, p. 181-189.

Soils producing crop plants that are toxic because of selenium are confined to

semiarid regions or areas of impeded drainage. Environmental contamination with selenium is increasing but will probably stay below a hazardous concentration although mining and industrial wastes may produce minor hazards. (Author's abstract, condensed.)

Lakin, H. W., and Davidson, D. F., 1966, The relation of the geochemistry of selenium to its occurrence in soils, in Muth, O. H., ed., *Selenium in biomedicine—Internat. Symposium*, 1st, Oregon State Univ. 1966: Westport, Conn., AVI, p. 27–56 [1967].

A review of selenium transformations through the geochemical cycle from rock to coal, rock, water, and soil is presented, including 78 references.

———1973, *Selenium*, in Brobst, D. A., and Pratt, W. P., eds., *United States mineral resources*: U.S. Geol. Survey Prof. Paper 820, p. 573–576.

A review of the uses, geochemistry, and resources of selenium is given. The possibility of a future shortage is noted. When the method of copper refining is changed from electrolysis to leaching, the supply of selenium will decrease; if at the same time the demand is increased for selenium as a soil additive to prevent selenium deficiency in animals and man, a shortage may develop.

Lakin, H. W., and Trites, A. R., Jr., 1956, The behavior of selenium in the zone of oxidation: *Internat. Geol. Cong.*, 20th, Mexico 1956, *Symposium de exploración geoquímica*, v. 1, p. 113–124, 1958; abs. in *Chem. Abs.*, v. 55, col. 8195b, 1961.

The selenium released during the oxidation of seleniferous sulfide minerals is in a less mobile form than the sulfur and tends to be concentrated in the oxidized zone. Studies of some of the seleniferous pyrite-bearing sandstone-type uranium deposits in Wyoming have shown that secondary selenium minerals are concentrated either in mantles overlying the unoxidized ore bodies or in halos enclosing these bodies. (Authors' abstract.)

Lansche, A. M., 1967, *Selenium and tellurium, a materials survey, with a chapter on Resources*, by D. F. Davidson: U.S. Bur. Mines Inf. Circ. 8340, 56 p.; abs. in *Chem. Abs.*, v. 68, item 70688h, 1968.

The properties, uses, history, resources, production, supply, and distribution of selenium and tellurium are presented.

Litsitsin, A. K., 1969, The conditions of precipitation of molybdenum and selenium in exogenic epigenic uranium deposits: *Litologiya i Polezn. Iskop.* 1969, no. 5, p. 27–35; translated in *Lithology and Mineral Resources* 1969, no. 5, p. 541–548; abs. in *Chem. Abs.*, v. 72, item 69163j, 1970.

The conditions of accumulation of molybdenum and selenium in exogenous epigenic uranium deposits are established from a comparison of analyses of the uranium, molybdenum, and selenium contents of subsurface waters with measured Eh and pH values and redox equilibria of the forms of migration of these elements in solution. (Author's abstract.)

Litvinovich, A. N., and Bespaev, Kh. A., 1971, *Selenium and tellurium in primary ores from complex metal ore deposits of Rudnyi Altai [in Russian]*: *Akad. Nauk Kazakh. SSR Izv., Ser. Geol.*, v. 28, no. 4, p. 6–21.

Selenium and tellurium are two of the characteristic accessory elements of complex metal ore deposits of Rudnyi Altai. Their distribution in the ores and their forms of occurrence are given. (Chem. Abs., v. 75, item 142981t, 1971, condensed.)

Loftus-Hills, G. D., Groves, D. I., and Solomon, M., 1969, The selenium content of some Tasmanian sulfides: Australasian Inst. Mining and Metallurgy Proc., no. 232, p. 55-65; abs. in Chem. Abs., v. 72, item 69302d, 1970; and Mineralog. Abs., v. 24, item 73-3764, 1973.

Sedimentary pyrites from Tasmania have high selenium contents for a province that shows no overall selenium enrichment. The high concentrations of selenium at Mount Lyell are consistent with enrichment in pyritic copper deposits in volcanic rocks elsewhere, and the dispersion of selenium is consistent with a surface volcanic origin for several of the orebodies. In contrast, sulfides from Cambrian volcanic rocks and associated granitic rocks and from the Roseberry and Hercules pyritic lead-zinc deposits, also believed to be of volcanic origin, are impoverished in selenium. The selenium content of Tasmanian sulfides seems to be an unsatisfactory discriminant of their genesis and temperature of formation. (Authors' abstract, condensed.)

Loftus-Hills, G. D., and Solomon, M., 1967, Cobalt, nickel, and selenium in sulfides as indicators of ore genesis: Mineralium Deposita, v. 2, no. 3, p. 228-242; abs. in Chem. Abs., v. 68, item 80349n, 1968.

Although pyrite in black shales from some areas contains as much selenium as that from magmatic hydrothermal ores in general, there seem to be major provinces where the S:Se ratio may be a useful indicator of genesis. However, further data are required to test this conclusion. (Authors' summary.)

Luttrell, G. W., 1959, Annotated bibliography on the geology of selenium: U.S. Geol. Survey Bull. 1019-M, p. 867-972.

Annotates nearly 400 papers from 1818 to 1957 on the geologic occurrence, mineralogy, geochemistry, metallurgy, analytical procedures, biologic effects, production, and uses of selenium.

Malakhov, A. A., Malakhov, D. A., and Bobrova, M. S., 1974, Selenium, tellurium, arsenic, and thallium in pyrites and chalcopyrites of the Makanskoye chalcopyrite deposits, southern Urals [in Russian with English summary]: Geokhimiya 1974, no. 1, p. 112-125, abs. in Chem. Abs., v. 80, item 123237s, 1974.

The syngenetic and epigenetic stages of sulfide precipitation have been singled out. Early pyrites are impregnated into rocks of the flat wall and participate in the formation of ore deposits. Epigenetic sulfides form a streaky mineralization in rocks; in ores they replace early pyrites. (English summary, condensed.)

Malevskii, A. Yu., and Chung, Chai-Jung, 1965, Isomorphic replacement of sulfur by selenium and tellurium in mercury sulfides [in Russian], in Vlasov, K. A., Bezsmertnaya, M. S., and Feklichev, V. G., eds., Eksperimental'no-metodicheskie issledovaniya rudnykh mineralov: Moscow, Akad. Nauk SSSR, Inst. Mineralogii, Geokhimii i Kristallokhimii Redkikh Elementov, p. 223-236; abs. in Chem. Abs., v. 63, col. 16035b, 1965.

Selenium and tellurium can isomorphously replace sulfur in the cinnabar lattice

within certain limits at various temperatures.

Markova, E. A., 1960, Selenium and tellurium in cobalt-arsenic ores [in Russian]: *Vses. Mineralog. Obshch., Zapiski*, v. 89, no. 5, p. 602–605; abs. in *Chem. Abs.*, v. 55, col. 3321a, 1961.

Selenium and tellurium were deposited (no locality) during an early stage of vein formation—tellurium mainly as tellurides associated with löllingite-danaite veins; selenium disseminated in other minerals of the polysulfide veins. (*Mineralog. Abs.*, v. 16, p. 345, 1963–1964.)

Mereiter, K., 1970, Synthesis and lattice constants of some selenate voltaites [in German]: *Österreich. Akad. Wiss., math.-nat. Kl.*, v. 107, p. 239–240.

The lattice constants of eight selenate voltaites are given. The crystals were grown from corresponding aqueous solutions with an excess of  $H_2SeO_4$ .

Mikhailova, Yu. V., 1969, Selenium and tellurium in endogenous ores of Chakchar and Yakkabag Mountains, southern Uzbekistan [in Russian]: *Akad. Nauk Uzbek. SSR, Zapiski Uzbekistan. Otdel. Vses. Mineral. Obshch.*, no. 20, p. 204–210.

The distribution of selenium and tellurium in the complex mineral endogenous sulfide deposits is discussed. The selenium and tellurium contents in pyrites are 0.06 and 0.0009 percent, respectively; in galena 0.002 selenium and 0.0003 percent tellurium. The content of the selenium always exceeds that of tellurium. In the Chakchar region, selenium is associated with the quartz-carbonate-barite-galena assemblage. Precambrian gneisses and Carboniferous sandstones have the maximum selenium content. (*Chem. Abs.*, v. 73, item 90142g, 1970.)

Mills, K. C., 1974, *Thermodynamic data for inorganic sulphides, selenides and tellurides*: London, Butterworths, 845 p.

Thermodynamic constants for binary compounds of sulfur, selenium, and tellurium are given. Literature surveys and computer-produced tables for the thermodynamic functions at various temperatures are included.

Milovskiy, A. V., Chitaeva, N. A., and Tang, Ch'ung-t'uan, 1970, Characteristics of selenium and tellurium distribution in mineral associations of ores of the Priorsk deposit: *Moscow Univ., Vestn., Ser. Geol.*, v. 25, no. 4, p. 56–64; translated in *Internat. Geology Rev.*, v. 13, no. 7, p. 1017–1023, 1971; abs. in *Chem. Abs.*, v. 74, item 33464k, 1971.

Selenium predominates over tellurium in the mineral associations of the Priorsk ores; the selenium content increases with depth. There is no distinct pattern for the distribution of tellurium. The higher selenium and lower tellurium contents distinguish the Priorsk deposit from the south and central Ural deposits. Chalcopyrite and pyrrhotite are the chief concentrator minerals for selenium. The distribution of selenium is apparently much affected by recrystallization of the ores.

Mogarovskii, V. V., 1963, The relation between the rhenium and selenium contents in molybdenite from the Kadzharan Deposit (Armenian SSR): *Geokhimiya* 1963, no. 6, p. 566–569; translated in *Geochemistry* 1963, no. 6, p. 580–583.

The concentrations of rhenium and selenium in molybdenite are directly related

(correlation coefficient equals +0.84 for 64 samples). (Mineralog. Abs., v. 16, p. 629, 1963-1964.)

Nechelyustov, N. V., Popova, N. N., and Mintser, E. F., 1962, On the isomorphism of selenium and tellurium in galena: *Geokhimiya* 1962, no. 11, p. 993-999; translated in *Geochemistry* 1962, no. 11, p. 1129-1135; abs. in *Chem. Abs.*, v. 58, col. 3201c, 1963.

Selenium or tellurium is directly correlated with Bi (or Sb) and Ag (or Tl) in galena from the eastern Karamazar ore bodies, U.S.S.R. Since the isomorphous substitution of selenium and tellurium for sulfur in PbS causes less distortion of the structure when two Pb atoms are simultaneously replaced by Bi (Sb) and Ag (Tl), the sums of the effective radii of the electrically neutral combinations of foreign anions and cations are close to the sum of the Pb and S radii in galena. (Mineralog. Abs., v. 16, p. 529, 1963-1964.)

Nechelyustov, N. V., Popova, N. N., Mintser, E. F., Belevitin, V. V., and Razina, I. S., 1963, Selenium and tellurium in lead-zinc deposits of the Altyn-Topkan ore field [in Russian]: *Akad. Nauk SSSR, Inst. Mineralogii, Geokhimii i Kristallokhimii Redkikh Elementov, Trudy*, no. 10, p. 125-135.

The selenium and tellurium in the deposits are concentrated mostly in the galena that formed in the last stage of high-temperature hydrothermal mineralization. The content of selenium and tellurium in galena varied sharply in samples from different deposits. Certain effects of some admixed cations (vanadium and silver and, to a lesser degree, antimony and thallium) on the increase of the accumulation of selenium and tellurium in galena were observed. These elements facilitate the isomorphic inclusion of selenium and tellurium anions into the lattice of galena. (*Chem. Abs.*, v. 61, col. 2840g, 1964, condensed.)

Nechelyustov, N. V., Zlenko, B. F., Gubanov, A. M., Kogan, R. I., Razina, I. S., Volkov, B. I., and Pikkat-Ordynskaya, A. P., 1970, Study methods of trace elements (selenium, tellurium, bismuth) in chalcopyrite-molybdenite ores of skarn deposits, in *Geokhimiya i geologiya nekotorykh rudnykh mestorozhdeniy*: Moscow, Nauka, p. 154-174.

In skarn deposits, the lithophile elements are concentrated in silicates and the chalcophile elements in sulfides. The contents of bismuth, tellurium, and selenium in molybdenite (0.35, 0.17, 0.027 percent, respectively) and in chalcopyrite (0.5, 0.225, 0.006 percent, respectively) were determined. (*Chem. Abs.*, v. 74, item 44217h, 1971, condensed.)

Nekrasova, A. N., and Borodaev, Yu. S., 1972, First find of selenium-containing canfieldite: *Akad. Nauk SSSR, Doklady*, v. 203, no. 4, p. 907-910; translated in *Acad. Sci. U.S.S.R. Doklady, Earth Sci. Sec.*, v. 203, p. 122-125.

The Karamkena canfieldite contains silver 69.9, tin 10.9, sulfur 13.6, and selenium 5.5 percent. The mineral is characterized by the absence of germanium and the partial isomorphous replacement of sulfur by selenium. X-ray diffraction data on the selenium-containing canfieldite are presented. (*Chem. Abs.*, v. 77, item 8122b, 1972, condensed.)

Niebuhr, P. E., and Macmillan, A. H., 1962, Field test for tellurium and selenium: U.S.

Bur. Mines Rept. Inv. 6006, 6 p.; abs. in Chem. Abs., v. 58, col. 7350f, 1963.

A procedure is given for sensitive spot tests for detecting tellurium or selenium. Small amounts of tellurium can be detected even when accompanied by relatively large amounts of selenium.

Novruzov, N. A., 1973, Distribution of trace elements in pyrrhotites [in Russian]: Akad. Nauk Azerbaydzhan. SSR Izv., Ser. Nauk o Zemle, no. 2, p. 114-118; abs. in Chem. Abs., v. 79, item 138688t, 1973.

The chemical composition of pyrrhotite and the distribution of cobalt, thallium, selenium, and tellurium in the Belokan-Zakataly deposits in Azerbaydzhan, U.S.S.R., were studied.

Nozato, Ryoichi, and Igaki, Kenzo, 1955, The equilibrium diagram of the lead-selenium system: Naniwa Univ. Bull., v. A3, p. 125-133, 135-141.

The phase diagram of the lead-selenium system was examined over the entire range of compounds by thermal analysis, microscopic and macroscopic examination, density measurement, and X-ray analysis. (Chem. Abs., v. 49, col. 15421a, 1955, condensed.)

Palei, I. P., 1957, The concentration of native selenium in the oxidized zone of a pyrite deposit: Geokhimiya 1957, no. 7, p. 640-641; translated in Geochemistry 1957, no. 7, p. 752-754; abs. in Chem. Abs., v. 52, col. 13555d, 1958.

In the Kul-Yurt-Tau deposit, selenium is concentrated in the leached zone, in the fines especially. A bed of black, loose, quartz sand continuing 11 percent of native selenium and about 40 percent in the fines (0.04 mm) has been found along the border of the sulfide concentration zone. (Author's abstract.)

Patsuk, V. V., 1960, Detection of small amounts of selenium in pyrites [in Russian]: Sverdlovsk. Gorn. Inst., Trudy, no. 36, p. 81-87; abs. in Anal. Abs., v. 9, abs. 2281, 1962; and Chem. Abs., v. 56, col. 1984b, 1962.

The detection of selenium is based on the reaction between  $\text{SeO}_3^-$  and  $\text{SO}_3^-$  accompanied by the release of elemental selenium which produces a reddish-orange ring at the boundary with a solution of sodium sulfite in hydrochloric acid. (Mineralog. Abs., v. 16, p. 10, 1963-64.)

Pelly, I. Z., and Lipschutz, M. E., 1971, Selenium (34), in Mason, B., ed., Handbook of elemental abundances in meteorites: New York, Gordon and Breach Sci. Pub., p. 271-278; abs. in Mineralog. Abs., v. 22, item 71-444, 1971.

A study of selenium occurrence in meteorites is presented.

Pidzhyan, G. O., 1967, Distribution of selenium and tellurium in ores from the copper molybdenum deposits in the Armenian SSR [in Russian]: Akad. Nauk Armyan. SSR Izv., Nauki o Zemle, v. 20, p. 81-85.

In the ore bodies, chalcopyrite and molybdenite were the predominant minerals, accompanied by subordinate pyrite, bornite, sphalerite, and galena. Selenium and tellurium were present isomorphously in the main ore-forming minerals; tellurium, in addition, was present in the form of many minerals. A maximum selenium and tel-

lurium content was recorded in chalcopyrites from Kadzharan (186 and 54 ppm) and Dzhindara (187 and 121 ppm, respectively). The weight ratio of Se:Te in the different deposits ranged 1.5:1 to 2.7:1. (Chem. Abs., v. 69, item 37818y, 1968, condensed.)

Plotnikov, V. I., 1958, Coprecipitation of small quantities of selenium with ferric hydroxide: Zhurn. Neorg. Khimii, v. 3, no. 8, p. 1761-1766; translated in Jour. Inorganic Chemistry, v. 3, no. 8, p. 56-64; abs. in Chem. Abs., v. 53, col. 21321e, 1959.

This paper gives the results of the investigation of the dependence of the coprecipitation of selenium with ferric hydroxide on a number of factors: pH of the solution, concentration of ammonia and selenium, amount of hydroxide, temperature, order of mixing the solutions, and time of contact of the precipitate with the solution. (Author's introduction, condensed.)

Pokrovskaya, I. V., 1970, Selenium and tellurium in the Tishin and Riddler-Sokol deposits [in Russian]: Akad. Nauk Kazakh. SSR Izv., Ser. Geol., no. 5, p. 53-66; abs. in Chem. Abs., v. 74, item 33463j, 1971.

Most selenium substitutes for sulfur in the isomorphic series PbS-PbSe. The copper sulfides and pyrites contain selenium  $\leq 20$  and  $\leq 5$  percent, respectively. Selenium and tellurium concentrations varied, but they showed a constant increase from the lowest in sulfides of the earliest sedimental-hydrothermal geological formations, through the hydrothermal complex ore stage, to the youngest galena ores containing selenium  $\leq 1.25$  and tellurium  $\leq 0.9$  kg/ton of the concentrate, respectively.

Postgate, John, 1949, Competitive inhibition of sulphate reduction by selenate: Nature, v. 164, p. 670-671; abs. in Chem. Abs., v. 44, col. 4963i, 1950.

Sodium sulfate is reduced by *Desulphovibrio desulphuricans* at an optimal pH of 6.3. Selenate ( $\text{Na}_2\text{SeO}_4$ ) is not reduced and is a powerful inhibitor of sulfate reduction. If the selenate:sulfate ratio is increased to 0.1, inhibition is complete.

Rapp, G. R., Jr., 1963, Rapid determination of trace amounts of selenium in rocks [abs.]: Canadian Mineralogist, v. 7, pt. 5, p. 820.

A rapid method using 3,3'-diaminobenzidine to determine content of selenium (1-100 ppm) in Cretaceous rocks is described.

Rapp, G. R., Jr., and Patraw, J. A., 1966, Distribution of selenium in the Niobrara Formation of the Black Hills region, South Dakota, in abstracts for 1965: Geol. Soc. America Spec. Paper 87, p. 300.

About 200 samples were analyzed; in these samples selenium ranged from a trace to 52 ppm. Although selenium follows sulfur in the sulfides, gypsum from limonite nodules is free of selenium.

Rapp, G. R., Jr., Willigman, M. G., and Patraw, J. A., 1964, A method for rapid determination of trace amounts of selenium in rocks and soils: South Dakota Acad. Sci. Proc. 1964, v. 43, p. 57-60; abs. in Mineralog. Abs., v. 17, p. 450, 1965-1966; and Chem. Abs., v. 63, col. 7646c, 1965.

A rapid method using 3,3'-diaminobenzidine is described for determining 1-100 ppm Se in rocks and soils.



Rees, C. E., and Thode, H. G., 1966, Selenium isotope effects in the reduction of sodium selenite and of sodium selenate: *Canadian Jour. Chemistry*, v. 44, no. 4, p. 419-427; abs. in *Chem. Abs.*, v. 64, col. 10742f, 1966.

Selenium isotope effects in the reduction of sodium selenite and of sodium selenate have been studied. Rate constant ratios for the selenium-76 and selenium-82 species have been determined for the reactions  $\text{Se}^4 \rightarrow \text{Se}^0$  (1.017),  $\text{Se}^6 \rightarrow \text{Se}^4$  (1.018), and  $\text{Se}^0 \rightarrow \text{Se}^4$  (1.010) at room temperature. Theoretical predictions of the first two ratios, from the use of models in which the rate-controlling steps are assumed to be Se-O bond cleavages in  $\text{SeO}_3^{-2}$  and  $\text{SeO}_4^{-2}$ , respectively, lead to predictions in good agreement with the experiment. (Authors' abstract.)

Rosenfeld, I., and Beath, O. A., 1964, *Selenium—Geobotany, biochemistry, toxicity, and nutrition*: New York, Academic Press, 411 p.

This book is a comprehensive review of the element selenium, including its origin and geological distribution in rocks, soils, and water. Physical and chemical properties of selenium and its compounds are given. Methods for the determination of selenium, the uses of its compounds, the accumulation of selenium in vegetation, and the significance of the element in nutrition are presented.

Ruzmatov, S. R., 1966, Geochemistry of selenium and tellurium in the central Kyzylkum ore occurrences [in Russian]: *Uzbek. Geol. Zhur.* 1966, no. 6, p. 55-60; abs. in *Chem. Abs.*, v. 68, item 89118u, 1968.

The geochemistry of selenium and tellurium in the oxidized zone of sulfide deposits in the area was studied. Over 250 mineral samples were analyzed for selenium and tellurium.

Ryabchikov, D. I., and Nazarenko, I. I., 1964, Advances in the chemistry of complex compounds of selenium and tellurium [in Russian]: *Uspekhi Khimii*, v. 33, no. 1, p. 108-123.

A review, including 145 references published through 1962, is presented.

Santos, E. S., 1968, Reflectivity and microindentation hardness of ferroselite from Colorado and New Mexico: *Am. Mineralogist*, v. 53, p. 2075-2077; abs. in *Chem. Abs.*, v. 70, item 39633d, 1969.

Measurements were made on ferroselite, identified by microprobe analysis, implanted on marcasite in uranium ore-bearing sandstone from the Kermac Sec. 10 mine, McKinley County, New Mexico, and on ferroselite from the Virgin no. 3 mine, Montrose County, Colorado. The mean value of all measurements of reflectivity at  $546 \text{ m}\mu$  is 48 percent. The mean value of all measurements of Vickers hardness is  $897 \text{ kg/mm}^2$ . (*Mineralog. Abs.*, v. 20, item 69-2620, 1969.)

Savel'ev, V. F., 1963, Selenium-containing minerals in the sedimentary rocks of Central Asia [in Russian]: *Byull. Nauchno-Tekh. Inf.*, no. 6, p. 12-14; abs. in *Chem. Abs.*, v. 62, col. 7535c, 1965.

Selenium-containing minerals and plants were found in one area of Central Asia. The average selenium content in sulfides from the Upper Cretaceous rock was 52 ppm.

- 1964, Discovery of natural gamma-selenium in Uzbekistan [in Russian], in Uklonskii, A. S., and others, eds., *Voprosy mineralogii i geokhimii*: Tashkent, Akad. Nauk Uzbek. SSR, Inst. Geologii i Geofizika, p. 200–206.

Selenium concentrations, mainly in the form of native selenium, were detected in the contact of limonitized and unaltered varieties of sandstone. The rocks containing the natural gamma-selenium had large amounts of pyrite that also contained an elevated amount of (0.00n percent) thallium. The natural selenium was formed by the liberation of isomorphic admixture of selenium from pyrite during its oxidation. (Chem. Abs., v. 62, col. 8848f, 1965, condensed.)

- 1964, Selenium mineralization in the Upper Cretaceous sedimentary rocks of some Central Asia areas [in Russian], in Shavlo, S. G., ed., *Poleznye iskopaemye Uzbekistana i voprosy ikh genezisa*: Tashkent, Akad. Nauk Uzbek. SSR, Otd. Geol. Nauk, p. 103–112.

Selenium formed considerable concentrations in a reducing medium of epigenetically altered sandstones containing organic remnants of plant origin. The main mineral form of selenium was natural gamma-selenium. Selenium-containing coalified plant remains, pyrite, marcasite, and galena were the main source of enrichment of selenium in the mineralization zones. In outcrops and in upper parts of the supergene zone, the selenium was dispersed. (Chem. Abs., v. 62, col. 6273c, 1965, condensed.)

- 1970, Selenium in Uzbekistan metamorphic rocks [in Russian]: Tashkent. Gos. Univ., *Nauchnye Trudy*, no. 372, p. 35–41.

A high content of selenium is recorded in the Cambrian carbonaceous and sulfide-bearing sedimentary-metamorphic rocks of Central Asia. A relation exists between the selenium concentration and the amount of original carbon and sulfur. A high concentration of selenium is noticed in arsenopyrite, chalcocite, pyrrhotite, and marcasite. (Chem. Abs., v. 74, item 144701e, 1971, condensed.)

- 1970, Selenium content of Upper Cretaceous sandstones, saline soils, and lakes, Central Asia [in Russian]: Uzbek, *Geol. Zhur.* 1970, no. 5, p. 79–82.

Selenium content ( $\times 10^{-5}$  percent) is given for Upper Cretaceous dolomitic limestones (13), shales and mudstones (6), sands and sandstones (20), and gravels and conglomerates (4). Selenium concentrations under different conditions are discussed. (Chem. Abs., v. 74, item 44348b, 1971, condensed.)

- 1972, Selenium in young sedimentary formations of Central Asia [in Russian]: Uzbek. *Zhur.* 1972, no. 2, p. 81–84.

The major mineral form of selenium in the epigenetically altered parts of Upper Cretaceous sedimentary rocks is the native trigonal  $\gamma$  Se. The selenium-containing carbonized plant remains with pyrite, marcasite, galena, and phosphorite constitute the sources for the enrichment of selenium in the epigenetically altered sediments. Selenium is depleted from the zones of interlayer oxidized rocks and is concentrated in limonites and subsurface oxidation zones containing jarosites and natrojarosites. Calcium and barium sulfates do not contain any selenium; significant amounts of selenium are concentrated in the organic residues of epigenetically altered sedimentary rocks. (Chem. Abs., v. 77, item 64797n, 1972.)

Savel'ev, V. F., Baskakov, G. D., and Trostyanskiy, G. D., 1968, Selenium in the supergene minerals of Middle Asia: *Litologiya i Polezn. Iskop.* 1968, no. 3, p. 129-135; translated in *Lithology and Mineral Resources* 1968, no. 3, p. 349-354; abs. in *Chem. Abs.*, v. 70, item 39699e, 1969.

A study was made of the distribution of selenium in 42 exogenetic minerals from sedimentary and sedimentary-metamorphic rocks of different ages. The study established that selenium accumulates in sedimentary formations mainly during their epigenetic change. The main selenium carriers are selenous native sulfur, sulfides, oxides, hydroxides of manganese and iron, complex hydrous iron sulfates, copper sulfates, phosphates, arsenate, carbonized plant residue, and pyrobitumens. (Authors' abstract, condensed.)

Savel'ev, V. F., and Trostyanskiy, G. D., 1970, Epigenetic minerals from Mesozoic-Cenozoic sedimentary rocks of the Kyzylkums [in Russian]: *Akad. Nauk Uzbek. SSR, Zapiski Uzbekistan. Otdel. Vses. Mineral. Obshch.*, no. 23, p. 97-101; abs. in *Chem. Abs.*, v. 75, item 11936y, 1971.

A high concentration of selenium occurs as native trigonal selenium and as iron, lead, and copper selenides.

Schnepfe, M. M., and Flanagan, F. J., 1973, The selenium content of USGS [U.S. Geological Survey] standard rocks: *Chem. Geology*, v. 12, no. 1, p. 77-80.

Selenium was determined in USGS standard rocks by a spectro-fluorimetric procedure. One-way analysis of variance of the several sets of data showed no significant differences in the selenium content among samples of any specific rock; these samples may be accepted as homogeneous for their selenium contents by this analytical method. (*Chem. Abs.*, v. 80, item 17627j, 1974.)

Shawe, D. R., 1966, Zonal distribution of elements in some uranium-vanadium roll and tabular ore bodies on the Colorado Plateau, in *Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550-B*, p. B169-B175; abs. in *Chem. Abs.*, v. 65, col. 16693b, 1966.

Uranium, vanadium, and selenium are zonally distributed. The concentric zones are compatible with the theory that ore and other introduced elements were precipitated at the interface between two solutions with different properties; this interface is now represented by the ore boundary. (*Mineralog. Abs.*, v. 20, item 69-1119, 1969.)

Shilovskii, P. P., and Sidel'nikova, V. D., 1966, Geochemical associations and zonal structure of uranium-selenium ore bodies in sandstones of a red-bed formation [in Russian], in Feodot'ev, K. M., and Batulin, S. R., eds., *Ocherki geokhimii endogennykh i gipergennykh protsessov*: Moscow, Akad. Nauk SSSR, Inst. Geologii Rudnykh Mestorozhdeniy, Petrografii, Mineralologii i Geokhimii, p. 273-280.

Data are given on the zonal structure of ore bodies in a uranium-selenium deposit developed in the area of Paleozoic folding. A relation was observed between the composition of the terrigenous part of rock and the concentration of various ore and accessory elements in this deposit. (*Chem. Abs.*, v. 66, item 57778b, 1967, condensed.)

Shmariovich, E. M., 1968, Concentration of rare elements associated with layered

oxygen zoning in water-bearing horizons [in Russian]: Vses. Litol. Soveshch., 8th, 1968, Doklady, v. 2, p. 180-189 [1970].

Uranium, uranium-selenium, and molybdenum-uranium deposits are concentrated in arid regions with supergene epigenetic zones. The hydrochemical conditions (gas composition in water, redox potential, content of radioactive elements) in the ore zones determine the nature of the mineralogy. High concentrations of uranium, selenium, and molybdenum are recorded in acid waters. Biochemistry, geophysics, mineralogical, geochemical, and hydrochemical characteristics of the epigenetic rocks are described. (Chem. Abs., v. 74, item 101659e, 1971.)

Sidel'nikova, V. D., 1973, Geologic occurrence of selenium in arid regions [in Russian], in Batulin, S. G., ed., *Geokhimiya landshaftov protsessy gipergenez*: Moscow, Nauka, p. 64-92.

The accumulation of selenium in soils and plants of arid lands can be explained by some of its solubility and supergene transport characteristics. Selenium is soluble in waters with oxidation solution potential  $> +0.241$  v, that is, in oxidizing media. It is readily precipitated with iron in limonites or as selenates of heavy metals or alkaline earth metals. Selenium salts are readily reduced to the elemental selenium, which is often codeposited with sulfur or replaces sulfur isomorphously. The selenium salts of alkaline metals are soluble. For this reason, in contrast to sulfur, selenium is not accumulated in the solonetz (dark, strongly-alkaline) soils. The increase of selenium concentration in desert soils is observed wherever the soil-forming strata also contain increased selenium concentrations and conditions for supergene selenium transport exist. (Chem. Abs., v. 80, item 147730y, 1974.)

Sidel'nikova, V. D., and Shvei, I. V., 1970, Selenium in Paleozoic formations of Central Asia, in Vol'fon, F. I., ed., *Ocherki po geologii i geokhimii rudnykh mestorozhdeniy*: Moscow, Nauka, p. 307-310.

The Paleozoic sedimentary formations in Central Asia consist of sandstones, shales, quartzites, flysch, mudstones, limestones, Upper Carboniferous molasse formations, and dolomites. Results of colorimetric estimation of selenium in different rock types show  $(4.2-28.0) \times 10^{-5}$  percent. The distribution and concentration of selenium is controlled by lithology, composition, age, and conditions of metamorphism. (Chem. Abs., v. 75, item 51612g, 1971.)

Simpson, D. R., 1964, The binary system PbS-PbSe: *Econ. Geology*, v. 59, no. 1, p. 150-153.

Liquidus-solidus relations of the galena-clausthalite series were determined. A complete solid solution of galena-clausthalite exists at temperatures as low as  $400^{\circ}$ . The m.p. of galena is  $1,109^{\circ}$  and that of clausthalite  $1,081 \pm 2^{\circ}$ . (Chem. Abs., v. 60, col. 12709g, 1964.)

Sindeeva, N. D., 1957, Data on geochemistry of selenium [in Russian]: *Akad. Nauk SSSR, Inst. Mineralogii, Geokhimii i Kristalloghimii Redkikh Elementov*, Trudy, no. 1, p. 7-13.

A review of the mode of occurrence of selenium minerals is presented. (Chem. Abs., v. 52, col. 15373b, 1958.)

- 1958, Selenium and tellurium in deposits of different genetic types: Akad. Nauk SSSR, Izv., Ser. Geol., no. 5, p. 78-94; translated in Acad. Sci. U.S.S.R., Izv., Geol. Ser., 1958, no. 5, p. 74-87.

A description of the various types of deposits containing selenium and tellurium is given, also the geological characteristics and industrial appraisal of the deposits.

- 1960, Geochemistry of selenium and tellurium [in Russian]: Internat. Geol. Cong., 21st, Copenhagen 1960, Sovetskikh Geologov Doklady, Problema 1, p. 129-136.

Large concentrations of selenium and tellurium are rarely formed during hypogene mineralization. The main industrial concentrations of selenium and tellurium are in deposits of their sulfur analogs. Selenium in sulfide deposits enters isomorphously into sulfides. Its minerals are formed either when the sulfur content in the deposit is low, or even when sulfur is in the form of  $\text{SO}_4^{=}$ . Tellurium minerals are formed in various paragenetic associations with sulfides. The largest tellurium and selenium deposits are related to ultrabasic and basic rocks, a considerable number of them are in acid and moderately acid rocks, and only a few, chiefly tellurium mineralization, are related to alkaline rocks. During oxidation of sulfide deposits, only an insignificant part of the selenium and, possibly, of the tellurium is carried out of the oxidation zone. Most of the selenium and tellurium is precipitated by iron hydroxides and fixed in iron ore hats. (Chem. Abs., v. 55, col. 20827f, 1961.)

- 1964, Mineralogy and types of deposits of selenium and tellurium [translated from original Russian]: New York, Interscience Publishers, 363 p.

An extensive study of the mineralogy, geochemistry, and ore deposits of selenium and tellurium is presented, including the properties of the elements, their behavior at different stages of mineralization, and the forms in which they occur in various types of ores.

- 1964, Selenium [in Russian], in Vlasov, K. A., ed., *Geokhimiya, mineralogiya i geneticheskie tipy mestorozhdeniy redkikh elementov*: Moscow, Nauka, v. 1, p. 557-585; translated by Israel Program for Scientific Translations, Jerusalem, 688 p., 1966.

A comprehensive review of selenium is presented.

- Sindeeva, N. D., and Kulikova, M. F., 1963, Rare elements in the oxidation zone of sulfide deposits [in Russian]: Akad. Nauk SSSR, Inst. Mineralogii, Geokhimi i Kristallokhimii Redkikh Elementov, Trudy, no. 10, p. 286-290.

Rare elements in the oxidation zone of sulfide deposits have a tendency to disperse. In most deposits the concentration of rare elements in the oxidation zone is considerably smaller than in the hypogene ore. Re, In, and Tl were rapidly and almost entirely removed from the oxidation zone. Gallium, which has a smaller dispersibility, concentrated in the iron caps in low amounts. Tellurium is also fixed by iron hydroxides in the iron caps. The only exceptions are cadmium, germanium, and selenium. Under certain conditions they accumulate in the oxidation zone, even in commercial amounts. (Chem. Abs., v. 61, col. 2840d, 1964.)

Sindeeva, N. D., and Kurbanova, N. Z., 1958, Element concentration of selenium in rocks of the U.S.S.R. [in Russian]: Akad. Nauk SSSR, Doklady, v. 120, p. 353-355.

New direct determinations of selenium in systematically collected samples of abyssal effusive metamorphic and sedimentary rocks of the U.S.S.R. are tabulated. The order of magnitude of the selenium concentration ("clarke") was previously mostly given near 0.6-0.8 ppm; an average of 0.14 ppm was found for the massive rocks of the U.S.S.R. For the sedimentary rocks it varied between 0.0001 and 0.1 ppm. In three Silurian schists from the Baltic Sea (Estonia) as high as 0.3 to 9 ppm was found. Also highly interesting is the genetic role of selenium-enriched Cretaceous rocks and related ore deposits of the Magadan Region. (Chem. Abs., v. 53, col. 2974i, 1959.)

Sobol, L. G., and Selivanova, N. M., 1973, Heat of formation of sodium hydrogen selenate ( $\text{NaHSeO}_4$ ) [in Russian]: Vyssh. Ucheb. Zavedenii, Khimiya i Khimicheskaya Tekhnologiya, Izv., v. 16, no. 10, p. 1493-1495; abs. in Chem. Abs., v. 80, item 41621y, 1974.

The method used to determine the heat of formation of sodium hydrogen selenate is presented.

Sokolova, E. G., and Pilipchuk, M. F., 1970, Selenium in present Black Sea sediments: Akad. Nauk SSSR, Doklady, v. 193, no. 3, p. 692-695; translated in Acad. Sci. U.S.S.R. Doklady, Earth Sci. Sec., v. 193, p. 225-228.

Selenium occurs in the isomorphous sulfides of hydrothermal origin. The migration of selenium occurs in the ionic form within a narrow pH range and is controlled by the redox potential of the system. The concentration contour map of selenium in Black Sea sediments shows that selenium content is high in the eastern and western peripheral areas. (Chem. Abs., v. 73, item 90143h, 1970, condensed.)

—1973, Geochemistry of selenium in sediments of the northwestern Pacific Ocean: Geokhimiya 1973, no. 10, p. 1537-1546; translated in Geochemistry Internat., v. 10, p. 1152-1160; abs. in Chem. Abs., v. 80, item 50657s, 1974.

The selenium content in these sediments varies from 0.1 to 1.7 ( $\times 10^{-4}$ ) percent. Elevated contents are found in deposits with reducing conditions, and the oxidized sediments of pelagic regions contain one order of magnitude less selenium. The geochemical barrier in selenium distribution in marine deposits is shown. Selenium has relatively high mobility under oxidizing conditions and almost complete immobility in the zone of reduction. The leading role of organic matter and iron sulfides in selenium fixation is noted. (Authors' abstract, condensed.)

Srebrodolskiy, B. I., and Sidel'nikova, V. D., 1969, Selenium in native sulfur: Geokhimiya 1969, no. 8, p. 1010-1013; translated in Geochemistry Internat., v. 6, p. 803-806; abs. in Chem. Abs., v. 71, item 83413b, 1969.

Selenium was determined in a large number of native sulfur samples from various volcanic and exogenous deposits. Possible sources of selenium in native sulfur are given.

Sun, Ming-Shan, and Weege, R. J., 1959, Native selenium from Grants, New Mexico: Am. Mineralogist, v. 44, p. 1309-1311; abs. in Chem. Abs., v. 54, col. 8471e, 1960.

Thin films of native selenium coat slickensides in a claystone gall. The specimen is

from the middle part of the Brushy Basin member of the Morrison formation (Jurassic) near Grants, McKinley County. (Mineralog. Abs., v. 15, p. 166, 1961-1962.)

Tamai, Tadaharu, Matsushita, Rokuji, Takada, Jitsuya, and Kiso, Yoshiyuki, 1973, Gamma ray energies of selenium-85 and selenium-86: Inorganic and Nuclear Chemistry Letters, v. 9, no. 11, p. 1145-1152.

Selenium isotopes were separated from other fission elements by using paper electrophoresis following thermal  $n$  irradiation of a uranyl nitrate solution. The energy and relative intensity of gamma rays from selenium-85 and selenium-86 are given. (Chem. Abs., v. 80, item 9255w, 1974.)

Timofeeva, T. S., 1966, Selenium minerals in Kon-i-Zak arsenic pyrite ore [in Russian]: Sredneaziatskii Nauch.-Issled. Inst. Geologii i Mineral'nogo Syr'ya, Trudy, no. 7, p. 23-31.

In this intensely mineralized deposit the ore bodies are massive arsenopyrites and pyrrhotites with mixtures of pyrite and chalcopyrite. Selenides occurred distinctly at the contacts of pyrrhotite monominerals and magnetite ores in Hastingsite skarns. Bismuth and copper selenides are associated with the final stage of gold-bismuth ore formation. Physical, optical, and X-ray properties of the minerals are described. (Chem. Abs., v. 69, item 108550t, 1968, condensed.)

Tischendorf, Gerhard, 1959, Formation of selenium enrichments in deposits [in German]: Neue Huette, v. 4, p. 19-21.

Study of the Harz selenium deposits indicates that they were formed by removal of selenium, sulfur, lead, copper, and cobalt from schists by hydrothermal solutions. Concentrations of selenium in the deposits are not important for the recovery of selenium, because they are too small. Selenium contents of various minerals are summarized. (Chem. Abs., v. 53, col. 14854i, 1959.)

———1966, On the distribution of selenium in sulfides [in German]: Freiburger Forschungshefte C208, 162 p.

The distribution of selenium in sulfide minerals is evaluated on the basis of 2,714 published and 463 new selenium analyses supported by optical studies. The selenium content of sulfide minerals is independent of the host mineral. Only bismuthinite and sulfosalts containing bismuth sulfide are specifically rich in selenium. The concentration of selenium ranges from 1 to 5,000 g/ton. Sulfides formed under equal conditions show the same relations between selenium and sulfur. (Chem. Abs., v. 65, col. 16061b, 1966, condensed.)

———1968, Sources of elements in selenide mineralization near Tilkerode (Harz): Geologiya Rudn. Mestorozhd., v. 10, no. 4, p. 79-82; translated in Internat. Geology Rev., v. 11, no. 11, p. 1298-1301.

Analysis of the selenide paragenesis in the vein and of the wallrock alterations shows definitely: that selenium and several other minor elements were derived from the host rocks of the vein and not from the depths, that the selenide stage of the mineralization (preceded by the oxide and followed by the sulfide stage) was able to develop because the S:Se ratio was still too low for the crystallization of sulfides, and the Eh was sufficiently high, at  $\text{pH} \geq 7$ , for the mobilization of selenium and the other

elements, in the orderly sequence of their migration capacities. (Chem. Abs., v. 70, item 39697c, 1969.)

Tischendorf, Gerhard, and Ungethüm, Horst, 1964, The conditions of formation of clausenthalite-galena and remarks to the distribution of selenium in galena in dependence of redox potential and of pH value [in German]: *Chemie Erde*, v. 23, p. 279-311.

The conditions for the formation of clausenthalite were investigated in connection with the occurrence of selenide in Tilkerode, Harz. The evaluation of thermodynamic data resulted in the construction of the activities of selenide and sulfide ions in the Eh-pH diagram regulating, in connection with the solubility products, the formation of clausenthalite-galena phases. Clausenthalite is separated at a higher redox potential than galena. (Chem. Abs., v. 62, col. 2621e, 1965, condensed.)

Todorov, T., 1973, Distribution of selenium, tellurium and rhenium in endogene mineralization of the copper and molybdenum deposits in Rossen Ore Field, Bulgaria: *Carpatho-Balkan Geol. Assoc. Cong.*, 9th, Budapest 1973, *Bull.*, v. 4, p. 119-124.

Distribution relations are given for chalcopyrite, pyrite, and molybdenite.

Tokarev, V. A., and Yashchenko, A. V., 1968, Keiv selenium-bearing pyrrhotite (Tyapyshe-Manyuk deposit) [in Russian]: *Mat. Mineralog. Kol'sk. Poluostr.*, no. 6, p. 67-69.

Polarographic study of pyrrhotite indicated a constant presence of selenium but an absence of tellurium. The selenium content in samples taken in the zone transitional from oxidized sulfides to nonoxidized ores is 5-17 ppm and in pyrrhotites from the nonoxidized zone is 12-21 ppm. (Chem. Abs., v. 73, item 68366m, 1970, condensed.)

Troshin, Yu. P., Mikheeva, Z. I., and Alekseeva, N. N., 1969, Distribution of gold, silver, tellurium, and selenium in the sulfide minerals of Transbaikalian hydrothermal deposits of diverse origin [in Russian]: *Zabaikal'skogo Filiala Geograficheskogo Obshch. SSSR, Zapiski*, no. 36, p. 97-102.

The Mesozoic hydrothermal deposits were contemporaneous with the granitic rock massifs including ultra-acidic granites, diorites, granodiorites, and amphibole-biotite granites. Two groups of ore deposits are recognized based on the Ag/Au and Se/Te ratios. A genetic relation exists between the rare metal-complex ore deposition and intrusive granites. The Ag/Au ratio was determined in arsenopyrite (29), pyrite (240), sphalerite (420) and galena (8,000). The Ag, Au, Te, and Se in the sulfides were deposited at high temperatures. (Chem. Abs., v. 77, item 103957m, 1972.)

Trostyanskii, G. D., 1964, Selenium minerals from sedimentary rocks of Uzbekistan [in Russian]: *Akad. Nauk Uzbek. SSR, Zapiski Uzbekistan. Otdel. Vses. Mineral. Obshch.*, no. 16, p. 40-43.

An elevated amount of selenium was related to the bedded zone of limonitization. Native selenium and ferroselite were found at the contact of oxidized and nonoxidized beds. (Chem. Abs., v. 63, col. 351e, 1965, condensed.)

—1970, Some minerals paragenetic with selenium in Uzbekistan sedimentary



rocks [in Russian]: Akad. Nauk Uzbek. SSR, Zapiski Uzbekistan. Otdel. Vses. Mineral. Obshch., no. 21, p. 69-73.

The selenium minerals (native selenium, ferroselite, and rare Pb, Cu, and Ag selenides) were found at the contact of limonitized and nonoxidized rocks. The native selenium, which was present in both nonoxidized and limonitized rock, is closely intergrown with pyrite and marcasite in the former and with limonite in the latter. Clausthalite was found in nonoxidized rock closely associated with marcasite and pyrite. This rock was formed under reducing conditions during epigenetic activation of the rocks. The clausthalite was also formed under conditions of a reducing medium, but later than the sulfides. The Cu and Ag selenides were found together with clausthalite in nonoxidized rocks. (Chem. Abs., v. 74, item 114134e, 1971, condensed.)

Tugarinov, A. I., and D'yachkova, I. B., 1966, Selenium in the Krivoy Rog region: *Geokhimiya* 1966, no. 9, p. 1035-1042; abs. translated in *Geochemistry Internat.*, v. 3, p. 828-829; abs. in *Chem. Abs.*, v. 65, col. 19859b, 1966; and *Mineralog. Abs.*, v. 19, p. 40, 1968.

Selenium concentration in sulfides of the metamorphic rocks does not exceed  $n \times 10^{-3}$  percent, and maximum concentrations coincide with sulfides closely associated with organic matter. The ratio of selenium to sulfur concentration in the pyrites of the different metasomatite zones increases in the most oxidized, rear zones of the metasomatic column, which are of calcic-hematitic composition, and decreases in the direction of the forward zones, parallel with a decrease of the  $Fe^{+3}/Fe^{+2}$  ratio in the principal minerals. Thermodynamic calculations of the stability fields of iron oxide, selenide, and sulfides have confirmed the possibility that separation of sulfur and selenium occurs where there is a jump in oxidation-reduction conditions in the metasomatic column. It is suggested that this effect is responsible for the emergence of selenium-rich sulfides in high-temperature deposits. (*Geochemistry Internat. abs.*, condensed.)

———1967, Some common features in the geochemistry of selenium and uranium [in Russian]: *Voprosy Prikladnoi Radiogeologii*, no. 2, p. 380-386.

The highest Se/S ratio in sedimentary rocks in which the selenium is present mostly as native selenium or selenides is usually accompanied by uranium mineralization. The mobility of selenium and uranium under oxidizing conditions and their almost complete inert behavior in reducing media are the main geochemical properties controlling selenium and uranium in exogenic processes. Extraction of selenium and uranium from rocks by solutions having sufficiently high Eh is possible through oxidation. The alkaline medium is most favorable for transfer of selenium and uranium into the mobile state. Selenium and uranium migrating in surface waters are concentrated in rocks having reducing capacity. (Chem. Abs., v. 68, item 106941b, 1968, condensed.)

Turdukeev, I. D., 1972, Paragenesis of selenium and mercury in mercury ore deposits of Turkestan-Alai [in Russian], in Surgai, V. T., ed., *Geologiya i geokhimiya rtuti i sur'my kirgizii*: Frunze, U.S.S.R., Ilim, p. 121-134.

Chemical analyses of ores and host rocks showed the presence of selenium in all mercury-bearing ores as an isomorphous trace element and a direct relation between selenium and mercury in the host rocks. Tellurium was present as traces in the host rocks but was absent in the ores. Selenium and mercury accumulated together in marine lime-magnesium sediments in the shallow reducing zones of the Upper Devo-

nian paleobasins forming sedimentary or sedimentary-diagenetic concentrations. Later, in the epigenetic stage, these elements were redistributed and concentrated in dolomite beds as sulfides. (Chem. Abs., v. 80, item 72747y, 1974.)

Turekian, K. K., and Wedepohl, H. H., 1961, Distribution of the elements in some major units of the earth's crust: *Geol. Soc. America Bull.*, v. 72, no. 2, p. 175-192; abs. in *Chem. Abs.*, v. 55, col. 10234h, 1961; and *Mineralog. Abs.*, v. 15, p. 279, 1961-1962.

A compilation, from numerous sources, of the distribution of 94 elements in the earth's crust is presented. Selenium is given as 0.05 ppm in various types of igneous rocks, 0.05-0.6 ppm in sedimentary rocks (highest in shales), and 0.17 ppm in deep sea sediments.

Vakhrushev, V. A., and Dorosh, V. M., 1966, Selenium and tellurium distribution in sulfide ore deposits of the Altay-Sayan region: *Geokhimiya* 1966, no. 11, p. 1349-1354; translated in *Geochemistry Internat.*, v. 3, p. 1076-1081; abs. in *Chem. Abs.*, v. 66, item 30893y, 1967.

Selenium and tellurium have been determined quantitatively in monomineralic sulfide samples from endogene deposits of two genetic types: skarn deposits and vein deposits of gold-quartz ore. Different behavior of selenium and tellurium has been established in skarn deposits including skarn-gold ore deposits on the one hand and in vein deposits on the other. It is proposed to single out deposits of gold-bearing skarns as a separate genetic type or as an independent skarn-gold ore formation. (Authors' abstract.)

Vasil'eva, E. G., 1972, Simulation of depositional processes of uranium, selenium and molybdenum during the interaction between metal-bearing oxygenated waters and a counterflow of gaseous reducing agents: *Litologiya i Polezn. Iskop.* 1972, no. 6, p. 54-67; translated in *Lithology and Mineral Resources*, v. 7, no. 6, p. 703-713; abs. in *Chem. Abs.*, v. 78, item 126854k, 1973.

An account is given of the results of an experimental simulation of the depositional processes of uranium, molybdenum, and selenium at a reducing barrier. The experiments consisted of either microbiologically active gray rock or limonitized rock, and a flow of gaseous reducing agents ( $H_2S$  and  $H_2$ ) rising from below counter to mobile metalliferous oxygenated waters. The precipitation of uranium has been observed as the Eh of the environment falls to 200 mv and below ( $pH=6.5-8$ ). Selenium has been precipitated by rocks with positive values of Eh. Molybdenum is not precipitated in general; moreover, it has been removed from the gray rocks both by oxygenated and by hydrogen sulfide waters. It has been established that up to 30 mg/litre of iron may be present in solutions saturated in  $H_2S$ . (Author's abstract.)

Velikii, A. S., and Sindeeva, N. D., 1966, Selenium and tellurium deposits [in Russian], in Vlasov, K. A., ed., *Geokhimiya, mineralogiya i geneticheskie tipy mestorozhdeniy redkikh elementov*: Moscow, Nauka, v. 3, p. 534-560, 832-833; translated by Israel Program for Scientific Translations, Jerusalem, 916 p., 1968; abs., in *Chem. Abs.*, v. 68, item 4791k, 1968.

A review of the distribution of selenium and tellurium in ores of hydrothermal sulfide deposits is given.

Vorob'ev, V. P., 1969, Two modes of origin of sedimentary selenium concentrations: *Akad. Nauk SSSR, Doklady*, v. 186, no. 2, p. 453-456; translated in *Acad. Sci. U.S.S.R. Doklady, Earth Sci. Sec.*, v. 186, p. 218-220; abs. in *Chem. Abs.*, v. 71, item 52346c, 1969.

Seleniferous strata of two lithofacies types are described from the epi-Hercynian platform in west-central Asia. Sapropelitic clay of the lower Eocene contains an average of 60 ppm selenium and reaches peak concentrations of 200-400 ppm. Sapropelitic marl of the middle and upper Eocene averages 50 ppm and reaches peak concentrations of 140 ppm selenium. Geochemical data for these deposits and for Oligocene and lower Miocene deposits are tabulated and figured. The source of the selenium was probably submarine volcanism. (*Mineralog. Abs.*, v. 22, item 71-2896, 1971.)

———1969, Selenium in supergene epigenetic deposits of native sulfur: *Geokhimiya* 1969, no. 2, p. 242-244; translated in *Géochimistry Internat.*, v. 6, p. 176-179, 1969; abs. in *Chem. Abs.*, v. 70, item 80077p, 1969.

Analyses of over 100 sulfurized rocks from ore bodies of the Guardak deposit show that most of the samples contain 1-10 ppm selenium.

Vorob'ev, V. P., Grushevoi, G. V., and Onashko, I. S., 1968, Paragenesis of uranium and selenium in multicolored Mesozoic-Cenozoic deposits [in Russian]: *Vses. Nauch.-Issled. Inst. Geol., Trudy*, v. 142, p. 114-121.

The contents of uranium in most rocks of a Mesozoic-Cenozoic varicolored formation of a platform were within Clarke values for the rocks. The degree of rock oxidation did not noticeably affect the uranium content in them. The distribution of selenium, however, was controlled by reduction-oxidation conditions of sedimentation. All reduced rocks have elevated contents of selenium. The correlation between uranium and selenium contents in unoxidized rocks indicated a parallel accumulation of these elements during sedimentation. Deposits of oxidized geochemical facies are poor in selenium and contain the Clarke value for uranium. Sharply reducing geochemical facies were favorable for the formation of syngenetic selenium-uranium concentrations of both elements that were fixed mostly by organic substances in the sediment. (*Chem. Abs.*, v. 70, item 70291q, 1969, condensed.)

Walsh, T., and Fleming, G. A., 1952, Selenium levels in rocks, soils, and herbage from a high selenium locality in Ireland: *Internat. Soc. Soil Sci. Commission II & IV, Trans.*, v. 2, p. 178-183.

Among the rocks examined, pyritiferous shale contained up to 28.5 ppm selenium. Soils on which conditions of toxicity occurred showed levels of 30-324 ppm selenium, compared with <2 ppm in adjoining healthy areas. (*Chem. Abs.*, v. 51, col. 11631c, 1957, condensed.)

Warren, C. G., 1968, The synthesis of ferroselite from an aqueous solution at low temperature: *Econ. Geology*, v. 63, no. 4, p. 418-419; abs. in *Mineralog. Abs.*, v. 21, item 70-364, 1970.

In this work, the synthesis of ferroselite was restricted to conditions approaching the conditions of the formation of sandstone-type uranium deposits—a low temperature and an aqueous environment. (Author's abstract, condensed.)

———1972, Sulfur isotopes as a clue to the genetic geochemistry of a roll-type uranium deposit: *Econ. Geology*, v. 67, p. 759–767.

Roll-type uranium deposits, occurring as crescent-shaped bodies, usually contain pyrite and uranium, selenium, vanadium and (or) molybdenum minerals. The sulfur isotope data of the Shirley Basin, Wyoming, deposit indicate that ore formation was not primarily a biogenic process but was the result of chemical disproportionation. (*Mineralog. Abs.*, v. 24, item 73–3778, 1973.)

Webb, J. S., Thorton, I., and Fletcher, K., 1966, Seleniferous soils in parts of England and Wales: *Nature*, v. 211, p. 327; abs. in *Chem. Abs.*, v. 65, col. 12811d, 1966.

Data on the selenium and molybdenum concentrations in stream sediments and soils in areas characterized by abnormally high (5–60 ppm) molybdenum content are presented. Values of selenium ranging from 3.8–9.0 ppm compared with normal background of <0.2 ppm are noted. The studies provide the first evidence of the existence of seleniferous soils in Britain. The principal bedrock appears to be certain marine shale facies of the Lower Carboniferous in Staffordshire and Devon and of the Ordovician in North Wales. (*Mineralog. Abs.*, v. 18, p. 33, 1967.)

Webster, C. L., Jr., 1972, Selenium isotope analysis and geochemical applications: Colorado State Univ. Ph.D. thesis, 74 p.

The selenium-74/selenium-80 ratios of laboratory and natural selenium samples were determined by an A.E.I. MS-20 isotope mass spectrometer. The selenium was analyzed as selenium hexafluoride that was prepared by fluorinating elemental selenium with cobalt (III) fluoride. Precision for any given run was  $\pm 1.01$  ppt (parts per thousand) providing the operating standards were met. A harmonic rate ratio (HRR) of 1.010 was obtained for the reduction of selenite by hydroxylamine. By using atom fragments and assuming the activated complex is identical to the stable selenite, Rees and Thode obtained the theoretical HRR value of 1.011. An investigation of the selenium-74 content of selenium associated with a uranium roll-type deposit, in Shirley Basin, Wyoming, revealed a  $\delta^{74}\text{Se}$  variation of 100 ppt over an 18-inch interval. (Author's abstract.)

Weiss, H. V., 1971, Determination of selenium in glacial ice by radioactivation: *Anal. Chim. Acta*, v. 56, no. 1, p. 136–139; abs. in *Chem. Abs.*, v. 75, item 104763r, 1971.

A laboratory procedure for measuring the amount of selenium in samples of glacial ice is given.

Weiss, H. V., Koide, M., and Goldberg, E. D., 1971, Selenium and sulfur in a Greenland ice sheet; relation to fossil fuel combustion: *Science*, v. 172, no. 3980, p. 261–263.

In the combustion of fossil fuels, selenium is mobilized in the atmosphere to a much lesser extent than is sulfur because of the chemical behavior of their respective tetravalent oxides. The ratio of selenium to sulfur in glacial ice is characteristic of terrestrial matter, and these elements may find their way to ice sheets by the formation of volatile compounds in biochemical processes. (*Chem. Abs.*, v. 75, item 8674s, 1971.)

Wells, N., 1966, Selenium content of some minerals and fertilizers: *New Zealand Jour. Sci.*, v. 9, p. 409–415; abs. in *Chem. Abs.*, v. 65, col. 9684d, 1966.

Selenium contents are given for many fertilizers used in New Zealand and for a few sulfur-rich minerals. The selenium content of phosphatic minerals and soils is generally between 0.2 and 3.0 ppm. The content in the sulfur-bearing minerals varies considerably; the maximum is 1,950 ppm selenium from White Island, Bay of Plenty. (Mineralog. Abs., v. 18, p. 108, 1967.)

—1967, Selenium content of soil-forming rocks: New Zealand Jour. Geology and Geophysics, v. 10, no. 1, p. 198–208; abs. in Chem. Abs., v. 67, item 46016w, 1967.

Average selenium contents of soil parent rocks in New Zealand are as follows (in ppm): rhyolitic pumice 0.16, andesitic ash and andesite 1.19, basalt 0.61, granite 0.15, ultrabasic rocks 0.20, greywacke 0.36, argillite 1.80, mudstone 0.33, limestone 0.20, schist 0.22, gneiss 0.25. The average selenium content of the parent rocks of soils in New Zealand, calculated from the outcrop areas, is 0.42 ppm. (Mineralog. Abs., v. 19, p. 39, 1968.)

—1967, Selenium in horizons of soil profiles: New Zealand Jour. Sci., v. 10, p. 142–179; abs. in Chem. Abs., v. 67, item 66629b, 1967.

The average content of selenium in topsoils is greater than that of the parent rocks. The average selenium content of New Zealand topsoils is 0.60 ppm. Many soil profiles are tabulated showing the distribution of selenium from top to bottom.

Wiersman, J. H., and Lee, G. F., 1971, Selenium in lake sediments; analytical procedure and preliminary results: Environmental Sci. and Technology, v. 5, no. 12, p. 1203–1206; abs. in Chem. Abs., v. 76, item 16725v, 1972.

A fluorometric analytic procedure for the determination of selenium in lake sediments is presented. Selenium contents of sediments from 11 Wisconsin lakes and 1 South Dakota reservoir range from about 1–3  $\mu\text{g Se/g dry wt.}$  (Authors' abstract, condensed.)

Wojeiechowska, Jadwiga, and Serkies, Juliusz, 1969, Selenium in the Fore-Sudetic copper deposit (region of Lubin): Acad. Polonaise Sci. Bull., Sér. Sci. Géol. et Géog., v. 17, no. 2, p. 91–96; abs. in Chem. Abs., v. 72, item 92158v, 1970.

A photometric method was used to determine the selenium concentration in the deposit. The selenium concentrations vary from 1.2–36 ppm. The average Se:Te ratio in the sampled profiles is 4:1. This ratio is interpreted to show that the deposit was formed under reducing conditions that favored tellurium. The ratio of selenium to copper in shales and marls containing primary chalcopyrite is greater than in associated sandstones containing secondary chalcocite.

Yakovlev, Yu. N., Astaf'eva, V. V., and Astaf'ev, Yu. A., 1968, Distribution of selenium in copper-nickel ores of the Pechenga and Allarechensk area [in Russian]: Mat. Mineralog. Kol'sk Poluostr., v. 6, p. 50–66.

The ores of both areas studied have much higher selenium content than similar ores in other parts of the U.S.S.R. The Allarechensk ores have an exceptionally high content of selenium; they are as high as 0.92 percent in individual samples and average 0.01–0.02 percent in massive ores and 0.00 $n$  percent in disseminated and brecciated ores. The Pechenga ores contain less selenium but still have more than any other ores in similar deposits of the U.S.S.R. (Chem. Abs., v. 73, item 68458t, 1970, condensed.)

Yanitskii, I. V., and Zelionkaite, V. I., 1957, The reaction of selenosulfate with selenious acid: *Zhurn. Neorg. Khimii*, v. 2, no. 6, p. 1349-1355; translated in *Jour. Inorganic Chemistry*, v. 2, no. 6, p. 222-233.

Experimental results of the action of selenious acid on selenosulfate are presented. A new method of synthesis for potassium diselenotetrathionate is given.

Yanitskii, I. V., Zelionkaite, V. I., and Patsauskas, E. I., 1957, Analysis of some oxygen compounds of selenium and sulfur: *Zhurn. Neorg. Khimii*, v. 2, no. 6, p. 1341-1348; translated in *Jour. Inorganic Chemistry*, v. 2, no. 6, p. 209-221.

Experimental results for analytical methods for determination of selenium and selenium compounds are presented.

Yudin, I. M., 1964, On the relation between the content of selenium, tellurium and thallium in the pyrite-polymetallic ores and the degree of crystallinity of the ores: *Akad. Nauk SSSR, Doklady*, v. 155, p. 368-369; translated in *Acad. Sci. U.S.S.R. Doklady, Earth Sci. Sec.*, v. 155, p. 160-162; abs. in *Chem. Abs.*, v. 60, col. 15611a, 1964.

Selenium and tellurium, occurring as anions in minerals, preferentially enter into the well-crystallized varieties of the sulfides, whereas thallium occurs in minerals as a cation and tends to unite with the negatively-charged colloidal particles of copper, lead, and other sulfides. Analyses for selenium, tellurium, and thallium of colloform ores and of crystalline-granular ores from two deposits are tabulated. (*Mineralog. Abs.*, v. 18, p. 93, 1967.)

Yushko-Zakharova, O. E., 1964, Geochemistry of selenium and tellurium in copper-nickel deposits [in Russian]: *Akad. Nauk SSSR, Inst. Mineralogii, Geokhimii i Kristallokhimii Redkikh Elementov, Trudy*, no. 10, p. 100-124.

In spite of a similar type of distribution of the selenium and tellurium (increase of content with increased depth, preferable concentration in certain minerals, etc.) in these copper-nickel deposits (Monchegorsk, Pechenga, and Noril'sk) and the fact that they are chemically very similar elements, the tellurium formed minerals much more easily than selenium. The copper-nickel mineralization occurred in five stages as temperature gradually decreased and physicochemical conditions changed. Elevated concentrations of selenium and tellurium in the copper-nickel deposits correspond, in general, to decreased partial pressures of the products of  $H_2S$  dissociation. (*Chem. Abs.*, v. 61, col. 2841b, 1964, condensed.)

———1964, The geochemistry and mineralogy of selenium and tellurium in copper-nickel deposits [in Russian]: Moscow, Nauka, 112, p.

The geological characteristics of some selected copper-nickel deposits and the distribution and geochemistry of selenium and tellurium in these deposits are presented.

———1966, Copper-nickel deposits with selenium and tellurium [in Russian], in Vlasov, K. A., ed., *Geokhimiya mineralogiya i geneticheskie tipy mestorozhdeniy redkikh elementov*: Moscow, Nauka, v. 3, p. 29-40, 808-809; translated by Israel Program for Scientific Translations, Jerusalem, 916 p., 1968; abs. in *Chem. Abs.*, v. 68, item 4891t, 1968.

A study of selenium and tellurium behavior during copper-nickel mineralization. Selenium replaced sulfur isomorphously in sulfide lattices, while tellurium formed its own minerals in addition to entering the sulfide compounds. The maximum concentration of both elements occurred during the hydrothermal stage of mineralization.

Zainullen, G. G., Korolev, N. V., and Marchukova, I. D., 1964, New data on the mode of occurrence of selenium and tellurium in the Noril'sk copper-nickel ores: *Geokhimiya* 1964, no. 9, p. 917-925; abs. translated in *Geochemistry Internat.*, v. 1, p. 897; abs. in *Chem. Abs.*, v. 61, col. 13054b, 1964.

Selenium and tellurium were detected in solid solution in platinum-group metals, sulfides, and sulfosalts.

Zainullen, G. G., and Pashinkin, A. S., 1963, Thermodynamic solution of some geochemical problems of selenium and tellurium in the copper-nickel sulfide ores of the Noril'sk region: *Geokhimiya* 1963, no. 9, p. 843-850; translated in *Geochemistry* 1963, no. 9, p. 874-881; abs. in *Chem. Abs.*, v. 59, col. 15045a, 1963.

Standard heats of formation and entropies are tabulated for 26 tellurides, selenides, and sulfides of Cu, Ag, Fe, Co, Ni, Sn, Sb, and Bi. Calculated changes in the Gibbs free energy at 800° and 1,000°C for 39 reactions involving these chalcogenides are used to explain the presence of certain tellurides and selenides in the ores of the Noril'sk, Kola, and Sudbury deposits. (*Mineralog. Abs.*, v. 17, p. 28, 1965-1966.)

Zelenova, O. I., Viselkina, M. A., and Perel'man, A. I., 1970, Two classes of reducing geochemical barriers in exogenic uranium deposits [in Russian]: *Atomnaya Energiya*, v. 28, no. 1, p. 3-9.

Two different types of reducing barriers (sulfide and gley) were found in stratum oxidation areas of a uranium and selenium-bearing deposit. The sulfide barrier was characterized by a relatively high iron pyrite concentration (~0.5 percent) and low iron carbonate concentration (0.9 percent) and an above-average concentration of chalcophilic elements (Pb, Ni, Co, and Zn). The gley barrier was characterized by low iron sulfide and high iron carbonate concentrations (0.1 and 3.5 percent, respectively) and by a low concentration of chalcophilic elements. (*Chem. Abs.*, v. 73, item 17311g, 1970.)

Zingaro, R. A., and Cooper, W. C., eds., 1974, *Selenium*: New York, Van Nostrand Reinhold, 800 p.

All aspects of selenium are discussed, including its history, occurrence, agricultural and biochemical significance, and industrial applications.