GEOLOGICKÝ ZBORNÍK — GEOLOGICA CARPATHICA, 36, 4, BRATISLAVA, AUGUST 1985, Pp. 485—489

VALENTIN POKALOV*

ENDOGENIC MOLYBDENUM CONCENTRATIONS IN THE EVOLUTIONARY HISTORY OF THE CONTINENTAL CRUST

A b s t r a c t: In the Earth's crust there are molybdenum concentrations of various importance in connection with different geotectonic setting. They occur in island arcs, folded belts and epiplatform orogeny areas. Molybdenum abundance (g/t) in magmatic rocks increases gradually from ultrabasites (0.2) to basites (0.3—0.4), intermediate and hybrid rocks (0.8—1.3) and granites (1.0—1.4); as granitic-metamorphic layer of the Earth's crust develops, its molybdenum concentrations increase. The source of molybdenum is believed to be crustal for the economic copper-molybdenum, molybdenum and tungsten-molybdenum deposits genetically related to hybrid and felsic magma, but it is considered to be subcrustal for the insufficient molybdenum concentrations in copper deposits of island arcs and carbonates.

Р е з ю м е: В земной коре в связи с разными геотектоническими обстановками и магматизмом находятся разные по своему значению концентрации молибдена. Они встречаются в островных дугах, складчатых поясах и областях эпиплатформенной орогении. Содержание молибдена (г/т) в магматических породах закономерно нарастает от ультрабазитов (0,2) к базитам (0,3—0,4), средним и гибридным породам (0,8—1,3) и гранитам (1,0—1,4); по мере развития гранитно-метаморфического слоя земной коры в ней увеличиваются концентрации молибдена; источник молибдена промышленных месторождений медно-молибденовой, молибденовой и вольфрам-молибденовой формаций, генетически связанных с гибридными и кислыми магмами — преимущественно сиалическая кора, а незначительных проявлений в медных месторождениях островных дуг и карбонатитов — мантийный.

In the Earth's crust there are molybdenum concentrations of various importance in connection with different geotectonic setting. They occur in island arcs, folded belts and epiplatform orogeny areas (П о к а л о в, 1972; 1977).

Present island arcs (Aleutian, Boninskaya, Marianas, The Western Melanesia, the Solomon Islands, the New Hebrides, Fiji and others) develop on the oceanic crust from Eocene and they are area of extremely seismic activity. According to M u r a t o v (1975) and others the granitic-metamorphic layer is generated of the depth within the island arcs during the uprinsg of geoanticline.

Basaltic volcanism manifested on the early stage of island arcs and andesite with comagmatic plutons of diorite mainly revealed later. Streaky-impregnated and rare skarn copper deposits with accessory gold, silver, magnetite and high contents titanium (rutile) are connected spatially and genetically with the plutons. Ore reserves in deposits are estimated dozens and hundreds mln. tons and copper content is 0.5 % and more; molybdenum content is the first thousandth of a per cent.

It follows from D i c k i n s o n (1970); Ф о р — П а у э л л, 1974; Ж у р а в л е в — Ч е р н и ш е в — Ц в е т к о в а и д р. (1983) works who had studied the

* Prof. V. P o k a l o v, Ministry of Geology of the U.S.S.R., Bolshaya Gruzinskaya, Moscow.

variations of strontium and neodymium isotopic ratio in the island arcs magmatic rocks including ore-productive diorites that these rocks were of a mantle origin. The average $^{87}Sr/^{86}Sr$ ratio in andesite and diorite plutons did not exceed 0.7037. Therefore in source of copper and all associated ore components including molybdenum is the upper mantle.

Folded belts, in which copper-molybdenum deposits (porphyry, skarn and other types) are widely spread, were formed as a result of geosynclines' development. Cordilleras, Andes, Mediterranean Sea, Ural-Mongolian, Atlantic in Europe and America, Tasmanian and other belts are related to them.

Geosynclines' evolution lead to the creation of granitic-metamorphic (sialic) layer of the Earth's crust, which distinguishes continental crust from the oceanic one. Age of copper-molybdenum deposits strictly coincides the epigeosynclinal orogeny in all above-mentioned folded belts. By that time sialic layer has already been formed to a considerable extent and essentially influenced on magmatism.

As a rule, copper-molybdenum deposits occur in eugeosyncline within geoanticlinal uplift mainly, with which development connects the formation of large masses of granitoids of hybrid nature. Deposits also occur in sites of joints of folded belts of different age, in relic geoanticlines and stable blocks of median mass type. Rarely rather as an exception, for example, in the North-American Cordilleras copper molybdenum deposits occur in miogeosyncline.

Location of deposits is determined by spatial relation and consanguinity with trachyandesite formation and its comagmatic batholite of varied composition, composed by monzonites, syenites, granosynenites, granodiorites, diorites and granites. As a whole this complex of volcanic and plutonic ore-productive rocks in comparison with the same of island arcs, is characterized by obvious hyperalkalinity and more distribution of acid rocks. More than 50 % of proved commercial copper reserves are in copper-molybdenum deposits of folded belts. Molybdenum is an accessory component (ratio copper/molybdenum in ores varies from 10 : 1 to 50 : 1). Proved molybdenum reserves in these deposits are about 30 % of its total world reserves. The average copper content in the primary ores varies from 0.2—0.3 % to 1.0—2.0 %, molybdenum from 0.005 % to 0.04—0.06 %. Sometimes in small deposits it reaches 0.2—0.3 %. Gold and silver are often simultaneously extracted from ores, but in contrast to island arc deposits their contents are considerably less. Magnetite is of no practical interest. High contents of titanium in ores are seldom or are not found at all. $^{87}Sr/^{86}Sr$ ratio in rocks, formed plutons of mixed composition in the Cordilleras of North America (batholites of Sierra Nevada, Coastal Ridge, Santo-Rito, the British Colombia) in Mediterranean belt (deposit Bakirkey, Turkey) vary within 0.7043—0.7250 (Taylor, 1981; Taylor—Fryer, 1983; Taylor—Silver, 1978). Many explorers come to a conclusion about mixing mantle and crustal melting while forming plutons of mixed composition and also rocks of trachy-andesite formation. Values $\delta^{18}0$ in pluton rocks in the Cordilleras (Taylor—Fryer, 1983) and the South of Krasnoyarsk Territory (U.S.S.R.) testify to it; these values are +9.0 up to +12.0 %. With decrease of rock basicity from early magmatic phase to later ones $\delta^{18}0$ value regularly increases that obviously testifies to the increasing role of sialic material in melt from early magmatic phases to later ones. Thus, hybrid, mixed magma of rather high alkalinity is the source of copper-molybdenum mineralization.

Epiplatform orogeny areas, where molybdenum and molybdenum with tungsten and bismuthite deposits occur can be divided into two types: 1) areas of large basin of extrageosynclinal origin (for example, the Eastern Asian type) with volcanites of trachyandesite-liparite formation and plutons of subalkaline-biotite and amphibole-biotite granites, granodiorites and granosyenites; 2) areas of less contrasting tectonic movements with trachyliparite formation and plutons of subalkaline leucocratic granites.

Mongolo-Okhotsk belt in Mesozoic, the Western Zabaikalye in the Upper Paleozoic, the eastern branch of the Rocky Mountains (U.S.A.) in Laramide, some regions of Korean-Chinese platform in Janshan are related to the first type. Here magmatism and mineralization manifestated after estabilization of platform where continental crust has been already formed and during the epigeosynclinal orogeny tectonic movements are less contrasting. Deposits localized in uplifts, divided basins and in the frame of the latter. In ores of molybdenum deposits copper is practically absent, though in some deposits it is advisable to extract it from ore as by-product. There is tungsten in small concentrations, that can be extracted from some deposits. Molybdenum reserves in stockwork reach 1 mln. t. Molybdenum content is up to 0.25 % (Genderson, U.S.A.).

Mesozoic igneous rocks of trachyandesite formation in Mongolo—Okhotsk belt are rich in light lanthanoids. Stable europium minimum in them can be caused by the mechanism of mixing the abyssal alkali-basaltic magma with acid melts of crustal origin. About the same mechanism of forming magmas testify high $\delta^{18}O$ (+9.0 — +10.0 %) values in the Upper Paleozoic granitoids of the Western Zabaikalye and initial ratio of strontium isotopes in mother pluton of Questa (U.S.A.), equal 0.7069. Predominance of granodiorites, granosyenites, biotite and amphibole-biotite granites in felsic ore-bearing plutons suggest of prevalent role of sialic crustal melts in ore-productive magma.

The second type of epiplatform orogeny areas with tungsten-molybdenum deposits one should relate Early Caledonides of the Western Zabaikalye in Mesozoic, Caledonides and Hercynides of Central Kazakhstan and the South Urals in the Upper Permian, some areas in Mongolia in Mesozoic, some areas in the South-American platform in Paleozoic, Tasmania folded belt in the Upper Paleozoic of Australia.

The tectonic movements were less tense and contrasting during the period of the epiplatform orogeny in areas of the second type than in areas of the first type. Large superpositioned basins are usually absent here. Both volcanism and intrusive magmatism are presented by exceptionally acid subalkaline formations, formed from melts of sialic part of the Earth's crust.

Spatially deposits are closely related to apical parts of hypabyssal plutons, composed by leucocratic granites. Ores are complex and contain molybdenum, tungsten, bismuth, sometines accessory beryllium, rarely tin. Copper is practically absent. Deposits of stockwork and skarn type are very large and molybdenum content is up to 0.1 and WO_3 is up to 0.3 %

Besides molybdenum mineralization of types in question on the platforms and in framed areas of completed folding occurrences a molybdenum are known in connection with carbonatites and in association with rare elements, copper and iron. Carbonatites are related to alkaline ultrabasites, which intrusion often preceded rifting. Ratios $^{87}Sr/^{86}Sr$ in carbonatite massives of Grenvil province vary from 0.7020 to 0.7040, average 0.7034 ± 0.0003. Within an error

this figure is identical to average $^{87}Sr/^{86}Sr$ ratio in oceanic basalts (0.7037), i. e. the source of molybdenum in this case is mantle as in island arc deposit.

Thus, short review of molybdenum concentration in the Earth's crust show the direct connection between geotectonic settings, kind of magmatism and the matter (elemental) ore composition. The copper deposits abundant in gold and silver and with minor amount of molybdenum (not exceeding 0.00n %) are formed at the early geosynclinal stage (present island arcs) in the state of incipient granitic-metamorphic layer, when magmatism is mostly associated with melting and differentiation of mantle (andesite sequences and its diorite comagmates). Magnetite and titanium minerals are also present in these deposits. Large complex molybdenum-copper deposits (the average Mo content — 0.02—0.04 %) are formed during the epigeosynclinal orogeny within the crust with developed granitic-metamorphic layer in association with hybrid magmatism in which mantle and crust melts (plutons of mixed composition) play an important role. Monometallic high grade deposits (up to 0.2—0.3 % Mo) with essential reserves are formed during epigeosynclinal orogeny within continental crust when crustal melts of moderately felsic granites dominate, but large complex tungsten-molybdenum deposits associate with leucocratic granites' development. The alkaline ultrabasites (subcrustal melts) and carbonates associated with the riftogenesis appear to have insufficient molybdenum concentrations. Molybdenum abundance (g/t) in magmatic rocks increases gradually from ultrabasites (0.2) to basites (0.3—0.4), intermediate and hybrid rocks (0.8—1.3) and granites (1.0—1.4); as granitic-metamorphic layer of the Earth's crust develops, its molybdenum concentrations increase. The source of molybdenum of commercial deposits genetically related to hybrid and acid magma is mainly sialic crust, but it is considered to be mantle for the insufficient molybdenum concentrations in copper deposits of island arc and carbonatites.

Magma generated molybdenum deposits contains plenty of silica and is characterised by high alkalinity. Obviously, in this connection kalispathization and silicification of host rocks, contained mineralization are widely spread in molybdenum deposits. Experimental studies showed high solubility of molybdenum in aquatic alkali-siliceous solutions (I s u k — C a r m a n, 1981). Such solutions can be derived from magma of above-mentioned composition, extracted and carried molybdenum enough for forming large deposits.

REFERENCES

DICKINSON, W. R., 1970: Relation of andesites, granites and derivative sandstones to arc-trench tectonics. Rev. Geophys. (Washington), pp. 813—860.

ISUK, E. — CARMAN, J., 1981: The system $Na_2Si_2O_5$ — $K_2Si_2O_5$ — MoS_2 — H_2O with implication for molybdenum transport in silicate melts. Econ. Geol. (Lancaster, Pa.), 76, 8, pp. 2222—2235.

TAYLOR, R. P., 1981: Isotope geology of the Bakirkey porphyry copper prospect, northern Turkey. Mineralium Depos. (Berlin), 16, 13, pp. 375—390.

TAYLOR, R. P. — FREYER, B. J., 1983: Strontium isotope geochemistry of the Santa Rita porphyry coper deposit, New Mexico. Econ. Geol. (Lancaster, Pa.), 78, 1, pp. 170—174.

TAYLOR, R. P. — SILVER, Z. T., 1983: Oxygen isotope relationships in the plutonic igneous rocks of the Peninsular Ranges batholith, Southern and Baja California. In: Zartman, R. E. ed., Short papers of the fourth international conference, geochronology, isotope geology. Open file report, U.S. geol. Surv., 78—701, pp. 423—426.

WESTRA, G. — KEITH, S. B., 1981: Classification and genesis of stockwork molybdenum deposits. Econ. Geol. (Lancaster, Pa.), 76, pp. 844—873.
ЖУРАВЛЕВ, Д. З. — ЧЕРНЫШЕВ. И. В. — ЦВЕТКОВА, А. А. и др., 1983: Вариации изотопных отношений $^{143}Nd/^{144}Nd$ и $^{87}Sr/^{86}Sr$ в магматических породах Алеутской островной дуги в связи с проблемой их петрогенеза. Докл. Акад. Наук СССР, Сер Геол., 270, 6, pp. 1457—1461.
МУРАТОВ, М. В., 1975: Происхождение материков и океанических впадин. Недра, 176 pp.
ПОКАЛОВ, В. Т., 1972: Генетические типы и поисковые критерии эндогенных месторождений жолибдена. Недра, 272 pp.
ПОКАЛОВ, В. Т., 1977: Формации месторождений молибдена. В кн.: Принципы прогноз и оценки месторождений полезных ископаемых. Недра, 1., pp. 156—215.
ФОР, Г. — ПАУЭЛЛ, Дж., 1974: Изотопы стронция в геологии. Мир, 214 pp.

Manuscript received October 1, 1984

The author is responsible for language correctness and content.