ON THE COMPOSITION AND NOMENCLATURE OF THE LOELLINGITE–GROUP DIARSENIDE MINERALS

Raisa A. Vinogradova
Lomonosov Moscow State University. Moscow

The composition of loellingite-group diarsenide minerals with wide range of Fe, Co, and Ni content is discussed. A nomenclature distinguishing mineral species loellingite, safflorite and rammelsbergite, and Co-bearing loellingite, Ni-bearing loellingite, Fe-bearing safflorite, Co-bearing rammelsbergite, and Fe-bearing rammelsbergiteis suggested. Chemical composition fields and Fe, Co, Ni concentration (at %) range in minerals and varieties are presented. This nomenclature allows to recognize features of individual compositions of the loellingite-group diarsenides that corresponds to their names.
1 table, 1 figure, 12 reference

Rhombic diarsenides of the loellingite group including loellingite $FeAs_2$, safflorite $CoAs_2$, and rammelsbergite $NiAs_2$ with structures similar to marcasite (Borishanskaya *et al.*, 1981; Vinogradova & Bochek, 1980). Rhombic pararammelsbergite $NiAs_2$, cubic krutovite $NiAs_2$, and monoclinic clinosafflorite $CoAs_2$ are less abundant and are different from the loellingite-group minerals in structure. However, the structure of clinosafflorite is very similar to the structure of loellingite/safflorite.

Diarsenides of the loellingite group (Borishanskaya *et al.*, 1981) are characteristic of Co-Ni-Ag-Bi-U deposits and similar Ni-Co arsenide deposits. In addition, they occur in Cu-Ni sulfide deposits and in niccolite-chromite veins. Loellingite and safflorite have been described from iron-bearing skarns, alkaline and granitic pegmatites. Furthemore, loellingite has been identified in greisen, sulfide-cassiterite, and arsenopyrite deposits.

Compositional data on the natural diarsenides of the loellingite group are reviewed by Borishanskaya *et al.* (1981), Vinogradova & Bochek (1980) and Gritsenko *et al.* (2004). All three metals of the iron group form these diarsenides with one or two of them predominating. Natural solid-solutions of the continuous loellingite-safflorite series are common, whereas the solid solutions of the continuous safflorite-rammelsbergite series are less abundant. Recently, solid solutions of the continuous safflorite-rammelsbergite series were discovered (Gritsenko *et al.*, 2004). Due to the latter discovery, the previously recorded field of ternary solid-solution (Vinogradova & Bochek, 1980) in the loellingite group indicates the practically complete isomorphic substitution between Fe, Co, and Ni in the loellingite-group diarsenides and wide range of concentrations of these elements (Fig. 1a).

Previously, some scientists have tried to define limits of the loellingite-group minerals on the basis of chemical composition, but such limits are not universally agreed upon (Vinogadova & Bochek, 1980). Current available compositional data for the loellingite-group diarsenides and suggested nomenclature of minerals in ternary systems (Nickel, 1992) allow development of a comprehensive nomenclature of the loellingite-group diarsenides. According to Nickel (1992), loellingite $(Fe,Co,Ni)As_2$, safflorite $(Co,Fe,Ni)As_2$, rammelsbergite $(Ni,Co,Fe)As_2$, and corresponding composition fields should be defined on the basis of the predominant iron-group metal (Fig. 1b). However, compositional features of individual representatives of the loellingite group are lost in this approach due to the wide range of composition of each mineral. Therefore, modification of the nomenclature is advisable, and proper minerals (loellingite, safflorite, and rammelsbergite) and their varieties should be defined. The 80 at.% content of the major metal is taken as the limit between a mineral species and a variety. This is justified by the observation that diarsenides with 80 and more at.% of the major metal are not zoned under reflected light, whereas diearsenides with more complex composition are characterized by zoning. It should be noted that the rhombic symmetry of safflorite is modified to monoclinic (clinosafflorite) at a Co content of 80 at.% (Radcliffe & Berry, 1968; 1971) and there is dimorphism of $CoAs_2$ at higher Co contents. Furthermore, it should be taken into account that simple formulae $MeAs_2$, corresponding to the compositions of type minerals with dominant content of Fe, Co, or Ni, are given in textbooks and handbooks on mineralogy. Previously reported Co-rich rammelsbergite (Vinogradova *et al.*, 1972), Ni-rich loellingite (Oen *et al.*, 1971; Bukovshin & Chernyshov, 1985; Cervilla & Ronsbo, 1992; Gamyanin & Lykhina, 2000), Ni- and Co-rich loellingite (Distler *et al.*, 1975), and Ni-rich safflorite (Radcliffe, Berry, 1968) correspond to varieties of corresponding minerals named according to their chemical features.

Taking into account the above arguments, the nomenclature of the rhombic diarsenides of the loellingite group can be presented as follows. In the composition fields of loellingite, safflorite and rammelsbergite (Fig. 1b), mineral species (end members) are defined as follows: loellingite, safflorite and rammelsbergite with a content of the major metal of 80 and more at.%. Varieties (intermediate members) are as having a content of major metal of less than 80 at.% and a predominance of one of two other metals: Co- and Ni-bearing loellingite, Fe- and Ni-bearing safflorite, and Co- and Fe-bearing rammelsbergite (Fig. 1c, Table).

The nomenclature suggested here is more exact and the individual compositions of diarsenide minerals are represented in the corresponding name.

Acknowledgements

The author is grateful to O.L. Sveshnikova, senior scientific researcher, Fersman Mineralogical Museum, Russian Academy of Sciences and S.N. Bubnov, scientific researcher, Institute of Geology of Ore Deposits, Russian Academy of Sciences, for the constructive discussion of this paper.

References

Borishanskaya, S.S., Vinogradova, R.A. & Krutov, G.A. (**1981**): Minerals of cobalt and nickel. Moscow State University Publ., Moscow (in Russ.).

Table. **Nomenclature and chemical composition of the loellingite-group diarsenides ($MeAs_2$) based on relationship of Fe, Co, and Ni**

Mineral species (end-members of isomorphic series)	Variety (intermediate members of isomorphic series)
Content of major Me > 80 at.%	Content of major Me < 80 at.%
1. Loellingite	1a. Co-bearing loellingite
Fe>>(Co+Ni)	Fe>Co>Ni
Fe_{80-100}* $(Co+Ni)_{20-0}$	$Fe_{80-33.3}Co_{10-50}Ni_{0-33.3}$
	1b. Ni-bearing loellingite
	Fe>Ni>Co
	$Fe_{80-33.3}Ni_{10-50}Co_{0-33.3}$
2. Safflorite	2a. Fe-bearing safflorite
Co>>(Fe+Ni)	Co>Fe>Ni
$Co_{80-100}(Fe+Ni)_{20-0}$	$Co_{80-33.3}Fe_{10-50}Ni_{0-33.3}$
	2b. Ni-bearing safflorite
	Co>Ni>Fe
	$Co_{80-33.3}Ni_{10-50}Fe_{0-33.3}$
3. Rammelsbergite	3a. Co-bearing rammelsbergite
Ni>>(Co+Fe)	Ni>Co>Fe
$Ni_{80-100}(Co+Fe)_{20-0}$	$Ni_{80-33.3}Co_{10-50}Fe_{0-33.3}$
	3b. Fe-bearing rammelsbergite
	Ni>Fe>Co
	$Ni_{80-33.3}Fe_{10-50}Co_{0-33.3}$

Notes: * is range of concentration of the iron-group metals (at.%). The composition fields of mineral species and varieties listed in this table are shown in Figure 1c.

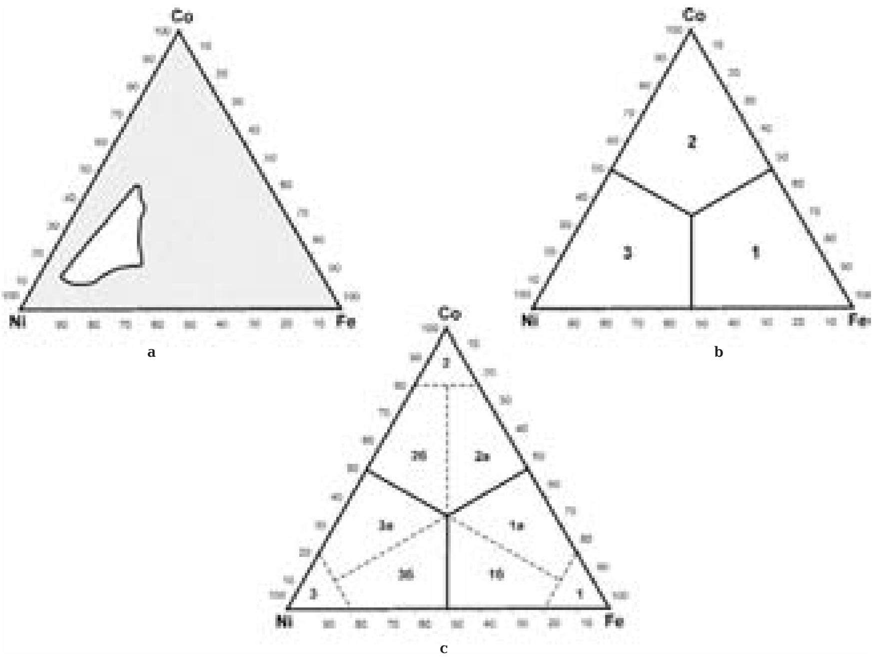

Fig. 1. Chemical composition and nomenclature of the loellingite-group diarsenide minerals on the basis of the proportion of Fe, Co u Ni (at. %).
(a) data on chemical composition (Vinogradova & Bochek, 1980; Gritsenko et al., 2004); not identified natural compositions are white field.
(b) nomenclature and composition fields according to (Nickel, 1992): loellingite (1), safflorite (2), and rammelsbergite (3).
(c) suggested nomenclature and composition fields: loellingite (1), Co-bearing loellingite (1a), Ni-bearing loellingite (1b), safflorite (2), Fe-bearing safflorite (2a), Ni-bearing safflorite (2b), rammelsbergite (3), Co-bearing rammelsbergite (3a), and Fe-bearing rammelsbergite (3b). Crosspoint of lines in the center of ternary plot corresponds to equal contents of three metals (by 33.3 at. %)

Bukovshin, V.V. & Chernyshov, N.N. (**1985**): Arsenides and diarsenides of the Cu-Ni ores from the Voronezh crystalline massif // Zap. VMO., 114(3), 335 – 340 (in Russ.).

Cervilla, F. & Ronsbo J. (**1992**): New date on (Ni,Co,Fe) diarsenides and sulfarsenides in chromite-niccolite ores from Malaga Provins, Spain // Neues Jahrb. Mineral Monatsh., 193 – 206.

Distler, V.V., Laputina I.P. & Smirnov A.V. (**1975**): Arsenides, sulfarsenides, and antimonides of nickel, cobalt, and iron in the Talnakh ore field // In: Minerals and mineral parageneses of endognic deposits. Nauka, Leningrad (61 – 74) (in Russ.).

Gamyanin, G.N. & Lykhina, E.I. (**2000**): Ni-Co arsenides and sulfoarsenides of gold-rare metal deposits, East Yakutia // Zap. RMO, 129(5), 126 – 138 (in Russ.).

Gritsenko, Yu.D., Spiridonov, E.M. & Vinogradova, R.A. (**2004**): New data on diarsenides of the loellingite-rammelsberite series // Dokl. RAS, Earth Sci. Sect., 399A(9), 1264 – 1267.

Nickel, E. H. (**1992**): Solid solutions in mineral nomenclature // Can. Mineral., 30, 231 – 234.

Oen, J.S., Burke, E.A., Kieft, C. & Westerhof, A.B. (**1971**): Ni-arsenides, Ni-rich- loellingite and (Fe,Co)-rich gersdorffite in Cr-Ni-ores Malaga Province, Spain // Neues Jahrb. Mineral. Abh. Bd 115. Hf. 2., 123 – 139.

Radcliffe D. & Berry L.G. (**1968**): The safflorite-loellingite solid series // Amer. Mineral., 53, 1856 – 1881.

Radcliffe D. & Berry L.G. (**1971**): Clinosafflorite: a monocllinic polymorphe of safflorite // Can. Mineral., 10, 877 – 881.

Vinogradova, R.A., Eremin, N.I. & Krutov, G.A. (**1972**): The Co-rich rammelsbergite from the Bouazzer district, Morocco // Dokl. AN SSSR, 207(1), 161 – 163 (in Russ.).

Vinogradova, R.A. & Bochek, L.I. (**1980**): Composiiotn and optical parameters of iron, cobalt, and nickel diarsenides // Izv. AN SSSR. Ser. Geol., No 2, 87 – 100 (in Russ.).