Sulfide Inclusions in Early Lamproite Minerals.

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The presence of small amounts of sulfides is typical of lamproites. They were recognized in the groundmass of different lamproite types: in the Smoky Butte hyalolamproites - pyrite and pyrrhotite, in the Ellendale-11 olivine lamproite - chalcopyrite, in the SE Spain jumillite - galenite *(Sharygin et al., 1998).* Pentlandite and pyrrhotite occur with talc in olivine pseudomorphs from the groundmass of the AK1 olivine-phlogopite lamproite *(Jaques et al., 1989).* However, taking into account the influence of alteration processes on the above rocks, the nature of these sulfides may be considered as secondary. Chalcopyrite has been previously identified as daughter phase in silicate-melt inclusions in leucite from the Leucite Hills wyomingite and the Oscar Plug olivine-leucite lamproite *(Mitchell, 1991).* This is a severe evidence about magmatic nature of chalcopyrite in lamproites. Polyphase sulfide inclusions were found in the earliest phenocrysts of lamproites during fluid inclusion study. They are observed in lamproites of Smoky Butte, Fortuna and Leucite Hills.

Olivine hyalolamproite, Smoky Butte, Montana, USA.

Sulfides rarely occur as rounded globules (1-30 μm) in olivine-1 phenocrysts only (Mg# - 0.87-0.92, 0.5-0.8 wt.% NiO, size -1-5 mm). Sometimes they are associated with primary silicate-melt inclusions (T_{hom}>1250°C) *(Sharygin, 1997; Sharygin et al., 1998).* The blebs are represented by following mineral associations: pentlandite + chalcopyrite; possible monosulfide solid solution (MSS) + chalcopyrite; violarite. Chalcopyrite in the essential amounts (up to 20 vol.%) occurs only in the largest (up to 20-30 μm) globules, while in small blebs it forms thin outer rim.

Fortunite, Fortuna, SE Spain.

Sulfides are observed as both single globules (up to 20 μm) and isolations in primary silicate-melt inclusions hosted by orthopyroxene and phlogopite phenocrysts. Sulfide globules in enstatite are represented by following assemblages: pentlandite + possible MSS, pentlandite, MSS, pentlandite + pyrrhotite. Small octahedral crystals of Fe-oxide (wüstite ?) occasionally occurs in some sulfide globules. Homogenization temperature of silicate-melt inclusions coexisted with sulfide blebs in enstatite occurred at 1350°C.

Olivine orendite, North Table Mountain, Leucite Hills, USA.

Sulfides are found as globules (1-20 μm) in phenocrystal (xenocrystal) olivine only. They form rare trails in the host olivine and are associated with secondary fluid inclusions, sometimes with secondary silicate-melt inclusions (T_{hom}=1010-1100°C). The large sulfide blebs consist of MSS or MSS + chalcopyrite. Sometimes oriented isolations of pentlandite may be observed in MSS.

Thus, homogenization temperatures of silicate-melt inclusions coexisted with sulfide globules are an evidence about high temperatures of trapping of sulfides (or sulfide melt) during crystallization of lamproitic liquid, which vary for different localities: >1250°C - Smoky Butte; 1350°C - Fortuna; >>1100°C - Leucite Hills.

Chemistry of sulfide minerals.

In general, phase composition of sulfide globules and chemistry of some phases (pentlandite, chalcopyrite, pyrrhotite) from lamproites studied approaches to that of sulfide inclusions in diamonds, in mantle xenoliths, in minerals of kimberlites and kamafugites *(De Waal and Calk, 1975; Yefimova et al., 1983; Gurenko et al., 1989; Bulanova et al., 1990; Deines and Harris, 1995; Szabo and Bodnar, 1995; etc.).* The main distinctive feature of sulfide inclusions in the Smoky Butte and Fortuna lamproites is extremely high Ni content in possible MSS (up to 50-63 wt.%) *(see Table).* No

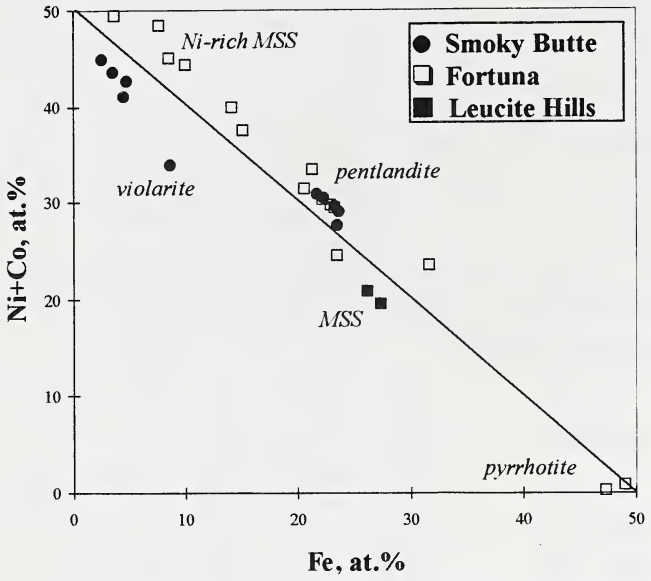
MSS with that composition are found anywhere. However, possible MSS from the Smoky Butte and Fortuna lamproites drastically differ in chemical composition *(see Figure)*. The MSS from fortunite has ratio Me/S (in at.%) equal to 1.13-1.29 and probably belongs to the pentlandite type of solid solutions $(Fe,Ni)_{9+x}S_8$. Nevertheless, it does not except that this phase may be godlevskite $(Ni,Fe)_7S_6$ (Me/S=1.14) found in Cu-Fe-Ni-ores of the Noril'sk group *(Kulagov et al., 1969; Czamanske et al., 1992)* or microintergrowth of heazlewoodite $(Ni,Fe)_3S_2$ and pentlandite. The MSS from the Smoky Butte lamproite is characterized by Me/S ratio equal to 0.98-1.00 and seems to be a member of the hexapyrrhotite solid solutions $(Fe,Ni)_{1-x}S$. The MSS from Smoky Butte and Fortuna are also distinguished in the Cu content (up to 5.5 and 0.3 wt.%, respectively). The MSS from Leucite Hills is also characterized by the high Ni content (up to 27 wt.%), but has composition intermediate between $(Fe,Ni)_9S_{10}$- and $(Fe,Ni)_7S_8$-types of solid solutions. The similar MSS has been found in diamonds *(Sobolev et al, 1997)*.

Table. Sulfide inclusions in the early lamproite minerals.

Host mineral Rock, *Locality*	**Phase composition of sulfide inclusions**	**Phase**	**Fe**	**Ni**	**Co**	**Cu**	**S**	**Total**	***n***
					wt.%				
Olivine-1	Pn + Cp	Pn	28,89	37,27	0,17	0,46	33,10	99,89	1
olivine	Pn+Cp	Pn	28,53	37,97	0,17	0,68	32,79	100,14	1
hyalolamproite	MSS+Cp	MSS	4,36	56,32	0,00	3,42	35,49	99,59	1
Smoky Butte	Pn+Cp	Pn	26,55	39,70	0,10	0,09	33,43	99,87	2
USA	Viol	Viol	11,07	45,47	0,13	1,60	41,50	99,77	2
	MSS+Cp	MSS	3,20	58,27	0,00	2,69	35,81	99,97	2
	MSS+Cp	MSS	5,52	53,03	0,00	5,51	35,79	99,96	2
	MSS+Cp	MSS	5,93	55,13	0,00	3,68	35,26	99,94	1
	MSS+Cp	Cp	30,37	0,14	0,00	34,28	34,91	99,70	1
	Pn+Cp	Pn	29,11	35,85	0,17	0,17	34,81	100,11	1
		Cp	30,50	0,21	0,00	34,30	34,92	99,93	1
	Pn+Cp	Pn	27,30	39,21	0,11	0,19	33,18	99,99	2
		Cp	30,67	0,21	0,00	34,19	34,90	99,97	1
Enstatite	Pn	Pn	28,56	31,29	0,09	7,25	32,73	99,92	1
fortunite	Pn+MSS	Pn	18,43	48,15	0,06	0,11	33,20	99,95	1
SE Spain		MSS	10,33	57,29	0,00	0,22	32,12	99,96	1
	MSS	MSS	4,44	62,85	0,00	0,05	32,62	99,96	1
	Pn+MSS	Pn	25,01	41,03	0,21	0,10	33,61	99,96	2
		MSS	9,10	60,67	0,00	0,31	29,91	99,99	2
	Pn	Pn	27,28	38,91	0,23	0,06	33,40	99,88	1
	Pn	Pn	25,18	40,52	0,12	0,50	33,51	99,83	1
	Pn+MSS	Pn	28,59	37,96	0,07	0,02	33,28	99,92	4
		MSS	12,04	56,13	0,07	0,09	31,60	99,93	1
	Pn+Po	Pn	36,60	29,96	0,35	0,04	32,95	99,90	1
		Po	62,22	1,11	0,00	0,02	36,56	99,91	1
	Pn+Po	Po	60,91	0,28	0,00	0,01	38,78	99,98	1
	MSS	MSS	17,13	50,78	0,08	0,25	31,71	99,95	1
	Pn±MSS	Pn	28,14	38,17	0,20	0,01	33,35	99,87	2
Olivine	MSS±Pn	MSS	34,73	25,59	0,61	0,00	38,72	99,65	6
olivine orendite	MSS+Ch	MSS	33,34	27,40	0,47	0,15	38,69	100,05	1
Leucite Hills		Ch	31,24	0,64	0,07	32,91	34,91	99,77	1

***Pn** - pentlandite, **Cp** - chalcopyrite, **Po** - pyrrhotite, **MSS** - possible monosulfide solid solution, **Viol** - violarite, **n** - number of analyses.*

Figure.
Fe-(Ni+Co) variations in Fe-Ni sulfides hosted by early lamproite minerals.



References

Bulanova, G.P., Spetsius, Z.V., and Leskova, N.V., 1990, Sulfides in diamonds and xenoliths from kimberlite pipes of Yakutia: *Novosibirsk, Nauka,* 119 pp.

Czamanske, G.K., Kunilov, V.E., Zientek, M.L., Carbi, L.J., Likhachev, A.P., Calk, L.C., and Oscarson, R.L., 1992, A proton-microprobe study of magmatic sulfide ores from the Noril'sk-Talnakh district, Siberia: *Can. Mineral.,* **30**, p. 249-287.

Deines, P., and Harries, J.W., 1995, Sulfide inclusion chemistry and carbon isotopes of African diamonds: *Geochim. Cosmochim. Acta,* **59**, p. 3173-3188.

De Waal, S.A. and Calk, L.C., 1975, The sulfides in garnet pyroxenite xenoliths from Salt Lake Crater, Oahu: *J. Petrol.,* **16**, p. 134-153.

Gurenko, A.A., Sobolev, A.V., and Kononkova, N.N., 1989, New data on the petrology of ugandites from East African rift based on the study of magmatic inclusions: *Dokl. Akad. USSR,* **305**, p. 1458-1463.

Jaques, A.L., Haggerty, S.E., Lucas, H. and Boxer, G.L., 1989, Mineralogy and petrology of the Argyle (AK1) lamproite pipe, Western Australia: *Geol. Soc. Austr. Spec. Publication,*, **14(1)**, p. 153-169.

Kulagov, E.A., Evstigneeva, T.L., and Yushko-Zakharova, O.E., 1969, Goglevskite, a new iron-nickel sulfide: *Geol. Rudnykh Mestorozhdenii,* **11(3)**, p. 115-121.

Mitchell, R.H., 1991, Coexisting glasses occurring as inclusions in leucite from lamproites: examples of silicate liquid immiscibility in ultrapotassic magmas: *Mineral. Mag.,* **55**, p. 197-202.

Sharygin, V.V., Panina, L.I., and Vladykin, N.V., 1998, Melt inclusions in minerals from lamproites of Smoky Butte, Montana: *Russian Geol. Geophys.*, **39(1)**, p. 38-54.

Sharygin, V.V., 1997, Evolution of lamproites suggested by inclusions in minerals: *Russian Geol. Geophys.*, **38(1)**, p. 136-147.

Sobolev, N.V, Kaminsky, F.V., Griffin, W.L., Yefimova, E.S., Win, T.T., Ryan, C.G., and Botkunov, A.I., 1997, Mineral inclusions in diamonds from the Sputnik kimberlite pipe, Yakutia: *Lithos,* **39**, p.135-157.

Szabo, Cs, and Bodnar, R.J., 1995, Chemistry and origin of mantle sulfides in spinel peridotite xenoliths from alkaline basaltic lavas, Nógrád-Gömör volcanic field, northern Hungary and southern Slovakia: *Geochim. Cosmochim. Acta,* **59**, p. 3917-3927.

Yefimova, E.S., Sobolev, N.V., and Pospelova, L.N., 1983, Sulfide inclusions in diamonds and specific features of their paragenesis: *Zap. Vsesoyu. Mineral. Obsch.,* **112**, p. 300-310.