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Fast Track Article

Cobaltoan Pyrite in a Lamprophyre from the Sidhi Gneissic Complex, Mahakoshal Belt, Central India

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ABSTRACT

Pyrite containing appreciable content of cobalt (up to 5.61 wt%) and minor amounts of nickel (up to 0.70 wt%) is being reported from electron microprobe studies in a lamprophyre dyke from the Sidhi complex, Mahakoshal belt, Central India. However, cobalt and nickel are conspicuously absent from the associated chalcopyrite reflecting that in a pyrite-chalcopyrite association these elements are preferentially sequestered in pyrite. The microprobe analysis of pyrite grains reveal that their Fe content is variable (40.62 to 46.02 wt%) and reciprocally related to cobalt and nickel concentrations implying the presence of latter as solid solution in the structure of pyrite. The cobalt contents of the pyrite are comparable to those (up to 3.21 wt%) reported from the cobalt-bearing pyrites of the Kalyadi copper deposits of Dharwar craton of southern India. Co:Ni (16.05 average) in the studied pyrite appears to be more consistent with a magmatic, rather than a hydrothermal, origin. However, further studies are in progess. This study highlights that besides gold and diamond, lamprophyres are also important carriers of cobalt when available in the magmatic system.

INTRODUCTION

Lamprophyres are small-volume, deep mantle-derived, volatile-rich alkaline igneous rocks and are widely considered as products of a metasomatised (enriched) mantle and owing to their occurrence in varied tectonic regimes are regarded to of geodynamic significance (e.g., Rock, 1991; Garza et al., 2013; Stoppa et al., 2014; Krmíèek et al., 2016). Lamprophyres contain high abundances of both compatible as well as incompatible trace elements and some of their occurrences are also known to be economically important hosts of diamond and gold (Rock and Groves, 1988; Lefebvre et al., 2005). During the course of petrological investigations on lamprophyres from the Sidhi Gneissic Complex of the Mahakoshal belt, central India, we have encountered pyrites which are exceptionally enriched in cobalt content. The purpose of this communication is to record the occurrence of these cobaltoan pyrites and to explore their plausible significance.

GEOLOGICAL SETTING

The Central Indian Tectonic Zone (CITZ; Fig.1A), a ENE–WSW trending Mesoproterozoic orogenic belt, is widely considered as a suture between the northern Indian block (comprising the Aravalli and the Bundelkhand cratons) and the southern Indian block (the Bastar, the Dharwar and the Singhbhum cratons) (see Yedekar et al., 1990; Jain et al., 1991; Roy and Devarajan, 2000; Roy and Hanuma Prasad, 2003). A number of shear zones traverse through CITZ of which the Son-Narmada shear system, and the Tan shear system are the crustal-scale shear zones. The Mahakoshal Group is ~500 km long ENE-WSW trending supracrustal belt (Fig. 1B) which is a part of CITZ and is characterized by presence of metavolcanics, pyroclastics, and metasediments (Bhattacharya et al., 2014). It is bordered by Son-Narmada-Nouth fault (SNNF) in north and Son-Narmada-South fault (SNSF) in south. The Mahakoshal (earlier termed as Bijawar) Group (Paleoproterozoic) and the Vindhyan Supergroup (Paleo- to Mesoproterozoic) of rocks unconformably overlie the Sidhi Gneissic complex (Archaean). Younger intrusives comprising granites, basic/ultramafic rocks and alkaline rocks such as lamprophyres and lamproites are reproted from the Sidhi Gneissic Complex as well as from the Mahakoshal Group (e.g., Nair et al., 1995; Srivastava and Chalapathi Rao, 2007; Bhattacharya et al., 2014; Satyanarayanan et al., 2017). The lamprophyre (24º20'21.3"N; 81º48'21.8"E) under study occurs as a small 2-3 x 1 metre NW-SE trending dyke south-west of Banjari (Fig. 1B) and intrudes the Sidhi Gneissic Complex.

ANALYTICAL TECHNIQUES

Mineral chemistry of various pyrite and chalcopyrite of this study was determined by a CAMECA SXFive electron microprobe analyser (EPMA) at Department of Geology, Banaras Hindu University, Varanasi. Wavelength-dispersive spectrometry and a LaB_6 source were deployed for quantitative analyses and for X-ray element 'dot' mapping. For X-ray 'dot' mapping an acceleration voltage of 15 kV and beam current of 105 nA was used whereas 15 kV and 11nA were deployed for BSE imaging. For quantitative analyses, an accelerating voltage of 15kV, a beam current of 10nA with 1μm diameter was used and TAP, LIF and LPET crystals were employed for measurement. A number of natural and synthetic standards supplied by M/s CAMECA were used for calibration. After repeated analysis it was found that the error is <1%, whereas the error on the trace elements varied between 3 and 5%.

PETROGRAPHY AND MINERAL CHEMISTRY

Petrographic study of the lamprophyre reveals that it has a porphyritic texture and contains mica (biotite-phlogopite) phenocrysts in major amounts and the groundmass is dominated by feldspar, titano-magnetite, apatite, secondary carbonates and sulphides (pyrite and chalcopyrite). The biotite-phlogopite belongs to two paragenesis: (i) primary (Ti-rich) and (ii) re-equilibrated (Ti-poor). The presence of secondary carbonates and re-equilibrated mica implies that lamprophyre experienced dueteric alteration and also possibly subjected to low-grade of metamorphism. Pyrite is found as fine to medium grained (0.04mm to 0.20mm), subhedral to euhedral disseminations, which are relatively undeformed (Figs. 2A and B). At places, clusters of pyrite are encountered (Fig. 2C) and rarely inclusions of pyrite in biotite-phlogopite are also observed. Optical and back scattered electron (BSE) imaging do not reveal any zonation in pyrites. Close association between pyrite and magnetite is seen at some places (Fig. 2A). Chalcopyrite (not shown) is in relatively lesser proportion than the pyrite, and is mostly subhedral in nature and occurs as fine to medium grains. No other sulphides, such as cobaltite are observed.

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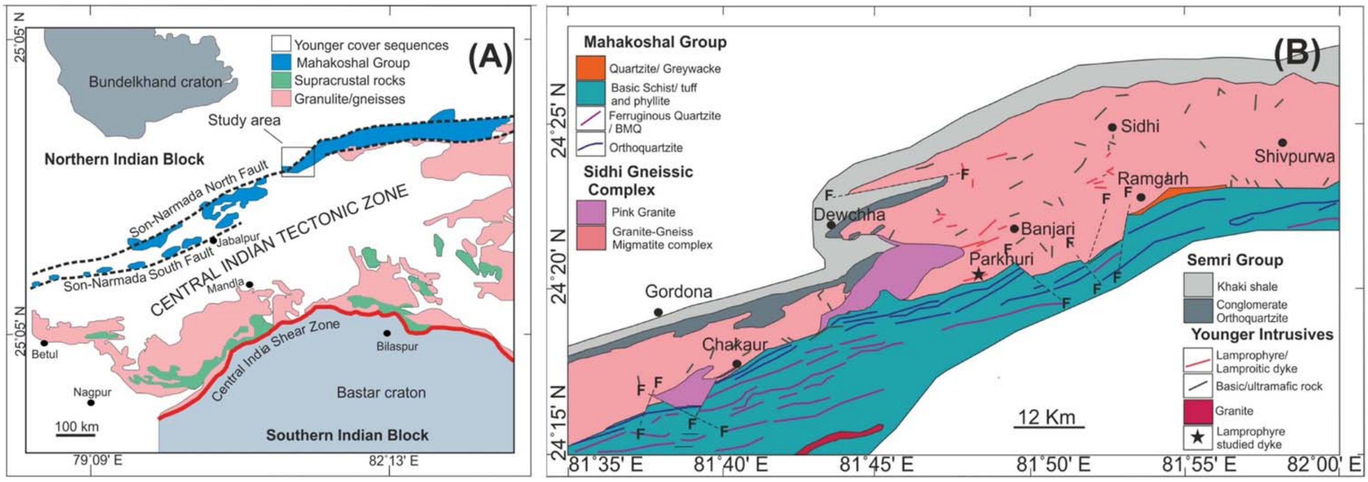

Fig.1. **(A)** Tectonic framework of central part of Central Indian Tectonic Zone (CITZ) (redrawn from Bhowmik et al., 2005). **(B)** Geological map of the Sidhi alkaline complex (modified from Narain and Thambi, 1978 and Bhattacharya et al., 2014). Lamprophyres and mafic dykes depicted are not to the scale.

The sulphidisation of primary magnetite by later hydroterhmal action is well-known to result in the pyrite formation,. However, the textural features of pyrite and chalcopyrite of the present study appear to be more consistent with their earlier crystallization from the lamprophyre magma rather than being late stage hydrothermal products filling up open spaces. Colour codes X-ray element 'dot' images generated by EPMA clearly bring out the distribution of Fe (Fig. 2D), S (Fig.2E) and Co (Fig.2F) in the studied pyrite grains.

The quantitative EPMA data of various pyrite and chalcopyrite grains from the lamprophyre are presented in Table 1. The cobalt (0.02 – 5.69 wt%) and nickel (0.02 to 0.70 wt%) contents are highly variable but almost every pyrite grain contains cobalt in high proportions (Table 1). On the other hand, the associated chalcopyrite conspicuously lacks cobalt but its nickel content is comparable to that in the pyrite. The theoretical chemical composition of pyrite is Fe = 46.6 wt % and S =53.4 wt% but the pyrite under study has a variable Fe content (40.62 to 46.02 wt%) which is reciprocally related to the cobalt and nickel concentrations. This implies that cobalt (and nickel) are present as solid solution in the structure of pyrite. This is also further substantiated by the elemental line scan (by EPMA) across a pyrite grain (Fig. 3A and B) which clearly shows Fe-depletion and concomitant Co-enrichment. The line scan, across a pyrite grain from

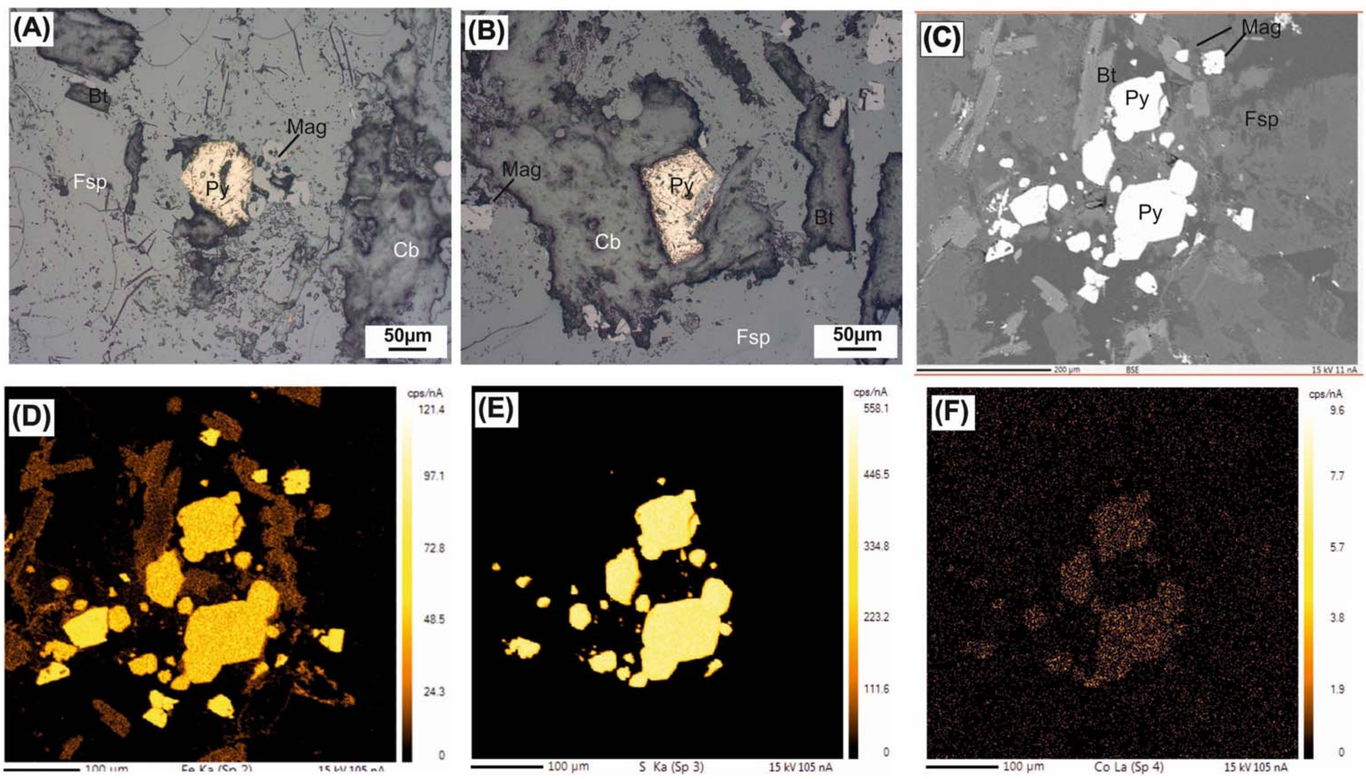

Fig.2. Photomicrographs (in reflected light) showing textural aspects of pyrite in the lamprophyre under study: **(A)** Euhedral pyrite surrounded by biotite in the ground mass dominated by feldspar and **(B)** Euhedral to subhedral pyrite in a carbonated ground mass and associated with magnetite. **(C)** Back scattered electron (BSE) image showing pyrite aggregates in feldpar groundmass. Colour coded X-ray element images of **(D)** iron **(E)** sulphur and **(F)** cobalt in the pyrite under study.

Table 1. Electron microprobe data (wt%) of pyrite and chalcopyrite grains from the lamprophyre under study (thin section No: RG/PK/3)

Fe	S	Co	Pb	Mn	Ag	Zn	Ni	Cu	As	Total
Pyrite										
44.90	53.70	2.38	0.00	0.00	0.01	0.00	0.24	0.00	0.16	101.40
43.24	52.25	2.19	0.00	0.00	0.03	0.00	0.02	0.10	0.66	98.49
40.99	52.89	4.78	0.00	0.00	0.06	0.06	0.17	0.04	0.32	99.31
45.82	53.52	1.25	0.00	0.01	0.08	0.11	0.39	0.00	0.36	101.52
45.36	52.94	1.03	0.00	0.00	0.01	0.28	0.24	0.00	0.06	99.91
43.24	54.41	3.06	0.00	0.06	0.00	0.24	0.10	0.00	0.26	101.35
47.26	53.07	0.02	0.00	0.00	0.01	0.30	0.15	0.00	0.05	100.84
46.96	52.89	0.10	0.00	0.00	0.03	0.31	0.32	0.00	0.09	100.71
45.97	53.43	0.12	0.00	0.00	0.02	0.11	0.14	0.00	0.15	99.95
46.41	53.37	0.40	0.00	0.00	0.02	0.22	0.12	0.00	0.10	100.64
44.61	52.68	1.10	0.00	0.00	0.08	0.13	0.58	0.00	0.24	99.42
45.58	53.35	0.61	0.00	0.00	0.01	0.26	0.36	0.07	0.02	100.26
45.91	53.57	0.70	0.00	0.00	0.07	0.18	0.58	0.00	0.18	101.18
44.27	52.55	0.88	0.00	0.02	0.00	0.09	0.70	0.00	0.25	98.75
43.16	52.64	2.61	0.00	0.02	0.04	0.07	0.10	0.15	0.43	99.20
44.66	52.60	1.89	0.00	0.00	0.03	0.18	0.12	0.00	1.13	100.63
44.51	51.16	1.54	0.00	0.01	0.03	0.00	0.19	0.00	0.28	97.72
45.27	52.79	0.84	0.00	0.00	0.00	0.24	0.19	0.02	0.17	99.52
43.79	52.11	1.85	0.00	0.05	0.00	0.48	0.14	0.00	0.15	98.57
46.39	52.60	0.05	0.00	0.04	0.03	0.04	0.07	0.10	0.06	99.36
45.30	51.38	0.49	0.00	0.00	0.01	0.20	0.10	0.00	0.11	97.58
44.39	53.65	2.56	0.00	0.00	0.03	0.39	0.43	0.00	0.18	101.63
44.57	53.35	3.03	0.00	0.00	0.00	0.05	0.44	0.00	0.29	101.73
42.02	53.56	4.60	0.00	0.00	0.00	0.22	0.14	0.00	0.59	101.13
44.48	53.74	1.73	0.00	0.02	0.09	0.09	0.38	0.00	0.66	101.19
42.52	50.27	4.43	0.00	0.00	0.02	0.35	0.05	0.00	0.37	98.02
40.62	52.38	5.69	0.00	0.00	0.00	0.15	0.46	0.30	0.20	99.80
45.60	53.20	1.09	0.00	0.00	0.00	0.15	0.14	0.01	0.19	100.37
45.79	53.80	0.89	0.00	0.00	0.02	0.30	0.02	0.00	0.22	101.03
45.09	54.28	2.21	0.00	0.00	0.04	0.02	0.07	0.00	0.16	101.87
Chalcopyrite										
29.78	34.27	0.03	0.00	0.10	0.09	0.18	0.23	34.69	0.02	99.39
29.17	34.50	0.03	0.00	0.07	0.09	0.13	0.25	34.68	0.00	98.92
29.56	34.86	0.00	0.00	0.07	0.09	0.13	0.14	33.94	0.00	98.79
29.26	35.02	0.15	0.00	0.07	0.03	0.42	0.23	34.42	0.00	99.61
29.40	34.74	0.00	0.00	0.03	0.07	0.24	0.25	34.85	0.00	99.58
29.92	34.44	0.00	0.00	0.02	0.09	0.16	0.19	34.36	0.05	99.22

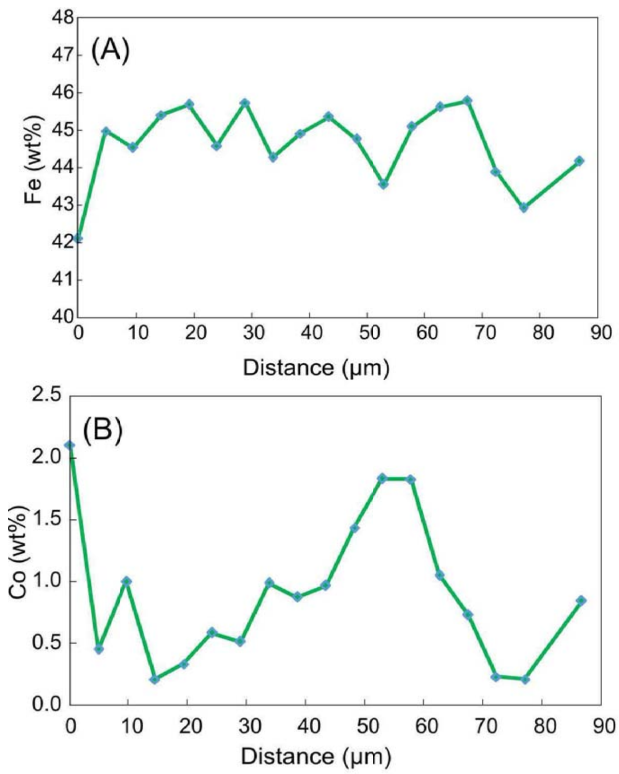

Fig.3. Elemental line scans of (**A**) Fe and (**B**) Co across a pyrite (rim to rim) under study.

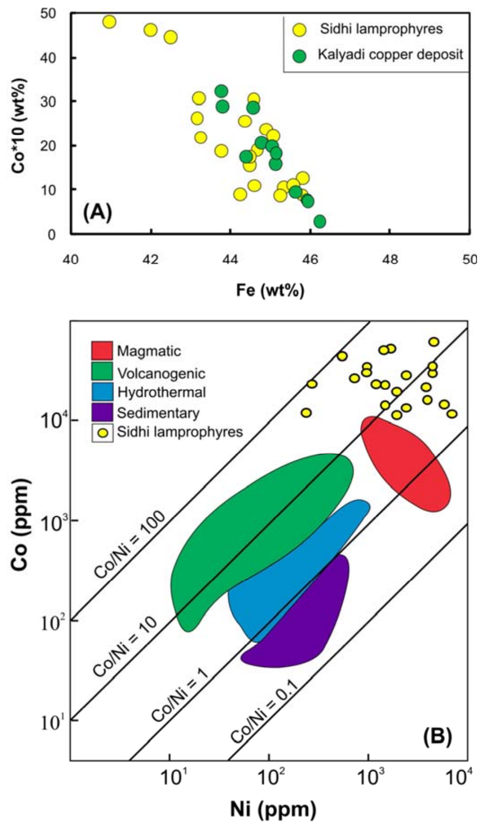

Fig.4. (**A**) Fe vs Co bivariate plot of pyrite from the lamprophyre this study. The data of pyrite from Kalyadi copper deposit, also shown for a comparison, is taken from Thomas et al. (2008). (**B**) Co vs Ni plot value of pyrite from the lamprophyre of this study. Other fields are taken from Bajwah et al. (1987).

the rim through the core to the rim, also brings out differential enrichment of Co as well as Ni and As (not shown for Ni and As) contents. The cobalt contents of the pyrite of this study are also comparable to those (up to 3.21 wt%) reported from the cobalt-bearing pyrites of the Kalyadi copper deposit of Western Dharwar craton of southern India (Fig. 4A). However, it should be pointed out that the Kalyadi deposit is a sedimentary exhalative (SEDEX) ore body (Subba Rao and Naqvi, 1997) having an altogether different genetic history and tectonic setting and its pyrite composition is utilised solely for compositional comparison.

DISCUSSION

Even though sulphide mineralization has been recorded from the Mahakoshal belt (see Rao and Ramam, 1965; Farooq and Hasan, 1996) to the best of our knowledge the occurrence of cobaltoan pyrite from this domain is unknown. Interestingly, a global compilation of the lamprophyres and potassic rocks undertaken by Rock (1991) and Muller and Groves (2000) also does not mention the presence of cobalt-rich pyrites. It is well-known that minor amounts of metals (Cu, Pb, Zn, Ni, Co etc) often occur in the structure of natural pyrites (Craig and Vaughan, 1990; Craig et al., 1998) but substantial proportion (> 5 wt%) of metals such as cobalt, as brought out from this study, highlights the ore-potential of the lamprophyre magma. Furthermore, an overall paucity of cobalt in the associated chalcopyrite (Table 1) implies that in a pyrite-chalcopyrite association, cobalt is preferentially sequestered in pyrite. The rocks of Mahakoshal belt are known to be subjected to multiple events of deformation and also experienced low-grade greenschist facies metamorphism (Roy and Hanuma Prasad, 2003). However, regional metamorphism even at higher grades is known not to homogenise the minor element constituents of pyrite and significant compositional variations are reported to persist through metamorphism (Craig et al., 1998). Therefore, the cobalt and nickel contents in the studied pyrites possibly assume genetic significance. Co:Ni ratios in pyrites are widely regarded as reliable indicators to discriminate between submarine exhalative, magmatic and sedimentary origin of ore deposits (Bralia et al., 1979; Bajwah et al., 1987; Kouhestani et al., 2017). The high Co:Ni content of the pyrites of this study appears to be more consistent with their high temperature magmatic to volcanogenic origin rather than a low temperature hydrothermal origin (Fig. 4B). Further ongoing detailed studies on the sulphide mineralization of the Mahakoshal belt are expected to throw more light in this regard. This study highlights that apart from gold and diamond, lamprophyre magmas can also, at times, constitute important carriers of cobalt if this metal is available in the magmatic system.

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