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SRI NIWAS

Department of Earth Sciences,
Indian Institute of Technology Roorkee,
Roorkee 247 667, India
e-mail: srsnpfes@iitr.ernet.in

Mineralogy of disseminated sulphides from the volcanics of Andaman Island

Hydrothermal sulphide mineralization in modern oceanic-spreading and back-arc environments has been a topic of increasing academic research ever since its first reported occurrence in the Galapagos spreading centre in 1979 (refs 1–3). Though the fundamental processes of sulphide mineralization are more or less similar for the mid-ocean ridge (MOR) spreading-axis and back-arc spreading centres, the host-rock association and mineralogy of the sulphides in these two settings varies significantly. For instance, in MOR, the sulphides are hosted within mafic and ultramafic rocks, whereas felsic hosts are more common in back-arc environment⁴. Similarly, the sulphides precipitating in back-arc systems typically have lower Fe, higher fO_2 and high Au contents⁵.

In contrast to the extensive studies on sulphide mineralization in back-arc hydrothermal systems along the active convergent plate boundaries of the western Pacific⁴, reported occurrences of hydrothermal activity and sulphide mineralization in the Andaman back-arc setting are sparse⁶. Here we report the mineralogy and chemical composition of sulphide mineralization associated with the late quartz vein within the volcanic suite. The volcanic rocks mainly include altered basalts of East coast volcanic group as described by Ray *et al.*⁷. Our studies suggest that the chalcopyrite–pyrite association probably co-precipitated within the quartz vein, originally formed at a marginal-basin setting. High Co and Mo content within the sulphides further supports their formation from the circulation of hot fluids.

The Andaman–Nicobar group of islands, located roughly in the central part of Burma–Sunda–Java subduction double-chain arc system, represent part of the outer sedimentary arc⁸. The dominant rock types of the islands are sandstone, grey shale, conglomerate and limestone forming part of the Flysch and Archipelago group of sediments. Ophiolite, closely associated with the Andaman flysch, occurred as rootless, thrust-bound slices, occupying parts of the South Andaman area⁹. Igneous rocks mostly associated with the ophiolites are peridotite/serpentine, pyroxenite, gabbro, anorthositic gabbro, plagiogranite, basaltic dykes, pillow basalts and East coast volcanics⁹. The East coast volcanic rocks range in

composition from basalt, basaltic andesite to acid differentiates⁷. Occurrences of plagiogranite within cumulate gabbro and East coast volcanics have also been reported⁹. The occurrence of pillow basalts has been attributed to their formation in a slow-spreading environment⁷. Geodynamic evolutionary studies of the Andamans reveal that there was a subduction event (during Eocene–Oligocene) prior to the currently active subduction processes initiated at Late Miocene¹⁰. The manifestation of these two events is exemplified as ophiolite obduction and inner-arc volcanism respectively.

Samples of sulphide hosted volcanics were collected from near Bedanabad village, South Andaman (11°56.912'N/

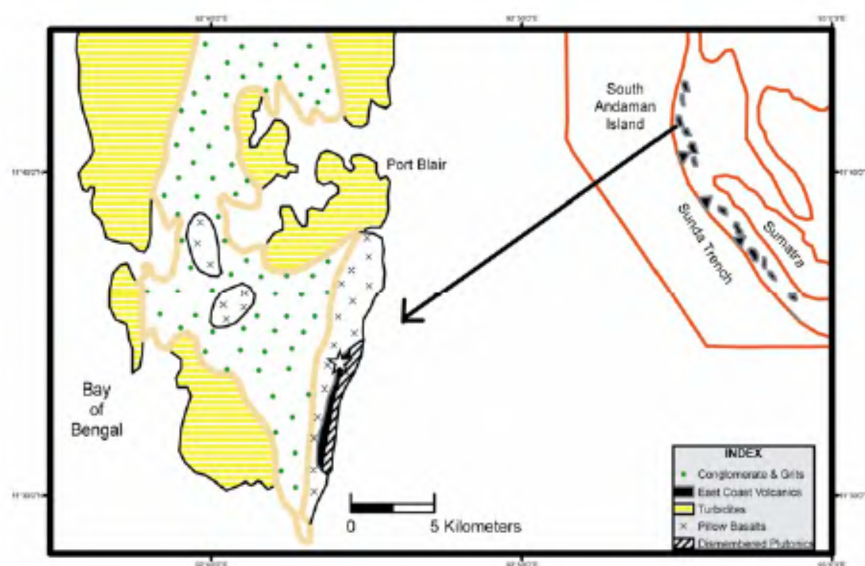


Figure 1. Generalized geological map of South Andaman (modified after Ray *et al.*⁷ and Jafri *et al.*⁹).

Table 1. Representative analyses (including average and range) of chalcopyrite and pyrite

Wt (%)	Cpy (<i>n</i> = 11)						Py (<i>n</i> = 11)					
	1	2	3	4	5	Range	1	2	3	4	5	Range
Cu	33.35	33.82	33.37	33.24	33.52	32.71–33.82	0.01	0	0.45	0	0	0–0.45
Fe	29.98	29.15	29.46	29.76	29.94	29.15–29.98	44.52	43.86	44.41	44.5	44.58	43.86–44.58
S	35.14	35.33	35.17	35.45	34.58	34.58–35.53	54.21	53.1	53.45	53.74	53.19	53.10–54.21
Mo	0.33	0.5	0.41	0.54	0.32	0.18–0.54	0.78	0.64	0.65	0.75	0.69	0.64–0.78
Zn	bdl	0.03	bdl	0.05	bdl	< 0.06	0	0.01	0	0	0	< 0.01
Co	0.02	bdl	bdl	0.04	0	< 0.05	1.49	1.27	1.31	0.66	0.72	0.66–1.49
As	bdl	0.11	0.08	0.1	0	< 0.11	0	0	0.06	0	0.09	< 0.09

Cpy, Chalcopyrite; Py, Pyrite; *n*, No. of analyses; bdl, Below detection limit.

Table 2. Comparative sulphide mineralogy from different oceanic environments

		End members (wt%)			
		Cu	Fe	Zn	S
Present study	Andaman Island	Cpy 33.30	29.57	n.d.	35.08
		Py n.d.	44.37	n.d.	53.54
Back-arc setting ⁴	Mariana	1.15	2.39	9.96	17.8
	Okinawa	1.77	7.33	22	—
	North Fiji	7.15	30.05	6.64	36.67
	Lau Basin	4.56	17.4	16.1	30.12
Central Indian Ridge (intermediate spreading), Indian Ocean ^{15,16}	MESO zone	Cpy 36.80	23.44	n.a.	39.76
		Py 3.07	38.59	n.a.	58.34
	SONNE field	Cpy 31.36	20.3	n.a.	48.1
		Py 3.76	39.62	n.a.	56.62
Slow-spreading setting ⁴	Galapagos	4.48	32.6	4.02	32.4
	Snake pit	12.42	35.47	7	30.88
	TAG ¹⁷	Cpy 33.52	30.50	n.a.	34.80
		Py 0.32	46.55	n.a.	53.34
	S Explorer	3.23	25.78	4.85	28.3
	Axial seamount	0.4	4.95	18.31	18.8
	S. Juan de Fuca	0.16	19.79	36.72	39.27
Fast-spreading setting ⁴	East Pacific Rise 13°N	7.83	25.96	8.17	35.12
	East Pacific Rise 11°N	1.92	22.39	28	35.7
	East Pacific Rise 21°N	0.58	12.44	19.76	31.41
	East Pacific Rise 17°26'S	1.25	36.25	5.55	41
	East Pacific Rise 21°50'S	2.39	28.59	21.74	40.74

92°73.758'E) in the course of field studies carried out during September–October 2009. The study area falls under the East coast volcanics as described by Ray *et al.*⁷ (Figure 1). The reddish-brown colouration in quartz-bearing sulphides similar to Gossan capping suggests development of iron sulphides as a result of surface or near-surface weathering and oxidation. Present sulphides are exclusively concentrated within the quartz grain. A few silicate minerals (plagioclase) are also noticed to be in association with quartz hosts. Sulphide grains mostly occur as fine disseminations, often as

small disconnected aggregates, and occasionally as thin stringers or blebs. These sulphides always exhibit a tendency to be concentrated along the zone of silicification.

Electron microprobe analyses of sulphides were performed at the Central Petrological Laboratory, Geological Survey of India, Kolkata, using five wavelength dispersive spectrometers (CAMECA SX 100). Analytical conditions were 20 kV accelerating voltage, 15 nA current and beam size was kept at 1 µm on point mode. Calibrations were performed using natural standard and the

data were PAP-corrected internally. Chalcopyrite and pyrite are the most common sulphides with magnetite as a common associate. Pyrites occur as euhedral cubes or as subhedral grains in clusters or in association with chalcopyrite grains (Figure 2). Individual surface of pyrite grains is easily identifiable under SEM. Chalcopyrites mostly occur as anhedral isolated grains, often associated with the pyrite grains or even as inclusion within the pyrite grains. Magnetites as appear as isolated anhedral grains. The characteristic chalcopyrite–pyrite association is suggestive of their close

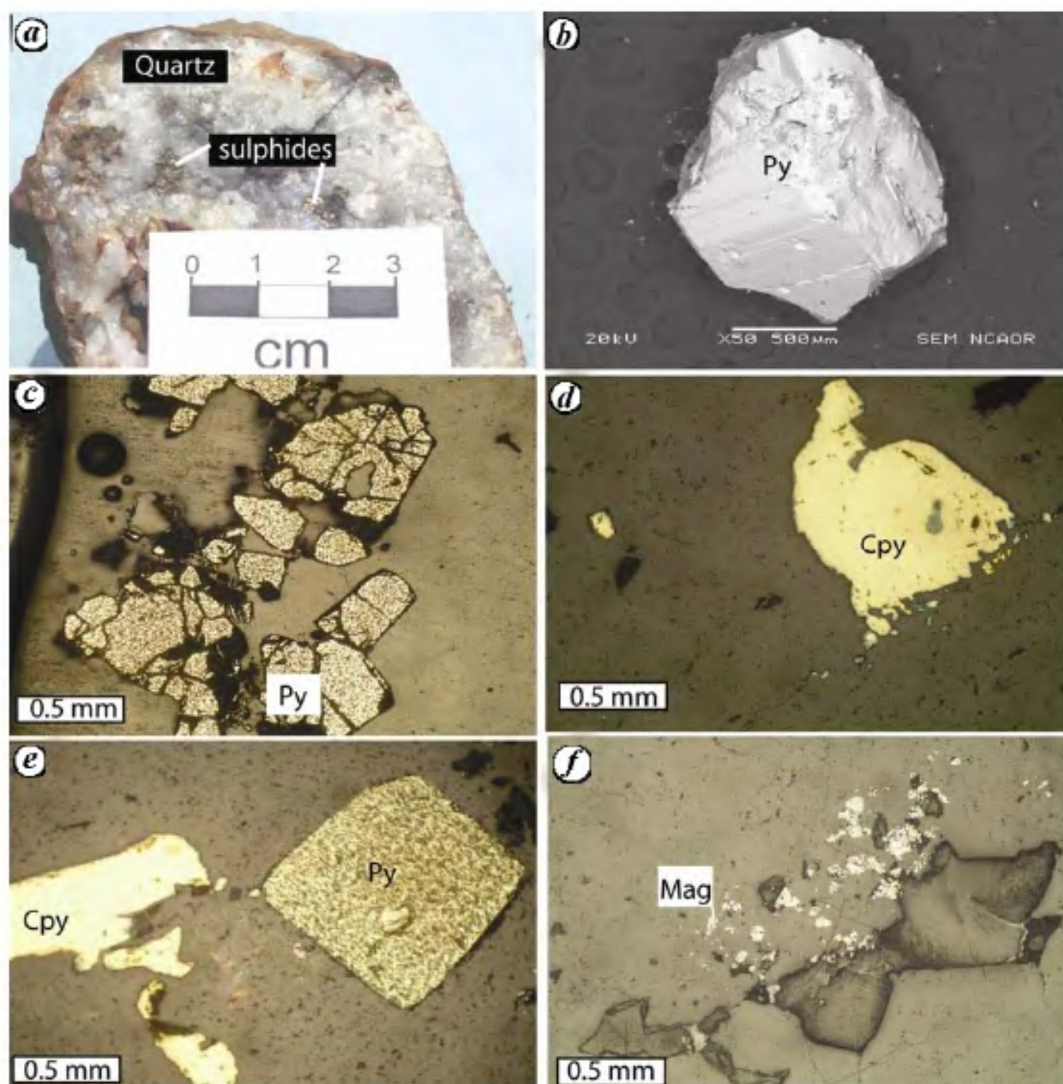


Figure 2. *a*, Hand specimen photograph of sulphide association with quartz grain; *b*, SEM image of pyrite crystal; *c-f*, Photomicrographs: *c*, Pyrite-clusters; *d*, Anhedral chalcopyrite grain; *e*, Pyrite cube and subhedral chalcopyrite, and *f*, Anhedral magnetites.

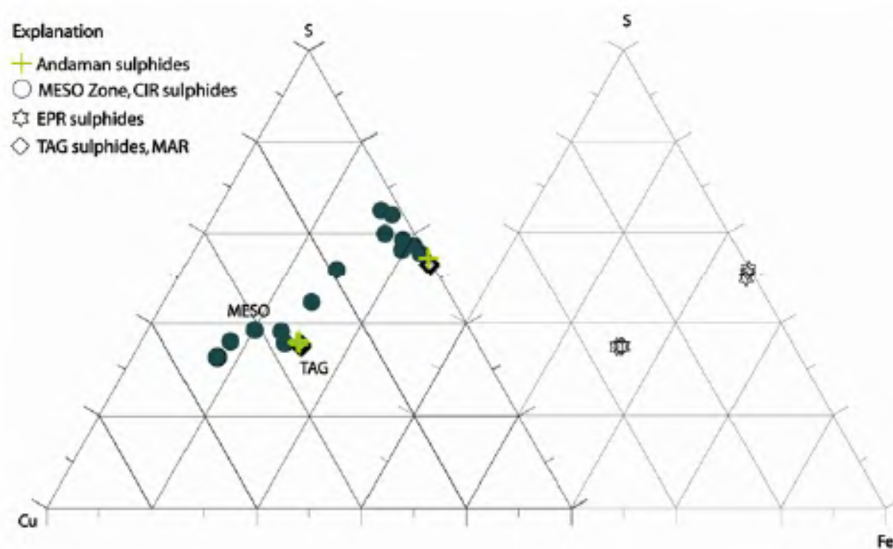


Figure 3. Cu-Fe-S ternary diagram showing sulphide composition from different oceanic environments.

paragenesis. Magnetite probably formed earlier than chalcopyrite and pyrite though there is no direct contact with the sulphides.

The mineral chemical composition of the sulphides is shown in Table 1. A comparison of the sulphide composition with those from different oceanic environments is given in Table 2.

As can be seen from the above, chalcopyrites of the Andamans show a restricted composition (Cu ~ 33–34 wt%; Fe ~ 29–30 wt% and S ~ 35–36 wt%; Table 1). The same is true of the pyrites as well (Fe ~ 44–45 wt% and S ~ 53–54 wt%). Mo and Co concentrations are higher in pyrites (0.64–0.78 wt% and 0.66–1.49 wt% respectively; Table 1) compared to chalcopyrites (0.18–0.54 wt%). Mo was probably hosted during the primary stage itself rather than during the later Cu-phases. High concentration of Mo in pyrites suggests rather high temperatures of formation (>300°C)¹¹. High Co-bearing pyrites similar to those of the Andamans have also been reported from MESO-zone sulphides, Central Indian Ridge (CIR; up to 1700 ppm)¹². Microchemical analyses of pyrites show a substitution of Co for Fe. According to Hekinian and Fouquet¹³, the enrichment in Co relative to Fe can be attributed to a preferential leaching of the latter. In a Cu–S–Fe ternary diagram, the Andaman sulphides plot roughly in the region of TAG chalcopyrites and pyrites (Figure 3). Sulphides from the MESO zone, CIR, show substantial variation and considerable scatter compared to Mid-Atlantic Ridge (MAR) and East Pacific Rise (EPR) due to its variegated mineralogical assemblages (Figure 3). Fe content of magnetite is uniform (~61 wt%). Mineralogical zonation is absent as revealed by the uniform composition of sulphides. High Co content, especially within pyrites, suggests direct precipitation from hot hydrothermal fluids. Hot fluids migrate laterally and start to cool and gradually get enriched in Mo. Moreover, the mixing front of hydrothermal fluid and sea

water probably enhances this trace element composition.

Since typical island arc signatures are absent in the Andaman volcanic rocks, it may be suggested that the Andaman ophiolites may represent a marginal basin floor⁷. Evidences for marginal basin signatures in ophiolite with silicic flows were supported earlier by the presence of plagiogranite^{9,14}. The sulphide association with quartz hosts suggests that generation of metal-rich solutions may be coeval with acidic magma as late-stage differentiates and part of the ophiolitic paragenesis. The low intensity of the mineralized zone additionally suggests a shorter period of metal-rich fluid precipitation at marginal basin setting. This could be further substantiated by less significant occurrences of acidic rocks compared to basic rocks of the area.

Close association of chalcopyrite–pyrite in the present sulphide ores suggests partly their simultaneous formation with magnetite as a minor phase with silica. High Co and Mo contents indicate high temperature of formation of sulphides (~300°C or more). Additional studies involving *in situ* sulphur isotopic data and trace-element data are required to quantify and comment on sulphide-ore genesis and the tectono-magmatic conditions more precisely.

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DWIJESH RAY*

S. RAJAN

RASIK RAVINDRA

National Centre for Antarctic and
Ocean Research,
Goa 403 804, India

*For correspondence.

e-mail: dwijesh@rediffmail.com