PIXE/PIGE microanalysis of trace elements in hydrothermal magnetite and exploration significance: a pilot study

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Abstract

Magnetite is a common iron oxide mineral in many giant ore deposits. However, chemical analyses of individual magnetite grains were hampered by high detection limits in electron probe microanalysis and use of techniques such as XRF or solution chemistry on mineral separates. Hear we present a pilot study of the geochemistry of magnetite using PIXE microanalysis, which reveals a correlation between its trace element concentrations and a variety of ore deposit types. This finding suggests that some element ratios (e.g., Sn/Ga, Al/Co) of magnetite may play a significant role as indicator elements to discriminate between the different ore deposit styles, particularly within magmatic-hydrothermal ore systems and to apply in mineral exploration.

Further works are in progress in combination with LA ICP-MS study of magnetites at CODES to acquire more data to test our hypothesis.

Key words: Magnetite, PIXE, magmatic-hydrothermal ore systems

Introduction

Magnetite is a common iron oxide mineral in many giant ore deposits such as Olympic Dam in South Australia and Cadia in NSW. However, chemical analyses of individual mineral grains were hampered by high detection limits in electron probe microanalysis and use of techniques such as XRF or solution chemistry on mineral separates. Recent development in micro-analytical techniques using non-destructive Particle Induced X-ray Emission (PIXE) at Institute for Environmental Research, Australian Nuclear Science and Technology Organisation (ANSTO) can provide more detailed information on trace elements of magnetite.

The main purpose of this extended abstract is to describe the trace element characteristics of magnetite from the Puthep 1 (PUT 1) and Phu Kham skarn-related porphyry Cu-Au deposits, Thailand and Laos (Fig. 1). Our preliminary results suggested that some elements ratios of analysed magnetite can be used as indicator elements to discriminate types of metal deposits.

Geological Background

Deposit geology of the Puthep 1

The PUT 1 skarn-related porphyry Cu deposit is located in the northern Loei Fold Belt (Fig. 1) and hosted by the carboniferous clastic sedimentary units intercalated with thick limestone sequences. These rocks were emplaced by intrusive porphyries, including diorite and monzodiorite during the Late Triassic age. At Puthep 1, two major- and mineralisation-styles have been recognised: 1) porphyry-style stockwork veining, alteration and mineralisation; and 2) skarn-style alteration and mineralisation.

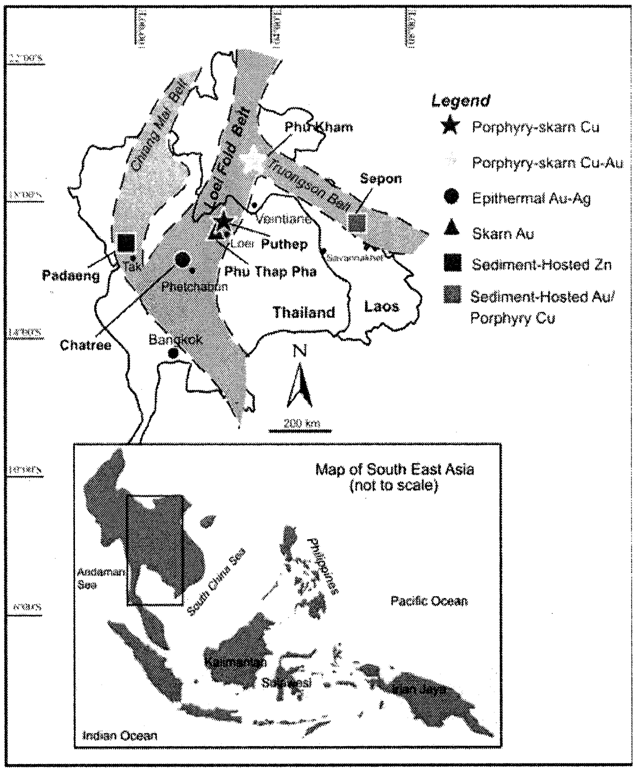

Figure 1. Location of the Puthep 1 (Thailand) and Phu Kham (Lao PDR) deposits.

Three main alteration mineral assemblages of porphyry-styles are distinguished: 1) biotite+K-feldspar+magnetite; 2) epidote+ chlorite ± calcite; and 3) sericite (white mica) + pyrite. Boundaries among these alteration mineral assemblages are gradational from centimeter- to decimeter-scales. Generally, the degree of quartz veining and mineralisation (chalcopyrite ± bornite ± molybdenite) is best developed both near the inner edge and in the inner zones of diorite porphyry. Skarn-style alteration formed in and around the Puthep 1 porphyritic intrusions. This includes both endoskarn and exoskarn. They are commonly hosted by calcareous argillite unit (exoskarn) and some porphyritic intrusive rocks (endoskarn). Three major alteration mineral assemblages have been recognised: 1) pyroxene ± epidote ± garnet endoskarn (proximal); 2) garnet exoskarn (proximal); and 3) epidote exoskarn (distal). Generally, the degree of mineralisation (chalcopyrite) is well developed in the epidote exoskarn zone where the retrograde minerals have been emplaced.

Deposit geology of the Phu Kham

The oldest stratified rocks within the Phu Kham deposit are Late Carboniferous in age and are limestone, siltstone (?) and conglomerate (?). They are overlain by a thick sequence of Early Permian volcaniclastic rocks. The volcaniclastic rocks, which are the main host of copper-gold mineralisation, are characterised by moderately to strongly foliated feldspar fragments in the reworked volcanic materials (probably of andesitic composition). The rocks are moderately to strongly altered by sericitic alteration and contain numerous quartz and mineralised veins. Five main intrusions have been identified in the Phu Kham deposit: 1) granitic body; 2) crowded feldspar porphyry (dioritic to monzodioritic compositions); 3) weakly porphyritic to equigranular diorite; 4) foliated quartz eye porphyry (felsic composition); and 5) felsic fine-grained intrusive.

At Phu Kham, two major types of large-scale hypogene ore and alteration assemblages have been identified: 1) porphyry-related Cu-Au and 2) skarn-related Cu-Au. These hydrothermal alteration-styles are similar to those at PUT 1. Porphyry-related alteration assemblages are characterised by four main alteration types: 1) biotite + magnetite ± K-feldspar alteration; 2) sericite + quartz + pyrite ± epidote alteration; 3) epidote + calcite + quartz ± chlorite alteration; and 4) pyrophyllite + quartz alteration. Based on observation of drill core samples, the endoskarn alteration is observed as patches and networks of garnet + epidote + chlorite which partially to totally replaced into the porphyry intrusive bodies. Two major exoskarn alteration assemblages at Phu Kham have been distinguished: 1) garnet skarn (proximal zone); and 2) garnet-epidote skarn (distal zone).

Methods

Magnetites that closely associated with porphyry-skarn copper-gold deposits have been sampled from the PUT 1 and Phu Kham deposits. Samples were made as polished grain mounts in epoxy and coated with carbon. These polished mounts represented the surface of the samples because PIXE is surface analytical techniques, which means it measures the average concentration in the top 100μm of samples. All sample preparation were conducted at the University of Tasmania. The prepared samples were analysed at ANSTO, Sydney using the PIXE analysis.

Table 1: Summary results of the PIXE Analysis* from various magmatic-hydrothermal deposit types

Location	Phu Kham	PUT 1	Mt Morgan	Mt Lyell	Kara	Juno
Deposit types	PS	PS	VHMS	VHMS	Skarn	IOCG
n	7	7	4	3	3	3
Mg	12714	5257	17775	10666	12100	17233
Al	6557	15243	29250	71666	7666	35866
Si	128428	160142	132500	383333	76666	41666
P	20857	30271	52000	2966	2766	2866
S	161628	219243	97575	13400	1266	2690
Cl	950	1183	780	430	646	506
K	1457	1160	847.5	28000	520	2120
Ca	128428	77042	71250	3256	19666	203
Ti	682	1110	1220	3643	1193	1636
V	467	390	1308	543	530	590
Cr	677	610	820	74	996	1176
Mn	3700	2600	6400	1233	6366	3166
Fe	432857	437142	475000	111333	603333	646666
Co	700	1095	483	166	423	503
Ni	218	223	235	49	330	380
Cu	13483	29138	1778	1181	154	1384
Zn	247	607	448	270	437	306
Ga	59	87	42	32	83	41
As	193	43	159	20	54	31
Se	25	7	15	7	41	299
Br	18	14	17	6	33	18
Rb	51	51	57	76	74	90
Sr	127	65	42	18	35	54
Y	21	25	42	14	26	26
Zr	27	29	60	153	37	47
Nb	16	21	20.5	14	31	27
Mo	18	18	23	24	39	47
Sn	71	71	85	92	450	59
Ba	393	391	468	1557	390	253
W	291	351	203	93	21086	293
Pb	104	107	118	27	197	327
Bi	71	53	65	23	100	1040

* = Analysed results (ppm) based on mean values of all PIXE Analyses

PS = porphyry-skarn; VHMS = volcanic-hosted massive sulphide; IOCG = Iron oxide copper-gold

Results and Interpretation

Major and trace element compositions were obtained from 14 samples (Table 1). In addition, we analysed magnetite for its element data from other major ore deposits such as VHMS system (Table 1) to compare the compositions with those of the PUT1 and Phù Kham skarn deposits. Our result shows that magnetite from skarn, VHMS, IOCG deposits are generally enriched in Ti, Cr, Mn, Co, Cu, Zn, Ba and W, Pb, Sr, Ni and V. Such characteristics indicate that those elements are an important trace element for the magnetite formation. Moreover, they also display variations and overlaps in concentrations (Table 1). These compositional variations may be dependent on several factors, including the f_{O2} conditions, changes in temperature, local availability of trace elements (e.g. Mn, Cr, Ba).

Recent studies of Singoyi et al. (2006) and Beaudoin et al. (2007) also suggested that the magnetite compositions are efficient to fingerprint types of several metal deposits. This indicates that compositions of magnetite may have a crucial role as indicator elements to discriminate the types of various mineral deposits. This is consistent with our preliminary results in which, some element ratios (e.g., Sn/Ga vs Al/Co) of magnetite show a good correlation between its element concentration for skarn and VHMS deposits (Fig. 2) and can be applied as a fingerprinting technique for mineral exploration.

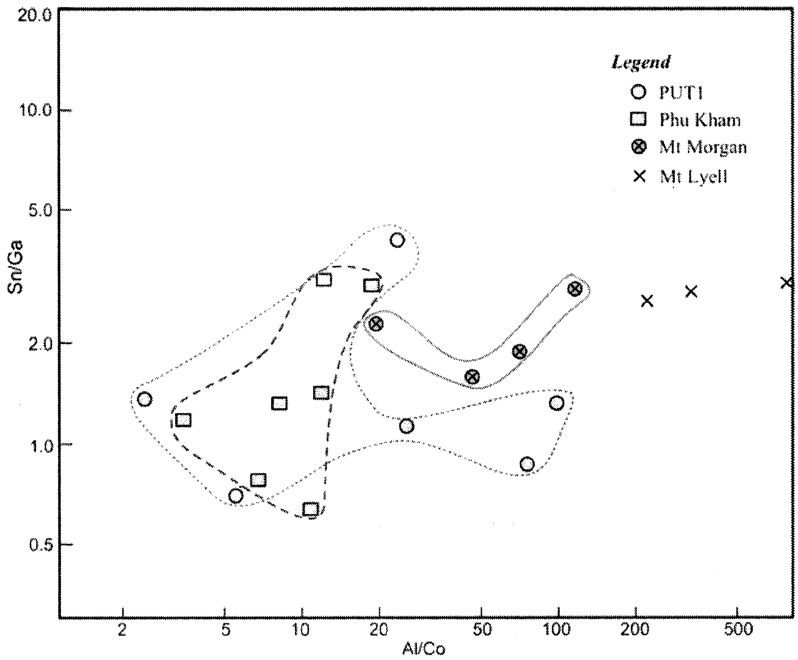

Figure. 2. Plot showing Sn/Ga vs Al/Co ratios of magnetite from porphyry-related skarn (Cu, Cu-Au) deposits (PUT1, Thailand and Phu Kham, Laos) and VHMS (Cu, Cu-Au) deposits (Mt Morgan and Mt Lyell) in Australia.

Acknowledgment

This work was funded by Australian Institute of Nuclear Science and Engineering (AINSE; AINSE ID No 2736- Dr. Khin Zaw). We thank research staffs of the Institute for Environmental Research, Australian Nuclear Science and Technology Organisation (ANSTO) for operating the PIXE analysis.

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