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Multi-stage growth and invisible gold distribution in pyrite from the Kundarkocha sediment-hosted gold deposit, eastern India

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ABSTRACT

Gold mineralization at Kundarkocha, India, is hosted in sheared gray quartz veins that were emplaced in carbonaceous pyritic phyllite. Gold occurs as enclosed grains within sulfides and free grains in quartz. Based on characteristic textural and chemical features, documented by X-ray element imaging, electron probe micro-analysis and laser-ablation inductively-coupled plasma mass spectrometry analyses, four pyrite types were identified in carbonaceous phyllites and auriferous veins. Rock-hosted fine-grained syn-sedimentary to early diagenetic pyrite framboids (PyI) have lower contents of Co and As but consistently high gold values. Pyrite of the next generation (PyII) has numerous silicate and rare sulfide inclusions; lower contents of Co and Ni, moderate As values; the highest mean value of invisible gold and maximum concentrations of trace elements such as Li, Ti, Zn, Rb, Sr, Y, Zr, Nb, La, Ce, Ta, Th, U and Cr. Pyrite of the third generation (PyIII) shows evidence of overgrowth over PyII, contains both silicate and sulfide inclusions, and are characterized by moderate contents of Co, high Ni and low Au values and higher concentrations of large ion lithophile elements, but lesser amount of high field strength elements. Pyrites of the latest type (PyIV) occur as polycrystalline aggregates that contain inclusions of gold, sulfides and rare silicates, show oscillatory zoning of Co and As and the lowest concentrations of all other trace elements. Successive decrease in contents of majority of trace elements from PyII to PyIV is attributed to fluid-assisted recrystallization during diagenesis and low grade metamorphism.

Later generation pyrites (PyII through PyIV) exhibit higher Au contents regardless of their As values, indicating occurrence of invisible gold mostly as nanoparticles, at times reaching up to 500 ppm. Unlike the majority of trace elements that underwent large-scale remobilizations, gold was somehow locked up in pyrite resulting in a rather lean deposit at Kundarkocha.

1. Introduction

Pyrite is the most dominant sulfide mineral in the Earth's crust and occurs in varied geological settings, including high grade metamorphic rocks (Craig and Vokes, 1993). In sedimentary systems, pyrite grows as micron-to-nanosize framboids and continues to form well developed cubic crystals as a consequence of recrystallization during diagenesis and metamorphism. Because of its refractory nature, pyrite preserves changes in pertinent fluid chemistry during these subsequent fluid-aided geological events. Accordingly, pyrite grains show zoning in terms of presence/absence of silicate inclusions and variation in its reflectivity. Besides optical microscopy, different zones in pyrite can be characterized as fingerprints of changing environments, by a range of micro-beam analyses (Belcher et al., 2004; Craig et al., 1998; Large et al., 2007). Apart from Co, Ni and As, a large number of trace elements may be irregularly distributed in pyrite forming diverse enriched zones and their element maps obtained by various micro-beam analytical tools. These maps may reveal information about pyrite growth history and relative time of transport of these elements in the ore fluids (Cook et al., 2009; Craig et al., 1998; Sung et al., 2009; Thomas et al., 2011; Reich et al., 2013). Furthermore, Winderbaum et al. (2012) demonstrated that statistical treatment, involving multivariate regression analyses of laser-ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS) data can discriminate different texturally distinct generations of pyrite.

Pyrite is a common ore mineral in various orogenic gold deposits. Diverse sources of gold have been proposed for the formation of these deposits. These include: from the (i) mantle (Barley and Groves, 1990), (ii) deep crust (Cline et al., 2005; Kerrich et al., 2005), and (iii) deep-seated magmas (Johnston and Ressel, 2004; Spooner, 1993). One of the characteristic features of many sediment-hosted gold deposits, a sub-group of the generalized orogenic gold deposits, is their striking association with pyritic carbonaceous shales that are generally metamorphosed to greenschist facies. Anomalously high contents of gold and arsenic can be seen from the data of Crocket (1990) and Ketris and Yudovitch (2009) in black carbonaceous

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shales, compared to other crustal rocks. In recent years, micro-beam analytical studies of pyrite from many sediment-hosted gold deposits reveal elevated levels of invisible gold in the mineral and higher concentration of trace elements such as Ni, As, Pb, Zn, Mo, Te, V and Se (Large et al., 2007, 2009, 2011). While such initial enrichment took place during sedimentary formation of pyrite, gold was released during diagenesis to subsequent low-grade metamorphism (Large et al., 2009). Invisible gold in pyrite can occur by various mechanisms such as substitution (Boyle, 1979; Cook and Chryssouilis, 1990; Johan et al., 1989; Marcoux et al., 1989; Tarnocai et al., 1997; Wu and Delbove, 1989), chemisorption (Fleet and Mumin, 1997), and occurrence as nanoparticles (Ciobanu et al., 2012; Hough et al., 2011; Palenik et al., 2004; Reich et al., 2005, 2006).

Gold mineralization occurs in gray quartz veins within carbonaceous phyllites at Kundarkocha in the eastern Indian Shield. The mine is owned by M/s Manmohan Mineral Industries Pvt. Ltd., and constitutes a small deposit with six underground levels developed at 30 m interval from the surface. The average strike length of the lodes is only 70 m. Reserves (and grades) are: proven: 41,500 t (3.3 g/t), possible: 88,000 t (2.04 g/t); and probable: 17,325 t (2.24 g/t), with a cut-off grade of 1 g/t Au. In spite of being a small deposit, the mine has been operational for some time. However, apart from two abstracts (Baidya, 1996; Mishra et al., 2008), there is no other published literature on this deposit. In this communication, we first briefly describe the general geology of the study area, with emphasis on gold mineralization, followed by results of detailed electron probe microanalysis (EPMA), X-ray imaging, quantitative line scan analyses and few LA-ICP-MS analyses of various generations of pyrite from the ore zone. Another important contribution of our study relates to anomalously high concentrations of invisible gold in pyrite.

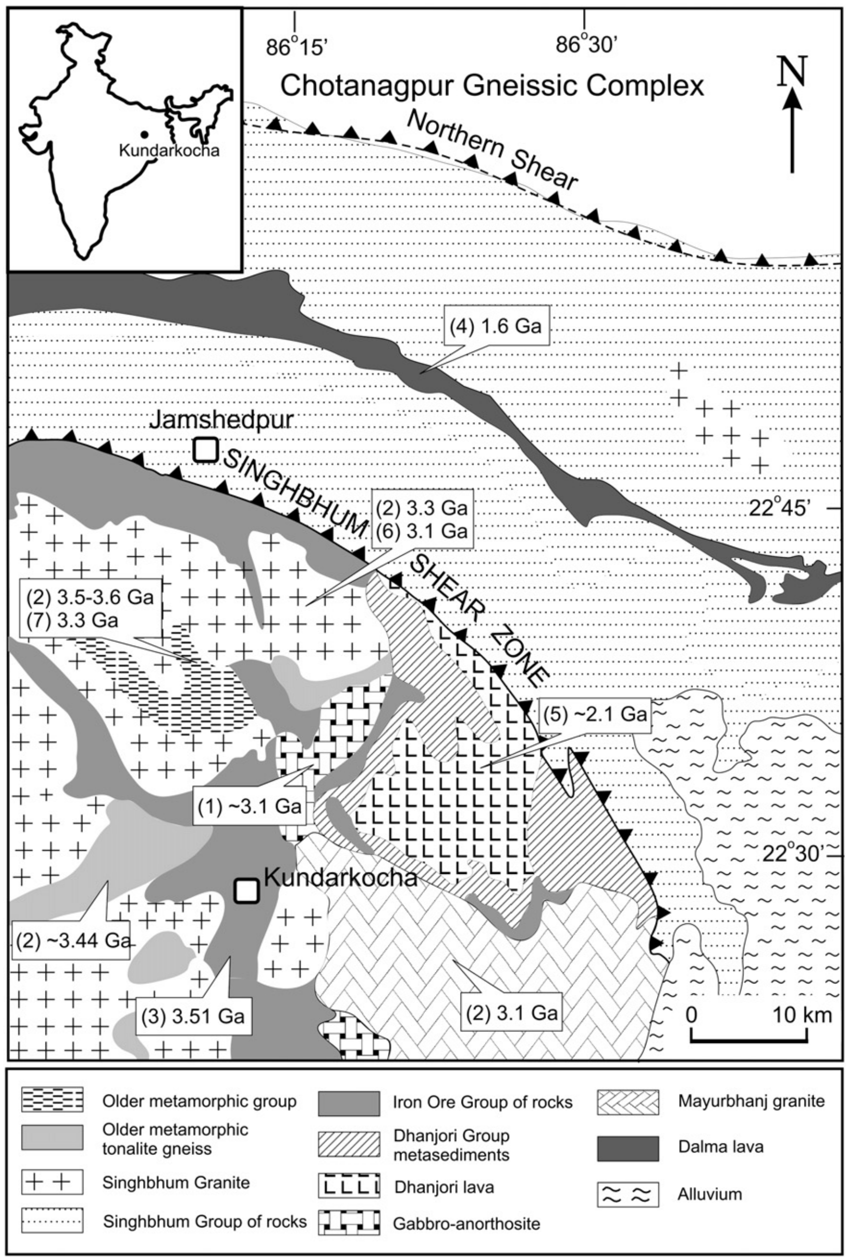

Fig. 1. Simplified geological map (modified after Saha, 1994) of the Eastern Indian Shield showing the Singhbhum craton, North Singhbhum Mobile Belt and the Chottanagpur Gneissic Complex. Ages of various rock units are shown in the map. (1) (Augé et al., 2003) Gabbro intrusion: U–Pb Zircon age; (2) (Mishra et al., 1999) Older metamorphic group, Older metamorphic tonalite gneiss, Singbhum granite and Mayurbhanj granite: ^{207}Pb–^{206}Pb zircon age; (3) (Mukhopadhyay et al., 2008) Iron Ore Group of rocks: U–Pb zircon age; (4) (Roy et al., 2002a) Dalma lava: whole rock Rb–Sr age; (5) (Roy et al., 2002b) Dhanjori lava: Whole rock Sm–Nd age; (6) (Saha et al., 1988) Singhbhum granite; (7) (Sharma et al., 1994) Older metamorphic group: whole rock Sm–Nd age. The ages are representative of the rock units, not location-specific.