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Baogutu: An example of reduced porphyry Cu deposit in western Junggar

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ABSTRACT

Classic oxidized porphyry copper deposits (OPCD) are characterized by high tonnage and elevated f_{O_2} and contain highly oxidized minerals including primary anhydrite and hematite. In contrast, the Baogutu deposit contains abundant hypogene pyrrhotite and methane-rich fluid inclusions, characteristic of lower tonnage, reduced porphyry copper deposits (RPCD). Mineral paragenesis and mineral chemistry studies reveal two mineralization periods (magmatic and hydrothermal) with the hydrothermal period further subdivided into three paragenetic stages including Ca–Na alteration, potassic alteration and propylitization, locally overlapped by phyllic alteration.

Several independent geothermometers indicate that the temperatures of the magma, potassic and propylitization alteration are estimated to be 600–900 °C, 200–400 °C and 200–300 °C, respectively. Multiple indicators including mineral assemblages, apatite SO_3 content, whole rock Fe_2O_3/FeO ratios and fluid compositions indicate the f_{O_2} of the magma and hydrothermal fluid to be NNO and NNO–NNO-2, respectively. Hydrothermal fluids associated with primary biotite yield $\log(f_{H_2O}/f_{HCl})^{fluids}$ values of 4.8–6.2 for diorite and 4.1–4.5 for granodiorite porphyry. The $\log f_{S2}$ of the magmatic and potassic alteration are estimated to be 0.7 to 3.0 and 5.5 to 11.0, respectively, based on pyrrhotite and sulfide assemblages. Mineral assemblage and hessite composition suggest the $\log f_{Te2}$ of the potassic alteration is 8.5 to 14.5.

The low tonnage Baogutu deposit displays significantly lower f_{O_2} than OPCDs (>NNO + 2), and, on this basis, could be classified as a RPCD. Other physicochemical conditions including T, f_{S2}, $\log(f_{H2O}/f_{HCl})^{fluid}$ do not show obvious differences to those of OPCDs. We deduce that the low f_{O_2} of Baogutu metallogenic granitoids and aqueous fluids likely produced the unusual pyrrhotite–arsenopyrite mineral assemblage, and the NaCl–H_2O–CH_4–CO_2 ore-forming fluids and small tonnage typical of RPCDs.

Previous obtained fluid inclusion H–O isotope data and sulfide S–Pb isotope data suggest the methane-rich ore-forming fluids were derived from deep mantle source with little contamination from sedimentary components. However, detailed studies are needed to clarify the origin of the CH_4.

1. Introduction

Classic oxidized porphyry Cu deposits (OPCD) emplaced in subduction zones or in post-subduction orogenic belts are spatially and genetically related to highly oxidized, magnetite-series I-type granitoids (Audétat et al., 2004; Gustafson and Hunt, 1975; Hedenquist and Lowenstern, 1994; Sillitoe, 2010) and contain highly oxidized minerals including primary anhydrite and hematite. Examples include El Teniente in Chile (Stern et al., 2007), Santa Rita in New Mexico (USA) (Audétat et al., 2004) and Yulong (Liang et al., 2009) in Tibet. The oxygen fugacity of these I-type magnetite-series granitoids shows high f_{O_2} varying between the hematite–magnetite (HM) and nickel–nickel oxide (NNO) oxygen buffers, most exceeding NNO + 2 (Mungall, 2002; Richards, 2003). Many studies have shown that high oxygen fugacity magma sources (f_{O_2} - ~NNO + 2) will ensure that sulfate is the exclusive sulfur species in the melt (Carroll and Rutherford, 1988; Jugo et al., 2005a; Moretti and Baker, 2008; Moretti and Ottonello, 2003), and significantly increase sulfur solubility in melt (Jugo, 2009; Jugo et al., 2005b). In addition, the high oxidation state will lead to the breakdown or dissolution of sulfide phases in the mantle and release chalcophile (e.g., Cu, Ni) and siderophile elements (e.g., Ru, Rh, Pd, Re, Os, Ir, Pt, Au) to the melt, migrating these ore-forming elements to the shallow crust (Botcharnikov et al., 2011; Jugo et al., 2005a, 2005b). Thus, almost all porphyry Cu deposits show very high oxidation as a characteristic feature.

In contrast, Rowins (2000) proposed the existence of reduced porphyry Cu deposits (RPCD) that: (i) lack primary hematite and sulfate minerals (i.e., anhydrite), (ii) contain abundant hypogene pyrrhotite and

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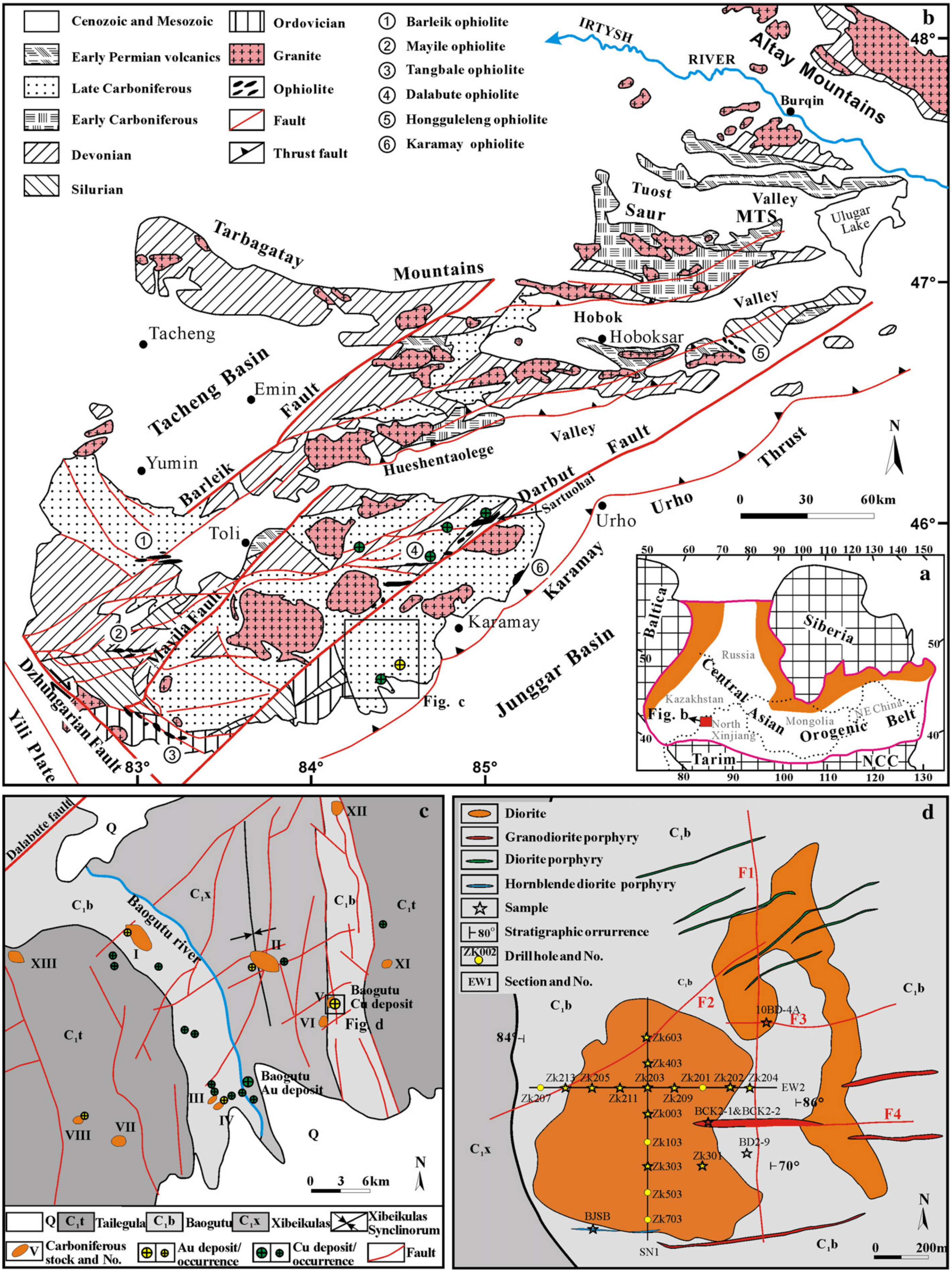
b
Cenozoic and Mesozoic
Early Permian volcanics
Late Carboniferous
Early Carboniferous
Devonian
Silurian
Ordovician
Granite
Ophiolite
Fault
Thrust fault
① Barleik ophiolite
② Mayile ophiolite
③ Tangbale ophiolite
④ Dalabute ophiolite
⑤ Hongguleleng ophiolite
⑥ Karamay ophiolite
IRTYSH RIVER
Altay Mountains
Burqin
Tuost Valley
Saur MTS
Ulugar Lake
Tarbagatay Mountains
Hobok Valley
Hoboksar
Tacheng
Tacheng Basin
Emin
Barleik Fault
Yumin
Hueshentaolege Valley
Darbut Fault
Sartuohai
Urho
Urho Thrust
Toli
Mayila Fault
Karamay
Junggar Basin
Dzhungarian Fault
Yili Plate
Fig. c
83°
84°
85°
46°
47°
48°
N
0 30 60km
a
Baltica
Siberia
Russia
Kazakhstan
Central Asian Orogenic Belt
Fig. b
North Xinjiang
Mongolia
NE China
Tarim
NCC
50 60 70 80 90 100 110 120 130 140 150
80 90 100 110 120 130
40
50
c
Dalabute fault
Q
C₁b
C₁x
C₁t
Baogutu river
I
II
III
IV
V
VI
VII
VIII
XI
XII
XIII
Baogutu Cu deposit
Fig. d
Baogutu Au deposit
0 3 6km
N
Q
C₁t Tailegula
C₁b Baogutu
C₁x Xibeikulas
Xibeikulas Synclinorum
V Carboniferous stock and No.
Au deposit/ occurrence
Cu deposit/ occurrence
Fault
d
Diorite
Granodiorite porphyry
Diorite porphyry
Hornblende diorite porphyry
Sample
80° Stratigraphic orrurrence
ZK002 Drill hole and No.
EW1 Section and No.
F1
F2
F3
F4
C₁b
C₁x
10BD-4A
84°
Zk603
Zk403
Zk213
Zk205
Zk203
Zk201
Zk202
Zk204
Zk207
Zk211
Zk209
EW2
Zk003
BCK2-1&BCK2-2
86°
Zk103
BD2-9
Zk303
Zk301
70°
Zk503
Zk703
BJSB
SN1
N
0 200m