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Epithermal gold deposits of China

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Abstract: Epithermal gold deposits have been found mainly in eastern China and recently in the northern Xinjiang Region. They are grouped into four belts based on their tectonic settings and belong to three mineralization episodes. They include: (1) the Cenozoic eastern Taiwan island arc belt; (2) the Late Paleozoic North Xinjiang island arc belt; (3) the Mesozoic continental margin belt along the northern border of the Sino-Korean Craton; and (4) the Mesozoic continental margin belt of SE China coastal area. Most of the reviewed deposits are of low sulfidation type, three are of high sulfidation type, and one is of Au-Te type related to alkaline rock series. Except the Chinkuashih deposit, the largest gold deposit in China, the epithermal gold deposits in general are of less economic importance at present in the mainland of China. The total reserve of epithermal gold deposits discovered in eastern China is not compared with the huge volume of widespread subaerial volcanic rocks of Mesozoic age. Relatively old mineralization age, Mesozoic in eastern China and Late Paleozoic in North Xinjiang, is an apparent feature of epithermal gold deposits in the mainland of China. Based on the analyses of metallogenic condition and preservation in China, and the comparison with western USA and eastern Russia, a preliminary assessment on the potential of epithermal gold deposits of China has been presented. Northern Xinjiang may be potentially significant for finding epithermal gold deposits.

Key words: epithermal gold deposits; China

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0 Introduction

Epithermal precious-metal deposits occur in, or are associated with, terrestrial volcanic/subvolcanic complexes[1], referred to in China as the "subaerial volcanic-hosted type"[2-3]. Carlin-type sedimentary rock-hosted deposits are not included in this category. Although epithermal deposits account for only about 2% of the known gold reserves in China, new deposits are a principal exploration objective[3]. Favorable geologic settings are widespread in China, particularly Mesozoic subaerial volcanic terranes along the east coast, and the settings are tectonically similar to productive regions in southeastern Russia (*e. g.*, the Baley and Darason). There are geologic similarities with the western United States as well. In addition to recent exploration successes elsewhere that continue to find world-class deposits in already explored areas (*e. g.*, Hishikari, Japan), these similarities increase the likelihood that world-class epithermal deposits may occur in China.

In general, the epithermal gold deposits of China are similar to those in the other parts of world. Both high- and low-sulfidation style deposits occur; for example, the advanced-argillic alteration related Zhijinshan copper-gold deposit in Fujian Province[4] and the quartz-adularia-illite style Axi gold deposit, Xinjiang Autonomous Region[5]. A list of the most important deposits is given in Table 1.

The purpose of this paper is to review the tectonic and geologic settings of epithermal gold deposits in China, their time-space distribution, and selected geologic and geochemical characteristics of the deposits. Problems regarding classification, relations to porphyry-style mineralization, gold/silver ratios compared to worldwide occurrences, and undiscovered resource

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Table 1 Selected geological characteristics of the major epithermal gold deposits of China

No.	Deposit (County)	Tectonic setting	Related volcanics	Ore age (Ma)	Volcanic setting	Form of orebody	Local fault control	Ore-related alteration	Associated mineralization	Host rock	Metal minerals	Gangue minerals	Grade (g/t)/ Reserve (t)
1	Chinkuashih (Jilong)	IA-Cz	Qz and CA	1.0 – 0.8	Flow dome	Vein + Brec + diss	Normal	HS(Au-Cu) sil + arg + alu	LS(Au)	Qz And + Mioc SS	ena, luz, py, Au, ele	qtz, bar, alu rho, cc	1 – 10 (2.2) /> 92 (404)
2	Zijinshan (Shanghang)	Cont	Dac-Ppy CA	110 – 95	Diatreme	Vein + lens in groups	Normal	HS (Cu-Au) sil + dic + alu + ser	Ppy (Cu-Mo) weak	Dac-Ppy + Brec + Gra	py, dig, cov, ena/Au, lem	qtz, alu, dic	4.2/8.2 + 0.2/6.9
6	Babaoshan (Longquan)	Cont	Dac-tuff CA, QzPpy	Mz	Caldera	Vein	Volc basin + Fault	LS (Au-Ag) sil + py + apy + adu	No	Metam-Pt + voc-Mz	gol, aca, py, apy, spl, gal	qtz, cha, ser	4.6/1.3
7	Zhilingtou (Suichang)	Cont	Rhy-And CA	Mz	Dome/Cald periphery	Vein + stockwork	Tensional	LS (Au-Ag) sil + py + ser + chl	No	Metam-Pt + volc-Mz	gol, py, spl, gal, apy, aca, Te, Se	qtz, rho, cc	12.1/18.9
8	Jinjiyan (Jinhua)	Cont	QzFelsoph Felso-CA	100.1	Dome/Cald	Lens + vein + bed vein	Tensional + volc Brec	LS (Au-Mo) flu + py + sil + ser	Loudian Au (Hot spring)	Felsoph Brec-vein	py, ele, spl, gal, mol, lem	ser, qtz, flu, fel, kao, chl	3.9/4.0
10	Dalingkou (Tiantai)	Cont	Felsic volc CA	78 – 97	Caldera	Vein	Tensional	LS (Au/Pb-Zn) sil + ser + py + carb	LS (Ag-Pb-Zn)	Felsic volc	gol, aca, pyr, py, spl, gal	qtz, cha, rho ser, chl	8.2/0.2
11	Huxu (Dongxiang)	Cont	QzDioPpy CA	Mz	Dome	Vein oxid-enrich	Tensional	LS (Au/Pb-Zn) sil + ser + chl + hem	Pb-Zn	QzDioPpy + volc-Mz	Au, gal, spl, cpy, py, hem, lim	qtz, ser, cc, bar, cha, cla	5.0/1.6
12	Jinqushan (Lishui)	Cont	Trac-and Sub-A	Mz	Volc basin	Vein (varied)	Tensional	Au-Te sil + ser + py	No	Trac-and volcanics	Au, Te, py, cpy, cha	qtz, ser, bar	4.8/0.3
14	Dongxi (Huoshan)	Cont	Trac-and CA-AC-A	Mz	Volc basin	Vein, Lens irregular	NW-fault tentional	LS (Au) sil + ser + carb + pro	Nanguanling LS (Au)	And & And-tuff	ele, mt, py, hem, (cpy, gal, spl)	qtz, cc, adu, ser, chl	5.7/3.3
15	Qiyugou (Songxian)	Cont	Qz-, Gran- & Sye-Ppy-CA	96, 102 (Ppy)	Uplift	varied in Brec pipe	Brec along faults	LS (Au) sil + chl + py-phy	No	Brec (Ppy, Arch/PtAnd	Au, py, (cpy, gal, Bi, Te)	qtz, chl, epi, cc	6.0/5.6
16	Guilaizhuang (Pingyi)	Cont	Mon-Sye Ppy Sub-A	189.8 (Ppy)	Dome?	Brec/Camb structural	Tensional + Rad	Au-Te sil + flu + adu + carb	No	Brec	Au, ele, Te, py, mar, cpy, gal	qtz, cha, opal, flu	9.9/15.0
17	Qibaoshan (Wulian)	Cont	QzDioPpy CA	140.1 (Ppy)	Dome?	Brec pipe	Ring + radial	LS (Au-Cu) sil + py-phy + carb	No	Brec of Ppy	py, cpy, bor, cha, spe, gal, Au, ele	qtz, ser, sid,	1.3/10.0
18	Gengzhuang (Fansi)	Cont	Qz-Ppy CA	152 – 130 (Ppy)	Subvolc	Altered rock/Vein	Brec pipe	LS(Au-Ag) sil + ser + kao + py	No	Ppy + Brec	Au, ele, py, gal, spl	ser, qtz, cc, feldspar, kao	9.7/5.2
19	Yixinzhai (Fansi)	Cont	MonDio-Gran-Ppy-CA	127.9 (Ppy)	Subvolc	Qz-Vein	Brec Pipe	LS (Au) sil + ser + kao + py	No	Ppy + Brec	Au, ele, cpy, py, gal, spl	qtz, ser, cc	9.8/10.2
20	Yuerya (Kuancheng)	Cont	Gran-Ppy CA	140 (granite)	Dome?	Vein + stockwork	Contact zone + fault	LS (Au-Polym) sil + py-phy + pyr	Ppy (Au) contact z.	Granite & spl, gal, mol	Au, py, cpy, pyr,	qtz, ser	10.7/24.6
23	Hongshi (Yixian)	Cont	Rhy-Ppy dike-CA	Mz	Volcanic Depression	Vein + Lens	Contact brec + Fract	LS (Au-Ag) pot + sil + py + ser	No	Rhy-Ppy + Ppy/And	Au, py, lim,	qtz, cha, cc	5.0/5.9
24	Erdaogou (Beipiao)	Cont	Granodio/ DioPpy-CA	< 130 ± 140 ±	Dome tensional	Vein + sil + ser + chl + cc	Ring + Rad	LS (Au-Polym) QzDio-Mz	Ppy (Cu-Mo) spl	Felsic volc	ele, py, cpy, gal,	qtz, ser, cc	13.6/20
	+ Jinchanggouliang (Aohan)	Cont	*idem*	120	Dome?	Vein	Rad & shear zone	LS (Au-Polym) chl + sil + cc + ser	*idem*	Metam-Ar	ele, py, cpy, gal, spl, bor	qtz, chl,	14/50
25	Nailingou (Aohan)	Cont	And-volc CA	Mz	Dome?	Vein + Lens compound	Tensional	LS (Au-Ag) sil + ser + py + chl	No	And volc	ele, py, arg, cpy, pyr, gal, spl, mar	qtz, cha, cc, flu	3.2/0.7
28	Xianluwanzi (Meihekou)	Cont	Granitic Felsite-CA	124 – 129 (felsite)	Subvolc brec	Vein(irreg) + Stockwork	Shear zone brittl-ductil	LS (Au) py + sil + ser + chl	No	Felso-Brec	Au, ele, gol, py, gal, spl, apy	qtz, ser, cc	6.5/7.5

29	Haigou (Antu)	Cont	DioPpy CA	143.9	Subvolc vein group	Vein + Stockwork	Intersect of 2 faults	LS (Au) sil + ser + chl + carb	Poly-metal + Se, Te, U	Monzonit granit + Pt$_2$	Au, py, gal	qtz, cc	5.9/23.0
30	Wufeng (Yanji)	Cont	Trac-and CA	Mz	Depression	Vein + Stockwork	Tensional	LS (Au) sil + adu + ser + zeo	WXS Au/LS (Stockwork)	And + pyroclast	py, cpy, ele, arg, pet, gal, spl	qtz, cc, cha, adu, zeo, ser	?/m
31	Naozhi (Wangqing)	Cont	And-Dac CA	127.8	Caldera	Vein + Compound vein	Ring + Rad	LS (Au-Cu) sil + py-phy + pro	No	Volcanics + fracture	Au, py, cpy	qtz, ser, chl	4.5/2.5
32	Ciweigou (Wangqing)		And-Dac CA	176.8	Caldera	Vein	Ring + Rad	LS (Au-Ag) sil + ser + chl + carb	No	Volcanics	ele, arg, Au, py, cpy, gal, spl	qtz, adu, cc	6.5/2.7
34	Axi (Yining)	IA-Pz	And-Ppy CA	324 – 388 275 – 346	Caldera	Vein	Ring	LS (Au) sil + ser + py + adu	YEMD Au silicified rock	And-Ppy + And	ele, Se, py, apy, gal, spl, cpy	qtz, ser, cc, adu	5.8/42.0
35	Kuoerzhen-kuola(Jimunai)	IA-Pz	And-Brec CA	Pz$_2$	Caldera	Vein	Ring	LS (Au) sil + arg + pro	No	And-Dac	Au, ele, py, apy volcanics	qtz, cha, ser, gal	?/m
36	Aketishikan (Fuyun)	Cont	Dac-rhy CA	178.5	Volcanic depression	Stratiform → Lens	Strato-horizon	LS (Au) py-phy + adu + arg	Magnetite	And-rhy volcanics	apy, py, pyr	qtz, ser, adu, mont	?/10
37	Jinshangou (Qitai)	IA-Pz	And-Ppy Trac-and-CA	354-310	Caldera	Veinlet + Stockwork	Ring + Rad	HS (Au) py-phy + sil	Alu + Polym + Bentonite	Volcanics	py, Au, spl, gal, cpy, apy	cha, ser, alu, cc	31.2/0.7
38	Xitan (Shanshan)	IA-Pz/ syncoll	And (volc) CA	244 – 288	Caldera	Vein	Ring + Tensional	LS (Au) sil + py-phy + pro	No	And-Dac volcanics	py, cpy, Au, ele, gol, apy, Te	cha, qtz, cc, ser, chl, adu	8.4/10.0 + 18.2/13.5
39	Kangguer (Shanshan)	IA-Pz	And-Dac CA	254-282	volc basin	Tab + Lens in mylonite	Shear zone → brittle	LS (Au) sil + chl + py-phy	Matoutan Au + Cu-Polym	And + tuff	py, mt, cpy, spl, gal, Au, ele	qtz, chl, ser,	5.5/19.4 + 6.3/34.9
40	Suoerbasitao (Balikuan)	IA-Pz	And, Bas, Fels-tuff, CA	C$_1$	Caldera	Vein	Ring	LS (Au) sil + ser + py + carb	Shuangfeng-shan Au (LS)	And, Bas, Fels-tuff	Au, ele, py, apy, gal, sti, bis	qtz, cha, ser,	?/s + ?/s
41	Mazhuangshan (Subei)	IA-Pz	Rhy-DacPpy CA	C$_1$	Caldera	Tab + Vein	Contact zone	LS (Au) sil + ser + pyroph	No	Subvolc RhyDacPpy	gol-Au, py, spl, gal, cpy, apy	qtz, ser, cc, pyroph	7.4/7.9
42	Lianghe (Tengcong)	Cont	Mafic-Dac CA	6.8 – 7.2 (basalt)	volc basin	Vein varied + stockwork	Fracture zone	LS (Au) Hot spr sil + arg + pro	No	Plioc sand	py, goe, mar, spl, conglom	qtz, cha, opa, cpy, gal, sti, clay	3.7/m
43	Longtoushan (Guigang)	Cont	Felsic Ppy CA	108 – 104	Subvolc	Vein + Lens	Tensional	LS (Au) sil + tou + py + ser	Ppy-Cu + Polym	Rhy-Ppy + Brec	Au, py, bis, cpy, gal, apy	qtz, tou, ser	5.0/5.0

Abbreviations: Tectonoc setting: IA – island arc; Cont – continental margin; syncoll – syncollision. Ages: Cz – Cenozoic; Mz – Mesozoic; Pz – Paleozoic; Pt – Proterozoic; Ar/Arch – Archean; Plioc – Pliocene; Mioc – Miocene; C$_1$ – Early carboniferous; Camb – Cambrian. Related volcanics/Host rock: A – alkali; AC – alkali-calcic; And – andesite; Bas – basalt; Brec – breccia; CA – calc-alkaline; conglom – conglomerate; Dac – dacite; Dio – diorite; Fels – felsic; Felso(ph) – felsophyre; gran/Gra – granite; Metam – metamorphosed rocks; Mon – monzonite; Ppy – porphyry; Qz – quartz; Rhy – rhyorite; SS – sandstone; Sub-A – subalkali; Sye – syenite; Trac-and – trachyandesite; volc – volcanics. Volcanic setting: Cald – caldera; Volc – volcanic. *Form of orebody*: *Brec* – *breccia*; Diss – disseminated; irreg – irregular; Tab – tabular. Local fault control: Rad – radial. Ore-related alteration/Minerals: HS – high sulfidation; LS – low sulfidation; aca – acanthite; adu – adularia; alu – alunite; apy – arsenopyrite; arg – argentite or argillation; Au – gold; bar – barite; Bi – Bi mineral; bis – bismuthine; bor – bornite; carb – carbonate; cc – calcite; cha – chalcosine or chalcodony; chl – chlorite; cla – clay; cov – covellite; cpy – chalcopyrite; dic – dickite; dig – digenite; ele – electrum; ena – enargite; epi – epidote; fel – feldspar; flu – fluorite; gal – galena; goe – goethitegol – goldargetid; hem – hematite; Hot spr – hot spring type; kao – kaolinite; lim – lemonite; luz – luzonite; mar – marcasite; mol – molybdenite; mont – montmorillonite; mt – magnetite; opa – opal; pet – petzite; phy – phyllic; Polym – polymetallic; pot – potassic alteration; pro – propylitization; py – pyrite; pyr – pyrrhotine; pyroph – pyrophyllite; qtz – quartz; rho – rhodochrosite; Se – selenides; ser – sericite; sid – siderite; sil – silicification; spe – specularite; spl – sphalerite; sti – stibnite; Te – tellurides; tou – tourmaline; zeo – zeolite. WXS – Wuxingshan; YEMD – Yiermande. Grade/Reserve: s – < 5 t; m – 5 – 20 t; ? – not available.

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potential in China are also briefly discussed.

1 Tectonic Setting of Epithermal Gold Deposits in China

Asia is an amalgamation of tectonic blocks that formed during sequential collisions of microcontinents during the Paleozoic and Mesozoic[16]. China is a composite of four Precambrian crystalline terranes — Sino-Korean, Tarim, Yangtze and Cathaysian blocks — surrounded by Phanerozoic fold belts (Fig. 1). Precambrian metamorphosed subaerial volcanic rocks have

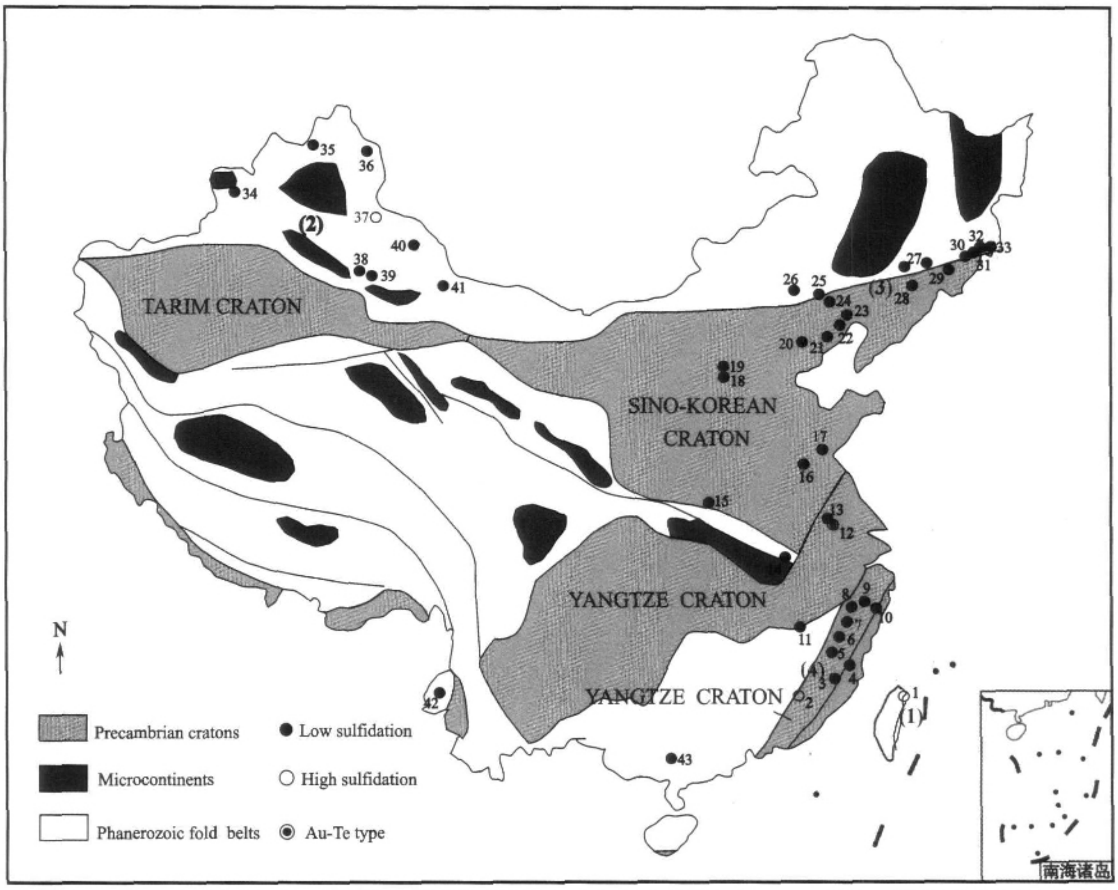

Fig. 1 Schematic spatial distribution of epithermal gold deposits of China

The tectonic sketch after Li Xian-hua pers. comm. (1993) revised.

Circle – High sulfidation; Solid circle – Low sulfidation; Double circle – Au-Te type.

Gold grade (in g/t) *vs.* reserve (in t) in brackets mainly based on 1996 National Reserves Table of China, supplemented or revised by Map Collection of Gold Mineral Resources of China (1992) and others.

1. Chinkuashih, Taiwan (1 – 10/> 92)
2. Zijinshan + Bitian, Fujian (4.2/8.2 & 0.2/6.9 + 0.3/1.9)
3. Anchun (6.0/1.3)
4. Luoqiao (5.2/0.5)
5. Dongyou (26.6/0.1)
6. Babaoshan, Zhejiang (4.6/1.3)
7. Zhilingtou (12.1/18.9)
8. Jinjiyan + Luodian (3.9/4 + vs)
9. Luoshan (4.0/1.0)
10. Dalingkou (8.2/0.2)
11. Huxu, Jiangxi (5.0/1.6)
12. Lishui, Jiangsu (4.8/0.3)
13. Tongjing (2.0/5.0)
14. Dongxi + Nanguanling, Anhui (5.7/3.3 + 5.4/> 1.1)
15. Qiyugou, Henan (6.0/5.6)
16. Guilaizhuang, Shandong (9.9/15.0)
17. Qibaoshan (1.3/10.0)
18. Gengzhuang, Shanxi (9.7/5.2)
19. Yixingzhai (9.8/10.2)
20. Yuerya, Hebei (10.7/24.6)
21. Nandaxian, Liaoning (9.4/4.5)
22. Shuiquan (6.6/4.6)
23. Hongshi (5.0/5.9)
24. Erdaogou (13.6/20) + Jingchanggouliang, Inner Mongolia (12/50)
25. Nailingou (3.2/0.7)
26. Guandi (7.8/0.8)
27. Erdaoling, Jilin (?/5.0)
28. Xianluwanzi (6.5/7.5)
29. Haigou (5.9/23.0)
30. Wufeng + Wuxingshan, Jilin (?/m + 5.4/0.5)
31. Naozhi (4.5/2.5)
32. Ciweigou (6.5/2.7)
33. Duhuangling (1.5/2)
34. Axi + Yiermande, Xinjiang (5.8/42.0 + ?/s)
35. Kuoerzhenkuola (?/m)
36. Aketishikan (?/10)
37. Jinshangou (31.2/0.7)
38. Xitan (8.4/10.0 + 18.2/13.5)
39. Kangguer + Matoutan (5.5/19.4)
40. Suoerbasitao (6.3/34.9) Shuangfengshan (?/s + ?/s)
41. Mazhuangshan, Gansu (7.4/7.9)
42. Lianghe, Yunnan (3.7/m)
43. Longtoushan, Guangxi (5.0/5.0)

Notes: vs – very small; s – < 5 t; m – 5 – 20 t; ? – not available.

been identified from several of the terranes. Paleozoic volcanic rocks are found in northwestern China, but are predominantly submarine[14, 17, 18], although some subaerial volcanic rocks are found in micro-continental fragments in the northern Xinjiang Autonomous Region[17-18]. Subaerial volcanic rocks are predominantly Mesozoic and are found mainly in eastern China in continental arcs along transform boundaries[19-20]. Intermediate to felsic volcanism was particularly widespread throughout this region from ~140 to 100 Ma[21]. Cenozoic subaerial volcanic rocks are found only in eastern and northern Taiwan. These are a part of the belt of active Southwest Pacific oceanic arcs. The epithermal gold deposits in China (Fig. 1) are found in both marginal and continental arcs[11, 13, 22].

1.1 North Xinjiang Island Arcs

A complex sequence of accreted terranes separated by strike-slip or thrust faults makes up the northern part of Xinjiang Autonomous Region in northwestern China. The Tarim craton (Fig. 1) forms the southern boundary of the region. The terranes of the Tianshan fold belt are to the north of the Tarim craton[23]. Farther north, there is a collage of microcontinental fragments, island arcs, and ocean basins that comprise the Junggar and Altayshan areas along on the border with Russia and Mongolia[24]. During Late Paleozoic, in the Junggar-Altayshan region two series of volcanic-arc terranes were separated by an isolated ocean, which was trapped during the consolidation of Central Asia[24]. The ocean had receded by Middle Permian. Collision with and accretion to the Tarim craton took place during Late Permian[24].

Epithermal gold deposits are found in both the Junggar-Altayshan region and Tianshan fold belt (Fig. 1, #34-41), and include the well-known Axi deposit in the northwestern part of the region and the Kanggurtag deposit in the southeast. Some deposits may be related to subduction beneath the Tarim craton, while others are related to island-arc volcanic rocks in the northern fold belts. The host volcanic rocks are mainly calc-alkaline and alkaline intermediate to felsic rocks. They are predominantly andesites and rhyolites with minor amounts of basalt[14].

1.2 Northeastern China

The Sino-Korean and Tarim cratons (Fig. 1) were formed at approximately the same time and have similar geologic histories along the northern margins. As in northwestern China, northeastern-most China is made up of the similar sutured fold belts, like Junggar-Altayshan and Tienshan. They adjoin the Sino-Korean craton on the south along a former south-dipping, Paleozoic subduction zone[16]. Accretion of these terranes into a single element began in the Late Permian in the west and continued into the Early Mesozoic in the east[25].

Epithermal deposits formed in the arc along the subduction boundary (Fig. 1, #24-33), and to the southwest along or paralleling the left-lateral Tanlu fault zone (Fig. 1, #16-17, #20-23). Thus, many deposits formed in a continental arc along a transform boundary[26].

1.3 North and South China Collision Zone

Prior to the Late Triassic, an extensive ocean separated the Sino-Korean (North China) and Yangtze (South China) cratons[16]. Shi *et al.*[27] interpret the geology of the East Qinling Mountains to indicate that subduction was to the south from Cambrian until Devonian. Late Devonian to Early Carboniferous nonmarine volcanic rocks overlay the subduction complex[16]. The continental blocks collided in Late Triassic and are joined along the Qinling suture zone[19]. Two epithermal gold deposits are known in this tectonic belt (Fig. 1, #14-15).

Uncommon among epithermal gold deposits in China are deposits related to alkali-rich intermediate-mafic and alkaline volcanic rocks. For example, the Tongjing, Dongxi, and Nanguanling deposits (Fig. 1, #13-14) are spatially associated with Early Cretaceous shoshonitic volcanic and subvolcanic rocks[10, 28]. The Lishui (Jinjushan) deposit is of the gold-tellurium type (Fig. 1, #12).

1.4 Southeastern China

The Cathaysia accretionary fold belt in southeastern China (Fig. 1) is sutured to the South China fold belt

(Yangtze craton) along a former west-dipping subduction zone[16]. From Late Jurassic to Cretaceous, Cathaysia was a nonmarine andesitic arc[29]. Yu[30] divided the Mesozoic volcanic rocks in this region into three types: andesitic to rhyolitic (predominant), latitic (mainly in the low reaches of Yangtze River), and alkali-basaltic (subordinate). Nine epithermal deposits (Fig. 1, #2 – 10) are located within the arc rocks including the Zijinshan copper-gold deposit, Fujian Province, and Yinkengshan (Zhilingtou) gold deposit, Zhejiang Province.

1. 5 Taiwan Island Arc

Taiwan is located along the boundary between the Eurasian and the Philippine Sea plates[31], and was formed as a result of the collision of the Luzon arc and the Asian continent during the Plio-Pleistocene[32]. There are four geologic provinces on Taiwan: from east to west, the Coastal Plain, Western Foothills, Slate Terrain, and the Coastal Range. A lower Miocene volcanic assemblage in the Coast Range marks the beginning of the development of an arc-trench system on Taiwan, the northern extension of the North Luzon Ridge[29]. During Pleistocene volcanism was concentrated in northern Taiwan and offshore to the north. The Ryukyu arc-trench system extends from Kyushu to just east of Taiwan, the western boundary of which is a transform, the Longitudinal Valley fault in eastern Taiwan. Behind the Ryukyu arc is a zone of back-arc spreading, the Okinawa trough, that extends into northeastern Taiwan in the Slate Terrain[33]. The Pleistocene volcanic rocks, Western Foothills province, in northeast Taiwan are host to the high-sulfidation epithermal Chinkuashih gold-copper deposit (Fig. 1, #1; *cf.* Tan *et al.*[6] and Tao[7]).

2 Geology of Epithermal Gold Deposits in China

2. 1 Classification

The epithermal deposit classification suggested by Hedenquist[34], the high- and low-sulfidation types, is frequently applied in China. Of the deposits listed in the caption to Fig. 1, most are of the low-sulfidation type. The ratio of high- to low-sulfidation type is similar to that found in the United States[35 – 36]. In China, only Chinkuashih, Zijinshan and Laojunmiao of the Jinshangou district are high-sulfidation type deposits. Two of the remainder, Jinjushan (Lishui[9]) and Guilaizhuang, are gold-tellurium variety low-sulfidation deposits.

2. 2 Volcanic setting

Regardless of age or tectonic setting, most of the epithermal gold deposits in China are related to calc-alkaline volcanic and subvolcanic rocks. The volcanic rocks are predominantly intermediate and intermediate to felsic, comparable to rocks hosting epithermal gold deposits in the rest of the world[2, 37, 38]. Volcanoes and associated basins play important roles in the localization of ore fields (mining districts), deposits, and ore bodies within deposits. As summarized by Wang *et al.*[15], pull-apart basins along strike-slip fault zones (extensional stepovers) are a favorable environment for the localization of epithermal gold deposits in eastern China and northern Xinjiang Autonomous Region.

2. 3 Structural control

In many regions, the epithermal deposits are spatially associated with regional-scale, deep-seated faults. For example, in eastern and southeastern China, the localization of epithermal gold deposits is controlled by regional faults parallel to plate boundaries[2, 15, 37, 39]). In some instances, reactivation of older fault zones played an important role in localizing subaerial volcanism and related deposits. For example, the east-west-striking deep-seated fault of the North China Craton was reactivated due to Mesozoic subduction of the Kula/Pacific Plate beneath the Eurasian Plate. Volcanism occurred along this zone predominantly at its junctions with north-northeast-trending deep-seated faults[15].

In southeastern China, the structural control on epithermal gold deposits has been investigated by Qi *et al.*[8]. Deposits are localized along a north-northeast-striking zone parallel to the Tancheng-Lujiang (Tanlu) deep fault. Examples of epithermal-style deposits include these gold deposits Dongyou, Babaoshan, Zhilingtou and Jinjiyan (Fig. 1, #5－8). A similar north-northeast linear array of epithermal gold deposits is in eastern Jiling Province.

Within volcanic fields, structural-basin bounding faults are the conduits for hydrothermal fluids, resulting in the localization of ore bodies along them. An example is the Zijinshan copper-gold deposit (Fig. 1, # 2) in southeast China, which is located at the northeastern margin of the Shanghang basin (Fig. 2). Other examples are the Wufeng and Wuxingshan deposits at the northern margin of the Yanji basin (Fig. 1, #30), Ciweigou at the western margin of the Laosongling basin (Fig. 1, #32), and Hongshi at the southern margin of the Fuxin-Yixian basin (Fig. 1, # 23)[12, 13, 15, 40].

The Zijinshan copper-gold deposit also illustrates the importance of crustal-scale faulting to the localization of magmatic hydrothermal systems (see Fig. 2). The Shanghang basin is one of several pull-apart basins (e. g., Shanghong-Songxi) that localize volcanism along the northwest-trending Shanghang-Yunxiao regional fault system. In general, the epithermal gold deposits are frequently located in secondary fractures or faults on both sides of regional faults, instead of being situated directly on the deep-seated faults[37].

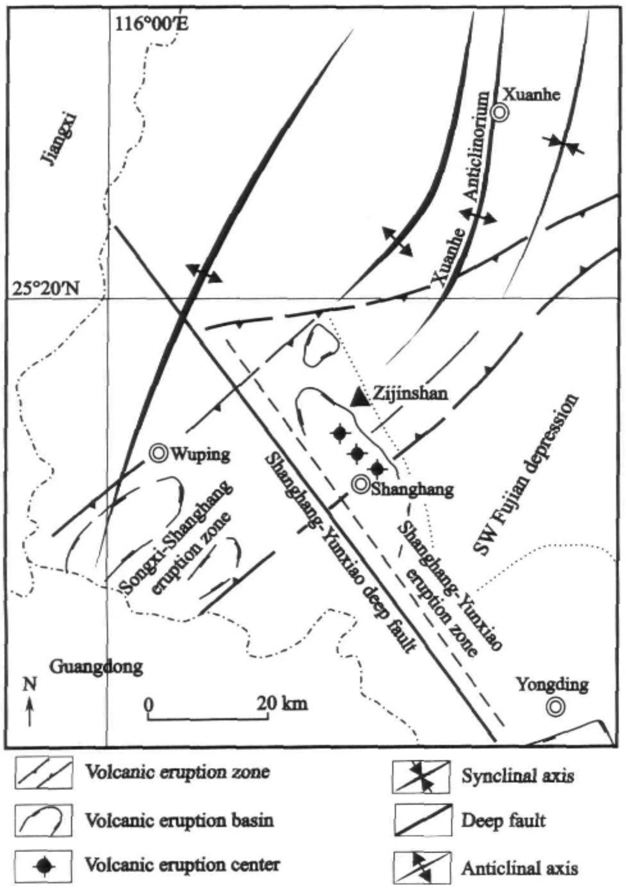

Fig. 2 Regional structure and volcanic eruption zones of the Zijinshan deposit, Fujian

After the No. 8 Geologic Survey Team, Fujian Bureau of Geol & Mineral Res.

Other structural settings for epithermal deposits include ring and radial faults, hydrothermal breccias, and volcanic breccias around volcanic domes[2, 15]. The Axi deposit (Fig. 1, #34) is located at the western periphery of a volcanic ring structure (Fig. 3; Mu *et al.* [5]). Seven quartz veins crop out in an arcuate pattern. In the Erdaogou-Jinchanggouliang goldfield, there are more than 200 gold-bearing veins controlled by radial faults[10, 41] (Fig. 4). There are several epithermal gold deposits localized in breccia pipes including the Qiyugou deposit in Henan Province (Fig. 1, # 15), Qibaoshan in Shandong Province (Fig. 1, #17), Jinjiyan in Zhejiang Province (Fig. 1, #8), Longtoushan in Guangxi Province (Fig. 1, #43), and the Chinkuashih district on Taiwan[6, 8].

Contrasts in mechanical properties between different host rocks appear to be important in the structural localization of ore bodies within some epithermal districts[3]. For example, in the Zhilingtou deposit, the unconformity between the volcanic rocks and underlying metamorphic basement appears to have focused hydrothermal fluid flow or even modified the physical and chemical conditions as has been suggested for Hishikari, Japan[38, 42]. At Zhilingtou, the main and most gold-rich parts of the veins are within the basement. Veins in the overlying volcanic rocks are, relatively, silver-rich. A similar condition may apply in the Axi deposit[3].

2.4 Alteration and ore deposit zonation

The classification of gold deposits in China has been problematic because of the antiquity of most deposits. Alteration assemblages have, in some cases, been metamorphosed, and textures commonly diagnostic of epithermal-style deposits are thermally annealed.

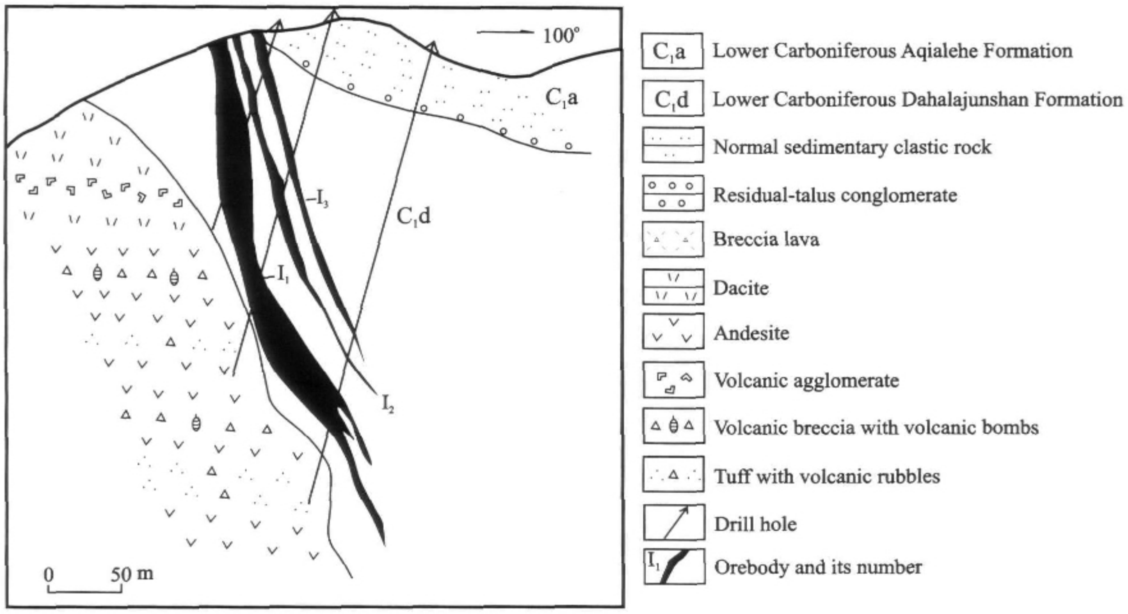

Fig. 3 Sketched profile of Axi No. 1 gold deposit, Northern Xinjiang

After the No. 1 Geologic Survey Team, Xinjiang Bureau of Geology & Mineral Resources.

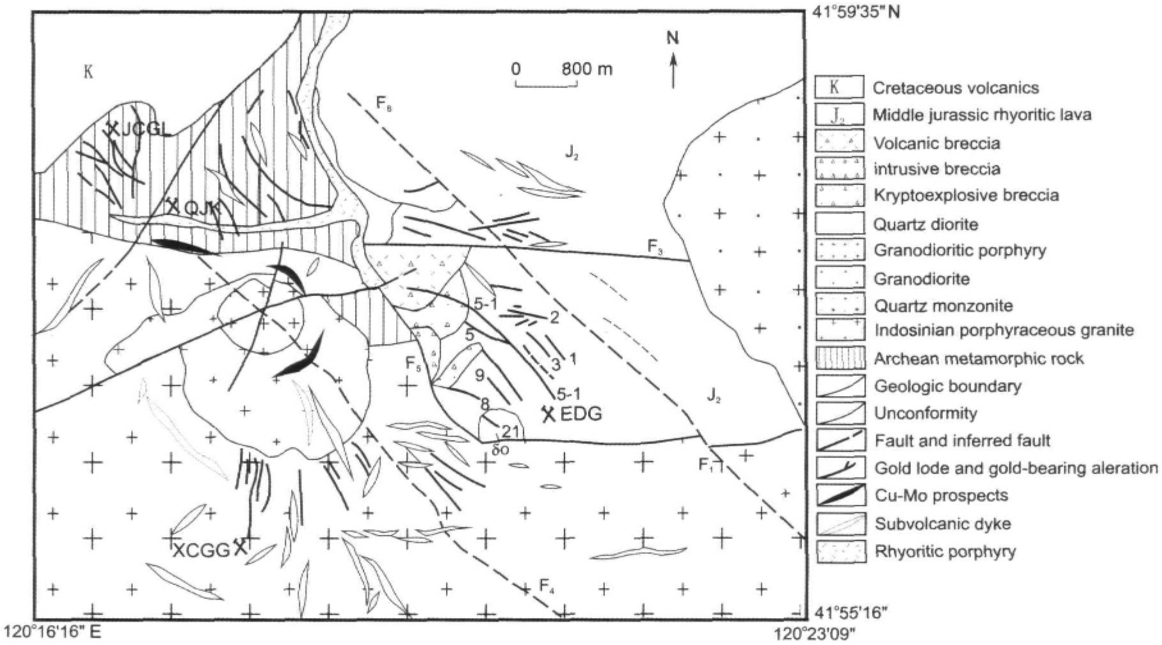

Fig. 4 Geologic map of Erdaogou-Jinchanggouliang gold district, Liaoning

After Pang[25,68]. EDG – Erdaogou; JCGL – Jinchanggouliang; XCGG – Xiaochanggaogou; JK – Qijinkuang.

Alteration and mineral assemblages in epithermal gold deposits in China are similar to those found elsewhere. Wallrock alteration zoning occurs both vertically and horizontally. The typical spatial relations of wallrock alteration suggested by Heald *et al.* [35] can be applied in China; for example, the gradation from the ore outward from silicification (+advanced argillization in high-sulfidation systems) to predominantly sericitization (+argillization in high-sulfidation systems) to an outer zone of propylitic alteration. For example, vertical zoning in the high-sulfidation Zijinshan copper-gold deposit is shown in Fig. 5.

The style of mineralization or the composition of ores may be zoned at a district and/or deposit scale. In some districts, porphyry copper-style mineralization occurs at depth below the zone of epithermal veins. In

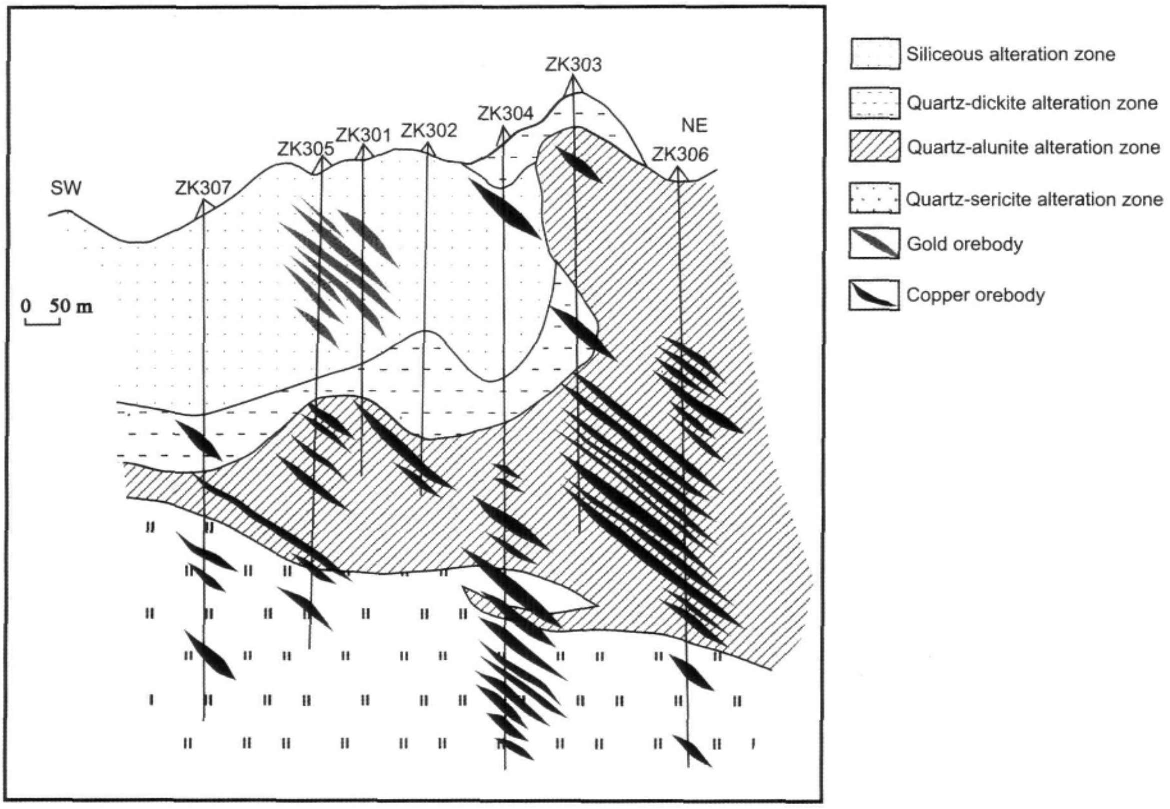

Fig. 5 Sketched profile of alteration zonations and copper/gold orebody occurrences of Zijinshan Cu-Au deposit, Fujian
After the West Fujian Geologic Survey Team and Zhang *et al.* [4]

the Chinkuashih district, Taiwan, the spatial distribution of gold, Au-Cu and Cu-Au veins, and Au breccia pipes shows a regular pattern with an enargite-luzonite copper center and a gold periphery[6, 43]. Deposit-scale zoning is manifested differently in different districts. For example, within the Penshan vein in the Chinkuashih district, Taiwan, there are systematic variations of the ore with depth along the vein. These variations include: (1) the transition from “upper gold” to “low copper”; (2) a downward increase in ore-deposition temperatures (from 200 ℃, through 200 – 300 ℃, to 375 ℃); (3) a change in the crystal habit of pyrite (from cubic in the upper ores, through pyritohedra in the middle, and octahedra in the lower ores) and (4) the pyrite composition changes from argentiferous in shallower ores to cupriferous in deeper ores. There is a positive correlation between the fineness of native gold and the ore-forming temperatures in the district, *i. e.*, the lower the temperature, the lower the fineness[6]. In the Kanggurtag deposit, northwestern China, Pirajno *et al.* [44] reported the vein to be gold-rich at shallowest levels grading downward through a gold-copper zone to a lead-zinc zone in the deepest levels. In Zhejiang Province of southeastern China, there is a close association between epithermal gold-silver deposits and base metal deposits, and they even occurred within same deposit[45].

2. 5 Geochemical characteristics

The geochemical characteristics of most epithermal gold deposits in China have been investigated to gain a better understanding of ore-forming conditions and mechanisms. These include the relation to magmatic systems, the source of ore-forming materials including the water, sulfur and metals, and ore-forming conditions as interpreted from fluid inclusion data.

Based on Sr and Nd isotopes and trace elements, two types of magmatic systems, similar to granites in southeastern China, were also identified for volcanic or subvolcanic rocks in Jiangxi Province and its vicinities[46]. The epithermal gold deposits are mostly associated with the I-type volcanism while the volcanic-hosted hydrothermal uranium deposits with the S-type. Late Yanshanean dacitic porphyre in the

Zhijinshan epithermal gold deposit has much younger Nd model age than the early Yanshanean rhyoro-dacite in the Xiangshan volcanic-hosted hydrothermal uranium deposit[47]. Ishihara *et al*.[48] investigated the alkalinity and initial Sr ratios for the Cenozoic igneous rocks related to gold deposits of the Ryokyo arc.

Isotopes have been used to determine sources of water in the ore-forming fluids. All the determinations and studies on oxygen and hydrogen isotopes from epithermal gold deposits in China give similar results as those from other parts of the world. For example, Wang *et al*.[49], in summarizing the data from different types of gold deposits in China, found the mixing of a large amount of meteoric water with lesser amounts of magmatic water to be characteristic of epithermal-style deposits, as well as effects related to latitude, geography, and proximity to the sea. Similarly, sulfur isotopic studies also yield results characteristic of epithermal gold deposits worldwide[5,8,12,14,41,50].

Lead isotope studies of epithermal gold deposits in China are also typical of studies elsewhere. In some cases magmatic sources are implied (*e.g.*, the Erdaogou district[41]), whereas in others the ore and host rock leads have similar compositions (*e.g.*, the Axi deposits[5]) implying a nonmagmatic inheritance.

Carbon isotopic studies are less common than other isotopic systems, but carbonate minerals generally reflect the leaching of carbon from host rocks by meteoric waters (*e.g.*, the Wufeng deposit[12]).

Fluid inclusion investigations have also found ore-forming thermal and chemical conditions to be similar to epithermal deposits found elsewhere. Typical studies include Wei *et al*.[50] in the Zijinshan district and the summary of Zhu *et al*.[51] for southeastern China.

3 Discussion

The common characteristics of epithermal gold-silver deposits worldwide and the recognition of permissive lithotectonic terranes in several parts of China indicate that there is significant potential for new epithermal gold deposit discoveries in China. A considerable difficulty in exploring for new deposits, however, arises from the ready annealing of diagnostic epithermal textures and the complex structural history that characterizes much of China. Thus, properly classifying gold deposits is challenging. Pirajno *et al*.[44] provide an example from the eastern Tianshan Mountains in northwestern China. At the Kanggurtag deposit, the vein occurs in siliceous to intermediate composition volcanic arc rocks. However, the occurrence of coarse-grained quartz, quartz in strain shadows around pyrite, and chlorite along shear bands in the vein suggests that its original textures have been modified to an unknown degree by post-mineralization deformation and thermal alteration. On the basis of alteration and geochemical characteristics, Parajno *et al*.[44] consider the deposit to be epithermal. However, because of the deformation and the regional tectonic setting, the possibility of it being a syn-orogenic-style vein must be carefully considered.

In addition to geologically permissive terranes, the association of mineral-deposit styles can be a good guide to the exploration potential of a region. For example, epithermal gold-silver deposits are known to be associated with porphyry copper deposits[52]. In China, porphyry Cu-Au deposits are one of the major producers of by-product gold, for example at Tongchang (Dexing) and Duobaoshan[53]. Furthermore, there are several epithermal gold deposits where porphyry Cu-Mo mineralization has been found at depth, for example in the Zijinshan[4] and the Erdaogou districts[41]. Interestingly, in spite of the apparent relationship between these deposit types, there are few districts around the Pacific Rim wherein world-class epithermal deposits are associated with world-class porphyry-style deposits. An exception is the Lepanto epithermal Cu-Au and Far Southeast porphyry Cu deposits on Luzon Island in the Philippines[54-55].

One of the enigmas regarding epithermal deposits in China is that few are very large. Is this because of the vagaries of the geologic evolution of China in that few were formed or does the antiquity of most of the magmatic arcs work against deposit preservation? Most epithermal deposits worldwide are Late Mesozoic to Cenozoic, but there are notable exceptions such as the world-class Proterozoic Mahd adh Dhahab deposit in

Saudi Arabia. Nevertheless, the size of deposits in China, as a proportion of volumes of volcanic rock still preserved, appears to be different from comparable volcanic fields elsewhere. Although many Mesozoic deposits have been discovered in eastern China in association with large volumes of volcanic rocks, they are smaller than deposits in eastern Russia and western North America of the same type and similar age[38, 56 – 58].

Tao[26] noted the uniqueness of tectonics and magmatism in the SE China coastal area at the circum-Pacific continental margin, and concluded that tectonic differences between the two sides of the Pacific Plate may imply the unequal in epithermal gold metallogenesis. Mesozoic epithermal gold deposits in eastern China were formed in a transitional tectonic setting between continental margin and within-plate, and this may be a factor in deposit genesis. Deposits in North Xinjiang were formed in former island-arc settings, whereas in eastern China deposits were formed in continental volcano-tectonic basins of the overlying type.

In contrast to the case in parts of the western United States, epithermal vein deposits in China are not spatially associated with Carlin-style deposits[59] . For example, there is epizonal mineralization (epithermal-, polymetallic-, and porphyry-style) in the Tuscarora, Shoshone, and Cortez mountains, Nevada, in the general vicinity of several large Carlin-style deposits and there are Carlin-style deposits in the Oquirrh Mountains, Utah, where the Bingham Canyon porphyry copper and related vein deposits are located.

4 Concluding remarks

Epithermal gold deposits in China may be grouped into four tectonic belts. They belong to three metallogenic episodes. The Cenozoic eastern Taiwan island arc belt contains the Chinkuashih (“golden melon stone”, in Chinese) deposit, the largest gold deposit in China with a resource of more than 500 tons of gold metal at a grade of 1 – 4 g/t Au or 404 t at 2.2 g/t[6, 60]. This region is part of the Circum-Pacific Great Gold Belt. In North Xinjiang, there have been recent discoveries in Late Paleozoic island- and continental margin-arc belt rocks. This region has significant mineral-resource potential and, as well, may offer a good model for exploration in older terranes. In eastern China, Mesozoic magmatic arcs may be divided into the northern and southern belts using the spatial distribution of deposits and deposit-controlling deep faults. The transitional aspect between continental margin and within-plate magmatism is characteristic of Mesozoic volcanism in eastern China and differs from the Andes of South America. An implication is this difference may have been important to the productivity of hydrothermal systems in China and, therefore, to undiscovered gold deposit potential.

There are different opinions regarding the potential for epithermal gold deposits in Mesozoic rocks in eastern China[3, 8, 47, 61, 62]. Are these Mesozoic subaerial volcanic rocks fertile in generating epithermal gold deposits? How many deposits were formed and how many of them remain after about 100 Ma of erosion? Is there a need to use different exploration methods that have been applied in the past? These questions remain to be resolved.

The great success in exploration for epithermal gold deposits in Paleozoic rocks in North Xinjiang is an important contribution to gold exploration in China. Detailed studies of the recently discovered deposits are just beginning. Given the antiquity of this terrane, what is potential for additional epithermal gold deposits? How have these deposits been preserved for on the order of 300 Ma? Further tasks are to obtain a better understanding of gold genesis in this region and to find more and larger deposits.

5 Acknowledgements

We wish to thank the many authors of exploration reports, non-open reference materials, and previously published papers whose work contributed to this overview but was not listed in references due to limited space. We are grateful to Prof. Wang Bi-xiang of the Institute of Geology, Chinese Academy of Geological Sciences and our colleagues Associate Professor Fang Tao and Prof. Wen Han-jie for their help in providing some deposit localities and plotting the distribution

maps of gold deposits. The authors express sincere thanks to Drs. J. Zhou, R. Goldfarb, and G. Y. Dong as well as Professor Z. L. Xu for their careful review and valuable comments on the manuscript, which helped to improve the presentation.

6 Words of the First Author

This paper is a posthumous work of Mister Tu although Qiu Yu-zuo is the first author according to his idea. It is highly appreciated to publish a special issue in memory of Mister Tu and to include this unpublished manuscript.

"Gold and uranium reserves, the foundation of a nation", Mister Tu paid great concerns on it during his life-time. He personally visited many Au and U deposits in China and other countries, and collected lots of related references. In 1990s, he arranged a sub-project, the subaerial volcanic-hosted Au and U deposits, under the state key project 85-A-30 Superlarge Deposits headed by him. The result obtained for this sub-project has been published[47]. Meanwhile, an abstract[62] and a poster[63], both in the same topic of this paper, had been presented at the International Symposium on Epithermal (Low-Temperature) Mineralization (Guiyang, China) and on the scientific corridor of the laboratory, respectively.

In late 1990s, Mister Tu was invited to compile an overview on epithermal gold deposits of China for an English journal. However, the draft and revised manuscript completed by Qiu and Tu were not matched with the interest of the invited editor and the layout of the journal mainly because of Qiu's lacking of experience, and later Dr. Berger was kindly invited as a co-author to do hard revision on it. Unfortunately, the long-lasting revised manuscript as presented here is still unpublished. It is very regretful that no time and energy to update it for further revision and complement from both sides since then.

In memory of Mister Tu, it is suitable and still worthy to publish this summarized work, although there are some points need to be corrected and revised, since new progresses obtained after then, including the identification of mineralization type of a few deposits such as the Haigou deposit[64]. Otherwise, a number of new referential materials concerning this topic occurred in two aspects, the studies, exploration and mining on individual deposits (*e. g.*, the Axi deposit[65]; the Zhijin Mining Group), and the new summary concerning the epithermal gold deposits[66]. Therefore, a new and further overview on this topic is expected in future.

In 2007, China became the world's largest gold producer[67]. There should be some portion of contribution attributed to the epithermal gold deposits. It must be the greatest happiness and consolation to the late predecessors in the field of epithermal gold deposits of China, Mister Tu, Mr. Li Wen-da and Mr. Li Zhao-nai.

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中国浅成低温热液金矿床

摘　要：浅成低温热液金矿床在中国传统上称为陆相火山岩型金矿床，主要发现在中国东部，后来在北疆地区也有新的发现。根据产出的大地构造背景，它们集中分布在 3 **个带，并分属于** 3 **个成矿时期。它们包括：**(1)**新生代台湾东部岛弧带；**(2)**晚古生代北疆岛弧带；**(3)**中生代沿中朝克拉通北界的大陆边缘带；**(4)**中生代中国东南沿海地区的大陆边缘带。绝大多数矿床是低硫化型的，只有** 3 **个是高硫化型的，另有** 1 **个是与碱性岩系有关的** Au-Te **型矿床。除了中国最大的金矿床金瓜石矿床外，迄今为止中国大陆上的浅成低温热液金矿床总的来说只有较小的经济重要性。在中国东部发现的浅成低温热液金矿床的总储量，与区内广泛分布的中生代陆相火山岩十分巨大的体积极不相称。较古老的成矿年龄，中国东部的中生代和北疆的晚古生代，是中国大陆浅成低温热液金矿床的一个鲜明的特点。根据中国的成矿条件和保存条件的分析，以及与美国西部和俄国东部的对比，提出了中国浅成低温热液金矿床成矿潜力的一个初步评估。北疆可能有较大的寻找浅成低温热液金矿床的潜在重要性。**

关键词：浅成低温热液；金矿床；中国

这是早年涂先生主持编写的一篇遗稿。他生前十分关注中国的金矿资源，亲自考察过许多金矿床，包括不少陆相火山岩型金矿床。整理刊登此文，以弘扬涂先生的学术思想，并作为对他的深切怀念。

QIU Yu-zhuo et al.: *Epithermal gold deposits of China*