Journal of Geology & Geosciences
ISSN: 2381-8719
Han et al., J Geol Geosci 2014, 3:3
DOI: 10.4172/2329-6755.1000158
Research Article Open Access

Major Types and Characteristics of the Late Paleozoic Ore Deposits in the East Tianshan Orogenic Belt, Central Asia

Chunming Han[1]*, Wenjiao Xiao[1], Benxun Su[1,2], Patrick Asamoah Sakyi[3], Guochun Zhao[1] Songjian Ao[1], Bo Wan[1], Jien Zhang[1] and Zhiyong Zhang[1]

[1]*State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China*
[2]*Department of Earth Sciences, The University of Hong Kong, Pokfulam Road, Hong Kong, China*
[3]*Department of Earth Science, University of Ghana, P.O. Box LG 58, Legon-Accra, Ghana*

Abstract

One of the most largest known and important metallogenic provinces in China is East Tianshan, where seven major types of Late Paleozoic metal deposits have been recognized: (1) porphyry-type Cu-Mo-(Au) ore deposit, (2) volcanic Fe-Cu deposit, (3) orogenic lode gold deposit, (4) magmatic Cu-Ni sulfide deposit, (5) epithermal gold deposit, (6) volcanic hydrothermal Cu deposit, and (7) skarn Cu-Ag deposit. Tectonically, the development of these Late Paleozoic metal mineral deposits was closely associated with the subduction and closure of the ancient Tianshan Ocean intervening between the Tarim craton and the Junggar-Kazakhstan block. In the Late Devonian to Early Carboniferous, the northern margin of the Tarim craton existed as a passive-type continental margin, whereas the ancient Tianshan ocean was subducted beneath the southern margin of the Junggar-Kazakhstan block, resulting in the formation of the Dananhu-Tousuquan magmatic arc and associated porphyry-type Cu-Mo-(Au) deposits. In the Middle Carboniferous, the ancient Tianshan ocean began to subduct beneath the northern margin of the Tarim craton, leading to the formation of the Aqishan-Yamansu magmatic arc and associated volcanic Fe-Cu deposits. In the Late Carboniferous, the ancient Tianshan ocean was closed, and a continent-arc collision occurred, leading to the formation of the Tianshan orogen. Following the collision was an extensional event, which was associated with the emplacement of large amounts of ultramafic-mafic complexes and the formation of a number of large- to medium-scale magmatic copper-nickel ore deposits along the Kangger suture zone. In the Early Permian, East Tianshan entered into a post-collision stage, associated with the widespread emplacement of granitoid bodies and eruption of within-plate volcanism, which led to the formation of volcanic hydrothermal copper deposits, skarn-type Cu-Ag deposits, post-orogenic gold deposits, and epithermal gold deposits in East Tianshan.

Keywords: Paleozoic; Deposits; Orogenic; Ore

Introduction

The Tianshan Mountains (Mts) are one of the largest mountain chains in Asia, extending west-east up to 3,000 km long, with its eastern segment being located in the middle part of Xinjiang, China and the west segment extending another 1,000 km to Kyrgyzstan, Uzbekstan and Kazakhstan. Conventionally, the Chinese part of the Tianshan Mts has been divided into three sections, called the West Tianshan Mts, East Tianshan Mts and Beishan Mts. Since 1980's, the Bureau of Geology and Mineral Resources (BGMR) and Bureau of Geology and Nonmetal (BGNM) Resources of the Xinjiang Uygur Autonmous District have carried out extensive investigations on the geological background of the East Tianshan Mts and related mineral deposits, which have led to discoveries of many Paleozoic Cu, Au, Ni, Fe and Ag deposits. These discoveries have made East Tianshan become a world-class metallogenic ore province [1,2]. However, most data and documents on these Paleozoic metal mineral deposits were reported in Chinese literature [3-15], and thus international geological communities know little about these ore deposits [16,17]. This paper undertakes the first major review on the general geological characteristics of Paleozoic metal mineral deposits in East Tianshan, especially on their alteration, mineralization, geochemistry, metallogenetic timing and associated lithologies.

Regional Geology

The South China, North China and Tarim cratons compose the tectonic framework of China. The South China craton consists of two major blocks: the Yangtze block to the northwest, which has a Late Archean–Paleoproterozoic (>1.7 Ga) nucleus, and the Cathaysia block to the southeast, which has a Paleoproterozoic nucleus and amalgamated with the Yangtze block along the Jiangshan–Shaoxing fault during the Jinning (~0.85 Ga) orogeny [18,19]. The North China craton also consists of two blocks, named the Eastern and Western blocks, which developed independently during the Archean and collided along the Paleoproterozoic Trans-North China orogen during a global collisional event at ~1.85 Ga [19-23]. The Tarim craton has a late Archean to Paleoproterozoic basement similar in lithology and age to that of the Western Block of the North China craton, and has no clear suture zone with the latter [24]. This led some geologists to propose that the two cratons have existed as a rigid block since the Archean [25].

Surrounding and separating the three cratonic blocks are young orogenic belts, of which the Tianshan orogen occurs along the northern margin of the Tarim craton (Figure 1) [6], and represents an important metallogenic enrichment zone in the western part of China, extending east up to hundreds of kilometers into the Beishan orogenic belt, Gansu Province [26]. The regional geology of the Tianshan orogen has been investigated and reported by many research units of which the BGMR of the Xinjiang Uygur Autonomous region has given the most details as shown in Figure 1. The following is a brief summary of structures, stratigraphic sequences and magmatic associations of the East Tianshan orogen.

***Corresponding author:** Chunming Han, State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029 China, Tel: +86 10 6200 7917; Fax: +86 10 6201 0846; E-mail: cm-han@mail.iggcas.ac.cn

Received February 28, 2014; **Accepted** April 11, 2014; **Published** April 15, 2014

Citation: Han C, Xiao W, Su B, Sakyi PA, Songjian Ao GZ, et al. (2014) Major Types and Characteristics of the Late Paleozoic Ore Deposits in the East Tianshan Orogenic Belt, Central Asia. J Geol Geosci 3: 158. doi: 10.4172/2329-6755.1000158

Citation: Han C, Xiao W, Su B, Sakyi PA, Songjian Ao GZ, et al. (2014) Major Types and Characteristics of the Late Paleozoic Ore Deposits in the East Tianshan Orogenic Belt, Central Asia. J Geol Geosci 3: 158. doi: 10.4172/2329-6755.1000158

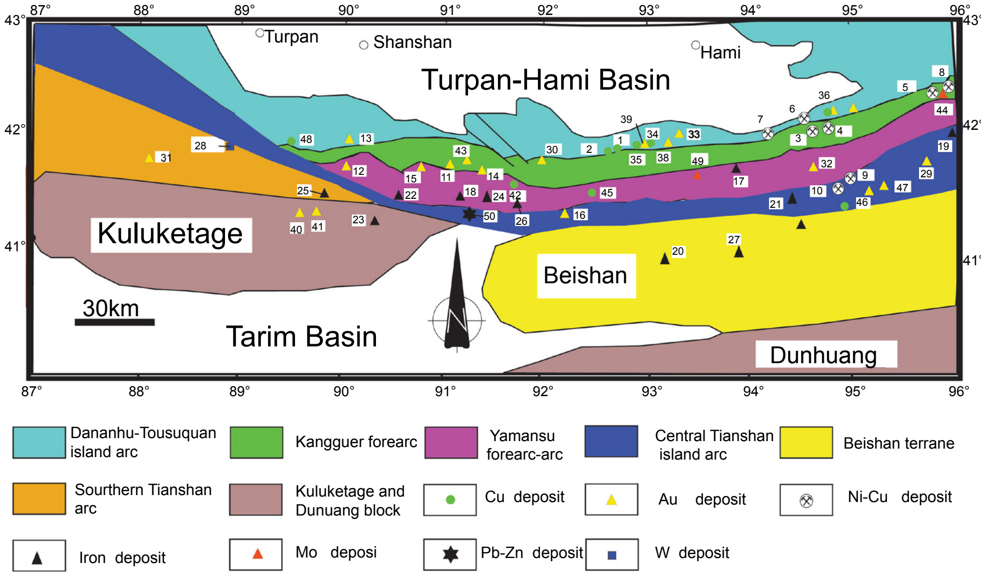

Figure 1: Tectonic setting and distribution of the studied intrusions showing the locations of significant mines in the eastern TianshanOrogenic Belt. The deposits numbered 1–50 are listed in Table 1.

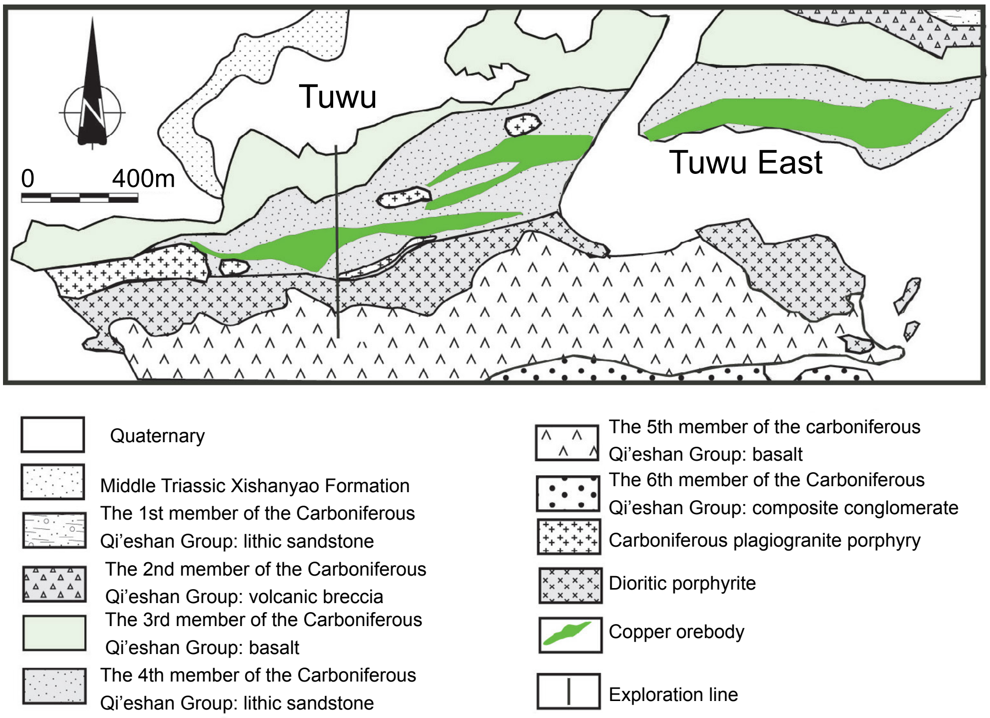

Figure 2: Geological map of the Tuwu Cu-Mo district [after Han and Zhao, 2003]. For location see No. 1 in Figure 1.

Structures

The tectonic history of the Tianshan orogen is considered to have been associated with the evolution of an ancient Tianshan ocean between the Tarim craton and the Junggar-Kazakhstan block [27-34]. The orogen is separated from the Tarim craton to the south by the Kanggguer ductile suture zone, and extends west to Gansu Province. The main structures of East Tianshan is characterized by a series of approximately east-west-trending faults, including the regional-scale Kalamaili-Maiqinwula, Kanggguer, Yanmansu, Aqikekudouke and Middle Tianshan faults, and many small-scale faults (Figure 2) [6,31]. Of these faults, the Kangguer fault is the most prominent one which consists of mylonite, tectono-clastic rocks, tectonic lenses, and breccia, and which not only forms the boundary between the Kazakhsta-

Ore deposits	Long./ lat.	Genetic types	Host rocks	Ore minerals	Alteration	Main economic elements	Grade[g/t], reserve/ utility	Reference
Tuwu [1]	92°37′ 42°07′	Porphyry copper deposits	Early Carboniferous plagiogranite, diorite and porphyrite	chalcopyrite, bornite , pyrite , magnetite , chalorite, cove;;it, molybdenite	Silicification, chloritization, albilization, sericitization and epidotization	Cu-Au-Ag	Cu 2.04Mt, 0.43% Au 19.4t; Ag 419t;	[1,10,43,44]
Yandong [2]	92°37′ 42°07′	Porphyry copper deposits	Early Carboniferous plagiogranite, diorite and porphyrite	Chalcopyrite, pyrite , magnetite , molybdenite	Silicification, chloritization, carbontion, sericitization and epidotization	Cu-Au-Mo-Ag	Cu 2.302Mt, 0.36% Mo 95430t Ag 2033t	[1,10,43,44]
Huangshan [3]	94°36′ 42°17′	Magmatic deposits	C1--2, Mafic-supermafic rocks	pyrrhotite , pentlandite, chalcopyrite , pyrite	Sphalerite, talcization, chalcocite	Cu-Ni	Cu 0.2083Mt, 0.31%; Ni 0.334Mt, 0.47%; Co 19500t, 0.026%	[41,43, 45]
Huang shandong [4]	92°43′ 42°18′	Magmatic deposits	C1--2, Mafic-supermafic rocks	pyrrhotite , pentlandite, chalcopyrite , pyrite	Sphalerite, talcization, chalcocite	Cu-Ni	Cu 0.1882Mt, 0.27%; Ni 0.3836Mt, 0.52%; Co 16700t, 0.024%	[41,43,45]
Hulu [5]	95°42′ 42°31′	Magmatic deposits	C1--2, Mafic-supermafic rocks	pyrrhotite , pentlandite, chalcopyrite , pyrite	Sphalerite, talcization, chalcocite	Cu-Ni	Cu39600t, 0.10-0.49%; Ni 80200t, 0.23-0.61%; Co 5100t, 0.02-0.042%	[41,43,45]
Xiangshan [6]	94°33′ 42°18′	Magmatic deposits	C1--2, Mafic-supermafic rocks	pyrrhotite , pentlandite, chalcopyrite , pyrite	Sphalerite, talcization, chalcocite	Cu-Ni	Cu 20000t, 0.30%; Ni 40000t, 0.50%	[41,43,45]
Tudun [7]	94°10′ 42°13′	Magmatic deposits	C1--2, Mafic-supermafic rocks	pyrrhotite , pentlandite, chalcopyrite , pyrite	Sphalerite, talcization, chalcocite	Cu-Ni	Cu 3000t, 0.20%; Ni 15000t, 0.30%	[41,43,45]
Tulaergen [8]	95°55′ 42°33′	Magmatic deposits	C1--2, Mafic-supermafic rocks	pyrrhotite , pentlandite, chalcopyrite , pyrite	Sphalerite, talcization, chalcocite	Cu-Ni	Cu 147000t, 0.30%; Ni 245000t, 0.50% Co 147000t, 0.03%	[41,43,45]
Ore deposits	Long./ lat.	Genetic types	Host rocks	Ore minerals	**Alteration**	Main economic elements	Grade[g/t], reserve/utility	**Reference**
Baishiquan [9]	94°55′, 41°55′	Magmatic deposits	Mafic-supermafic rocks	Chalcopyrite, pentlandite, native copper, pyrite, and chalcocite	uralitization, chloritization, sericitization, limonitization, magnetization, pentlanditization.	Cu-Ni	Cu:7.01@0.48%, Ni: 9.43@0.32%	[43,45]
Tianyu [10]	94°55′, 41°55′	Magmatic deposits	Mafic-supermafic rocks	Chalcopyrite, pentlandite, native copper, pyrite, and chalcocite	uralitization, chloritization, sericitization, limonitization, magnetization, pentlanditization.	Cu-Ni	Cu:7.01@0.48%, Ni: 9.43@0.32%	[43,45]
Kanggur [11]	91°05′, 42°01′	orogenic	C_1, Intermediate-acidic volcanic rocks	Native Au, electrum ,pyrite, chalcopyrite, galena, sphalerite , magnetite	sericitization, pyritization, silicification , chloritization	Au-Ag	Au 7.281t, 9.20 ppm; Cu 58t, 1.11%; Pb 17t; Zn 32t	[43,45]
Shiyingtan [12]	91°05′, 42°01′	Epithermal	P1, Andesite, dacite, volcanic breccia	Native Au, electrum ,pyrite, chalcopyrite	sericitization, pyritization, chloritization, silicification	Au-Ag	Au 6.295t, 6.14 ppm	[43,45]
Harla [13]	90°07′, 42°11′	Epithermal	C_1, Andesite, dacite, volcanic breccia	Native Au, pyrite, chalcopyrite	sericitization, pyritization, chloritization, silicification	Au	Au 5.76t, 1.207 ppm	[43,45]
Yanjianpo [14]	91°18′, 42°01′	orogenic	C1, Intermediate-acidic volcanic	Native Au, pyrite, sphalerite, chalcopyrite, pyrrhotite	sericitization,pyritization, silicification, chloritization	Au	Au 3.16t, 2.86 ppm	[43,45]
Ore deposits	Long./ lat.	Genetic types	Host rocks	Ore minerals	**Alteration**	Main economic elements	Grade[g/t], reserve/utility	**Reference**
Hongshi [15]	90°50′, 42°03′	orogenic	C1, Intermediate-acidic volcanic	Native Au, pyrite, sphalerite, chalcopyrite, pyrrhotite	sericitization,pyritization, silicification, chloritization	Au	Au 5.39t,3.60ppm	[43,45]
Huanglong Shan [16]	90°50′, 42°03′	orogenic	PT, Marble, tuffaceous sandstone, limestone	Native Au, pyrite, sphalerite, chalcopyrite, pyrrhotite	sericitization,pyritization, silicification, chloritization	Au	Au 0.325t, 0.49ppm	[43,45]
Yamansu [17]	93°52′, 41°53′	VMS	C1, Intermediate-acidic volcanic	Magnetite, hematite	Chloritization,carbonation	Fe-Cu	FeO_{Total} 33.5Mt,39.84-54.52%	[44]
Tieling [18]	91°04′, 41°46′	VMS	C1, tuff, volcanic breccia	Magnetite, hematite	Chloritization,carbonation ,sericitization, silicification	Fe	FeO_{Total}39.97Mt, 38.01%	[44]
Baishanquan [19]	95°59′, 42°10′	Metagenesis	C1, schist, tuff	Magnetite, hematite, chalcopyrite , pyrite	Chloritization,carbonation ,sericitization, silicification	Fe	FeO_{Total}44.06Mt, 31.35%	[44]
Cihai [20]	93°20′, 41°08′	Magmatic	P1, diabase	Magnetite, hematite, chalcopyrite , pyrite	Chloritization,carbonation , silicification,skarnization	Fe	FeO_{Total}99.99Mt, 36.31-54.54%	[44]
Tianhu [21]	94°30′, 41°40′	Metagenesis	Schist,gneiss, migmatite	Magnetite, hematite, chalcopyrite , pyrite	Chloritization,carbonation , silicification,skarnization	Fe	FeO_{Total}104Mt, 37.80-61.00%	[44]
Hongyuntan [22]	90°35′, 41°47′	Skarn	C1, Intermediate-acidic volcanic	Magnetite, hematite, chalcopyrite , pyrite	Chloritization, silicification,skarnization	Fe	FeO_{Total}32.25Mt, 45.50%	[44]
Ore deposits	Long./ lat.	Genetic types	Host rocks	Ore minerals	**Alteration**	Main economic elements	Grade[g/t], reserve/utility	**Reference**

Citation: Han C, Xiao W, Su B, Sakyi PA, Songjian Ao GZ, et al. (2014) Major Types and Characteristics of the Late Paleozoic Ore Deposits in the East Tianshan Orogenic Belt, Central Asia. J Geol Geosci 3: 158. doi: 10.4172/2329-6755.1000158

Paergang [23]	90°17′, 41°29′	Metagenesis	Schist, tuff	Magnetite, hematite	Chloritization,carbonation , silicification,skarnization	Fe	FeO_{Total}101Mt, 33.00-51.00%	[44]
Bailingshan [24]	91°29′, 41°42′	VMS	Andesitic tuff, volcanic breccia	Magnetite, hematite	Chloritization,carbonation , silicification,skarnization	Fe	FeO_{Total} 13.06Mt, 44.94%	[44]
Wutonggou [25]	89°49′, 41°48′	VMS	Andesitic tuff, volcanic breccia	Magnetite, hematite,siderite	Chloritization,carbonation , silicification,skarnization	Fe	FeO_{Total}32.47Mt, 37-47%	[44]
Chilongfeng [26]	91°40′, 41°42′	VMS	Andesitic tuff, volcanic breccia	Magnetite, hematite,siderite	Chloritization,carbonation , silicification,skarnization	Fe	FeO_{Total}11.62Mt, 26-34%	[44]
M1033 [27]	93°56′, 41°14′	Metagenesis	Biotite quartz schist, tremolitehornfels	Magnetite, hematite, chalcopyrite , pyrite	Chloritization,carbonation , silicification,skarnization	Fe	FeO_{Total}29.42Mt, 29.02-35.47%	[44]
Zhongbao [28]	88°52′, 42°11′	Skarn	Schist, marble, biotite quartz schist, quartz schist,	Scheelite, cassiterite, magnetite, pyrite	Chloritization,carbonation , silicification,skarnization	W	WO_3 11600t, 3.06%	[44]
Mazhuangshan [29]	95°45′, 41°59′	Epithermal	Volcanic rocks, rhyoliticporphyry, dacitic porphyry	Native Au, electrum , pyrite, chalcopyrite, galena, sphalerite	Sericitization, pyritization, carbonation, silicification	Au	Au 21t, 0.10-12.55 ppm	[43]
Qi'esahn [30]	92°00′, 42°06′	orogenic	Andesite, basalt, tuff	Native Au, pyrite, hematite	Sericitization, pyritization, carbonation, silicification	Au	Au 0.153t, 3.51-15.75 ppm	[43]
Tiancai [31]	88°06′, 42°07′	orogenic	Quartz schist	Native Au, pyrite, hematite, chalcopyrite	Sericitization, pyritization, carbonation, silicification	Au	Au 1.147t, 1.48-7.14ppm	[43]
Baiganhu [32]	94°39′, 42°02′	orogenic	Sericitephyllite	Native Au, electrum , pyrite, chalcopyrite	Sericitization, pyritization, carbontion, silicification	Au	Au 0.134t, 4.21 ppm	[43]
Hongtan [33]	93°22′, 42°14′	orogenic	Andesite, basalt, tuff	Native Au, electrum , pyrite, chalcopyrite, galena, sphalerite	Sericitization, carbonation	Au	Au 0.991t, 30.33 ppm	[43]
Ore deposits	Long./ lat.	Genetic types	Host rocks	*Ore minerals*	**Alteration**	Main economic elements	Grade[g/t], reserve/utility	**Reference**
Chihu [34]	93°02′ 42°10′	Porphyry	Diorite-porphyrite	*chalcopyrite , bornite , pyrite , molybdenite , chalcocite*	Sericitization,chloritization, silicification, carbonation	Cu-Mo	Cu 9129.6t, 0.20-0.30% Mo 7998.5t, 0.03-0.04%	
Linglong [35]	92°47′ 42°07′	Porphyry	Diorite-porphyrite	*chalcopyrite , pyrite , molybdenite*	Sericitization,chloritization, silicification, carbonation	Cu	Cu 0.20-0.67%	[43]
Sanchakou [36]	94°42′ 42°22′	Porphyry	Diorite-porphyrite	*chalcopyrite , pyrite , molybdenite , chalcocite*	Sericitization, chloritization, silicification, carbonation	Cu-Mo	Cu 0.35-2.34% Mo 42357t, 0.024-0.047%	
Tianmu [37]	93°09′, 42°11′	**orogenic**	Andesite tuff, andesite, basalt,dacite	*Native Au, electrum , pyrite, chalcopyrite*	Sericitization, pyritization, carbontion, silicification	Au	Au 0.835t, 0.50-36 ppm	[43]
Shahai [38]	93°09′, 42°07′	**orogenic**	Tuff	*Native Au, pyrite*	Sericitization, pyritization, silicification	Au	Au 0.934t, 10.09-22.40 ppm	[43]
Longxi [39]	92°59′, 42°07′	**orogenic**	Andesite, tuff, basalt	*Native Au, chalcopyrite*	Sericitization, pyritization, carbonation, silicification	Au	Au 5-100 ppm	[43]
Exingshan [40]	89°36′, 41°35′	**orogenic**	Dolomite,limestone	*Pyrite, chalcopyrite*	Sericitization, carbonation, silicification	Au	Au 2.316t, 1.15-9.46 ppm	[43]
Wunan [41]	89°40′, 41°36′	orogenic	Dolomite, limestone	*Native Au, electrum , pyrite, chalcopyrite, galena, sphalerite*	Sericitization, pyritization, carbonation, silicification	Au	Au 4.791t, 12.02 ppm	[43]
Weiquan [42]	91°43′ 41°52′	Skarn	Biotite granite	*Chalcopyrite,bornite, sphalerite, pyrite, chalcocite, galena, argentite, molybdenite*	Silicification , chloritization, skarnization	Cu-Ag-Au	Cu 59516t Ag 1272t	[43]
Matoutan [43]	91°08′ 42°08′	orogenic	Intermediate-acidic volcanic rocks	*Native Au, electrum , pyrite, chalcopyrite, magnetite, pyrrhotite*	Sericitization, pyritization, silicification , chloritization	Au-Ag	Au 6.175t, 1.46-25.33 ppm	[43]
Baishan [44]	95°55′ 42°30′	Porphyry	Diorite-porphyrite	*chalcopyrite , bornite , pyrite , molybdenite , chalcocite*	Sericitization, chloritization , silicification, carbonation	Re-Mo	Re 0.7-1.9ppm; Mo 77500t, 0.058%	
Ore deposits	Long./ lat.	Genetic types	Host rocks	Ore minerals	**Alteration**	Main economic elements	Grade[g/t], reserve/utility	**Reference**
Jiyuan [45]	92°31′ 41°46′	Skarn	Carbonate rcoks	Chalcopyrite, sphalerite, pyrite, chalcocite, galena	Sericitization,chloritizationsili cification, skarnization	Cu-Pb-Zn-Ag	Cu 1.06%, Zn 1.73% Pb 2.77%, Ag 133.93 ppm	
210 [46]	95°09′, 41°30′	orogenic	Tuffstone,shale, tuff	Chalcopyrite, sphalerite, pyrite, chalcocite, galena	Sericitization, pyritization, carbonation, silicification	Au	Au 4.565t, 3.00-10.00 ppm	[43]
Jinwozi [47]	95°17′, 41°38′	orogenic	Tuffstone, shale	Chalcopyrite, sphalerite, pyrite, chalcocite, galena	Sericitization, pyritization, silicification	Au	Au 13.40t, 3.00-12.00 ppm	[43]

Xiaorequanzi [48]	89°32′, 42°17′	VMS	Tuff, volcanicsedmentary rocks	Chalcopyrite, bornite, sphalerite, pyrite, chalcocite, covellit, galena	Sericitization, chloritization	Cu-Pb-Zn	Cu 140000t, 0.22-4.33%	[43]
Donggebi [49]	93°20′, 41°55′	Porphyry	Diorite-porphyrite	Chalcopyrite, bornite, sphalerite, pyrite, chalcocite, covellit, galena	Sericitization, pyritization, carbontion, silicification	Mo	Mo 508032t, 0.115%	[43]
Caixiashan	89°32′, 42°17′	Metagenesis	Dolomite marble, sandstone, silestone	Sphalerite, galena,pyrite, pyrrholite	Sericitization, carbonation, silicification	Pb-Zn	Pb+Zn 2.04Mt, 1.68-3.73%; Ag 3.59-24.61 ppm	[53]

Table 1: Basic geologic features of selected gold and copper deposits of the Kanggurtagmetallogenic belt in eastern Tianshan.

Name of deposit	Dated minerals/ rocks	Dating method	Ages[Ma]	Data resources
Tuwu	Volcanic rocks/Zircon	SHRIMP	416-361	[11]
:	Plagiogranite porphyry/Zircon	SHRIMP	367-358	[11]
:	Molybdenite	Re-Os	322.7±3.2	[11]
:	Plagiogranite porphyry/Zircon	SIMS	339.3±1.3	This study
Yandong	Plagiogranite porphyry/Zircon	SHRIMP	356±8	[2]
	Quartz	Ar-Ar	347.3±2.1	[2]
	Sericite	K-Ar	341.2±4.9	[2]
	Molybdenite	Re-Os	343±26	[43]
:	Plagiogranite porphyry/Zircon	SIMS	338.3±1.4	This study
Baishan	Molybdenite	Re-Os	224.8±4.5	[46]
:	Pyrite	Re-Os	233±14	[46]
	Molybdenite	Re-Os	229.4±1.7	[49]
	Plagiogranite porphyry/Zircon	SHRIMP	245-235	[49]
	Molybdenite	Re-Os	227.7±4.3	[46]
Kangguer	Altered andesite	Rb-Sr	290±5	[47]
	Ryolite porphyry	Rb-Sr	300±13	[47]
	Tonalite/zircon	TIMS U-Pb	275±7	[47]
	Quartz	Rb-Sr	282.3±5	[47]
	Quartz	Rb-Sr	258±21	[47]
	Quartz	Rb-Sr	254±7	[47]
Shiyingtan	Altered andesite	Rb-Sr	285±12	[47]
	Quartz	Rb-Sr	244±9	[47]
Mazhuangshan	Rhyolite porphyry	Rb-Sr	301±12	[47]
	Dacite porphyry	Rb-Sr	303±26	[47]
	Quartz	Rb-Sr	298±28	[38]
Jinwozi	Granodiorite	Rb-Sr	354±31	[38]
	Quartz	Rb-Sr	228±22	[38]
	Quartz	Rb-Sr	230±5.7	[38]
	Granodiorite/Zircon	SIMS	427.1±1.6	This study
Xiangshan	Gabbro/Zircon	TIMS U-Pb	285±1.2	[47]
	Gabbro/Zircon	TIMS U-Pb	279.6±1.1	This study
Hulu	Gabbro/Zircon	TIMS U-Pb	282.3±1.2	This study
Huangshan	Olivine norite/Zircon	SHRIMP	274±3	[48]

Table 2: Available geocharonological data for ore deposits in EasternTianshan.

Juanggar block and the Tarim craton, but also an important structural zone along which major magmatic activities and associated ore mineralization took place [31].

Two distinct belts separated by the Kangguer fault can be recognized. The belt north of the Kangguer deep-crustal fault is interpreted as an arc, named the Dananhu-Tousuquan magmatic arc [3,31,35], which consists mainly of Middle Devonian to Carboniferous volcanic rocks, hosting most metallogentic deposits [17]. The south belt is located between the Kangguer and Aqikekudouke faults, and is also interpreted as an arc, named Aqishan-Yamansu magmatic arc [4,36], which consists of Carboniferous rocks along the northern side of the Tarim craton, including the Early carboniferous Aqishan and Yamansu Formations, and gray-wackes of the Middle Carboniferous Kushui Formation, separated by the Yamansu (or Kushui) Fault. The Kangguer fault separates this arc from the Tousuquan-Dananhu magmatic arc to the north, and is considered to represent a Late Carboniferous to Early Permian suture along which folding and thrusting within the arc sequences occurred during the subduction of a Paleo-Tianshan ocean [4,6,36]. By the end of the Carboniferous, an extensional tectonic regime developed along the major faults and the Kangguer orogenic lode deposits formed along some brittle-ductile shear zones within subordinate faults, which represent dilational zones that were opened along an east-west-trending extension [6].

Stratigraphic sequences

The Devonian strata in East Tianshan can be divided into the lower, middle and upper sequences. The lower Devonian sequence is called

Citation: Han C, Xiao W, Su B, Sakyi PA, Songjian Ao GZ, et al. (2014) Major Types and Characteristics of the Late Paleozoic Ore Deposits in the East Tianshan Orogenic Belt, Central Asia. J Geol Geosci 3: 158. doi: 10.4172/2329-6755.1000158

the Danhu Formation (D1d) that is composed of tholeiite, andesite, lithic sandstone, tuff, siltstone and lithic arkose [31]. The Middle to Upper Devonian sequences, named the Tousuan Formation (D2-3t), consist of tholeiite, tuff, felsite, andesite, trachyandesite, quartz andesite and dacite [31].

The Carboniferous rocks in East Tianshan have also been divided into the lower, middle and upper sequences, of which the lower Carboniferous consists of four formations: Xioarequanzi, Yanmansu, Gandun and Wutongwozi Formations [31,36]. The Xioarequanzi Formation (C1x) contains andesite, volcanic breccia, tuff, felsite, rhyolite, trachyte basalt, and normal clastic rocks. The Yanmansu Formations (C1y) is composed of bioclastic limestone, lithic sandstone, siltstone, conglomerate, pyroclastic rock and quartz keratophyre. The Gandun Formation (C1g) consists of sedimentary tuff, siliceous slate, siliceous tuff and siltstone. The Wutongwozi Formation (C1w) is composed of basalt, felsite, keratophyre, quartz keratophyre, vitric tuff and silicalite.

The Permian strata in East Tianshan have only the lower sequence, named the Aqikbulake Formation (P1a), which consists of sandstone, siltstone, shale, basalt, andesite felsite and basal conglomerate.

Igneous rocks

Much of magmatism in East Tianshan is Paleozoic in age [36], and formed in a convergent continental margin environment during the early period of the Middle Carboniferous. Two chains of diorite-granodiorite-adamellite suites were emplaced in the north and south Jueluotage area at the convergent stage [27,31,34]. The Yandong, Tuwu, Linglong, Chihu, Sanchakou, and Hongshan stocks in the northern part of the area consist predominantly of dioritic porphyrite, plagio-granitic porphyry, quartz dioritic porphyry, granodioritic porphyry and granitic porphyry, whereas the Lingtietan, Chilongfeng, Shaquanzi, Shabei and Baishan stocks in the southern part of the area are composed primarily of dioritic porphyrite, quartz dioritic porphyry, granodiorite, porphyry and granitic porphyry [31]. In the northern part of the area, the Xiaopu pluton yielded a Rb-Sr isochron age of 312.1 Ma [37], and the Qi'eshan pluton yielded a single-zircon U-Pb age of 308.5 Ma [15].

Following the compressional deformation at the convergent stage, extensionally faulting took place along the ductile shear zone in the north Kangguer area [31]. The extension was associated with widespread emplacement of mafic-ultramafic complexes in the Huangshan-Jiangerquan region, including the Tudun, Erhongwa, Xiangshan, Huangshan, Huangshandong and Hulu plutons, and the formation of a number of magmatic-type copper-nickel sulfide deposits [31,36]. Of these plutons, the Huangshan and Huangshandong plutons yielded whole rock Sm-Nd isochron ages of 308.9 ± 10.7 Ma and 320 ± 38 Ma, respectively [38]; the Xiangshan pluton yielded a single-zircon age of 285 ± 1.2 Ma [2]; and the Huangshandong pluton yielded a Re-Os isochron age of 282 ± 20 Ma [6].

Ore deposit types and their major characteristics

Middle- and large-scale metal ore deposits in East Tianshan have been assigned to seven major types: (1) porphyry-type Cu-Mo-(Au) ore deposit, (2) orogenic lode gold deposit, (3) volcanic Fe-Cu deposit, (4) magmatic Cu-Ni sulfide deposit, (5) epithermal gold deposit, (6) volcanic hydrothermal Cu deposit, and (7) skarn Cu-Ag deposit. They are primarily distributed around the Tousuquan – Dananhu – Huangshan magmatic belt north of the Kangguer fault and the Aqishan-Yanmansu magmatic belt south of the Kangguer fault (Figure 2). The main characteristics of these seven types of ore deposits are listed in Tables 1 and 2.

Porphyry-type Cu-Mo-(Au) ore deposit

More than 10 porphyry-type Cu-Mo-(Au) ore deposits have been discovered in East Tianshan since the late-1980's, represented by the Yandong, Tuwu, East Tuwu, Linglong, Chihu, Sanchakou, East Sanchakou, Xiaopu, East Xiaopu and Yaziquan ore deposits [10,11]. They constitute a metallogenic cluster of porphyry-type Cu-Mo-(Au) ore deposits. Of these, the Tuwu and Yandong ore deposits have been assigned to large-scale ore deposits [10]. Comparatively, the Tuwu deposit has been well studied and considered to be one of the most economically significant deposits in China, and thus, as a typical example, we describe and discuss it in detail as follows.

The Tuwu ore deposit, discovered in 1994 during regional mapping and prospecting, is located in the western part of the porphyry-type copper enrichment zone in the central par of the East Tianshan orogen.

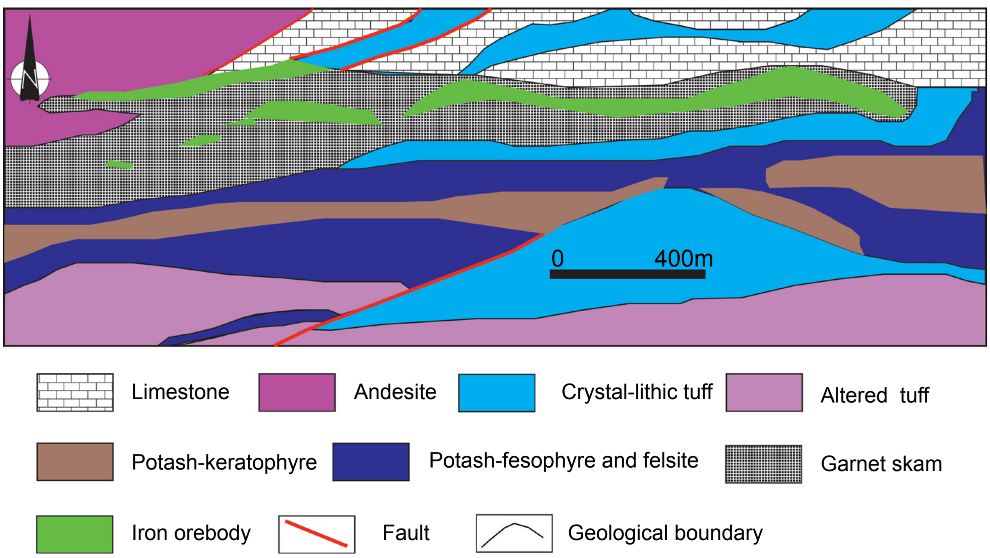

Figure 3: Geological map of the Yamansu Fe-Cu district [after Han and Zhao, 2003]. For location see No. 17 in Figure 1.

It is about 1~3 km north of the Kangguer fault and is hosted within the Carboniferous intermediate to mafic volcano-clastic rocks [10] (Figure 3). The Xinjiang Bureau of Geology and Mineral Resources (BGMR) interpreted the intrusive rocks to be the Permian in age, whereas SIMS zircon U-Pb data for the Tuwu deposit hosting rocks indicate an age range of 338-339 Ma [39], suggesting that the country rocks formed at in the Carboniferous.

An initial report by the BGMR of Xinjiang indicates that the Tuwu porphyry-type deposit contains 2.23 million tons of copper at a cut off 0.20% Cu, and has 2.1 million tons of copper at a cut off 0.50% Cu. Moreover, the deposit contains 95 tons of gold at an average of 0.34 g/t, and has 1207 tons of silver at an average of 4.3 g/t [15].

The host rocks for the Tuwu deposit constitute the Carboniferous Qi'eshan Group that consists mainly of basalt, andesite, gravelly lithic sandstone and composite conglomerate [11]. The distribution of ore bodies is largely controlled by a series of brittle-ductile shear zones, and the ore bodies mainly occur in the middle segments of the shear zones.

The copper ores in Tuwu occur are present as small stocks and veinlets along E-W trending ductile shear zones. The ore textures are disseminated, vein-like and veinlet-disseminated. Wall-rock alteration types include silication, sercitization, chloritization, biotitization and carbonation. Wang et al. [1,13] illustrated the hydrothermal alteration zoning of wall rocks and divided it into five zones from the center of plagiogranite-porphyry to the margin: (1) quartz-core zone, (2) biotite zone, (3) phyllic zone, (4) chalorite-epidote-albite zone, and (5) argillite zone. Alternatively, Han et al. (2002) divided it into three zones in terms of the intensity of alteration: (1) sericite-quartz zone, (2) chlorite-biotite zone, and (3) chalorite-epidote-albite zone.

The main ore minerals in the Tuwu copper deposit are chalcopyrite and pyrite, with minor bornite, chalcocite, digenite, magnetite, sphalerite and hessite. Quartz and plagioclase are main gangue minerals, and are associated with sericite, chlorite, biotite, amphibole and epidote.

Rui et al. [11] reported that the mineralization temperature of the Tuwu copper deposit ranges from 101˚C to 409˚C, and the ore fluid salinities are 0.35 to 42.68 equiv.nacl weight percent. Stable isotope values for δ 18 O water is between -7.09×10^{-3} and 1.611×10^{-3}; δ D is between -69×10^{-3} and -44×10^{-3}; and δ 34 S is between -0.9×10^{-3} and $+1.13\times10^{-3}$ [11]. The values of δD and δ18 O water means that the ores fluids of the Tuwu deposit have an affinity to source of meteorological water, and the $\delta^{34}S$ values are close to the values of meteorite, indicating that the sulfur comes from abyssal [11,15].

The altered plagiogranite porphyry was dated at 310.95 ± 4.57 Ma by using the K-Ar method and at 347.3 ± 2.1 Ma by using the Ar/Ar method [2], whereas the plagiogranite porphyry was dated at 338-339 Ma by using the SIMS zircon U-Pb method [39], and a molybdenite was dated at a Re-Os isochron age of 322.7 ± 2.3 Ma [11].

Volcanic Fe-Cu deposit

Most Fe-Cu ore deposits recognized within East Tianshan (e.g. the Aqishan, Yamansu, Heilongfeng, Shuangfengshan and Shaquanzi

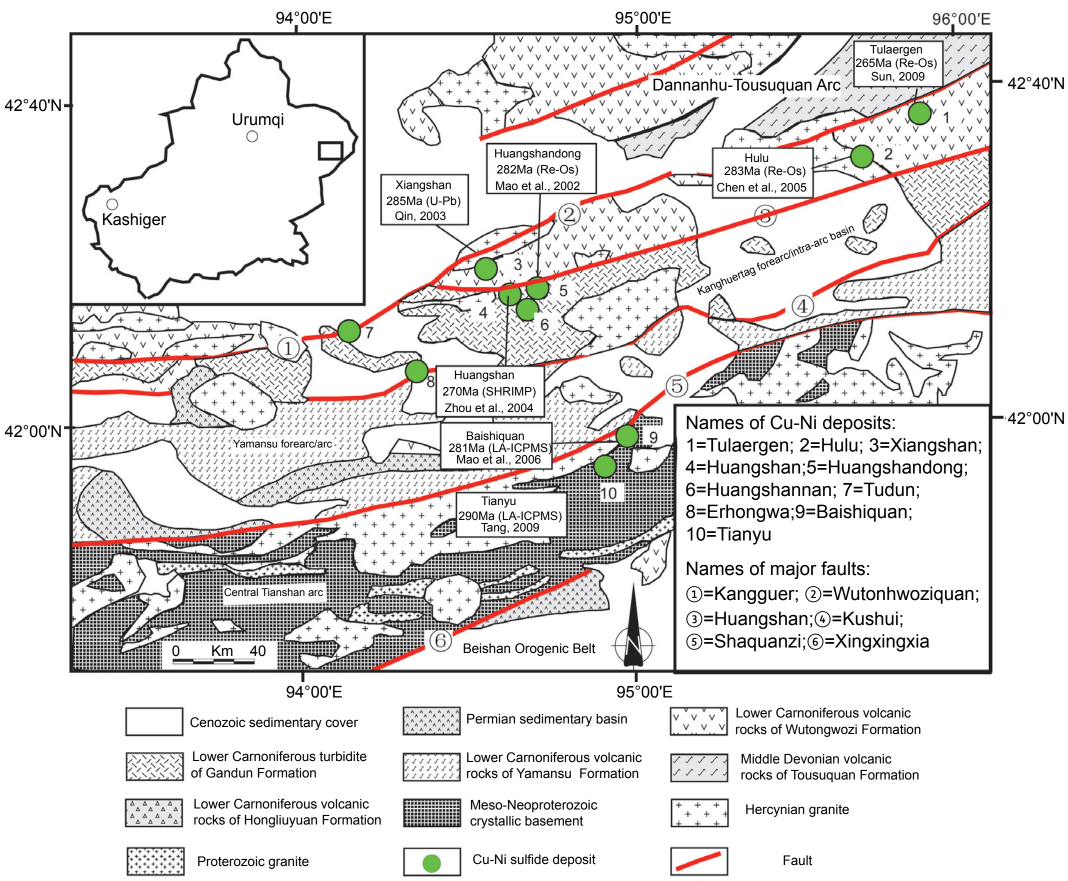

Figure 4: Schematic map of the Huangshan-Jingerquan showing principal mineral deposits in the East TianshanOrogenic Belt .

ore deposits) are clustered in a 400 km-long and 15-km-wide corridor, between the Kuishui fault and Aqikekudouke fault, exending from Aqishan to Shaquanzi. The Yamansu ore deposit defines the eastern part of the Aqishan-Shaquanzi Fe-Cu province, and is characterized by geological features that are common to many other Fe-Cu ore deposits in the region [5].

The ores of the Yamansu ore deposit are hosted in the Lower Carboniferous Yamansu and Upper Carboniferous Baishaquanzi Formations (Figure 4). The Yamansu Formation contains tuff, tuff breccia and agglomerate, whereas the Baishaquanzi Formation consists of potash-keratophyre, potash-felsophyre and felsite. The main ore-hosting rock is potash-felsophyre (Figure 4).

Ore minerals are mainly magnetite, hematite, kamiokite, pyrite and chalcopyrite, and the gangue minerals are garnet, diopside, epidote and albite. The ore textures are disseminated, massive and banded, and the wall-rock alteration is mainly skarnization, albitization and carbonation.

Studies of the ore minerals in the Yamansu Fe-Cu deposit indicate that the mineralization temperature is 330-340°C for magnetite and 150-220°C for pyrite [5], and ore fluid salinities are 2.7 to 12.9 equiv Nacl weight percentage. Stable isotope values of magnetite for δ 18 O solid are between 5.25×10^{-3} and 12.8×10^{-3}, and δ 34 S of disseminated pyrite is between -22×10^{-3} and 25×10^{-3} [5], implying that the ore sources may have come from the upper crust.

Orogenic lode gold deposit

The orogenic lode gold deposit in East Tianshan is represented by the Kangguer Au deposit, which was discovered in 1988 during regional geological survey and mapping [3,40]. The Kangguer Au deposit is located at the north edge of the Aqishan-Yamansu magmatic arc on the northern continental margin of the Tarim craton [17], and contains a measured resource of 40 tons Au that is hosted in several ore bodies, of which the main bodies are No VI and No VIII (Figure 5). Gold mineralization in Kangguer occurs over an area of 10×5 km^2, about 5 km southeast of a large Varisican tonalite stock, and a number of small granite dikes crop out within 1 km distance of the ore zones. Most of the ore bodies at the Kangguer Au deposit are hosted in NE- to E-striking, steeply N-dipping ductile shear zones.

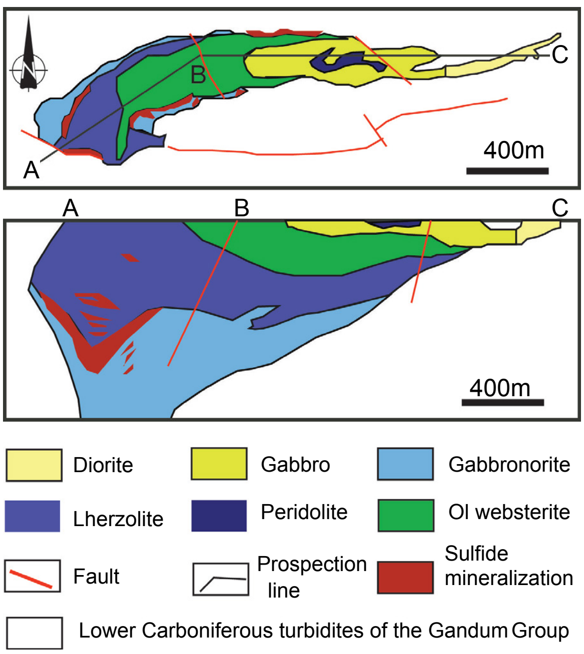

Figure 5: Plan view [a] and cross section [b] of the Huangshan Ni-Cu deposit. For location see No. 3 in Figure 1.

Sedimentary rocks in the Kangguer Au mining area are the Lower Carboniferous Aqishan Formation (C_1a), which can be divided into two distinct lithological sequences [3,17]. The upper sequence occurs in the north and central mining area, and consists of andesite, dacite, trachyandesit, rhyolite, tuff and volcanic breccia, interlayered with sedimentary tuff, tuffstone and biolimestone [17]. The lower sequence crops out in the southeast mining area and contains medium- to coarse-grained sandstone and calcarenite [17].

Six ductile faults are recognized in the Kangguer Au mining area, trending NEE and dipping 70-75 N. Brittle faults are also well developed, trending NEE, NW and NE, with NE striking faults cutting the NEE and NW striking faults.

Minerals of the Kangguer Au deposit ore are dominated by pyrite and magnetite, with minor chalcopyrite, galena, sphalerite, pyrrhotite and hematite. Quartz, chlorite, sericite, calcite, dolomite, barite and siderite are the main gangue minerals. Gold ore texture is grained, brecciated, and are present in vein-like and disseminated structures.

Hydrothermal alteration in association with Au occurrences in the Kangguer Au deposit includes sericization, chloritization, beresitization and silicatization. Gold ores are closely related to chloritization, berositization and silicatization. Supergene zones contain liomonite, jarosite, malachite, anglesite and chalcanthite.

Geochemically, the Kangguer Au deposit contains anomalous concentrations of Au, Ag, Pb, Cd, Bi, As, Sb, Hg, Cu, Zn, B and W, which are generally compatible with those anomalies of other orogenic lode gold deposits in the East Tianshan orogen. Studies of ore minerals in the Kangguer Au deposit indicate that the temperature of the ore formation (Tf) is 137 to 259 with ore fluid salinities of 12.18 to 17.10 equiv. NaCl weight percent [17]. Stable isotope value for δ18O is between 3.2×10^{-3} and 11.3×10^{-3}; δ D is between -55×10^{-3} and -66×10^{-3}; andδ34S is between -0.9×10^{-3} and $+3.3\times10^{-3}$ (average 2.0×10^{-3}) [9], Both S and O isotopic compositions suggest a magmatic source, with little or no involvement of meteoric water [16].

Vertical zoning consists of Au-Ag-As ores in the upper, and Cu-Pb-Zn ores in the central or lower. Almost all gold exists as native gold, with very minor electrum and gold-bearing tellurides. Ji et al. [3] divided the auriferous hydrothermal activity in the Kangguer Au deposit into five stages: (1) early gold – pyrite – sericite – quartz, (2) pyrite – magnetite – chlorite - quartz, (3) gold – pyrite – chalorite - muscorite, (4) pyrite – chalcopyrite – galena – sphalenite - quartz, and (5) pyrite – chalcopyrite – calcite – quartz. Except the last stage, the former four stages are associated with the deposition of gold.

The ore-forming ages of the Kangguer gold deposit were dated at 290-254 Ma by using the Rb-Sr and Sm-Nd methods, and the U-Pb zircon age of a tonalite in the adjacent area is 275 ± 7 Ma [4,12,17].

Magmatic copper-nickel sulfide deposits

In East Tianshan, a compressive event in the Late Carboniferous was followed by an extensional event that was associated with the emplacement of Cu-Ni-bearing ultramafic-mafic rocks along the Kangguer ductile shear zone [6]. There is a series of ultramafic-mafic

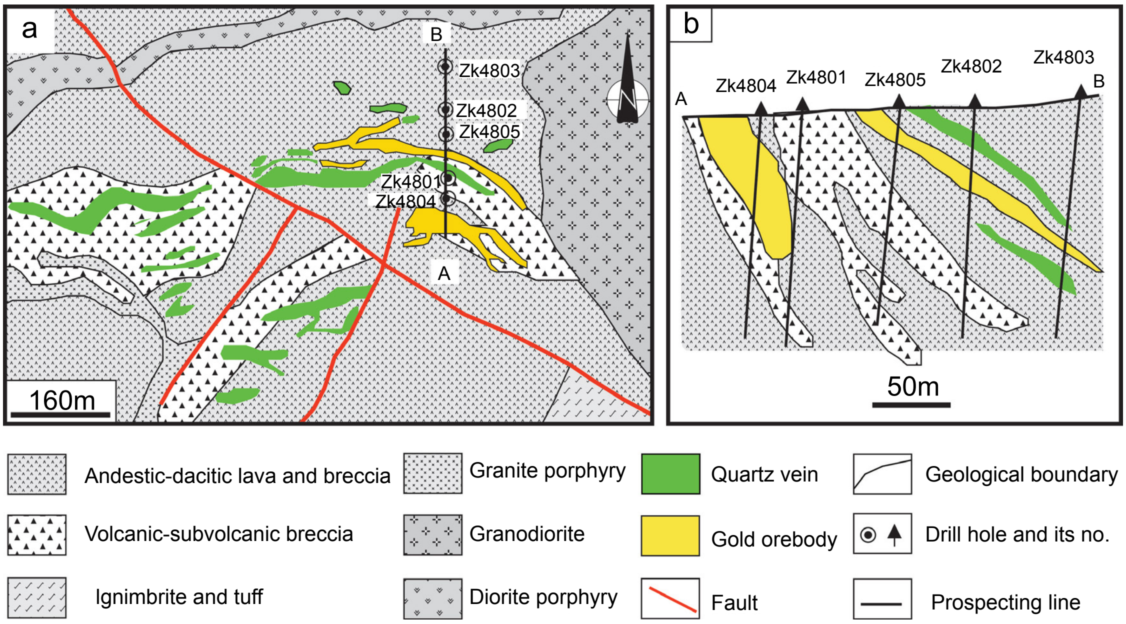

Figure 6: Plan view[a] and cross section[b] of the Shiyingtan Au deposit . For location see No. 18 in Figure 1.

plutons along the eastern segment of the Kangguer fault. They are variable in size and were emplaced into sedimentary rocks of the Early Carboniferous Gandun Formation and the Middle Carboniferous Wutongwozi Formation that is over one hundred kilometers long, spreading discontinuously with ultramafic-mafic igneous complex. More than 10 ultramafic-mafic Cu-Ni sulfide deposits have been discovered, including the Huangshan, Huangshandong, Huangshannan, Xiangshan, Erlongwa and Hulu ore deposits. They formed a Cu-Ni metallogenic province in East Tianshan. Of these ore deposits, the Huangshan and Huangshandong deposits are large scale; the Tudun and Xiangshan deposits are medium-sized; and the Huangshanndn and Erlongwa deposits are small-scale.

The available isotopic data show that most ultramafic-mafic complexes in the Huangshan-Jingerquan Cu-Ni metallogenic province formed in the Late Carboniferous and Early Permian [6]. The gabbros in the Huangshandong deposit were dated at 319.8 Ma and 320 ± 38 Ma, by using the K-Ar and whole-rock Sm-Nd isochron methods, respectively [38]. The Cu-Ni ores in the Huangshandong deposit yielded a Sm-Nd isochron age of 314 ± 14 Ma [38], and a Re-Os isochron age of 282 ± 20 Ma [6].

Sedimentary rocks in the Huangshan Cu-Ni mining area comprise the Lower Carboniferous Gandun Formation (C1g), which is divided into five sequences [41] (Figure 6). The first sequence consists of spilite porphyrite interlayered with quartz keratophyre. The second is composed of sandy conglomerate and sandstone interleaved with carbonaceous blastosandstone. The third sequence contains blastosiltstone intercalated with sandy conglomerate and sandy limestone. The fourth sequence consists of sandy limestone, bioclastic limestone, interbedded with carbonaceous limestone and medium-fine-grained sandstone. The fifth sequence contains calcareous conglomerate and medium- to fine-grained calcareous sandstone interlayered with carbonaceous limestone and sandy limestone lens (Figure 6).

Main ore minerals in the Huangshan Cu-Ni sulfide deposit are pyrrhotite, pentlandite and chalcopyrite, with minor violarite, mackinawite, pyrite, marcasite, sphalerite, millerite, vallerite, vaesite and cubanite. Supergene minerals are malachite, annabergite, jarosite, limonite and gypsum. Gangue minerals consist of olivine, pyroxene, amphibole, plagioclase, phlogopite, serpentine, talc, antimolite, chlorite, magnesite and quartz. The ore textures are sparse disseminated, dense disseminated, massive, brecciform and banded. The main useful ore mineral is nickel; secondary useful components are copper, silver and cobalt; and other useful components are gold, silver and PGE [42].

Stable isotope values for δ 34S of pyrrhotite are between -2.0×10^{-3} and $+0.86\times10^{-3}$ with an average value of -0.314×10^{-3} [41], nearly equal to the value δ 34S of meteorite, implying that the ore sources may have come from upper mantle.

Li et al. reported a whole-rock Rb-Sr isochron age of 280 Ma, and Li et al. [38] obtained a Sm-Nd isochron age of 308.9 ± 10.7 Ma and a sulfide ore isochron age of 305.4 ± 2.4 Ma for the Huangshan deposit, indicating that the rocks and ores of the Huangshan deposit formed in the Late Carboniferous to Early Permian.

Epithermal gold deposit

The Epithermal gold deposit in East Tianshan is represented by the Shiyingtan (or Xitan) gold deposit, which was discovered in 1989 during regional geochemical survey. The deposit has geological features similar to many other epithermal vein-like ore deposits. The total Au reserves are about 200,000 oz, of which about 30,000~35,000 oz have been recovered since 1993 [10]. The ore is hosted in the Lower Permian Aqikekudouke Formation (Figure 7), which consists of andesite, dacite, volcanic breccia, agglomerate brecciated lava and tuff. Although only 2 km north of the Kangguer ductile shear zone, the hosting rocks of the mining area show only weak deformation.

The deposit consists of three ore bodies, Ore bodies I, II and III, which are hosted in green amygdloidal andesites, striking EW and dipping E with an angle of 83° (Figure 7). Ore body I contains two offsets, L1-1 and L1-2, of which L1-1 is 350 m long and 0.89~6.76 m thick (average 4.20 m); and L1-2 extends 305 m long, with an average thickness of 4.96 m. Ore body II is hosted in andesite and volcanic

Citation: Han C, Xiao W, Su B, Sakyi PA, Songjian Ao GZ, et al. (2014) Major Types and Characteristics of the Late Paleozoic Ore Deposits in the East Tianshan Orogenic Belt, Central Asia. J Geol Geosci 3: 158. doi: 10.4172/2329-6755.1000158

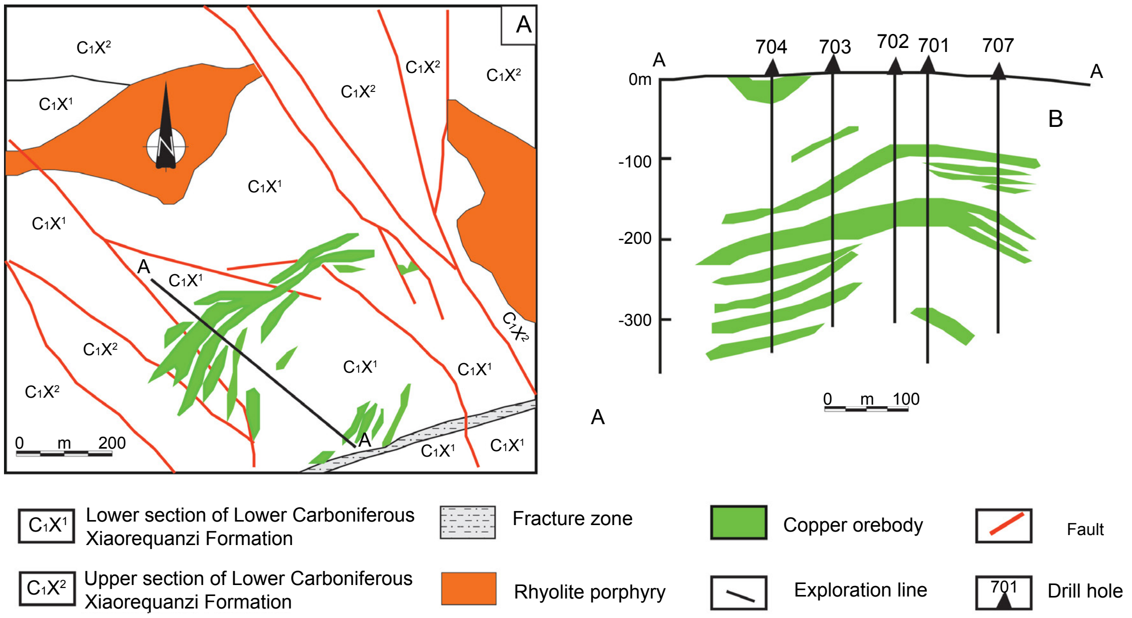

Figure 7: Plan view[a] and cross section[b] of the Xiaorequanzi Cu-Pb-Zn deposit. For location see No. 48 in Figure 1.

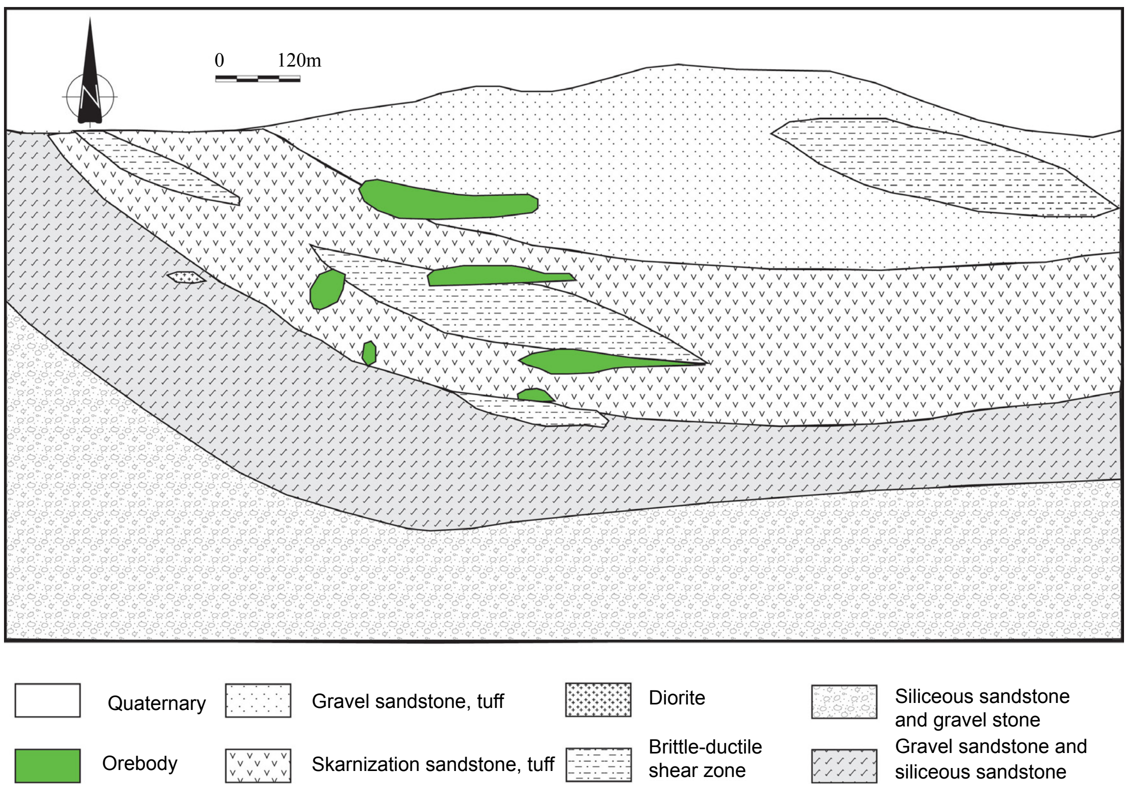

Figure 8: Geological map of the Weiquan Ag-Cu district. For location see No.42 in Figure 1.

breccia, and contains two ore bodies, L2-1 and L2-2, of which L2-1 is 160 m long and with an average thickness of 1.75 m, and L2-2 extends 280 m long, with a thickness of 0.83 m. Ore body III is hosted in purplish red hydrothermal breccia, and is 320 m long and 12.2~20.3 m thick (Figure 7).

The main ore minerals are pyrite, lomonite and natural gold, and the gangue minerals are quartz, chalcedony, plagioclase, calcite and sericite. The main hydrothermal alterations include silicification, phyllic alteration, carbonation and argillic alteration. The ores show massive, breccia, network and schlieren structures.

Measured $\delta^{18}O$ values of quartz range between 4.7×10^{-3} and -8.5×10^{-3} [7] and are consistent with a predominantly meteoric water source to the ore-forming fluids [10,11]. Stable isotope value for δ D is between -82×10^{-3} and -95×10^{-3}, and S isotopic values of the ores are between 0.61×10^{-3} and 1.33×10^{-3}. Studies of the ore minerals in the Shiyingtan Au deposit indicate that the temperature of the mineralization ranges from 108.5°C to 190.5°C , with ore fluid salinities of 9.18 to 19.24 equiv. NaCl weight percent [38].

Volcanic massive sulfide deposit

The Xiaorequanzi Cu deposit, discovered during regional geological survey in 1991, is a typical Volcanic massive sulfide deposit in East Tianshan. It is located 100 km southwest of Shanshan County of Xinjiang, northwestern China.

The deposit is hosted in the Lower Carboniferous Xiaorequanzi Formation that consists of tuff, tuffstone, volcanic and basaltic andesite. A northwest trending dome and a south-dipping monocline dominate the structures of the Xiaorequanzi deposit area. The major faults in the Xiaorequanzi deposit area are mainly NEE-trending, but minor faults are NW-trending. The ores are mainly hosted in a NEE-trending zone (Figure 8).

The igneous rocks hosting the ores are late Variscan in age. For example, a dacite porphyry yielded a Rb-Sr isochron age of 209 ± 7 Ma, and an albitophyre yielded a single zircon U-Pb age of 267~245 Ma [38].

The Xiaorequanzi deposit contains 22 ore bodies, which are mainly distributed in the north of the mining area, and of which the largest one is ore body I that is 520 m long and 1~30 m wide, with an average width of 12.46 m.

The primary minerals are chalcopyrite, cubanite, sphalerite, chessylite, digenite, tennantite, cobaltite, pyrite, pyrrhotite, galena, altaite, clausthalite and electrum; the gangue mineral are quartz, chlorite, sericite, carbonate, rutile, arsenopyrite and fluorite; supergene and oxide minerals include malachite, chalcanthite, limomite, chrysocolla, szomonokite, melanerite and jarosite. The ore structures are massive, veinlet-disseminated and banded. Hydrothermal alterations are silicification, albitization, carbonation, chloritization, epidotization, sericitization, and limonite-jarosite alteration. From top to bottom, the hydrothermal alteration shows vertically zoning characteristics. The upper is dominated by limonite and jarosite alteration, whereas the middle and the lower are characterized by carbonation and chloritization, and silicification, respectively.

Stable isotope values of $\delta^{34}S$ for pyrite and$\delta^{34}S$ for chalcopyrite are between 3.3×10^{-3} and 11.1×10^{-3} (average 6.0×10^{-3}) and between 1.5×10^{-3} and 7.2×10^{-3} (average 5.1×10^{-3}), respectively. Measured $\delta^{18}O$ values from quartz of the ores range between 8.0×10^{-3} and 9.3×10^{-3} (average 8.7×10^{-3}), and $\delta^{30}Si$ values range between -0.0×10^{-3} and -0.3×10^{-3}. These values indicate that ore-forming components of the Xiaorequanzi Cu deposit come from the upper crust.

Skarn Cu-Ag deposit

The Skarn Cu-Ag deposit in East Tianshan is represented by the Weiquan skarn Cu-Ag deposit, which was discovered in 2000 during a regional prospecting. It is located 158 km southeast of Shanshan County of Xinjiang, northwestern China. It lies in a Carboniferius volcanic basin along northern margin of the Tarim craton, and is only 3 km north to the Yamansu fault. The deposit is hosted in the Middle Carboniferous Tugutubulake Formation (C_2t) that is NW-striking and south-dipping with an angle of 44º~64º, and consists of four siliceous and calcareous sequences [15]. The first sequence comprises grayish green heterogranular sandstones interlayered with tuffs; the second sequence consists of fine-grained sandstones interleaved with tuff lens; the third sequence is composed of greenish grey heterogranular sandstones interleaved with siliceous sandstone lens; and the fourth sequence consists of grey siliceous sandstones interlayered with calcareous sandstones and biolimestones. Diorite, dioritic porphyry and albitophyry crop out in the south of the mining area, and intrude the Tugutubulake Formation.

The main body of the Weiquan Cu-Ag deposit is about 250 m long and 0.40~24.00 m wide (average 9.28 m). It strikes EW and dips north, with a dipping angle of 54~75º. The main Cu body grades range from 0.24×10^{-2} to 10.16×10^{-2}, with the maximum of 32.68×10^{-2}. There occur silver ore bodies in the middle and lower parts of the Cu ore bodies and the silver ore body can be blocked out as a single body. The maximum silver grade is 2679.4×10^{-6}, with an average grade of 378.85×10^{-6}.

The main ore minerals are chalcopyrite, chalcocite, sphalerite and magnetite, and the gangue minerals are quartz, plagioclase, sericite, garnet, chlorite, biotite, amphibole, pyroxene, epidote and calcite. The ores textures are disseminated, massived and nodular, and the ore types include copper skarn, breccia skarn and nodular sulfides.

Measured $\delta^{34}S$ values of sulfides ores range from -2.7×10^{-3} to -0.6×10^{-3} (average -1.7×10^{-3}). Calcite inclusions in the Weiquan Cu-Ag deposit indicate that the ore-forming temperature is between 129° and 264° (average 178°), with the majority between 100° and 200°, and associated ore fluid salinities of 9.5 to 12.5 equiv. NaCl weight percent (average 11.12). The ore-forming temperature calculated from fluid inclusions in quartz ranges from 151° to 297° (average 195.5°), with the majority between 150° and 220°, and the salinities of quartz being 9.5 to 12.1 equiv. NaCl weight percent (average 10.10).

Amphiboles from the skarn ores of the Weiquan Cu-Ag deposit were selected for ^{40}Ar-^{39}Ar dating, and the step-heating age is 275.8 ± 2.87 Ma, interpreted as the age of an extensional event of the Tianshan orogen [6]. This age is similar to the mineralization ages of the Cu-Ni sulfide, orogenic gold and epithermal gold deposits, suggesting that the mineralization was related to an extensional event of the Tianshan orogen.

Tectonic model for the late paleozoic metal deposits in east tianshan

The major types of Late Paleozoic (350~250Ma) metal deposits in the East Tianshan metallogenic province can be divided into: (1) porphyry-type Cu-Mo-(Au) ore deposit, (2) volcanic Fe-Cu deposit, (3) orogenic lode gold deposit, (4) magmatic Cu-Ni sulfide deposit, (5) epithermal gold deposit, (6) volcanic hydrothermal Cu deposit, and (7) skarn Cu-Ag deposit. Of these seven major ore deposits, porphyry-type Cu-Mo-(Au) and volcanic hydrothermal Cu deposits are restricted to the Dananhu-Tousuquan belt in the north of the Kangguer fault; whreas volcanic Fe-Cu ore deposits, orogenic lode gold deposits, magmatic Cu-Ni sulfide deposits, epithermal gold deposits and skarn Cu-Ag Cu-Ag deposits occur in Aqishan-Yamansu belt in the south of the Kangguer fault.

Tectonically, the development of Late Paleozoic metal deposits in East Tianshan was closely associated with the subduction and closure of the ancient Tianshan ocean intervening between the Tarim craton and the Junggar-Kazakhstan block [12,31]. In the Late Devonian to Early Carboniferous, the northern margin of the Tarim craton existed

Citation: Han C, Xiao W, Su B, Sakyi PA, Songjian Ao GZ, et al. (2014) Major Types and Characteristics of the Late Paleozoic Ore Deposits in the East Tianshan Orogenic Belt, Central Asia. J Geol Geosci 3: 158. doi: 10.4172/2329-6755.1000158

as a passive-type continental margin, whereas the ancient Tianshan ocean was subducted to the north beneath the southern margin of the Junggar-Kazakhstan block, resulting in the development of the Tousuquan-Dananhu magmatic arc and associated porphyry-type Cu-Mo-(Au) deposits (Figure 9a). In the Middle Carboniferous, the ancient Tianshan ocean began to subduct beneath the northern margin of the Tarim craton [28,29], leading to the formation of the Aqishan-Yamansu volcanic arc and associated volcanic Fe-Cu deposits (Figure 9b).

In the Late Carboniferous to Early Permian, following the subduction in the eastern part in the eastern Tianshan Orogenic Belt, along which large amounts of ultramafic-mafic complexes were emplaced, resulting in the formation of a number of large- to medium-scale magmatic copper-nickel ore deposits in East Tianshan orogen (Figure 9C).

In the Late Permian, the Tianshan orogen entered into a post-collosion orogenic stage, leading to the formation of Kangger ductile shear zone and associated with the widespread emplacement of granitoids rocks and eruption of within-plate volcanism at 254~234 Ma, which led to the formation of volcanic hydrothermal copper deposits in the Dananhu-Tousuquan belt and skarn-type Cu-Ag deposits (~276Ma), post-orogenic gold deposits of Kangguer gold field (258~254 Ma), and epithermal gold deposits (288~244 Ma) in the Aqishan-Yamansu belt (Figure 9D).

Acknowledgement

Acknowledgements We are indebted to Jingwen Mao, Bin Cui, Kezhang Qin, Lianchang Zhang, Tianlin Ma and Jianming Yang for thoughtful discussions. Many of the ideas in this paper were initiated and rectified during these discussions. This study was financially supported by funds from the Chinese State 973 Project (2014CB44801, 2012CB416603), Summary of the North China block iron ore deposits metallogenic regularity (20089950), the Innovative Program of the Chinese Academy of Sciences (KZCX2-YW-107), the NSFC Project (41230207, 41390441, 41190070 and 40572043), and Hong Kong RGC (7060/12P). This paper is a contribution to the IGCP 592.

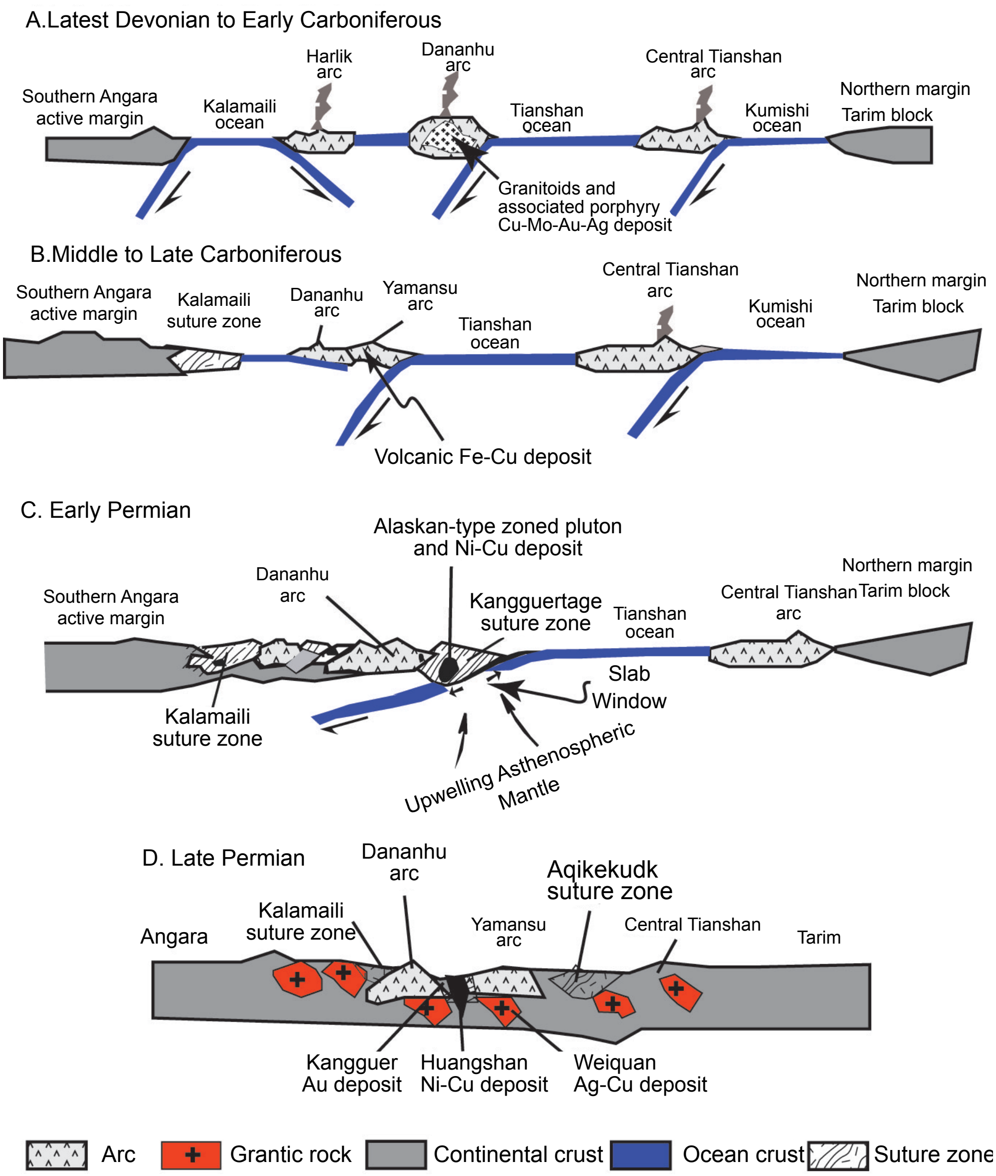

Figure 9: Schematic diagrams showing the late Paleozoic secular evolution and the formation of metal deposits in the eastern TianshanOrogenic Belt.

Citation: Han C, Xiao W, Su B, Sakyi PA, Songjian Ao GZ, et al. (2014) Major Types and Characteristics of the Late Paleozoic Ore Deposits in the East Tianshan Orogenic Belt, Central Asia. J Geol Geosci 3: 158. doi: 10.4172/2329-6755.1000158

References

1. Wang FT, Feng J, Hu JW (2001a) Characteristics and significance of the Tuwu porphyry copper deposit, Xinjiang. Chin Geol 28: 36-39.
2. Qin KZ (2000) Metallogenesis in relation to central-Asia style orogeny of northern Xinjiang. Unpbl Report Inst Geol. Geophy CAS Beijing 1-230.
3. Ji JS, Tao HX, Lu ZR (1994) Geological characteristics and mineralization of the Kangguer gold deposit zone in eastern Tianshan mountains. Beijing: Geological Publishing House 1-280.
4. Ji JS, Li HQ, Zhang LC (1999) Sm-Nd and Rb-Sr isotopical ages of magnetite-chlorite formation gold deposit in the volcanic rock area of Late Paleozoic Era, East Tianshan: Chin Sci Bull 44: 1801-1804.
5. Liu DQ, Tang YL, Zhou RH (1996) Metallogenic series types of deposits in Xinjiang. Miner Depos 15: 207-215.
6. Mao JW, Yang JM, Qu WJ (2002) Re-Os dating of Cu-Ni sulfide ores from Huangshandong deposits in Xinjiang and its geological significance. Miner Depos 21: 323-330.
7. Feng CY, Xue CJ, Zhang, LC (2000a) Geochemistry of the Xitan epothermal gold-silver deposit, East Tianshan Mountains. Miner Depos 19: 322-329.
8. Feng JZ, Zeng Y, Fu SX (2000b) Geology, genetic types and metallogeny of gold deposits in the eastern Tianshan, Xinjiang. Acta Geol Sin 74: 559-564.
9. Zhang LC, Ji JS, Li, HQ (2000) Geochemical characteristics and source of two-type ore-forming fluids in Kangguer gold Ore belt, east Tianshan. Acta Petrol Sin 16: 535-541.
10. Rui ZY, Wang FT, Li HH (2001) New advance of porphyry copper deposits in eastern Tianshan mountain, Xinjiang. China Geol 28: 11-17.
11. Rui ZY, Wang LS, Wang YT (2002a) Discussion on matallogenic epoch of the Tuwu and Yandong porphyry copper deposits in Eastern Tianshan Moutains, Xinjiang. Miner Depos 21: 16-22.
12. Rui ZY, Goldfarb RJ, Qiu YM, Taihe Z, Renyi C (2002b) Paleozoic-early Mesozoic gold deposits of the Xinjiang Autonomous Region, northwestern China. Miner Depos 37: 393-418.
13. Wang FT, Zhuang, DZ, Hu JW (2001b) Appilication of geophysical exploration method in the Tuwu area, Xinjiang-on the prospecting model of porphyry copper deposits. Chin Geol 28: 40-46.
14. Li XJ, Liu W (2002) Fluid inclusion and stable isotope constraints on the genesis of the Mazhuangshan gold deposit, eastern Tianshan Mountains of China. Acta Petrol Sin 18: 551-558.
15. Han CM, Mao JW, Yang JM (2002) Types of late Paleozoic endogenetic metal deposits and related geodynamical evolution in the east Tianshan. Acta Geol Sin 76: 222-234.
16. Pirajno F, Luo ZQ, Liu SF (1987) Gold deposits in the eastern tianshan, Northwestern China. Inter Geol Rev 39: 891-904.
17. Zhang LC, Liu TB, Shen YC (2002) Isotopic geochronology of the Late Paleozoic Kangguer gold deposits of East Tianshan Mountains, Xinjiang, northwest China. Resour Geol 52: 249-261.
18. Shui T (1987) Tectonic framework of the southeastern China continental basement. Sci Sin 1987 30: 414-422.
19. Zhao GC, Wilde SA, Cawood, PA, Liangzhao L (1998) Thermal evolution of Archean basement rocks from the eastern part of the North China Craton and its bearing on tectonic setting. Inter Geol Rev 40: 706-721.
20. Zhao GC, Cawood PA (1999) Tectonothermal evolution of the Mayuan assemblage in the Cathaysia Block: implications for Neoproterozoic collision-related assembly of the South China Craton. Am J Sci 299: 309-339.
21. Zhao GC, Wilde SA Cawood PA (1999) Tectonothermal history of the basement rocks in the western zone of the North China Craton and its tectonic implications. Tectonophysics 310: 37-53.
22. Zhao GC, Cawood PA, Wilde SA, Sun M, Liangzhao L (2000) Metamorphism of basement rocks in the Central Zone of the North China Craton: implications for Paleoproterozoic tectonic evolution. Precambrain Res 103: 55-88.
23. Zhao GC (2001) Paleoproterozoic amalgamation of the North China Craton. Geol Mag 138: 87-91.
24. Zhao GC, Wilde SA, Cawood PA, Sun M (2001) Archean blocks and their boundaries in the North China Craton: Lithological, geochemical, structural and P–T path constraints and tectonic evolution. Precambrian Res 107: 45-73.
25. Huang JQ (1977) Basic outline of China tectonics. Acta Geol Sin 52: 117-135.
26. Guo LX, Hu SX, Yu CS (2000) Carboniferous volcanics in the Bogda orogenic belt of eastern Tianshan: their tectonic implication. Acta Petrol Sin 2000 16: 305-316.
27. Allen MB, Windley BF, Zhang C (1992) Paleozoic collisional tectonics and magmatism of the Chinese Tianshan, central Asia. Tectonophysics 220: 89-115.
28. Allen MB, Windley BF, Zhang C, Guo J (1993) Evolution of the Turfan basin, Chinese Central Asia. Tectonics 12: 889-896.
29. Allen MB, Vincent SJ (1997) Fault reactivation in the Junggar region, northwest China-the role of basement structures during Mesozoic-Cenozoic compression. J Geol Soc, London 154: 151-155.
30. Guo JC, Hu, SX Gu LX (1992) The discovery of Archean zircons from mantle-derived granitoids in East Tianshan Caledonian orogenic belt and its geological significance. Chin Sci Bull 37: 1903-1905.
31. He GQ, Li MS, Liu DQ, (1994) Paleozoic crust evolution and mineralization of Xinjiang, China: Wurumqi, Xinjiang People Publishing House 1-328.
32. Carrol AR, Graham SA, Hendrix MS (1995) Late Paleozoic tectonic amalgamation of northwestern China: sedimentary record of the northern Tarim, northwestern Turpan, and southern Junggar basins. Geol Soc Am Bull 107: 571-594.
33. Biske YS, Shilov GG (1998) Structure of the northern margin of Tarim massif (Eastern Kokshaal area, Tien Shan). Geotectonics 32: 51-59.
34. Chen C, Lu H, Jia D (1999) Closing history of the southern Tianshan ocean basin, western China-an oblique collisional orogeny. Tectonophysics 302: 23-40.
35. Guo FX (2000) Affinity between Paleozoic blocks of Xinjiang and their suturing ages. Acta Geol Sin 74: 1-6.
36. Ma RS, Shu LS, Sun JQ (1997) Tectonic framework and crust evolution of eastern Tianshan mountains. Beijing: Geological Publishing House 1-320.
37. Zhou RH (1987) Advance in isotope geochronology of rocks in Xinjiang. Xinjiang Geo 5: 5-15.
38. Li HQ, Xie CF, Chang HL (1998) Study on metallogentic chronology of nonferrous and precious metallic ore deposits in Northern Xinjiang, China. Beijing, Geological Publishing House 1-268.
39. Han ZK, Han CM, Xiao WJ, Zhaoc G, Wang Z, et al. (2013) Paleozoic porphyry Cu-Au and ultramafic Cu-Ni deposits in the Eastern Tianshan Orogenic Belt: temporal constraints from U-Pb geochronology. Inter Geo Rev 55: 842-862.
40. Chen Y (1997) Mineralization during collisional orogenesis and its control on the distribution of gold and other deposits in the Junggar orogen, Xinjiang, China. Acta Geologica Sinica 71: 69-79.
41. Wang RM, Li SC (1987) Copper and nickel sulfide deposits of diagenetic and minerogenetic physical and chemical evolution in Hami, Xinjiang. J Chengdu Geol Univ 14: 1-10.
42. Wang ZH, Wang RM, Li SC (1986) Study on components of copper and nickel sulfide deposits in east Huangshan: Min Petrol 6: 88-101.
43. Zhang LC, Xiao WJ, Qin KZ (2004) Types, geological features and geodynamic significances of gold copper deposits in the Kanggurtag metallogenic belt, eastern Tianshan, NW China. Inter J Earth Sci 93: 224-240.
44. Han CM, Zhao GC (2003) Major types and characteristics of the late Paleozoic ore deposits, East Tianshan, Northwest China. Int Geol Rev 2003 45: 798-814.
45. Han CM, Xiao WJ, Zhao GC, Songjian A, Zhan J (2010) In-situ U–Pb, Hf and Re–Os isotopic analyses of the Xiangshan Ni–Cu–Co deposit in Eastern Tianshan (Xinjiang), Central Asia Orogenic Belt: Constraints on the timing and genesis of the mineralization. Lithos 120: 547-562.
46. Zhang LC, Xiao WJ, Qin KZ (2005) Re-Os isotopic dating of molybdenite and pyrite in the Baishan Mo-Re deposit, eastern Tianshan, NW China, and its geological significance. Miner Depos 39: 960-969.
47. Zhang LC, Shen YC, Ji JS (2003) Characteristics and genesis of Kanggur gold deposit in the eastern Tianshan mountains, NW China: evidence from geology, isotope distribution and chronology. Ore Geol Rev 23: 71-90.
48. Han BF, Ji JQ, Song B (2004) SHRIMP U–Pb zircon age of the mafic-ultramafic rocks 750 and geological significance in Kalatongke and Huanogshan, Xinjiang. Chin Sci Bull 49: 2324-2328.
49. Li HQ, Chen FW (2004) Isotopic, Geochronology of Regional Mineralization in Xinjiang, China. Geological Publishing House, Beijing 1-361.