Bulletin of the Geological Survey of Japan, vol. 51(10), p. 505-516, 2000

Reviews

Review on Exceptional Large Ore Deposits

Rongfu PEI[1], Yasuo KANAZAWA[2] and Ping'an WANG[3]

Rongfu PEI, Yasuo KANAZAWA and Ping'an WANG (2000) Review on Exceptional Large Ore Deposits. *Bull. Geol. Surv. Japan,* vol. 51 (10), p. 505-516, 3 figs, 4 tables.

Abstract: Exceptional large ore deposits with very large ore reserves have been called so far different names as superlarge ore deposits, supergiant ore deposits, unique ore deposits, gigantic ore deposits, world-class ore deposits and so on. As they are identical, we propose a unified term of exceptional large ore deposits for these deposits.

From the viewpoint of ore-forming process, the exceptional large ore deposits are stressed by the facts that they were formed under an explosive anomaly of mineralization in the normal state of ore-forming processes. The explosive anomaly usually includes plenty of metal supply, exceptional metallotect convergence and stable physical- chemical condition for the super accumulation of metals. They especially depend on preferences to ore-forming elements, deposit types, metallogenic geochronology, and metallogenic geological settings.

The minimum reserve criteria of exceptional large ore deposits have been proposed for 17 ore-forming commodities, and the exceptional large ore deposits are selected from world deposits. Their macroscopic distribution generally shows the concentration in two gigantic active belts, four stable massifs and on the transitional zone between those two tectonic units. The specific localities could be decided by exceptional metallotect convergence.

New attempts were put forward to assess the intensity of an explosive anomaly and prove the super accumulation of metals. These attempts include studies of: (1) ore-forming geochronology by a multidiscipline method, (2) analysis of thermal events of certain deposit types, (3) analysis of relative abundance of ore reserve and ore-forming period of the deposit. Regarding the genesis of an explosive anomaly, we hereby propose that they were created by global thermal events in certain eons and eras in geologic history. The global thermal events are tentatively recognized as oxyatmversion (excess oxygen atmospheric event) in Archean, redoxyatmversion (lack oxygen atmospheric event) in Proterozoic-Paleozoic, and tectonosphere thermal erosion (great amount of tectonic magmatic event) in Mesozoic-Cenozoic. One example of banded iron formation (BIF) related to the oxyatmversion is explained.

1. Criteria for exceptional large ore deposits

Economic geologists generally have classified ore deposits on scales of small, intermediate and large for many years. In recent years, as more large ore deposits have been discovered, their special economic importance should be emphasized. A new type of scale for exceptional large ore deposits has been made from the large ore deposit category. This kind of deposit is called superlarge ore deposits (Tu, 1989, 1994, 1995), supergiant ore deposits (Laznicka, 1983, 1989, 1999), unique ore deposits or gigantic ore deposits (Pei and Wu, 1990; Tu, 1998), world class ore deposits (Sangster, 1993; Naldrett, 1996; Robert and Poulsen, 1997), and so on by different authors.

However, these terms vaguely imply both the size of ore reserves and characteristics of metallogeny. In this paper, a unified term is recommended for exceptional large ore deposits with both special large ore reserves and special ore-forming processes.

Different criteria for minimum reserve of exceptional large ore deposits have been suggested by Laznicka (1983, 1999) and Tu (1989). Laznicka proposed the Tonnage Accumulation Index (TAI) which is a ratio of ore reserve tonnage vs. average crustal abundance of the ore-forming element, and divided exceptional large ore deposits into giant ore deposits by 10^{11} of TAI and supergiant ore deposits by 10^{12}. However this classification is not suitable for most

---

[1] Institute of Mineral Deposits, Chinese Academy of Geological Sciences, Beijing 100037, China
[2] Geological Information Center, GSJ
[3] Institute of Geomechanics, Chinese Academy of Geological Sciences, Beijing, 100081, China

Keywords: exceptional large ore deposits, metallogenic explosive anomaly, metallogenic preference, thermal event, China

Table 1 The minimum reserve criteria of exceptional large ore deposits (after Mei *et al.*,1997).

Commodity	Minimum criterion (reserve)	Commodity	Minimum criterion (reserve)	Commodity	Minimum criterion (reserve)
Fe	Ore, 1×10^9 t	Al	Ore, 100×10^6 t	Nb	Nb_2O_5, 100×10^3 t
Mn	Ore, 200×10^6 t	Ni	Metal, 500×10^3 t	Nb (placer)	Mineral, 10×10^3 t
Cr	Ore, 25×10^6 t	W	WO_3, 250×10^3 t	Ta	Ta_2O_5, 50×10^6 t
V	V_2O_5, 10×10^6 t	Sn	Metal, 400×10^3 t	Ta (placer)	Mineral, 25×10^6 t
Ti (rutile, primary ore)	TiO_2, 1×10^6 t	Mo	Metal, 1×10^6 t	Li (mineral)	Li_2O, 1×10^6 t
Ti (ilmenite, primary ore)	TiO_2, 50×10^6 t	Hg	Metal, 10×10^3 t	Li (salt lake)	LiCl, 2.5×10^6 t
Ti (rutile, placer)	Mineral, 0.5×10^6 t	Sb	Metal, 1×10^6 t	Be	BeO, 50×10^3 t
Ti (ilmenite placer)	Mineral, 5×10^6 t	Bi	Metal, 250×10^3 t	REE	TR_2O_3, 5×10^6 t
Cu	Metal, 5×10^6 t	Au	Metal, 100 t	REE (monazite placer)	Metal, 0.1×10^6 t
Pb	Metal, 5×10^6 t	Au (placer)	Metal, 40 t		
Zn	Metal, 5×10^6 t	Ag	Metal, 5×10^3 t		

nonmetallic deposits but only for metal ore deposits. In China, superlarge ore deposits were defined by 5 ~ 10 times of the reserve of large ore deposits (Tu, 1989). Based on the latter definition, Mei *et al.* (1997) gave the actual minimum reserve criteria for most metals of the exceptional large ore deposits as listed in Table 1.

2. Explosive anomaly of mineralization

The formation for exceptional large ore deposits needs extremely suitable geological settings for metal accumulation. Pei *et al.* (1999a) explained these ideal conditions by the term, 'explosive anomaly'. Exceptional large ore deposits were formed under an explosive anomaly in normal state of ore forming processes with plenty of metal supply, exceptional metallotect convergence and stable conditions for metal accumulation. The explosive anomaly in the ore-forming processes could be compared with gravitational tide resonance of meteorological anomaly (Ren, 1998). For example, the torrential rain causing disaster of the whole drainage area of the middle - lower reaches of the Yangtze River is a result of gravitational tide resonance. The superaccumulation of metals should also be regarded as a result of gravitational tide resonance, which is induced by geological processes superimposing on the common ore-forming processes and stimulating a mass concentration of ore-forming elements (Pei *et al.*, 1999a).

In a global sense, the explosive anomaly is again compared with a kind of common phenomena in meteorology. It is regarded to relate to El Nino caused by global thermal events coming from the activities of deep fault zones in the eastern Pacific Rim (Li and Chen, 1998). However, what caused thermal events in the past geological history? Based on the study of geochronology for typical ore deposits as criteria for geological thermal events, the authors propose that three primary thermal events had arisen in geological history. They are (1) "oxyatmversion" (meaning excess oxygen events in Archean to Lower Proterozoic) relating to banded iron formation (BIF) and greenstone gold superlarge deposits in Archean, (2) "redoxyatmversion" (meaning lack oxygen events in Mid-Late Proterozoic to Paleozoic) relating to sediments hosted exhalative superlarge deposits in Proterozoic (Pei and Xiong, 1999) and (3) "tectonosphere thermal erosion" (meaning disharmonious movement between crust and mantle to form events of a great amount of crustal remelt) relating to magmatic hydrothermal superlarge deposits in Mesozoic-Cenozoic (Pei and Xiong, 1999). Hereby we only show an example of ore-forming thermal events of the metallogenic province in the north margin of the North China platform in Table 2 (Pei *et al.*, 1999b).

Since exceptional large ore deposits were formed under an explosive anomaly, their metallogenic characteristics are indeed special and show inevitable preference. That means that exceptional large ore deposits prefer to special conditions. Their favorable metallogenetic conditions are very limited and not easily discovered, if their preference is not recognized.

Metallogenic preference of exceptional large ore deposits are mainly marked by their special selectivity toward specific ore-forming commodities, deposit types, ore-forming ages and geological settings, depending chiefly upon combinations of geological, geochemical and geophysical ore-controlling factors. Such combinations are called exceptional metallotect convergence (Pei *et al.*, 1997), which can be divided into Archean-

Table 2 One-forming thermal events and age identification of metallogenic province in north margin of North China platform.

Tectonic domain (belt)		Tectonic process	Metallogenic thermal event and geologic expression		Host rock	Ore-forming commodities	Dating of ore-forming age (Ma)	Case deposits
Circum- Pacific	Mesozoic intra-continental active belt	Compression, extension, shearing, cataclasis	Intra-continental tectonosphere thermal erosion	Tectonic remelting magma	Rhyolitic volcanic rock; Quartz vein; Porphyritic granite	Au	122-100 (K-Ar); 197-165 (K-Ar); 163.8 (Rb-Sr)	Erdaogou (Au) Jinchangyu (Au) Yu'erya (Au)
				Tectonic syntectic magma	Explosion breccia; Skarn; Porphyritic granite	Mo; Fe, Cu, Mo, Pb, Zn, Ag; Mo	149 (K-Ar): 211-186 (K-Ar); 193-104 (K-Ar)	Dakezhuang (Mo) Yangjiazhangzi (Mo) Shouwangfen (Cu-Mo), Bajiazi (Mo-Pb-Zn) Lanjiagou (Mo)
Paleo-Asian	Paleozoic inter-continental orogenic belt	Epicontinental subduction; Inter-continental collision		Marginal oceanic trench-arc-basin volcanic sedimentation & epicontinental tectonic-magmatic chain	Diorite porphyry; Alkali granite	Cu-Mo; Au	>400; 350.9 (Zr, U-Pb)	Bainaimiao (Cu-Mo) Dongping (Au)
Precambrian tectono-metallogenic	Proterozoic continental accreting belt	Intracratonic rifting	Redoxyatmo-version	Marginal basin sedimentation	Detrital rock	Mn (Fe); Fe	1100 (K-Ar); 1902 (whole-rock U-Pb)	Wafangzi (Mn) Xuan-Long (Fe)
				Epicontinental rift deep faulting	Carbonate-black shale series; Mafic rock	Pb-Zn-S; V-Ti-Fe-P Cu-Ni	1500 (Pb-Pb); 2190-1920 (Sm-Nd); 2090-2050 (model-Pb); 1590 (Rb-Sr); 2240 (K-Ar)	Gaobanhe; (Pb-Zn) Qingchengzi (Pb-Zn) Guanmenshan (Pb-Zn) Damiao (Fe-V-Ti-P) Chisongbai (Cu-Ni)
				Epicontinental rift deep-seated faulting	Carbonate-black shale series	Pb-Zn-S Fe-Nb-REE	1490 (Sm-Nd); 1530 (Sm-Nd); 1730 (Zr, U-Pb)	Langshan-Zhaertaishan (Pb-Zn-S) Bayan Obo (Fe-Nb-REE)
	Archean continental nucleus	Pericratonic mobilization	Oxyatmversion	Submarine hypogene exhalation	Silica-iron formation; Granite-greenstone belt	Fe (Au); Cu-Zn-Au	2750-2650 (Zr, U-Pb); 3500-2500 (Sm-Nd); 2800 (Sm-Nd)	Anshan (Fe) Shuichang (Fe) Hongtoushan (Cu-Zn-Au)
				High-temperature and high-pressure transformation	Granulite-gneiss	Graphite	3060 (Zr, U-Pb)	Huangtuyao (Graphite)

Paleo- Proterozoic syn-shearing exceptional metallotect convergence, Proterozoic-Paleozoic trinity (ore-forming process associated with syn-sedimentary, syn-faulting and syn-brecciation) exceptional metallotect convergence, Mesozoic-Cenozoic "row-line-cluster" magmatic exceptional metallotect convergence and Cenozoic multi-level lake confluence exceptional metallotect convergence in China. Each convergence is the optimum ore-controlling site for preference of exceptional large ore deposits.

3. Global distribution of exceptional large ore deposits

Seventeen ore-forming commodities and their 137 largest deposits in the world are listed in Table 3 and shown in Fig.1. Their macroscopic distribution is generally concentrated between latitudes of N35°-N50° and S10°-S35° except for the SE Asia region. Geo-tectonically, they are related to two crustal gigantic Mesozoic – Cenozoic active belts and four stable Precambrian massifs in the followings.

The two crustal gigantic active belts (Pei *et al.*, 1998):

(1) Island-arc-trench and coast marginal range active belts on the Pacific Rim, especially the Andean and Los Angles on the eastern Pacific Rim and island arcs on the southwestern Pacific Rim;

(2) The Mediterranean-Indonesian active belts, especially the Alps, Kirbarchan and northern Caucasus ranges. Besides, some exceptional large ore deposits also distribute in Paleo-Asia tectonic active belts, which belong to the Paleozoic.

The four Precambrian stable massifs:

(1) North American massif, especially in Lake Superior between the territory of USA and Canada;

(2) South American massif; especially in Brazil and Chile;

(3) Australia massif;

(4) Africa massif, especially in southern Africa.

Besides, some exceptional large ore deposits also distribute in the Siberia, Indian, China-Korea and Eastern Europe massifs, but these massifs are less concentrated than the four massifs mentioned above.

It is noted that more exceptional large ore deposits tend to distribute on the transitional zone between two tectonic units, especially on the marginal zone of a tectonic unit. The tectonic localities of the specific distribution should be related to exceptional metallotect convergence. For example, at least five porphyry copper deposits with more than 10 million tons of ore reserves in Chile distribute in the exceptional metallotect convergence of the NS-trending deep great fault zone in the west margin of the south America massif. At least seven sediment-hosted copper deposits with more than 5 million tons of ore reserves in Zambia-Zaire occur in an exceptional metallotect convergence of the central basin in the south margin of the South Africa massif.

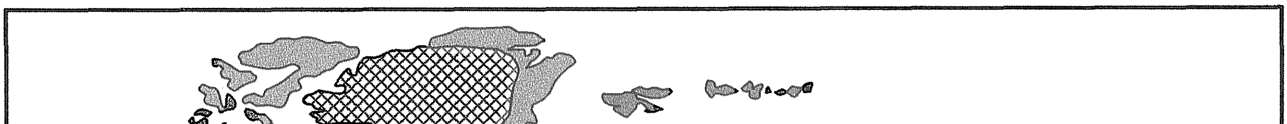

Fig. 1 The distribution map of exceptional large ore deposits. Ore deposit numbers are same to those of the 1st column in Table 3.

Table 3 The reserves tonnage of exceptional large ore deposits*.

No.	Metal	Country	Ore deposit	Reserve (10^6 ton)	Grade (metal %)	Type	Epoch
1	Cu	Chile	Chuquicamata	69	0.56	Porphyry	Cenozoic
2			El Teniente	68	0.68	Porphyry	Cenozoic
3			La Escondida	19	1.60	Porphyry	Cenozoic
4			Chuqui Norte	17	0.89	Porphyry	Cenozoic
5			Collahuasi	12	1.20	Porphyry	Cenozoic
6		USA	Bingham	23	0.98	Porphyry	Cenozoic
7			Duluth	20	0.5	Cu-Ni sulfide	Proterozoic
8			Butte	18	0.8	Porphyry	Mesozoic-Cenozoic
9			Morenci	13	1.0	Porphyry	Cenozoic
10		Canada	Sudbury	10	0.8~1.9	Cu-Ni sulfide	Proterozoic
11		Panama	Cerro Colorado	13	0.66	Porphyry	Cenozoic
12		Mexico	Cananea	13	0.70	Porphyry	Cenozoic
13		Zambia	Nchanga	16	4.1	Sandy shale	Proterozoic
14		Zaire	Kolwezi	35	4.5	Sandy shale	Proterozoic
15		Russia	Udokan	18	1.5	Sandy shale	Proterozoic
16		Poland	Lubin	15	1.0	Sandy shale	Paleozoic
17		Spain	Rio Tinto	10	0.70	VMS	Paleozoic
18		Mongolia	Erdeintyin Obo	10	0.3~1.5	Porphyry	Paleozoic
19		Indonesia	Grasberg	12	1.3	Porphyry	Cenozoic
20		Afghanistan	Akinak	11	2.0	Sandy shale	Proterozoic
21		Australia	Olympic Dam	32	1.6	Magmatic hydrothermal	Proterozoic
22		China	Yulong	10	0.4~9.7	Porphyry-skarn	Eocene
23	Pb-Zn	USA	Viburnum Trend	>30	3.5~9.0	MVT	Paleozoic
24			Old Lead Belt	10	3.0	MVT	Paleozoic
25			Tri State	13	2.9	MVT	Paleozoic
26			Coeurd Alene	>10	12	Hydrothermal vein	Mesozoic
27			Red Dog	19	22	SEDEX	Paleozoic
28		Canada	Howards Pass	36	12	SEDEX	Paleozoic
29			Sullivan	>21	12	SEDEX	Proterozoic
30			Bathuist	>11	13	VMS	Paleozoic
31		Peru	Serro de Pasco	10	13	Magmatic metasomatic	Cenozoic
32		Australia	Broken Hill	>55	25	Meta-SEDEX	Proterozoic
33			McArthur River	26	14	SEDEX	Proterozoic
34			Mount Isa	12	13	SEDEX	Proterozoic
35			Wood Lawn	12	20	VMS	Paleozoic
36			Century	16	12	SEDEX	Proterozoic
37			Admirals Bay	14	8.7	SEDEX	Paleozoic
38		Algeria	Bejaia	>12	>6.0	/	/
39		Korea, DPR	Komdok	70	7-10	Metamorphosed sedimentary	Proterozoic
40		Poland	Upper Silesia	32	12	MVT	Mesozoic
41		Germany	Freiberg	14	57	Hydrothermal vein	/
42		South Africa	Gamsberg	11	8.0	SEDEX	Proterozoic
43		China	Jinding	16	9.6	Sandy shale	Mesozoic
44			Changba-Lijiagou	>10	8.3~8.8	SEDEX-hydrothermal	Devonian-Mesozoic
45	Al	Brazil	Trombetas	1000	27	Lateritic	Cenozoic
46		Australia	Darling	1000	16~19	Lateritic	Cenozoic
47			Mitchell	1200	19~25	Lateritic	Cenozoic
48			Weipa	2500	28~31	Lateritic	Cenozoic
49		Guinea	Ayekoye	1100	26	Lateritic	Cenozoic
50			Tougue	1500	23	Lateritic	Cenozoic
51			Dabola	1000	23	Lateritic	Cenozoic
52		Vietnam	Plateaux	>1000	39~42 (Al_2O_3)	Lateritic	Cenozoic

Table 3 continued.

No.	Metal	Country	Ore deposit	Reserve (10^6 ton)	Grade (metal %)	Type	Epoch
10	Ni	Canada	Sudbury	11	1.5	Cu-Ni sulfide	Proterozoic
53			Thompson	3.4	2.5	Cu-Ni sulfide	Late-Proterozoic
54		Russia	Norilsk	2.5	2.5	Cu-Ni sulfide	Mesozoic
55		South Africa	Bushveld	2.5	0.35	Cu-Ni sulfide	Proterozoic
56		China	Jinchuan	>5	1.5	Cu-Ni sulfide	Proterozoic
57		Cuba	Moa Bay	6.1	1.3	Lateritic	Cenozoic
58	Au	South Africa	Witwatersland	0.054	9.8×10^{-6}	Au-U conglomerate	Proterozoic
59		Canada	Hemlo	0.00060	7.8×10^{-6}	Greenstone	Proterozoic
60		USA	Homestake	0.0012	15×10^{-6}	Iron formation	Archean
61			Mother Lode	0.0010	8.4×10^{-6}	Transgressive vein	Paleozoic
62			Cripple Cree	0.00076	12×10^{-6}	Terrestrial volcanic	Tertiary
6			Bingham	0.0010	0.22×10^{-6}	Porphyry	Paleogene
63			Post-Betze	0.00055	610×10^{-6}	Carlin	Tertiary
64		Papua New Guinea	Lihir Island	0.00050	3.5×10^{-6}	Terrestrial volcanic	Cenozoic
65			Panguna	0.00051	1.9×10^{-6}	Porphyry	Tertiary
66		New Zealand	Hauraki	0.0014	87×10^{-6}	Terrestrial volcanic	Tertiary
67		India	Kolar	0.00079	10×10^{-6}	Greenstone and iron formation	Archean
21		Australia	Olympic Dam	0.0012	0.60×10^{-6}	Magmatic hydrothermal	Middle-Proterozoic
68			Golden Mile	0.0013	6.0×10^{-6}	Greenstone	Late-Proterozoic
69			Bendigo and Ballarat	0.00060	$(12\sim28)\times10^{-6}$	Turbidite	Paleozoic
70		Brazil	Serra Pelada	>0.00050	/	Placer	Quaternary
19		Indonesia	Grasberg	0.0015	1.6×10^{-6}	Porphyry	Triassic
71		Uzbekistan	Muruntau	0.0040	2.4×10^{-6}	Turbidite	Early Paleozoic
72		Dominica	Pueblo Viejo	0.00060	4.8×10^{-6}	Terrestrial volcanic	Early Cretaceous
26	Ag	USA	Coeurd Alene	>0.03	160×10^{-6}	Hydrothermal Vein	Mesozoic
8			Butte	0.04	$(62\sim100)\times10^{-6}$	Porphyry	Mesozoic-Cenozoic
73			Comstock	0.021	3000×10^{-6}	Terrestrial volcanic	Miocene
74		Mexico	Guanajuato	0.0033	340×10^{-6}	Terrestrial volcanic	Triassic
75			Pachuca Realdel Mt.	0.040	310×10^{-6}	Terrestrial volcanic	Cenozoic
76		Bolivia	Potosi	0.020	$(150\sim250)\times10^{-6}$	Terrestrial volcanic	Tertiary
66		New Zealand	Hauraki	0.041	/	Terrestrial volcanic	Neogene
31		Peru	Cerro de Pasco	0.048	$70\sim90\times10^{-6}$	Hydrothermal replacement	Tertiary
77		China	Fuwan	Very large	$130\sim280\times10^{-6}$	Epithermal	Mesozoic
78	W	China	Shizhuyuan	0.63	0.23	Greisen-skarn	Mesozoic
80		Canada	Mactung	0.48	0.7~68	Skarn-porphyry	Mesozoic
79			Xingluokeng	0.030	0.23	Porphyry	Mesozoic
81	Sn	China	Gejiu	0.084 (preserved)	0.67	Skarn	Mesozoic
82			Dachang	0.074 (preserved)	0.21	Skarn-hydrothermal replacement	Mesozoic
83		Burma	Heinda	0.072	0.5~1.0	Hydrothermal and& placer	Mesozoic-Cenozoic
84		Thailand	Ranong-Phuket	1.5	/	Placer	Cenozoic
85		Indonesia	Bangka Isl.	1.5	/	Placer	Mesozoic-Cenozoic
86	Mo	USA	Climax	3.8	0.23	Porphyry	Tertiary
87			Henderson	3.0	0.23	Porphyry	Tertiary
88		China	Sandaozhuang	2.1	0.11	Skarn-porphyry	Mesozoic
89	Sb	China	Xikuangshan	0.82	3.4~6.6	Stratabound	Jurassic
90		South Africa	Murchison	0.53	38	Hydrothermal	Mesozoic
91	U	Canada	Cigar Lake	U_3O_8 0.13 (main orebody)	U_3O_8 14	Discordant	Proterozoic
92			McArthur River	U_3O_8 0.12	U_3O_8 5	Discordant	Proterozoic
93			Elliot Lake-Blind River	U_3O_8 0.10	U_3O_8 0.15	U-bearing conglomerate	Early-Proterozoic
94		Australia	Jabiluka	U_3O_8 0.20	U_3O_8 0.39	Discordant	Proterozoic
95			Ranger	U_3O_8 0.10	U_3O_8 0.3~0.5	Discordant	Proterozoic
21			Olympic Dam	U_3O_8 1.2	U_3O_8 5.4	Magmatic hydrothermal	Early-Proterozoic
58		South Africa	Witwatersland	U_3O_8 0.14	U_3O_8 0.025	Au-U-bearing conglomerate	Early-Proterozoic
96		Namibia	Rossing	U_3O_8 0.15	U_3O_8 0.03~0.04	Magmatic	Late-Proterozoic
97		Russia	Streltsovsky	U_3O_8 >0.20	U_3O_8 0.2	Volcanic	Mesozoic
98	Fe	Russia	KMA**	Fe ore 63000	Fe 32~66	Metamorphosed sedimentary	Early-Proterozoic
99		Ukraine	Krivoyrog	29000	34~56	Metamorphosed sedimentary	Early-Proterozoic
100		Australia	Hamersley	35600	50~64	Metamorphosed sedimentary	Early-Proterozoic
101		Brazil	Quadrilatero Fe	22000	40~65 (rich ore)	Metamorphosed sedimentary	Early-Proterozoic

Table 3 continued.

No.	Metal	Country	Ore deposit	Reserve (10^6 ton)	Grade (metal %)	Type	Epoch
102			Carajas	18000	63~66	Metamorphosed sedimentary	Early-Proterozoic
103		Canada	Labrador	21000	30~66	Metamorphosed sedimentary	Early-Proterozoic
104		USA	Superior L.	16000	25~45	Metamorphosed sedimentary	Proterozoic
105	Mn	South Africa	Kalahari	Cr ore 4300	31~42	Metamorphosed sedimentary	Proterozoic
106		Ukraine	Nikopol	940	20	Sedimentary	Oligocene
107		Georgia	Chiatora	600	20	Sedimentary	Oligocene
55	PGE	South Africa	Merensky Reef, Bushveld	0.0042	6.0 (ppm)	Ultra-basic magmagene	Proterozoic
55	Cr	South Africa	Bushveld	Cr ore 960	Cr_2O_3 43~48	Stratiform	Early-Proterozoic
108		Zimbabwe	Great Dyke	350	43~52	Stratiform	Proterozoic
109		Kazakhstan	Kempirsai	120	50~59	Podiform	Late Paleozoic
110		India	Sukinda-Nausash	130	40~44	Stratiform	Late-Proterozoic
111	REE-Nb	China	Bayan Obo	Very large	Nb_2O_5 0.08; RE_2O_3 2.5	Carbonatite and volcano-sedimentary-hydrothermal	Middle-Proterozoic —Paleozoic

* Origin of materials: Dai (1993), Pei *et al.* (1998) and Laznicka (1983, 1999); **KMA: Kursk magnetic abnormity

4. Preference of exceptional large ore deposits

One hundred fifty-six exceptional large ore deposits including 48 in China were investigated, and their preference to some geologic factors are concluded as follows:

4.1 Preference to ore-forming elements

The investigation shows that exceptional large ore deposits were not formed for all of metallic elements. According to the relationship between the number of giant and super-giant ore deposits and sequence of ore-forming elements (Laznicka, 1983) (Fig.2), a group of ore-forming elements of Cu, Au, Fe, Ag, Cr, Mn, Zn, Pb, Sb, Hg is listed at a relatively high rank to form super-accumulation easily. The next group of As, PGE, Mo, W, Ni, Nb, Bi, Zr, REE, V, Se, Co, U is at a middle rank and relatively difficult to form super-accumulation. The last group of Li, Cs, Ta, Tl, Ti, Th, Y is the most difficult to form super-accumulation. However, based on different metallogenic condition, the preference of ore-forming elements has also regional trends because the exceptional geological preference varies in different countries or regions. For example, (1) W, Bi and Be of the Shizhuyuan W-Sn-Mo-Bi-Be deposit in Nanling Metallogenic Province of China, (2) REE and Nb of the Bayan Obo Fe-Nb-REE deposit in North China Platform Metallogenic Province, and (3) Al of the Boke-Gaoual deposit in Guinea, were concentrated to form exceptional large deposits.

4.2 Preference to deposit types

Exceptional large ore deposits evidently have a preference for particular deposit types of particular elements. Based on the preliminary statistics, it is obvious that exceptional large ore deposits can occur only in two to four types, especially porphyry and sandy-shale types. Among the 21 deposits of lead and zinc ores with reserves more than 10×10^6 tons, there are 9 of SEDEX type (amounting to 43%), 4 of MV type (19%), 2 of VMS type (9%) and 2 of vein type (9%). Almost half of the Pb and Zn ore deposits occur as SEDEX type. Besides, deposit types of hydrothermal metasomatic, sandystone or sedimentary metamorphic could also be gigantic. Exceptional large ore deposits of some other elements have also preference to particular deposit types such as, only laterite sedimentary type for Al, Cu-Ni-sulfide type for Ni, volcanic rock type for Ag, skarn type for S and W, and porphyry type for Mo.

4.3 Preference to metallogenic geochronology

Ore-forming periods for exceptional large ore deposits were analyzed throughout the world. Most of these deposits were formed during particular periods of geological history. This time dependency is generally true in any part of the world (Table 4). Some examples are as follows:

(1) Most exceptional large iron deposits occurred in the period from late Archean to Early Proterozoic;
(2) Most exceptional large SEDEX type Pb-Zn deposits occurred from Proterozoic to Paleozoic;
(3) Most exceptional large MV type Pb-Zn deposits formed in Paleozoic;
(4) Most exceptional large porphyry Cu and Mo deposits formed from Mesozoic to Cenozoic;
(5) Most exceptional large epithermal volcanic rock type Au deposits formed in Cenozoic;
(6) Most exceptional large magmatic hydrothermal W, Sn deposits formed from Paleozoic to Mesozoic;
(7) Most exceptional large salt lake type Li deposits formed in Cenozoic and modern times.

4.4 Preference to metallogenetic geological settings

Exceptional large ore deposits are not present in all kinds of geological conditions. Available data of more than 200 exceptional large ore deposits in the world indicate that they are dependent mainly on the following conditions:

Table 4 The primary statistics of the types and the metallogenic ages of the world exceptional large ore deposits.

Ore-forming metals	Type and age		Number of deposits	Percentage (%)	Preferentiality
Cu	Type	Porphyry	12	57	Cenozoic porphyry type; Paleozoic and Proterozoic sandy-shale type
		Sandy shale	5	24	
		Magmatic Cu-Ni sulfide	2	9	
		VMS	1	5	
		Cu-U-Au (Olympic Dam)	1	5	
	Age	Mesozoic	10	48	
		Mesozoic	1	5	
		Paleozoic	3	14	
		Proterozoic	7	33	
Pb-Zn	Type	SEDEX	9	43	SEDEX type in Paleozoic and Proterozoic; MV type in Paleozoic
		MV	4	19	
		VMS	2	9	
		Vein	2	9	
		Hydrothermal replacement	1	5	
		Sandstone	1	5	
		Metamorphosed sedimentary	1	5	
		Unclassified	1	5	
	Age	Mesozoic	1	5	
		Mesozoic	3	14	
		Paleozoic	8	38	
		Proterozoic	7	33	
		Unidentified	2	10	
Al	Type	Lateritic	10	100	Lateritic type in Cenozoic
	Age	Cenozoic	10	100	
Ni	Type	Cu-Ni-sulfide	5	83	Proterozoic Cu-Ni-sulfide type
		Lateritic	1	17	
	Age	Cenozoic	1	17	
		Mesozoic	1	17	
		Proterozoic	4	66	
Au	Type	Greenstone	4	22.2	Volcanic and sub-volcanic types in Cenozoic; greenstone and Au-U conglomerate types in Precambrian
		Volcanic rock	4	22.2	
		Porphyry	3	17	
		Turbidite	2	11.1	
		Carlin	1	5.5	
		Au-U conglomerate	1	5.5	
		Cu-U-Au	1	5.5	
		Transgressive vein	1	5.5	
		Lateritic	1	5.5	
	Age	Cenozoic	8	44	
		Mesozoic	1	5	
		Paleozoic	3	17	
		Proterozoic	3	17	
		Archean	3	17	
Ag	Type	Volcanic rock	5	63	Volcanic and sub-volcanic types in Mesozoic and Cenozoic
		Porphyry	1	12.5	
		Vein	1	12.5	
		Hydrothermal replacement	1	12.5	
	Age	Cenozoic	6	75	
		Mesozoic	2	25	
W	Type	Skarn	2	67	Mesozoic skarn type and hydrothermal vein
		Hydrothermal vein	1	33	
	Age	Mesozoic	3	100	
Sn	Type	Placer	3	60	Cenozoic placer type and Mesozoic skarn type
		Skarn	2	40	
	Age	Cenozoic	3	60	
		Mesozoic	2	40	
Mo	Type	Porphyry	3	100	Porphyry type in Mesozoic and Cenozoic
	Age	Cenozoic	2	67	
		Mesozoic	1	33	

Table 4 continued.

Sb	Type	Stratabound Hydrothermal	1 1	50 50	Mesozoic stratabound type and hydrothermal type
	Age	Mesozoic	2	100	
U	Type	Discordant Fossil conglomerate Cu-U-Au-type Volcanic rock Magmatic	4 2 1 1 1	44.5 22.2 11.1 11.1 11.1	Proterozoic discordant type and fossil conglomerate type
	Age	Mesozoic Proterozoic	1 8	11 89	
Fe	Type	Metamorphosed sedimentary	7	100	Proterozoic metamorphosed sedimentary type
	Age	Proterozoic	7	100	
Mn	Type	Sedimentary Metamorphosed sedimentary	2 1	67 33	Cenozoic sedimentary and Proterozoic metamorphosed sedimentary types
	Age	Cenozoic Proterozoic	2 1	67 33	
Cr	Type	Stratiform magmatic Podiform magmatic	3 1	75 25	Proterozoic stratiform type
	Age	Paleozoic Proterozoic	1 3	25 75	

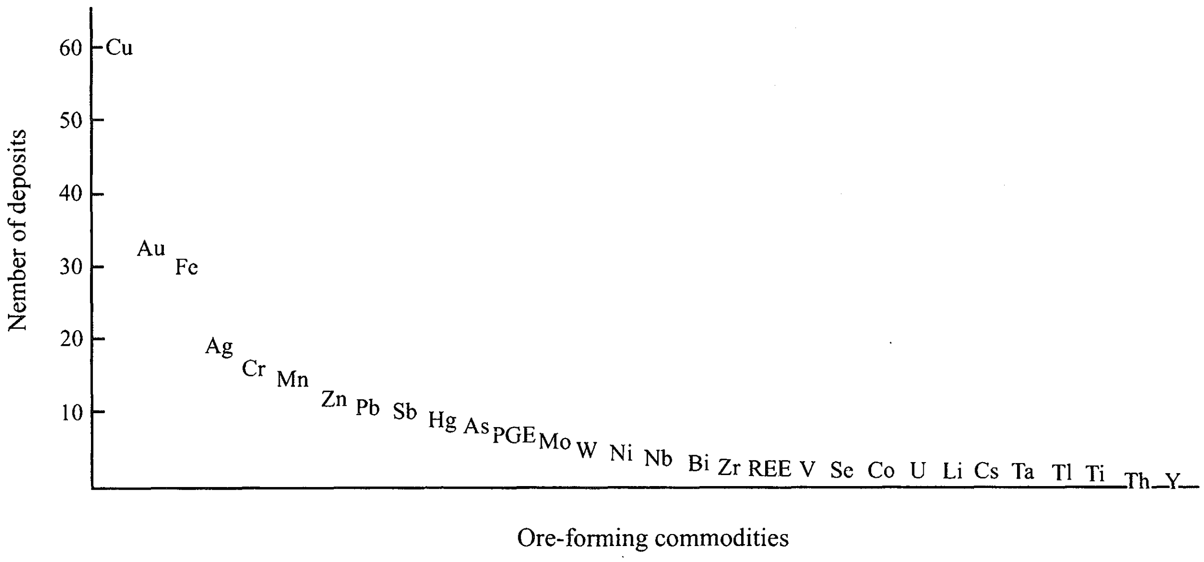

Fig. 2 Number of giant and super-giant ore deposits for sequence of ore-forming elements (After Laznicka, 1983).

(1) Accretion belts along continental margins or plate convergent belts;
(2) Intra-cratonic or pericontinental rifts;
(3) Intra-continental tectono-magmatic complex belts;
(4) Precambrian granite-greenstone belts;
(5) Large ductile shear zones.

Recent studies show that the above conditions are likely to be related to the mantle plume and exceptional large deposits usually occur around the intersection and transitional zone of two tectonic units.

5. The relationship between ore reserve and ore-forming period of exceptional large ore deposits, and its correspondence to global thermal events

A new attempt for assessing the intensity of an explosive anomaly has been made (Pei, 1993, 1997; Pei *et al.*, 1998; Pei *et al.*, 1999a; Tu, 1998). It was taken through studies of ore-forming geochronology by a multidiscipline, also through analysis of ore-forming thermal events for a certain type of deposits. In this paper, the authors show only an example of the exceptional large

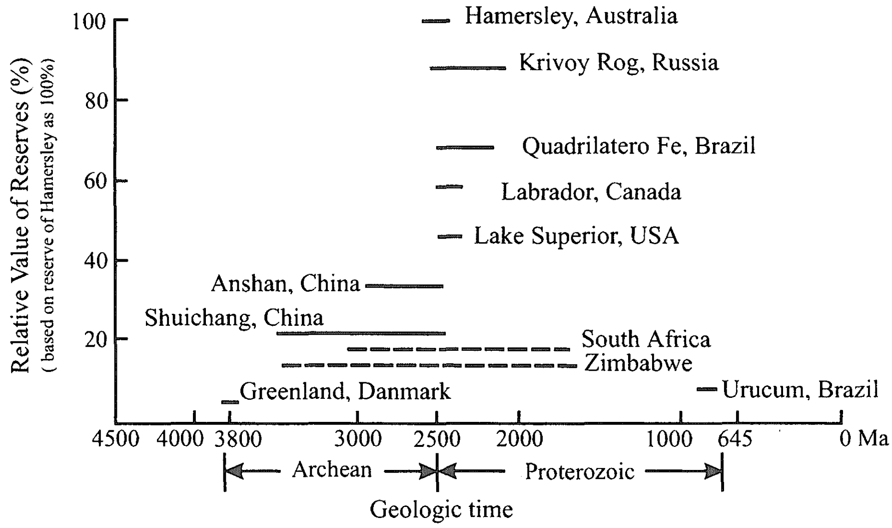

Fig. 3 The relationship between relative abundance of ore reserves and ore-forming period of Precambrian Iron Formation.

Banded Iron Formations (BIF) relating to thermal events of "oxyatmversion".

Fig. 3 shows the relationship between ore reserve and ore-forming period (OFP) of banded iron formation deposits. The reserve is shown by relative abundance of ore reserve (RAOR) compared with the biggest Hamersley iron deposit (RAOR = 100%; reserve = 36,500 million tons; OFP = 2600-2450 Ma). The subsequent deposits in a decreasing order are Krivoy Rog (RAOR = 79%; reserve = 29,000 million tons; OFP = 2500-2200Ma), Quadrilatero Fe (RAOR = 60%; 22,000 million tons; OFP = 2500 ~ 2150 Ma), Labrador (RAOR = 56%; 20,600 million tons; OFP = 2500 ~ 2350 Ma), and Superior Lake (RAOR = 44%; 16,200 million tons; OFP = 2500 ~ 2450 Ma). These five largest BIF deposits with more than 44 percent of the RAOR were formed in a relatively short duration of about only 50-300 million years, compared with Zimbabwe and South Africa which possess Fe ore reserves less than 50 million tons (RAOR = 17% ~ 18%) but with very long OFP of 1250 million years (from 3050 Ma to 1800 Ma).

The fact suggests that a strong "oxyatmversion" should have happened in the duration from 2500 Ma to 1900 Ma, which is a common knowledge among the geology academia.

6. Summary

For the purpose of unification of all the gigantic, giant, supergiant, superlarge, unique and world-class ore deposits, a new term of exceptional large ore deposit was put forward as a general term. An exceptional large ore deposit is defined as one that possesses five to ten times the minimum value of their large ore deposit reserves.

The geological analyses of exceptional large ore deposits indicate that such deposits were formed under special metallogenic conditions and have exceptional large ore reserves. However, in the past, there was no unified term for such a group of large ore deposits.

The term special metallogeny of exceptional large ore deposits is to emphasize the effect of an explosive anomaly superimposing on the normal ore-forming processes. This anomaly effect is suggested to be indicated by a strong super-accumulation of metals in a short time. Regarding the genesis of an explosive anomaly, we hereby propose that they were created by global thermal events in certain eons and eras in geologic history. The global thermal events are tentatively recognized as oxyatmversion (excess oxygen atmospheric event) in Archean, redoxyatmversion (lack oxygen atmospheric event) in Proterozoic-Paleozoic, and tectonosphere thermal erosion (great amount of tectonic magmatic event) in Mesozoic-Cenozoic. The understanding of geological settings for their metallogenic preference of exceptional large ore deposits indicate that exceptional metallotect convergence could give a guideline for prospecting exceptional large ore deposits.

References

Dai, Z.X. (1993) Superlarge ore deposits recently discovered abroad. In: Papers presented to 5th all-China symposium on mineral deposits: Geological Publishing House, Beijing, China, 184-186 (in Chinese).

Laznicka, P. (1983) Giant ore deposits, a quantitative approach. *Global Tectonics and Metallogeny,* **2** (1-2), 41-63.

Laznicka, P. (1989) Derivation of Giant Ore Deposits, ABSTRACT of 28th IGC, vol. 2 of 3: 268-269.

Laznicka, P. (1999) Quantitative relationships among giant deposits of metals, *Economic Geology*, **94**, 455-473.

Li, Y.J. and Chen, Y.C. (1998) New understanding on genesis of El Nino. *Chemical Industry and Mineral Resources*, **20**, 109-204. (in Chinese with English abstract)

Mei, Y.X., Zhu, Y.S. and Ye, J.H. (1997) Statistical characteristics of superlarge ore deposits in China. *Acta Geologica Sinica*, **18**, 358-366 (in Chinese with English abstract).

Naldrett, A.J. (1996) Ni-Cu-PGE deposits of the Noril'sk region and other world-class nickel sulfide deposits. Abstracts – Geological Society of Australia, **41**, 311.

Pei, R.F. (1993) New advance of geological historical evolution and ore-forming chronology of metallogenic province. *Mineral Deposits*, **12**, 265-266 (in Chinese).

Pei, R.F. (1997) Metallogenic province evolution and superlarge ore deposits. *Mineral Deposits*, **16**, 169-170 (in Chinese).

Pei, R.F. and Wu, L.S. (1990) Several basic problems on exploring superlarge deposits in China. *Mineral Deposits*, **9**, 287-289 (in Chinese).

Pei, R.F. and Xiong Q.Y. (1999) Metallogenic preferentiality and metallotect convergence of unique ore deposits in China. *Mineral Deposits*, **18**, 37-46 (in Chinese with English abstract).

Pei, R.F., Wu, L.S. and Xiong, Q.Y. (1997) Metallogenic preferentiality and exceptional metallotect convergence (site) of giant ore deposits. *Global Tectonics and Metallogeny*, **6** (2), 103-105.

Pei, R.F., Wu, L. S., Xiong, Q.Y., Xu, Z.G., Yang, Y.Q., Song, X.X., Mao, J.W., Wang, S.F., Huang, M.Z., Zheng, M.P., Qi, W., Lu, J.R., Rui, Z.Y., Bai, G., Tang, Z.L., Sun, H.T., Hu, X.W., Li, C.Y., Luo, J.L., Peng, C., Dai, Z.X., Wang, J.S., Liu, M.H. and Mei, Y.X. (1998) Metallogenic preferentiality and exceptional metallotect convergence of giant ore deposits, Geological Publishing House, Beijing, China, 262-284 and 312-323 (in China with English Abstract).

Pei R.F., Qiu X.P., Yin, B.C. and Xiong, Q.Y. (1999a) The explosive anomaly of ore-forming processes and super-accumulation of metals, *Mineral Deposits*, **18**, 333-340 (in Chinese with English Abstract).

Pei, R.F., Xiong, Q.Y. and Mei Y.X. (1999b) New advance of ore-forming chronology of metallogenic province----a case study of north margin of North China platform. *Earth Science Frontiers* (China University of Geosciences, Beijing), **6**, 325-334 (in Chinese with English abstract).

Ren, Z.Q. (1998) Accurate forecasting of causing of heavy rain falling process of the Yangtze River using "gravitational tide resonance", Abstract Volume of Annual Meeting of 50th Anniversary of the Chinese Science and Technology, 35 (in Chinese).

Robert, F. and Poulsen, K.H. (1997) World-class Archaen gold deposits in Canada; an overview. Australian Journal of Earth Sciences, **44**, 329-351.

Sangster, D.F. (1993) Evidence for, and implications of, a genetic relatioship between MVT and SEDEX zinc-lead deposits. Australasian Institute of Mining and Metallurgy, **7**, 85-94.

Tu, G.Z. (1989) On exploring and theoretical study of superlarge deposits. *Mineral Rock Geochemical Research*, **8**, 163-168 (in Chinese with English abstract).

Tu, G.Z. (1994) Recent progresses on the studies and searches for superlarge mineral deposits. Earth Science Frontiers (China University of Geosciences, Beijing), **1** (3 & 4), 45-53 (in Chinese with English abstract).

Tu, G.Z. (1995) Some problems pertaining to superlarge ore deposits of China. *Episodes*, **18**(1 & 2), 83-86.

Tu, G.Z. (1998) The unique nature in ore composition, Geological background and metallogenic mechanism of non-conventional superlarge ore deposits: A preliminary discussion, *Science in China* (series D), **41**, Supplement, 1-6.

Bulletin of the Geological Survey of Japan, Vol. 51, No.10, 2000

特大型鉱床概説

裴栄富・金沢康夫・王平安

要　旨

この総説では，「特大型鉱床」について解説する．特大型鉱床は，非常に大きな埋蔵鉱量を持つと同時に特別な鉱床形成過程を経てできたことを強調したい．これまで，この種の鉱床については，他にいろいろな名前，例えば，超大型鉱床，超巨大鉱床，ユニーク鉱床，巨型鉱床，世界級鉱床などで呼ばれてきた．しかしこれらはすべて同じものである．ここでは用語を統一するために，この種の鉱床に特大型鉱床という名称を提案する．

鉱床形成過程の観点から言うと，特大型鉱床は通常見られる鉱床形成条件の中で爆発的とも言える異常濃集によりできたことを強調したい．すなわち，大量の金属元素の供給源があったこと，鉱石形成に適した地質構造上の収れん場所があったこと，鉱石が極度に累積するための良好な物理化学条件が広範囲に持続したことが挙げられる．これらは，特に，鉱石元素，鉱床タイプ，鉱床形成時代，地質セッティングとの好ましい組み合わせに依存している．

特大型鉱床を認定するための埋蔵鉱量について考察して，17種のコモディティ（鉱物種）について，特大型鉱床たる埋蔵鉱量の基準値と世界の鉱床を列挙した．これら鉱床の巨視的分布を見ると，鉱床は，2つの巨大な造山帯，4つの安定地塊，及び前者2つの漸移帯に配列している．これらの位置は特別な鉱床生成・収れん条件により決定される．

爆発的濃集の規模を評価し，金属の極度の累積を証明するために次の解析を試みた：(1) いろいろな関連分野からの鉱床形成の年代決定，(2) 鉱床タイプについての地球規模の熱的イベントの解析，(3) 埋蔵鉱量と鉱床形成期間についてである．爆発的濃集の原因として，地質時代のある時期に地球規模的熱的イベントが発生し，それによって特大型鉱床が生成した可能性があることを提案する．それは，始生代の酸素過剰イベント，原生代－古生代の還元イベント，中生代－新生代の造山運動によるマグマイベントである．酸素過剰イベントに関係する縞状鉄鉱床を例として紹介する．