GENERAL CHARACTERISTICS OF SEDIMENTARY ROCK-HOSTED GOLD DEPOSITS

In order to describe Chinese Carlin-type gold deposits and to compare them with those in Nevada, a description of the known characteristics of these typical Carlin-type deposits is summarized below, on the basis of summaries of previous workers (see Hofstra, 1994; Peters and others, 1996; Arehart, 1996; Teal and Jackson, 1997).

Carlin-type gold deposits are deposits mainly hosted in sedimentary rocks. The ores typically have low gold concentrations but are present as large tonnage masses, so that large, low-cost open-pit mining methods are used to exploit them. These deposits commonly have 0.5 to 30 million ounces Au per deposit (Cox and Singer, 1992). Carlin-type deposits get their name from the first deposit discovered in 1960, the Carlin gold mine, near the town of Carlin, Nevada (Hausen and Kerr, 1968). Since then, gold reserves of over 80 million ounces Au have been discovered in north-central Nevada.

Carlin-type deposits also are known as sedimentary rock-hosted or carbonate-hosted, or disseminated gold deposits. The main ore minerals typically consist of disseminated sub–micron-sized gold and arsenic-rich pyrite, *in* variably silicified, argillized, and decalcified sedimentary rocks and other minor rock types (Tooker, 1985; Berger, 1986; Hofstra and others, 1990; Christensen, 1993, 1996; Peters, 1996; Arehart, 1996). Most common host rocks are thin-bedded, flaggy, mixed carbonate and silici-clastic rocks, although host rocks for many Nevada deposits also include skarn, mafic metavolcanic, and felsic intrusive rocks. Gold is hosted in all rock types; however, along the Carlin trend, 98 percent of all known gold occurrences are hosted within a 350–m-thick stratigraphic interval composed of para autochthonous Devonian and Silurian age carbonate rocks (see Armstrong and others, 1997).

Deposition of ore minerals was at moderate depths of at least 1 to 3 km and the deposits formed at pressures approaching 1 kbar, (Rytuba, 1985; Kuehn and Rose, 1985, 1995; Kuehn, 1989; Lamb and Cline, 1997). Mineralogy in the ore zones includes gold-bearing arsenopyrite, As-rich pyrite, pyrite, marcasite, stibnite, realgar, orpiment, cinnabar, thallium-sulfide minerals, rare silver-Sb-Hg and lead-Sb sulfosalt minerals, sphalerite, chalcopyrite, and galena. Barite, calcite and fine-grained quartz are common gangue minerals. Total sulfide mineral content in the ores ranges from less than 1 vol. percent to local massive accumulations of pyrite (Bagby and Berger, 1985; Percival and others, 1988; Berger and Bagby, 1991; Simon and others, 1997).

Physical characteristics of sedimentary rock-hosted gold deposits commonly depend on the nature of the host rock. In calcareous rocks, stratabound replacement and local brecciation is common. In non-reactive rocks, orebodies are made of millimeter-sized stockwork veinlets to meter-sized vitreous quartz veins and jasperoid. Stratabound jasperoid also is common at contacts between rock units and along other planar structures. Brecciated rocks of several different origins are very common in many of the deposits (see Peters and others, 1997). Ore-associated alteration types typically are decalcification and dolomitization of carbonate strata, as well as argillization and silicification. Silicified rocks are present as jasperoidal replacement, silica cementation, siliceous breccia bodies, or as open-cavity fillings of quartz veinlets. K–feldspar in the detrital sedimentary and igneous rocks alters to illite and kaolinite in the most intensely altered areas. Carbonaceous material typically is present and formed early, such that solid carbon arrived in a cryptocrystalline state before the gold, and consists of up to 0.1 to 3 vol. percent graphite plus some disordered carbon in many of the deposits.

Ore-controls may be considered at a number of different scales. Generally, regional-scale control in Nevada is defined by "trends" or linear zones (Roberts, 1960, 1966; Shawe and

Stewart, 1976; Bagby, 1989; Berger and Bagby, 1991; Shawe, 1991) that commonly are associated with tectonic windows, or associated structural highs, through regional-scale thrust faults in a region of tectonically over-thickened crust in the Great Basin. Local control of individual orebodies is associated with faults or folds or favorable stratigraphic horizons that are contained in and commonly parallel with the trends. An example of trend control is the northern Carlin trend, a 20–km-long by 8–km-wide zone of continuous gold mineralization, composed of at least 40 gold deposits that contain more than 70 million ounces of announced gold reserves. Gold mineralization there is concentrated along a series of NW- and NE-trending, medium- to low-angle, regional, Jurassic age shear zones, and NNW-trending, low-angle shear zones of post-Jurassic age. These structures represent part of a NW-SE strike-slip zone coincident with tectonic windows through the Roberts Mountains allochthon (Evans and Theodore, 1978; Peters, 1997 a, b and c).

Close spatial association exists between some sedimentary rock-hosted gold deposits and Mesozoic plutons (Silberman and others, 1974; Berger and Bonham, 1990; Margolis, 1997); closely related Tertiary intrusive rocks are relatively uncommon and are interpreted as post-ore in many of the large sedimentary rock-hosted gold-silver deposits. However, evidence from a regional perspective suggests that Carlin-type gold deposits may owe their origins to the initial Tertiary age extension of the Great Basin and its associated deeply circulating fluids (Seedorff, 1991; Ilchik and Barton, 1995; Gao, Z.B. and others, 1996; Hou, Z.L. and Guo, G.Y., 1996; Henry and Boden; 1997). Structures in Proterozoic basement rocks also may be important localizers of deposits and districts (Grauch, 1986; Grauch and Bankey, 1991; Grauch and others, 1995). Local control can be either typically structural (see Peters, 1996; Peters, 1997 a, b and c) or stratigraphic. Formations and even narrow stratigraphic intervals or zones in them are considered to be significant factors in localizing gold.

Generally, deep weathering of the deposits usually results in outcropping or sub-cropping mineralized rock, which involves some prominent outcrops of hematitic jasperoid. The geochemical signature is typically gold, silver with Au : Ag ratios generally greater than 1 (that is, silver is not of significant value), with arsenic, Sb, and Hg. Thallium is anomalously high in some deposits, but minor to absent in others. Tellurium and bismuth usually are absent to very low (Hill and others, 1986), but locally occur (see also Hitchborn and others, 1996). Base-metals usually are at background levels, but, locally in some deposits, such as Gold Quarry, base-metals attain concentrations in the thousands of parts per million in the upper parts of the deposits, although they do not contribute to the overall value of the deposit (Hausen and others, 1982; Rota, 1987).

Sedimentary rock-hosted gold deposits can be subdivided into a subclass of deposits, the distal-disseminated silver-gold deposits (Cox, 1992; Cox and Singer, 1992), which are directly attributable to fluids emanating from porphyry Cu systems (see Sillitoe, 1988; Sillitoe and Bonham, 1990). Ore-forming fluids responsible for most Carlin-type gold deposits do not show evidence for a relationship to porphyry-type systems (Seedorff, 1991), although some deposits (Twin Creeks, Getchell) may have been generated from fluids involving a significant magmatic component (Norman and others, 1996). Ilchik and Barton (1995) postulate the genesis of most of these deposits is associated with an amagmatic thermal process associated with middle Tertiary extension in the Basin and Range.

Distal disseminated silver-gold deposits contain silver and gold in stockworks of narrow quartz-sulfide veinlets and (or) iron oxide-stained fractures in sedimentary rock, and they contain lead, Zn, manganese, Cu, and bismuth, which suggests that they may be plutonic-related (Cox and Singer, 1992). In addition, stable-isotope studies indicate that the fluids involved in the generation of the silver-gold deposits in the northern part of the Battle Mountain Mining District include a significant magmatic component (Howe and others, 1995; Norman and others, 1996). Several deposits of this type show significant potassium metasomatism (Bloomstein and others, 1993), which is comparatively rare in most Carlin-type deposits. Distal-disseminated silver-gold deposits are present in or near mining districts that contain major porphyry-related skarn, replacement, and vein base-metal ores, such as the Battle Mountain mining district (Doebrich and Theodore, 1995, 1996; Doebrich and others, 1995).

Examples of distal disseminated subclass of sedimentary rock-hosted gold-silver deposits are the Lone Tree deposit (Bloomstein and others, 1993; and Norman and others, 1996), the Marigold deposits (Graney and others, 1991). Gold, arsenic, Sb, barium (as barite), and Hg are enriched, but silver is generally low. The Marigold deposits, as well as the Lone Tree deposit, are considered by Howe and Theodore (1993), and Howe and others (1995) to be distal-disseminated silver-gold deposits, partly on the basis of the apparently abundant magmatic components of the fluids responsible for their genesis, and partly on the basis of the geologic setting in which they occur (see also Doebrich and Theodore, 1995, 1996).

LOCATION OF SEDIMENTARY ROCK-HOSTED DEPOSITS

Besides the Great Basin of the United States, sedimentary rock-hosted gold deposits have been identified in the China, Australia, Dominican Republic, Spain, Russia (Liu, D.S. and others, 1994), Malaysia (Sillitoe and Bonham, 1990), Philippines (Mercado, and others, 1987), Yugoslavia, and Greece (Radtke and Dickson, 1976a). This section summarizes the location of these deposits in Nevada, US and in P.R. China.

Location of deposits in Nevada, the United States of America

After the Carlin gold mine was developed in 1960, similar gold deposits were found along the Carlin-trend and elsewhere in north-central Nevada (Thorman and Christensen, 1991). There are several hundred million ounces of known and inferred gold in the northern Great Basin, of which over half is contained in the Carlin-type deposits, most along the Carlin trend. About 114 (table 1) sedimentary rock-hosted deposits have been found in Nevada, US. Most of them are distributed along three mineralization trends: Carlin, Battle Mountain–Eureka, and Getchell trends (see fig. 5). There are at least 40 small to large gold deposits present along the Carlin trend. Since 1965, 660 t (21 million ounces) of Au has been produced from mines along the Carlin trend. In 1995, three companies with 8 mines have produced more than 100 t (3 million ounces) of Au (Christensen, 1996). Additional significant amounts of Au have been produced from the Getchell and Battle Mountain–Eureaka trends and other areas in Nevada.

Location of deposits in Dian-Qian-Gui, Qinling and Jidong areas, P.R. China

Chinese sedimentary rock-hosted gold deposits are distributed in two main areas in southwest and central China respectively (fig. 6), each of these two main clusters of deposits lies in several government Provinces (fig. 7). Most of the 114 Carlin-type gold deposit occurrences are in the form of mines or prospects (Li, Z.P., and Peters, 1996) in the Dian-Qian-Gui and Qinling areas. The known size distribution of these occurrences includes eighteen large, fifteen medium, and twenty two small deposits (table 2; fig. 8; appendix I-1). A few sedimentary rock-hosted gold deposits, such as the Greatwall deposit, were recently discovered in the Proterozoic Lengkou basin in the eastern Hebei Province, north China (fig. 6), although they are considered to be a new type gold deposit that differs from typical Carlin-type gold deposits (Qiu, Y.S. and Yang, W.S., 1997; appendix III). Other sedimentary rock-hosted gold deposits are scattered in the Guangdong, Hunan, Huabei, and Liaoning Provinces (Liao, J.L., 1987; Shi, X.Q., 1990; Cai, G.X, 1991; Liu, B.G. and Yeap, E.B., 1992; and Cheng, Q.M., and others, 1994).

Table 1. List of Carlin-type Gold Deposits in Nevada (MRDS, USGS)

Location	Large	Medium	Small	Unknown	Total
Carlin Trend	5	10	20	5	40
Battle Mountain	2	5	15	5	27
Getchell trend	3	4	5	5	17
Other	2	7	15	5	29
Total	**12**	**26**	**55**	**20**	**113**

Table 2. Size* and Location of Chinese Carlin-type Deposits

Location	Province	Large	Medium	Small	Unknown	Total
	Yunnan	1	1		3	5
Dian-Qian-Gui	Guizhou	3	2	8	16	29
	Guangxi	1	1	3	8	13
	Guangdong	1				1
	Shannxi	4	1	3	4	12
Qinling	Sichuan	4	3		6	13
	Gansu	1	5	4	12	22
	Hunan	1		1	4	6
	Huabei	1	2	3		6
Other	Laoning	1				1
	unknown				4	4
	Total	18	15	22	57	112

* Large: >20 tons Au (include extra large >50 tons Au)
Medium: 5 to 20 tons Au
Small: <5 tons Au
Unknown: not yet identified resource

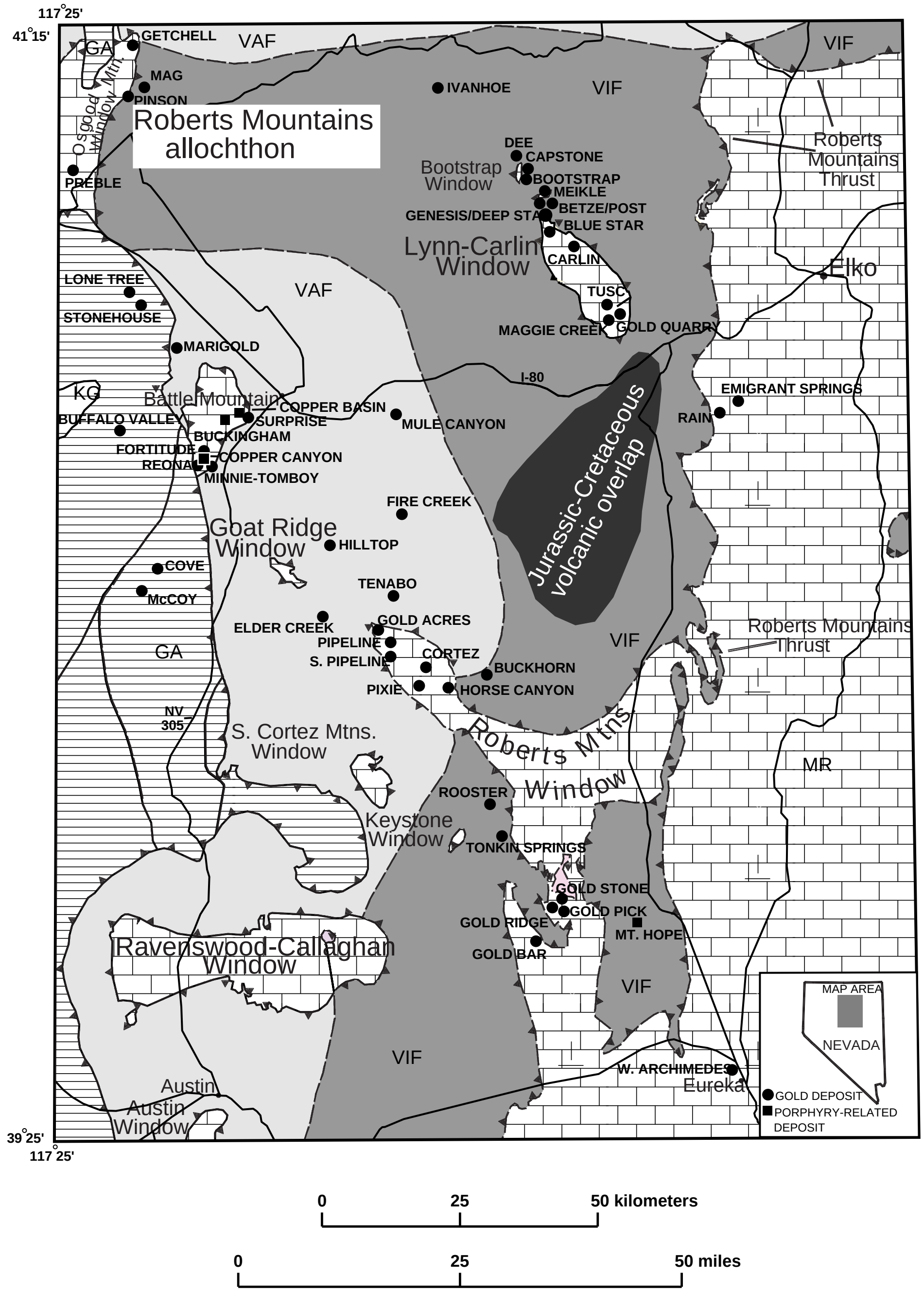

Figure 5. Gold deposits and tectonic units in north-central Nevada. The Carlin trend lies along the Carlin-Lynn window. Other windows through the Roberts Mountains allochthon also have associated gold deposits. Geologic units are designated by letters and shaded. VIF = Vinini Formation, VAF = Valmy Formation, GA = Golconda allochthon, MR = Miogeosynclinal (rocks of the lower-plate), KG = Koipato Group. Gold deposits are related to porphyry and gold-skarn deposits, and are also sedimentary rock-hosted (Carlin-type) gold deposits. Adapted from Prihar and others (1996) and Lahren and others (1995).

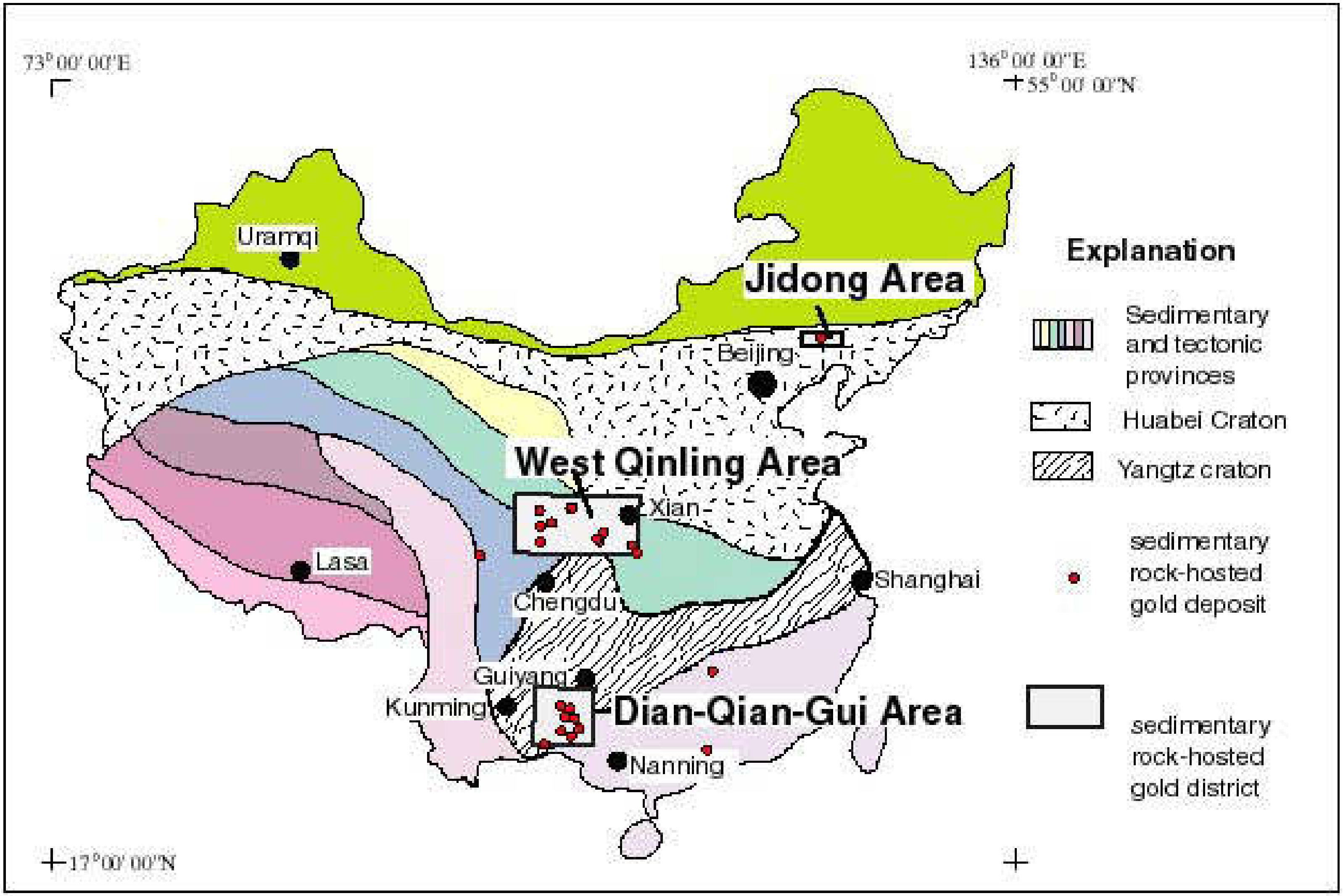

Figure 6. Location of Carlin-type gold deposits in China. The deposits are mainly in two areas: the Dian-Qian-Gui area in the south, at the southwestern margin of the Yangtz craton, and the Qinling area on the northern margin of the Yangtz craton. The Greatwall deposits, newly discovered, are in the Jidong area near Beijing. Major cities are noted with open circles, shaded areas represent Yangtz craton. Compiled from Li, D.S. (1994) and Wang, J. (1993).

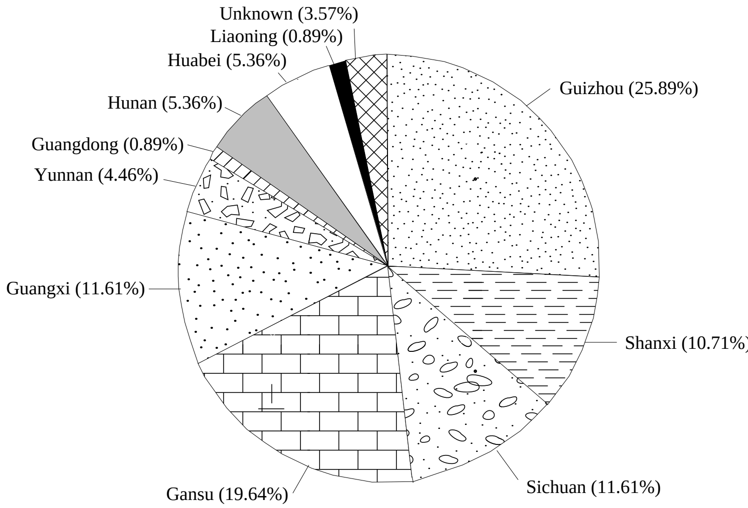

Figure 7. Distribution of Chinese Carlin-type gold deposits by Provinces

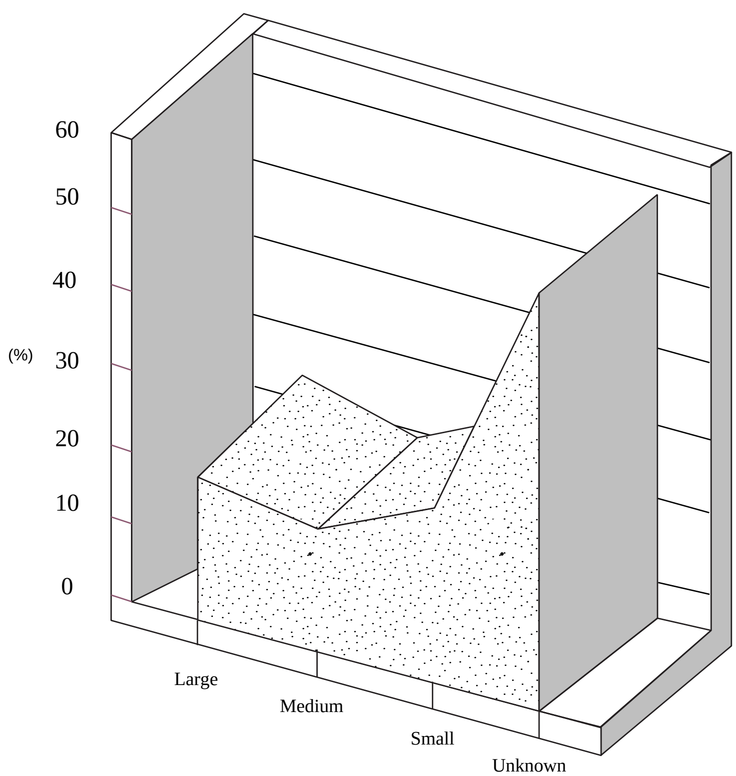

Figure 8. Diagram showing relative size of Chinese Carlin-type gold deposits. Small deposits contain less than 5 tons Au, medium deposit range between 5 and 20 tons; large deposits contain greater than 20 tons Au. (see appendix I).