GEOCHEMISTRY OF THE SEDIMENTARY ROCK-HOSTED GOLD DEPOSITS

Basic geochemical characteristics of sedimentary rock-hosted gold deposits, such as composition of host rock, and of ore, trace elemental assemblages, and fluid inclusion and isotope studies will be discussed in this section. The composition of the host rock and ore reflects the geological and geochemical environments of formation (see Dean and others, 1988). Certain elemental assemblages are characteristic of gold-bearing hydrothermal solutions. Fluid inclusion and isotope data give important parameters about the fluids that formed the deposits.

Composition of Host Rock and Ore

The host rock lithology of Chinese sedimentary rock-hosted gold deposits vary from one deposit to another, and their geochemical compositions also vary. Tan, Y.J. (1994) summarized the geochemical characteristics of host rock in the Dian-Qian-Gui area, partially mudstone, siltstone and argillaceous limestone (tables 14, 15 and 16, and figs. 47, 48 and 49). Generally, host rocks in the deposits are shelf facies sedimentary rocks in the northwest part of the area, with lower SiO_2, higher TiO_2 compositions, and Fe_2O_3+FeO, MgO/CaO ratios than those in abyssal facies in the southeast part.

The most simplified description for the characteristics of ore in Carlin-type gold deposit is "look like rock" or in Chinese "Xiang shi tou", because orebodies of this type of deposit were formed by replacement of the host rock by hydrothermal fluids and therefore there is no clear boundary between the orebody and the unmineralized host rock. Gold assays commonly are the only means to distinguish between rock and ore; therefore, a very important geochemical feature to identify mineralized area is the inheritance of minerals and geochemical components from the unmineralized host-rocks, because in most cases, the ores have similar petrologic oxides as the original protolith. Another common geochemical feature of ore in sedimentary rock-hosted gold deposits, both in Nevada and P.R. China, is the introduction of large amounts of SiO_2 from ore-forming fluids that accompany gold mineralization. In addition, CaO and MgO in the host rocks are dissolved and removed by hydrothermal fluids. At the Carlin mine, about 40 vol. percent loss may have occurred in the Roberts Mountain Formation due to dissolution of carbonate (Bakken, 1990a, b). Vol. percent of CO_3 drops from 30 percent to less than 1 percent (Leonardson and Rahn, 1996). Some of the high SiO_2 contents may be due to residual quartz rather than new SiO_2 introduction (Madeisky, 1996). Similarly, the siliceous carbonate ore in the Changkeng deposit only contains between 20.80 and 22.47 wt. percent CaO, and more than half of the carbonate minerals in the altered limestone have been leached out during decalcification (Du, J.E. and Ma, C.K., 1994).

Similar geochemical classification of ore types is used both in Nevada and in P.R. China (see Radtke, 1985; Tan, Y.J., 1994). The common ore types are siliceous, pyritic, arsenic, and oxidized ore. Normal ores are composed of dolomite, illite, quartz, and carbonaceous materials (with organic carbon content ranging from 1 to 6 wt. percent) as documented in the Carlin mine, Nevada by Radtke (1985) and in the Betze deposit, Nevada, by Peters (1996). These ores also are present in the Chinese deposits, and in addition, argillaceous and carbonate ore also are recognized in the Dian-Qian-Gui area, P.R. China. The geochemical chemical compositions of five types of ore from Carlin-type deposits in Dian-Qian-Gui area are shown in table 17. And also, 18 ores (rocks) sample assays, which were taken from five Chinese sedimentary rock-hosted gold deposits by the authors in August of 1997, are shown in table 18.

Elemental Assemblages in Ore

Sedimentary rock-hosted gold deposits have characteristic elemental assemblages that

Table 14. Analysis of argillaceous limestone (host-rock) in the Carlin-type gold deposits, Dian-Qian-Gui area, P.R. China (in wt. percent) (After Tan, Y.J., 1994)

SiO_2	TiO_2	Al_2O_3	T Fe	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Au*
30.43	0.16	3.07	2.24	0.10	1.39	15.01	0.02	0.68	0.28	2.13
30.58	0.57	10.11	7.39	0.12	5.37	32.18	0.08	1.78		2.44

* Au ppm

Table 15. Chemical Composition of Argillite (host-rock) in Carlin-type Gold Deposits, Dian-Qian-Gui area, P. R. China (in wt. percent) (From Tan, Y.J., 1994)

Oxide	**Gedang**	**Maxong**	**Getang**	**Dachang**	**Zimudang**	**Yata**	**Gaolong**	**Banqi**	**Jinyia**
SiO_2	59.08	43.2	48.87	57.52	43.13	62.74	62.62	52.5	58.12
TiO_2	0.95	0.78	2.46	4.13	2.34	0.68	0.56	-	0.59
Al_2O_3	15.67	21.28	16.76	16.38	15.14	16.58	17.86	16.52	15.23
T Fe	7.37	9.46	12.63	8.72	12.94	5.57	4.86	5.68	6.5
MnO	0.12	0.09	0.06	-	0.11	0.05	0.02	-	0.1
CaO	0.06	2.84	0.47	0.42	1.89	2.89	0.61	5.05	3.72
MgO	2.08	3.28	0.21	0.56	2.76	1.33	0.53	1.78	1.92
Na_2O	0.22	0.09	0.76	0.05	0.1	0.26	0.38	0.78	0.46
K_2O	4.6	6.7	1.45	4.55	3.28	3.55	3.89	4.24	2.56
P_2O_5	0.14	0.16	0.18	0.35	0.23	0.21	0.08	-	0.46
LOI	2.68	10.9	15.7	6.59	13.45	6.64	7.49	11.83	8.89
Au*	0.02	0.93	0.077	-	3.29	7.155	2.369	6.8	5.85

* Au ppm, - no data available

Table 16. Chemical Composition of Siltstone (host rock) in Carlin-type Gold Deposits, Dian-Qian-Gui Area, China (in wt. percent) (From Tan, Y.J., 1994)

Oxide	Gedang	Maxong	Zheyi	Longchang	Getang	Zimodang	Banqi	Yata	Lannigou	Jinyia
SiO_2	67.11	67.45	69.44	67.95	66.03	53.20	73.47	65.94	68.80	59.63
TiO_2	0.78	0.33	1.64	3.12	1.87	1.09	0.54	0.46	0.24	0.46
Al_2O_3	12.07	8.72	12.51	8.54	6.87	6.79	10.89	10.90	6.40	11.12
Fe_2O_3	8.87	7.84	6.51	9.42	15.24	5.17	6.15	5.40	2.46	4.28
FeO	0.73	0.43	1.13	0.65	0.92	1.15	0.97	1.45	5.24	2.66
MnO	0.04	0.35	0.11	0.041	0.044	0.10	0.05	0.14	0.195	0.11
CaO	0.27	1.92	0.13	0.17	0.23	14.54	0.44	2.08	2.78	6.0
MgO	0.74	1.52	0.68	0.21	0.19	0.86	0.32	1.25	1.46	1.70
Na_2O	0.14	0.052	0.10	0.058	0.32	0.012	0.05	0.19	0.38	0.75
K_2O	3.57	2.74	3.30	0.94	0.40	1.66	1.39	2.26	1.70	1.42
P_2O_5	0.31	0.28	0.10	0.274	0.134	0.38	1.03	0.090	0.15	0.43
LOI	-	8.74	3.93	6.70	6.78	14.13	4.40	8.50	9.01	3.025
Au*	4.71	1.68	0.021	1.080	1.94	5.18	4.42	3.486	7.47	0.174

* ppm

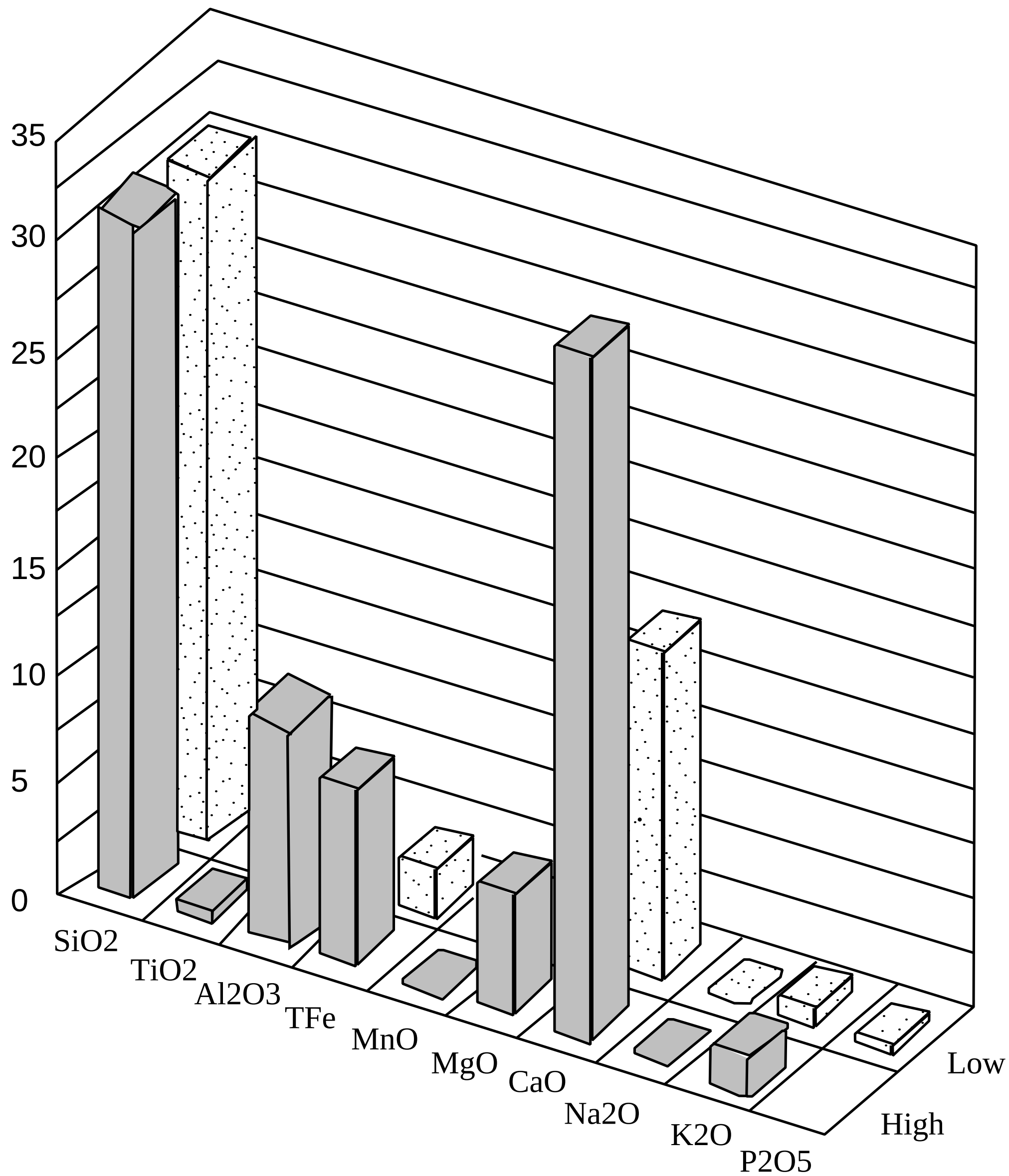

Figure 47. Analysis of argillaceous limestone in host rock of Chinese gold deposits, which are present in Dian-Qian-Gui area, Low and High means the arrangement of oxides contents.

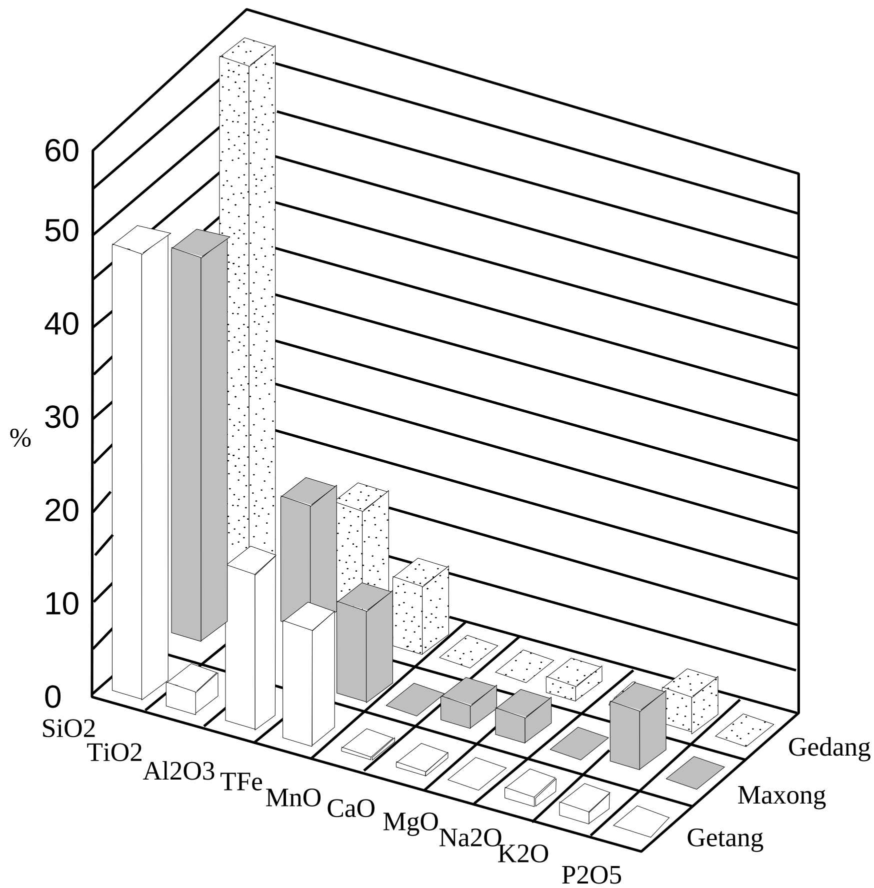

Figure 48. Analysis of argillite in host rock of Chinese gold deposits, which are presented in Dian-Qian-Gui area, showing oxide content of argillite in the Gedang, Maxong and Getang gold deposits.

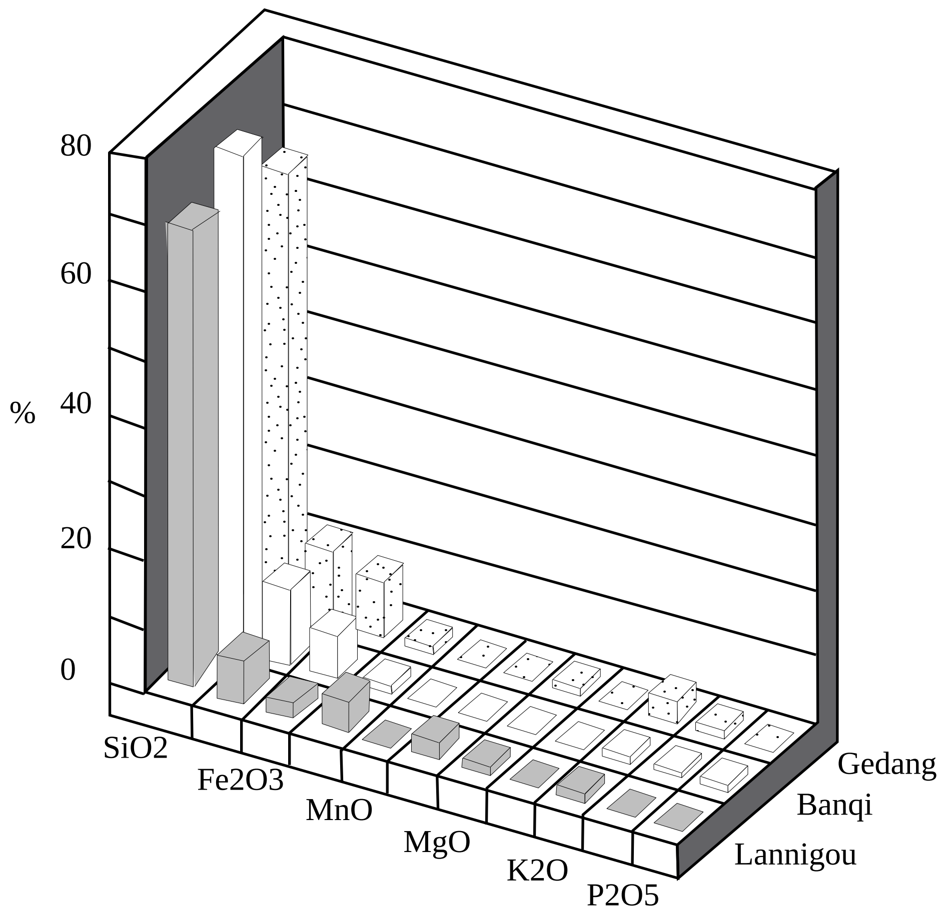

Figure 49. Analysis of siltstone in host rock of Chinese gold deposits, which are presented in Dian-Qian-Gui, showing oxide content of siltstone on figure in the Gedang, Banqi and Lannigou gold deposits.

Table 17. Chemical Composition of Five Types of Ore in Carlin-type Gold Deposits, Dian-Qian-Gui area, P.R. China (From Tan, Y.J., 1994)

Oxide (%)	**siliceous**	**clay**	**pyrite**	**arsenic**	**carbonate**
SiO_2	83.49	57.92	63.5	61.95	33.28
TiO_2	0.35	1.1157.92	0.84	0.59	0.32
Al_2O_3	5.77	14.38	9.67	13.3	8.45
T Fe	3.62	6.97	14.17	7.14	6.76
MnO	0.07	0.07	0.06	0.09	0.11
MgO	0.47	1.81	0.74	1.19	3.28
CaO	0.75	1.59	0.98	3.23	18.11
Na_2O	0.13	0.36	0.22	0.21	0.05
K_2O	1.39	3.9	1.83	2.94	1.77
P_2O_5	0.47	0.39	0.22	0.37	0.28
H_2O	1.65	3.63	-	-	1.32
S	1.42	2.04	-	-	-
Au (ppm)	8.84	8.81	6.86	6.1	2.29
As (ppm)	1525.2	1415.4	1262	4914.9	-
Sb (ppm)	-	31.9	-	-	-
Hg (ppm)	-	4.8	-	-	-
LOI (%)	-	-	-	-	26.16

\- No data available

reflect the mineral association found in the ores. These element assemblages vary from one deposit to another, but usually contain several common elements. For instance, there is a general association of certain trace elements in most Carlin-type gold deposits. As shown in table 18, Au, Ag, As, Sb, Hg in the ores (rocks) of the Chinese deposits are much higher than their average value in the regional rocks and the Clark value of the crust; while Cu, Pb, Zn and other base-metals are lower in the deposits than their Clark value in regional and the crust. A typical geochemical characteristic of sedimentary rock-hosted gold deposits is a low Au : Ag ratio. A ratio of between 9.2 to 66.9 in the Lannigou deposit may reflect common local variations in the amount of Ag there and is not uncommon in these deposits. The following paragraphs discuss several typical geochemical characteristics of these deposits.

High Au : Ag. ratios are an important geochemical feature of Carlin-type gold deposits (table 19). Ag and base-metals such as Cu, Pb, and Zn are rare; however, exceptions have been observed both in Nevada and P.R. China (Rota and Ekburg, 1988; Du, J.E. and Ma, C.K., 1994). The distal-disseminated class of Ag-Au deposits, discussed earlier as related to porphyry systems, have higher amounts of Ag and base-metals. The average Ag content is usually less than 1 ppm in most Carlin-type gold deposits of Nevada, but the Gold Quarry deposit has ore that contains Ag values up to 80 ppm (Rota and Ekburg, 1988). High Ag values and Ag minerals also are noted in late-stage isolated polymetallic breccia bodies in the Betze orebody, Nevada (Peters and others, 1997; Ferdock and others, 1997). In the Changkeng gold deposit, P.R. China, there are two gold orebodies and three silver orebodies that occur separately along the same brecciated NE-trending fault zone (Du, J.E. and Ma, C.K. 1994). These orebodies do not overlap or enclose each other. In vertical section, the gold orebodies are located at the top and the silver orebodies are present at the bottom of a fault zone. The gold orebodies in the Changkeng deposit contain high As, Sb, Bi, Hg, Ba, and S contents; in particular, the values of As, Bi, and Hg are one to two times higher than in those in the silver orebodies. The silver orebodies contain one to two times more Zn, Pb, and Cu relative to gold orebodies. The Au : Ag. ratio is 1/0.8 in gold orebodies, and 1/644 in silver orebodies.

As is the most common trace element associated with gold mineralization in most sedimentary rock-hosted gold deposits. It is usually present in pyrite as isomorphism, as growth rims, and also occurs in independent minerals such as arsenopyrite, realgar, orpiment, or as native As. The content of As in the Carlin Mine ores ranges from 400 to 500 ppm, with a maximum value of 2.5 wt. percent (Togashi, 1992). In some Chinese sedimentary rock-hosted gold deposits, As has been enriched up to an economic level, such as at the Jinyia deposit (As: 0.44 to 1.89 wt. percent), and the Pingding deposit (As: 3.99 to 15 wt. percent) (Liu, D.S. and others, 1994).

Sb is a principle associated trace element in most Carlin-type gold deposits, both in Nevada and P.R. China. Sb is concentrated both in unoxidized and oxidized ores at levels of 100 ppm in the Carlin mine (Radtke, 1985; Kuehn, 1989). A distinct zoning of minerals and geochemistry (fig. 50) was observed in the Betze orebodies of Goldstrike Mine, Nevada (Peters, 1997c), where Sb is present in siliceous breccia as stibnite in fracture coatings and vug fillings with late quartz veinlets along with calcite, sphalerite, and barite. This siliceous stibnite-bearing breccia ore is located at the core of the orebody and is one of the late stage events. In P.R. China, Sb prospects have played an important role in the history of exploration of Carlin-type gold deposits. For example, the Banqi gold deposit was found in 1978 by investigation of an Sb prospect. Afterward, a group of gold prospects associated with Sb, As, and Hg were discovered surrounding the Banqi deposit. Then, the Getang, Zimudang, Xongwu, and Ceyang sedimentary rock-hosted gold deposits also were found in the Dian-Qian-Gui area (appendix I) (Mai, C.R., 1989).

Hg also has a positive correlation with Au and in most Carlin-type gold deposits.

Unoxidized ores in the Carlin Mine contain an average of 20 ppm Hg, with Hg values up to 280 ppm in As-rich ores (Togashi, 1992). Ore minerals containing Hg, Zn, Cu, Ag, and other base-metals have been identified as late-stage components of the Betze orebody, Nevada (Ferdock and others, 1997; Peters and others, 1997). Similarly, most Hg-rich Chinese Carlin-type gold deposits are present in or near zones of economic Hg mineralization (Liu, D.S. and Geng, W.H., 1987). For example, the Sando-Danzhai Hg mineralized zone (Huang, G.S. and Du, Y.Y., 1993), located in the southern Guizhou Province, is 50 km long, elongated NS, and 7 km wide in an EW direction, and occurs in Cambrian silty and argillaceous limestone. There are 3 large, 1 medium and 11 small Hg deposits in this zone. Recently, this Hg zone was confirmed to be a Carlin-type gold mineralization zone, *in* which 1 medium and 6 small Chinese sedimentary rock-hosted gold deposits (prospects) were discovered since 1978. Some of them, such as the Sixiangchang and Miaolong deposits (appendix I), were old Hg mines. Another typical example, the Sixiangchang deposit—a new Carlin-type gold deposit composed of 13 gold orebodies (not all shown on fig. 51) with 7.19 ppm average Au was discovered in the Sixiangchang (fig. 51)—was a large old Hg deposit, and has been developed by mining to a depth of 500 m (Huang, G.S. and Du, Y.Y., 1993. Another Au (As)-Hg-(Sb) mineralized zone (Li, Y.D. and Li, Y.T., 1994), which extends from Nima (Maqu County, Gansu Province) to Manaoke (Nanping County, Sichuan Province) in the Qinling area, occurs in Permian and Triassic carbonate and clastic rocks. The host rocks are silty slate, *in*terbedded dolomitic limestone, and diorite dikes. Some Hg-bearing sedimentary rock-hosted gold deposits occur in this zone, such as Manaoke (Nanping county), Shijiba (Wenxian county), and Geerzhongqu (Maqu county). Gold prospects associated with Hg also are found at Baxi, Tuanjie, Qilicun and Jiawuchi (Sichuan province), as well as the Nima Hg (As) prospect. The Laerma to Pingding sedimentary rock-hosted gold trend in the Qinling area overlaps an extensive Hg-Sb-U province, and Hg is enriched up to economic levels (0.01 wt. percent) in the Laerma gold deposit (table 20).

Tl is a common trace element in many Carlin-type gold deposits in Nevada; at the Carlin Mine, the ore contains between 40 to 50 ppm Tl in most unoxidized ores, about 150 ppm in arsenic ores, and 3 ppm in unaltered rock (Togashi, 1992). The Zimudang deposit, P.R. China is reported as a Au-Hg-Tl Carlin-type gold deposit, and an unidentified red thallium mineral was found in the Lanmuchang deposit near the Zimudang deposit. The Lannigou mineralization contains a Au-As-Tl-Cr-Cu element assemblage, and the Shuangwang deposit also contains elevated concentrations of Tl, Li, Ti, Ba, Sn, V, and Cr.

Ba is usually present as barite, a very common mineral in alteration or late stage barite-calcite veins. It is associated with many sedimentary rock-hosted gold deposits both in Nevada and in P.R. China. However, it does not positively correlate with gold. In the Rain Mine barite ore with a barite content in excess of 40 vol. percent is common (Thoreson, 1990). In the Laerma gold deposit barite together with quartz is found in veinlets and veins, which lie in alteration zones on the flanks of orebodies (Li, Y.D and Li, Y.T., 1994). Gray to gray-white quartz-barite veins contain 0.39 to 2.46 ppm gold. Generally, baritization in Chinese deposits is less than that found in Nevada deposits.

U is an associated element in some Chinese Carlin-type gold deposits in the Qinling area. Uranium and REE minerals are reported by Peters (1996), and Peters and others (1997) in the Betze deposit, Nevada as detrital grains in localized layers of the host rock and also associated with the contacted zone of the Goldstrike diorite stock. These are not considered part of the ore sequence. The Laerma deposit is the typical gold deposit with enriched U. In this deposit, the host rock consists of carbonaceous siliceous slate, silici-clastic rock and carbonaceous silty slate and contains between 5.19 and 15.50 ppm U. The U

Table 18. Assay of ore and rocks in Chinese sedimentary rock-hosted gold deposits (in ppm)

DEPOSIT	LAB	USML	USML	USML	USML	USML	USML	USML	USML	USML	ACME	USML	USML	USML
	Sample No.	**Au**	**Ag**	**As**	**Sb**	**Hg**	**Cu**	**Pb**	**Zn**	**Mo**	**Ba**	**Se**	**Te**	**Tl**
Qinglong	SP97901	0	0.042	95.9	101	0.023	1.4	7.28	10.4	0.332	10	0.169	0.259	0.596
	SP97902	0.0004	0.116	145	156	0.014	2	10.7	12.1	0.973	9	0.257	0.268	0.402
	SP97903	0.0002	0.07	248	2.46	2.83	31.1	2.48	40.2	0.355	19	0.107	0.223	0.424
Zimudang	SP97904	0	0.066	281	3.83	4.82	14.5	2.2	42.3	0.541	36	0.017	0.249	0.577
	SP97905	1.16	0.082	170	4.76	0.693	5.89	0.861	7.21	2.43	10	0.04	0.204	0.612
	SP97906	2.49	0.272	2883	29.8	48.4	15.1	17	56.1	4.38	147	0.59	0.318	0.933
Lannigou	SP97907	3.92	0.253	2224	7.32	8.63	26.2	10.2	39.5	4.52	117	0.609	0.333	0.954
	SP97908	30.5	0.456	5819	23.3	19.4	48.5	11.1	94.6	4.47	146	1.73	0.53	1.31
	SP97909	16.9	0.267	4749	9.3	18	53.5	6.98	45.9	5.52	104	2	0.586	0.812
	SP97910	0.001	0.1	1898	11.7	0.43	28.1	8.78	30.4	2.37	391	0.897	0.173	1.23
	SP97911	0.052	0.49	85.1	80.3	1.01	16.2	2.33	47.6	8.94	91	0.25	0.253	2.72
Gaolong	SP97912	0.064	0.228	37.3	32.8	1.31	5.51	1.51	15.3	6.86	99	0.193	0.22	0.758
	SP97913	0	0.091	340	14.7	0.271	21.1	7.5	79.9	1.95	321	0.178	0.312	0.673
	SP97914	0.0004	0.137	408	28.6	0.285	22.6	7.97	89.6	1.32	343	0.266	0.213	0.909
	SP97915	1.92	5.14	1259	9634	15.5	17.3	928	6.75	4.55	379	57.4	0	17
Hengxian	SP97916	4.8	44.6	468	9690	28.1	136	14.2	9.15	12.1	1144	39.5	0.419	5.52
	SP97917	0.308	21.2	79.7	9823	13.5	13.4	43.4	1.06	1.45	4	54.9	22.6	27.7
	SP97918	0.718	6.73	70.1	9690	8.91	59.3	45.8	0.739	1.74	5	63.2	20	26.5
Ave. value	in Rocks[1]	0.0025	0.11*	12*	-	0.15	112	32*	117	0.75	-	-	-	-
Clarke value	of the Crust[2]	0.0043	0.070	1.7	0.50	0.083	47.0	32.0	83.0	-	650	-	-	-

1-The average value of elements in rocks in the southwest or whole of the Guizhou province (*) according to He, L.X. and others (1993).
2-Clarke value of elements in the Crust according to Vinogradov (1962).

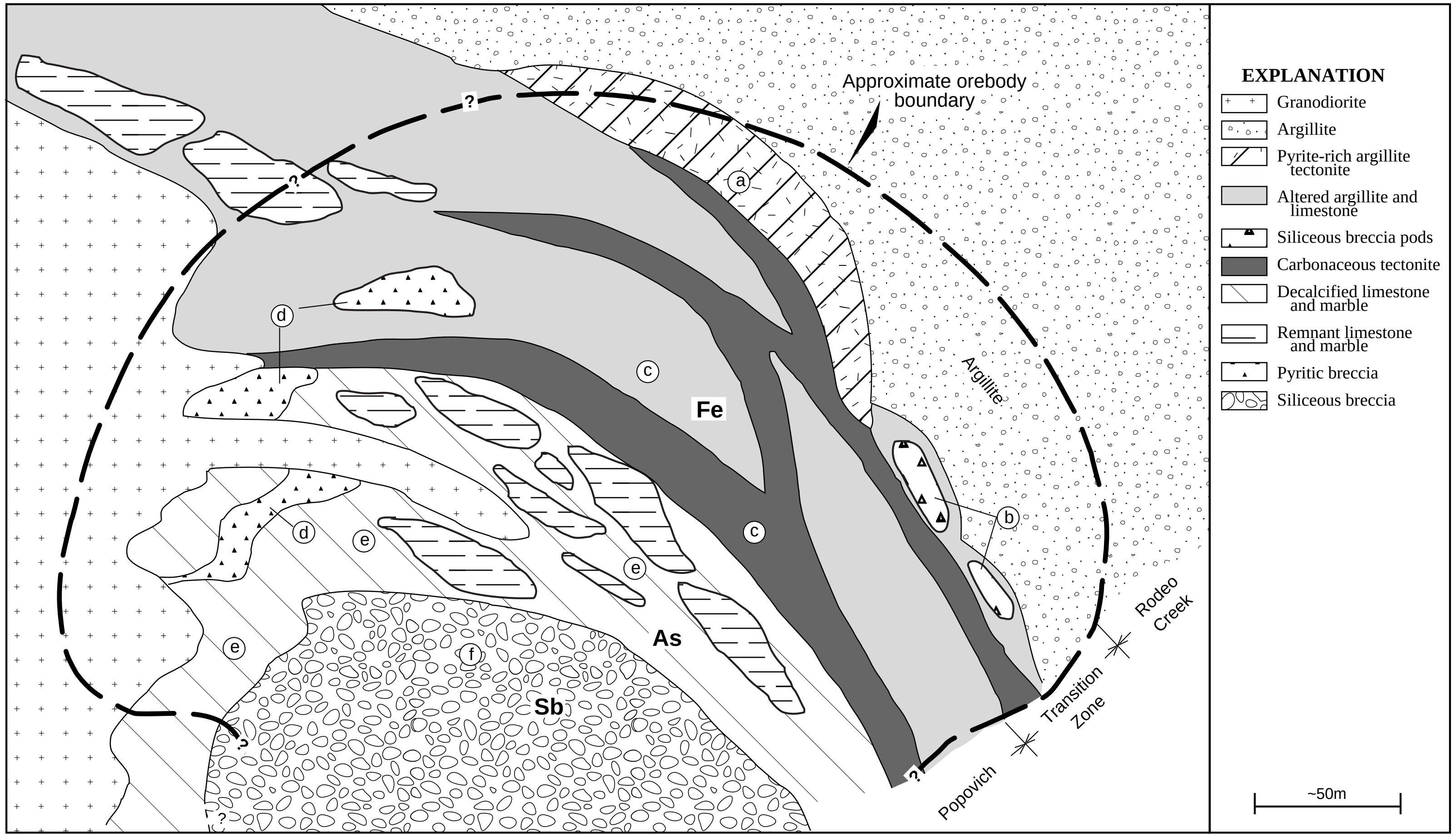

Figure 50. Idealized sketch of a cross section through the central Betze orebody, looking WNW. General zoning in the orebody is Illite-clay pyrite, Fe-rich ores on the top, realgar- and orpiment-rich As-rich ores in the central parts, and Sb- and Ba-rich siliceous ores at the bottom. The oreshoots are characterized by higher metal content than the adjacent parts of the host conduit. The mass of most oreshoots ranges between 2 x 104 and 1 x 106 tonnes and grades are generally 0.1 oz/t Au. There is a tendency for oreshoots to have a heterogeneous grade distribution, such that they are thicker and richer in the center or in a lobe along one side. Oreshoots in the Betze orebody may terminate abruptly, usually at geologic features, or may taper in thickness or grade to assay cut-offs. A characteristic feature of many oreshoots is their unique internal geologic complexity and mineralogy that reflect episodes of formation. Six distinct ore types are recognized by Peters (1996, 1997c) and by Leonardson and Rahn (1996) designated by letter as: (a) cataclastic and sulfidic breccia ore; (b) siliceous, sulfidic breccia pods in argillite; (c) disseminated, carbonaceous ore; (d) sulfidic breccia pods; (e) seam ore; and (f) siliceous stibnite-bearing breccia.

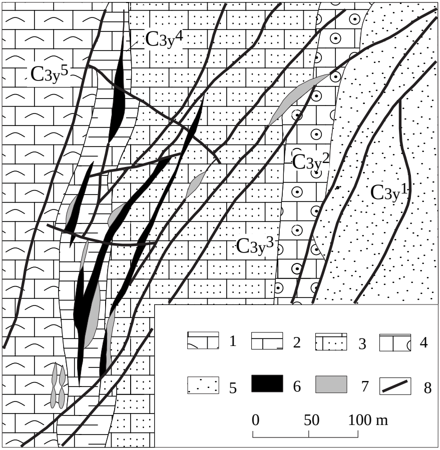

Figure 51. Geological plan of 405 m level of the Sixiangchang Hg-Au deposit. Gold and mercury orebodies are controlled by the same faults in this deposit. 1-micritic limestone, argillaceous siltstone; 2-thick limestone; 3- micritic limestone, argillaceous siltstone; 4-thick limestone, strip micritic limestone and argillaceous siltstone; 5- micritic limestone, argillaceous siltstone; 6-Au orebody; 7-Hg orebody; 8-fault. Adapted from Huang, G.S. (1993). Approximate location of figure is 107^0 51' 00'' E; 26^0 00' 00'' N.

Table 19. Au, Ag Content and Au / Ag ratio of Chinese Carlin-type Gold Deposits (After Liu, D.S., 1994)

Deposit Name	**Au**			**Ag (average)**	**Au/Ag**	**Number. Of samples**
	low	**high**	**average**			
Dongbeizhai	-	5.2	3.78	0.15	25.2	-
Qiulou	2.78	16.21	-	1.00	3-17	-
Laerma	2.87	14.62	3.92	2.34	1.68	-
Jiuyuan	-	40.0	8.81	3.03	2.91	-
Liba	-	22.0	4.2	2.19	1.92	31
Baguamiao	-	14.59	5.85	1.00	5.85	7
Shuangwang	-	17.10	3.30	0.18	18.33	-
Zimodang	1.05	5.18	2.72	<0.09	>30	7
Lannigou	-	13.82	5.80	0.68	8.53	-
Banqi	1.25	18.0	8.92	<0.5	>18	8
Yata	1.27	15.83	4.52	<0.66	>6.85	9
Gedang	2.15	7.14	3.96	0.22	18.0	9
Jinyia	1.55	7.20	4.38	0.46	9.52	2
Gaolong	1.68	16.78	5.82	1.71	3.4	15
Maxong	1.15	4.30	2.05	<0.28	>7	5
Changkeng	-	-	8.32	6.49	1.28	-

1 Not available

Table 20. Elemental Assemblage of Chinese Carlin-type Gold Deposits

Deposit Name	Element assemblage	Product	By product
Jinyia	Au-Ag-Cu-Pb-Zn-Sb-S-As	Au	As
Lannigou	Au-As-Tl-Cr-Cu	Au	
Laerma	Au-Hg-Sb-Mo-Y-U(Cu-Zn-Ni)(Pt-Os-Pd)	Au	Hg (0.01%)
Shuangwang	Mn-S-Te-Au-Se-Ag (Pt-Pd)	Au	
Banqi	Au-As-Sb-Ag-Hg	Au	
Getang	Au-As-Sb-Hg-F-Mo	Au	As 3.99-15% S>4%
Changkeng	As-Bi-Hg (in gold orebodies)	Au	
	Zn-Pb-Cu (in silver orebodies)	Ag	
Baguamiao	Au-Ag-As-Sb-Bi-Pb	Au	

content of altered rocks ranges from 16.86 to 53.33 ppm, and the average U content in ore is 28.41 ppm U (Li, Y.D. and Li, Y.T., 1994). Some independent economic grade U deposits were formed near the sedimentary rock-hosted gold deposits in this area.

Pt group elements, *in*cluding *Os* and *Pd* are enriched in several Chinese sedimentary rock-hosted gold deposits, *in*cluding the Laerma and Shuangwang deposits. In the Laerma gold deposit, analysis of 20 samples of carbonaceous siltstone, contained 0.02 to 0.022 ppm Pt, 0.001 to 0.005 ppm (highest 10 ppm) Os, and 0.001 to 0.024 ppm Pd. A few small orebodies rich in Pt group elements also have been found. In the Shuangwang gold deposit, electron microprobe analysis of pyrite and ankerite grains show a Pt value of 2.66 wt. percent and a Pd value of 0.34 wt. percent.

In general, Au, As, Sb, and Hg make up the typical elemental assemblage in both Nevada and Chinese sedimentary rock-hosted gold deposits (Radtke, 1985; Hill and others, 1986; Togashi, 1992; Tu, G.Z., 1992; Liu, D.S. and others, 1994). Among seven gold deposits along the Carlin-trend, high As is associated with six, Sb and Hg with four, Zn and Ba with three, and Ag, Tl, Pb with two (Jones, 1989). Trace element assemblages of Chinese Carlin-type gold deposits are shown in table 20, and clearly As, Sb and Hg are closely associated with Au in most deposits. Tl and Ba also are present in many sedimentary rock-hosted gold deposits. Ag, Cu, Pb, Zn, Bi, and Mo are generally present but in low concentrations, however they are associated elements in some Carlin-type deposits. U is enriched in the Laerma, Pingding and nearby deposits in the Qinling area, P.R. China. Pt group elements also may be enriched up to ore levels in some Chinese Carlin-type gold deposits.

Fluid and Isotope Characteristics

Fluid inclusions and stable isotopes from sedimentary rock-hosted gold deposits have been studied in Nevada and P.R. China (Lu, H.Z., 1988; Li, W.K. and others, 1989; Hofstra and others, 1991a, b; Bagby and Cline, 1991; Zheng, M.H. and others, 1991; Lu, G.Q. and others, 1992; He, L.X. and others, 1993; Liu, D.S. and others, 1994; Cline and others, 1996; He, M.Y., 1996; Hofstra, 1997). Although fluid inclusion and isotope data vary from one deposit to another, an epithermal to mesothermal hydrothermal model is suggested for most Carlin-type gold deposits.

The fluid inclusion data on Carlin-type gold deposits in Nevada indicates that main-stage ore-formation occurred between 200 and 250 °C, at pressures between 400 and 800 bars. Boiling in genetically associated fluids is not documented by many fluid-inclusion studies (Hofstra and others, 1991a, b; Lamb and Cline, 1997). In P.R. China, the formation temperature for these deposits varies from between 165 and 290 °C, and from 52 to 560 bars. Depths of formation calculations are between 300 and 1,500 m, *in*dicating upper-epithermal to mesothermal conditions for these deposits (Liu, D.S. and others, 1994). Similarly, He, L.X. and others (1993) suggested a medium formation temperature of 170 °C with a range from 160 to 200 °C for Carlin-type gold deposits in southwest Guizhou Province on the basis of the homogeneous temperature data of fluid inclusions from late-stage Hg-Sb mineralization. In the same study they considered the deposits in Guizhou Province to have formed at least 1,000 m below surface, because there are not any boiling fluid inclusions found in these deposits. Fluid inclusion analysis has proven to be only a partially successful tool in Carlin-type gold deposits because of the fine-grained nature or scarcity of the inclusions.

Stable isotope data from sedimentary rock-hosted gold deposits show a wide range, and vary from one deposit to another. In Nevada, there is a wide range of $d^{34}S$, from –5 to +20 per mil, *in* gold-associated minerals see Radtke, 1985). Hydrothermal fluids are considered to be dilute (between approximately 0.5 to 10 wt. percent NaCl equivalent) and are dominantly from fluids with isotopic signatures similar to evolved meteoric water (Hofstra and others, 1991a, b; Hofstra, 1997), except at Getchell and Twin Creeks (Cline and others, 1996) where either magmatic or metamorphic water also is suggested by D and O isotope signatures. Fluid characteristics in Carlin-type deposits suggest an environment below the epithermal zone but the fluid source and the source of the gold is still equivocal.

In P.R. China, Zheng, M.H. and others (1991) conducted systematic isotopic research on the Dongbeizhai gold deposit, Qinling area, using S, H, O, C, Pb, and Rb-Sr stable isotopes, and concluded that the ore-formation fluids were mainly derived from meteoric water; the sulfur was derived from the host rock; carbonate-bearing sedimentary units are the main source of many metallic elements (see Wang, X.C. 1996). Isotope data from some Carlin-type gold deposits in Dian-Qian-Gui area are shown in table 21, and parts of the H and O isotopic data of these gold deposits are summarized in figure 52. The plotted isotope data form complex fields, and suggests that there may have been several possible fluid sources, *in*cluding hydrothermal fluids arising from the deep crust or from distal magmatic bodies. The field of D and O isotopes in the Chinese deposits has some similarities with those in the Getchell trend, Nevada (see fig. 52, table 21, and Cline and others, 1996). As a supplementary isotopic research method, Li, Z.H. and others (1994) analyzed the Co, Ni, and As content of pyrite from the Jinyia deposit, Dian-Qian-Gui area, and considered that the nature of fluid is similar to those in hot-spring type gold deposits (fig. 53).

An analysis geochemical and fluid parameters in Chinese sedimentary rock-hosted gold deposits compared to those in Nevada suggests that common features are: (1) ore-forming fluids containing complex stable isotopic signatures; (2) indications that some ore fluids may have been derived from meteoric water, but magmatic, basinal brine, and metamorphic sources also are possible; (3) low to medium temperatures of formation; (4) formation pressures indicating a medium to shallow geological crustal environment of formation; and (5) low salinity combined with high Au : Ag. ratios and low base-metal contents typify most Carlin-type gold deposits.

Table 21 Isotope Data of Some Carlin-type Gold Deposits in Dian-Qian-Gui Area, China (He, L.X. and others, 1993)

$\delta^{34}S$ ($^{0}/_{00}$)	+30.8 to -15.6
$\delta^{13}C$ ($^{0}/_{00}$)	+2.49 to -8.55
$\delta^{18}O$ ($^{0}/_{00}$)	+27.51 to +9.61
δD ($^{0}/_{00}$)	-73.7 to -87

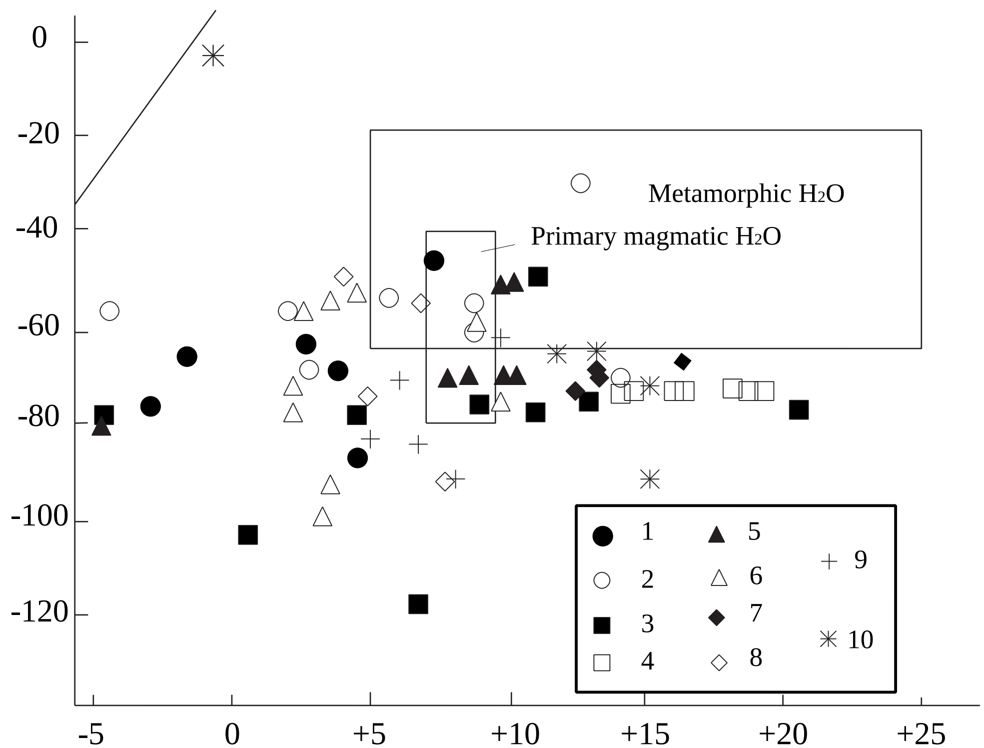

Figure 52. dD vs. d18O diagram showing that H and O data of Chinese Carlin-type gold deposit are scatted over a large area. This implies that metallogenic fluids may derive from different sources. Adapted from Liu, D.S. and others (1994).

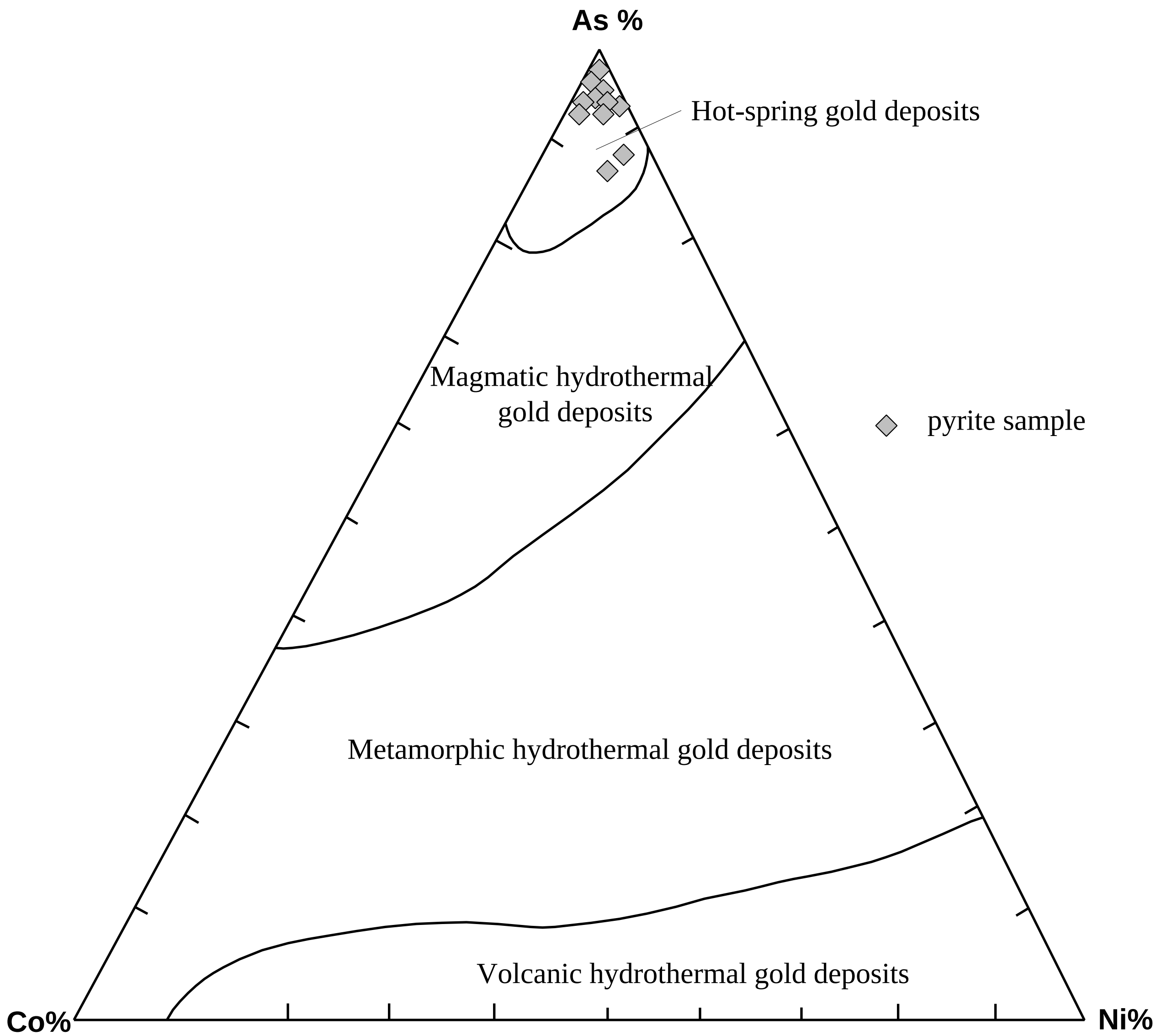

Figure 53. Co, Ni, As in pyrite from Jinyia gold deposit. Pyrites of Jinyia gold deposits fall in the area of Hot-spring gold deposits. This indicates that some Chinese Carlin-type gold deposit may be formed by hot-spring hydrothermal fluids. Adapted from Li, Z.H. and others (1994).

CONCLUSIONS

The purpose of this paper has been to describe the general geological and geochemical characteristics of Chinese Carlin-type gold deposits and compare them to those in Nevada so that common aspects of the mineralizing system can be recognized. As the economic value and scientific significance of sedimentary rock-hosted gold deposits becomes more important to science, industry and human society, increased research, prospecting, and mining of these deposits is receiving more attention in areas outside of Nevada. To successfully discover and exploit these deposits in new regions, it is important to recognize their known characteristics and to build on the existing knowledge of their origin in order to apply this data correctly to exploration models. Previous ore deposit models, developed from the mining of the oxide parts of Carlin-type deposits in Nevada, have influenced the worldwide exploration for this type of gold deposit. New studies on the hypogene parts of these systems are developing updated genetic models and exploration techniques. The definition of sedimentary rock-hosted and Carlin-type gold deposits is expanding, and may include some skarn and metamorphic rock-related gold deposits, as well as those related to porphyry systems. The US and P.R. China contain the two largest groups of sedimentary rock-hosted gold deposits in the world, and therefore recognition of the similarities and differences of the deposits in these two regions will help identify new models. Similarities between these two large regional groups suggest that a similar mineralizing type of hydrothermal system most likely operated in both areas. The following are some geological similarities and differences of the gold deposits (table 22) in these two regions.

(1) Chinese sedimentary rock-hosted gold deposits have some similar regional sedimentary and tectonic features to many Carlin-type gold deposits in Nevada. For example: (a) all deposits occur near the margin of one or more Precambrian cratons, or in areas where craton-scale tectonic units join; (b) the deposits are hosted in Paleozoic or Mesozoic sedimentary basins, which contain both shallow water cratonic shelf and sedimentary rocks from the adjacent deeper basins; (c) tectonically, there is a history of both compressional and extensional deformation; and (d) there is evidence of alignment of geologic features that reflect regional deep-crustal rifts or zones that were developed by major orogeny. It is likely that many or all of these features contribute to the localizing and formation of clusters of sedimentary rock-hosted gold deposits.

(2) Both Chinese and U.S. deposits are hosted by carbonate and silici-clastic sedimentary rocks, especially rocks formed in shelf transitional zones of sedimentary facies, such as argillaceous limestone, calcareous siltstone, and silty argillite. Chinese sedimentary rock-hosted gold deposits are more commonly hosted in silici-clastic sedimentary facies, whereas Nevada deposits generally formed in carbonate-bearing rocks. Some carbonaceous, black clastic rocks host U deposits in China. Phyllite, slate, and low-grade metamorphic rocks are only known at some Chinese sedimentary rock-hosted gold deposits. Host rocks of Carlin-type deposits in Nevada are Paleozoic in age, whereas host rocks of Chinese deposits are Mesozoic (Triassic) and Paleozoic (Devonian) in age.

(3) A high content of organic material is common in or near most sedimentary rock-hosted gold deposits in both Nevada and P.R. China, although the role of carbon in gold mineralization is not yet clear. Organic matter may have preceded gold-bearing fluids or may have been introduced or remobilized by the hydrothermal event. Mineralization of carbonaceous matter is evident in many deposits, and the worldwide correlation with these gold deposits suggests there may be a genetic link. Some of the Chinese carbonaceous ores have syngenetic characteristics. Chinese gold deposits in Proterozoic rocks in northeast China may also have volcanogenic or exhalative-sedimentary characteristics.

Table 22. Comparison of Carlin-type gold deposits between Nevada and China (After Liu, D.S., 1994)

Geological Feature	Nevada Carlin-type Gold Deposits	Chinese Carlin-type Gold Deposit
tectonic setting	transform zone of miogeoclinal	rift area of cratonic margin
host strata	carbonate rocks of Paleozoic, and S, D are important	carbonate and clastic rocks of mostly Devonian and Triassic age
host rock types	impure carbonates, fine-grained clastic rock, breccia; high carbon content in some rocks	fine-grained clastic rock, Carbon + Silica argillite, breccia; high carbon content in some rocks
metamorphic grade	slate - phyllite, dynamo-metamorphic	slate - phyllite
igneous intrusions rocks	igneous intrusion of Cretaceous - Jurassic; Tertiary volcanic rarely present	dikes of Tertiary age present in some deposits
metallogenic epoch	late Cretaceous - Tertiary	Tertiary
paragenetic deposits	Hg, Sb, barite, and skarn-related porphyry Cu	Hg, Sb, As, barite; granitic and C-Si argillite U; stratabound Pb-Zn
ore control structure	structural window in low-angle faults, high- angle normal faults, breccia zone in strata	regional base faults, faults parallel to axis of anticlines, breccia zone in strata, density squeezed fracture zones, and unconformable plane
deposits morphology	stratiform, lensoidal, vein, irregular	stratiform lensoidal, vein
alteration	decalcification, jasperoids, solidification, argillization, pyritization, dolomitization	silicification, argillization, pyritization, dolomitization, albitization
structure of ore	disseminated, stockworks, breccia	disseminated, stockworks, breccia
size of gold grains	microscopic - submicroscopic grains native gold	microscopic - submicroscopic grains native gold, rare visible
mineral assemblage	native gold, pyrite, realgar, orpiment, cinnabar, stibnite, arsenopyrite, Tl minerals, quartz, clay minerals, carbonate barite, organic carbon	native gold, pyrite, realgar, orpiment, cinnabar, stibnite, arsenopyrite, (pyrrhotite), quartz, clay minerals, carbonate, barite, organic carbon
pathfinder elements	Au, As, Hg, Sb, Tl, W, Mo	Au, As, Hg, Sb (Ag)
Au / Ag	3 to 17	> 1 to 25
zone of oxidation	common	insignificant

(4) Lack of evidence for distinct temporal links between gold mineralization and igneous rocks is another common feature for most Carlin-type gold deposits. There is no obvious relation between most Carlin-type gold deposits and igneous intrusions both in Nevada and China, but many of the Carlin-type deposits in Nevada occur near Mesozoic stocks and locally Tertiary plutons and volcanic rocks. A few sedimentary rock-hosted deposits in Nevada, particularly the distal-disseminated deposits in the Battle Mountain Mining District and the Getchell deposit may have formed in association with igneous activity. Contact metamorphic rocks have been shown as prolific hosts for ore in the Betze deposit, Nevada. A few Chinese Carlin-type deposits, such as at the Liba, Pangjiahe, and Qiuluo, occur near igneous intrusions. Both Nevada and Chinese Carlin-type gold deposits may coexist with some volcanic-hosted gold deposits.

(5) Common hydrothermal alteration types, such as silicification, argillization, and decalcification have been observed in most sedimentary rock-hosted gold deposits in both Nevada and P.R. China. Decalcification is more often observed in Nevada Carlin-type gold deposits; whereas, carbonization, decarbonatization and local albitization are specific and unique to some Chinese sedimentary rock-hosted gold deposits.

(6) Pyrite, arsenopyrite, stibnite, realgar, orpiment, quartz, barite, calcite, and illite-clay minerals are the common minerals associated with sedimentary rock-hosted gold deposits in both P.R. China and Nevada. The combination of minerals is different in each deposit depending on the host rocks. For instance, arsenopyrite, realgar and orpiment are more common in silici-clastic host rocks; whereas stibnite is more common in carbonate host rocks. Chalcopyrite, sphalerite, and galena are present in trace amounts in the Nevada deposits, but may be more abundant in some Chinese deposits. Different mineral assemblages may also be the result of zoning in individual deposits. Pyrrhotite, tungstite, albite and several native metals are special features in some Chinese sedimentary rock-hosted gold deposits.

(7) The Au-As-Sb-Hg-Ba elemental assemblage is common in sedimentary rock-hosted gold deposits in both Nevada and P.R. China, but Tl seems to be more common in the Nevada deposits and is only found in a few Chinese deposits, such as Zimudang. U and PGEs are uniquely related to some Chinese deposits not known in the Nevada Carlin-type deposits.

(8) Gold is present in hypogene ores mainly as invisible sub-microscopic particles in As-bearing pyrite in sedimentary rock-hosted gold deposits. Illite-clay minerals, quartz, barite, and pyrrhotite also act as host minerals in some Chinese Carlin-type gold deposits.

(9) The high Au : Ag. ratios, low fluid salinity, and moderate ore-forming temperatures, as well as stable isotope data of Carlin-type gold deposits in Nevada and P.R. China, can only partially explain the genesis gold deposits. A contribution of igneous activity is possible and in China the volcanic rocks also may play a part in some systems. Deep-seated igneous intrusions may have provided heat to the ore-forming system rather than be directly involved in the process of metallogeny.

(10) Oxidation zones in Nevada sedimentary rock-hosted deposits are more developed than in Chinese deposits. This has had a negative economic impact on the development of such deposits in China.

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