GEOLOGICAL SETTING OF SEDIMENTARY ROCK-HOSTED GOLD DEPOSITS

The geologic setting of the Carlin-type deposits is important to understand their genesis. Below, we briefly discuss the tectonic, sedimentary environment and the metallogenic epochs of both Nevada and Chinese Carlin-type gold deposits.

Tectonic and sedimentary environment

Sedimentary rock-hosted gold deposits lie in their own spatial geological environment. The description below summarizes these tectonic and sedimentary environments of these gold deposits in both Nevada and P.R. China.

Nevada, The United States of America

Sedimentary rock-hosted gold deposits in the western United States are located in the Great Basin and are spatially related to the western boundary of the North American Precambrian craton—this boundary can be determined by both stratigraphic sequences and by isotopic measurements (Cunningham, 1988). On the eastern part of this boundary, miogeosynclinal sediments—composed mainly of Silurian, Devonian and Ordovician carbonate rocks (eastern assemblage)—were formed across the Antler foredeep and continental shelf (fig. 9). To the west, eugeosynclinal sediments consisting of fine-grained, siliceous, clastic rocks, chert, and local basalt (western assemblage) were also deposited in the early Paleozoic (figs. 9 and 10). The Antler orogeny, a Mediterranean type orogeny, took place during the late Paleozoic to early Mesozoic, and resulted in the Robert Mountains thrust, a west-dipping thrust fault (Burchfield and Roydon, 1989). This thrusting resulted in western assemblage (or upper-plate, allochthon) rocks to be thrust over the eastern assemblage (or lower-plate) rocks. Several erosional or tectonic windows through the upper-plate exposed lower-plate rocks. Most of the Carlin-type gold deposits in Nevada are spatially related to these windows or their associated structural highs (Christensen, 1993, 1996; Peters, 1997 a, b, c). Several intermediate composition Mesozoic and Tertiary stocks and plutons, as well as lamprophyre dikes, are located near the sedimentary rock-hosted orebodies in north-central Nevada, but no direct relation has been documented between these igneous rocks and gold mineralization. Most of the Mesozoic intrusions were clearly emplaced earlier than the gold deposits.

Cunningham (1988) emphases the relation between Carlin-type gold deposits and the regional paleothermal anomaly, the eastern edge of which is coincident with the edge of both the Robert Mountains thrust and the Northern American Precambrian craton. Some of the largest sedimentary rock-hosted gold deposits, *in*cluding Jerritt Canyon, Betze, Gold Quarry, Carlin, Hose Canyon, Northumberland, and Round Mountain, are located near the boundary of the area containing dominantly supermature (>300°C) rocks. Most deposits lie in clusters or trends that are proximal to isotopic contours that indicate the western edge of the North American craton, such as the $^{87}Sr/^{86}Sr$ 0.708, $^{87}Sr/^{86}Sr$ 0.706, and $^{143}Nd/^{144}Nd$ -7 contour lines (Cunningham, 1988). These contours also lie parallel to and in the vicinity of the regional paleothermal anomaly that has been ascertained by conodont maturation indices (see Cunningham, 1988; Togashi, 1992). The various deposit models used in Nevada call upon connections to igneous activity at depth, complex evolution of tectonic windows, *in*herent host rock permeability, ore genesis resulting from evolved meteoric fluids, oil brines or organic fluids, and many other factors. The striking alignment of the gold deposits along trends suggests that these structural trends may possess features that have served as traps or conduits for the gold fluids.

Chinese Carlin-type gold deposits are present in two Paleozoic to Mesozoic

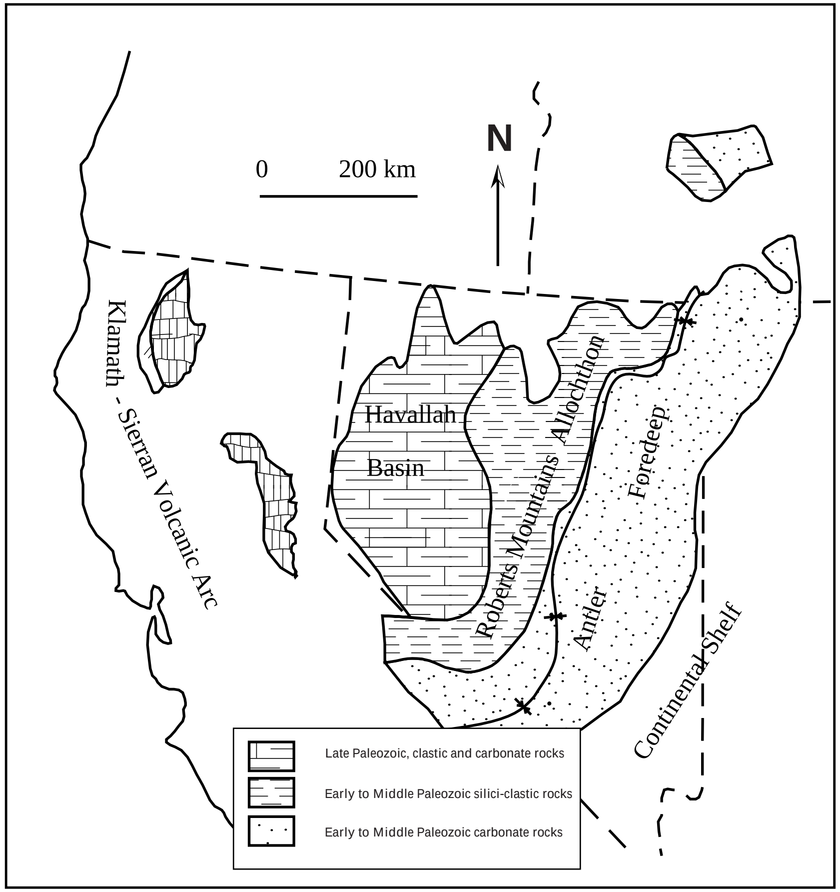

Figure 9. Generalized tectonic map of the Roberts Mountains allochthon, Antler orogeny and related tectonic units of the Great Basin, western United States. Tectonic units are shown in their present position except the Havallah Basin, which has been restored to a position west of the Antler belt (For discussion and details see Burchfiel and Royden (1991) from which this is modified).

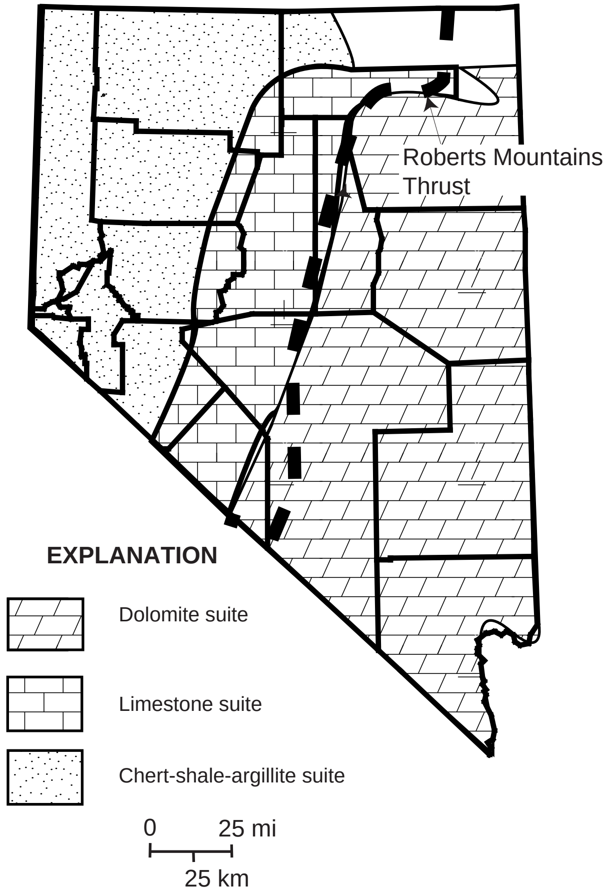

Figure 10. Distribution of late Silurian and early Devonian lithofacies and the approximate position of the Roberts Mountains thrust, Nevada. Compiled and adapted from Cunningham, (1988); Poole (1991), and Matti and McKee (1977).

sedimentary basins, which tectonically surround the Yangtz Precambrian craton (fig. 6). The Dian-Qian-Gui area is located on the southwest margin of the Yangtz craton and the Qinling area is located on the northwestern margin of the Yangtz craton (fig. 6, appendix I-5). The geological features and tectonic history of the two areas are similar. However, each of them has some local, unique geologic structures and lithofacies that influence the style of mineralization (Yao, Z.Y., 1990; Wang, Y.M. and others, 1996). Additionally, the Jidong area is geologically located in a late Proterozoic (Sinian) sedimentary Lengkou basin that is much order than Dian-Qian-Gui and Qinling areas.

Dian-Qian-Gui area, P.R. China

The tectonic and sedimentary environment in the Dian-Qian-Gui area surrounds a cluster of sedimentary rock-hosted gold deposits that are present in an area at the juncture between the Yangtz craton and Youjang orogenic belt (figs. 6 and 11). From late Paleozoic to early Mesozoic, this area consisted of shallow and deep water sedimentary environments along the northeast-trending southwest margin of the Yangtz Craton (fig. 12). Platform, shallow water (miogeosynclinal) assemblage carbonate sedimentary rocks were deposited on the northwest part of continental shelf of the carton during the late Paleozoic and early Mesozoic (fig. 13). Limestone and bioclastic limestone were deposited during the Carbonaceous and are overlain by Permian cherty limestone, limestone, bioclastic limestone, and tuffceous argillite. These rocks are in turn overlain by Triassic argillite, limestone, and dolomite. Coeval deep basin (euogeosynclinal) assemblage rocks consist of siliceous sediments, *in*cluding feldspathic graywacke, siltstone and argillite, formed during the same periods in the southeast part of the basin. Sedimentary rock-hosted gold deposits are present in both the deep and shallow water facies rocks, but are associated with distinct geological and geochemical features in these two parts of the basin.

Airborne magnetic data show that the upper crust in Dian-Qian-Gui area is made up of blocks which have been subjected to different types of stress. This typical tectonic pattern is clearer in the southwest Guizhou Province (fig. 14), where the Yangtz craton mainly consists of weakly strained of blocks, while the Youjang orogenic belt is composed of strongly strained blocks. The contact between these two tectonic units is a series of large-scale thrust structures (Wang, Y.G. and others, 1994). The structural pattern also is different in these two tectonic units at the margin of the Yangtz craton (fig. 15). On the northwest side, *in* the carbonate platform rocks, brittle faults and short-axial folds are more common, whereas tight folds and low-angle ductile-brittle thrust faults are more common in deep basin rocks in the southeast parts (Luo, X.H., 1994). The northwest-trending Indosinian-Yanshanian age Youjiang rift fault system (including all of the northwest-trending faults, such as the Xingyi and Ziyun faults) crosses the boundary of the Yangtz craton and has been interpreted as an extensional structure that post-dated compression tectonism in the region (fig. 14). The distribution of sedimentary rock-hosted gold deposits in the Dian-Qian-Gui area is spatially related to the Youjiang rift fault system (Tan, Y.J., 1994).

Qinling (Chuan-Shan-Gan) area, P.R. China

The tectonic and sedimentary setting of the Qinling area is between the Huabei and Yangtz Precambrian cratons (figs. 6, 16 and 17). Gold ore deposits are located in an area approximately 750 km long in an east-west direction and about 200 km wide in a north-south direction. Between these cratons is a Paleozoic sedimentary basin that contains greater than 10,000 m of sedimentary rocks deposited during the Devonian to Triassic periods. The east-trending Lixian-Baiyun-Shanyang deep-crustal rift, or subduction zone, trends east-west within this basin (fig. 17) and is generally considered as the boundary between the Yangtz and Huabei cratons (Liu, M., 1994). Most of the sedimentary rock-hosted gold

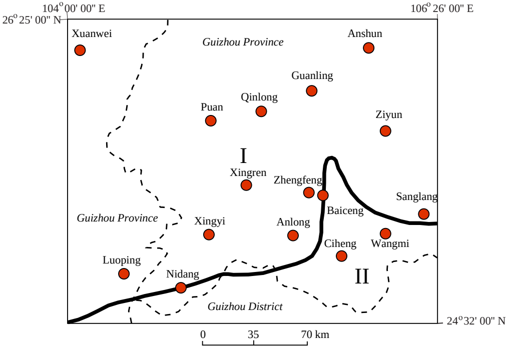

Figure 11. Generalized tectonic map of Dian-Qian-Gui area. I -Yangtz craton; II - Youjang orogenic belt. (boundary is heavy dark line). Adapted from Wang, Y.G. and others (1994). Circles represent main cities.

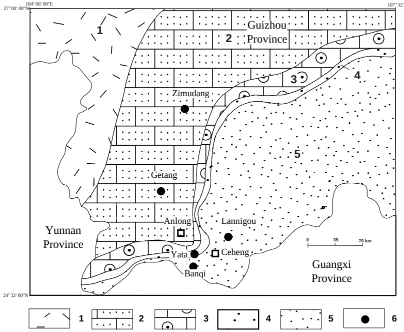

Figure 12. Sedimentary facies of Middle Triassic age rocks in the Dian-Qian-Gui area, Guizhou Province. Yangtz craton: 1-Lagoon tidal flat facies, 2- tidal flat facies, 3-biostromic reef facies; Youjang orogenic belt: 4-shelf facies, 5-abyssal facies. Main Carlin-type gold deposits are shown as dark circles (6): County cities are shown as open squares. Compiled and adapted from Yao, Z.Y. (1990).

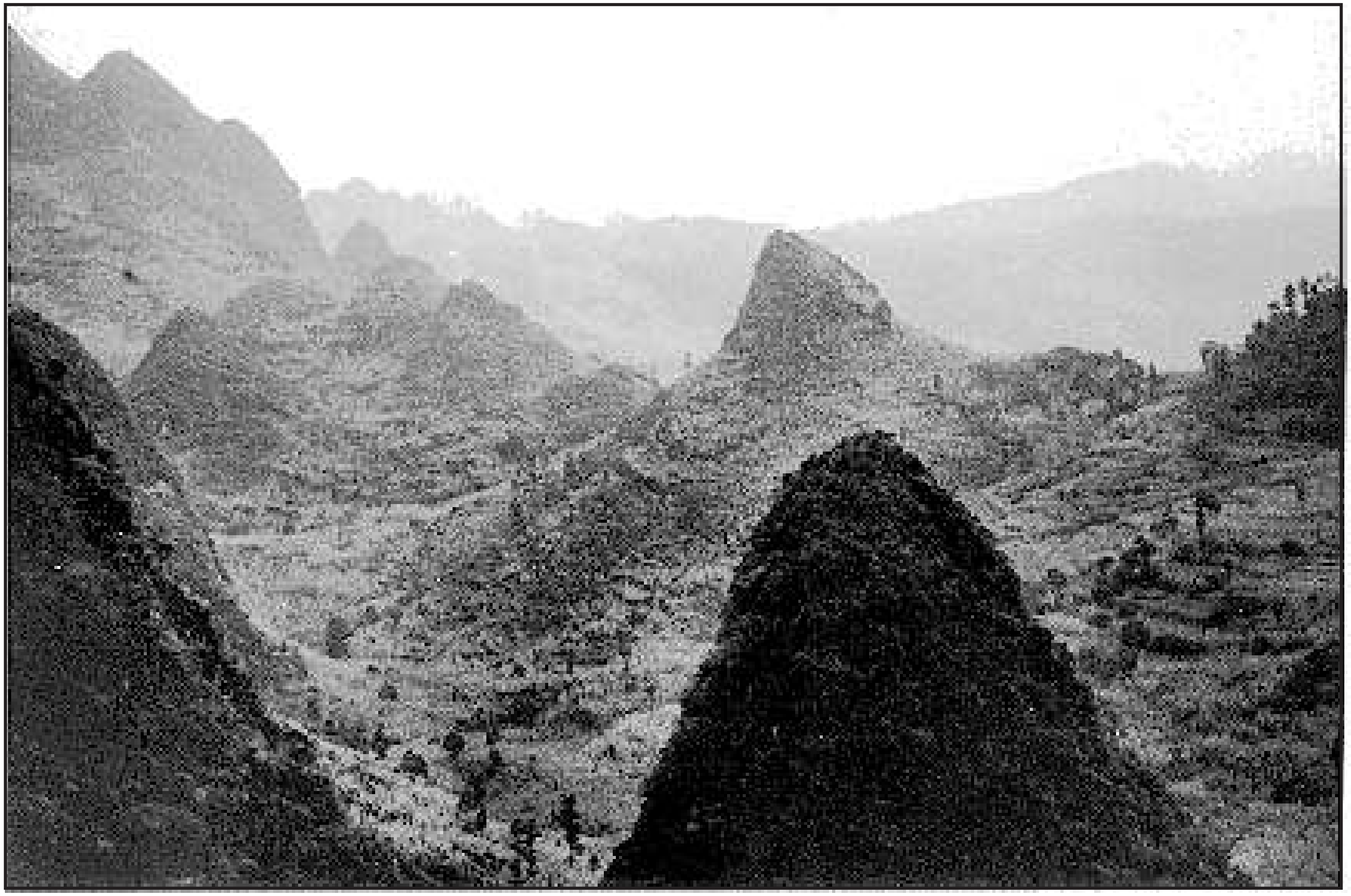

Figure 13. Photograph of the karst topography in southwest Guizhou Province, P.R. China. This is the typical topographic expression of the carbonate shelf facies in the interior of domal-shaped short axial anticlines. Horizontal field of view approximately 750 m.

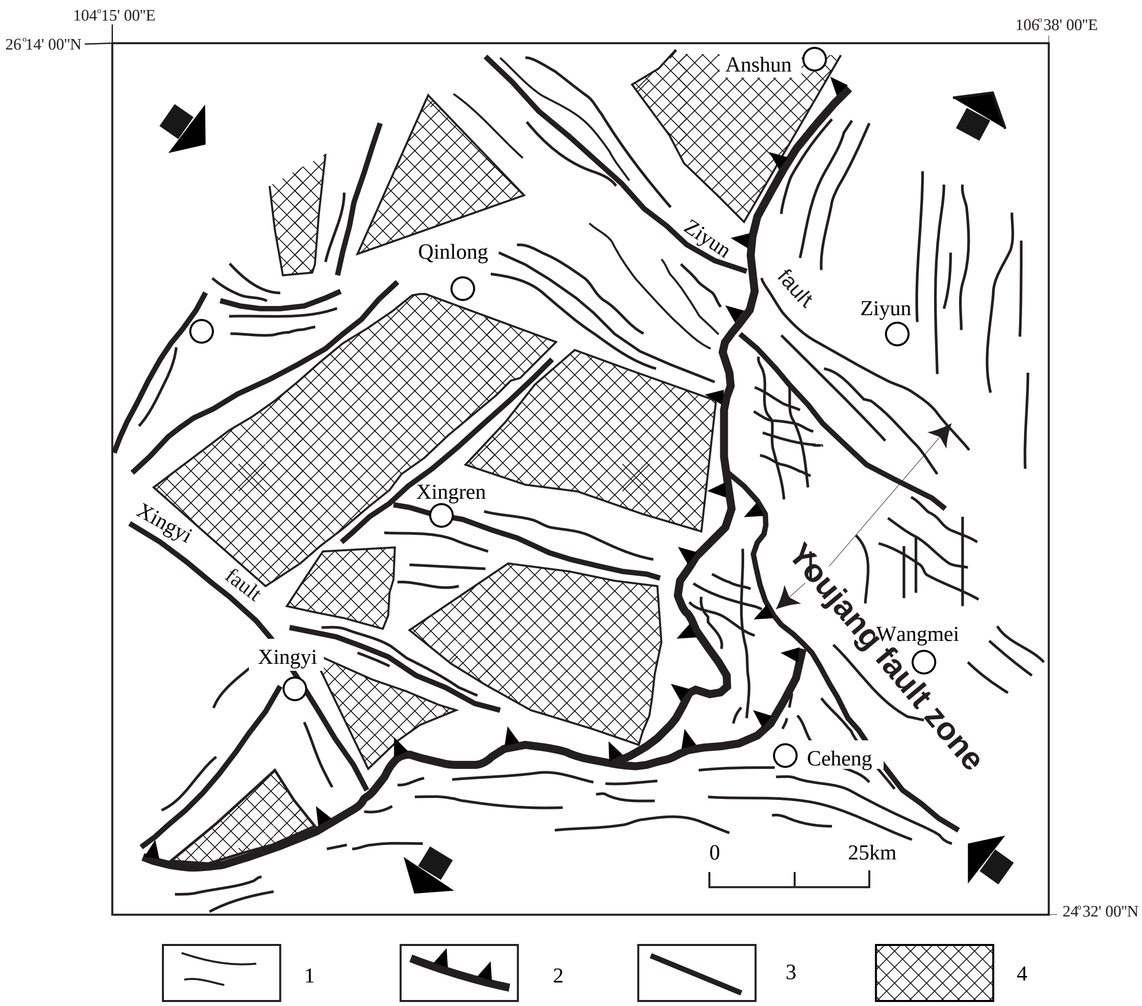

Figure 14. Structure map of upper crust in the southwest Guizhou province China, interpreted from areomagnetic data. 1-Axial plane of folds; 2-thrust fault zone; 3-Fault; 4-weakly strained block; arrows show the directions of compression and extension; county cities are shown open circles. Adapted from Wang, Y.G. and others (1994).

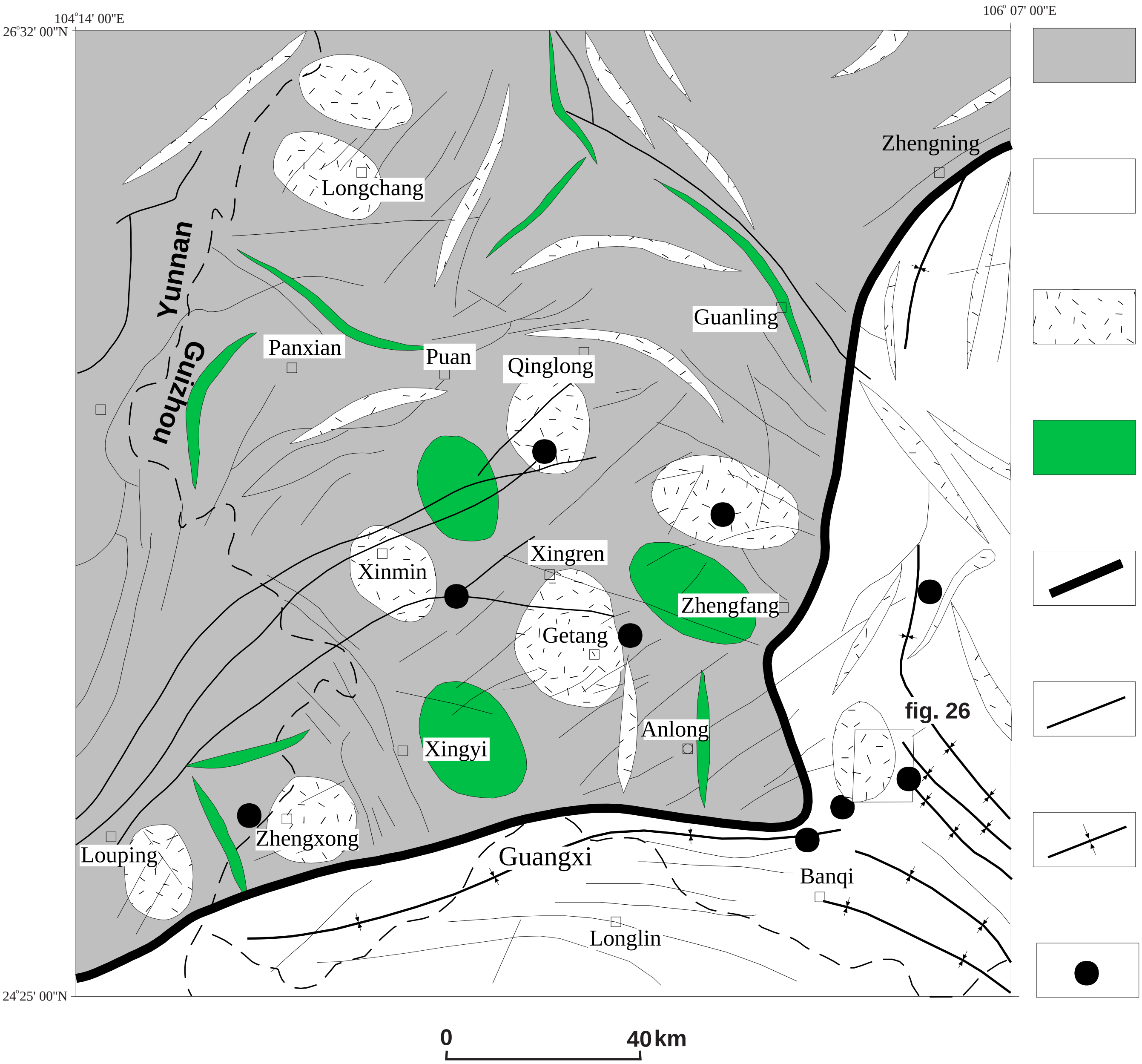

Figure 15. Regional structural framework of the Dian-Qian-Gui area showing the difference in structural pattern between platform area, which are short-axial anticline or dome in northwest Dian-Qian-Gui, and basin area in the southeast, which are with tight folds and thrust structure. 1-Yangtz craton; 2-Youjang orogenic belt; 3-short axial anticline; 4-short axial syncline; 5-tectonic boundary; 6-fault; 7-tight fold axial plane; 8-sedimentary rock-hosted gold deposit. County cities are shown by open squares. Adapted from Cheng, J.H. (1994).

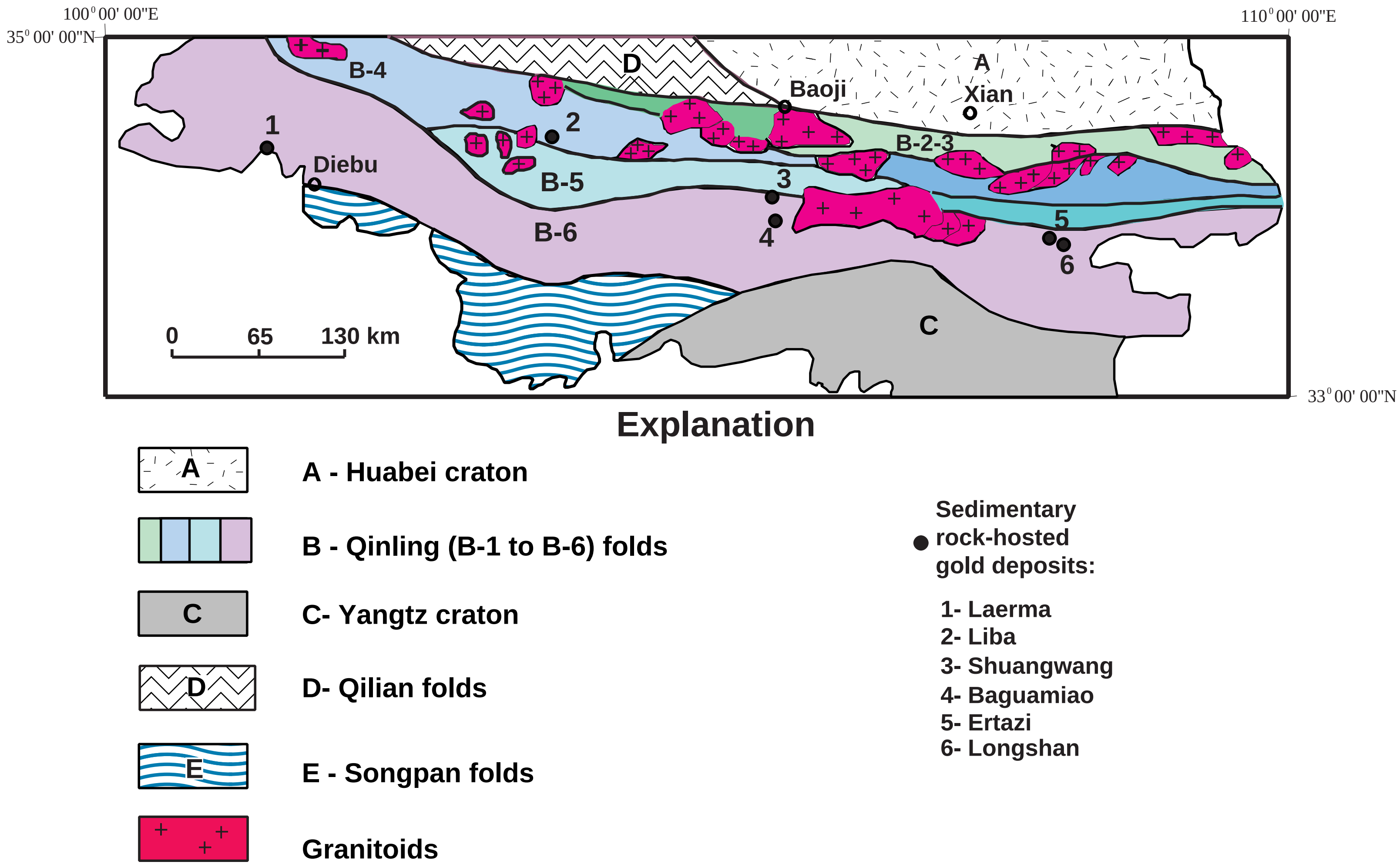

Figure 16. Structural geologic map of the Qinling area, showing litho-tectonic units and approximate location of the Lixian-Baiyun-Shanyang deep crustal lineament between the Yangtz and Huabei cratons: A - Huabei craton, B - Qinling fold belt (B1 to B6), C - Yangtz craton, D - Qilian fold belt, E - Songpan fold belt. Sedimentary rock-hosted gold deposits are noted as dark, round circles: 1 - Laerma, 2 - Liba, 3 - Shuangwang, 4 - Baguamio, 5 - Ertazi, 6 - Longshan. Adapted and compiled from Mio Liu (1994).

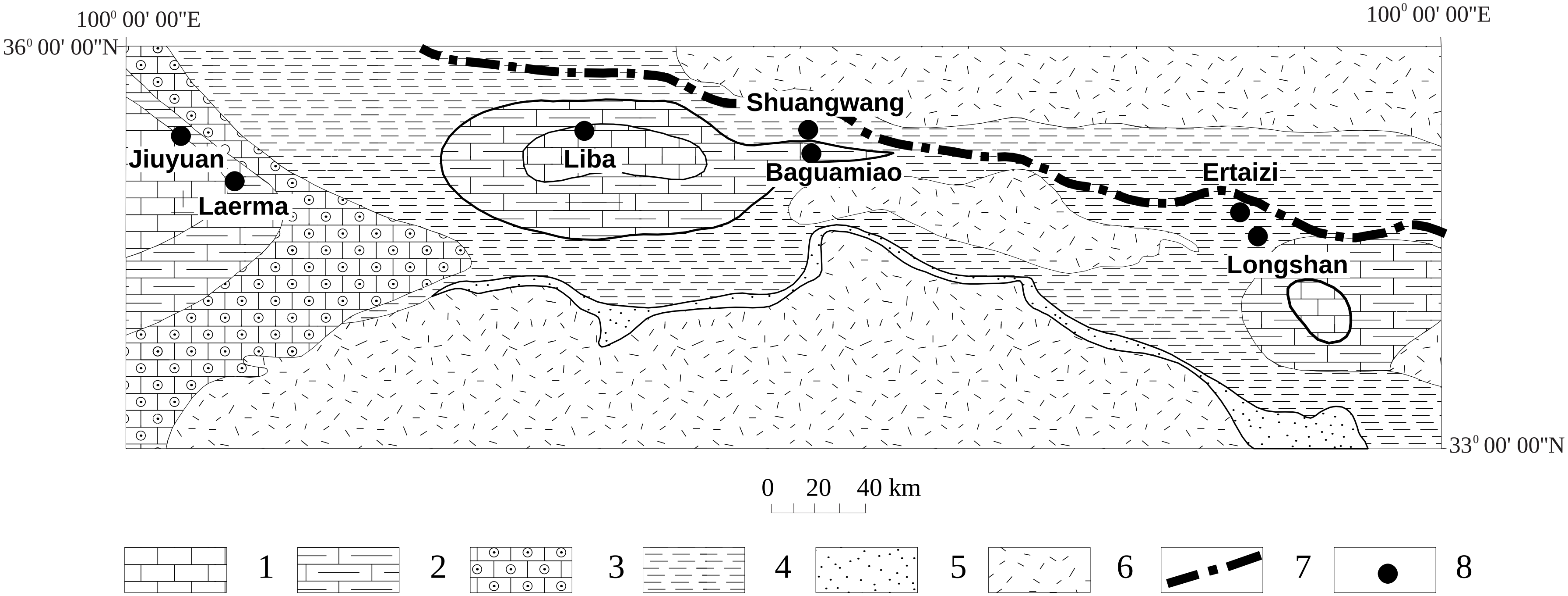

Figure 17. Relationship of lithofacies paleography to the distribution of gold deposits in the Qinling area. 1-carbonate area; 2-shale-carbonate area; 3-bio-reef facies at the margin of craton; 4-shallow sea platform facies; 5-transitional facies; (1through 5 are Devonian age). 6-craton; 7-deep crust rift; 8-gold deposit. Adapted from Yao, Z.Y. (1990).

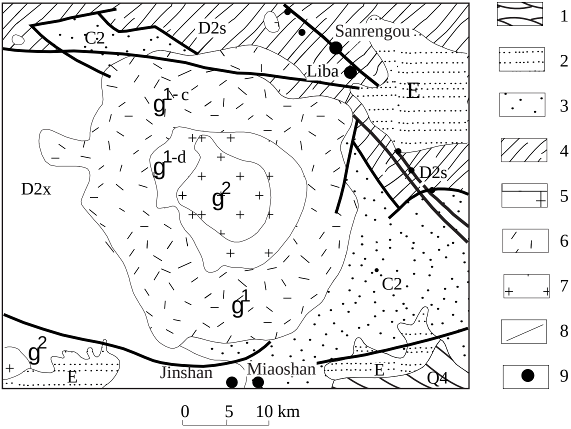

Figure 18. Regional geologic map of the Liba gold deposit area, showing a group of sedimentary rock-hosted gold deposits, which include the Liba, Sanrengou, and Jinshan deposits (appendix I). They are located near the Zhongchuan granite intrusion. 1-Quaternary; 2-lower Tertiary; 3-slate, meta-sandstone and conglomerate (C2); 4-phyllite, silty phyllite (Shujiaba group D2S); 5-meta-sandstone, marble, phyllite (Xihanshui group D2X); 6, 7-granite (Zhongchuan intrusion); 8-boundary of lithology; 9-sedimentary rock-hosted gold deposit. Compiled from Liu, M. (1994). Approximate location of figure is 104^0 48Õ 00ÕÕE;^{0} 34 36Õ 00ÕÕN.

deposits in this area are distributed along this deep-crustal rift zone. Several major deposits, such as the Longshan, Ertaizi, Shuangwang, Baguamiao, Pangjiahe, and Anjiacha deposits are present in this east-west zone (figs. 16, and 17; appendix I).

A complete upper Paleozoic stratigraphic section of rocks is present in the basin between the Huabei and Yangtz Precambrian from the Devonian to Permian. Permian sedimentary rocks mainly are carbonate rocks and include limestone, argillaceous limestone, *in*terbedded silty shale, and siltstone. Littoral facies sedimentary rocks, such as quartz sandstone, carbonaceous shale, together with some limestone, were formed during the Carboniferous period. Devonian sedimentary rocks consist of upper limestone, *in*terbedded calcareous sandstone, limestone, argillaceous limestone, and lower bioclastic limestone (fig. 17).

Magmatic activity was widespread in the Qinling area, compared to the Dian-Qian-Gui area (figs. 12 and 16). Igneous intrusions in the Qinling area mainly consist of intermediate composition stocks and plutons, such as biotite granite, and granodiorite, which were emplaced during the Mesozoic (149 to 230 Ma) (Liu, M., 1994); (198.3 to 212.8 Ma), (Fan, S.C. and Jin, 1994). A few small, late Paleozoic, mafic intrusive bodies and some andesite porphyrite bodies represent volcanic rocks present locally in the area. Igneous rocks are not generally exposed in or associated with the sedimentary rock-hosted gold deposits.

The Liba deposit (figs. 17 and 18) is an a exception to this general non-igneous association and it is located in a contact metamorphic zone about 2 km north of the Zhongchuan granite intrusion. Typical Carlin-type minerals are absent in the Liba deposit, such as stibnite, cinnabar, realgar, and orpiment. Instead the deposit contains a mesothermal mineral association of pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, galena, and sulfate minerals, which indicate that ore-forming temperatures were higher in the Liba deposit than in most sedimentary rock-hosted gold deposits. Igneous rocks in Liba gold deposit may have provided a heat source for the ore-forming system (Liu, M., 1994), and account for this different mineralogy.

Jidong area, P.R. China

The tectonic and sedimentary setting of the Jidong area is at the margin of Huabei craton, bounded on the north by the inter-Mongolia fold system (fig. 6). The Proterozoic sedimentary basin that contains sedimentary rock-hosted gold deposits is the northwest-trending Lengkou basin (fig. 19), which is about 5 to 15 km wide, more than 60 km long, and crosses the Qinglong, Kuancheng, Qianxi, Qianan and Lulong Counties of eastern Hebei Province, north P. R. China. The Lengkou basin consists of Ca- and Mg-carbonate rocks that belong to the late Proterozoic (Sinian system) Great Wall and Jixian stratigraphic systems (see appendix II-2). Sedimentary rock-hosted gold deposits mainly are present in the carbonate rocks of the upper Gaoyuzhuang group of the Great Wall system, and the lower Yangzhuang and Womishan groups of the Jixian system (figs. 20, appendix I-2). The gold deposits are hosted in stratabound breccia zones, which extend along the Lengkou basin (Qiu, Y.S. and Yang, W.S., 1997).

Both the Dian-Qian-Gui and Qinling areas in P.R. China have similar regional sedimentary and tectonic features to the sedimentary rock-hosted gold deposits in Nevada. The age of the Lengkou basin in Jidong area, however, is much older, and may have different metallogenic affinities. It is likely that many or all of the following features contributed to the localizing and formation of sedimentary rock-hosted gold deposits:

(1). Deposits cluster at the margins of one or more Precambrian cratons, or in areas where craton-scale tectonic units join.

(2) Deposits are hosted in or lie at the margins of Paleozoic and (or) Mesozoic sedimentary basins, which contain both shallow-water carbonate-rich rocks from the cratonic shelf and

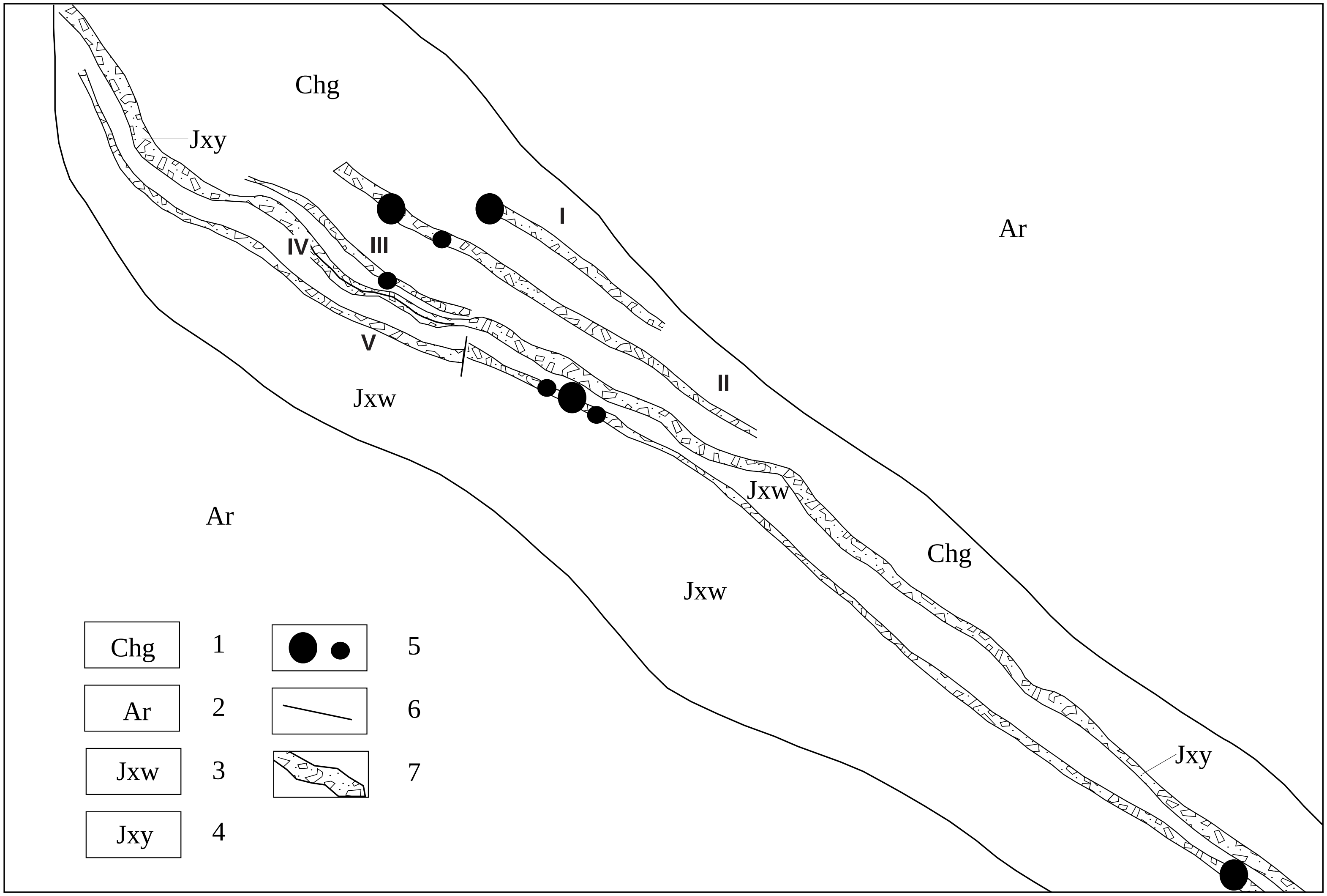

Figure 19. Geology and gold deposits in the Lengkou basin, Jidong area, China, showing the gold deposits are controlled by five northwestern-trending, stratabound breccia bodies . 1-Gaoyuzhuang group of the Greatwall system (Chg); 2-Archaeozoic stratigraphy (Ar); 3-Wumishan group of the Jixian system (Jxw); 4-Yangzhuang group of the Jixian system (Jxy); 5-Gold deposits (prospects); 6-Boundary of the Lengkou basin; 7-Au-bearing breccia bodies, labeled by number (I, II, III, IV, V). Adapted from Qiu, Y.S. and Yang, W.S. (1997, unpublished). Approximate location of figure is 118^{0}18Õ 00ÕÕE; ^{0}40 00Õ 00ÕÕN. See Figure 6 for approximate location.

Figure 20. Photograph of several Greatwall gold deposits, Jidong area, China (Looking to the north). Skyline shows the Greatwall. Field of view of middle ground approximately 1 km.

fine-grained silici-clastic sedimentary rocks from the deeper basins.

(3) Tectonically, there is a history of both compressional and extensional deformation in the geologic histories, with both crustal thickening and thinning.

(4) There is evidence of alignment of geologic features of regional deep-crustal rifts or zones that were developed after or during major orogenies.

Metallogenic Epochs of Gold Mineralization

Sedimentary rock-hosted gold deposits are hard to date and contain many conflicting relations that contribute to controversies of their genesis and age. Stratigraphic chronology can only give a maximum age, because the orebodies are epigenetic and are commonly controlled by high-angle faults crossing several stratigraphic units that represent long periods of geological time. The radiometric methods require robust syn-ore alteration minerals, which are usually lacking in Carlin-type deposits. Illite and kaolinite are the most common alteration minerals, and these have not given reproducible ages in individual deposit or in ore districts (Folger and others, 1996; Arehart and others, 1993a). The following summary describes our understanding of the ages of these deposits in Nevada and in P.R. China.

Age of deposits in Nevada, the United States of America

The age of gold mineralization of sedimentary rock-hosted gold deposits in north-central Nevada is controversial, with published ages ranging from Jurassic to Late Mesozoic to early Tertiary (see Arehart and others, 1993c; Hofstra, 1995; Groff, 1996; Hitchborn and others, 1996; Hall and others, 1997; Parry and others, 1997). Most gold deposits along the Carlin trend in Nevada are present in the lower Paleozoic sedimentary rocks of eastern assemblage rocks, and their maximum age is between the Jurassic pre-ore Goldstrike stock at 158 Ma and the post-ore Tertiary Carlin Formation at 5 Ma.

Age of deposits in the Dian-Qian-Gui and Qinling area, P.R. China

Chinese Carlin-type deposits, with the same geologic characteristics as those in Nevada, also are as difficult to date, and a similar controversy also is present regarding their age. Chinese Carlin-type gold deposits have been found in sedimentary formations ranging from Paleozoic to Mesozoic in age (table 3, fig. 21). Of these, about 41 percent of the deposits are hosted in rocks of lower Triassic age. These rocks have proven to be ideal host rocks for the deposits, especially in Dian-Qian-Gui area (see also Zhang, F., and Yang, K.Y., 1993). Some deposits, such as Yata, Sanchahe, Ceyang, and Banqi deposits, are present near high-angle reverse or normal faults, which were formed in the Yanshanian orogeny, suggesting that the age of gold mineralization is less than 100 Ma (Ashley and others, 1991). However, radiometric dating of these deposits is not available.

About 21 percent of Carlin-type gold deposits in P.R. China are in Devonian age rocks (table 3, fig. 21), particularly in the Qinling area. Ages of gold mineralization derived from radiometric isotope methods (K/Ar, $^{40}Ar/^{39}Ar$ and U-Th-Pb) give many ages ranging from >300 Ma to <15 Ma (see table 4). The youngest age of gold mineralization (49.5 to 12.7 Ma) in the Laerma deposit is on the basis of analysis of both whole rock and ore minerals (Li, Y.D and Li, Y.T., 1994). The oldest ages reported are 337.5 to 234.3 Ma from the Pingding deposit by isotope analysis of realgar and orpiment associated with gold mineralization using the U-Th-Pb method (Lin, B.Z. and others, 1994). Other age dates are 168 Ma (pyrite, U-Th-Pb), 183.09 Ma (pyrite, $^{40}Ar/^{39}Ar$) in the Shuangwang deposit (Fan, S.C. and Jin, Q.H., 1994), and 210 Ma (whole rock and ore, U-Th-Pb) in Baguamiao deposit (Wei, L.M. and Cao, Y.G. 1994).

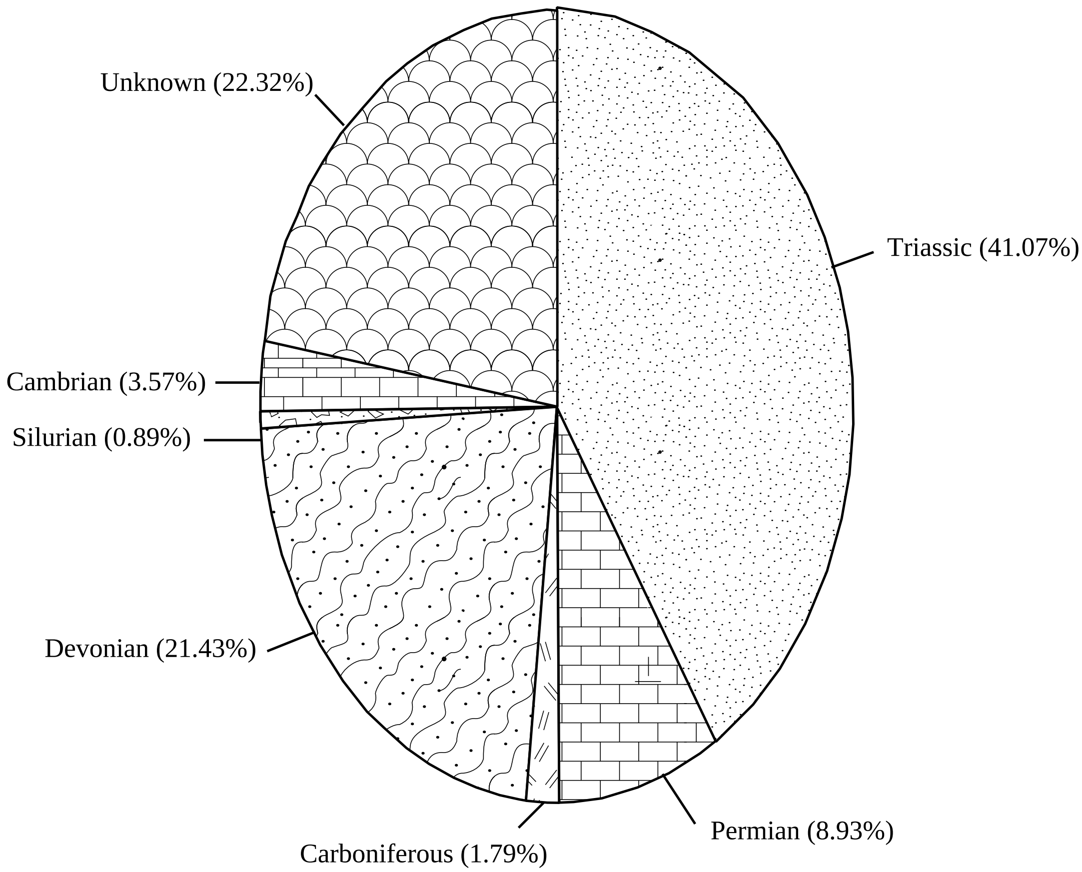

Figure 21. Chinese Carlin-type gold deposits according to host-rock age. Triassic and Devonian age rocks are the main host rocks of Chinese Carlin-type gold deposits.

Table 3 Distribution of Chinese Carlin-type Gold Deposits by Age of Host Rock

Host-rock age	Number of Deposits	Percent (%)
Triassic	46	41.07
Permian	10	8.93
Carboniferous	2	1.79
Devonian	24	21.43
Silurian	1	0.89
Ordovician	0	0.00
Cambrian	4	3.57
Unknown	25	22.32

Table 4. Age of Gold Mineralization in the Qinling Area, P.R. China

Deposit name	Age of gold mineralization (Ma)	sample	Result of Dating (Ma)	Method	Calculate method	Source
Laerma	49.5-12.7	Dacite(barren)	172	K-Ar		Li, Y. 1994
		Dacite(gold-bearing)	12.77	K-Ar		
		ore	56.8-117.5	U-Th-Pb		
		Quartz(gold-bearing)	47.3-49.5	$^{40}Ar/^{39}Ar$		
		U ore associated gold	46-10	U-Pb		
Pingding	Late Mesozoic	Dike	214.1	K-Ar		Lin, 1994
		Realgar orpiment	392-265	U-Th-Pb	Double stages	
			337.5-234.3		Single stages	
Jiuyuan		Intermediate dike	200.7	K-Ar		
Shuangwang	168	II pyrite	183.08	$^{40}Ar/^{39}Ar$		Fan, 1994
		IV pyrite	168.0	$^{40}Ar/^{39}Ar$		
Baguamiao	210	strata	399.62	U-Th-Pb	Double stages	Wei, 1994
		"	386.11	"	Single stages	
		ore	289.89	"	Double stages	
			208.22	"	Single stages	

In general, the interpretive ages of sedimentary rock-hosted gold deposits in both Nevada and P.R. China span an interval between the age of the host rocks and the age of the post mineralization cover. Many of the dates are compatible with known metallogenic events and coincide with tectonic or magmatic activity in the region. The spread of ages is due to the limits of the analytical methods and to the unique features of the sedimentary rock-hosted gold deposits. It is likely, using some of the minimum age dates from the Chinese Carlin-type deposits, that they may have formed at a younger age than the Nevada deposits. As discussed below, possible evidence for syngenetic formation of the Chinese deposits is also present.