GEOLOGY OF SEDIMENTARY ROCK-HOSTED GOLD DEPOSITS

The deposit-scale geologic characteristics—such as host-structure, host-rock, alteration, and ore minerals for both Nevada and Chinese sedimentary rock-hosted gold deposits—are well documented in the geologic literature (see Christensen, 1993; Liu, D.S. and others, 1994; Wang, Y.G. and others, 1994; Bagby and Berger, 1985; Kuehn and Rose, 1995; Arehart, 1996). The following discussion outlines these characteristics, and compares the difference between deposits in P.R. China and Nevada. This discussion also helps us understand the difference in geologic characteristics between Carlin-type and other type of gold deposits that are directly related to igneous and metamorphic activity.

Host Structures and Feeder Systems

World-wide distribution of Carlin-type deposits is controlled by Paleozoic or Mesozoic sedimentary basins at the margins of Precambrian cratons. Location of Carlin-type deposits is closely related to compression and extensional regional structural tectonic events in these sedimentary basins. Tectonic structures and faults are related to these events, such as the Robert Mountains thrust and weakly defined trends in Nevada, the Youjiang deep-crustal rift system in the Dian-Qian-Gui area, and the Baiyun-Lixian-Shanyang rift in the Qinling (Jidong) area, P.R. China.

Regional-scale structures or lineaments usually serve as conduits or host-structures for most sedimentary rock-hosted gold deposits. In the Carlin trend area, these structures are high-angle faults, associated folds or tectonic windows (see Poole, 1991; Prihar and others; 1996), which are oriented parallel or perpendicular to the main trend or primary lineament. High-angle faults are generally considered to playing a key role in ore-control in these deposits (Togashi, 1992). Christensen (1993, 1996) summarized the styles of gold mineralization into three models, which form a spectrum between undeformed stratabound replacement bodies with little structure, more structurally controlled orebodies with either high-grade vein-like ores, and massive breccia- or stockwork-type (fig. 22). Peters (1996, 1997c) has suggested that shear folding of pre-existing regional folds was a major ore-control in the large Betze deposit in the Carlin trend and that some of the deformation was synchronous with ore deposition. Syn-deformational genesis has also been documented in the Lannigou deposit, Guizhou Province, by Luo, X.H. (1993, 1996).

Liu, D.S. and others (1994) identify four main types of host-structure in Chinese sedimentary rock-hosted gold deposits. These are: (1) short-axial anticlines; (2) stratabound breccia bodies; (3) unconformity surfaces; and (4) joints associated with faults and anticlines. Shear zones with ductile-brittle deformation textures of ore and rocks also are observed in some Chinese sedimentary rock-hosted gold deposits (figs. 23, and 24).

Short-axial anticlines—defined as folds with a length in the axial direction roughly equal to its limb widths—are common and important ore-controlling structures in the Dian-Qian-Gui area (fig. 15). Almost all Carlin-type gold deposits are related to folds or domes in this area (Luo, X.H., 1994). For example, the Banqi deposit is controlled by the Naban fold (fig. 25); the Lannigou deposit is in the Laizishan dome (fig. 26). In addition, the Zimudang deposit is controlled by the west part of Huijiapu anticline and the Sanchahe, Puzilong, and Beiyinbe deposits (prospects) are located on the eastern Huijiapu anticline; the Getang deposit occurs in the Daba dome. The ore deposits typically cluster along structures on the outer most parts of the domes near the contact between carbonate and silici-clastic rocks.

Short-axial anticlines are generated by the interference of two fold systems crossing each other, similar to refolding or partial doming. High-angle breccia zones and

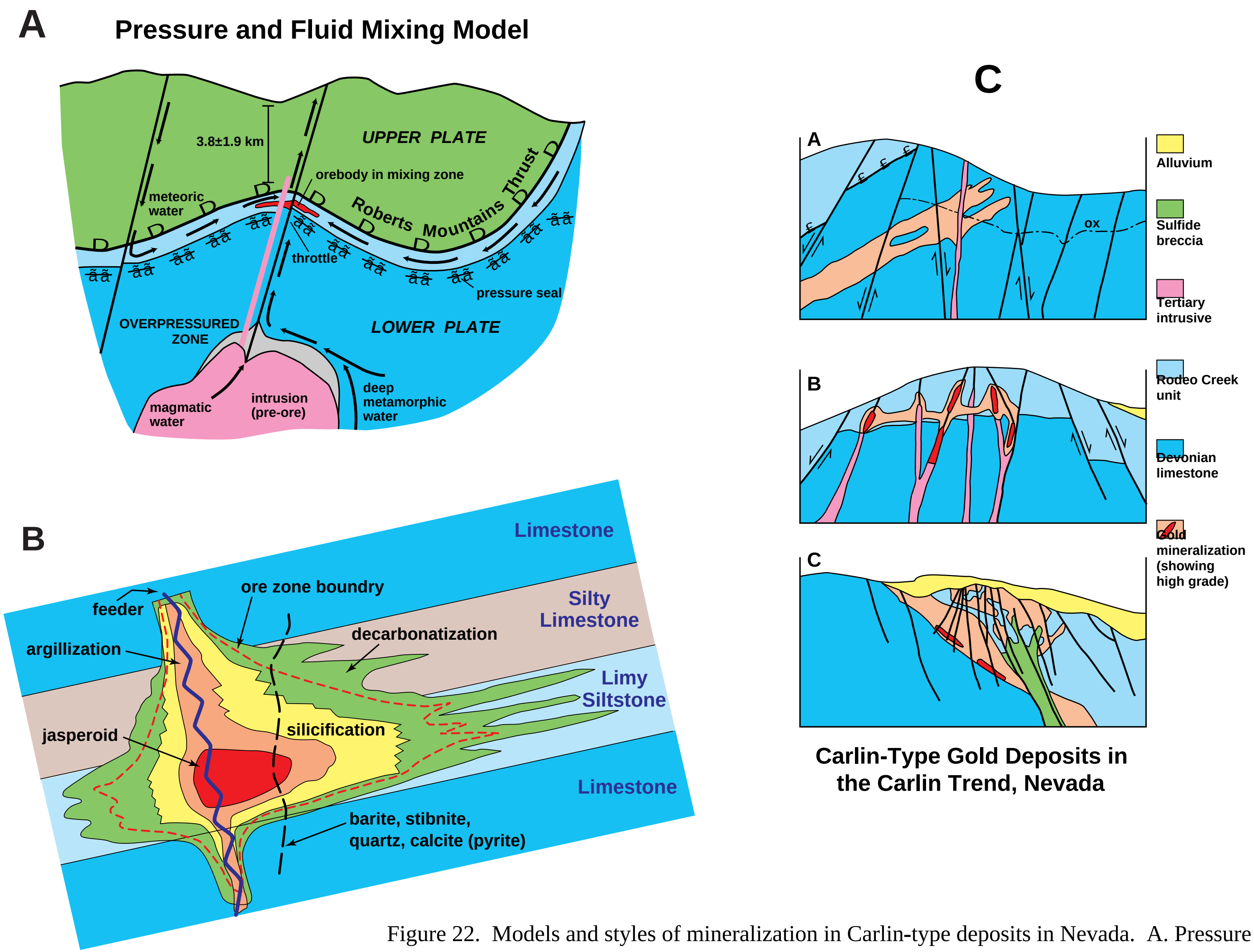

Figure 22. Models and styles of mineralization in Carlin-type deposits in Nevada. A. Pressure and fluid mixing model, adapted from Kuehn and Rose (1995). B. Model of typical sedimentary rock-hosted gold deposit, adapted from Arehart (1996). C. Three styles of Carlin deposit, stratabound, structure and complex (breccia), adapted from Christensen (1993, 1996).

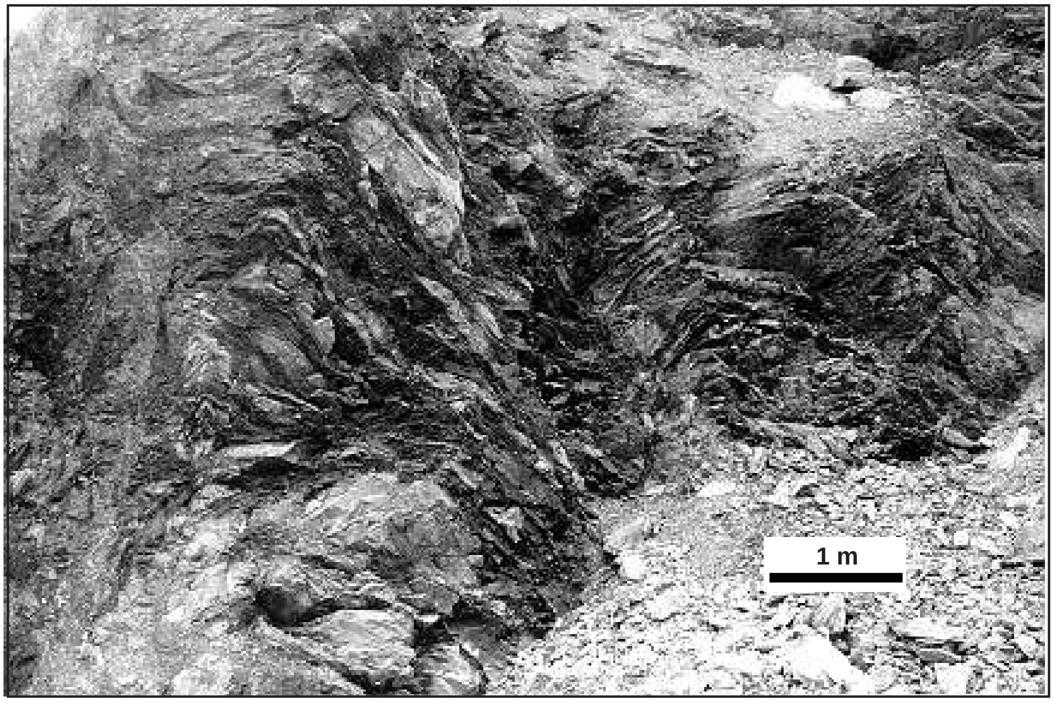

Figure 23. Photograph of deformation of carbonaceous laminated rocks in the Gaolong gold deposit (looking to northwest).

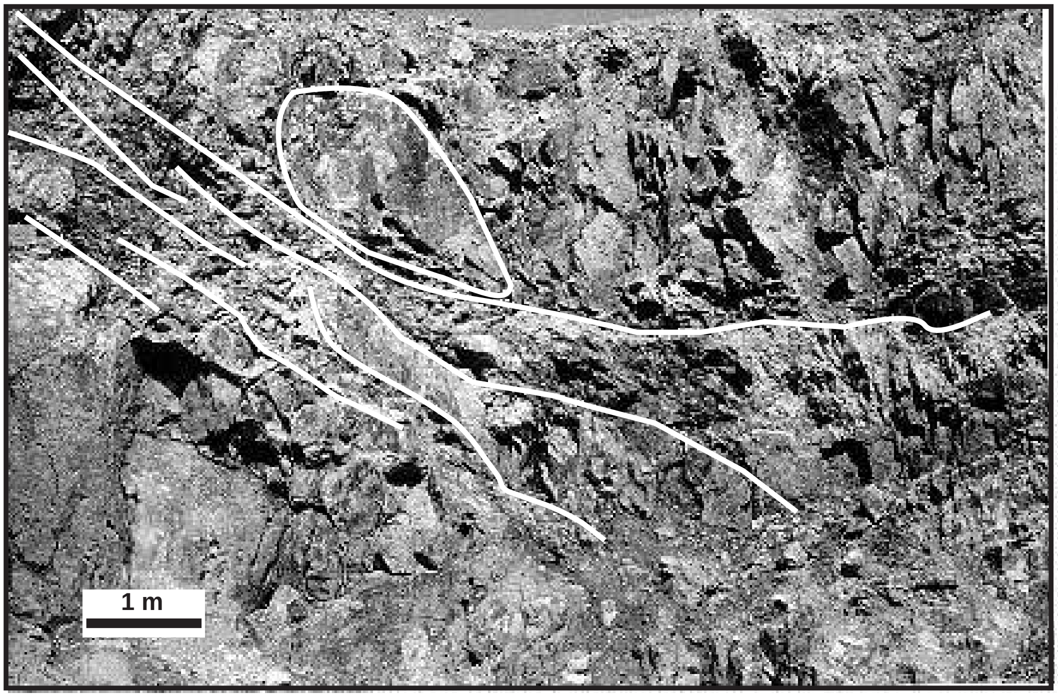

Figure 24. Photograph of flat, ductile-brittle deformation (shear zone) in the Gaolong gold deposits (looking to northwest). From a vertical mine bench.

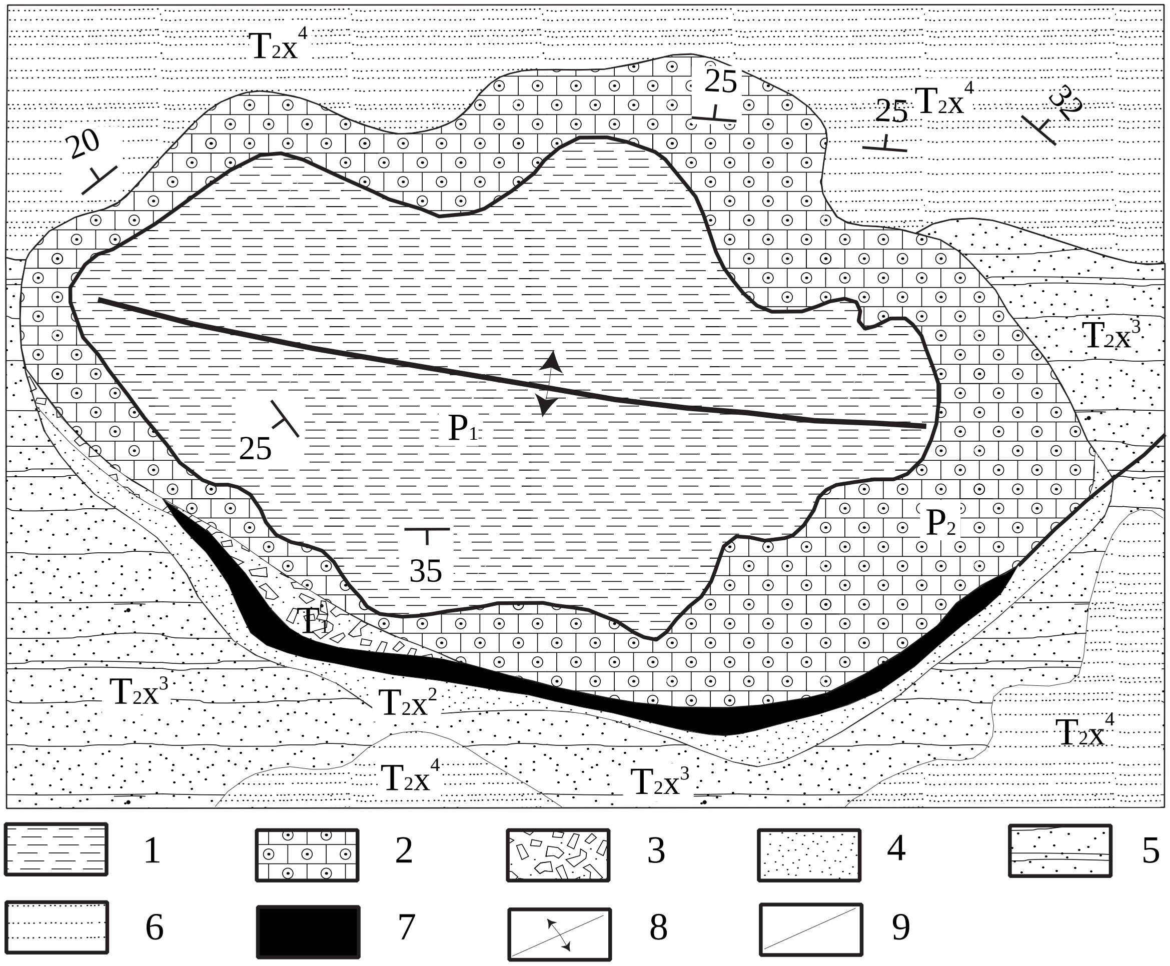

Figure 25. Geologic map of the Banqi gold deposit, showing the domal short-axial anticline structure that controls ore called the Naban fold. 1,2-the Permian rocks (P1, P2); 3-the Triassic Ziyun group rocks (T1Z); 4, 5, 6-the Triassic Xinyun group rocks (T2X2, T2X3 and T2X4); 7-the gold orebody; 8-Axis of short-axial anticline; 9-fault. Modified from Pu, Hanke (1987); and Liu, D.S. (1994). Approximate location of figure is 105^0 39' 00" E; 24^0 48' 00"N.

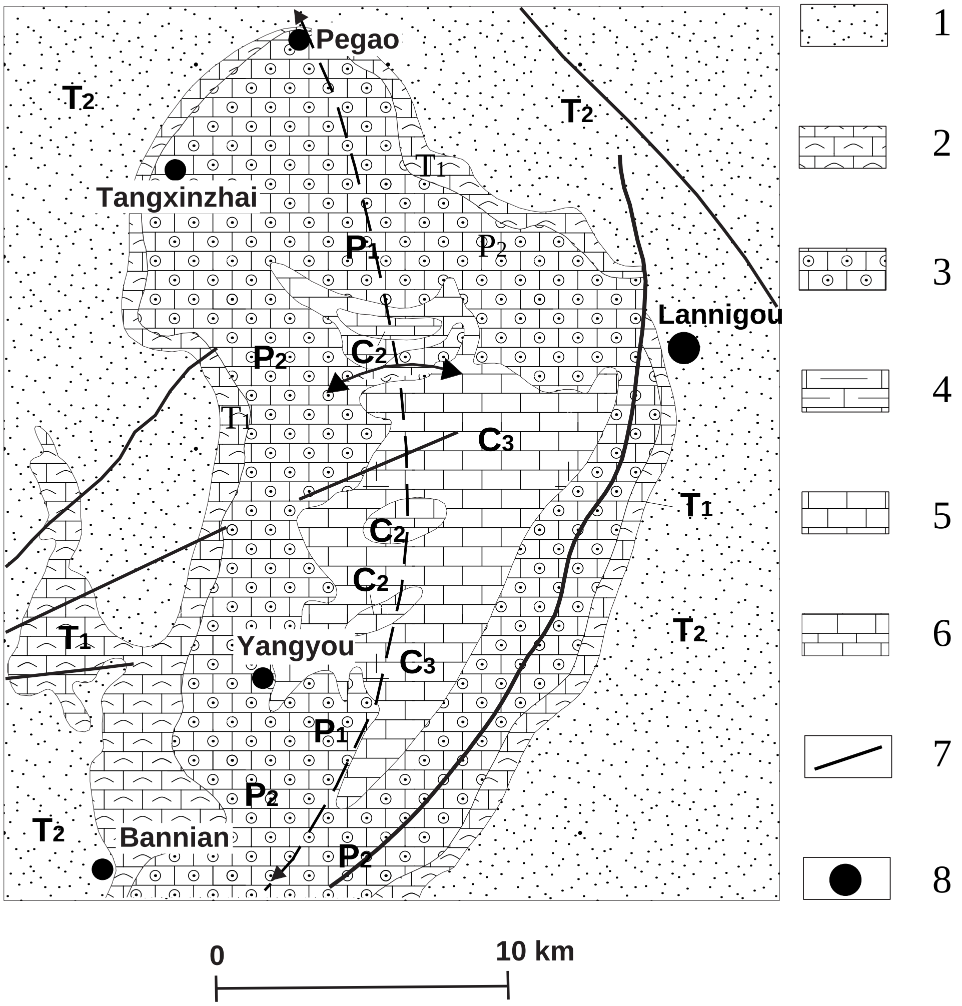

Figure 26. Laizishan dome (short-axial anticline structure). 1, 2 Triassic stratigraphy (T2b, T1l), which is located on the east and west flanks; 3, 4, 5, 6-Carbonaceous to Permian limestone, and bioclastic limestone, located in the anticlinal core; 7-Faults surrounding the fold are related to Carlin-type gold mineralization such as the Lannigou deposit; 8-Gold deposit. Adapted from Luo, X.H. (1994). Approximate location of figure is 105^0 41' 24" E; 25^0 21' 00" N.

detachment faults host gold orebodies on the axial margin of these domes. The Laizishan dome is 25 km long and 12 km wide and is typical of short-axial anticlines (fig. 26). The central domal area is comprised of approximately 1,300 m of Carbonaceous to Permian limestone, bioclastic limestone, and reef limestone, with interlayered argillite and tuffaceous argillite (Dachang unit) exposed at its core. Triassic sediments (1,000 m thick) are distributed on the west and east limbs of this dome. The western limb consists of carbonate rocks of the platform facies that dip 5° to 20° to the west, whereas the eastern limb is composed of clastic rock of the abyssal sedimentary facies with dips of 20° to 40° to the east. The faults surrounding this short-axial anticline are well-developed, and are spatially associated with Au, As, Hg, and Sb mineralization. The Lannigou deposit, the largest sedimentary rock-hosted gold orebody (shown on figs. 27, and 28) in this district, is located on the eastern limb of the Laizishan short-axial anticline (fig. 26). Other sedimentary rock-hosted gold deposits surrounding this fold are the Bannian, Yangyuo, Begao, and Luodong deposits, and the Qingping, Tangxinzhai prospects (appendix I) (Luo, X.H., 1994).

Stratabound breccia bodies also are a type of ore-controlling structure or host of sedimentary rock-hosted gold deposits in P.R. China. These breccia bodies are conformable with stratigraphic units in the host rock. An example of this is the Shuangwang gold deposit (Fan, S.C. and Jin, Q.H., 1994), which is a large Carlin-type gold deposit in the Qinling area, hosted by stratabound breccia bodies (fig. 29), and located in Devonian age Xinhongpu Formation rocks, which consist of silty slate, *in*terbedded argillaceous silty limestone, mirolitic limestone, argillaceous limestone, and interbedded slate. Eight gold-bearing breccia bodies are present in a composite extensional breccia zone that is 11.5 km long and 700 to 500 m wide, trending N290° to 310° W. The breccia occurrences are conformable or cross cut stratigraphy at low-angles. The breccia clasts (size ranges from 10 cm to several meters) are composed of altered slate, siltstone, marble, and micritic limestone. The breccia matrix is made up of albite, ankerite, and calcite, as well as local quartz and pyrite formed at multiple stages of hydrothermal activity. About fourteen orebodies have been defined at Shuangwang inside a 1 ppm Au cut-off. The No. 8 orebody, the largest one, is approximate 680 m long, 28.3 m wide, and 348 m deep.

Another example of stratabound breccia bodies is the Greatwall gold deposit, Jidong area, where gold mineralization is hosted by five stratabound breccia bodies. These breccia bodies are 5 to 15 km wide, up to 25 to 30 km long, and are present in Ca- and Mg-rich carbonate rocks containing chert layers and nodules (figs. 19, 30, 31) in the Gaoyuzhuang (Great Wall system) and Wumishan groups (Jixian system). Most orebodies are hosted in conformable breccia zones (figs. 32, 33), and have a layered or stratified appearance and tabular shape. The breccias usually strike between NW 290° to 310°, and dip SW between 50° to 80°, and vary locally with host strata. Clear boundaries between the orebodies and host-rock (brecciated-dolomitic limestone) are sometimes lacking. Out of 34 rock chip samples randomly taken from 4 mining sites, from northwest to southeast along the breccia zone, gold assays were 0.044 to 4.5 ppm (avg. 1.65 ppm); 0.20 to 23.03 ppm (avg. 6.24 ppm); 0.04 to 8.82 ppm (2.55 ppm); 0.018 to 85.23 ppm (avg. 11.43 ppm) (Qiu, Y.S. and Yang, W.S., 1997).

Unconformity surfaces or bedding planes, and bedding plane faults often serve as ore-control structures in Dian-Qian-Gui area. Karst caves and paleo-erosional surfaces are common near unconformities, and some gold orebodies take the shape of karst pots. These features also are more easily subjected to weathering and laterite development and are the sites of local oxidized (“red earth”)

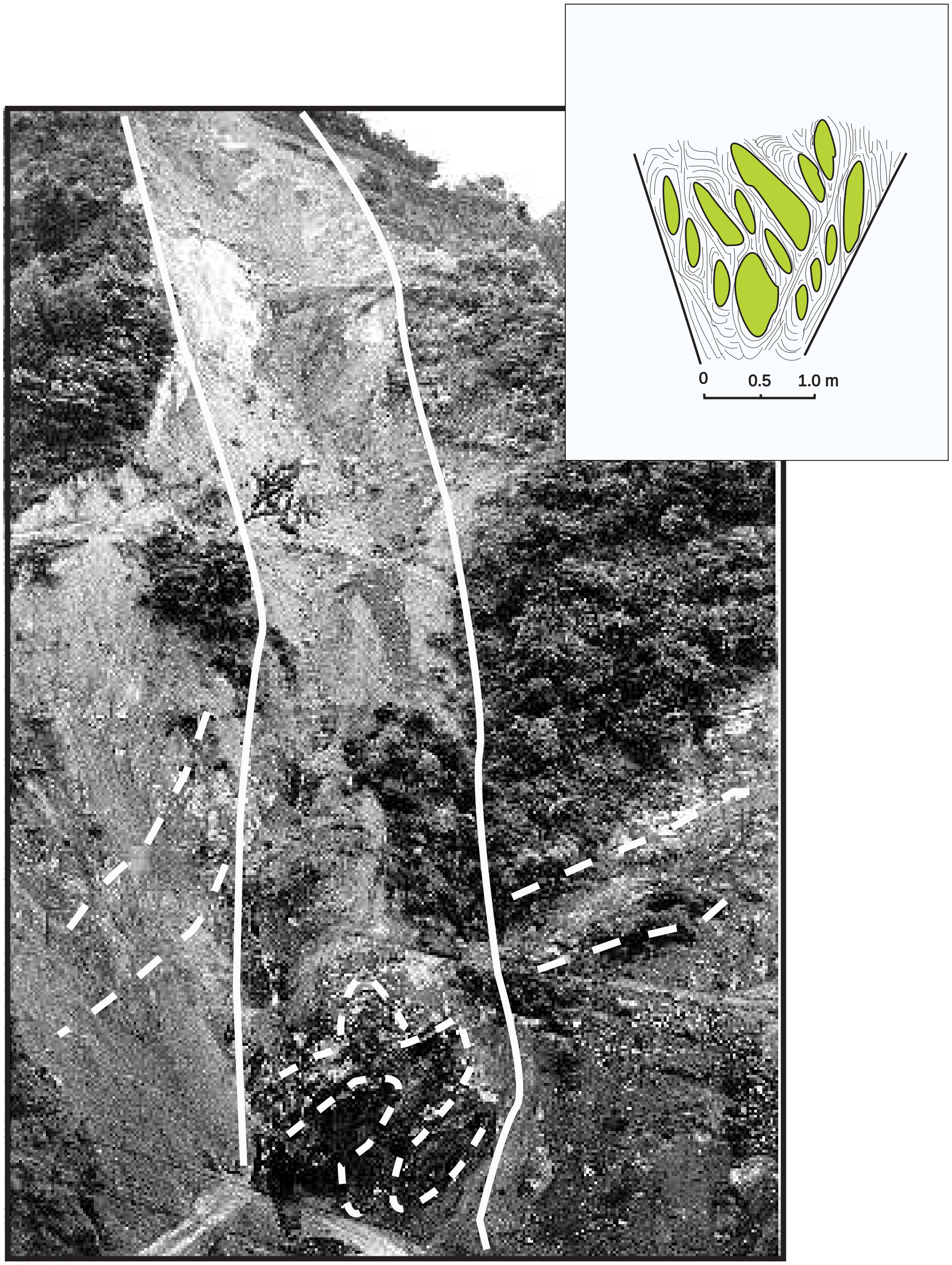

Figure 27. Photograph of No. 1 orebody of the Lannigou gold deposit, Guizhou province (looking to north). Center scarred area is the host shear zone (bounded by white lines) Bedding is shown in dashed lines. Inset: phacoidal deformation style typical in host shear zone of the Lannigou deposits, suggesting multiple periods of syn-deformational mineralization (from Lou, X., 1993, 1996).

Figure 28. Photograph of bedding slip in No. 1 orebody of the Lannigou gold deposit, Guizhou province (looking to north). The darker, sheared pelitic, carbonaceous bands contain the pyrite-gold mineralization.

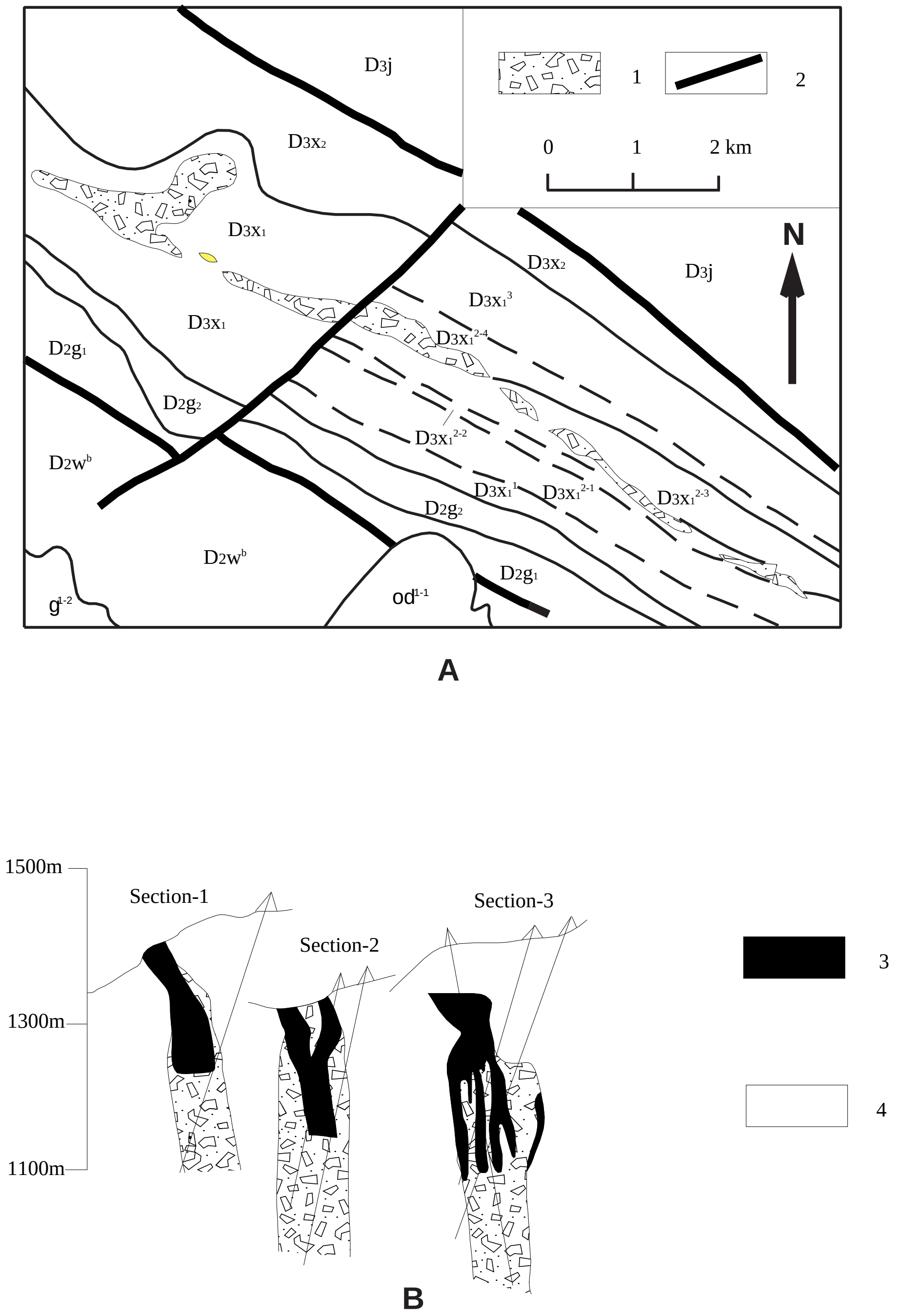

Figure 29. Stratabound breccia ore control in the Shuangwang gold deposit, Qinling area. A. Plan geologic map of the Shuangwang gold deposit showing localization of the orebody in the D3 x1 unit. B. Sections 1, 2, and 3 showing gold orebody in the upper parts of the stratabound breccia zone. 1-breccia body; 2-fault; 3-orebody; 4-host rocks; D2wa-b- meta sandstone interbedded limestone, carbonaceous shale (Wangjialeng group); D2G1-2-limestone, sandstone (Gudaoling group); D3x1-2- siltstone, limestone, phyllite (Xinghongpu group); D3j-siltstone, slate (Jiuliping group). Adapted from Fan, S.C. (1994). Approximate location of figure is 107° 18' 00" E; 34° 00' 00"N.

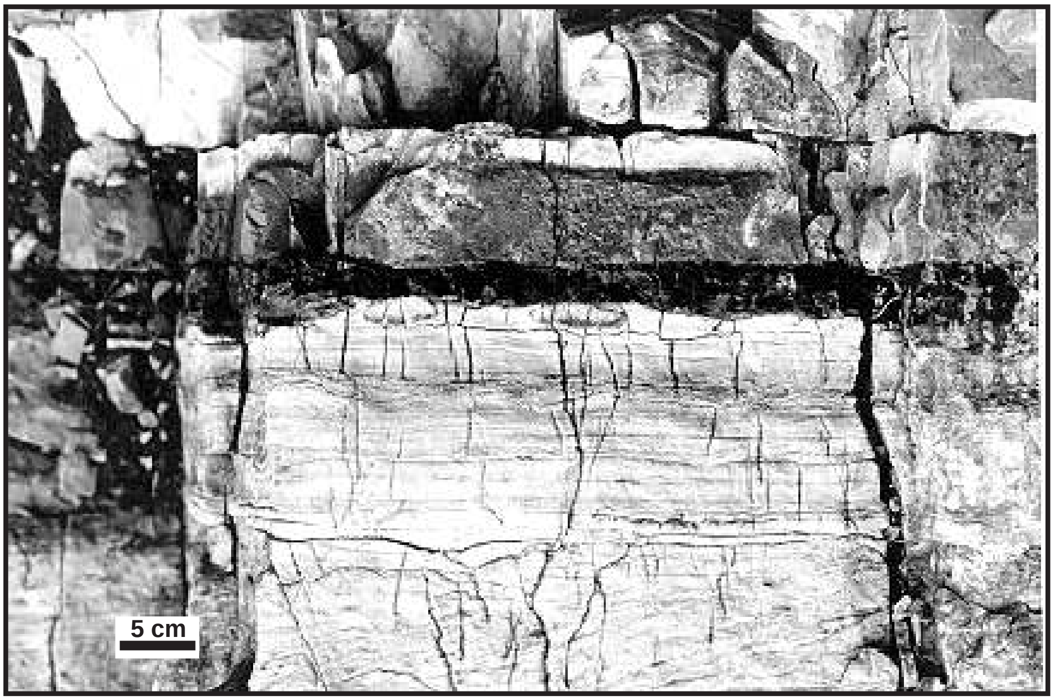

Figure 30. Photograph of dolomite interbedded with black chert lenses in wall rock of the Greatwall gold deposit, Hebei Province (looking to east). Black chert locally has a back ground of 2 ppb Au.

Figure 31. Photograph of layered black chert in the wall of open pit in the Greatwall gold deposit, Hebei Province (looking to north). Breccia zone no. 3.

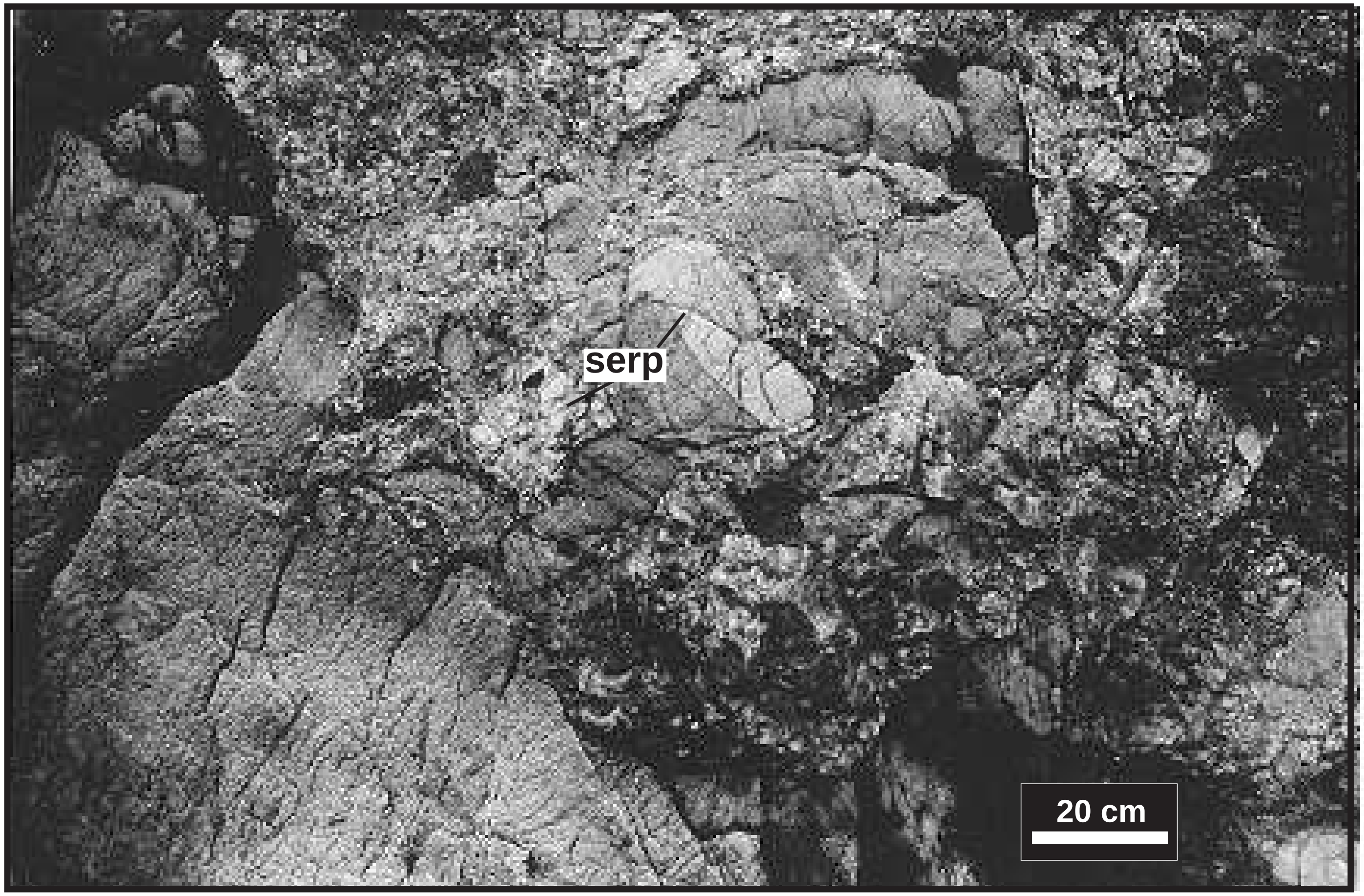

Figure 32. Photograph of dolomite breccia with serpentine clasts (serp) in the Greatwall gold deposit, Hebei Province. This is typical of the main host rock for many of the ore deposits.

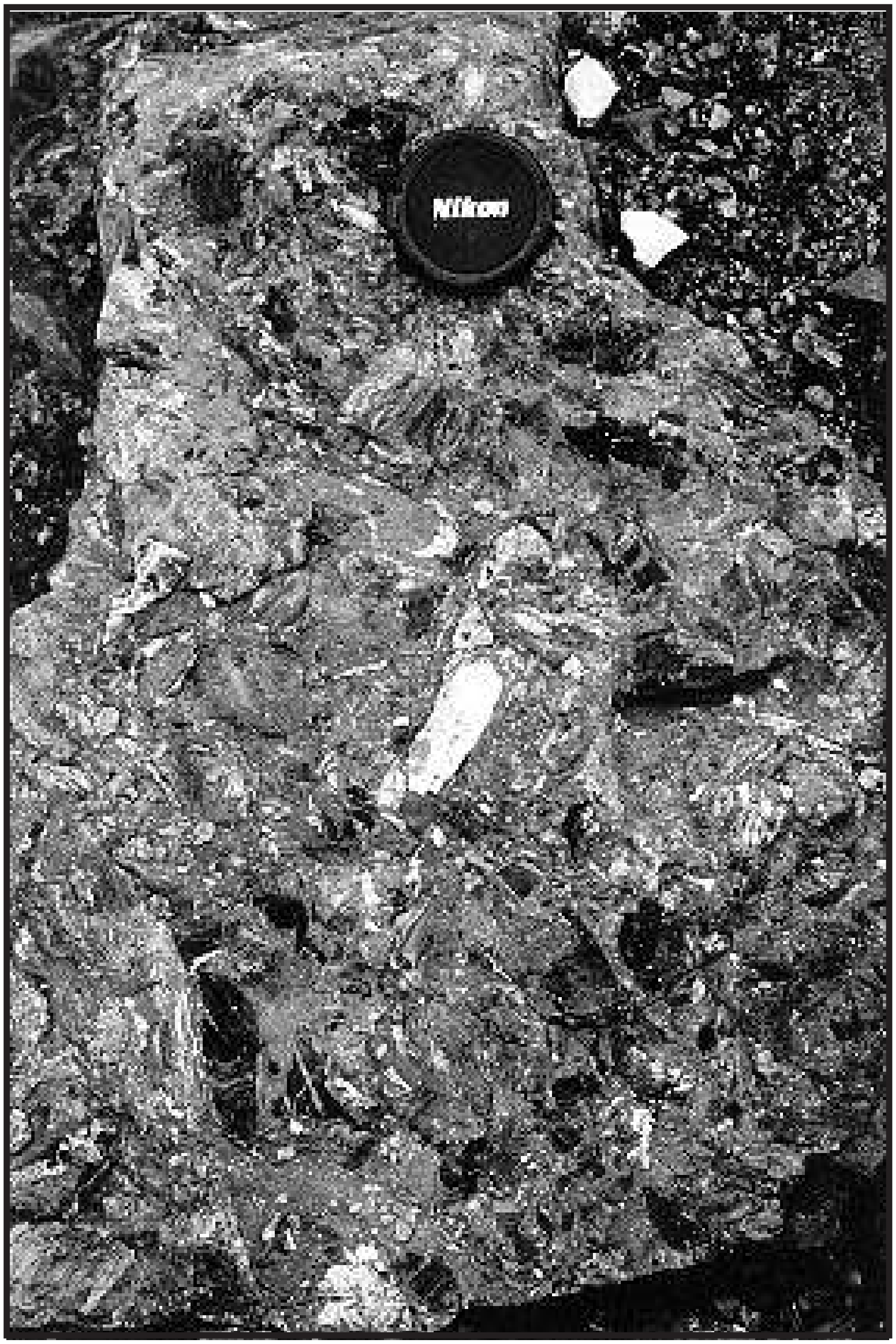

Figure 33. Photograph of mineralized dolomite breccia with black chert in the Greatwall gold deposit, Hebei Province. This breccia is typical of many heterolithic breccias that contains abundant red to black matrix fill (cement). This breccia is from the No. 3 Breccia ore zone.

orebodies. The orebodies in the Changkeng deposit (fig. 34), for example, are strictly controlled by the unconformity surface between the upper Triassic rocks (T_3X) and lower Carbonaceous rocks (C_1Z^{a-b}). Some karst caves exist in the bioclastic limestone at the footwall of the orebodies (Du, J.E and Ma, C.H., 1994). The Getang deposit (fig. 35) is present in siliceous, brecciated argillite, and siliceous limestone breccia. This group of breccia bodies is located at the unconformity surface between the Longtan unit (P_2l) and Maocou unit (P_1m) (Tao, C.G., 1990). Similarly, the Jinyia deposit (fig. 36) in Triassic rocks is controlled by a bedding-plane faults. Other gold ore bodies with this style of mineralization are the Lubuge, Beyian, Maxiong, Kagou, Dachang and Shaziling deposits or prospects (Deng, X.N., 1993).

Joints associated with folds and faults are important local ore-control structures in the Chinese sedimentary rock-hosted gold deposits. Folds usually control the overall distribution of the deposit, whereas, structural breccia zones control the local shape of the orebodies. The Zimudang (figs. 37, 38, and 39) and Yata gold deposits (fig. 40) serve as typical examples, where joints associated with folds and faults exert a strong control on the breccia-hosted gold mineralization.

In general, anticlines and faults (including high-angle and bedding faults) have been documented as the important host structures in both Nevada and Chinese Carlin-type gold deposits. There is a similarity of scale between these two regions where anticlines play a role in controlling the gold deposits regionally, while local high-angle faults, bedding faults, breccia bodies, unconformity surfaces, and other weak zones locally host or control the shape of the orebodies. The anticlines in Carlin trend, Nevada are well aligned along northwest, and some important high-angle faults such as Post and Gen faults that parallel the trend, are documented as important for orebody location and shape (Teal and Jackson, 1997). In contrast, the short-axial anticlines—important in the sedimentary rock-hosted deposits in P.R. China—contain high-angle faults which arc around the domal structures, rather than cross cut them.

Regional deep-crustal rifts are major influences on the host structures in sedimentary rock-hosted gold deposits. This is because these deep, through-going structures play a significant role in localizing the deposits by providing regional-scale permeable conduits and by providing foci for tectonic and hydrothermal activity. District- and local-scale high-angle faults proximal to these deep-crustal rifts provide local conduits for hydrothermal fluids. Other structures provide conduits for deposition or replacement of hydrothermal fluids rich in gold, silica, and other constituents found in the deposits. Most structures in sedimentary rocks have potential to serve as host-structures for Carlin-type gold deposits, which implies that these deposits have the potential to occur at any particular structural weakness in sedimentary rocks.

Host-rocks

The host rocks of sedimentary rock-hosted gold deposits in the area of the Carlin trend, Nevada are shown in table 5. Two main kinds of sedimentary assemblages, carbonate and silici-clastic rocks, are the most common host rocks of sedimentary rock-hosted gold deposits in north-central Nevada. Their lithology includes silty limestone and dolomite, siltstone, sandstone, conglomerate, and argillite with interbedded clay and shale. Silty carbonate, calcareous siltstone, and specifically local debris flows or sedimentary breccias—that represent transitional lithofacies between massive limestone units—are the most favorable host rocks Carlin-type gold deposits (Christensen, 1996; Arehart, 1996).

Most Chinese sedimentary rock-hosted gold deposits are hosted in marine carbonate- and clastic-rich sedimentary rocks, and locally interbedded volcanic flow rocks or tuff. The host-rocks of the main Chinese Carlin-type gold deposits are listed in table 6. These rocks

Table 5. Host rocks of Carlin-type Gold Deposits in Carlin Trend, Nevada

Deposit Name	**Host Rocks**	**Formation**	**age**
Gold Quarry	Rhythmically thin-bedded gray siltstone, mudstone, chert and argillite	Rodeo Creek unit	Devonian
Post, Blue Star, Bootstrap, Deep Star, Genesis, Betze	Medium to thick-bedded gray limestone, with variably micritic, sparry, and grainy texture and locally fossiliferous	Devonian Limestone (Popovich limestone or Devils Gate limestone)	Devonian-Silurian
Carlin, Betze	Thin-bedded platy gray silty limestone, dolomitic calcareous siltstone, debris flow and fossil debris beds	Robert Mountains Formation	Ordovician

Compiled from Christensen (1994)

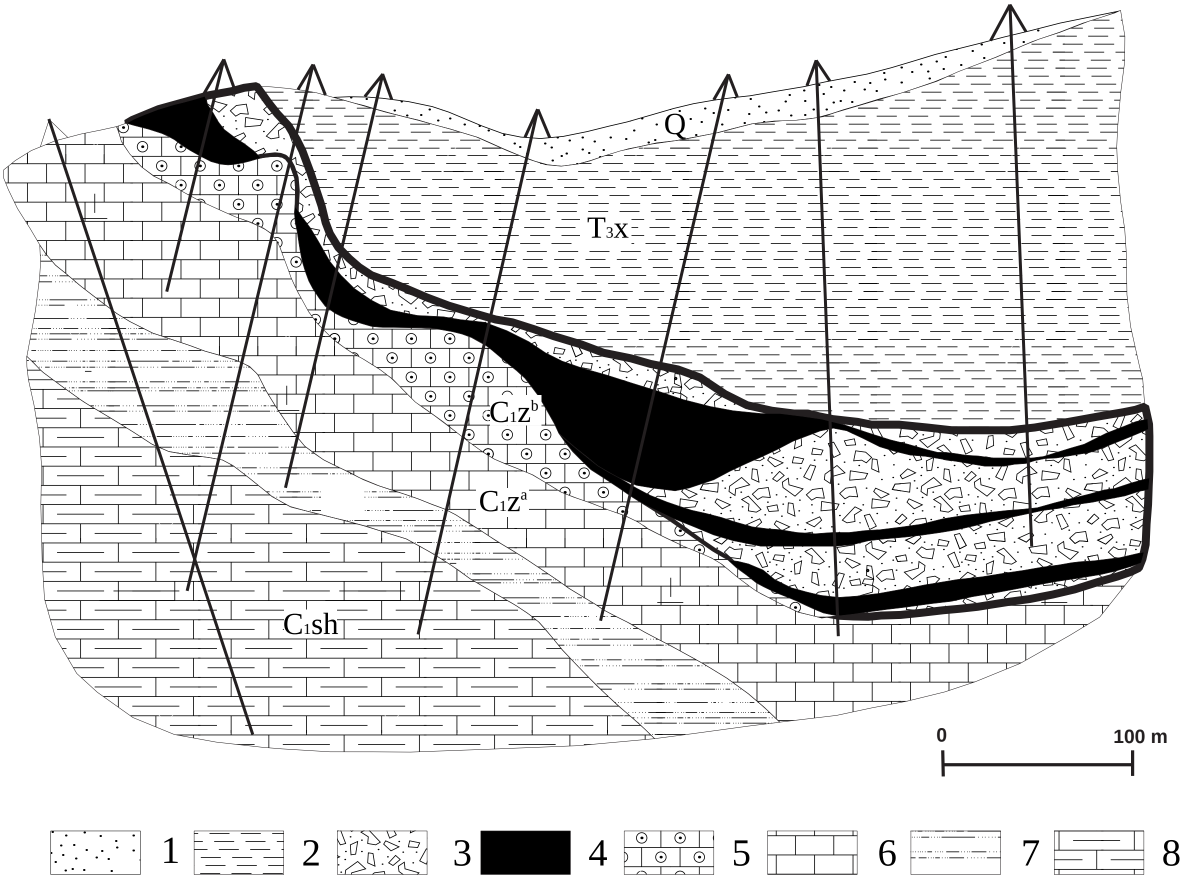

Figure 34. Geologic section of the Changkeng gold deposit, showing ore control on and between unconformity surfaces T3x and C1b. 1-Quaternary rocks; 2-shale, carbonaceous shale, siltstone; 3-breccia alteration zone; 4-orebody; 5- bioclastic limestone; 6- argillaceous limestone; 7-siltstone, calcareous siltstone, thin-bedded limestone, coal; 8-thick limestone. Compiled from Du, J.E and Ma (1994).

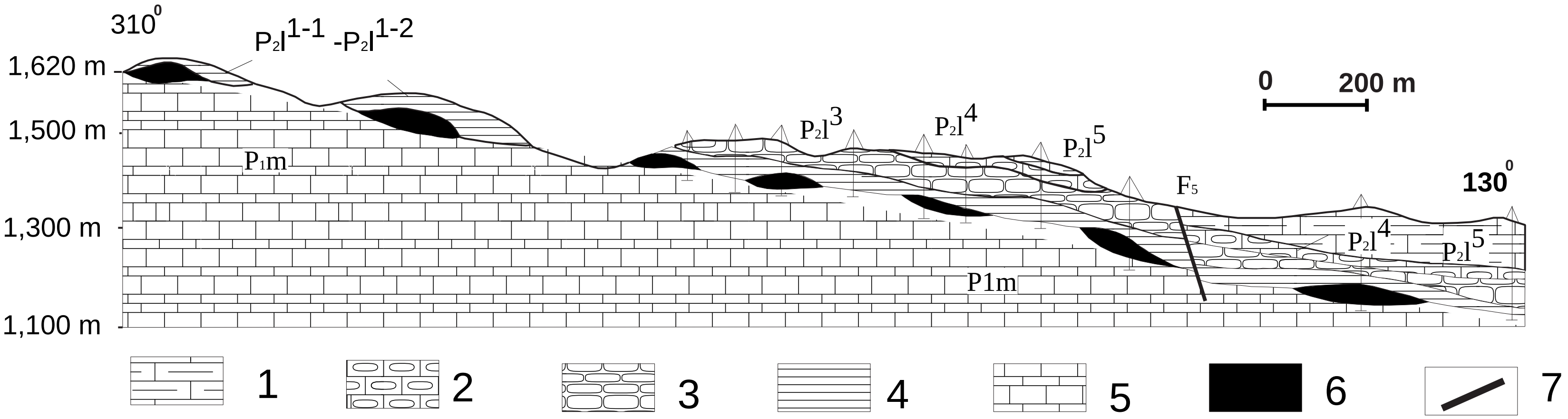

Figure 35. Geological section of Getang gold deposit. Orebodies are located on the unconformity between unit P2l3 and P1m and have the shape of topographic surface. The orebodies were formed on the old erosion surface. 1-limestone (Maokou group); 2, 3, 4, 5-mudstone, siltstone, limestone and coal (Longtan group); 6-orebody; 7-fault. Adapted from Tao, C.G. (1990).

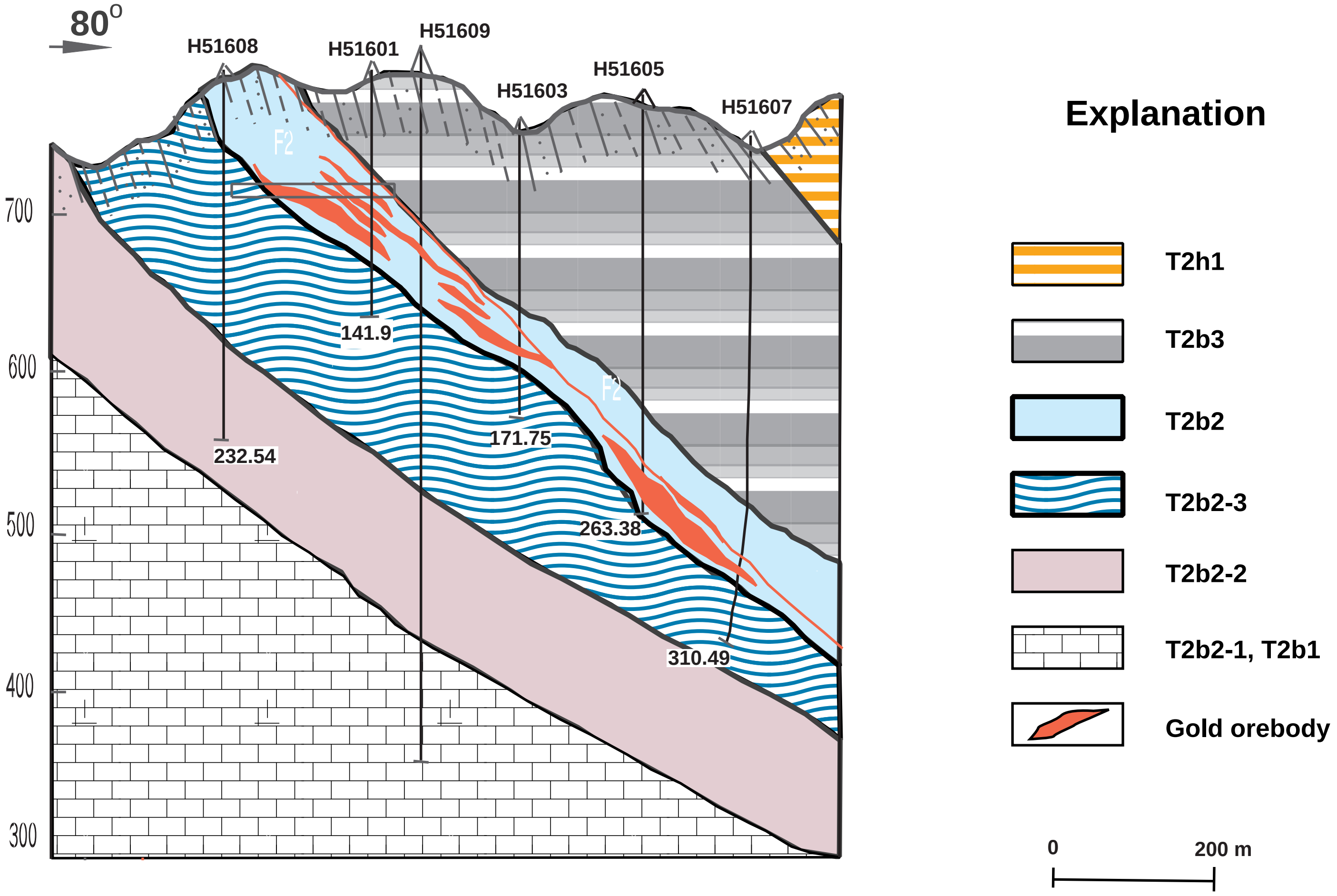

Figure 36. Geologic section from the Jinyia gold deposit, showing ore-control along lithofacies contact between units T2b2 and T2b3. Adapted from Li, Z.H. and others (1994).

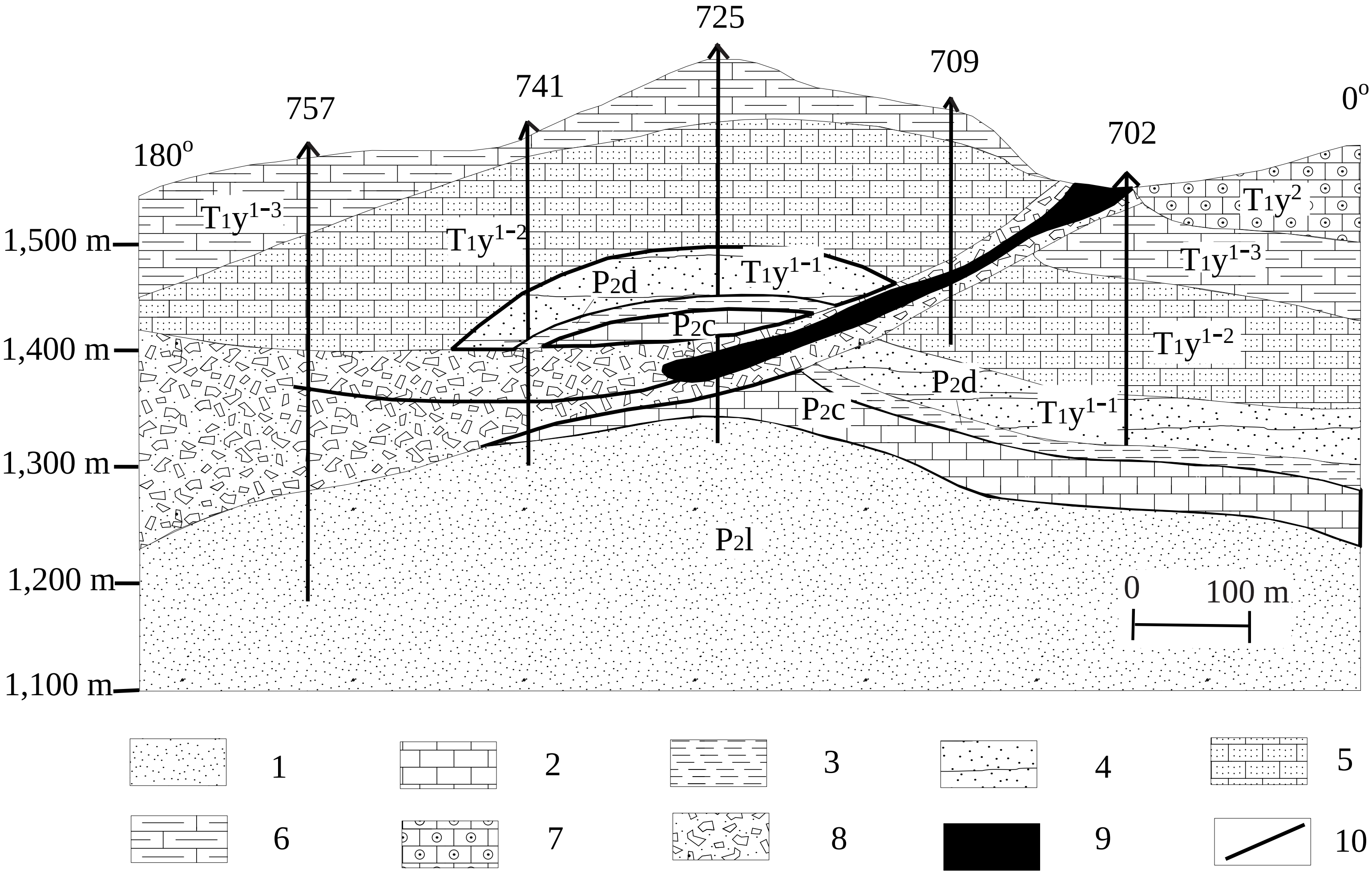

Figure 37. Geologic section of the Zimudang gold deposit. Joints associated with fault and anticlines provide the localizing host structure for the ore. 1-siltstone, silty argillite, bioclastic limestone, coal; 2-bioclastic limestone interbedded argillite; 3-thick argillite; 4-siltstone, argillite; 5-strip marl interbedded silty argillite; 6-thick bioclastic limestone; 7-bioclastic limestone, dolomitic limestone interbedded silty argillite; 8- breccia alteration zone; 9-orebody; 10-fault. Adapted from Guo, Z.C. (1994).

Figure 38. Photograph of ore with breccia texture in the Zimudang gold deposit, Guizhou Province.

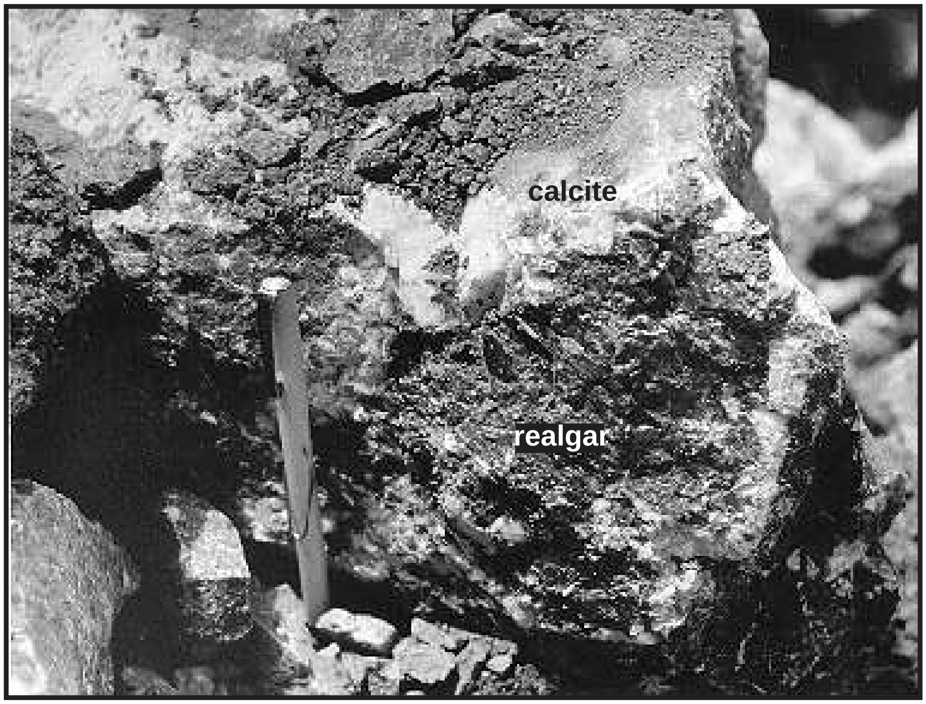

Figure 39. Photograph of ore with realgar and calcite in the Zimudang gold deposit, Guizhou Province.

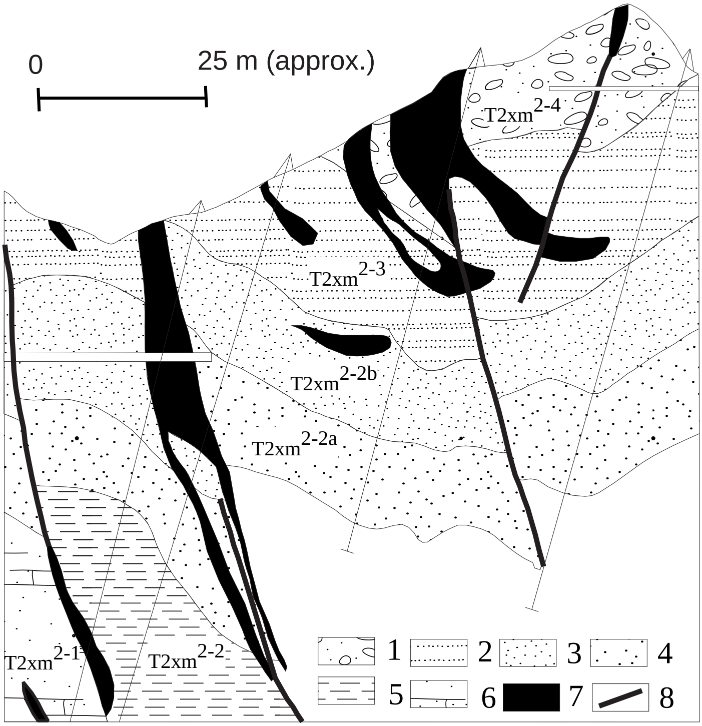

Figure 40. Geological section of the Yata gold deposit, showing the joints associated with faults and anticlines that control the orebodies. 1-sandstone, argillite; 2-sandstone interbedded limestone; 3, 4, 5-argillite, siltstone; 6-calcareous sandstone, siltstone interbedded lenses of limestone; 7-orebody; 8-fault. Adapted from Tao, C.G. (1990).). Approximate location of figure is 105^{0}39' 00"E; 24^{0}56' 00"N.

Table 6. Host rocks of Carlin-type Gold Deposits in P.R. China

Deposit	**Overlying strata**	**Host-rock**	**Underlying strata**
Jinya	dolomitic, argillic siltstone, silty mudstone, dolomite	medium to thick silty mudstone inter-layers argillic siltstone	thin, bioclastic limestone; medium limestone inter-layers carbonaceous mudstone, tuffaceous mudstone and tuff
Shuangwang	calcareous sandstone, siltstone, crystalline limestone, bioclastic limestone	breccia, silty slate inter-layers argillic limestone, crystalline limestone	siltstone, slate, argillic limestone
Getang	chert limestone, siliceous shale	siliceous limestone breccia	limestone, clay rocks
Liba	phyllite, spotted phyllite, siltstone	silty phyllite, meta-siltstone	phyllite, spotted phyllite, siltstone
Pingding	tuffaceous slate, limestone, silty slate	tuffaceous slate, carbonaceous, calcareous slate, bioclastic limestone argillic dolomite	argillic slate, silty slate, limestone
Baguamiao	siltstone, silty slate	spotted silty phyllite inter-layers crystalline limestone	medium limestone, dolomitic phyllite,
Lannigou		thick sandstone, siltstone inter-layers clay rocks	clay rocks, limestone, *in*ter-layers clay rocks, micritic limestone, bioclastic limestone

typically were formed in abyssal or bathyal and turbidite environments, such as limestone, argillite, siltstone, sandstone, and shale. Low-grade metamorphic rocks such as spotted phyllite, slate, and crystalline limestone, which had original carbonate and clastic sedimentary protolith, host some deposits.

In the Dian-Qian-Gui area (fig. 6), siltstone, argillite and impure limestone are the main host rocks. A very important feature, similar to Nevada Carlin-type gold deposits, is the presence of impure carbonate and calcareous clastic rocks that represent a transitional zone of sedimentary facies. These are the best host rocks, and gold mineralization is more common in the clastic rocks of the transitional zone. For example, *in* the Zimudang gold deposit, the main host rocks are argillite, silty argillite, basaltic tuffaceous siltstone and silty dolomite. All of these rocks near the orebody have been broken by faults and are strongly silicified. Gold orebodies occur along these faults with the largest tonnages and grades located where argillite and clastic rocks intersect the fault. There is little ore or no gold mineralization in thick dolomite and limestone, which also intersect the faults (Peng, Y.Q., 1994).

Sedimentary rock-hosted deposits in the Dian-Qian-Gui area usually are stratabound, and this has lead several workers to suggest that specific sedimentary or volcanic horizons should be considered as source-beds for the gold in the deposits, even suggesting that the gold deposits could be syngenetic (Tan, Y.J., 1994). Three kinds of sedimentary formations, which were formed in different environments and are related to different types of gold mineralization, are considered as the main host stratigraphic units or source-beds for Carlin-type gold deposits in this area by Tan, Y.J. (1994):

(1) terrigenous clastic or volcanic-terrigenous siliceous clastic rocks formed in a littoral environment, *in*cluding the Bejiao (Yujiang) units (lower Devonian) and the Longtan unit (including Dachang group, upper Permian);

(2) carbonate-bearing fine-grained clastic rocks deposited in a platform shallow sea environment, *in*cluding the upper Permian Changxing unit and lower Triassic Yielang assemblages; and

(3) turbidites deposited at the continental slope and in a deep sea environment, *in*cluding Xinyuan (local name: Xuman, Baifeng and Banna group, upper Triassic).

The characteristics of these host stratigraphic units (Tan, Y.J., 1994) are as follows:

(1) **Terrigenous clastic or volcanic-terrigenous clastic rocks**, the lower Devonian Yujiang assemblage, consisting of greenish gray to dark gray, silty argillite, and interbedded siltstone, has an average Au content of 4.6 ppb. The upper Permian Longtan assemblage is argillite (1.92 ppb Au, locally averaging 8 ppb Au, with some horizons up to 19 ppb Au), siltstone (2.67 ppb Au), coal layers (1.63 ppb Au), basalt (44.7 ppb Au), and pyroclastic rock (54.33 ppb Au). These rocks host Au-Sb-pyrite mineralization (Tan, Y.J., 1994) in the northwest part of the Dian-Qian-Gui area, *in*cluding the Gedang, Maxiong, Getang and Dachang deposits (appendices I and II).

(2) **Carbonate-fine clastic rocks**, the upper Permian Changxing unit and lower Triassic Yielang assemblages, consisting of argillite, siltstone, and impure limestone averaging 8 ppb Au. Of these, the silty argillite contains gold values up to 15 ppb. They host Au-Hg-Tl mineralization in the northwest Dian-Qian-Gui area including the Zimudang gold deposits (Tan, Y.J., 1994).

(3) **Turbidites,** the middle Triassic Xinyuan assemblage rocks, *in*cluding 70 vol. percent siltstone and argillite, 10 vol. percent graywacke, and 20 vol. percent carbonate (micritic limestone, bioclastic limestone). Their gold content ranges from 2 to 12 ppb, averaging 6.73 ppb. These rock contain Bouma sequences (fig. 41), which consist of rhythmic bedding of calcareous fine sandstone, siltstone, calcareous

argillite; there also are inter-beds and lenses of argillaceous limestone and limestone. Au-As-(Sb) mineralized occurrences are typically related to these turbidites in the southeast part of the Dian-Qian-Gui area (Tan, Y.J., 1994).

In the Qinling area, sedimentary formations of Devonian age are the main host rocks (figs. 6 and 17). Lithology and local names vary from one place to another so that correlation of different rock units is not well understood. Generally, the sedimentary lithofacies in the Qinling area can be divided into three zones, which are exposed as stripes with an east-west orientation: The north and south stripes are the Tangzang-Shanyang sub-basin and the Hueixian-Xunyang sub-basin. The central stripe is the Fengxian-Zhengan sub-basin in which the well-known Shuangwang gold deposit resides. The main characteristics of the Devonian stratigraphic sequence in the middle of the Fengxian-Zhengan sub-basin stratigraphic zone, according to Fan, S.C. and Jin, Q.H. (1994) are: the middle Devonian Gudaoling assemblage of calcareous sandstone, siltstone, *in*terbedded micritic limestone is present at the top, and a medium-thick micritic limestone and bioclastic limestone, *in*terbedded with carbonaceous calcareous slate is present at the bottom. The upper Devonian Xinghongpu assemblage includes micritic limestone and argillaceous limestone interbedded with slate at the top and silty slate interbedded with thin layers of argillaceous limestone at bottom. The upper Devonian Jiuliping assemblage consists of a sequence of siltstone, slate, and argillaceous limestone, which were deposited in a flysch sedimentary environment at the top, and calcareous siltstone interbedded with silty slate at the bottom.

The Qinling area, along the northwest margin of Yangtz Craton, also contains sedimentary rock-hosted gold deposits with high organic carbon content. Many large or extra-large gold deposits occur in or are associated with these carbon-rich, black sedimentary units. The Laerma deposit is a typical example, and others include the Dongbeizhai, Pingding, Jiuyuan, and Heidousi gold deposits (appendices I and II), all of which are hosted by fine-grained, black clastic rocks (Zeng, Y.F. and Yin, H.S., 1994). The organic carbon content ranges from 0.66 to 14.63 wt. percent (average 3.42 wt. percent) at the Laerma deposit (Li, Y.D. and Li., Y.T., 1994), and 0.2 to 0.7 wt. percent (average 0.45 percent) in the host rocks of the Dongbeizhai deposit (Mao, Y.N. and Li, X.Z., 1994). The high gold content in these carbon-rich, black-colored sedimentary rocks is a common geochemical feature. For example, the gold content of the host rock at Laerma (21.06 to 30.70 ppb) is 10 to 15 times higher than the regional background gold content (1.95 to 2.1 ppb).

Some geologists consider that these black formations are the source-beds for both petroleum and gold deposits (Li, Y.D. and Li, Y.T., 1994; Zeng, Y.F. and Yin, H.S., 1994). Their theories suggest that organic carbon was involved in the process of gold mineralization and was an important factor in the enrichment of gold; however, other geologists think there is no direct relation between gold enrichment and organic carbon (see also Huang, Y., 1993; and Mao, Y.N., and Li, X.Z., 1994).

The Liba and Dongbeizhai gold deposits in the Qinling area are hosted in low-grade metamorphic Devonian and Triassic meta-siltstone, phyllite, and slate. Igneous rocks are more plentiful in the Qinling area relative to the Dian-Qian-Gui area (figs. 15, 18). Six large late Mesozoic granitic intrusions, several small Middle Paleozoic basic rock intrusions, and local andesitic porphyritic-dacite bodies, as well as Cenozoic alkalic to ultramafic volcanic rocks are exposed near the Liba gold deposits. Spessartite, diorite, oligoclase aplite, and granodiorite dikes also are present in the Liba gold deposit (Liu, M., 1994). Some dikes are mineralized by gold. The geochemical signature of the granitic intrusions, Sn, W, Mo, Bi, is different from intrusions found near most sedimentary rock-hosted gold deposits in Nevada.

In summary, the host rocks of sedimentary rock-hosted gold deposits in P.R.

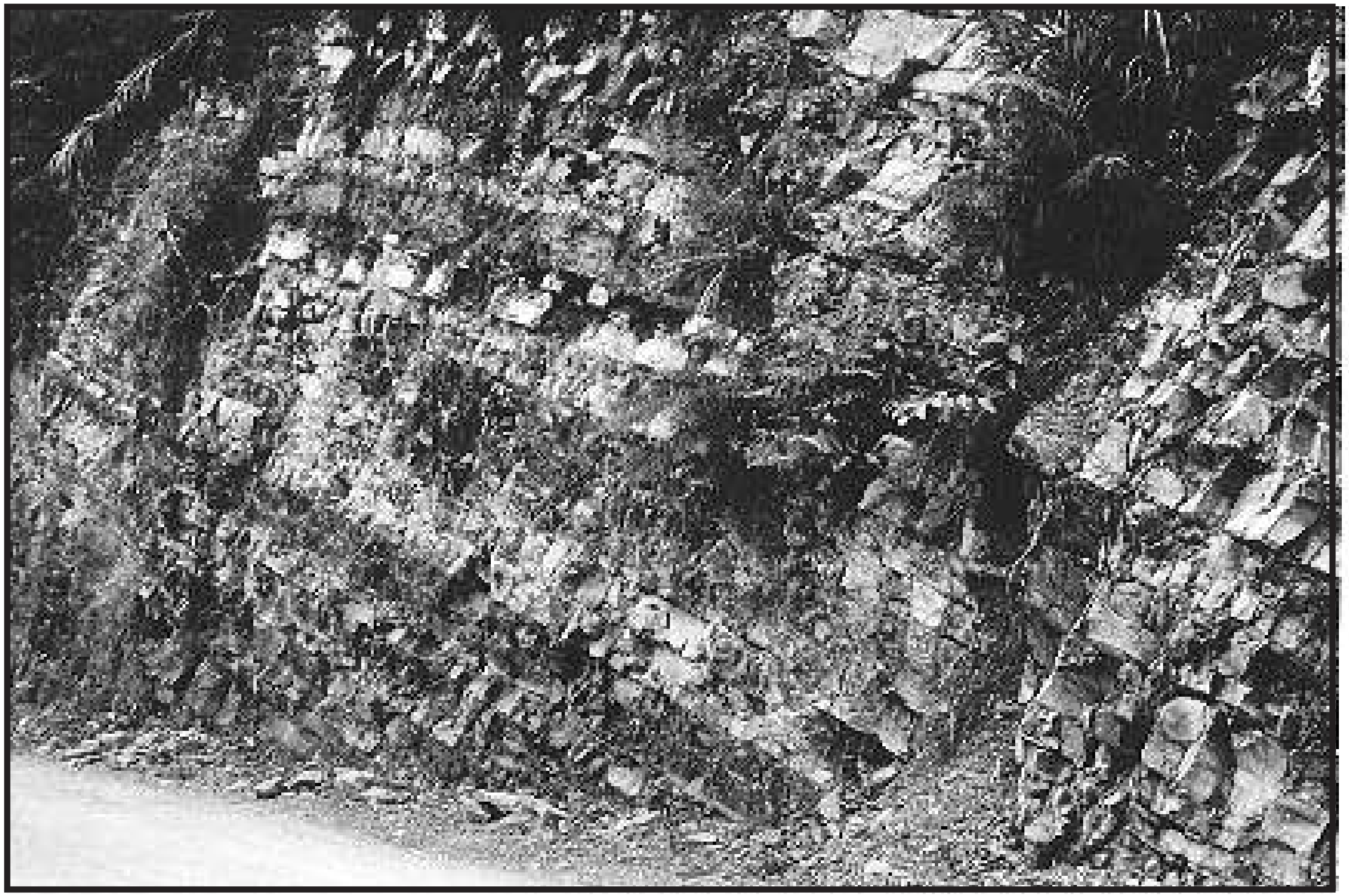

Figure 41. Photograph of turbidite stratigraphy in the Guangxi Province. Horizontal field of view approximately 15 m.

China are carbonate-bearing sedimentary units that are interbedded with siliciclastic and volcanic rocks, similar host rocks in Nevada. In the Dian-Qian-Gui area, impure limestone, silty argillite and siltstone (carbonate-clastic formation) are related to Au-Hg-Tl type gold deposits; Au-Sb-pyrite deposits are present in silty argillite, siltstone interbedded with basaltic lava, breccia, and tuff, (terrigenous or volcanoclastic formations). Turbidites, *in*cluding siltstone, argillite, graywacke, and carbonate-bearing rocks (micritic and bioclastic limestone) also host Au-As-(Sb) type gold deposits. In the Qinling area, argillaceous limestone, bioclastic limestone, argillite, siltstone, carbonaceous calcareous slate and shale host most of the sedimentary rock-hosted gold deposits. However, some carbon-rich black clastic sedimentary rocks (black shale) host both large and extra-large sedimentary rock-hosted gold deposits and also U deposits. Low-grade metamorphic rocks and some igneous dikes also serve as host rock to some of gold deposits, but a direct connection of gold mineralization to igneous activity is usually lacking in most deposits.

In general, Chinese sedimentary rock-hosted gold deposits are more common near the transitional zone between carbonate and siliceous clastic rocks, particularly on the siliceous clastic rock side (for example, Lannigou deposit). Many of the deposits are hosted in sandstone or calcareous sandstone. The diagnostic characteristics of these host-rocks are: (1) carbonate and siliceous clastic rocks; (2) turbidite layering; (3) interbedded tuff or other volcanic rocks; and (4) organic carbon content in host rocks up to 0.5 wt. percent (Liu, D.S. and others, 1994).

Hydrothermal Alteration

Common hydrothermal alteration types—such as silicification, and argillization—have been observed in most sedimentary rock-hosted gold deposits both in Nevada and in P.R. China (Radtke, 1985; Kuehn and Rose, 1985, 1992; Bakken, 1990a, b; Ferdock and others, 1996). Decalcification (decarbonatization), sericitization, alunitization, baritization, and carbonization vary from one deposit to another. Carbonization, decarbonatization and albitization are specific and common alteration types found only in some Chinese sedimentary rock-hosted gold deposits (Wang, J. and Du, L.T., 1993; Fan, S.C. and Jin, Q.H., 1994; Liu, D.S. and others, 1994).

Silicification is the most important hydrothermal alteration type related to gold mineralization in most sedimentary rock-hosted gold deposits, and also is widespread in other types of gold deposits. Most gold deposits (including Carlin-type, hot-spring, porphyry-related, volcanic-hosted, and low-sulfide gold quartz-veins) are related to silicification and to quartz veining (Li, Z.P., 1989, 1992; Li, Z.P. and Yang, W.S., 1989; Yang, M.Z. and Li, Z.P., 1989). Silicification in Carlin-type deposits may take one of several forms. Commonly, silicification is present as cryptocrystalline, hard replacements and as microcrystalline jasperoid, as well as quartz stockwork veinlets and veins in fractures of altered host rocks. Silicification in Carlin-type gold deposits is more common as replacement silica in host rocks relative to veining.

Silicification has been reported in most sedimentary rock-hosted gold deposits in Nevada, P.R. China and elsewhere (Arehart, 1996; Liu, D.S. and others, 1994). Multiple episodes of silicification are often observed. For example, at least seven different episodes of silicification related to gold mineralization have been recognized in the Gold Quarry Mine, southern Carlin trend (Dean and others, 1990); multiple silcification episodes are recorded by Leonardson and Rahn (1996) in the Betze deposit; two to five of episodes silicification are described in the Pingding deposit (Lin, B,Z. and others, 1994); three episodes of silicification are known in the Lannigou (Luo, X.H., 1994) and the Jinlongshan gold deposits (Hu, J.M. and Zhang, H.S., 1994). In general, silicification in Carlin-type gold deposits can be divided into three stages, with different characteristics and relation to gold mineralization:

(1) Cryptocrystalline silica with chalcedony and microcrystalline jasperoid are formed by replacement of host rock at an early stage. These silicified rocks contain silica-replaced bedding layers and breccias, and may be distributed as cap rock above the deposits. This often constitutes good landmarks for exploration such as at the Gaolong gold deposit (figs. 42, 43, 44, 45).

(2) Stockwork veining is a type of silicification that is commonly formed during the middle stages of ore formation. It is often present on the flanks of orebodies along ore-controlling faults and is closely related to gold deposition.

(3) Late-stage ore formation is accompanied by silicification that consists of quartz-calcite-(stibnite-barite) veinlets, which occur in fractures and cavities in brecciated host rock (see Peters and others, 1997).

This three-stage silicification pattern has been observed in the Gaolong, Lannigou and the Jinlongshan Chinese Carlin-type gold deposits (Luo, X.H.; 1994, Hu, J.M. and Zhang, H.S., 1994) and is similar to silicification stages in the Betze deposit in the Carlin trend (Leonardson and Rahn, 1996).

Decalcification (also referred to as decarbonatization, Arehardt, 1996) is widespread in those Carlin-type deposits in Nevada that are hosted by limestone, for example in the Carlin, Gold Quarry and Betze deposits (Dean and others, 1990; Christensen, 1996; Leonardson and Rahn, 1996). Decalcification is not as common in deposits in P.R. China, because carbonate host rocks are not as common there. However, decalcification has been reported in a few Chinese sedimentary rock-hosted gold deposits such as the Pingding, Jinlongshan, and Gaolong gold deposits where decalcification has a direct spatial relation to gold mineralization. This is also discussed below in the section on geochemistry of ores. Decalcification is a typical alteration type in most sedimentary rock-hosted gold deposits and has a direct spatial relation to gold mineralization in these deposits. This alteration type reflects dissolution and leaching of carbonate components in the host rock, especially limestone and dolomitic limestone, and increases host rock permeability. Silicification and gold mineralization may have occurred simultaneously when ore-forming fluid enriched in silica and gold moved through the porous, decalcified host rock.

Decalcification at the Carlin Mine accounts for a volume loss of 40 percent in the host Roberts Mountain Formation due to dissolution of carbonate minerals (Bakken, 1990a, b). Similarly, only 20.80 to 22.47 wt. percent CaO remains in the siliceous carbonate ore at the Changkeng deposit, which means that more than half of the carbonate in the limestone has been leached by decalcification (Du J.E. and Ma, C.H., 1994). Decalcification typically precedes early stage silicification during hydrothermal alteration and mineralization, whereas carbonization, which forms quartz-calcite veins in the host rock, is part of the late stage of the silicification process. In this way, decalcification, silicification and carbonatization may be thought of as three stages. Carbonate components in the host rock are remobilized, transported and re-precipitated, *in* the hydrothermal process. Carbonate rocks in the Pingding deposit are altered to jasperoid, which is composed of fine-grained gray quartz (or chalcedony) and hosts the orebodies. Similarly, gold orebodies are present in jasperoid along ore-controlling structures in the Jinlongshan and Gaolong gold deposits (fig. 42). Decalcification, silicification and carbonization in these Chinese deposits are thought of by Lin, B.Z. and others (1994), Hu, J.M. and Zhang, H.S. (1994) as three stages in the hydrothermal process of gold ore formation.

Argillization is a general term that includes the processes of sericitization, kaolinitization, illitization and alunitization. This type of alteration is common in sedimentary rock-hosted gold deposits, specifically those hosted by felsic volcanic rock or by clastic sedimentary rocks such as sandstone, siltstone and mudstone (Parry and others, 1997). Illite-kaolinite assemblages also

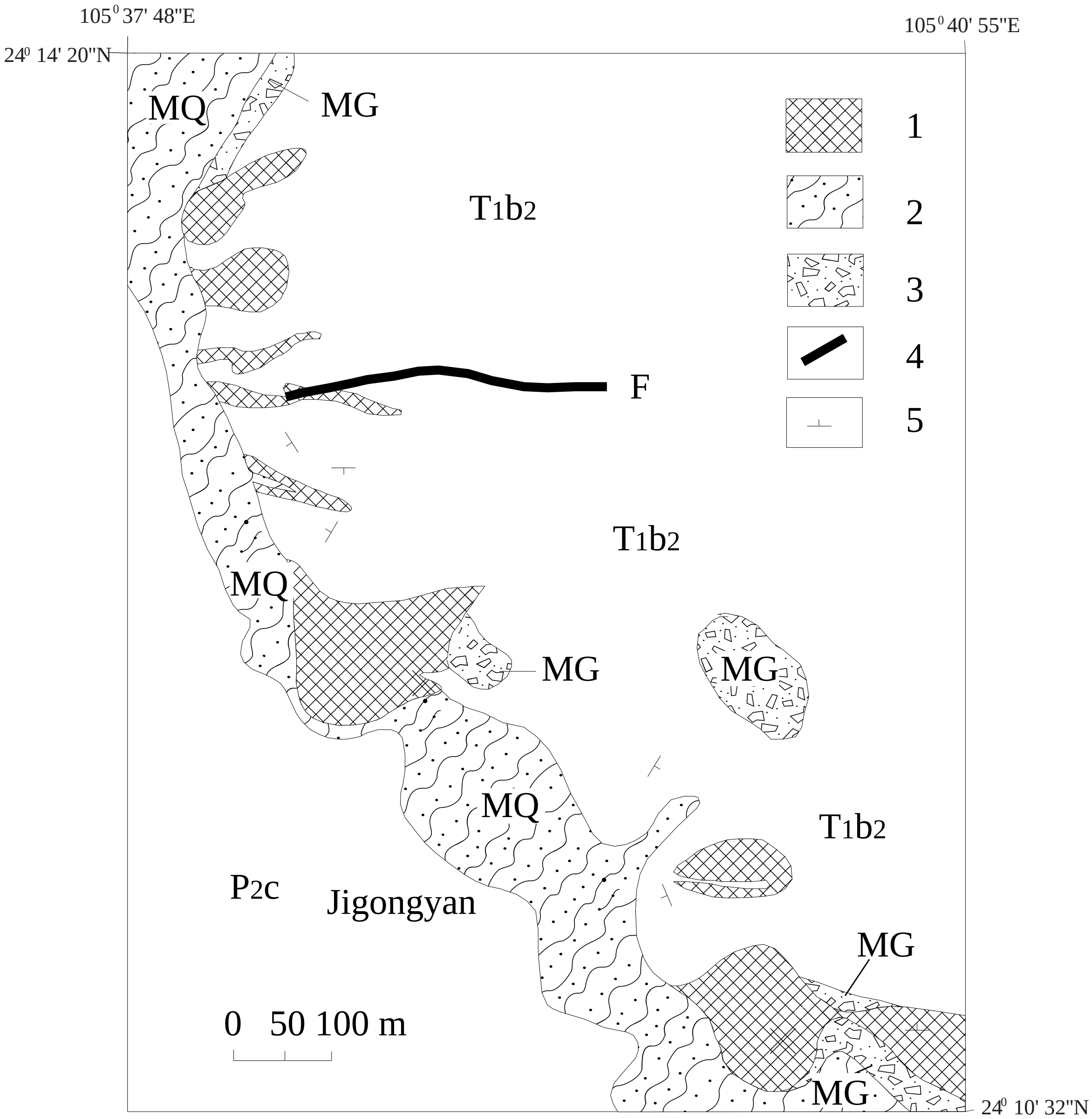

Figure 42. Silicification cap in Gaolong gold deposits area, composed of silicification breccia rock (MG) and quartz veins (MQ) that are closely associated with gold orebodies. 1-orebody; 2-quartz vein; 3 -silicification breccia; 4 -fault; 5-stike-dip. Adapted from the Second Team of Geology, Guangxi Province (Liu, D.S. and others, 1994).

Figure 43. Photograph of overview of the Gaolong gold deposit, Guangxi Province (looking north). Field of view approximately 0.75 km.

Figure 44. Photograph of mineralized jasperiod breccia in the Gaolong gold deposit, Guangxi District.

Figure 45. Photograph of mineralized jasperiod breccia in the Gaolong gold deposit, Guangxi District. White areas are hydrothermal quartz; darker areas are silicified bedrock.

are common in the decalcified limestone in the Betze deposit (Ferdock and others, 1996, 1997). Sericitization is known in deposits proximal to igneous intrusions, but commonly is interpreted to be pre-gold alteration (see Phinisey and others, 1996). Argillization typically is present when host rocks, rich in feldspar and argillaceous components, are altered by epithermal or shallow surface acidic fluids, but formation of clay minerals also has been documented in the deeper zones of Carlin-type deposits (Bakken and Einaudi, 1986; Kuehn and Rose, 1985).

Argillization often converts the host rock to a pale color, and therefore may be a marker for gold deposit exploration. Argillization has been reported as a common alteration type in most sedimentary rock-hosted gold deposits both in Nevada and P.R. China. For example, sericitization is closely associated with gold mineralization in the Liba deposits, where the alteration pattern is observed as zones grading from pyrite-sericitization, sericitization, to chloritization (from inner to the outer zones of ore-bodies). Ore-bodies are present in the sericitization zone, and the grade and thickness of orebodies directly correlate with the intensity of sericitization (Liu, M., 1994).

Carbonization is defined as alteration that enriches the host rock in carbon content and is widely present in most Carlin-type deposits (Ballantyne, 1988; Berger and Bagby, 1991; Arehart, 1996; Zeng, Y.F. and Yin, H.S., 1994). This is a part of the metallogenic process, *in* which organic materials—together with gold—are remobilized, transported and re-precipitated in the hydrothermal, ore-forming system. Graphite and pitchblende usually are the products of carbonization in Chinese deposits. Carbonization alteration has been reported in the Dongbeizhai, Laerma, and Jinyia gold deposits (Liu, D.S. and others, 1994).

Decarbonatization results from oxidation and this process could decrease the carbon content of the host rock, and promote leaching of gold from its source bed. It is considered to be favorable for gold mineralization (Wang, J. and Du, L.T., 1993). Carbon is mobilized and driven outward by hydrothermal fluids, or in the case of the Betze deposit, Nevada, by contact metamorphism (Leonardson and Rahn, 1996).

Albitization has been observed in the Shuangwang, Ertaizi, Baguamiao and other sedimentary rock-hosted gold deposits in Qinling area, but is not common in Dian-Qian-Gui area and in the Nevada deposits. Albite- and rutile-rich layers in Devonian strata in these deposits are considered to be favorable host rocks. Rutile- and other Ti-rich ores also are present in parts of the Betze deposit in the Carlin trend and are thought to be derived from detrital components in the host sedimentary rocks (Peters, and others 1997). In the Shuangwang gold deposit, a light-colored alteration zone consists of early albite, sericite, and late ankerite that extends beyond the gold-bearing breccia bodies, and is a chief prospecting marker for gold deposits in this area. Fan, S.C. and Jin, Q.H. (1994) studied the relation between gold mineralization and alteration in the Shuangwang deposit, and divided the intensity of alteration into strong, medium and weak classes (table 7). Although Au is inversely related to areas of intense albitization in most deposits, albitization is associated directly with gold in two occurrences in the Shuangwang gold deposit; one is as a gangue mineral with the gold ore; another is as matrix in the host breccia of the ore body. Albite is generally considered to be formed at an early stage of hydrothermal activity, perhaps pre-ore (Fan S.C. and Jin, Q.H., 1994).

Ore Mineralogy

Hydrothermal mineral species in Chinese sedimentary rock-hosted gold deposits are numerous (Shao, J.L. and others, 1982; Xu, G.F. and others, 1982; Geng, W.H., 1985; Liu, D.S. and Geng, W.H., 1985; Shao, J.L., 1989; Wang, K.R. and Zhou, Y.Q., 1992; Wang, X.C., 1993). At least fifty minerals have been identified from these gold deposits. However, what is the typical ore mineral association of the Carlin-type gold deposit? How numerous are

Table 7. Intensity of Albitization and gold mineralization in the Shuangwang gold deposits. (Modified from Fan, S.C. and Jin, Q.H., 1994)

albitization		**Gold mineralization**	
Intensity	Feature of rock	Gold content	Mineralization type
Strong	Brownish red, hard, albite is as main mineral	0-1 ppm	Au-bearing breccia
Medium	—	>1-3 ppm	Poor gold orebodies
	Gray yellow, medium hardness, carbonate & albite	>3-5 ppm	Rich gold orebodies
weak	Dark gray, soft, sericite & albite	>5 ppm	High grade orebodies

the ore minerals in the ore? And, where is the gold?

Mineral association: In general, the hydrothermal minerals in Chinese sedimentary rock-hosted gold deposits are similar to those present in Nevada. Typical ore minerals associated with Carlin-type gold deposits are pyrite, As-rich pyrite, stibnite, realgar, and orpiment. Gangue and alteration minerals are typically quartz, calcite, barite, clay minerals, and sericite(illite)-clay. A list of minerals and their frequency of occurrence in Chinese sedimentary rock-hosted gold deposits is contained in table 8. Pyrite is present in 96.4 percent of the Chinese deposits, and 73.2 percent of these deposits contain arsenopyrite (and/or As-rich pyrite). Other common ore minerals are stibnite, realgar, orpiment, cinnabar and some base-metal sulfide minerals, such as chalcopyrite, sphalerite, and galena. Sub micron-size gold is identified in 51.7% of the Chinese deposits. Common gangue minerals in Chinese sedimentary rock-hosted gold deposits are quartz, calcite, barite, clay minerals, sericite, and fluorite. The mineral association is different in different subtypes of deposits.

Wang, J. and Du, L.T. (1993) considered Chinese Carlin-type gold deposits as CSA type deposits (carbonaceous-siliceous-argillaceous) and classified them into three types according to host rock, and further into five subtypes differentiated by geochemical elemental and mineral association (table 9). The five mineral associations in these subtypes of Chinese Carlin-type gold deposit are: (1) gold, stibnite, aurostibnite, tungstite, pyrite, and arsenopyrite as Au-Sb-W mineralization in argillite and siltstone; (2) gold, arsenopyrite, and pyrite as Au-As mineralization in argillite and siltstone; (3) gold, stibnite, barite, and pitchblende as Au-U mineralization in cryptocrystalline silica rock; (4) gold, galena, and sphalerite as Au-Pb-Zn mineralization in silica rocks; and (5) gold, cinnabar, realgar, orpiment, chalcopyrite, pyrite, arsenopyrite, flourite as Au-As mineralization hosted by carbonate rock, considered by Wang, J. and Du, L.T. (1993) to be similar to those gold deposits in Nevada. Wang, J. and Du, L.T. (1993) think that the first four subtypes of gold mineralization are different because they are in a different host rock from sedimentary rock-hosted gold deposits in Nevada.

Similar classifications have been described by Wang, Y.G. (1994), who recognized two main subtypes of Chinese sedimentary rock-hosted gold deposits in the Dian-Qian-Gui area. One subtype is the gold deposit at Lannigou, which is hosted in silici-clastic rocks such as siltstone, and fine-grained sandstone that contain pyrite, gold, arsenopyrite, orpiment, and cinnabar with quartz, and clay mineral alteration. Another subtype is typified by the Getang and Zimudang deposits, which are hosted by limestone and interbedded shale, and contain pyrite, marcasite, gold and stibnite, with carbonate and kaolinite alteration. The differences between these two subtype implies that arsenopyrite, orpiment and cinnabar are more related to clastic sedimentary host rocks, whereas gold marcasite, and stibnite are more commonly related to limestone host rocks.

Chinese sedimentary rock-hosted gold deposits contain some unique minerals not commonly found in the Nevada deposits (Liu, D.S. and others, 1994); for example, pyrrhotite is present in the Baguamiao gold deposit as one of the main gold host minerals. Albite is present in the Shuangwang and Ertaizi gold deposits and is closely associated with gold mineralization. Carbon and U minerals, including pitchblende and graphite, are more common in some Chinese sedimentary rock-hosted gold deposits such as the Laerma, Banqi, Yata, Jinyia and Dongbeizhai deposits. In addition, several native elements are present in Chinese sedimentary rock-hosted gold deposits, such as native sulfur (Qinlong deposit), native Cu, Zn, iron, aluminum (Getang deposit), and arsenic (Yata and Jinyia deposits). Native arsenic has also been reported in the north-central Carlin trend (Barrick Goldstrike unpublished data).

In summary, mineral associations of pyrite, arsenopyrite, stibnite, realgar, orpiment, quartz, barite, calcite, and illite-clay minerals are characteristic of most Carlin-type gold deposits

Table 8. Frequency of Minerals Present in Chinese Carlin-type gold Deposits

Ore minerals[1]			**Non-ore minerals**[2]		
mineral	**present**	**%**	**Mineral**	**present**	**%**
Native gold	29	51.7	Quartz	41	83.7
Pyrite	54	96.4	Chalcedony	3	5.4
Marcasite	15	26.8	Barite	30	61.2
Arsenopyrite	41	73.2	Calcite	32	65.3
Stibnite	32	57.1	Clay mineral	24	54.7
Realgar	22	39.3	Fluorite	11	22.4
Orpiment	18	32.1	Sericite	15	30.6
Cinnabar	15	26.7	Dolomite	9	18.4
Chalcopyrite	21	37.5	Carbon	8	16.3
Sphalerite	19	33.9	Ankerite	6	12.2
Galena	10	17.8	Rutile	4	8.1
Tennantite	4	7.1	Serpentine	1	2.0
Tungstite	4	7.1	Gypsum	1	2.0
Argentite	3	5.4	Chlorite	1	2.0
Chalcocite	3	5.4	Jarosite	2	4.1
Limonite	13	23.2	alunite	1	2.0
Hematite	3	5.4	Albite	1	2.0
Pyrrhotite	3	5.4	Sulfur	1	2.0
Electrum	2	3.6	Native mercury	1	2.0
Silver	2	3.6	Muscovite	2	4.1
Magnetite	3	5.4			
Molybdenite	3	5.4			
Bornite	5.4	3			
Cerussite	1	1.7			
Siegenite	1	1.7			
Bismite	1	1.7			
Pearceite	1	1.7			
Scheelite	1	1.7			

1- the statistic result of ore mineral is based on 56 deposits; 2- the statistic result of non-ore mineral is based on 49 deposits

Table 9. Mineral Associations in Chinese Carlin-type Gold Deposits (Modified from Wang, J. and Du, L.T., 1993)

Type	**subtype**	**Host rock**	**Age**	**Mineralogy**	**Deposit example**
Deposits in argillite and siltstone	Au-Sb-W	Argillite, slate, siltstone	Proterozoic, Sinian	Gold-stibnite-aurostibnite-tungstite-pyrite-arsenopyrite	Woxi, Longshan, Mobing, Gutaishan
	Au-As	Siltstone, carbonaceous argillite, argillaceous limestone, carbonaceous slate	Proterozoic, Triassic, Cambrian, Ordovician,	Gold-arsenopyrite-pyrite-realgar	Banqi, Yata, Dongbeizhai
Deposit in jasperoid	Au-U	Carbonaceous silicalite, carbonaceous slate	Cambrian	Gold-stibnite-barite-pitchblende	Laerma
	Au-Pb-Zn	Siliceous-argillaceous limestone, silicified breccia	Permian	Gold-galena-sphalerite	Kangjiawan
Deposit in carbonate	Au-Hg	Limestone, dolomitic limestone, silty dolomite	Silurian, Devonian	Gold-cinnabar-realgar-orpiment-chalcopyrite-pyrite-arsenopyrite-picrofluite-christite	Ertaizi, Shixia, Jinyia, Langquan

Table 10. Mineral Percent and Au Content of Minerals in Ore of the Banqi Gold Deposit (After Tao, C.G., 1990)

Items	**Pyrite (including Marcasite)**	**Arsenopyrite**	**carbon**	**Clay mineral**	
Mineral (%)	3.55	0.13	0.05	40.11	
Gold (%)	5.03	0.30	0.99	92.99	
Grade (ppm)	45.89	75	53.60	75	
Items	Quartz	Carbonate minerals	Illuminate(diopside, siderite, barite)	Magnetite	total
Mineral (%)	55.85		0.20	0.11	100
Gold (%)	1.55		0.02	0.02	100
Grade (ppm)	1.76	0.03	2.94	6.50	

Table 11. Mineral Percent and Au Content of Minerals in Ores of the Yata Gold Deposit (After Tao, C.G., 1990)

Items	**Pyrite**	**Stibnite**	**Clay mineral**	**carbon**
Mineral (%)	4.72	0.05	42.51	0.11
Gold (%)	62.425	0.01	35.01	0.48
Grade (ppm)	83.2	1.32	5.2	27.32
Items	Quartz	Carbonate minerals	Pyrrhotite & Magnetite	total
Mineral (%)	47.96	4.6	0.05	100
Gold (%)	1.82	0.55	0.005	100
Grade (ppm)	0.24	0.75	0.61	

in both P.R. China and Nevada. Specific mineral associations depend on rock type, such that in P.R. China, arsenopyrite, realgar and orpiment are more common in silici-clastic rock hosts, whereas stibnite is more prominent in carbonate rocks. In general, the type and combination of ore, gangue and alteration minerals in Chinese sedimentary rock-hosted gold deposits are more complicated than those in Nevada. The reason for this may be due to different classification schemes or may be due to different crustal conditions or metallogenic epochs. The Chinese Carlin-type gold deposits are more widely spaced and distributed, and contain host rocks that represent more diverse geological settings. The presence of pyrrhotite, tungstite, and albite, as well as native metals, chalcopyrite, sphalerite and galena, are prominent features in a few Chinese sedimentary rock-hosted gold deposits.

Content of gold in ore: A characteristic feature of Carlin-type gold deposits is a very low ore mineral content, with typically fine-grained and disseminated ore minerals. For example, the average pyrite content varies from 0.5 to 3 vol. percent in the ores of the Carlin Mine, Nevada (Togashi, 1992). Similarly, about 4 vol. percent of ore minerals are contained in ores of the Banqi gold deposit (table 10), and 4.8 vol. percent ore minerals are present in the Yata gold deposits (table 11) (Tao, C.G., 1990).

State of gold and its host minerals: Gold mainly is present as sub-microscopic particles in Carlin-type gold deposits and is one of the distinct characteristics of these deposits; however, where is the gold? Satisfying answers to the total distribution of gold have not been found in current studies of Carlin-type gold deposits, even through several modern techniques such as Mossbauer spectroscopy have been applied on this research (Xu, G.F. and others, 1982; Wagner and others, 1986; Bakken and others, 1989; Wu, X. and others, 1989; Li, J.L and others, 1993, unpublished; Aerhardt and others, 1993b; Wang, K.R. and Zhou, Y.Q., 1994).

Sub-micron inclusions of native gold in the crystal lattice of pyrite or chemically bound gold in pyrite—particularly in As-rich pyrite rims on earlier pyrite—are considered as the most common probable occurrences of gold in Carlin-type deposits. Most geologists consider that gold is present as native gold, as tiny inclusions in the host minerals. For example, Mossbauer spectroscopy of pyrite in the Ertaizi deposit, P.R. China, indicates that there is no difference between gold-bearing and barren pyrite; and therefore, it is difficult to understand how the gold entered into the crystal lattice of gold-bearing pyrite (Xu, G.F., and others, 1981). According to microscopy and electron microprobe research, gold particles in the Ertaizi deposit are from 0.5– to 20–mm-size with granular or irregular and sheeted shapes, hosted mainly in pyrite and also in oxide minerals. In other research on the Shixia gold deposits, P.R. China, by transmitted electron microscopy, spherical 0.05– to 0.2–mm-size gold particles are attached to the surface of halloysite and hematite (Zhang, Z.R., 1984).

Studies using Mossbauer spectroscopy by Wagner and others (1986) revealed that some invisible gold was present in an undetermined non-metallic chemical state in pyrite and arsenopyrite. Laboratory experiments on gold-bearing arsenopyrite indicated that gold content increased with increasing As and decreasing Fe content in the pyrite grains (Wu, X. and others, 1989). Because gold is present in a metal state, it is possible that Au may substitute for Fe in the lattice of arsenopyrite, such as 2Au ´ Fe. The same result comes from dissolution experiments on arsenopyrite and pyrite (Li, Z.H. and others, 1994). Li, J.L and others (1993, unpublished data) also have suggested that gold in Carlin-type gold deposits may occur in a non-metallic chemical state, and possibly as negatively charged ions in pyrite and arsenopyrite. Research also suggests that the proportions of three forms of gold in the Jinyia deposit, P.R. China, are 90.6 to 96.9 vol. percent of sub-micron-size native gold; 9.4 to 3.1 vol. percent of chemically bound gold in pyrite, and arsenopyrite; and small amounts of gold attracted by the surface of clay minerals (Li, Z.H.

and others, 1994). In summary, the most likely occurrence of gold is as sub-micron native gold inclusions in and as chemically bound gold.

Several hydrothermal minerals in sedimentary rock-hosted gold deposits also may be potential host minerals for gold, depending on mineral association, host rock, and metallogenic conditions of the individual deposits (Mao, S.H., 1991), although As-rich pyrite is considered to be the most common gold host. Arsenopyrite, stibnite, cinnabar, realgar, orpiment, barite, quartz, organic carbon, clay, and carbonate minerals may also be gold-bearing in individual Carlin-type gold deposits. The host mineral and proportion of gold in some of the Chinese Carlin-type gold deposits are shown in table 12 and figure 46. It is clear that pyrite, arsenopyrite and clay minerals play an important role for hosting sub-micron gold in the Chinese Carlin-type gold deposits, and to a lessor extent, quartz, stibnite, and barite also are important.

Pyrite, especially As-rich pyrite, is considered to be the most favorable host mineral of Au both in Nevada and Chinese sedimentary rock-hosted gold deposits. At least two main kinds of gold-bearing pyrite are reported in the Carlin, Cortez and Getchell Mines in Nevada. One is fine-grained pyrite (<0.005 mm) with a gold content of up to 4,200 ppm; another is euhedral, coarse-grained, zoned pyrite that contains 700 to 900 ppm Au in its cores and 1,500 ppm Au in its rim. A common feature of these two gold-bearing pyrites is a high As content of about 2.25 wt. percent (7.4 wt. percent As in fine-grained pyrite and 0.29 wt. percent As in coarse-grained pyrite). Barren and As-poor pyrite is present as well in unaltered, unmineralized rocks that contain about 0.05 wt. percent As (Wells and others 1969; Wells and Mullens, 1973). In the Laerma gold deposit, P.R. China, two types of pyrite with the same features as those in Nevada deposits are present in quartz-veinlets and in the host rock as disseminations. Most of these pyrites contain very low As and a corresponding low Au content, suggesting that the ability of pyrite to host sub-micron gold depends on its As content. This positive correlation between As and Au in pyrites often is observed in sedimentary rock-hosted gold deposits (Wells and Mumin, 1973; Bakken and others, 1989; Arehart and others, 1993b; Fleet and Hamid, 1997). Corona textures of pyrites, which are formed by alteration of arsenopyrite, also are common both in Nevada and Chinese Carlin-type gold deposits. It is interesting that these pyrites usually have gold and arsenic enriched margins and depleted cores (table 13).

Quartz is a common non-metallic mineral and also an important gold-bearing host mineral in some of the sedimentary rock-hosted gold deposits. Quartz, as the main host mineral of gold in the Laerma deposit (Zhang, Z.A., 1993), and contains 1 to 28 ppm Au, 13 ppm Hg, and elevated values of As and Sb. Gold-bearing quartz can be distinguished from barren quartz by: (1) high Al_2O_3 contents (>0.20 wt. percent)—generally, the Al_2O_3 concentration of quartz ranges from 0.001 to 0.01 wt. percent; (2) high Hg content; and (3) the high correlation of Au to high thermoluminescence values of quartz, a property of thermal analysis when quartz is heated.

Stibnite is reported as a host for gold in some Chinese sedimentary-rock hosted gold deposits (Zhang, Z.A., 1993; Liu D.S. and Geng, W.H., 1987). The highest gold content of stibnite in the Laerma deposit is 233.40 ppm Au, and this stibnite also contains 135 ppm Hg.

Lower gold values also are found in stibnite of the Miaolong deposit 2.87 ppm, and in the Banqi deposit stibnite contains up to 10 ppm Au. A new sedimentary rock-hosted gold deposits, *in* which stibnite is present as the main gold host mineral, also are present in Huabei Province, P.R. China (Liu, D.S. and Geng, W.H., 1987).

Barite is widespread in most Carlin-type gold deposits, and sometimes can serve as a host mineral for sub-micron gold. For example, barite in the Laerma deposit, P.R. China, contains between 1 to 98.56 ppm Au, and also has elevated values of Ag, Sb, Se, and Hg (Zhang, Z.A., 1993).

Table 12

Gold Content of Host Minerals in Chinese Carlin-type Gold Deposits.

(Compiled from Liu, D.S., 1994)

Mineral	Changkeng		Yata	Getang	Jinyia	Banqi
Pyrite	14.05	8	62.13	52.61	12.42	5.03
Arsenopyrite	4.34	-	-	-	76.92	0.3
quartz	17.00	38	1.82	5.6	3.65	1.55
clay minerals	56.80	31	35.01	38.6	4.93	92.99
carbonate minerals	-	-	0.55	-	1.83	-
carbon	-	-	0.48	4.65	0.23	0.99
others	7.81	19	0.015	-	-	0.04

- No data available

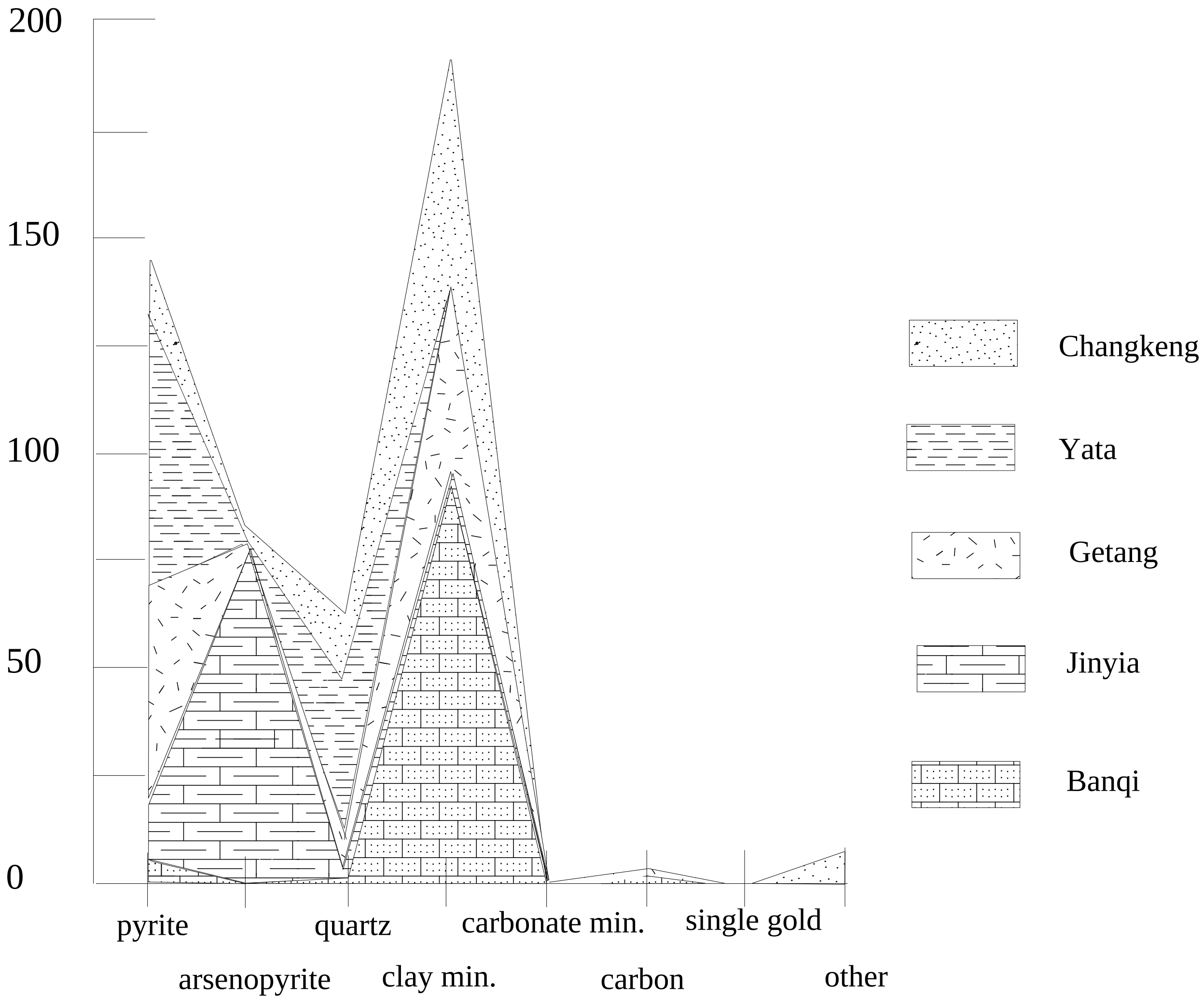

Figure 46. Percentage of gold in host minerals of Chinese Carlin-type gold deposits, showing pyrite and clay minerals are the most important host minerals for gold in some Chinese Carlin-type gold deposits.

Table 13. Analysis by Electron Probe of Corona Pyrite in Gedang Gold Deposit, P.R. China (in wt. percent)
(After Tianjin Geological Academy, 1992)

Sample	**location**	**Fe**	**S**	**Au**	**Cu**	**Ni**	**Co**	**As**	**Zn**	**Sb**
LL32-G	core	45.47	52.75	0	0.04	0	0.03	0	0	0
	margin	45.33	52.20	0.09	0	0.01	0.02	0.51	0.2	0
	core	45.59	53.83	0	0	0	0.01	0	0.04	0.01
LL32-G	middle	44.06	52.99	0.01	0.04	0	0.01	1.81	0.03	0
	margin	46.02	50.48	0.06	0.01	0.06	0.03	3.75	0	0.02
	core	46.82	52.96	0	0.04	0	0.02	0	0	0
LL32-G	middle	44.50	52.80	0.01	0.03	0.01	0.03	1.33	0	0
	margin	45.92	51.14	0.07	0.04	0	0.02	2.56	0.01	0
	core	45.96	53.18	0	0.037	0	0.020	0	0	0.003
Total	middle	44.28	52.90	0.010	0.035	0.005	0.020	1.570	0.015	0
	margin	45.76	51.27	0.073	0.017	0.023	0.023	2.273	0.010	0.007

Clay minerals also are important gold host minerals in the Banqi, Yata, Getang, Shixia, and Changkeng Chinese sedimentary rock-hosted gold deposits. X-ray diffraction analysis indicates that clay minerals contain very fine-grained metallic minerals, such as pyrite and arsenopyrite. A dissolution experiment (Geological Institute, Chinese Academy of Science, 1992) showed that 90 wt. percent of gold in clay minerals is enclosed in fine-grained pyrite (arsenopyrite), whereas, only 5 to 10 wt. percent of the gold is on the surface of clay minerals (Liu, D.S. and others, 1994).

In general, As-rich pyrite and arsenopyrite are the most important host mineral for gold in sedimentary rock-hosted gold deposits. Clay minerals serve either as host for gold-enriched fine-grained pyrite and arsenopyrite or host sub micron-size gold adsorbed on its surfaces. Stibnite, quartz, and barite also are host minerals for gold in individual deposits. Other minerals such as cinnabar, realgar, orpiment, and tetrahedrite, generally have low gold contents in most sedimentary rock-hosted gold deposits.