# CHAPTER 4

# Geology and Geochemistry of Sedimentary-Rock-Hosted Au Deposits of the Qinling Fold Belt (Chuan-Shan-Gan) Area, Shaanxi, Sichuan, and Gansu Provinces, P.R. China

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***Abstract***

The west-northwest-trending Qinling fold belt in central China lies in Sichuan, Gansu, and Shaanxi Provinces. It is a long-lived mobile belt between the Huabei (North China) and Yangtze Precambrian cratons. The 750–km-long and about 200–km-wide fold belt contains several groups of epigenetic, stratabound, and tectonized sedimentary rock-hosted Au deposits that are hosted in deformed and folded late Paleozoic to early Mesozoic sedimentary and volcanoclastic rocks. The eastern parts of the Qinling fold belt contain Carlin-type and syndeformational sedimentary rock-hosted Au deposits, and the west parts of the belt contain mainly Carlin-type deposits in north Sichuan and south Gansu Provinces. In addition a cluster of deposits are present along the Luhuo-Daofu fault zone to the west of these deposits.

Sedimentary rocks in the Qinling fold belt are folded in east-west-oriented fold zones that contain low-grade metamorphic rocks, which are composed of calcareous sandstone, chert, siltstone, interbedded micritic limestone, carbonaceous and calcareous slate, and local mafic volcanic units. Widespread magmatic activity in the Qinling fold belt resulted in emplacement of Paleozoic and Mesozoic geochemically intermediate composition stocks and plutons. Igneous rocks are not consistently spatially associated with most of the sedimentary rock-hosted Au deposits, although some deposits are hosted in dikes or in contact metamorphic zones and some of the deposits may have genetic associations with the intrusive rocks.

Geochemical elements anomalous in the deposits are Au, Hg, Sb, and Ag, with less consistently high concentrations of Tl, U, and W. Mercury and Sb deposits are widely distributed in Devonian and Carboniferous strata and Au is associated with some of these deposits. Ages of the deposits are poorly constrained and may be any time within the Phanerozoic. Alteration and mineralogy of the gangue minerals and ores in most Carlin-type Au deposits in the Qinling fold belt include illite and quartz, local carbonation, decarbonatization, and many typical sulfide assemblages such as pyrite, arsenical pyrite, As sulfide mineral and stibnite. Realgar and orpiment are abundant in many of the deposits, particularly in the West Qinling fold belt. Some minerals and elements not normally common to Carlin-type sedimentary rock-hosted A deposits locally are present in some deposits in the Qinling fold belt, such as scheelite, U, Ti, and PGE minerals.

## 摘 要

华北和扬子前寒武克拉通之间的走向西－北西的秦岭褶皱带是一个长期活动带。该褶皱带有几组层控和构造化的沉积岩型金矿床，产于已变形和褶皱的晚古生代至早中生代沉积岩和火山碎屑岩中，呈东西向展布，长约 750 公里，宽约 200 公里。东秦岭地区产有卡林型金矿床和造山带沉积岩型金矿床，西秦岭褶皱带金矿床以卡林型为主，产于川北和甘南地区，而且沿其西部的炉霍－道孚裂谷带成群分布。

秦岭褶皱带的沉积岩构成许多东西向的褶皱带，其岩性为低级变质的钙质砂岩、燧石、粉砂岩、互层的微晶灰岩、钙质和碳质板岩，局部有镁铁质火山岩。该带的岩浆活动普遍，形成许多古生代和中生代中性成分岩株和侵入体的侵位。大多数沉积岩型金矿床周围都没有火成岩出露，虽然李坝金矿床有许多与侵入体有关的地球化学特征。

与沉积岩型金矿有关的地球化学元素是 Au、 Hg、 Sb和 Ag，其次为 Tl 、U 和 W。汞和锑矿床广泛分布于中－下泥盆系地层。金矿与其中一些汞锑矿床有关。这些矿床的年龄可能在古生代与新生代之间。确切的年龄尚不十分清楚。秦岭褶皱带沉积岩型金矿床的围岩蚀变有伊利石化、硅化，局部碳化、脱碳化。硫化物组合为黄铁矿、砷黄铁矿、含砷硫化物和辉锑矿。许多矿床中都有大量的雄黄、雌黄。一些在卡林型金矿床不常见的矿物，如有钨矿、铀矿、钛矿物和铂族矿物出现在秦岭褶皱带的一些金矿床中，局部还有钠长石。

## INTRODUCTION

The west to northwest-trending Qinling fold belt lies in central China and a large number of sedimentary rock-hosted Au deposits lie along it in Sichuan, Gansu, and Shaanxi Provinces (Yang, Z. and others, 1986; Yang, K., 1996; Mao, J.W. and others, 2001) (fig. 4-1). The Chinese Province nickname of the three Provinces is Chuan-Shan-Gan and it is one of the most important Au producing regions in the country (pers. communication, Gold Bureau of Shaanxi Province, 1999). The fold belt contains a variety of types of Au deposits that are widely distributed in most of the geologic units and include Carlin-type, metamorphic rock- and sedimentary rock-hosted orogenic Au-quartz veins, porphyry- and breccia-associated deposits, as well as abundant placer Au deposits. Sedimentary rock-hosted Au deposits include Carlin-type deposits and some other types of Au deposits, all of which commonly form as stratabound lenses in deformed or folded late Paleozoic to early Mesozoic sedimentary and volcanoclastic rocks. These Au deposits commonly lie along bedding-parallel shear zones and are associated spatially with deposits of Sb, Hg, and locally U and W (Liu, D.S., 1992; Liu, D.S. and others, 1994; Xie, Y.H. and others, 1996; Li, Z.P. and Peters, 1996, 1998; Hu, R.Z. and others, 2001).

This chapter results from field and laboratory investigations conducted in 1999 and 2000 in the Qinling fold belt area as part of a joint collaborative agreement between the U.S. Geological Survey and the Tianjin Geological Academy. The agreement was designed to study and compare sedimentary rock-hosted Au deposits in the P.R. China and in Nevada. The agreement calls for joint field visitations and compilations and has resulted in research and preliminary classification of sedimentary rock-hosted and Carlin-type Au deposits (Chapters 1 and 2) and descriptions of these deposits in the Dian-Qian-Gui (Chapter 3), Qinling fold belt (this Chapter 4), and Middle-Lower Yangtze River areas (Chapter 5) P.R. China. An earlier project report is contained in Li, Z.P. and Peters (1998) with an interactive Web-based database on sedimentary rock-hosted Au deposits at [http://geopubs.wr.usgs.gov/open-file/of98-466/]. This chapter contains descriptions and results of field and laboratory studies of the Jinlongshan, Maanqiao, Songpangou, and Qiaoqiaoshang Au deposits visited in 1999. In addition, this chapter contains information from a number of prominent sedimentary rock-hosted Au deposits in the Qinling fold belt area that has been compiled from the available Chinese literature. For more detailed discussion of metallogenesis and deposit classification, see Chapters 1 and 2.

In this chapter, the regional geology and metallogeny are first summarized and then sedimentary rock-hosted Au deposits in the Qinling fold belt are described first in the East Qinling fold belt that contains the Ding-Ma Au belt (Jinlongshan (Zhenan) Au deposit) and several syndeformational sedimentary rock-hosted Au deposits (Maanqiao, Baguamiao and Shuangwang Au deposits). Then, sedimentary rock-hosted Au deposits are described in the West Qinling fold belt along the Snow Mountain Fault (Songpangou, Qiaoqiaoshang, and Dongbeizhai Au deposit), and then other deposits in the region (Liba, Yinchanggou, Lianhechun, Laerma, and Manaoke deposits). The Pulongba and Quiluo Au deposits, along the Luhuo-Daofu fault zone in the far west part of the Qinling fold belt, also are described. These deposit descriptions allow comparison of mineralogic, ore control, and geochemical characteristics of the sedimentary rock-hosted Au deposits in the Qinling fold belt with similar deposits in the Dian-Qian-Gui and Middle-Lower Yangtze River areas in China and with deposits in Nevada.

Stratigraphic nomenclature used in this chapter conforms, in most cases to that proposed by the Ministry of Geology and Mineral Resources (1985) and updated by the Committee for Determining and Approving Terminology in Geology (1993). In many local mine areas, sedimentary formation names and the names for structural features may differ, because of old and new names, and because of the use of different names by different Provincial Geologic Bureaus. Assignment of nomenclature and age assignment of units to local mine areas may also vary, because a number of relatively independent geologic governmental agencies have conducted work in some areas. These differences in nomenclature use take place at local and provincial levels in daily usage, on mine maps and in written reports and published literature.

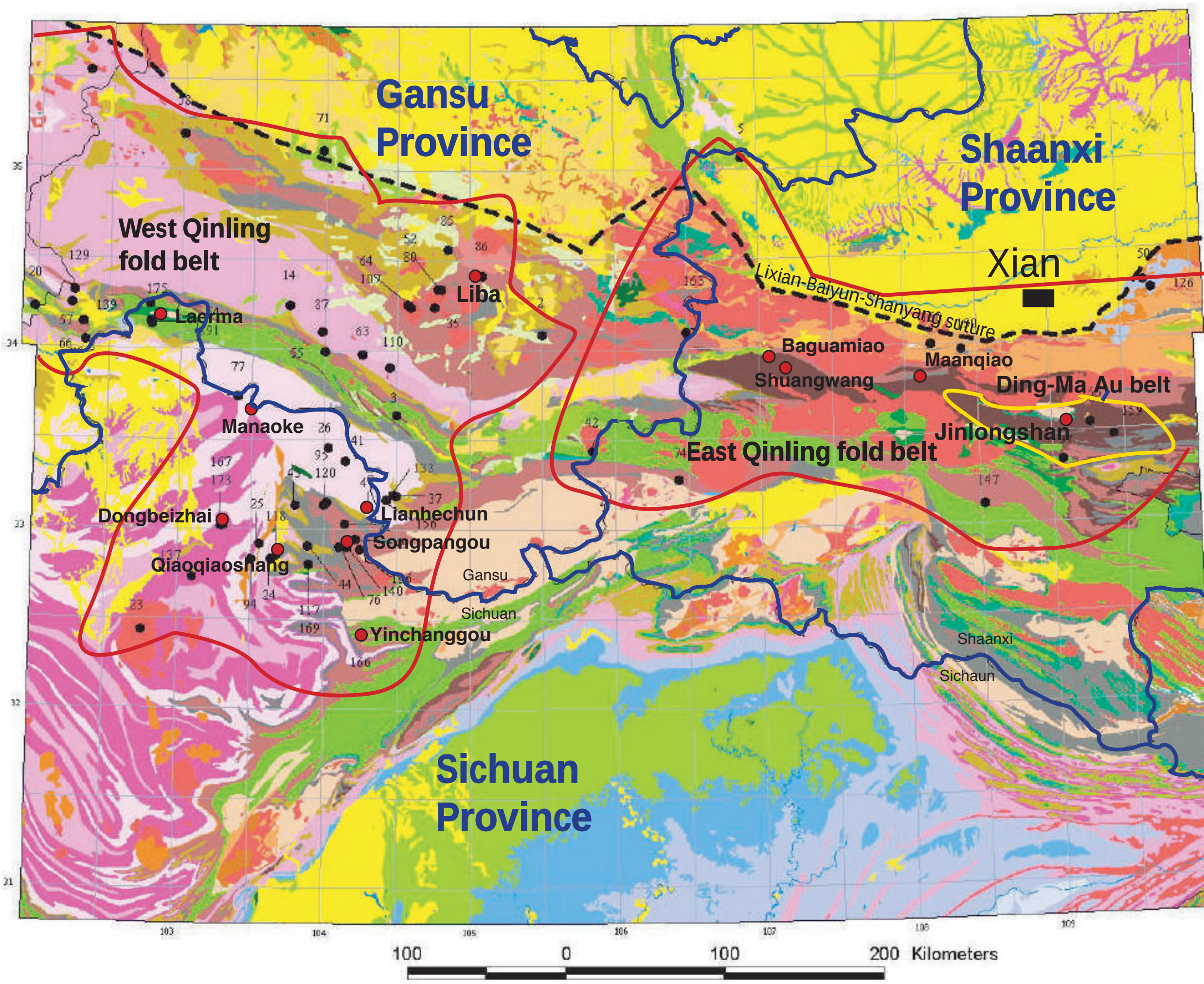



Figure 4-1A. Geologic map and distribution of sedimentary rock-hosted Au deposits in the Qinling fold belt. Dark circles sedimentary rock-hosted Au depopsits from Chapter 6 (see also, Appendix III). Larger red circle deposts discussed in text. Luhuo-Daofu fault zone deposits not shown and lie to west of figure. For geologic legend, see Fig. 4-1B.

## EXPLANATION

### STRATIGRAPHY

**Quaternary**

Q — Alluvium, mud, silt, loess; pebble beds in west Qinling area

**Neogene**

N — Mainly continental clastics, volcanics in Jinghong area

**Eogene**

E — Clastic rocks with volcanics in eastern Yunnan

**Cretaceous**

K, K2, K1 — Mainly continental and marine clastics with minor volcanics in western Qinling area

**Jurassic**

J, J3, J2, J1 — Continental clastic rocks with intrusives in western Qinling area

T-J — Incorporated beds; undivided

**Triassic**

T, T3, T2, T1 — Carbonates interbedded with sandstone and shale, volcanics in Zhongdian and Baoshan areas

P-T — Incorporated beds; undivided

**Permian**

P, P2, P1 — Continental clastic rocks interbedded with coal in Qinling area, volcanics in north Yunnan

MP-P — Incorporated beds; undivided

**Missisipian-Pennsylvanian**

MP, MP3, MP2, MP1 — Continental clastics; limestone interbedded with volcanics in Weixi area

D-MP — Incorporated beds; undivided

**Devonian**

D, D3, D2, D1 — Marine and continental clastics, volcanics in Jinghong area

S-D — Incorporated beds; undivided

**Silurian**

S, S3, S2, S1 — Marine clastics & mixed carbonate rocks in Yangtze region, vocanic rocks in west Qinling area

O-S — Incorporated beds; undivided

**Ordovician**

O, O3, O2, O1 — Continental carbonate and clastic rocks, shallow marine volcanics west Qinling

**Cambrian**

C — Clastic and carbonate rocks in Yangtze region

**Precambrian**

pC, pC3, pC2, pC1 — Undivided

### INTRUSIVE ROCKS

**1. Granitoids**

- gd — granodiorite
- g — granite
- xo — quartz-syenite (porphyry)
- eo — quartz-monzonite (porphyry)
- do — quartz-diorite (porphyry)

**2. Diorites**

- d — diorite

**3. Mafic rocks**

- n — gabbro
- bm — diabase

**4. Ultramafic rocks**

- s — peridotite
- pi — pyroxenite (porphyrite)

**5. Alkanline rocks**

- k — alkaline rocks
- b — Basalts
- x — syenite (porphyry)

### VOLCANIC ROCKS

- a — Andesites

### AGE SUBDIVISIONS

Age subdivisions appear as suffixes to formation alpha-numeric codes:

5 = Yanshanian
5-3 = Late Yanshanian
5-2 = Early Yanshanian
5-1 = Indosinian
4 = Variscan
3 = Caledonian
3-2 = Late Caledonian
3-1 = Early Caledonian

Figure 4-1B: Legend for the geological map of the Qinling and Dian-Qian-Gui areas. Legend layout, style, and geological map unit classification scheme is adopted from the Geological Map of China (Cheng, 1990). See Cheng (1990) and Wang (1990) for additional details.

## GEOLOGIC and TECTONIC SETTING

Sedimentary rock-hosted Au deposits described in this chapter cluster in several areas that are defined as discrete geologic or tectonic zones along the complex Qinling fold belt (Gu, X.X., 1996; Xie, Y.H. and others, 1996; Li, Z.P. and Peters, 1998) (fig. 4-1). The Qinling fold belt is a long-lived mobile zone between the Huabei (North China) and Yangtze Precambrian cratons (fig. 4-2) with a complex geologic tectonic and sedimentary history (Mattauer and others, 1985; Hsu, K.J. and others, 1987, 1990, 1993; Deng, S.S., 1993; Dong, S.B., 1993; Hacker and others, 1993; Yin, A., and Nie, 1996; Shao, S., 2000). Gold ore deposits in sedimentary rocks are located in an east-west-elongated area approximately 750 km long and about 200 km wide between these cratons where a Paleozoic sedimentary basin contains greater than 10,000 m of sedimentary rocks deposited during the Devonian to Triassic periods. Proterozoic and Cambrian rocks also underlie this sedimentary basin and locally are tectonically emplaced adjacent to Paleozoic rocks.

The east-trending Lixian-Baiyun-Shanyang deep-crustal suture, or subduction zone, trends east-west within and along the northern margin of the sedimentary basin (figs. 4-1, 4-2 and 4-3) and generally is considered the boundary between the Yangtze and Huabei (North China) cratons (Hu, N.G. and others, 1993; Liu, M., 1994). Many of the sedimentary rock-hosted Au deposits, particularly those with syndeformational characteristics, are distributed proximal to this deep-crustal suture, or its parallel tectonized zones, such as the Longshan, Ertaizi, Maanqiao, Shuangwang, Baguamiao, Pangjiahe, and Anjiacha Au deposits (Li, Z.P. and Peters, 1998) (figs. 4-1, 4-2 and 4-3; see also, Appendix III). Clusters of sedimentary rock-hosted Au deposits have other local controls. Deposit clusters are present along the Ding-Ma Au belt in the East Qinling fold belt, and other clusters are present in the West Qinling fold belt in northwestern Sichuan and southern Gansu Provinces (fig. 4-1), and in the far western part of the Qinling fold belt along the Luhuo-Daofu fault zone (to the west of fig. 4-1). Antimony and Hg deposits also are present in the Qinling fold belt and many Au deposits contain anomalous or economic concentrations of Sb, Hg. (Wang, X.C., 1992; Zhang F.X and others, 1997a,b; 1998).

The Qinling fold belt formed mainly between the Middle Paleozoic and Early Triassic, but has been geologically active from the Archaean to the Cenozoic. The fold belt is known for its internal complex structural relations, most of which have a west-northwest-trending grain (Zheng, Z.M. and others, 1984; Ji, X. and Coney, 1985; Ames and others, 1993; Ernst and Liou, J.G., 1995; Gilder and Courtillot, 1997; Meng, Q., and Zheng, G., 1999). Major structural subdivisions of the Qinling fold belt have been inherited from the accreted or gneissic Qiling Group that consists of slabs of Archaean and Proterozoic [226 Ma (U-Pb), 1982 Ma (Sm-Nd)] rocks derived from basal mafic volcanic rocks, clastic and carbonate-bearing sedimentary rocks, and late Proterozoic terrigenous clastic sediments. Early and middle Paleozoic sedimentation that followed in the Qinling region mainly consisted of deposition of limestone, carbonaceous pelite, volcanic rock, and sandstone. These rocks were folded and metamorphosed during the Caledonian (570 to 405 Ma) orogeny.

During the Hercynian (405 to 230 Ma) orogeny, a complete upper Paleozoic stratigraphic section of rocks was deposited in the basin that developed above the Early Paleozoic (Caledonian) fold belt between the Huabei (North China) and Yangtze cratons Gu, X.X., 1994; Zhou, D. and Graham, 1996). This new sedimentation consisted of thick Devonian flysch and limestone units interlayered with volcanic rocks. The Devonian sedimentary rocks host many of the sedimentary rock-hosted Au deposits in the Qinling fold belt and consist of upper limestone

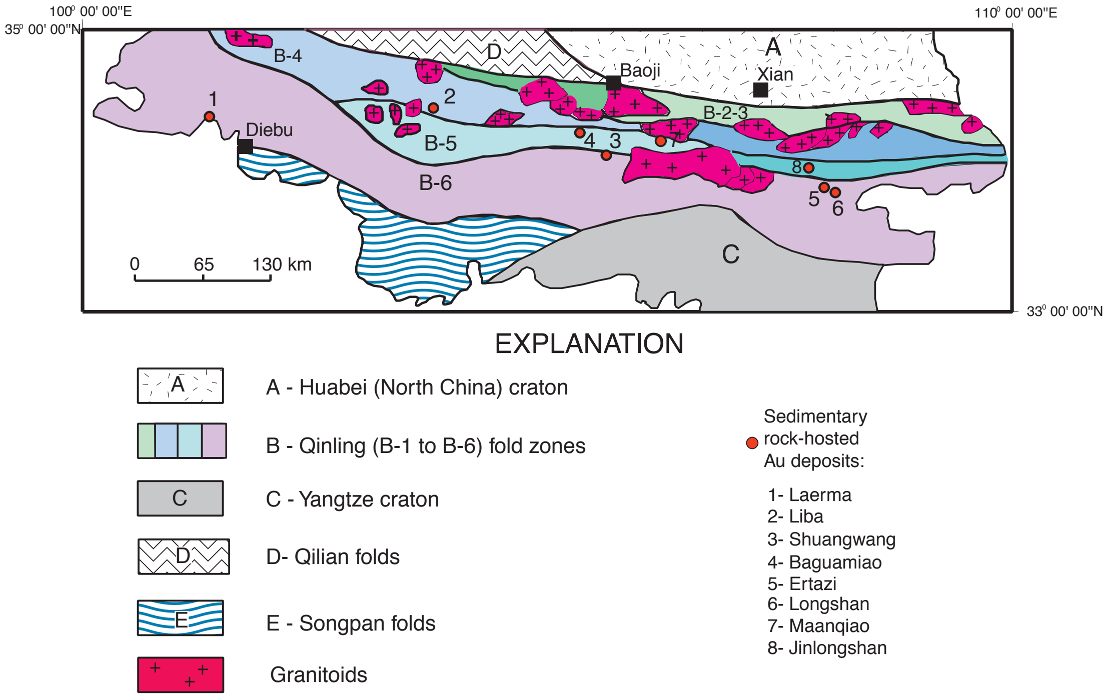



Figure 4-2. Structural geologic sketch map of the Qinling fold belt area, showing litho-tectonic units and approximate location of the Lixian-Baiyun-Shanyang deep crustal lineament between the Yangtze and Huabei (North China) cratons: A - Huabei (North China) craton, B - Qinling fold belt (B-1 to B-6 ), C - Yangtze craton, D - Qilian fold belt, E - Songpan fold belt. Sedimentary rock-hosted Au deposits are noted as red, round circles. Adapted and compiled from Liu, M. (1994) and Li, Z.P. and Peters (1998).

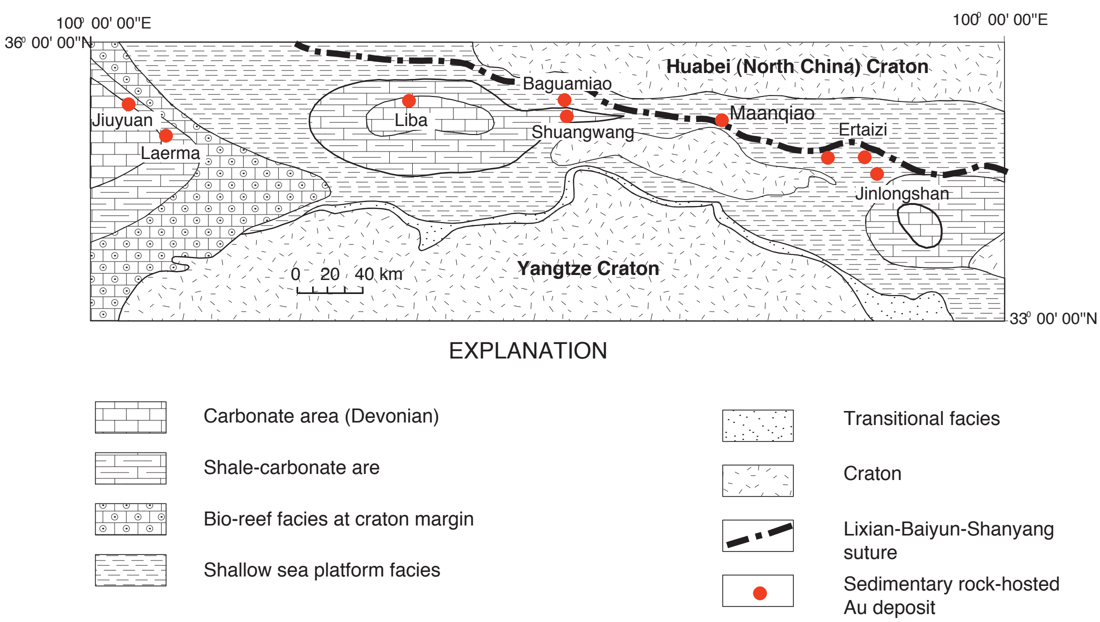



Figure 4-3. Sketch map of relation of Devonian lithofacies paleography to the distribution of Au deposits in the Qinling fold belt area. Adapted from Yao, Z.Y. (1990) and Li, Z.P. and Peters (1998).

units overlying interbedded calcareous sandstone, limestone, argillaceous limestone, and lower bioclastic limestone units (figs. 4-1 and 4-3). This Devonian sequence is overlain by Carboniferous littoral facies quartz sandstone, carbonaceous shale, and limestone. Permian sedimentation, consisting of deposition of additional limestone, accompanied by argillaceous limestone, interbedded silty shale, and siltstone, lays on top of the Carboniferous rock sequence. These rocks underwent progressive folding from west to east during Upper Devonian to Permian time and this tectonic cycle culminated with deposition of early Triassic shale and limestone in the west parts of the fold belt (figs. 4-1, 4-3) (see also; Yang, Z. and others, 1986; Wang, Y.M and others, 1996).

Proterozoic and Paleozoic rocks in the Qinling fold belt were intensely overprinted by the Mesozoic orogenic collision between the Huabei (North China) and Yangtze cratons (Zheng, Z.M. and others, 1984; Xie, Y.H. and others, 1996). This tectonism affected margins of both cratons, specifically metamorphosing and deforming previously metamorphosed Archaean migmatite and gneiss, Proterozoic terrigenous and marine sedimentary and volcanic rocks, and early and late Paleozoic and early Mesozoic sedimentary rocks (see also; Mattauer and others, 1985; Gilder and Courtillot, 1997). Sedimentation ceased at the end of the Indochina (230 to 195 Ma) orogeny and culminated in additional folding and faulting, and intrusion of intermediate to felsic, northeast-elongated plutons into the Paleozoic rocks (figs. 4-1 and 4-2). This was followed by late Mesozoic to Cenozoic extensional tectonism and block faulting.

In addition to the complex tectonic history, lithology and local names vary from one place to another so that correlation of different rock units is not well understood. Sedimentary lithofacies in the Qinling fold belt have been divided into a number of east-west-oriented lithotectonic zones by Liu, M., (1994) (fig. 4-2). The north and south main zones are the Tangzang-Shanyang sub-basin and the Hueixian-Xunyang sub-basin, which host the Liba Au deposit in the north and the Laerma, Ertazi, and Longshan Au deposits in the south (fig. 4-2). A central lithotectonic zone is the Fengxian-Zhengan sub-basin that hosts the syndeformational Shuangwang, Baguamiao, and Maanqiao Au deposits and the Jinlongshan Au and associated deposits in the Ding-Ma Au belt (Fan, S.C. and Jin, Q.H., 1994).

The main Devonian stratigraphic sequences in the central Fengxian-Zhengan zone were subdivided by Liu, M. (1994) into:

(1) Middle Devonian Gudaoling Formation consisting of upper calcareous sandstone, siltstone, interbedded micritic limestone, and a lower medium-bedded micritic limestone and bioclastic limestone, interbedded with carbonaceous calcareous slate;

(2) Upper Devonian Xinghongpu Formation containing upper micritic limestone and argillaceous limestone interbedded with slate and a lower silty slate interbedded with thin layers of argillaceous limestone, and

(3) Upper Devonian Jiuliping Formation containing upper flysch, siltstone, slate, and argillaceous limestone and a lower calcareous siltstone interbedded with silty slate.

Identification of individual lithotectonic zones is important because local control of the sedimentary rock-hosted Au deposits is directly related to specific sedimentary horizons in throughout the Qinling fold belt.

Magmatic activity was widespread along the Qinling fold belt (fig. 4-1). Intrusive rocks mainly consist of geochemically intermediate composition stocks and plutons, such as biotite granite, and granodiorite, which were emplaced during the Mesozoic (149 to 230 Ma) (Liu, M., 1994) and (198.3 to 212.8 Ma) (Fan, S.C. and Jin, 1994; Lerch and others, 1995; Zhang, G., 199). A few small, late Paleozoic mafic intrusive bodies and some andesitic porphyry bodies locally are present in the area. Paleozoic-age (230 to 195 Ma) plutons are present as equant-shaped, south-north elongated, small batholiths and grouped stocks of adamellite and granodiorite (Xu, F., and others, 1996, 1997) (fig. 4-1). Yanshanian-age (185 to 65 Ma) granite also is present as batholiths or as hypabyssal porphyry stocks that are associated with regional-scale faults and Xie, Y.H. and others (1996), suggest that orogenic quartz vein Au deposits and also some of the sedimentary rock-hosted Au deposits have a spatial and temporal relation to these granites. Normally, igneous rocks in the Qinling fold belt area are not specifically exposed in or associated with most of the sedimentary rock-hosted Au deposits, although the Liba and Maanqiao Au deposits are located in thermal contacts zones of Mesozoic intrusives, and some other deposits (*e.g*. Qiaoqiaoshang and Pulongba Au deposits) locally contain geochemically intermediate composition Mesozoic dikes along their host structures.

## DISTRIBUTION and METALLOGENY

Sedimentary rock-hosted Au deposits in the Qinling fold belt, shown on Figure 4-1, are concentrated in the Hercynian-Indonesian (405 to 195 Ma) fold belt in upper Paleozoic to early Triassic clastic and carbonate sedimentary rocks (Peng, D.Q., 1992; Zheng, M.H., 1994; Zheng, F., and others, 1998; Mao, J.W. and others, 2001). The deposits mainly hosted in specific horizons of middle and late Devonian to Carboniferous rocks in the east, and in early Triassic rocks in the west part of the fold belt (fig. 4-1). Some sedimentary rock-hosted Au deposits, such as the Laerma Au deposit, are hosted in early Paleozoic sedimentary rocks, or in Middle to Lower Jurassic volcanic rocks, such as the Jiuyuan Au deposit (Xie, Y.H. and others, 1996). Geochemical elements associated with these deposits are anomalous concentrations of Au, Hg, Sb, and Ag and lesser concentrations of Tl, U, and W. Mercury and Sb deposits with associated Au are widely distributed in middle to lower Devonian strata (Xie, Y.H. and others, 1996). Similar Au deposits also are spatially associated with some Pb and Zn deposits at the Xiahe-Chengxian, Fengxian-Taibei deposits and in the Yuexi and Xitonggou deposits along the Ding-Ma fold belt area in the East Qinling fold belt (Zhang, M.H., 1997a,b; Li, Z.P. and Peters, 1998).

Features and characteristics of sedimentary rock-hosted Au deposits along the Qinling fold belt are not necessarily diagnostic of their origin. The deposits are not easily dated. Some contain strong syndeformational or tectonized fabrics, while other ores have high organic contents. Alteration, ore mineralogy and geochemistry of the deposits have many characteristics, and Sb and As are ubiquitous.

Age of the deposits is not clear and may range from original age of the sedimentary beds, in terms of a source bed genetic theory, to orogenic ages in the Mesozoic and early Tertiary, on the basis of theories of orogenic concentration. The youngest age of Au mineralization recorded in the Qinling fold belt area for sedimentary rock-hosted Au deposits (49.5 to 12.7 Ma) is from analysis of both whole rock and ore minerals in the Laerma Au deposit (Li, Y.D and Li, Y.T., 1994). The oldest ages reported are 337.5 to 234.3 Ma from the Pingding Au deposit by isotope analysis of realgar and orpiment associated with Au 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 Au deposit (Fan, S.C. and Jin, Q.H., 1994), and 210 Ma (whole rock and ore, U–Th–Pb) in the Baguamiao Au deposit (Wei, L.M. and Cao, Y.G. 1994). This wide range of ages is compatible with long or multiple metallogenic Au events along the Qinling fold belt. Age ranges, such as these, are not uncommon from dating of Carlin-type sedimentary rock-hosted Au deposits, due to both the–problematic mineralogy of the dated ore minerals, and to a complex metallogenic history (see also, Arehart and others, 1993a, Folger and others, 1996; Groff, 1996, Parry and others, 1997; Henry and Boden, 1997).

Shear zone-hosted, syndeformational, sedimentary rock-hosted Au deposits, such as the Maanqiao, Shuangwang, and Baguamiao Au deposits along the Lixian-Baiyun-Shanyang fault zone (fig. 4-2) in the East Qinling fold belt are contained in similar host rocks and have similar trace element geochemistry to the Carlin-type sedimentary rock-hosted Au deposits in the Jinlongshan and Ding-Ma Au belt are (fig. 4-1). These syndeformational deposits also contain local quartz veining and native Au that are similar to features in orogenic vein- or shear zone hosted-type deposits (Peters, 2001). The geochemistry, mineralogy, and host rock types of the syndeformational sedimentary rock-hosted Au deposits lie along the same Devonian lithotectonic belt as the Jinlongshan Au deposits in the Ding-Ma Au belt to the east (figs. 4-1, 4-2) and may be deeper expressions of these deposits.

Stratabound Au mineralization styles in many of these syndeformational Au deposits may have predated by or were simultaneous with Au mineralization that developed along the shear zone (Peters, 2001). Growth rim zoning of some pyrite grains in the syndeformational Au deposits is similar to sulfide textures contained in Carlin-type deposits (Shao, J.X. and others, 1982; Zhang, F., 1996). Ores in these syndeformational sedimentary rock-hosted Au deposits and in Carlin-type deposits both contain similar ore minerals, such as arsenopyrite, stibnite, and trace complex sulfide grains composed of As, Ni, As, Pb, Zn and Cu (Zheng, Z., 1984; Wang, X.C., 1992). The geochemical signature of the Maanqiao Au deposit ores, consisting of elevated As, Sb, also is similar to Carlin-type deposits. These sedimentary rock-hosted Au deposits therefore contain some features that represent permissive processes that are common to both orogenic–Au and to Carlin-type Au models types–(see also, Goldfarb and others, 1998; Groves and others 1998; Mao, J.W. and others, 2001).

The West Qinling fold belt, contains many sedimentary rock-hosted Au deposits with high organic C content, such as the Songpangou, Qiaoqiaoshang, Dongbeizhai, Pingding, Jiuyuan, and Heidousi Au deposits (Zeng, Y.F. and Yin, H.S., 1994). The organic C content in many of these deposits ranges from 0.20 to 14.63 weight percent (Li, Y.D. and Li., Y.T., 1994; Mao, Y.N. and Li, X.Z., 1994). Stratigraphic horizons that host these deposits also contain high Au background concentrations on a regional basis 10 to 15 times higher than the regional background Au concentration and therefore, these organic-rich, mainly late Paleozoic and early Triassic horizons, have been considered as source-beds for both petroleum and for Au deposits (Li, Y.D. and Li, Y.T., 1994; Zeng, Y.F. and Yin, H.S., 1994). Genetic theories proposed by Huang, Y. (1993) and Mao, Y.N. and Li, X.Z. (1994) suggest that organic carbon was an important factor in enrichment of Au, due mainly to providing a geochemically reducing environment for Au precipitation. Organic C also is common to most Carlin-type deposits in the Dian-Qian-Gui area (Chapter 3) and in Nevada (Chapters 1 and 2).

Alteration styles and mineralogy of gangue minerals and ores in sedimentary rock-hosted Au deposits in the Qinling fold belt area have many similarities. These include illite-quartz, local carbonation, decarbonatization and many common sulfide mineral assemblages, such as pyrite, arsenical pyrite, As-sulfide minerals, and stibnite. Realgar and orpiment are abundant in many of the deposits, such as the Songpangou and Qiaoqiaoshang Au deposits in the West Qinling fold belt (Zheng, M.H., 1989) (fig. 4-4). High–As ores in the Qinling fold belt have many textural and mineralogical similarities to high As ores in Carlin-type deposits in Nevada (Hofstra and Cline, 2001).

Figure 4-4. Sacks of stock-piled realgar and orpiment high-As ore at the Qiaoqiaoshang Au deposit, West Qinling fold belt area, northern Sichuan Province. The sacks will be transported by pony to about 10 km to the main road to be shipped to GuizhouProvince for processing.

Some minerals not normally common to Carlin-type sedimentary rock-hosted Au deposits also are present in some deposits in the Qinling fold belt. Scheelite locally is present in some deposits, such as the Manaoke and to a lesser extent at the Dongbeizhai Au deposit. Paragenetically late W sulfide also is present in the Betze Au deposit, Nevada (Peters and others, 1998, 1999), but W is not a common mineral in Carlin-type deposits. Uranium is common in the Laerma Au deposits. Albitization has been observed in the Shuangwang, Ertaizi, Baguamiao, and other sedimentary rock-hosted Au deposits in Qinling fold belt area, but is not common in the Dian-Qian-Gui area and in the Nevada deposits (Chapter 3). Albite- and rutile-rich layers in Devonian strata in these deposits are considered to be favorable host rocks. Titanium-rich zones also are present in the Betze Au deposit in Nevada (Peters and others, 1998, 1999) and pyrite-rutile intergrowths, similar to those as Betze, are present in the Carlin-type Zhanghai Au deposit in the Middle-Lower Yangtze River area (Chapter 5). PGE minerals locally are present in some sedimentary rock-hosted Au deposits in the Qinling fold belt areas, such as the Laerma, Baguamiao, and Shuangwang Au deposits.

The following descriptions of sedimentary rock-hosted Au deposits mainly are from field observations and laboratory investigations in the Jinlongshan, Maanqiao, Songpangou, and Qiaoqiaoshang Au deposits from visits in 1999 by the authors. Other deposit information is from literature compilations (see also, Li, Z.P. and Peters, 1998; and Wang, X.C., 1992; 1994,1995; and Zheng, M.H., 1989; 1994). The descriptions have been divided into deposits that lie in the East Qinling fold belt, in Shaanxi Province, which contains stratabound and tectonized deposits and also syndeformational sedimentary rock-hosted Au deposits to the west. In addition, deposits in the West Qinling fold belt are described and they contain stratabound and fault- or shear zone-hosted Carlin-type deposits in north Sichuan and south Gansu Provinces. Finally a cluster of similar deposits along the Luhuo-Daofu fault zone to the west of these deposits is described (fig. 4-1).

## EAST QINLING FOLD BELT

Shaanxi Province has the third largest Au production in P.R. China with about 35 active Au mines, many of which are sedimentary rock hosted Au deposits in the Qinling fold belt (Li. W., and others, 1993; Shaanxi Gold Bureau, pers. communication, 1999). Many of these deposits are orogenic-au vein deposits hosted in Archaean rocks. Most sedimentary rock-hosted Au deposits are hosted in or lie proximal to Devonian shallow marine platform facies—calcareous rocks that have been folded, tectonized and locally thermally metamorphosed (figs. 4-1, 4-2, 4-3). About a dozen sedimentary rock-hosted Au deposits are present in the southeastern part of the Qinling fold belt along the Ding-Ma Au belt, which contains mines around Zhenan in the Qin Long San Au area (fig. 4-1), such as the Jinlongshan Au deposit. Syndeformational sedimentary rock-hosted Au deposits also are located to the west in the East Qinling fold belt area, such as Maanqiao, Baguamiao, and Shuangwang. Most of these deposits lie proximal to a common west-northwest-trending lithotectonic zone in the fold belt (figs. 4-1, 4-2, 4-3).

## Paleozoic and Early Mesozoic Stratigraphy in the East Qinling fold belt

The following summary of the Paleozoic stratigraphic section in the East Qinling fold belt is presented to serve as a common background to descriptions of geology and lithologic host rocksin the deposit descriptions that follow.

The **Cambrian** and **Ordovician** stratigraphic sequence in the East Qinling fold belt is 613 m thick, and is divided into two units. The lower unit is composed of carbonaceous, micaceous quartzose slate that is interbedded with carbonaceous and siliceous clastic rocks, which is interlayered with limestone, arenaceous phyllite, thin-bedded limestone, and dolomitic limestone. The upper unit is composed of dolomitic limestone and dolomite, interlayered with limestone and banded chert, and dolomitic limestone.

The **Silurian** sequence is composed of two sequences: (1) Lower Silurian, 800 to 1,400 m thick, composed of carbonaceous phyllite, carbonaceous-siliciclastic rocks (chert), which is interlayered with calcareous phyllite and limestone; and (2) Middle to Upper Silurian that is more than 1,300 m thick, composed of phyllite and lesser sandstone.

The **Devonian** sequence is the most important ore host for sedimentary rock-hosted Au deposits and is divided into lower, middle, and upper sequences. The Lower Devonian is further divided into two formations (from bottom to top):

(1) Xichahe Formation ($D_1x$) is 20 to 708 m thick, composed of conglomerate, sandstone, siltstone and dolomitic limestone, interlayered with slate; and

(2) Gongguan Formation ($D_1g$) that is 40 to 1,125 m thick, composed of dolomite and dolomitic limestone.

The Middle Devonian also is divided into two formations (from bottom to top):

(1) Shijiagou Formation ($D_2sh$) is 100 to 400 m thick, composed of marl and limestone, interlayered with argillaceous stone; and

(2) Dafenggou Formation ($D_2d$) is 124 to 780 m thick, composed of ferriferous quartz sandstone interlayered with slate, argillaceous bioclastic limestone, argillaceous limestone and bioclastic limestone, interlayered with slate.

The Middle to Upper Devonian Yanglinggou Formation ($D_{2-3}y$) is 300 m thick, composed of calcareous clastics, reef limestone, microlitic limestone.

The Upper Devonian is divided into two formations (from bottom to top):

(1) Lengshuihe Formation ($D_3l$) is 91 to 1,092 m thick, mainly composed of clastic rocks in the lower unit and carbonate rocks in the middle and upper units; and

(2) Nanyangshan Formation ($D_3y$) that is 180 to 557 m thick. Fine-grained clastic rocks dominant in the west, whereas carbonate-bearing rocks dominate in the east. Carbonate interlayered with fine-grained clastic rocks is present in the central part of the East Qinling fold belt area. The Nanyangshan Formation is one of the main hosts of Au, Sb and Hg deposits and is conjectured to be a source bed for these elements (Zhang, X.F. and others, 1997a,b).

**Carboniferous** rocks in the East Qinling fold belt are divided into lower, middle, and upper sequences. The Lower Carboniferous Yuanjiagou Formation ($C_1y$) is 195-m thick, and composed of bioclastic limestone, fine-grained limestone, banded chert interlayered with limestone, and microlitic limestone. The Lower to Middle Carboniferous Sixiakou Formation ($C_{1-2}s$) is 258 m thick, and is composed of carbonaceous silty slate and argillaceous slate, interlayered with sandstone, conglomerate, and limestone. The Upper Carboniferous Nangouhe Formation ($C_3n$) is 347 m thick, composed of limestone and argillaceous limestone, interlayered with clastics.

The **Permian** sequence is divided into lower and upper sequences. The Lower Permian Shuixiakou Formation ($P_1sh$) is 397 m thick, and is composed of dark gray and argillaceous limestone, interlayered with black shale, arenaceous shale, and sandstone. The Upper Permian is divided into three formations (from bottom to top):

(1) Xikou Formation ($P_2x$) is 383 m thick, and is composed of gray-black limestone and argillaceous limestone, interlayered or interbedded with marl, quartz sandstone, and siltstone;

(2) Yundoutan Formation ($P_2y$) is 875 m thick, composed of gray-red, massive limestone and argillaceous limestone, interlayered with conglomeratic argillaceous limestone and conglomeratic limestone; and

(3) Longdongchuan Formation ($P_2l$) is 789 m thick, composed of gray-white, massive limestone interlayered with reddish marl and limestone.

The **Triassic** sequence is not as an important or host in the East Qinling fold belt as it is in the West Qinling fold belt. It is divided into lower and middle sequences. Upper Triassic rocks are absent. The Lower Triassic Jinjiling Formation ($T_1j$) is 113 to 663 m thick, and is composed of conglomeratic fine-grained limestone and calcareous shale, interlayered with marl. The Middle Triassic Linggou Formation ($T_2l$) is 700 m thick, and is composed of argillaceous microlitic limestone interlayered with calcareous sandstone at the bottom, and calcareous mudstone interlayered with calcareous sandstone and argillaceous microlitic limestone at the top.

### Deposits along the Ding-Ma Au belt

A number of sedimentary rock-hosted Au deposits lie in Devonian and Carboniferous calcareous and siliciclastic rocks in the Qinling Mountains along the west-northwest-trending 120–km-long Ding-Ma Au belt near the County city of Zhenan including the Jinlongshan, Ertazi, Longshan, Qilixia, Quiling, and Yaojian Au deposits (Zhang, F.X. and others, 1997a,b; Li, Z.P. and Peters, 1998) (figs. 4-1, 4-5 and 4-6). Associated with these deposits are a number of Sb–Au deposits, such as the Jiashigou and Xipo deposits (Fig. 4-5*B*). In the east part of the Ding-Ma Au belt, a number of Hg–Sb–(Au) deposits, such as Dingjiashan and Xipoling Hg deposits, and the Yangjialing Sb deposit (fig. 4-5), lie along an east-striking tectonized zone (Zhang, F.X., 1996; Zhang, F.X. and others, 1997b). In addition, Pb–Zn deposits, such as the Xitonggou and Yuexi deposits, also lie to the west and southwest of the main part of the belt in similar age rocks. Average Au grades of ores along the Ding-Ma Au belt are 2 to 5 g/t Au. In 1999, 11.7 tonnes Au of oxide ore with high As content had been proven along the belt and an approximate additional 50 tonne Au potential is likely (Shaanxi Gold Bureau, pers. communication, 1999).

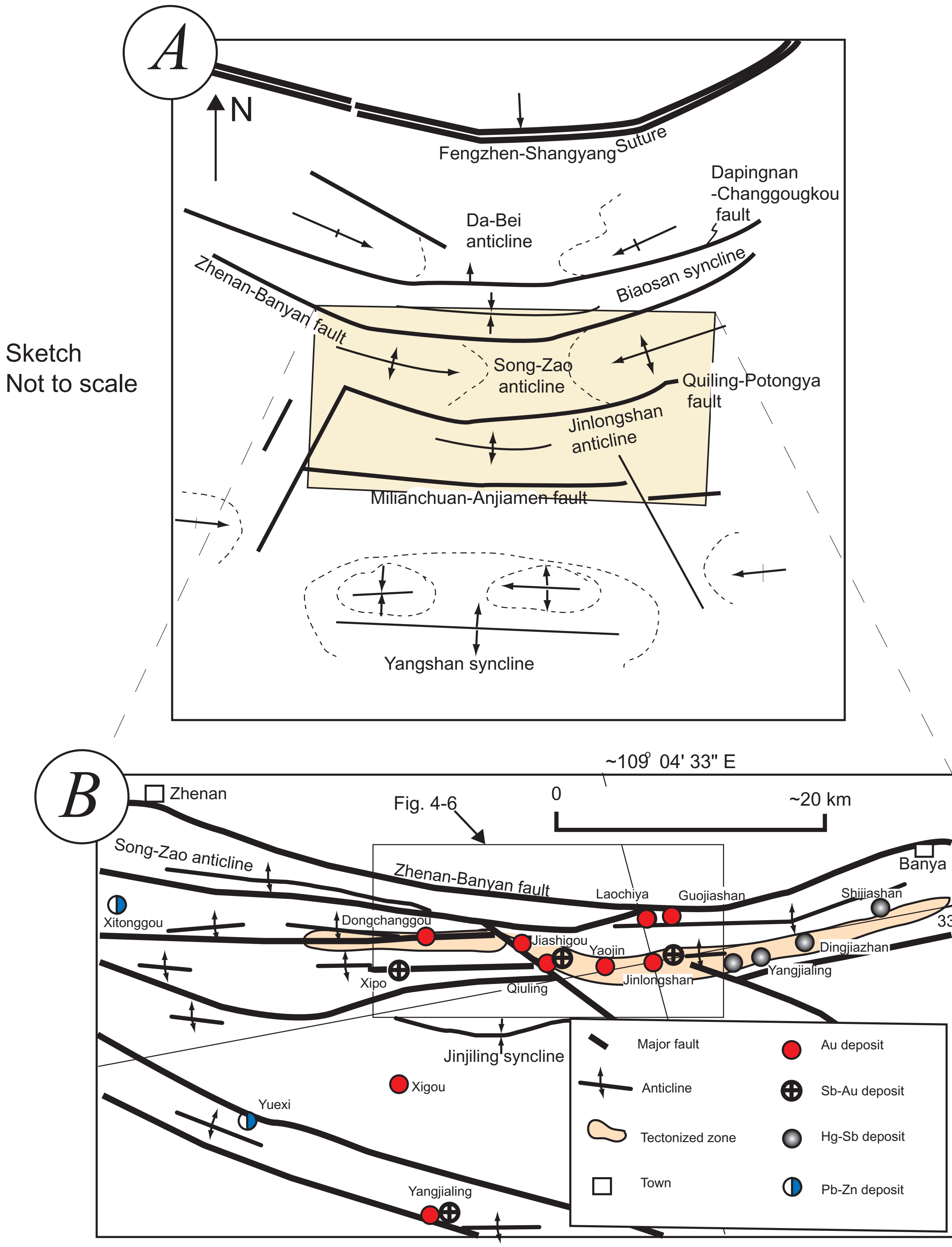



Figure 4-5. Sketch map of structural setting and ore deposits in the Ding-Ma Au belt, East Qinling fold belt, Shaanxi Province. (A) Sketch of major folds and faults within and adjacent to the Ding-Ma Au belt. The belt lies between the Zhenan-Banyan and Milianchuan-Anjiamen faults and involves the Song-Zao and Jinlongshan anticlines. (B) Inset to A showing Au, Sb-Au, Hg-Sb and Pb-Zn deposits in the Ding-Ma Au belt and their spatial relation to a central tectonized zone. Adapted from Zhang, F.X. and others (1997a,b).

The Ding-Ma Au belt lies south of the east-striking regional-scale Fengzhen-Shangzeng suture zone in east- striking, folded upper Paleozoic rocks. The most prominent folds are the Song-Zao and Jinlongshan anticlines, which are parallel to and lie south of the Zhenan-Banyan fault and are bound by the Quiling-Potongya fault to the north, and Milianchuan-Anjiamen fault to the south (fig. 4-5*A*). Additional deposits, such as the Xigou and Yangjialing Au deposits lie south of this main folded and faulted zone (fig. 4-5*B*). The central part of the Ding-Ma Au belt contains three main centers that are defined by deposit clusters and by zones of anomalous sediment-sample, rock, and soil geochemistry: (1) the Guloushan-Qiuling in the west; (2) the central Yaojian area; and (3) the Jinglonshan-Qilixia area in the east (fig. 4-6) (Zhang F.X. and others, 1997b). A central deformation zone along these deposits is locally mylonitic.

Stratigraphy in the Ding-Ma Au belt consists of an east-striking Lower Devonian to Upper Permian sedimentary sequence of lagoonal and restricted platform facies, fine-grained, locally carbonaceous, clastic and carbonate rocks, and sparse tuffaceous sedimentary rocks that fill the Zhen-Xun basin (basin not shown on figures 4-5 and 4-6). The basin resulted from early Paleozoic extension and is characterized by metal-rich sedimentation and growth faults. Rocks in the basin contain biogenic and framboidal pyrite. Two stratigraphic intervals, the Devonian Nanyangshan and Carboniferous Yuanjiagou Formations, are thought to be specific source beds

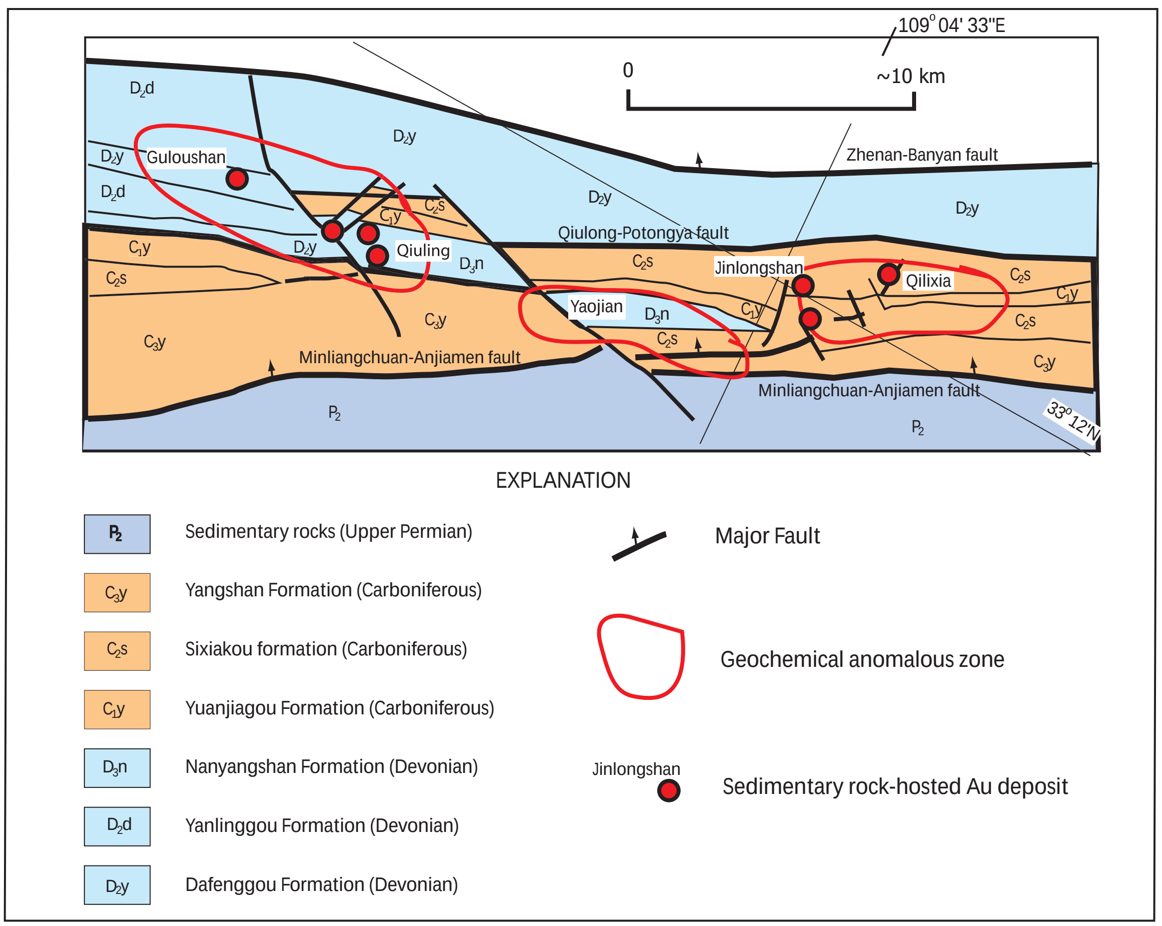



Figure 4-6. Geologic sketch map showing the structures, lithology, geochemically anomalous zones and major ore deposits in the central, Au-rich part of the Ding-Ma Au belt. See Figure 4-5 for approximate location. Adapted from Zhang, X.F. (1997a,b).

for the Au–Sb–Hg mineral deposits by Zhang, X.F. (1997a,b). Tectonism is interpreted to have remobilized and concentrated the Sb–Au–Hg–(As) deposits from these source beds during four progressive orogenic stages accompanied by hydrothermal processes: (1) regional folding; (2) ductile shearing; (3) ductile-brittle shearing and deformation; and (4) brittle faulting and deformation (Zhang, X.F., 1996; Zhang, X.F., 1997a,b).

**Jinlongshan (Zhenan) Au deposit,**

The Jinlongshan (Zhenan) sedimentary rock-hosted Au deposit is located in the southeast part of Zhenan County, approximately 20 km from the Zhenan County town in Shaanxi Province south of the city of Xian (fig. 4-1). Three ore zones in the Jinlongshan Mine area were active in 1999:

(1) the No. 1 (Jinlongshan), 5.46–m-thick, underground orebody, grading 6.3 g/t Au, striking 235 to 270°, dipping 82° N, and containing 1.69 tonnes Au;

(2) No. 304, (Quiling) surface orebody, about 30 km west of Jinlongshan No 1 orebody, is 23.21–m-thick, grading 3.18 g/t Au, striking east-west, dipping 60 to 70° N, with 6.17 tonne Au reserve; and

(3) No. 301 surface orebody, striking east-west, 12.93–m-thick, grading 3.82 g/t Au (figs. 4-7, 4-8, 4-9, 4-10 and 4-11). The Au orebodies are 4.93– to 16.08–m-wide and grade 2.17 to 9.05 g/t Au, with the maximum grades of 52.58 g/t Au.

The Au orebodies are present as stratabound bodies, saddle reefs, veins, pods that pinch and swell and locally cut across bedding planes.


Figure 4-7. Photographs of the Jinlongshan (Zhenan) Au Mine, No. 304 orebody on geologic structures, Shaanxi Province East Qinling fold belt area. (A) Ore along brittle-ductile deformed zone between two steep-dipping faults, looking north. (B) Orebody along faults, looking northwesterly. See Figure 4-10.

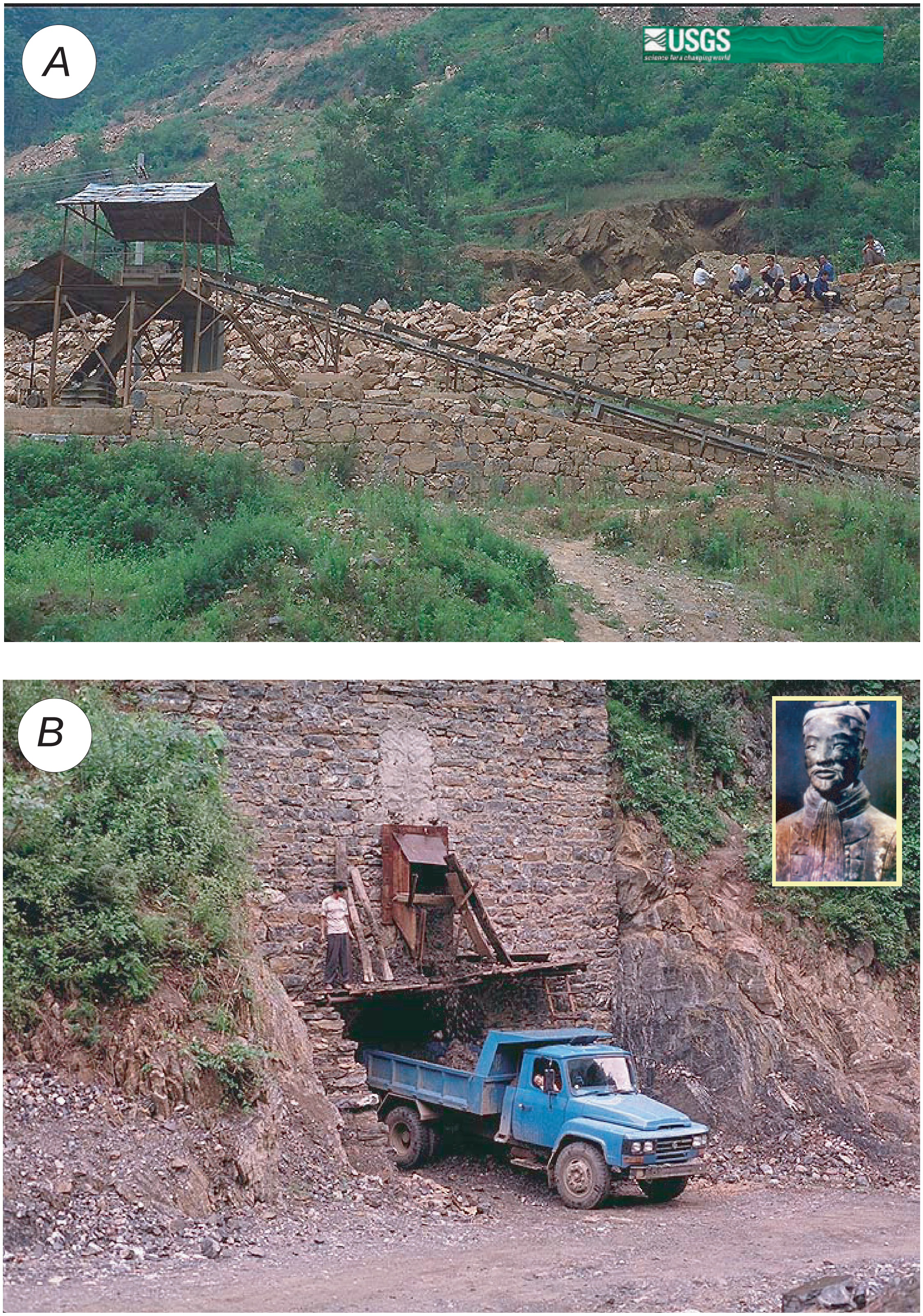



Figure 4-8. Photographs of the Jinlongshan (Zhenan) Au deposit area, Shaanxi Province, East Qinling fold belt, Ding-Ma Au belt. (*A*) Ore hopper 304 orebodey area. (*B*) Underground No. 1 Jinlongshan orebody ore hopper.

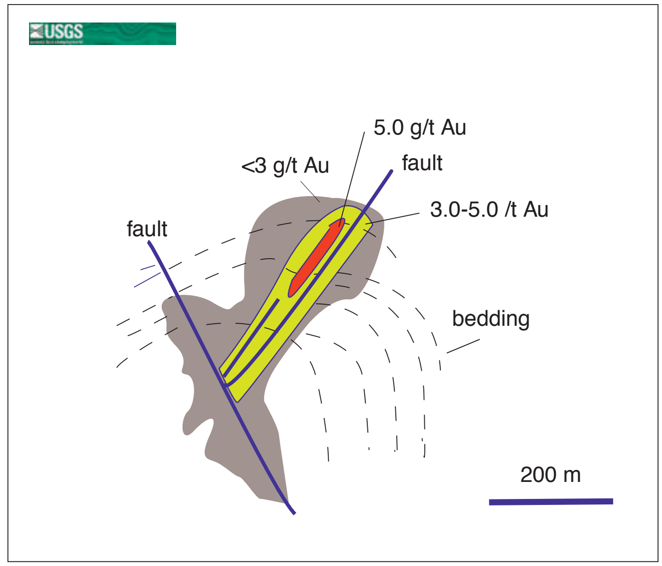



Figure 4-9. Sketch plan of part of the No. 304 orebody Jinlongshan (Zhenan) Au orebody, Shaanxi Province, East Qinling fold belt, Ding-Ma Au belt, showing distribution of Au values in relation to stratigraphy, folding, and faulting. Note that the main part of the mineralized zone lies along an axial plane of the fold and that a <3 g/t Au halo is present surrounding the main orebody.

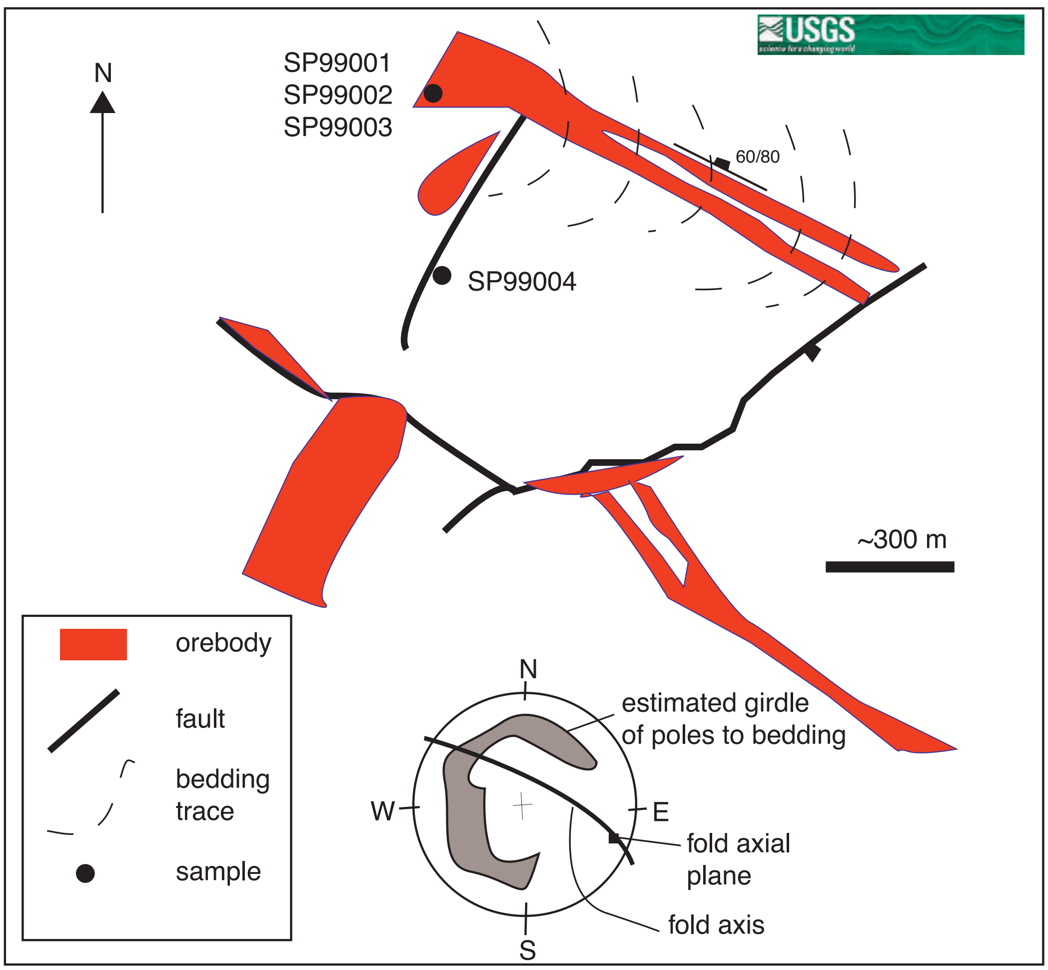



Figure 4-10. Plan sketch map of the No. 304 orebody, Jinlongshan (Zhenan) Au orebody area, Shaanxi Province. 1999. Gold lodes are located along folds and faults, as well as along bedding. Stereonet at bottom of figure is a sketch of poles to bedding, showing that the axial plane is parallel to the northwest-striking faults and that the fold plunges at shallow angles to the southeast.

The Jinlongshan Au deposit was discovered in 1993 and by 1999 was producing 300 tonnes of Au ore per day and retaining a staff of 500 from 3 mines that produced 5,000 to 12,000 oz. Au per year (Zhenan County Au Bureau, pers. communication, 1999). The main feature of the orebodies in the Jinlongshan (Zhenan) Au deposits is the clustering of more than 10 orebodies, at cut off grade of 1 g/t Au, along a zone of 100 to several 100s of meters in length. Gold is recovered by heap-leach methods (see also, Hu, J.M., and Zhang, H.S., 1994). The Jinlongshan Au mine was visited in 1999 and information is from this visit, laboratory studies, and from the Zhenan County Au Bureau; Hu, J.M., and Zhang, H.S., (1994); and Zhang, F.X. (1997a,b).

The host sedimentary sequence in the Zhenan area mainly is composed of upper Paleozoic (Carboniferous and Devonian) argillaceous and arenaceous sedimentary rocks. The main host horizon for the Au deposits is a turbiditic sequence of fine-grained sandstone, siltstone-silty shale, calcareous siltstone, and limestone of the Upper Devonian Nanyangshan Formation that contains about 90% of the Au reserve (fig. 4-12). Siltstone, intercalated with silty shale, is the important ore-bearing host. Another horizon, representing about 10% of the Au ore, is in the Lower Carboniferous Yuanjiagou Formation and consists of cherty, banded limestone that is intercalated with silty shale, silty sandstone, argillaceous limestone, and calcareous shale (figs. 4-6, 4-12*A* and *B*).

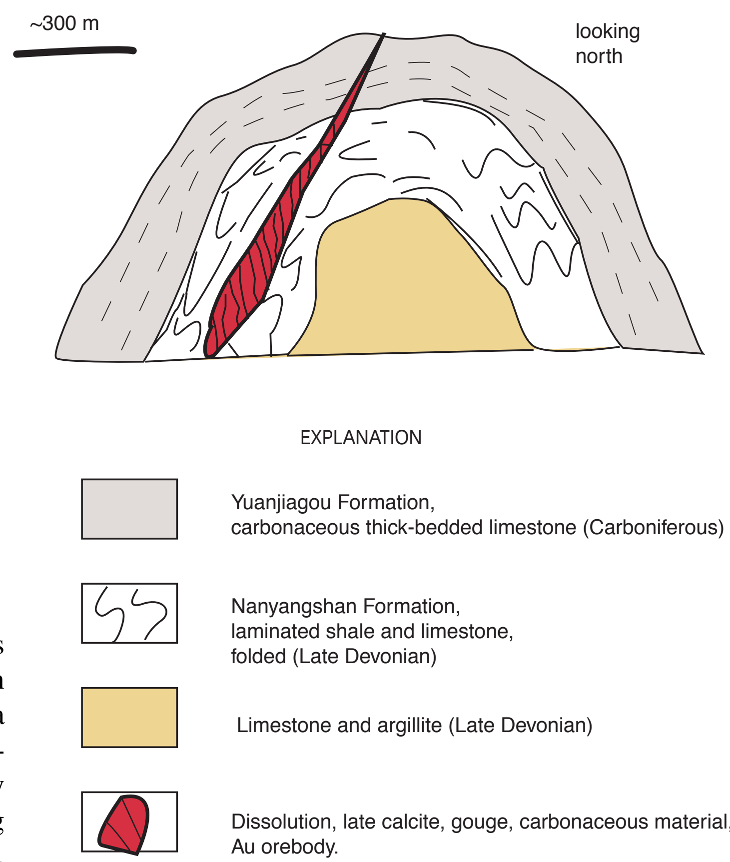



Figure 4-11. Geologic sketch of a cross section through the Jinlongshan (Zhenan) Au deposit in the No. 301 area along limb of anticline in Late Devonian and Carboniferous sedimentary rocks. Shaanxi Province, East Qinling fold belt, central Ding-Ma Au belt area.

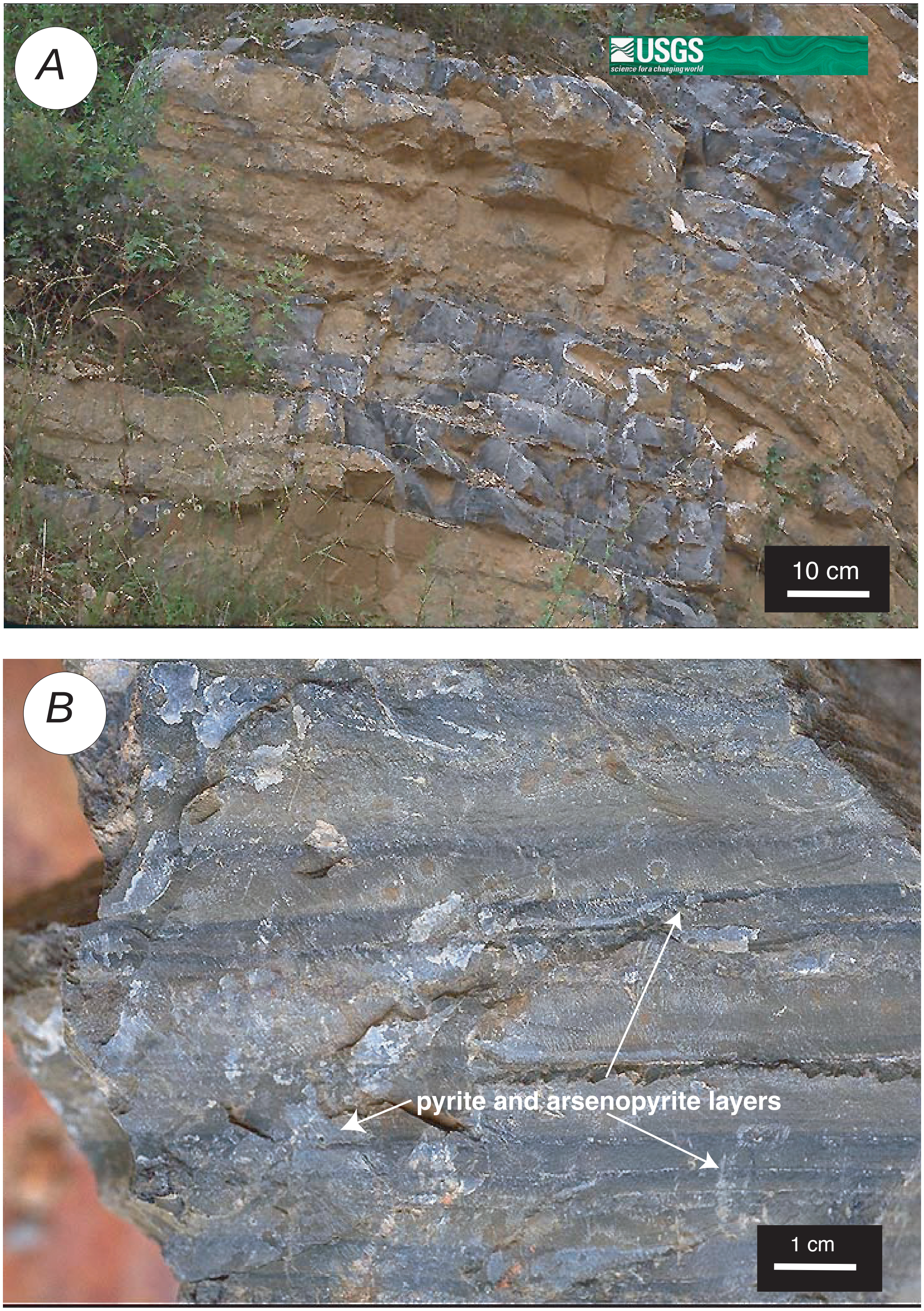



Figure 4-12. Host rock types, Devonian Nanyangshan Formation, in the Jinlongshan (Zhenan) Au deposit area, Shaanxi Province, East Qinling fold belt. (*A*) Bedded dolomitic sandstone, main host rock. (*B*) Layered calcareous sandstone, Darker layers are pyrite and arsenical pyrite replaced along bedding. See Figure 4-17 for close up of sulfidic layers in (*B*).

Structures in the Jinlongshan (Zhenan) Au mining area and along the greater Ding-Ma Au belt are megascopic, anticlinal, upright and mesoscopic, recumbent folds and faults (figs. 4-13, 4-14). Ore mainly is present along east-trending anticlines and commonly is hosted in east-striking, brittle-ductile shear zones that contain breccia, fault gouge, and fracture networks (fig. 4-14). Ore also is present along either fold axes or fold limbs (figs. 4-10, 4-11). Fractures generally strike east-, northeast, northwest, and north. A main conjugate fracture set strikes northeast and north and is closely related to Sb ores (fig. 4-15), which are characterized by silicification and jasperoid development. Gold grades are highest at intersections of strong compressional, ductile and ductile-brittle deformation zones (fig. 4-14) and are most intense along northeast-striking fractures (fig. 4-9). A pervasive cleavage ($S_1$) cuts through most rocks (fig. 4-16). Neither bedding ($S_0$) or cleavage ($S_1$) are fissile. Microstructual textures do not cross cut the stratabound ore layers, which suggests that cleavage post-dates sulfide micro-layering along bedding. This observation is compatible with syngenetic, stratiform Au deposition prior to brittle-ductile shearing, which is consistent with the source bed theories of Zhang, F.X. and others (1997a,b).

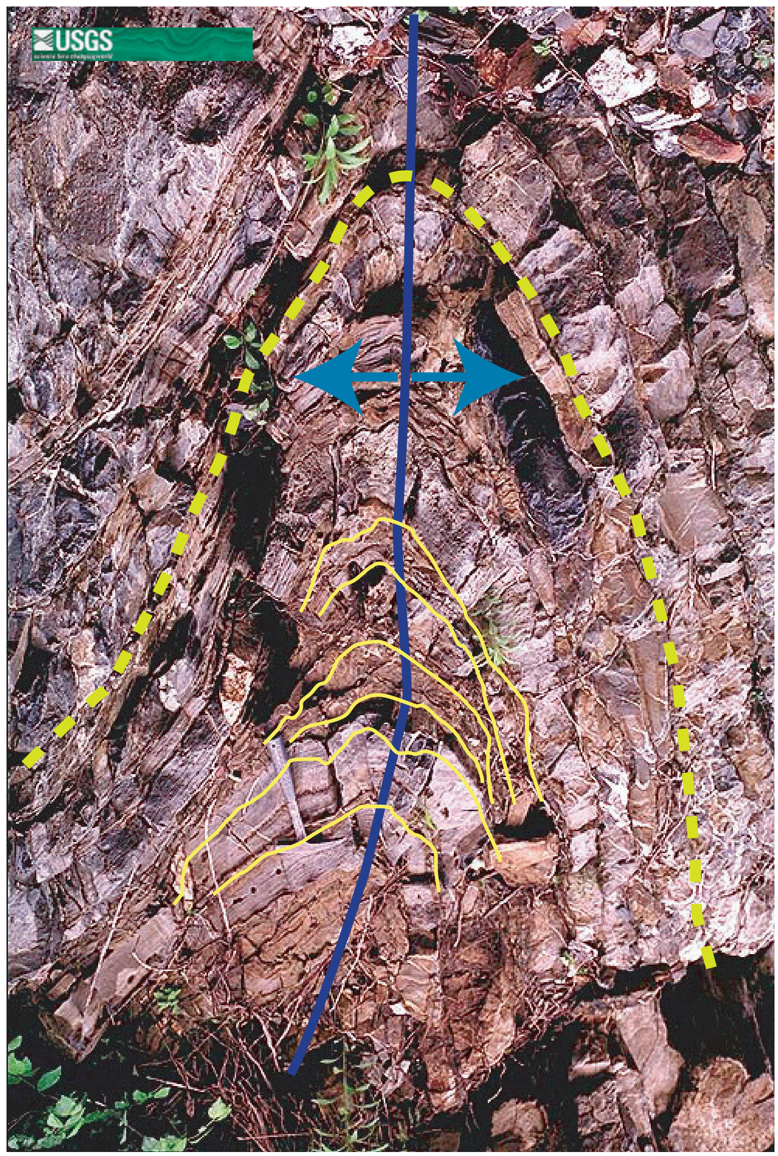



Figure 4-13. Folding in Late Devonian laminated shale and limestone, No. 1 301, Jinlongshan orebody area, Jinlongshan (Zhenan) Au deposit, East Qinling fold belt, Ding-Ma Au belt, Shaanxi Province, Devonian Nanyangshan Formation.

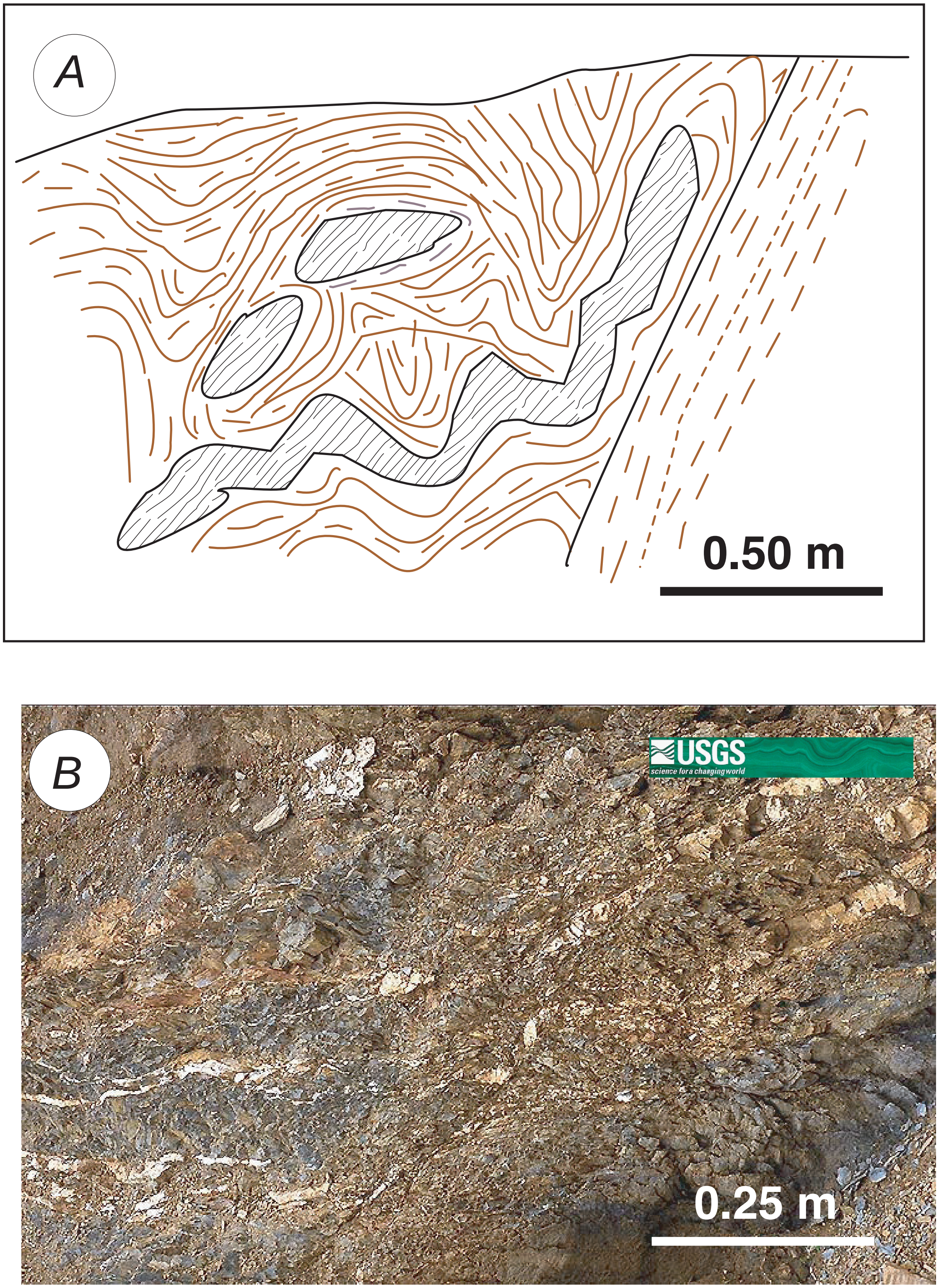



Figure 4-14. Ductile and brittle-ductile deformation textures at the Zhenan (Jinlongshang) Au Mine area, Ding-Ma Au belt, Shaanxi Province, East Qinling fold belt. (*A*) Typical chaotic deformation textures near orebodies (sketch). Darker areas are phacoidal lenses of dismembered sandstone that are surrounded by a pelitic matrix. (*B*) Photograph of outcrop-scale brittle-ductile fault zone with quartz veinlets in Au ore zone, 304 ore body.

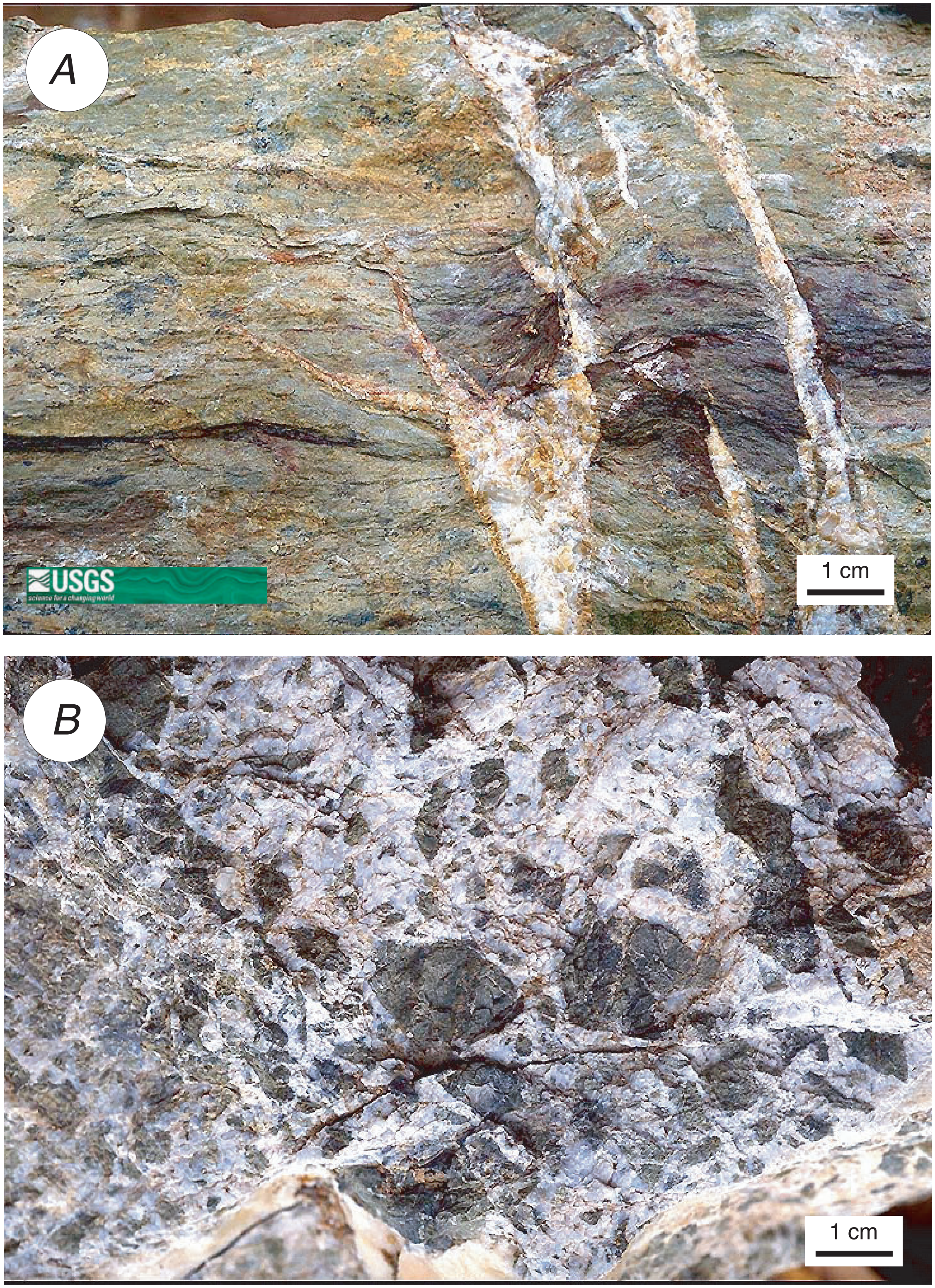



Figure 4-15. Photographs of quartz vein and breccia textures from the Jinlongshan (Zhenan) Au Mine, Shaanxi Province, East Qinling fold belt, Ding-Ma Au belt. (*A*) Quartz veinlets crosscutting stratabound ore. (*B*) Post-ore quartz matrix breccia with silicified fine-grained sandstone clasts. Many late quarts veins are associated with Sb ores.

Hydrothermal alteration types associated with Au occurrences in the Jinlongshan Au deposit area include silicification and calcite as replacements and veinlets with lesser veinlets of pyrite, arsenopyrite, barite, and kaolinite. In addition, dickite and fluorite locally are present. Gold ores are closely related to silica and pyrite. Supergene zones contain abundant limonite.

Mineralogy of the Jinlongshan Au deposit ore is dominated by pyrite, arsenical pyrite, arsenopyrite, stibnite, sphalerite, and chalcopyrite. Quartz, calcite, sericite, barite, and clay minerals are the main gangue minerals (figs. 4-17, 4-18, and 4-19). Pyrite-bearing Au is disseminated in euhedral to subhedral crystals along bedding planes and in dissolution-replacement zones and commonly has a strawberry (growth-zoned As-rich pyrite rims) texture. The main Au ore minerals are As-bearing pyrite and arsenopyrite, where Au is present as superfine micro-spheres or chains (0.375 to 0.08–µm-sized) along the fringe of As-bearing pyrite and arsenopyrite, and also is present in micro-fractures or in micro-crystal rings on the crystal planes of these minerals.

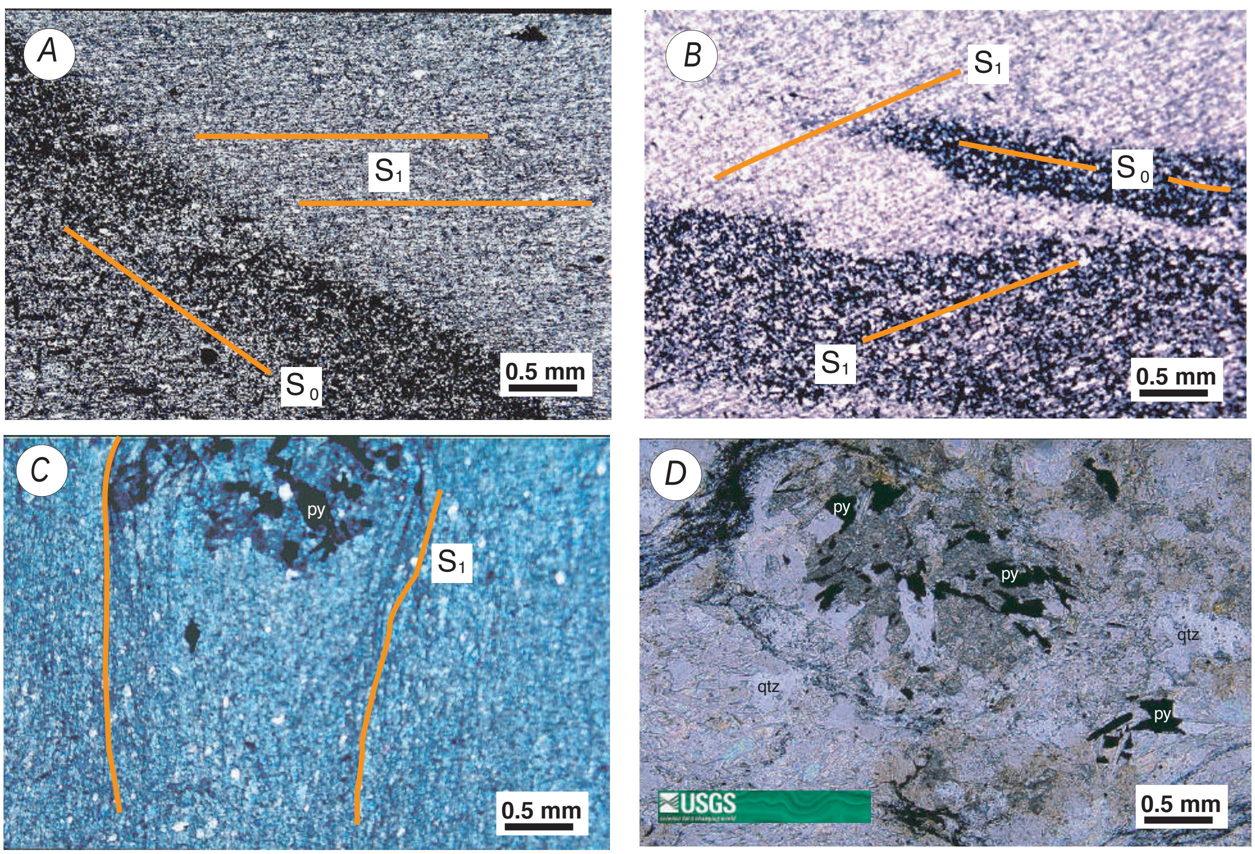



Figure 4-16. Microphotographs of relations among Au-pyrite mineralization, bedding, cleavage, and late quartz veins, Jinlongshan (Zhenan) Au Mine, Shaanxi Province, East Qinling fold belt. (A) Pyrite, As-rich pyrite, and arsenopyrite disseminations (darker areas) along bedding rather than along cleavage. (B) Au-mineralization also is preferentially along bedding, rather than cleavage. (C) Cleavage is wrapping around knot of pyrite. These fabric relations suggest that cleavage may have post- dated Au deposition along bedding. (D) Quartz vein (similar to those shown in Figure 4-15) appear to post-date Au-associated pyrite. Note that no pyrite is contained within the quartz.

Gold ore characteristically is massive, banded, brecciated, and present in veinlets and disseminations, but also is developed in mesoscopic fracture networks. The stratabound textures are consistent with stratiform, primary syngenetic ore deposition, but the other textures are more compatible with epigenetic and superimposed orogenic processes (figs. 4-16, 4-17, 4-18, 4-19, 4-20). When controlled by brittle fractures, abrupt ore grade contacts are present, but gradational contacts are more common where ore is controlled by ductile fractures (fig. 4-9). Stages of ore genesis most likely began with replacement or precipitation of 0.5– to 2–mm-thick, or less, pyrite and arsenopyrite along bedding ($S_0$) layers, which also contain sporadic As-rich, zoned (strawberry) pyrite (fig. 4-18). Cleavage post-dates the stratabound layers (fig. 4-16).

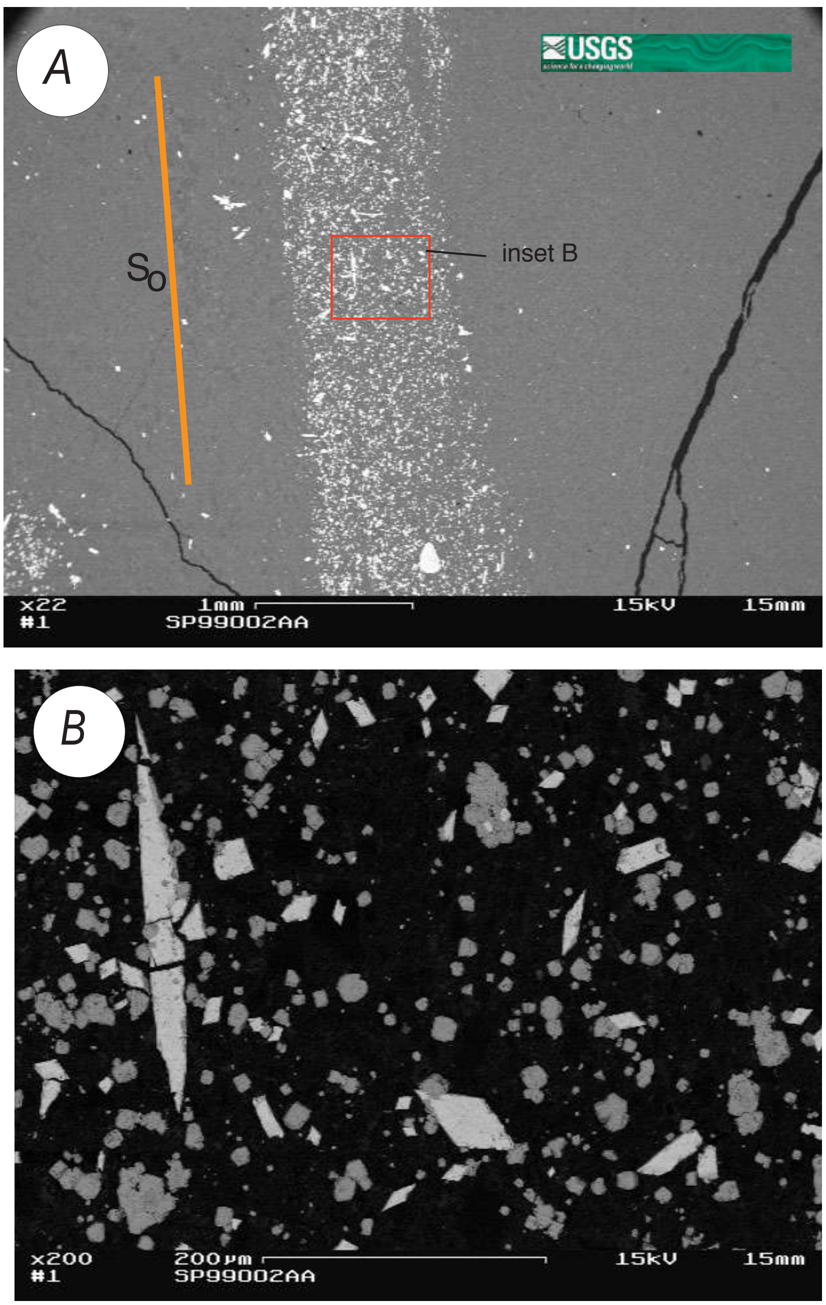
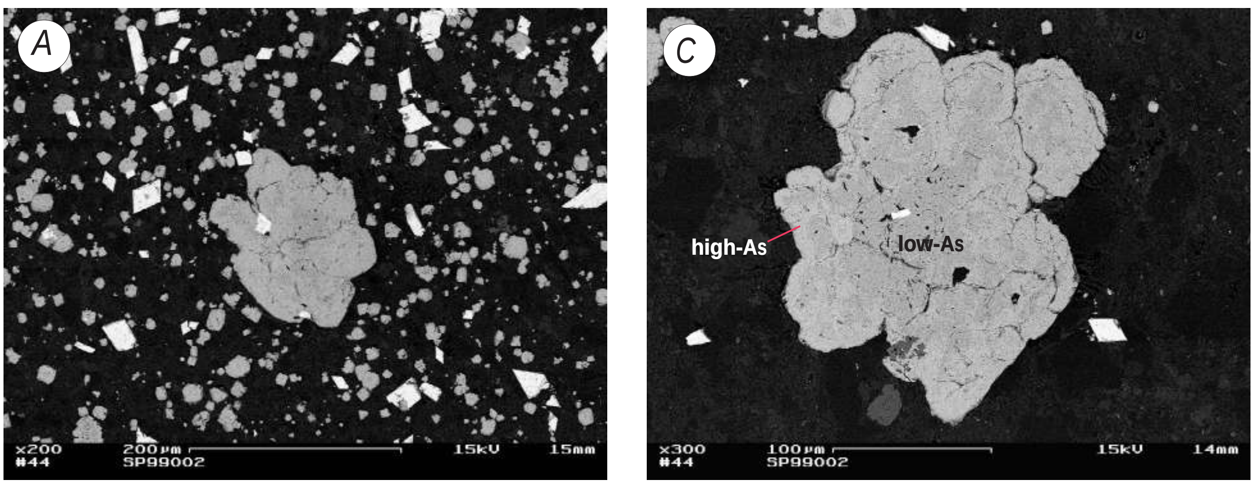



Figure 4-17. SEM backscatter image of stratabound ores, Jinlongshan (Zhenan) Au deposit, Shaanxi Province. East Qinling fold belt, Ding-Ma Au belt. (*A*) Sulfidic layer, parallel to bedding, consisting of pyrite and arsenopyrite. (*B*) Arsenopyrite (bright, euhedral) and pyrite (anhedral, gray) blowup—see inset.

A secondary ore stage involved tectonic As-rich pyrite veinlets (fig. 4-19). Zoning of As-rich and As-poor pyrite along these veinlets is consistent with possible microbarometric control of As and (possibly) Au deposition, because As-rich zones are in sheared areas, whereas As-poor zones are in tension gashes (fig. 4-19). Timing of these events is not well constrained (Peters, 2001). Microscopic cross-cutting relations suggest that early stratabound mineralized layers may have been remobilized by late brittle-ductile tectonism, but were not mobilized along post-ore cleavage. A post-Au ore quartz vein event produced a series of ductile veins and veinlets and tabular quartz matrix breccia pods (fig. 4-15), which locally were synchronous with late Sb-enriched zones and ores.

Geochemically, the Au ores of the Jinlongshan Au deposit contain lower values of Sb compared to most sedimentary rock-hosted Carlin-type deposits, although high-Sb ores are present in the district (Zhang, F.X., 1997b). The Jinlongshan Au ores also contain elevated to anomalous concentrations of As, F, Cu, Pb, Co, and Ni (Appendix IV), which is a geochemical suite generally compatible with other Carlin-type deposits in the West Qinling fold belt area and in the Dian-Qian-Gui area (Chapter 3). Studies of ore minerals in the Jinlongshan Au deposit by Zhang, F.X. and others (1997a) indicate that temperature of formation ($T_f$) is 187 to 250 ºC with ore fluid salinities of 5.7 to 7.85 equiv. NaCl weight percent. Fluid-inclusion $C0_2$ densities suggest formation depths of 1.5 to 1.9 km. Fluids were in these studies to be characterized by



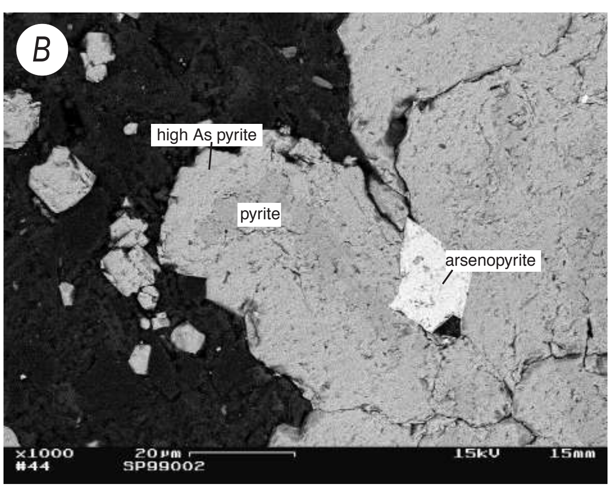




Figure 4-18. SEM back scatter images of As-rich pyritic ores, Jinlongshan (Zhenan) Au deposit, Ding-Ma gold belt, East Qinling fold belt, Shaanxi Province. (*A*) Pyrite and arsenopyrite in Zhenan Au deposit. Central, large 150-mm-size pyrite is zoned with As-poor internal parts and cuspate growth rings of slightly higher As-rich pyrite. Bright, euhedral minerals are arsenopyrite. (*B*) Part of large 150-µm-diameter, zoned pyrite. Left lobe has zoned As-poor interior to As-rich exterior. (*C*) Poorly zoned (As-poor centers, As-rich exteriors) pyrite showing growth rims. Small euhedral minerals are arsenopyrite. Smaller round pyrites also show growth zoning from As-poor to As rich. These textures are typical of Carlin-type deposits.

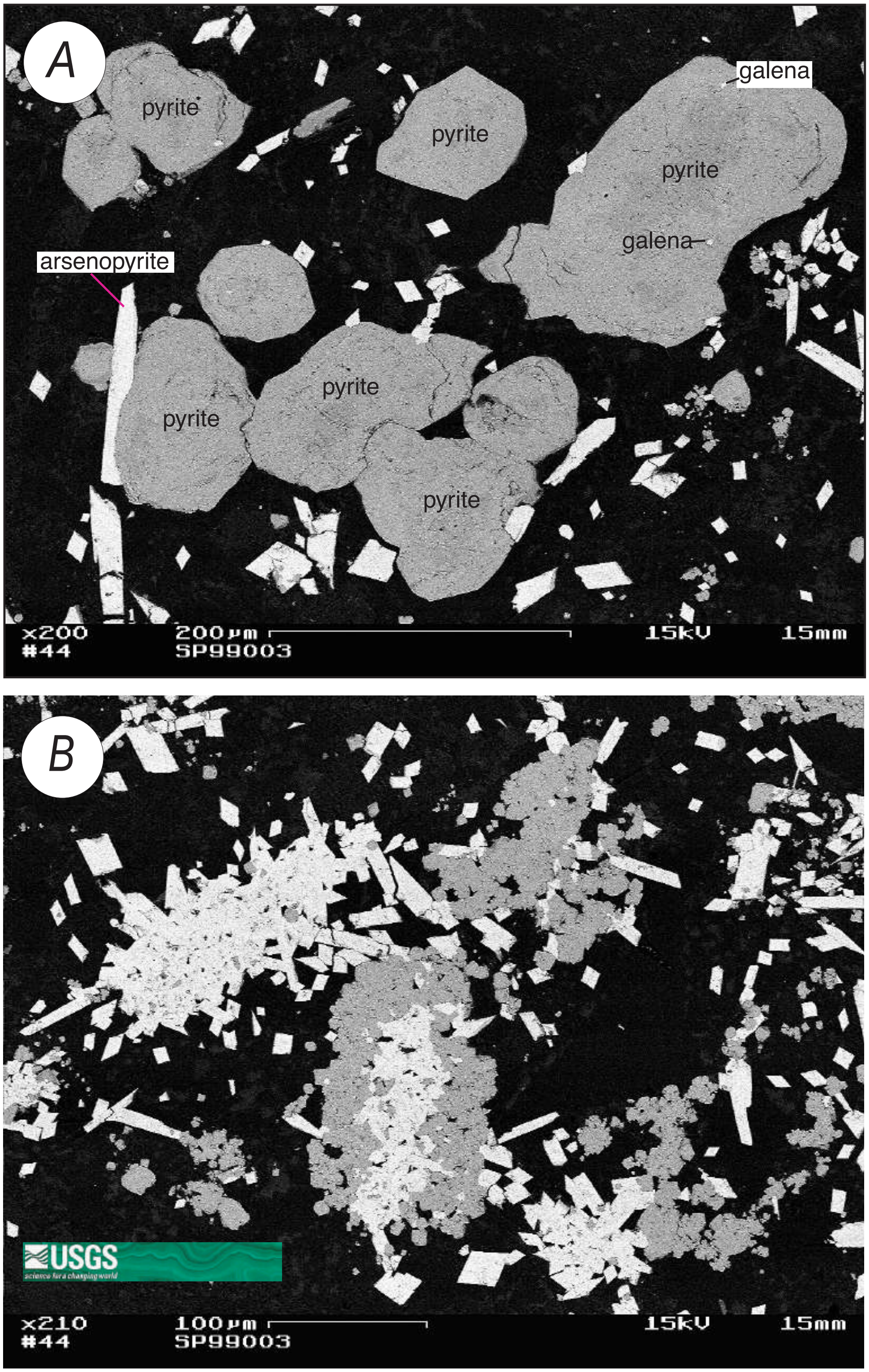
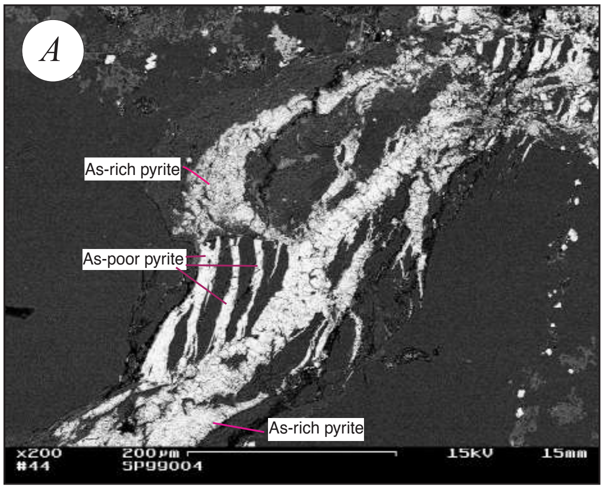
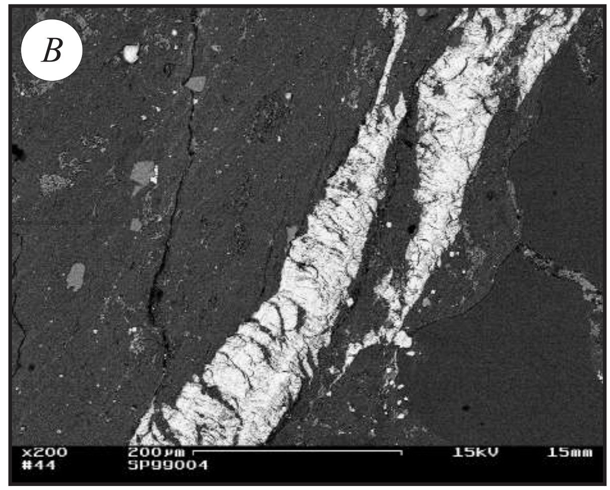



Figure 4-19. SEM back scatter images of zoned pyrite clusters, Jinlongshan (Zhenan) Au deposit, Shaanxi Province, East Qinling fold belt. (*A*) Rounded pyrite with growth rings and smaller euhedral pyrite. Small 1- to 5-μm-diamter minerals along growth rings in pyrite are galena. (*B*) Zoned skeletal clusters of arsenopyrite in centers surrounded by less bright pyrite.



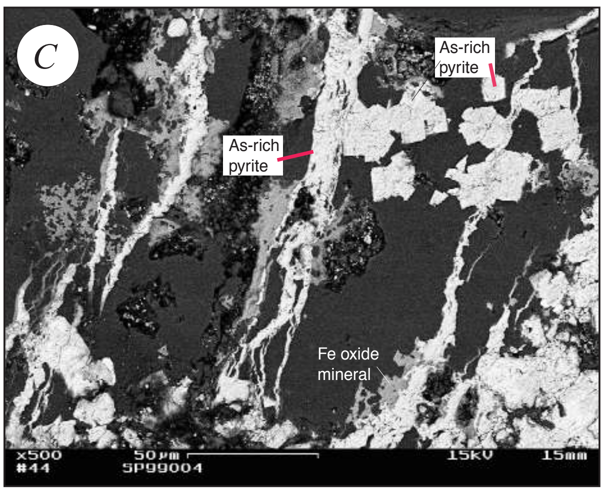




Figure 4-20. SEM back scatter images of tectonic pyrite veinlets in the Jinlongshan Zhenan Au deposit, Shaanxi Province, East Qinling fold belt, Ding-Ma Au belt. (*A*) As-rich pyrite vein injected in a ductile-brittle micro shear zone. Tensional veinlets appear to be part of same veinlet event, but exhibit low-As, suggesting that local mm-scale pressure gradients may have affected the geochemistry and deposition of pyrite phases and perhaps Au. (*B*) Ductile, locally As-rich, pyrite veinlet. (*C*) Ductile pyrite veinlets (locally As-rich) cutting euhedral As-rich pyrite. Specimen is partially oxidized.

low acidity and low S fugacity. Stable isotope value for $\delta^{18}O$ is 23 X $10^{-3}$ and $\delta D$ is –90 25 X $10^{-3}$, and S isotopic values of diagenetic pyrite are between 12 X$10^{-3}$ and 16 X $10^{-3}$. Vertical zoning consists of outboard or upper Sb ores with As–Au –(Hg) ores in the central or lower parts. These fluid and geochemical parameters are cited by Zhang, F.X. and others (1997a) as evidence of tectonic mobilization of primary syngenetic ore material from source beds.

### Syndeformational Au deposits

A 10–km-long Au belt that includes the Maanqiao, Baguamiao, and Shuangwang Au deposits is proximal to the west-northwest-trending Lixian-Baiyun-Shanyang suture along the northern margin of the Qinling fold belt (fig. 4-1. 4-2, and 4-3). The deposits are hosted in Devonian marine sedimentary rocks and lie along the same lithotectonic zone as the sedimentary rock-hosted Au deposits to the east in the Ding-Ma Au belt, but display slightly different mineralogy and morphology. The syndeformational Au deposits (see also, Chapter 1 for discussion of classification) are associated with and usually are hosted in stratabound, ductile, locally mylonitic shear zones or ductile-brittle breccia zones, and may either be deeper equivalents of the deposits in the Ding-Ma Au belt or may be related to Mesozoic orogenic quartz vein-type Au deposits. Anomalous contents of PGE also are characteristic of the Baguamiao and Shuangwang Au deposits (see below).

## Maanqiao Au deposit

The Maanqiao Au deposit is located in the Qinling Mountains, west-southwest of the city of Xian, in southern Zhouzhi County, 65 km south from the Zhouzhi County town, Shaanxi Province (fig. 4-1). The mine is a joint venture between Shaanxi Province Gold Bureau and Gold Company of Shaanxi. Gold ore is hauled from the mine site in the mountains to Zhouzhi City, an industrial area, and processed at between 400 to 500 tonnes per day in a cyanide mill with a feed grade of 4 g/t Au. The mine-mill complex produces (1999) between 12,000 and 15,000 oz Au per year. Mill recovery is approximately 86 percent. The mill circuit consists of ore that is dropped to a hopper that feeds a primary jaw crusher—with over size return—to a coarse ore bin, to a ball mill that, in turn, feeds a carbon-in-pulp tank that then feeds a cyanide tank. The mine and mill complex employs approximately 80 staff, but ore trucking from the mine to the mill is contracted (figs. 4-21. and 4-22. ad 4-23).

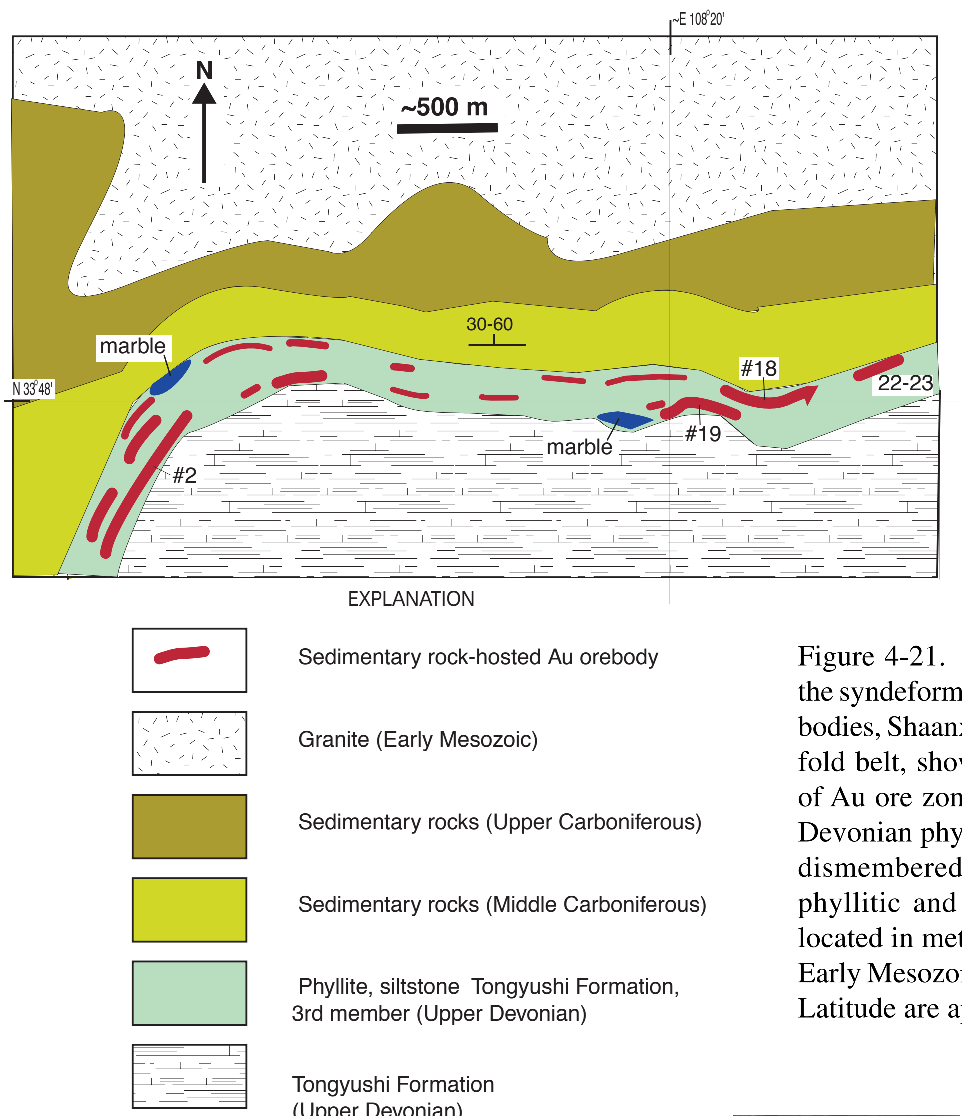



Figure 4-21. Plan geologic sketch of the syndeformational Maanqiao Au ore bodies, Shaanxi Province, East Qinling fold belt, showing stratabound nature of Au ore zones in mylonitized upper Devonian phyllite and siltstone. Note dismembered pods of marble along phyllitic and mylonitized host zone located in metamorphic aureole of the Early Mesozoic pluton. Longitude and Latitude are approximate.

Development of the mine took place after about six years of exploration, which included trenching, drilling, and underground sampling. This work resulted in the identification of 27 mineralized zones, of which 12 have current economic potential (fig. 4-21). Current (1999) exploration sampling is to a depth of 450 m. Potential resources of economic orebodies, at ≥4 g/t Au cut off grade, is 1,000,000 tonnes ore, along a 3–km-long strike length in the 4–km-long and 1– to 3–km-wide mine area (see fig. 4-21, 4-22, and 4-23). Three main economic stratabound orebodies, K2, K5, and K13, are each 400 to 550 m long, and 2.505 to 2.94 m thick, and have been traced 150 to 320 m deep by drilling (fig. 4-24). The total Au ore reserve is 7.6 tonne Au from ore that grades 4.95 g/t. Au. The mine and mill were visited in 1999. Information is from this visit and laboratory studies, and from the Gold Bureau of Shaanxi Province, and Maanqiao Gold Co.

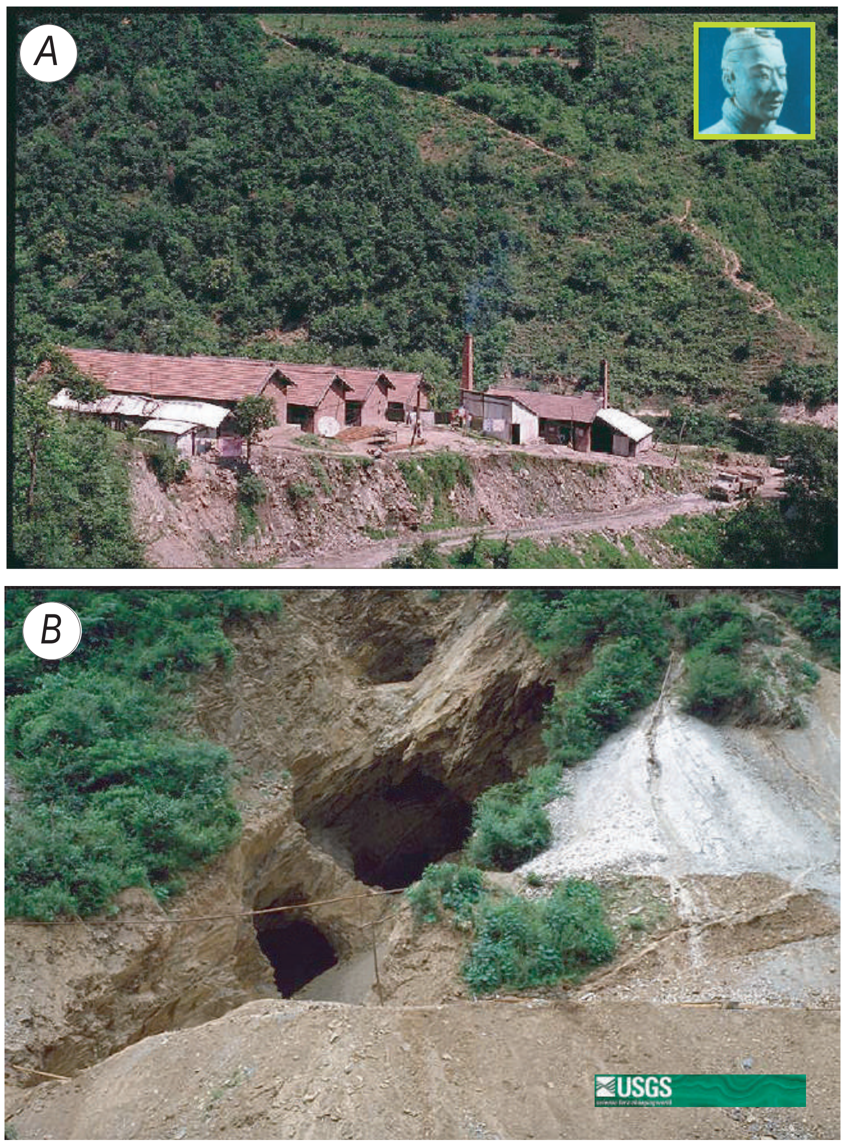



Figure 4-22. Photographs of the Maanqiao Au Mine area, Shaanxi province, East Qinling fold belt area. (*A*) Main Mine complex and Administrative Office. (*B*) Stope openings and outcrop of host shear zone of No. 2 orebody located along highway and river.

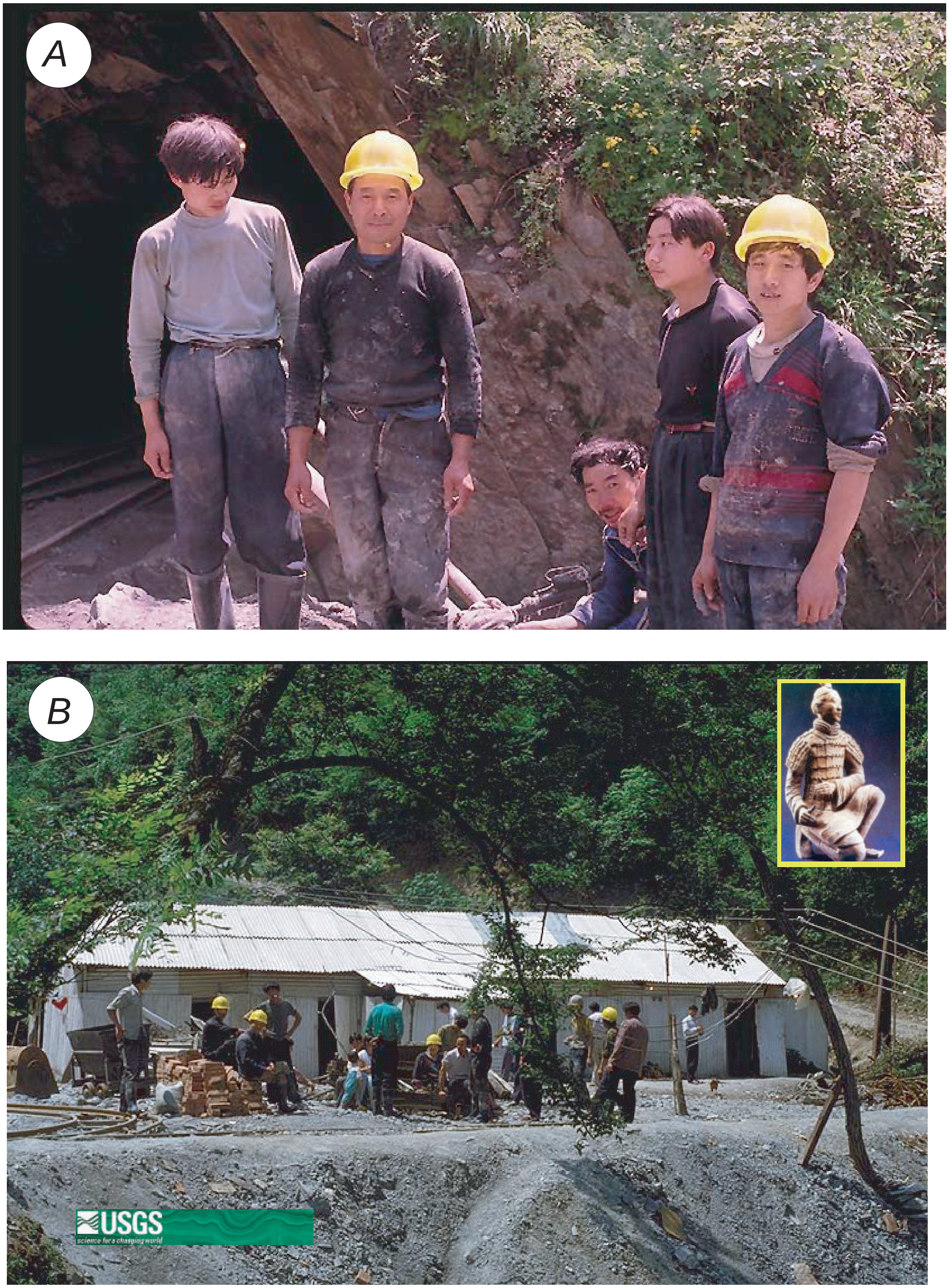



Figure 4-23. Photographs of portal to No 18 orebody. (*A*) Opening of portal. Miners are waiting for air to clear after a blast. (*B*) Work force on dump of hypogene ore near opening of portal on work break. Mine dry and mess are in background.

Geology of the Maanqiao Au deposit area consists of an east-west-striking sequence of moderately, north-dipping, late Devonian to late Carboniferous fine-grained clastic, carbonaceous slate and limestone units, the upper parts of which are in contact with an early Mesozoic granite to the north (Cheng, Y.Q., 1990; pers communication, Gold Bureau of Shaanxi Province, 1999) (fig. 4-21). The 3rd member of Upper Devonian Tongyushi Formation, composed of phyllite and silty sandstone, is the main ore horizon. Contact metamorphism locally has converted the limestone in the ore-bearing horizon to marble. Bedding planes locally have been disrupted by intense, post-intrusive, ductile shear zones that have dismembered many marble pods along phyllite and quartz-sericite stratabound mylonite (figs. 4-21 and 4-25).

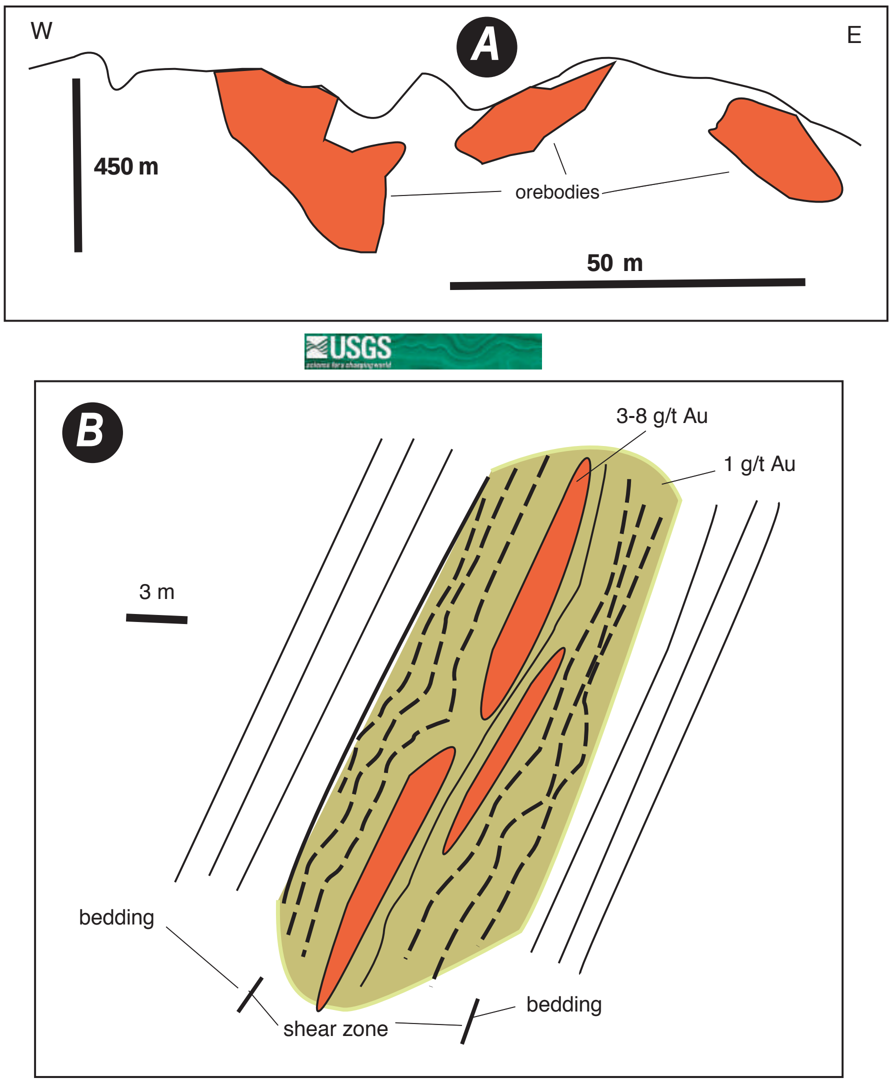



Figure 4-24. Diagrammatic sketches of the Maanqiao Au orebodies at different scale, Shaanxi Province, East Qinling fold belt area. (*A*) Longitudinal projection sketch of the Maanqiao No. 18 orebody, looking north. (*B*) Idealized lode area where host rock is ductile shear zone in upper Devonian silty sandstone, argillaceous siltstone, interlayered with carbonaceous carbonate rocks. Highest Au grades are in pod-shaped bodies along intensely sheared parts of the stratabound shear zone. Outside of shear zone in the undeformed halo around the shear zone bedded rocks also contain about 1 g/t Au in disseminations.

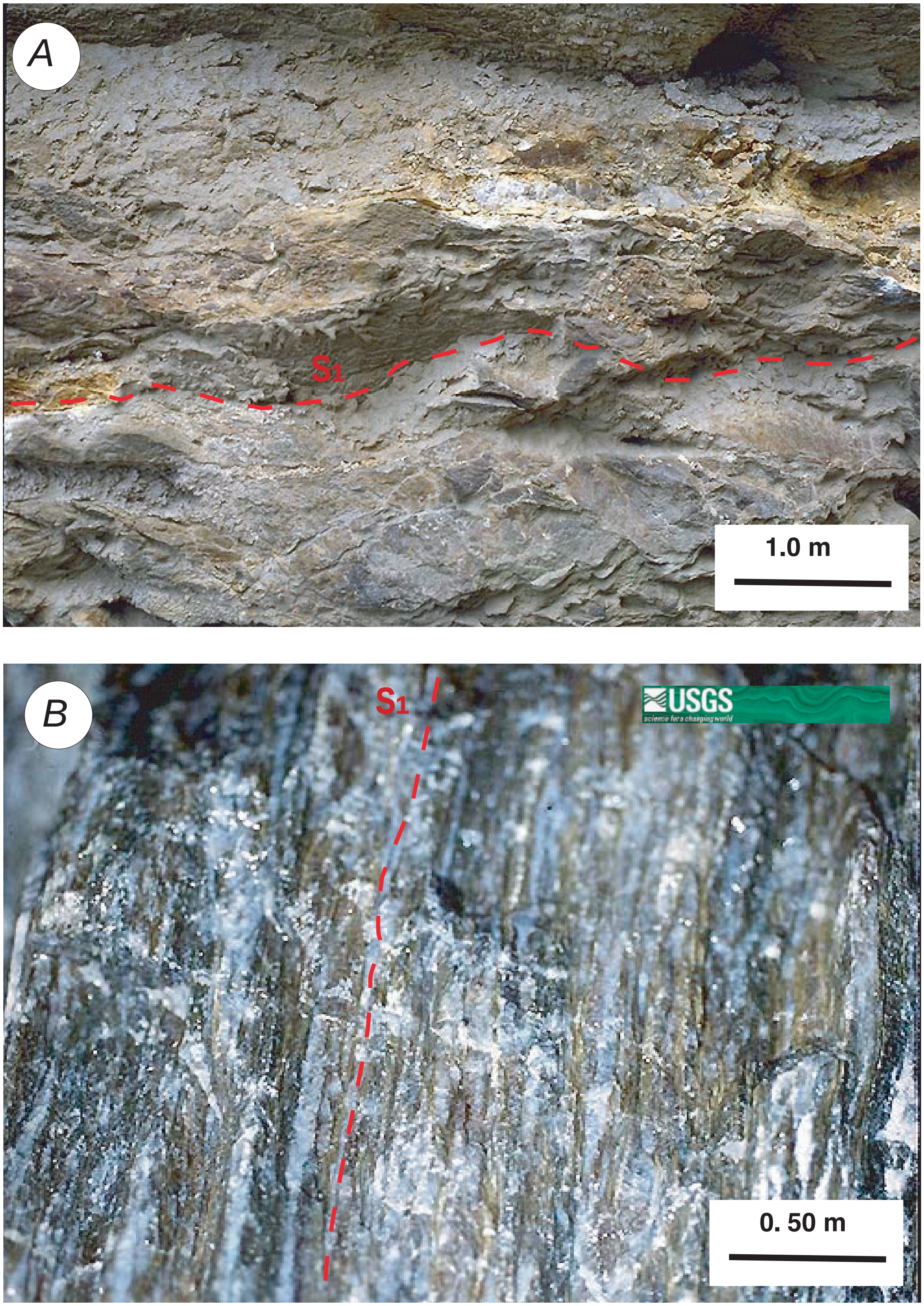



Figure 4-25. Photographs of outcrop-scale shear zones that hosts the Maanqiao Au ores. (*A*) Surface, weathered No. 2 orebody. (*B*) Underground exposure of No. 18 orebody. White areas are quartz and darker areas are pyrite and sericite. Dashed lines represent approximate attitude of shear plane (S1).

Structures in the Maanqiao mine area are dominated by a 42º to 60º south-dipping isocline and by the east-west-striking Wangjiashan-Zhengnangou ($F_1$) and Maanqiao ($F_2$) compressional faults (not shown on figure) that bound the 4,400–m-long and 150–m-wide, locally mylonitic, ductile shear zone–that hosts and controls the orebodies (fig. 4-21). Late, brittle, stratabound faults parallel the ductile shear zone and contain black, carbonaceous fault gouge and flukin, especially along the north stratigraphic contact between Devonian and Carboniferous rocks.

Stratabound, shear zone-hosted Au ore zones are surrounded by conformable, disseminated haloes of Au and sulfide minerals in the undeformed strata around the shear zones and these halos generally are thicker than the shear zones and grade between <3 g/t and 0.3 g/t Au (fig. 4-24), whereas the main Au oreshoots in the shear zones usually grade between >3.0 and 5.0 g/t Au. Alteration consists of intense quartz-sericite-pyrite along the strands of the shear zones (figs. 4-24*B* and 4-25) and is accompanied by biotite, plagioclase, ankerite, dolomite, apatite, and calcite (figs. 4-24*B* and 4-26). Locally within the shear zone, and throughout the outside of the shear zone, lie disseminated, non-texturally destructive growths of these minerals. Ore grade generally increases with the amount of quartz veinlets (fig. 4-25). The ore is black to dark gray and contains foliation-parallel quartz veinlets in a mylonitic fabric. Host rock and ore are siliceous, hard and usually schistose.


Figure 4-26. Photograph of hand specimen of quartz-rich ore from No. 19 orebody, Maanqiao Mine, Shaanxi Province, East Qinling fold belt. Dark areas are biotite, sericite, and pyrite defining ductile shear zone fabric. Note the textural similarity to shear zone-hosted Au-quartz veins or syndeformational veins. Quartz in the Maanqiao Au orebody usually is not well developed, but is most common in the No. 19 orebody.

Ore mineralogy at the Maanqiao Au deposit mainly consists of pyrrhotite, pyrite, with lesser magnetite, arsenopyrite, chalcopyrite, sphalerite, galena, native Au, local stibnite, and Ni–Sb, Pb–Cu–Zn, and Pb–Sb sulfide minerals (figs. 4-27, 4-28, 4-29, 4-30, and 4-31). Limonite is common in the oxide zones. Gold mainly is present as grains of native Au (about 81.3 volume percent) along boundaries of metal and non-metal sulfide minerals (figs. 4-28 and 4-31) and locally is present in the alteration matrix along the strands of the shear zone. Gold in micro-fractures is about 7.1 volume percent and in inclusions of sulfide minerals is 11.6 volume percent. Gold grain size is dominated by medium-fine particles (77 volume percent), then micro-grains (8.9 volume percent), and then coarse grains (14.15 volume percent). Ore minerals typically are present as disseminations, veinlets, and locally in massive clusters of sulfide minerals along the shear zone fabric (figs. 4-27, 4-28).

The geochemical signature of the Maanqiao Au deposit ores consists of elevated As and Sb concentrations and is similar to other Carlin-type sedimentary rock-hosted Au deposits in the Qinling fold belt (Appendix IV). PGEs at Maanqiao were not analyzed for in this study. Additional elevated geochemical values of Cu, Pb, Zn, Ni and Co also are compatible with

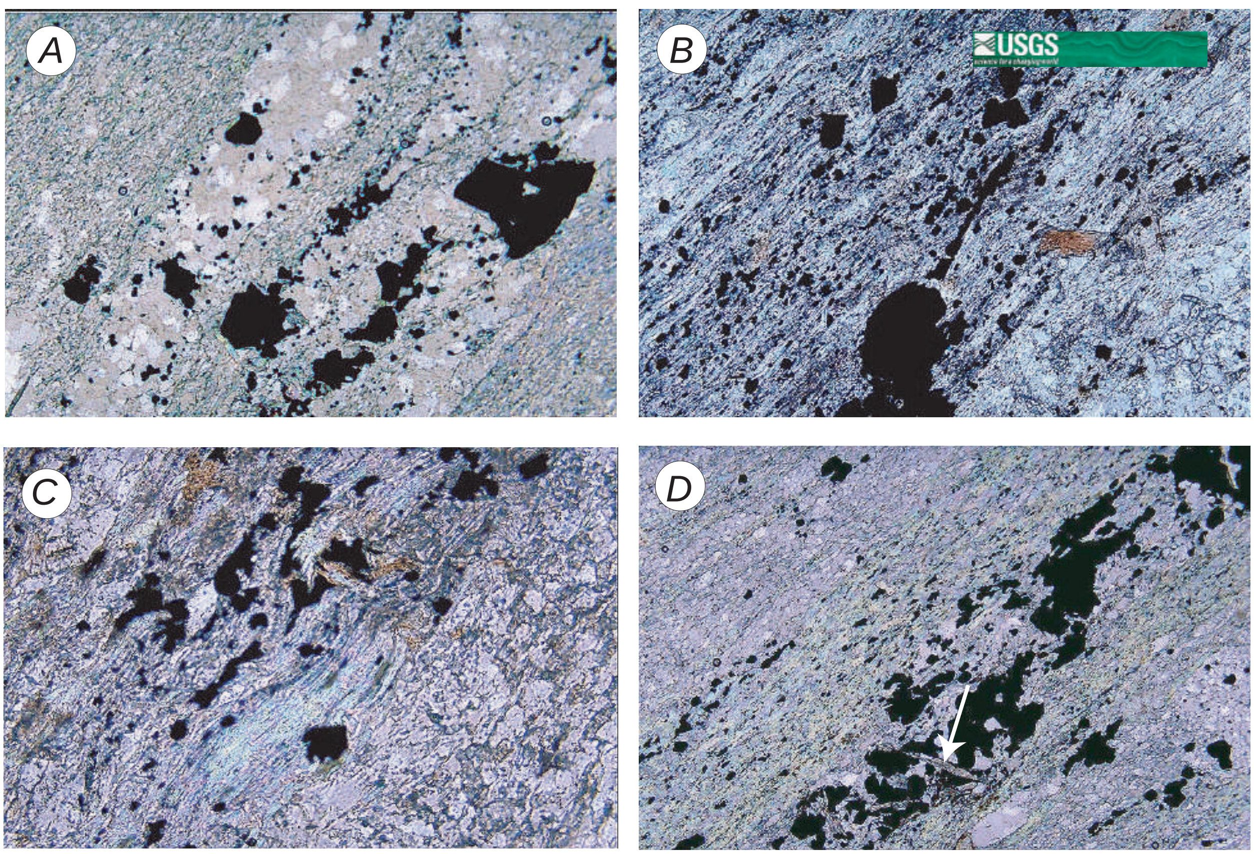



Figure 4-27. Microphotographs of crossed-nicols examples of relations among sulfide minerals and mylonitic foliation in the Maanqiao Au Mine, Shaanxi Province, East Qinling fold belt. Black minerals are sulfides: pyrite, arsenopyrite, and pyrrhotite. (*A*) Sulfide minerals lying along boundaries and inside phacoidal zones composed of dolomite and quartz. (*B*) Large and small sulfide mineral grains within finely laminated shear fabric. (*C*) Medium-sized sulfide minerals following or lying in cuspate undulations in foliation fabric. (*D*) Large sulfide grains preferentially following central foliation zone, cross-cut by blade of sericite (arrow), suggesting syndeformational growth of sulfide grains. Fields of view for each microphotograph is 4.5 mm.

Carlin-type deposits and the trace minerals in the Maanqiao Au ores, but also are similar to those found in some orogenic quartz-vein deposits. Local values of Bi and Ag are higher in the Maanqiao Au deposit than in most other Qinling fold belt Carlin-type ores (with the exception of Liba and Pulongba; Appendix IV), but could reflect the proximity and influence of the Mesozoic intrusive to the north (figs. 4-1 and 4-21) and inclusion of the deposit area in its contact zone.

The deposit has similarities to orogenic shear zone-hosted Au quartz vein deposits, such as native Au, quartz-sericite alteration, and local quartz veining along the host shear zone (fig. 4-26). Dolomite-ankerite alteration at the Maanqiao Au deposit may be remnant products of thermal alteration and shear zone remobilization from the dolomitic host rock, rather than products of hydrothermal carbonate alteration that commonly is associated with orogenic shear zone-hosted Au deposits. There also are some features, such as host rock, geochemistry, and geologic setting that are similar to Carlin-type deposits (see also, Peters, 2001). A tentative Carlin-type deposit classification is made for Maanqiao on the basis of mineralogy, geochemistry, and similarities in host rock and deformation style of the deposit to sedimentary rock-hosted Au deposits in the Ding-Ma Au belt to the east that have strong Carlin-type features.

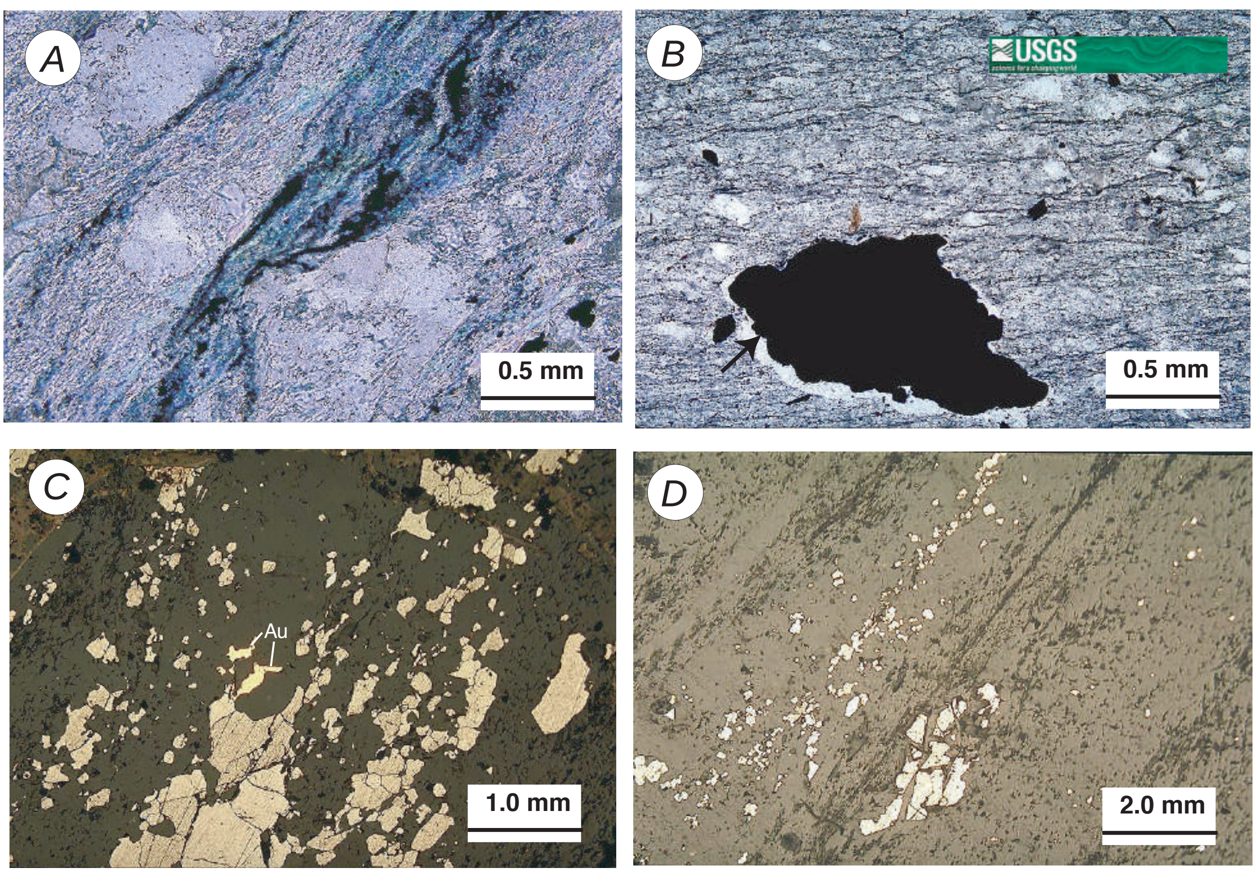



Figure 4-28. Microphotographs of examples of relation among sulfide minerals and Au to mylonitic foliation in the Maanqiao Au Mine, Shaanxi Province, East Qinling fold belt. (*A*) Elongated sulfide minerals along sericite-rich part of foliation. Crossed nicols. (*B*) Porphyroblastic sulfide grain with quartz-rich strain shadow (arrow) on left hand side. Crossed nicols. (*C*) Large mass of pyrite and pyrrhotite with Au along foliation. Reflected light. (*D*) Sulfide grains as porphyroblastic clusters, elongated along foliation plane. Reflected light.

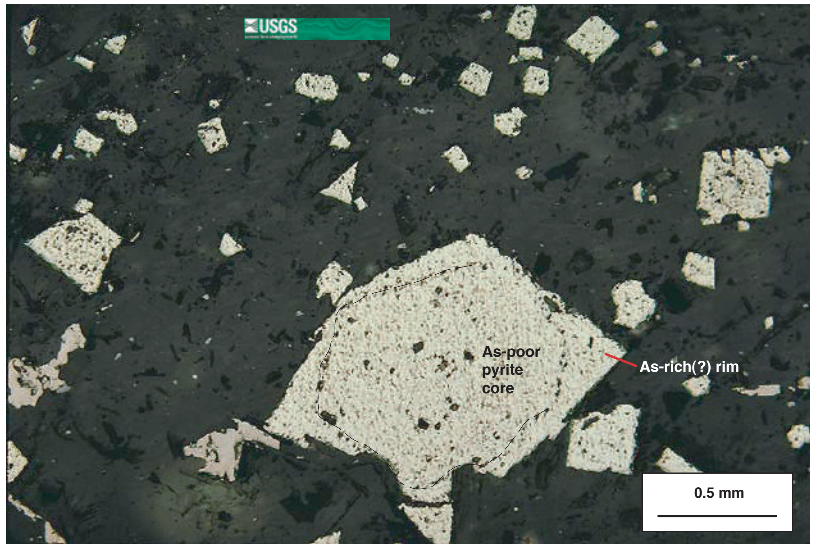



Figure 4-29. Scanning electron microscope back scatter image of disseminated, growth-zoned pyrites, Maanqiao Au deposit, Shaanxi Province, East Qinling fold belt. Note euhedral nature of growth rims. Area is from lessor deformed part of ductile host shear zone.

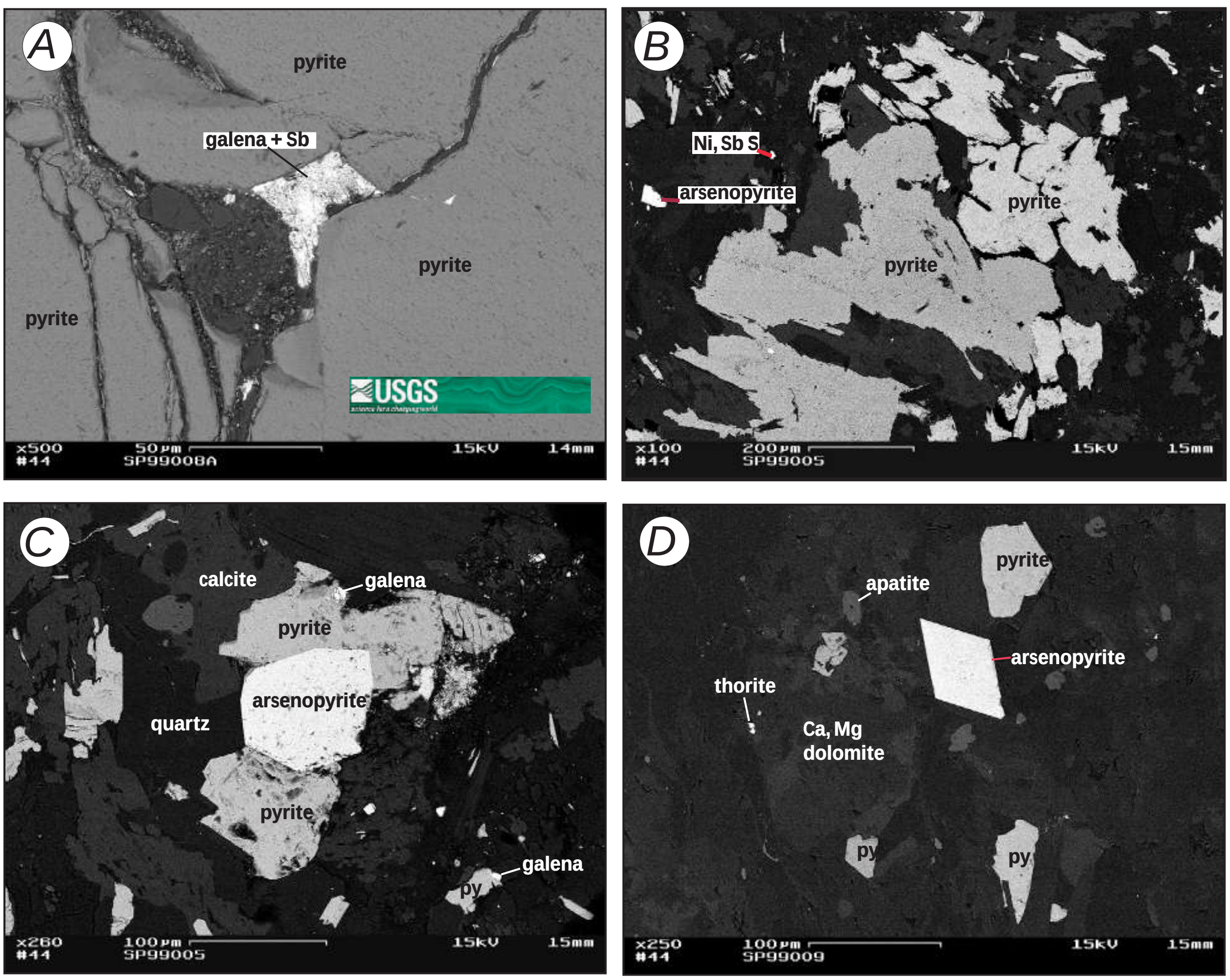



Figure 4-30. Scanning electron microscope back scatter images of trace minerals in Au ores from Maanqiao Au deposit, Shaanxi Province, East Qinling fold belt. (*A*) Sb-rich galena inclusions in pyrite grain. (*B*) Pyrite grains, arsenopyrite, and Ni-Sb sulfide trace mineral. (*C*) Pyrite grains with galena inclusions. (*D*) Disseminated pyrite, apatite, and thorite in a dolomite and quartz matte.

Genesis of the Maanqiao Au deposit, and the similar Baguamiao Au deposit to the west, most likely is related to processes that formed the host ductile shear zones. Sulfide minerals and Au appear to have grown simultaneous with deformation along the shear fabric of the shear zone (figs. 4-27, 4-28 and 4-31*B*), as suggested by strain shadows adjacent to sulfide mineral grains and by alignment of ore minerals along discrete micro-strands in the shear zones, and by growth of muscovite across some sulfide grains (figs. 4-27*B* and 4-28*A*). Growth rim zoning of local pyrite grains contains similar mineralogy—such as arsenopyrite, stibnite, and Au— as that found in strands along the shear zones (compare figs. 4-31*B* and *C*), implying that paragenesis and mineral precipitation was similar, and perhaps simultaneous, inside and outside the strained zones. Disseminated sulfide minerals and Au also are present in the undeformed zones in the hanging wall and foot wall of the shear zones.

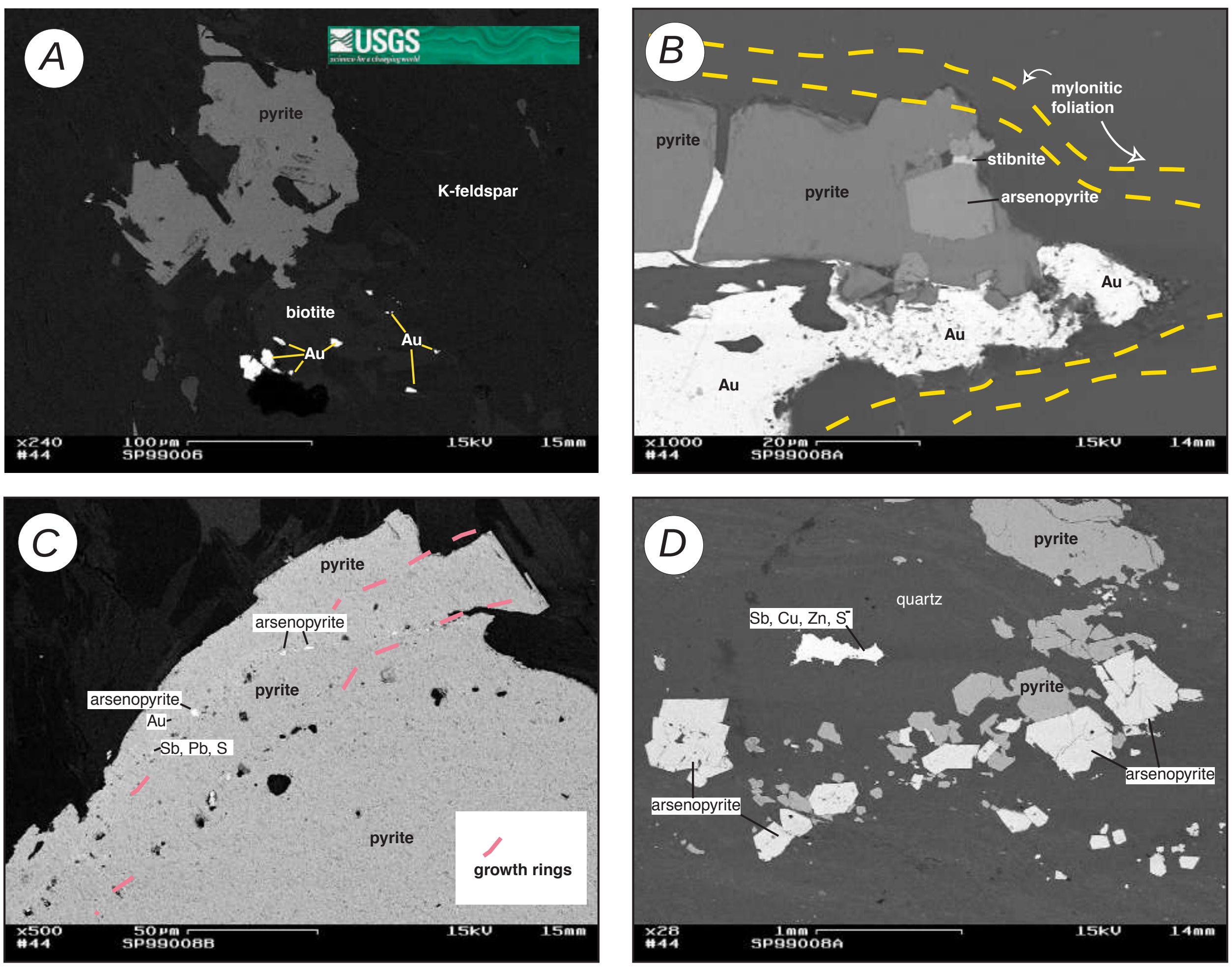



Figure 4-31. Scanning electron microscope back scatter images of Au ores, Maanqiao Au deposit, Shaanxi Province, East Qinling fold belt. (*A*) pyrite and Au in a matrix of K-feldspar, quartz, and biotite. (*B*) Gold and sulfide minerals in mylonitic foliation. (*C*) Growth rings on pyrite grains that contain arsenopyrite, Au, and Sb- and Pb-rich sulfide grains. Note that this is the same assemblage that is contained in the mylonitic foliation, B. (*D*) Pyrite and arsenopyrite and Cu- and Zn-rich stibnite.

Two genetic alternatives are possible: (1) the ore fluid entered and was concentrated along the shear zones and emanated into the adjacent wall rock as the shear zoned formed, or (2) stratabound Au mineralization predated the shear zone and was concentrated by a deformation-fluid processes during shear zone formation. The second hypothesis is similar to the source bed theory proposed by Zhang, X.F. and others (1997a,b) for the Carlin-type Au deposits along the Ding-Ma Au belt in similar Devonian age sedimentary host rocks (see above). The Maanqiao Au deposit may be a syndeformational-style deposit of the Carlin-type family of deposits, rather than part of the orogenic-type quartz vein deposits, but contains features and represents processes that bridge between the two deposit models (see also, Chapter 1; Phillips and Powell, 1993; Kerrich and others, 2001).

**Baguamiao Au deposit**

The Baguamiao Au deposit, in Fengxian County, Shaanxi Province is at E. 106° 56' 50" and N 33° 55' 45" about 40 km away from the Fengxian County town southwest of the city of Xian in the East Qinling fold belt area (fig. 4-1). The deposit was not visited as part of this study and information has been compiled from reports supplied by the Shaanxi Gold Bureau, Xian and from Zhong, J. and Zhang, G. (1997), and is included here for comparison with the Maanqiao Au deposit to which it has many similarities (Li, Z.P. and Peters, 1998). The deposit is a large-size (>50 tonne Au), syndeformational, sedimentary rock-hosted Au deposit that lies northwest of the Shuangwang Au deposit (figs.4-1, 4-2, 4-3). The deposit is proximal to the Lixian-Baiyun-Shanyang suture and is hosted in Devonian marine sedimentary rocks, similar to the Maanqiao Au deposit and Au deposits along the Ding-Ma Au belt.

The Baguamiao Au deposit is 1.7 km long, 50 to 160 m wide and has been explored 500 m down dip. It contains a measured resource of 80 tonnes Au. The Baguamiao Au deposit contains 12 orebodies at grades of 1 g/t Au and 10 orebodies at grades of 5 g/t Au. The 10 main orebodies are distributed as 8 orebodies in the north part of the district and 2 orebodies in the middle part of the district. The north orebodies are 1,680 m long and 50 to 160 m wide, strike northwest, and are 120 to ~520 m deep. The largest, No.14 orebody, is 500 m long and 4.84 m thick, and 220 m deep with a grade of 5.17 g/t Au. At a cut-off grade of 1 g/t Au, the No. 14 orebody is 11.76 m thick with an average grade of 2.93 g/t Au. The orebodies are stratabound layers or lenses that branch, merge, swell, and pinch along sheared bedding layers.

Geotectonically, the Baguamiao Au deposit is located along the north margin of the Fengxian-Zhenan fold zone of the south Qinling fold belt of Qinling fold system. The regional structural lineaments generally are west-northwest-striking with parallel folds and faults. The deposit lies within in the Baguamiao syncline, which is an internal fold at the west end and north limb of west-northwest-trending Sujiagou-Kongguangou synclinorium (these features not shown on figure 4-1). These are similar geometries to those in the Ding-Ma Au belt. The north limb of the Baguamiao syncline is overturned and plunges northwest (110° to 130°) at an angle of 36° to 40°. The axial plane in the northwest part of the syncline dips southwest at an angle of 70° to 80°, but in the southeast part the axial planes dips northeast at an angle of 80°. Interformational flow cleavage, flow folds, tongue folds, sheath folds, and recumbent folds are characteristic structural features and textures in the syncline.

Sedimentary rocks in the Baguamiao Au mine district are a 121.73– to 764.32–m-thick Middle Devonian sequence of:

(1) the upper member of the Gudaoling Formation, which includes medium- to thick-bedded limestone interlayered with ankerite phyllite at the bottom and biotic limestone interlayered with ankerite phyllite and thin-bedded limestone at the top; and

(2) the lower member of the Xinghongpu Formation, which contains carbonaceous silty sericite-phyllite, calcareous sericite-phyllite interlayered with muddy limestone; ankerite siltstone interlayered with ankerite, sericite-phyllite; spotted silty sericite-phyllite, silty phyllite and intercalations of crystalline limestone or calcareous ankerite siltstone (important host of Au ore); and silty phyllite, chlorite, sericite-phyllite (less important host of Au ore).

These rocks were deposited in a shallow shelf-tidal flat environment.

The two main faults in the Baguamiao Au mine area are the west-northwest-striking $F_1$ fault, near the contact between the Gudaoling and Xinghongpu Formations and the $F_2$ fault in the north part of the district. These two faults merge in the southeast part of the district and their acute intersection defines a several–km-long, 10– to 20–m-wide cataclastic zone. Limestone and phyllite in this zone are highly fragmented and brecciated and are converted to local zones of mylonite and phyllonite. Brittle-ductile shear zones control distribution of orebodies and contain quartz stockworks along the ore zones. In the northeast part of the district, small cross faults cut the strata and orebodies.

Gold ores in the Baguamiao Au deposit are located along a northwest-striking ductile shear zone and are present as small stockworks and veinlets within this shear zone. The ore textures are brecciated, disseminated, and clumped, but also are present as layers and massive accumulations of ore and gangue minerals. Alteration minerals form a broad, bleached zone that surrounds the host shear zone, similar to the Maanqiao Au deposit to the east.

The main ore minerals in the Baguamiao Au deposit are pyrite, pyrrhotite, and marcasite with lesser chalcopyrite, ilmenite, molybdenite, rutile, native Au and Ag, and rare arsenopyrite, galena, sphalerite, Te and Bi minerals, and Au. Sericite and quartz are the main gangue minerals, but are accompanied by ankerite, chlorite, biotite, hydro-mica, and tourmaline. Microscopically, the ores are granoblastic, showing deformation features. Gold is present as inclusions in minerals or at interstices of mineral crystals and partings of minerals, or as intergrown particles. Visible Au (.0.01 mm) is about 35 volume percent and microscopic Au (0.01~0.05µm) is about 45 volume percent, and super-microscopic gold (0.01µm) is about 20 volume percent. The average fineness of Au is 878 (range from 836 to 931) and the average content of Ag is 11.53 weight percent.

PGE minerals are contained in limonite in the Baguamiao Au deposit. According to Su, R.X. and others (2000), PGE minerals were concentrated in late hydrothermal fluid stages and were accompanied by silicification and ferrodolomitization. The concentration of PGE minerals is correlated with values and occurrences of Au. PGE minerals are very fine (~0.5 µm) and are present in microscopic joints of quartz and along contacts between quartz and sericite. Composition of the main PGE mineral is Ru = 66.8 weight percent, W = 23.63 weight percent, Co = 7.189 weight percent and Fe = 2.32 weight percent (Su, R.X. and others, 2000).

## Shuangwang Au deposit

The Shuangwang Au deposit is a large breccia-hosted sedimentary rock-hosted Au deposit in the East Qinling fold belt area (fig. 4-32) also located along the strong, regional-scale Lixian-Baiyun-Shanyang suture that lies north of Shuangwang and the Baguamiao Au deposit. The Shuangwang Au deposit, however, does not contain strong shear fabric or mylonitic foliation found at Baguamiao and Maanqiao. The deposit was not visited as part of this study. Information is summarized from Shi, Z. and others (1993) Fan, S.C. and Jin, Q.H., (1994), Li, Z.P. and Peters (1998). Eight economically significant Au-bearing breccia bodies are present in a composite extensional, 11.5–km-long, 700– to 500–m-wide, N 290° to 310° W-trending breccia zone (fig. 4-32). All together 14 breccia-hosted orebodies have been defined in the Shuangwang Au deposit area using a 1 g/t Au cut-off. The No. 8 orebody, the largest one, is approximately 680 m long, 28.3 m wide, and 348 m deep. Platinum and Pd are enriched in pyrite and ferruginous dolomite in the Shuangwang Au deposit, similar to Baguamiao. The maximum values in these minerals is Pt = 2.66 weight percent and Pd = 0.348 weight percent (Fan, S.C. and Jin, Q.H., 1994).

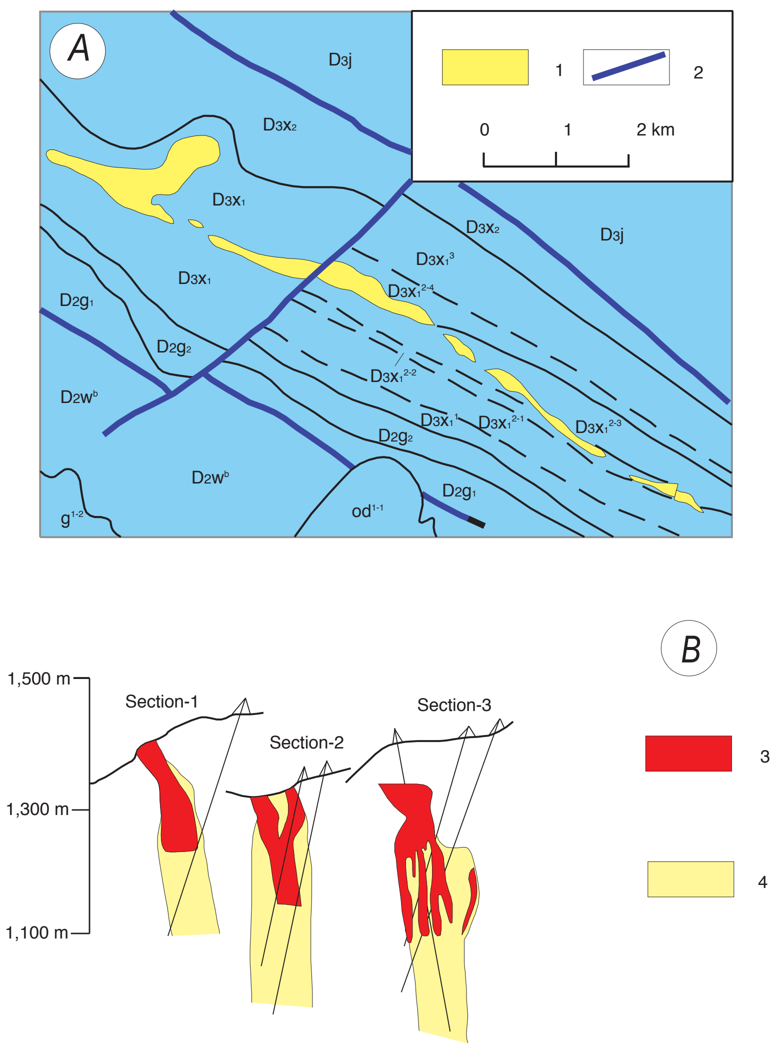



Figure 4-32. Stratabound breccia ore-control in the Shuangwang Au deposit, Qinling fold belt area. (*A*) Plan geologic map of the Shuangwang Au deposit showing localization of the orebody in the D3x1 unit. (*B*) Sections 1, 2, and 3 showing Au orebody in the upper parts of the stratabound breccia zone. 1-breccia body; 2-fault; 3-Au orebody; 4-brecciated host rocks; D1wa-b- meta sandstone interbedded limestone, carbonaceous shale (Wangjialeng Formation); D2g1-2-limestone, sandstone (Gudaoling Formation); D3x1-2- siltstone, limestone, phyllite (Xinghuongpu Formation); D3j-siltstone, slate (Jiuliping Formation). Adapted from Fan, S.C. (1994).

The host breccia bodies locally crosscut Devonian Xinhongpu Formation rocks, which consist of silty slate, interbedded argillaceous silty limestone, mirolitic limestone, argillaceous limestone, and interbedded slate. Middle Devonian Gudaolong Formation rocks, which also host ore in breccia bodies, are composed of calcareous sandstone and siltstone interlayered with limestone and calcareous slates. The breccia bodies are conformable or crosscut stratigraphy at low-angles. The breccia clasts (size ranges from 10 cm to several m) 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 that were formed at multiple stages of hydrothermal activity. Breccias also are a common host for many Carlin-type deposits in Nevada, USA (see also, Peters and others, 1997).

A light-colored alteration zone associated with the breccia bodies contains early albite and sericite in the breccia bodies, and late ankerite that extends beyond the steep-dipping Au-bearing breccia bodies. This alteration assemblage, along with dolomite, calcite, quartz, rutile, and apatite constitute a chief prospecting marker for Au deposits in this area (Fan, S.C. and Jin, Q.H., 1994). Although Au is inversely related to areas of intense albitization in most deposits, albitization is associated directly with Au in two occurrences in the Shuangwang Au deposits; one occurrence is as a gangue mineral with the Au ore; another is as breccia matrix in the orebody. Albite generally is considered to be formed at an early paragenetic stage of hydrothermal activity, and is most likely pre-Au ore (Fan S.C. and Jin, Q.H., 1994).

## WEST QINLING FOLD BELT

The West Qinling fold belt area constitutes much of the "northern golden triangle" area of Sichuan, Gansu, and Shaanxi Provinces and contains groups of sedimentary rock-hosted Au deposits on the north side of the Qinling fold belt in Gansu Province, on the south side of the fold belt in northern Sichuan Province, and also deposits to the west along the north-northwest-trending Luhuo-Daofu fault zone in west-central Sichuan Province(figs. 4-1 and 4-33). The deposits mainly lie in the Kekexin-Bayankala massif between the Jinshajiang suture zone to the west and the Longmenshan nappe to the east (features not all shown on figures). Many deposits also lie along the northwest-striking Ganzi-Litang suture (fig. 4-33). The West Qinling sedimentary rock-hosted Au deposits are part of a large Au-(As)–Hg–(Sb) metallogenic zone that extends from Nima in Maqu County, Gansu Province to Manaoke, Nanping County, Sichuan Province where Permian and Triassic carbonate and clastic rocks also host Hg-bearing sedimentary rock-hosted Au deposits (Li, W., and others, 1994; Li, Y.D., and Li, Y.T., 1994; Li, Z.P. and Peters, 1998).

### Stratigraphy in West Qinling fold belt

The West Qinling fold belt is divided into three lithotectonic sub-belts from south to north. Sedimentary rock-hosted Au deposits mainly are present in Paleozoic and early Mesozoic rocks in parts of the south belt. Stratigraphically, the south belt is divided into western and eastern parts. The following description of the stratigraphic sequence in the West Qinling fold belt is presented to serve as a background for district geology and lithologic host rocks for the deposit descriptions that follow and is from the Bureau of Geology and Mineral Resources of Gansu Province (1989).

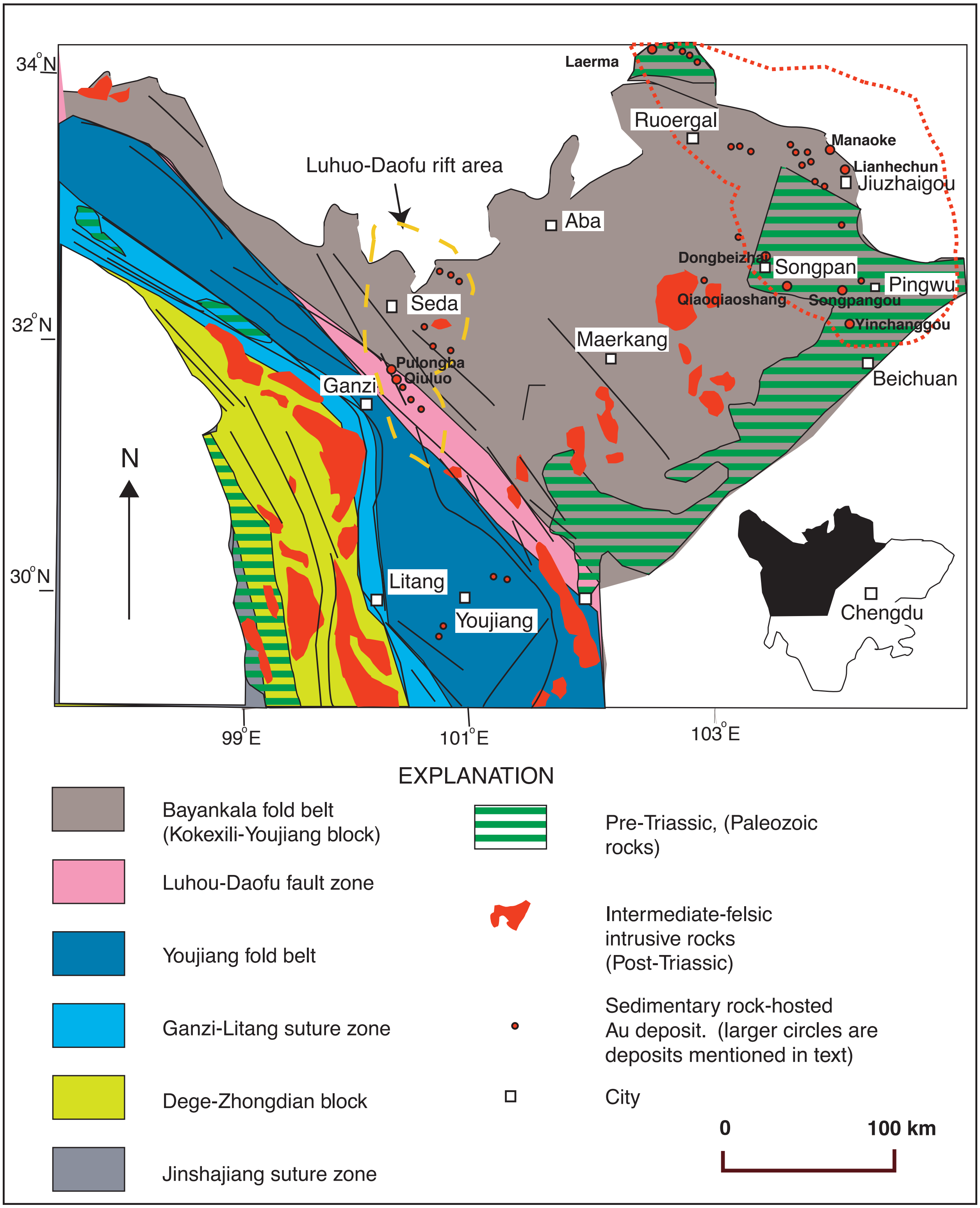



Figure 4-33. Geologic and tectonic units of northwestern Sichuan Province, West Qinling fold belt, showing distribution of sedimentary rock-hosted Au deposits. Red dashed line indicates approximate outline of northern golden triangle at the the Gansu, Sichuan and Shaanxi Province boundaries. (Modified from Zheng, M.H. (1989, 1994).

The **Cambrian** sequence is 2,117m thick, composed of metamorphic sandstone and slate that is interlayered with intermediate to basic volcanic rocks. The Lower Cambrian Taiyangding Group, in the south area of Gansu Province and northwest parts of Sichuan Province is more than 497 m thick, is composed of pyrite-bearing silty slate, carbonaceous siliciclastics (chert and argillite), carbonaceous argillaceous slate, sericitic slate and phyllite and is the important Au ore horizon. Rocks in this group contain high organic C with a range of 0.66 to 14.63 weight percent C, and an average 3.24 weight percent C. These are important host rocks for the Laerma Au deposit (see below).

The **Ordovician** sequence hosts very few sedimentary rock-hosted Au deposits and is divided into the upper and lower sequences**.** The Lower Ordovician sequence is composed of arenaceous slate, carbonaceous and siliceous slate. The Upper Ordovician Dabao Group ($O_3d$) is more than 1,932 m thick and is composed of slate, carbonaceous silty slate, carbonaceous siliceous slate, argillaceous limestone, and metamorphic siltstone with interlayers of tuff.

The **Silurian** sequence is present in a number sedimentary rock-hosted Au deposits districts in the southern part of the West Qinling fold belt and is divided into lower, middle, and upper sequences**.** The Lower Silurian Deibu Group is divided into two formations (from bottom to top):

(1) the Anzigou Formation ($S_1a$) is 742 m thick, composed of phyllite, silty slate and siliceous and carbonaceous slate interlayered with argillaceous rock and coarse crystalline, clastic tuff;

(3) the Jiannigou Formation ($S_1j$) is more than 1,657m thick, composed of black, siliceous, carbonaceous slate, phyllitic silty slate, carbonaceous silty phyllite and sericite phyllite, interlayered with siliceous slate; and

(4) the Middle Silurian Zhouqu Group ($S_2zh$) is more than 693 m thick, composed of gray-green slate, meta-quartz sandstone, and carbonaceous siliceous slate, and thin-bedded limestone. The Upper Silurian Bailongjiang Group ($S_3b$) is more than 2,396 m thick, composed of sericite-phyllite, meta- fine-grained quartz sandstone, thin-bedded crystalline limestone and carbonaceous slate.

The **Devonian** sequence is a very important host for many sedimentary rock-hosted Au deposits and related deposits of Sb and Hg. Devonian rocks are divided into a lower, middle, and upper series. The Lower Devonian is divided into three formations (from bottom to top):

(1) Xiapugou Formation ($D_1x$) is 240 m thick, composed of dolomitic marl, gray-green slate and gray calcareous slate, interlayered with thin-bedded limestone;

(2) Shangpugou Formation ($D_1sh$) is 281 m thick, composed of dolomite interlayered with dolomitic marl, slate interlayered with dolomitic marl; and

(3) Gala Formation ($D_1g$), 1,091 m thick, composed of microlitic dolomite interlayered with arenaceous dolomite and carbonaceous argillaceous siltstone.

The Middle Devonian is divided into two formations:

(1) Lure Formation ($D_2l$) is 389 m thick, composed of crystalline limestone and argillaceous limestone, interlayered with arenaceous limestone, quartz sandstone and shale;

(2) Xiawuna Formation ($D_2x$); the upper clastic unit is 261 m thick, composed of black shale, argillaceous siltstone and thin-bedded limestone; the lower carbonate unit is composed of thick-bedded limestone, thin-bedded argillaceous limestone and marl, interlayered with shale. Fine-grained calcareous quartz sandstone is present in the bottom. $D_2x$ is the important host horizon for many sedimentary rock-hosted Au and Sb deposits.

The Upper Devonian is divided into two formations (from lower to upper):

(1) Cakuohe Formation ($D_3c$) is 560 m thick, composed of argillaceous limestone and limestone, interlayered with black shale and silty slate. Gravel-bearing limestone and conglomerate present in the bottom;

(2) Doushishan Formation ($D_3d$) is 663 m thick, composed of chert band or nodule-bearing thin- medium bedded crystalline limestone, massive crystalline limestone. Argillo-arenaceous band-bearing dolomitic limestone is present in the bottom.

A **Carboniferous** sequence of sedimentary rocks in the West Qinling fold belt is divided into a lower, middle, and upper series. The Lower Carboniferous is divided into two formations (from bottom to top):

(1) Yiwagou Formation ($C_1y$) is 593 m thick, composed of thin-medium bedded limestone interlayered with argillaceous limestone and calcareous mudstone;

(2) Lieyang Formation ($C_1l$) is 1,290 m thick, composed of medium- to thick-bedded limestone and oolitic limestone, interlayered with argillaceous limestone and carbonaceous arenaceous shale.

The Middle Carboniferous Mingshan Formation ($C_2m$) is 363 m thick, and is composed of giant, thick-bedded limestone, interlayered with medium- to thin-bedded limestone. Oolitic texture is present in the limestone locally. The Upper Carboniferous Gahai Formation ($C_3g$) is 545 m thick, composed of massive clastics, limestone, and oolitic limestone.

The **Permian** sequence in the West Qinling fold belt is divided into the Upper and Lower Permian. The Lower Permian is further divided into two formations (from bottom to top):

(1) Qixia Formation ($P_1q$) is 320 m thick, composed of medium bedded limestone, interlayered with thick-bedded limestone with chert band or nodule;

(2) Maokou Formation ($P_1m$) is 226 m thick, composed of thin-medium bedded limestone with chert band or nodule, interlayered with arenaceous limestone and siltstone.

The Upper Permian also is divided into two formations (from bottom to top):

(1) Dieshan Formation ($P_2d$) is 113 m thick, composed of thin-bedded limestone interlayered with calcareous mud stone, carbonaceous calcareous shale interlayered with thin-bedded limestone;

(2) Changxing Formation ($P_2c$) is 179 m thick, composed of medium bedded limestone, brecciated limestone, oolitic limestone. Dolomitic limestone is present in the top.

The **Triassic** sequence in the West Qinling fold belt is more 2,216 m thick, composed of river- and lake-sandstone, fine-grained sandstone, siltstone, shale, mudstone, marl, conglomerate, and coal beds. The Triassic rocks contain a number of sedimentary rock hosted Au deposits and is divided into upper, middle, and lower sequences. The Lower Triassic Bocigou Formation ($T_1b$) is lesser than 101 m thick, composed of thin-bedded metamorphic sandstone, thin-bedded micrite limestone and Fe, and Mn-bearing slate. In some areas, such as the Maqu area, Lower Triassic mainly is composed of oolitic and pisolitic limestone. The Middle Triassic rocks are 1,200 to 1,500 m thick and divided into two formations:

(1) Zagunao Formation ($T_2z$) composed of medium bedded-massive metamorphic sandstone and siltstone, interlayered with slate; and

(2) Zagashan Formation ($T_2zg$) composed of metamorphic dacitic tuff, metamorphic tuffaceous sandstone and slate, interlayered with crystalline limestone.

Upper Triassic is divided into two formations;

(1) Zhuwo Formation ($T_3zh$) that is 362 to 917 m thick, and composed of thin-thick-bedded metamorphic sandstone, siltstone and silty slate; and

(2) Xinduqiao Formation ($T_3x$) that is more than 800 m thick, composed of gray-black carbonaceous silty slate and carbonaceous slate, interlayered with sandstone. $T_3x$ is the important host horizon for sedimentary rock-hosted deposits of Au, Sb, and Hg.

**Cretaceous** rocks in the West Qinling fold belt are more than 2,629 m thick, composed of river-and lake facies sandstone, siltstone, argillaceous siltstone, silty mudstone, mudstone, and conglomerate, locally interlayered with lava, tuffaceous breccia and volcanic breccia.

The **Tertiary** sequence in the West Qinling fold belt is more than 1,698 m thick, composed of river- and lake-phase mudstone, arenaceous mudstone, gravel-bearing mudstone, fine-grained sandstone, and sandstone.

Most sedimentary rock-hosted Au deposits are hosted in late Paleozoic and early Triassic stratigraphic sequences consisting of fine-grained clastic rocks, subvolcanic rocks, ophiolite, mÈlange, ferruginous dolomite, debris-bearing quartz-greywacke, slate, and highly carbonaceous rocks. Igneous rocks locally are common and usually are Mesozoic granite porphyry dikes, such as at the Laerma and Lianhechun Au deposits, or diabase dikes at the Qiuluo deposit. At the Pulongba Au deposit, Paleozoic mafic volcanic rocks also are present in the stratigraphic section. The Paleozoic rocks were folded during development of the post-Triassic Indonesian (230 to 195 Ma) trough in the Himalayan orogeny and produced west-northwest, northwest- and northeast-striking faults and folds. Many deposits are controlled by regional-scale structures, such as the Ganzi-Litang suture—similar to the Lixian-Baiyun-Shanyang fault zone in the East Qinling fold belt—and east-striking faults, such as the Snow Mountain Fault, or the Luhuo-Daofu fault zone.

### Deposits along the Snow Mountain fault

A number of sedimentary rock-hosted Au deposits, including the Songpangou, Qiaoqiaoshang, and Dongbeizhai Au deposits, contain similar mineralogical, geochemical and other characteristics. These deposits are hosted in late Paleozoic to early Mesozoic carbonaceous and calcareous rocks along shear zones near the east-striking Snow Mountain fault and near the north-striking White Horse (Beima) fault. Northeast-striking faults and northeast-trending folds also have local control and host some orebodies (figs. 4-33 and 4-34).

#### Songpangou Au deposit

The Songpangou Au deposit is in a remote, mountainous part of northeast Pingwu County, Sichuan Province 83 km from the Pingwu County town (figs. 4-33 and 4-34). Access is by four-wheel drive road. Elevation is over 3,000 m and the terrain is steep. Prospecting and mining sites are accessed by foot about 1 km above a base camp at the end of the road. The deposit is located adjacent to the Snow Mountain fault. Sources of information for the Songpangou Au deposit are from a field visit in 1999 and from personal communication with the Gold Bureau of Sichuan and Southwest Geological Exploration Bureau, Chengdu.

Ore is present as sheared, stratabound, and layered bodies, which locally pinch out into swollen pods that branch and merge with each other. The mine area contains two main clusters of deposits that also are differentiated by land ownership. The 800–m-long 160–m-wide east cluster contains three 100– to 400–m-long, 2.6– to 7.5–m-thick orebodies that grade 0.41 to 2.1

g/t Au and are owned by local villagers (figs. 4-35 and 4-36). The west cluster contains deposits with higher Au grades and is at the intersection of east- and north- striking fractures. The west cluster is owned by the Southwest Geological Exploration Bureau and contains three orebodies. The 900–m-long, 0.48- to 11.9–m-thick (average = 2.38 m) No. 5 orebody is the largest and grades 1.0 to 30 g/t Au (average = 4.76 g/t Au) (fig. 4-36).

Mining is conducted by local villagers and farmers on the east lodes and batch processing and evaluation by the Southwest Geological Exploration Bureau is conducted (1999) on the west lodes. Hand-made vat cyanide leach tanks are lined with tarps and cut into the steep hillsides (figs. 4-35*C*, *D* and 4-37). Mining at the surface is conducted by hand methods in steep open cut slots along the lodes that strike perpendicular to the slope (fig. 4-35*B*). Prospecting, exploration, and evaluation are conducted by adits driven along the strike of the lodes (fig. 4-35*A*) using hand-drilling and hand-mucking methods.

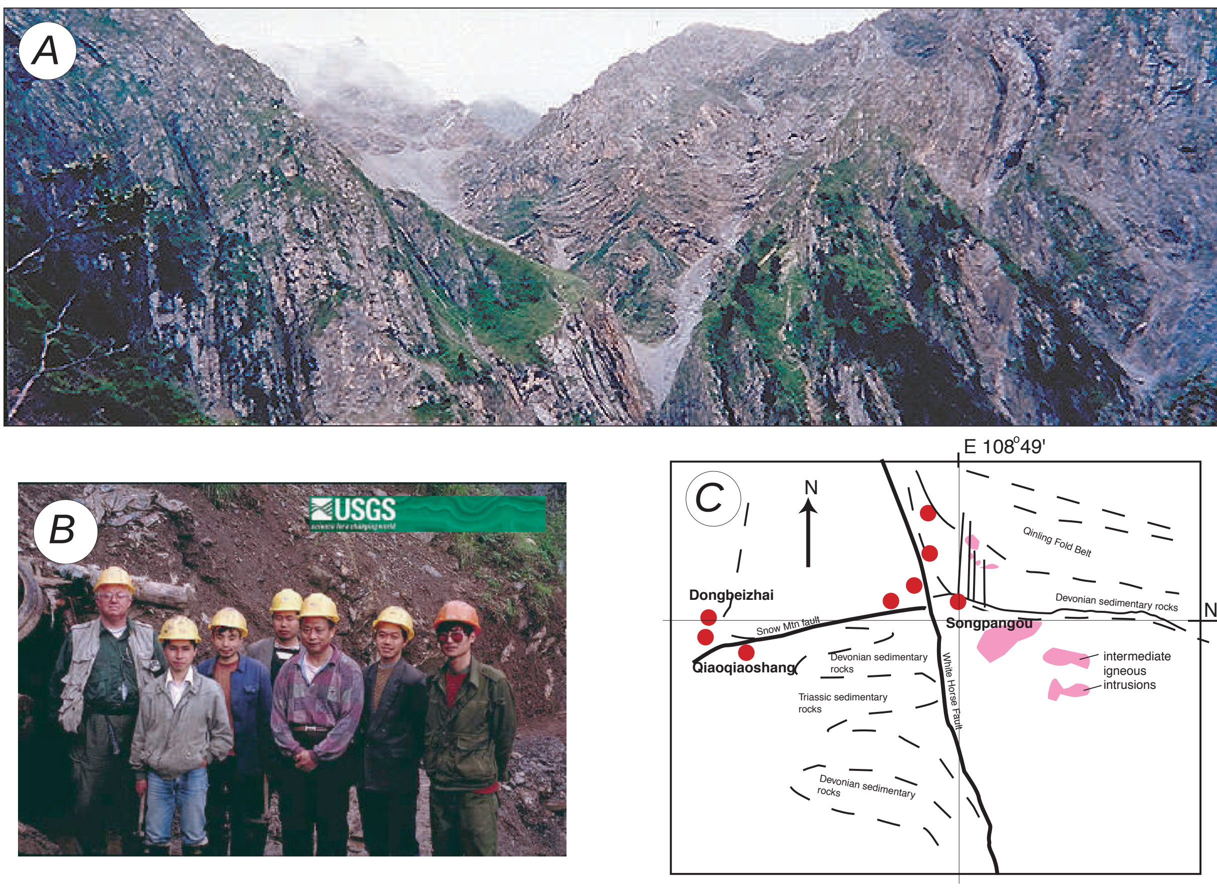



Figure 4-34. Photographs of Songpangou Au deposit area, West Qinling fold belt area, Sichuan Province.. (*A*) Panoramic view of area, looking west, above the Songpangou prospects at elevation of +3,000 m, showing folded Devonian sedimentary sequence. (*B*) Geologic exploration staff at Songpangou deposit, 1999. (*C*) Sketch map from 1:2,000,000 scale geologic map of sedimentary rock-hosted Au deposits in the Songpangou-Qiaoqiaoshang-Dongbeizhai area, northern Sichuan Province, West Qinling fold belt. Note main control by east-west-striking Snow Mountain Fault and auxiliary control by the north-striking White Horse Fault. Longitude and latitude are approximate.


Figure 4-35. Photographs of Songpangou Au deposit area, northern Sichuan Province, West Qinling fold belt area. (*A*) Main No. 4 and 5 prospect areas showing two lodes (between dashed lines) and adit-portals (arrows). (*B*) Eastern lode mined by local farmers in open cast. Ore is present in low area that as been mined. (*C*) Vat leach pits in eastern lode area. (*D*) Vat leach pits in west lode area excavated on hill side below exploration office (on left).

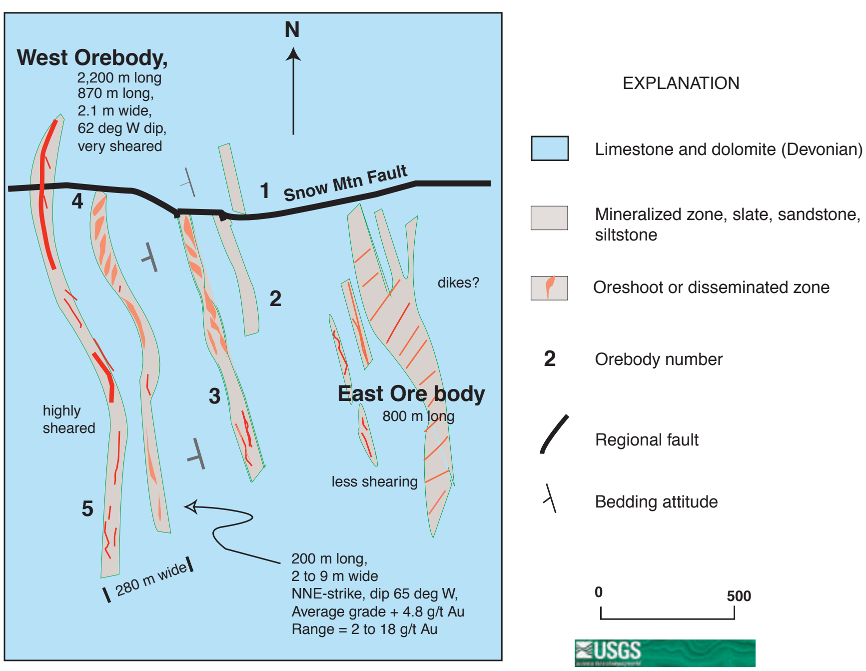



Figure 4-36. Geologic sketch map of Songpangou Au deposit area, Pingwu County, Sichuan Province, West Qinling fold belt. Largest orebody is theWest Orebody, which is at 3,090 to 3,330 m elevation. See text for longitude and latitude.

Figure 4-37. Photograph of western Songpangou Au deposit area in foreground, exploration camp in the middle ground, and Snow Mountain fault (dashed line) in the background. Looking west.


The main regional-scale ore controlling structure is the Snow Mountain fault that strikes through the main part of the Songpangou Au deposit area (fig. 4-34*C*). Structure in the area also is dominated by the Longdishui-Songpangou anticline and regional- and district-scale east-west-, north-south- (for example, White Horse fault) and northeast-striking fault zones. Composite folding within the anticline is well exposed along steep mountain walls adjacent to the deposit (figs. 4-34*A,* 4-37). Orebodies mainly are controlled by northeast-striking, bedding-parallel fracture zones.

Host rocks are the upper member of the Middle Devonian Shanhe Formation consisting of thin-bedded carbonaceous, argillaceous, silty slate, medium- to thick-bedded, medium- to fine-grained psammitic sandstone, quartz sandstone, banded and lenticular limestone, and dolomite (fig. 4-36). Early Mesozoic granitic and dioritic dikes locally are present along the shear zones that host ore in the Songpangou Au deposit area.

Ore minerals are similar to those found in most Carlin-type deposits and include pyrite, arsenical pyrite, realgar, orpiment, siderite, stibnite, cinnabar, arsenopyrite, rutile, sphalerite, and magnetite (figs. 4-38, 4-39, 4-40, and 4-41). Pyrite displays intense and intricate growth zoning of As-rich and As-poor, 1– to 20–μm-thick rims and zones concentrically around As-poor cores (figs. 4-40*A*, *B*). Realgar is present as 0.25– to 0.5–m-thick, irregular masses along brittle-ductile shear fabrics in carbonaceous zones (fig. 4-38). Realgar also is present as mm-scale disseminations and as <1–µm-size inclusions along As-rich pyrite growth zones in arsenical pyrite (figs. 4-39, 4-41*B*).

Alteration assemblages and wall rock gangue consist of quartz, carbonate minerals, clay minerals, chlorite, epidote, barite, white mica, zircon, and apatite. Ore is located along lodes that characteristically contain disseminated pyrite and arsenical pyrite and these minerals also are present in bands and along fractures associated with intense realgar and orpiment. Gold is present as micron-scale; single grains that are absorbed on the surface of limonite and in realgar crystals in the oxide zone, as submicron inclusions in pyrite, and in As-rich pyrite growth rims.

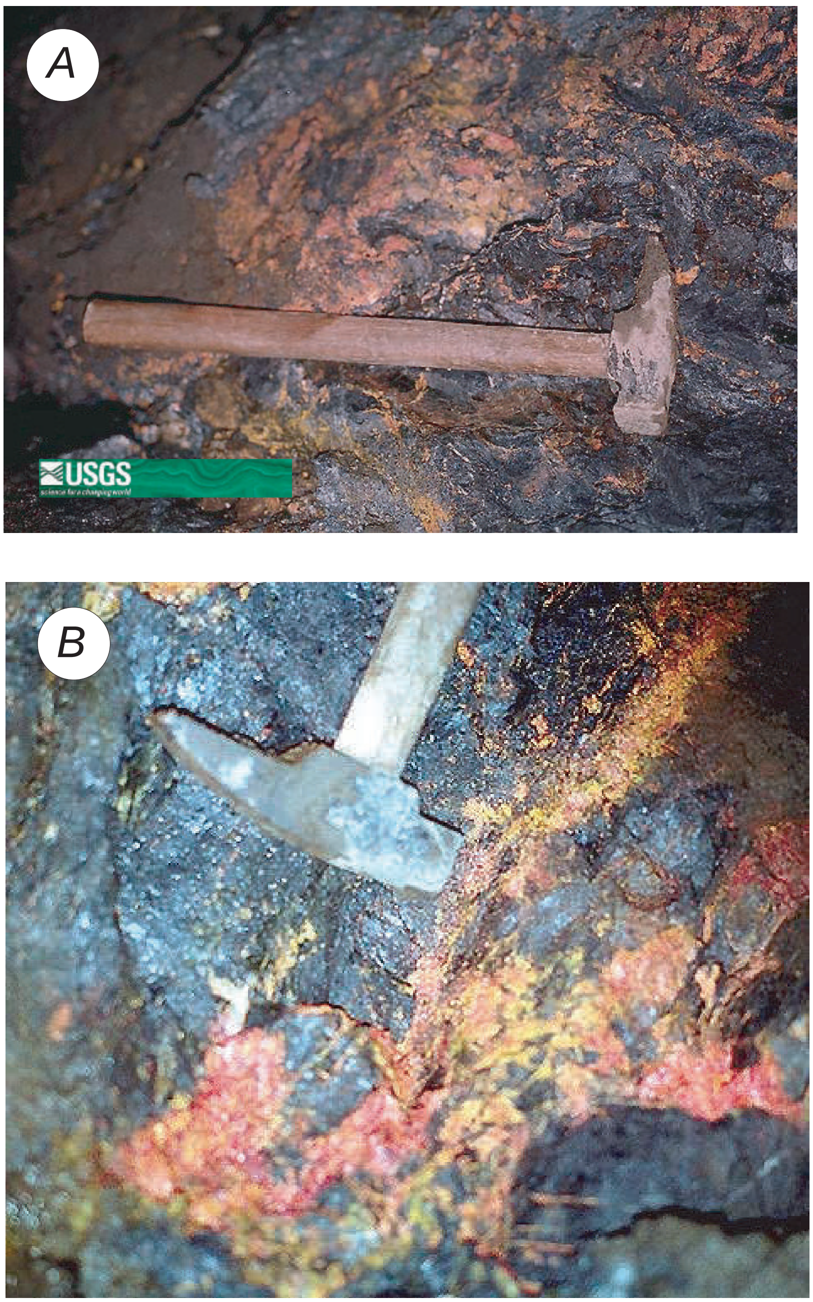



Figure 4-38. Photographs of hypogene ore in underground workings, showingtextural relation of realgar-orpiment ore to wall rock, Lode no 4. (*A*) Realgar and orpiment ore in folded and sheared, black, phyllitic, carbonaceous wall rock. (*B*) Realgar and orpiment in irregular mass along controlling structure.

Figure 4-39. Photograph of hand-specimen of realgar ore associated with calcite-filled crackle breccia from eastern orebodies, Songpangou Au deposit, Sichuan Province, West Qinling fold belt area.

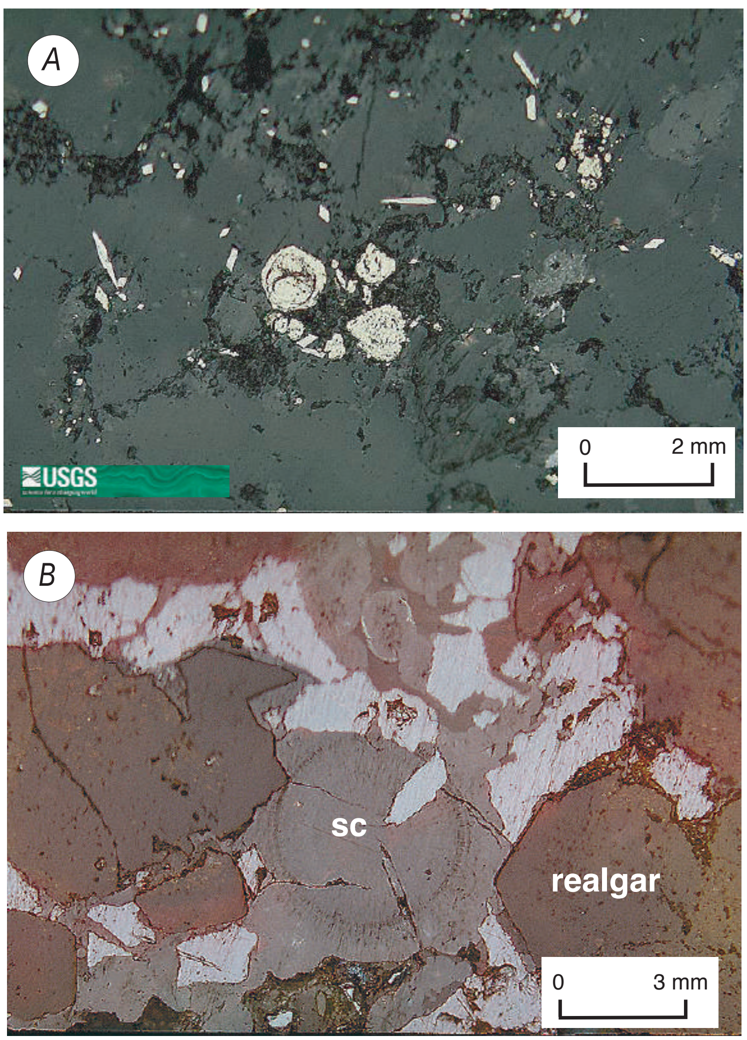




Figure 4-40. Microphotographs of polished sections of hypogene and supergene ores from the Songpangou Au deposit, Sichuan Province, West Qinling fold belt area. (*A*) Disseminated, arsenically-zoned pyrite and needles of skeletal arsenopyrite in hypogene ores. (*B*) Botryoidal scorodite (As-oxide) and realgar in oxide vug at supergene-hypogene transition zone.

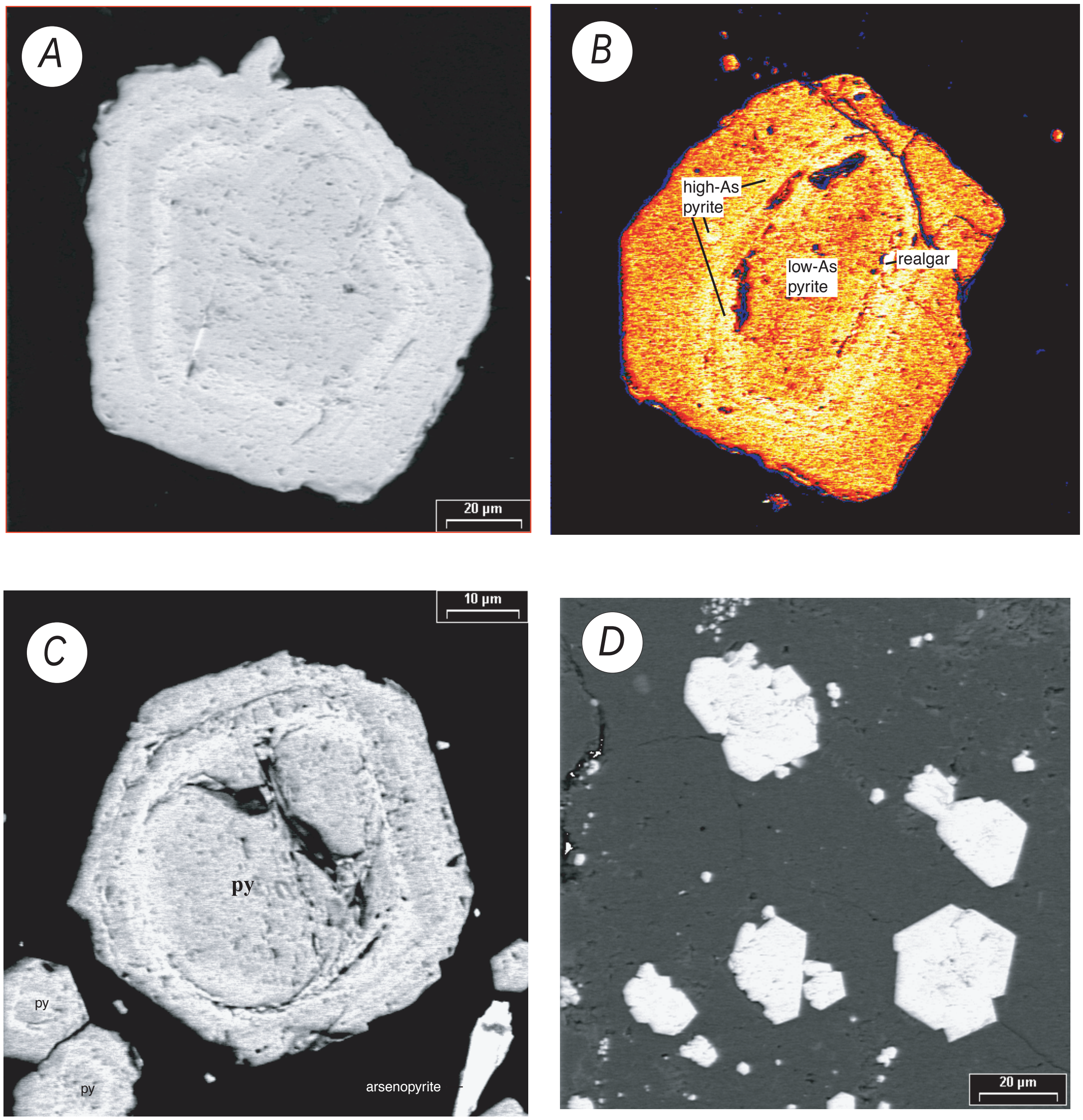



Figure 4-41. SEM back scatter images of zoned As-rich pyrite grains, Songpangou Au Mine, Sichuan Province, West Qinling fold belt. (*A*) Concentrically-zoned pyrite. Darker areas are As-poor; lighter areas are higher in As. (*B*) Color-enhanced SEM image of concentrically-zoned pyrite with As-rich (light colors) and As-poor (yellows and reds) layers. Center of pyrite is low-As. Light-colored rings are high-As. Very bright spots are realgar. This pyrite is part of a cluster of similarly zoned pyrite crystals in a dark colored calcite-dolomite-quartz matrix. Veinlets of realgar also cross -cut the specimen and are probably paragenetically later than the pyrite. (*C*) Concentrically-zoned pyrite. Lighter areas are higher in As than the lower areas. (*D*) Pyrite cluster in calcite-dolomite-quartz -realgar matrix. Euhedral growths on exterior are arsenical.

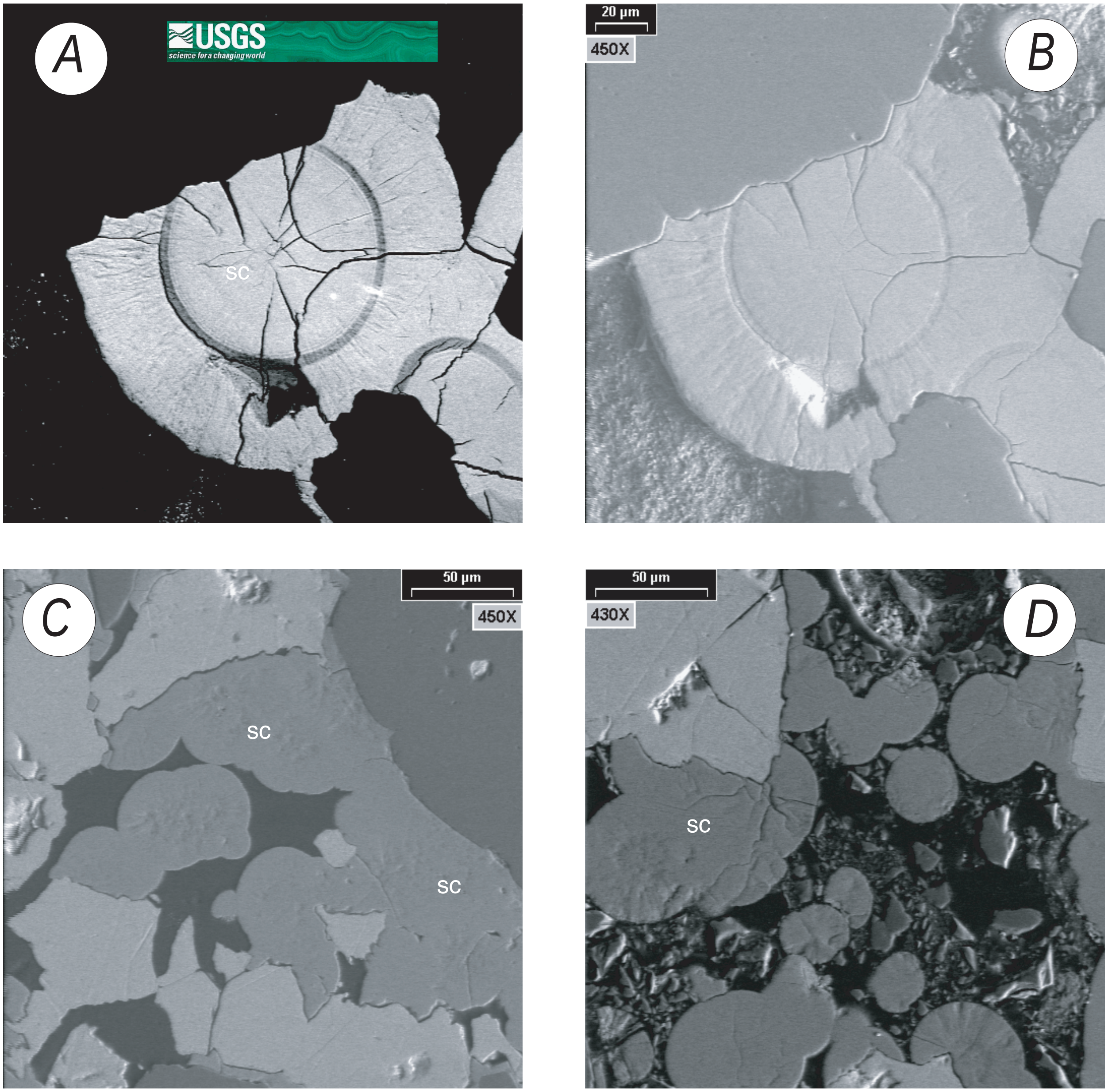



Figure 4-42. SEM back scatter images of supergene As-rich Au ores, Songpangou Mine, Sichuan Province, West Qinling fold belt. Specimen SP990013A. (*A*) Botryoidal scorodite from Songpangou mine. Darker rings are Fe-rich parts of As oxides. (*B*) Botryoidal scorodite in vug in massive orpiment-realgar showing textural relations among other minerals. (*C*) Botrioydal scorodite in orpiment-realgar zone. (*D*) Botryoidal scorodite in vug along orpiment mass.

Oxidation penetrates to a depth of 10 to 20 m. Supergene and oxide minerals include goethite, limonite, scorodite, and orpiment, as well as clay minerals. Botryoidal scorodite is present along oxidized fractures at the hypogene-supergene interface (figs 4-40*B*, 4-42).

Geochemical contents of elements in hypogene ores of the Songpangou Au deposit are anomalous in As and Hg and have moderately high values of Pb, Zn, Ni (Appendix IV) and Tl, which is an anomalous geochemical suite similar to the geochemical signature of other Carlin-type deposits in the west Qinling fold belt and in the Din-Qian-Gui area (Chapter 3).

The host rock, ore textures and mineralogy of the Songpangou Au deposit have many similarities to the Getchell (Berger and Tingley, 1985) and Betze (Peters and others, 1998, 1999) Au deposits in north central Nevada, USA, where intense brittle-ductile, carbonaceous deformation fabrics locally dominate in realgar- and orpiment-rich ore zones. These fabrics and textures are compatible with a syndeformational genesis of the ores.

**Qiaoqiaoshang Au deposit**

The Qiaoqiaoshang Au deposit is in the mountainous northeast part of Songpan County, 20 km from the Songpan County town, Sichuan Province. Access is by road to within about 3 km of the deposit and then by foot or pony. The orebody is one of several Carlin-type Au deposits located along the east-striking Snow Mountains Fault (fig. 4-33 and 4-34). Orebodies are east-striking, multi-layered, stratabound, large lenses, veins, envelopes, and columnar-shaped bodies that are 35º to 45º north-dipping (fig. 4-43). About 14, 140– to 1,000–m-long (average = 336 m) and 1.46– to 24.37–m-wide (average = 6 m) orebodies have cut-off grades of 1 g/t Au. Maximum grade is 3.025 g/t Au and average grade is 2.0 g/t Au. Six of the 14 orebodies are currently economic with lengths of 190 m, thicknesses of 4.63 m, and average ore grades of 4.056 g/t Au. Total resource of the mine area is 22.82 tonnes Au (see also, Hu, J.P., 1991).

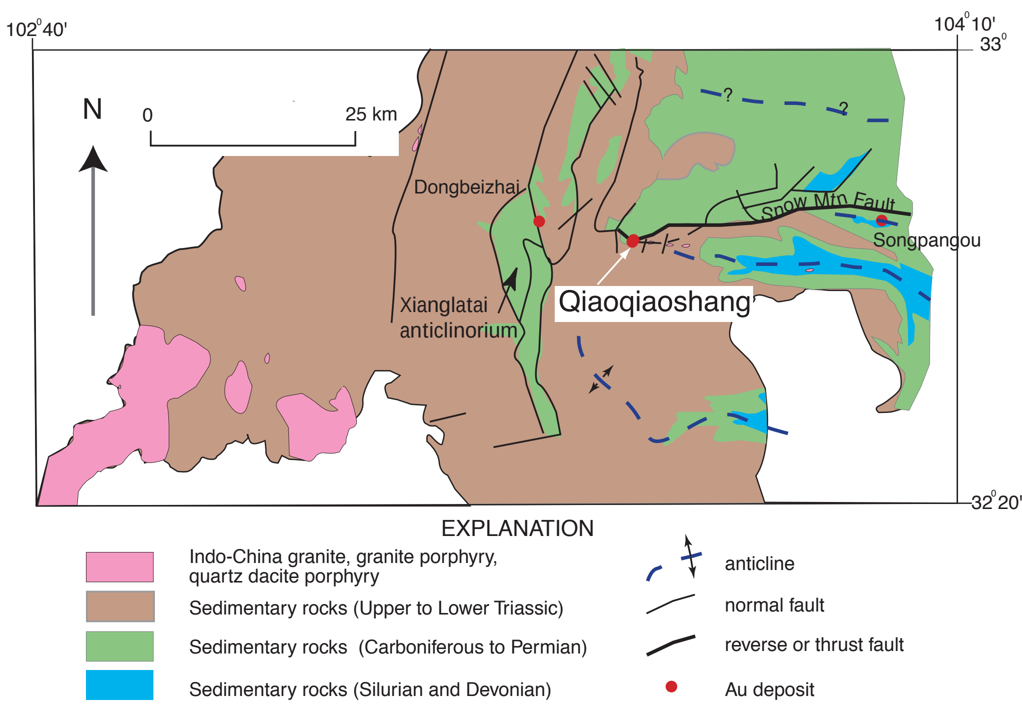
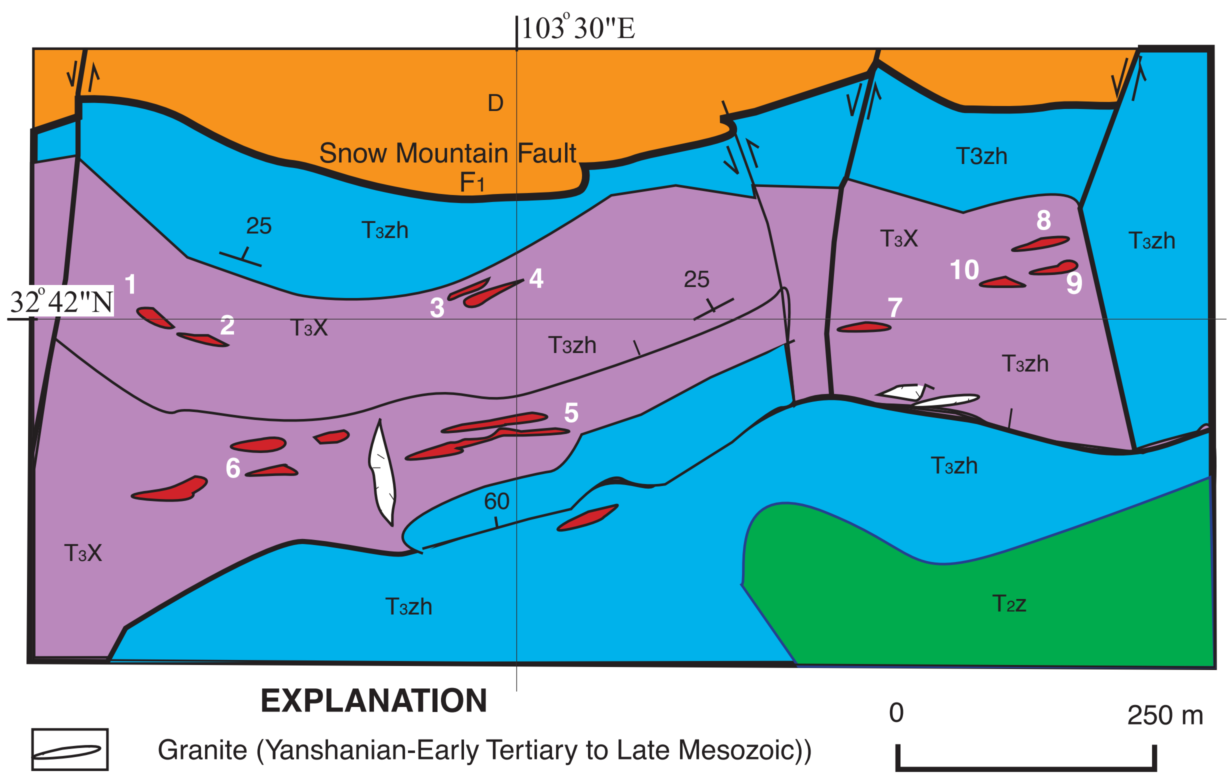



Figure 4-43. Simplified geologic map of the Qiaoqiaoshang Au deposit area, north Sichuan Province, West Qinling fold belt. The deposit is adjacent to the east-striking Snow Mountain Fault, as are the Songpangou and Dongbeizhai au deposits, which have similar characteristics.

Mining is conducted on oxide ore in the south part of the area at lower elevations and in hypogene ores in the higher, northern part of the area (figs. 4-44 and 4-45). The oxide ores are processed by cyanide vat-leach methods (fig. 4-46). The high-As hypogene ores are sacked and transported by pony (fig. 4-47) to the main town where they are trucked to Guizhou Province for processing. Sources of information for the Songpangou Au deposit are a field visit in 1999 and from personal communication with the Gold Bureau of Sichuan and Southwest Geological Exploration Bureau, Chengdu.

The Qiaoqiaoshang Au deposit is hosted in the 3rd member of the Upper Devonian Series Xindu Qiao Formation ($T_3x$) that is an east- striking, north-dipping calcareous slate interlayered with psammitic quartz sandstone. The second most important ore horizon is the 2nd member of this sedimentary rock series, which consists of thick sandstone interlayered with thin-bedded slate and silty sandstone (figs. 4-44 and 4-47).

Ore is hosted along east-striking fractures in semi-stratabound bodies. Oreshoots mostly are present at intersections of fractures with north - and northeast-striking fractures (fig. 4-44) and folds. Local dikes and pods of Yanshanian (185 to 67 Ma) granite locally are present in the host stratigraphy; however, pluton-related features, such as hornfelsing, calc-silicate development, and veining are not present near the orebodies.



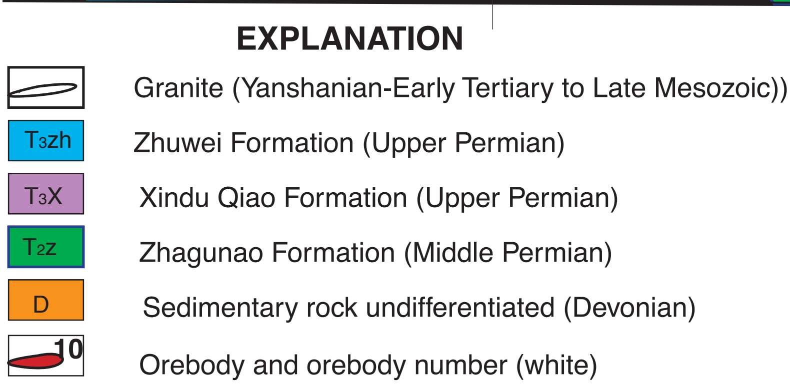




Figure 4-44. Geologic sketch map of the Qiaoqiaoshang Au deposit, Songpan County, Sichuan Province, West Qinling fold belt. Longitude and latitude are approximate.


Figure 4-45. Photographs of Qiaoqiaoshang area, Sichuan Province, West Qinling fold belt. (*A*) Looking north perpendicular to the strike of strata; bedding dips into hill. Upper area is hypogene ore and lower area is oxide ore. (*B*) Excavation by multiple adits driven perpendicular to strike of orebodies in hypogene zone. Looking north. (*C*) Close up of adit entrance. (*D*) View of eastern extension of ore horizon (between dashed lines) and its relation to a strand of the Snow Mountain Fault, which lays in valley. Looking east.


Figure 4-46. Cyanide processing of oxide Au ores at Qiaoqiaoshang Au deposit, Sichuan Province, West Qinling fold belt., southern, or lower, oxide ore horizon. (*A*) Vats and waste piles. (*B*) Hand unloading of finished vat.

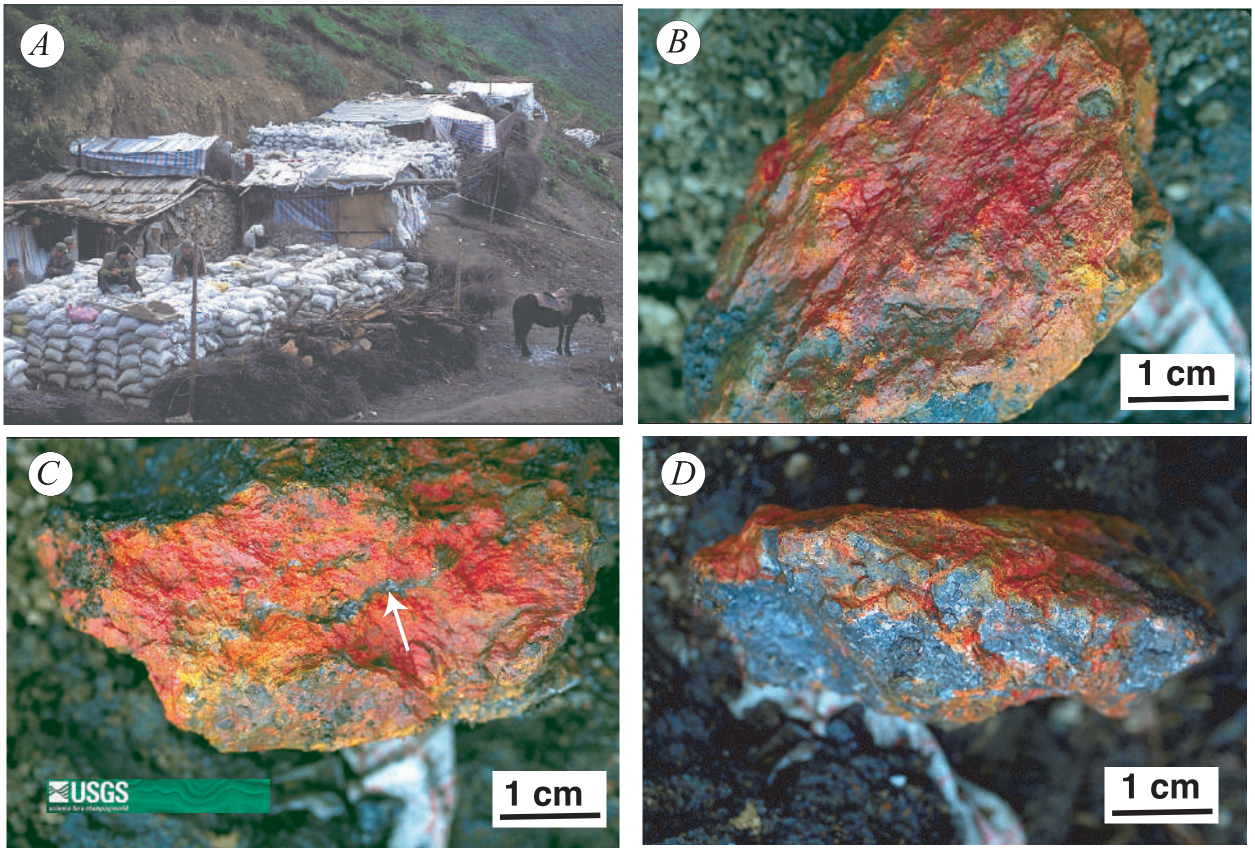



Figure 4-47. Arsenic-rich ores of the Qiaoqiaoshang Au deposit, Sichuan Province, West Qinling fold belt. (*A*) Sacked realgar ore stock-piled for shipment by pony to smelter complex in Guizhou Province. (*B*) Massive realgar ore with orpiment disseminations and clusters. Gold mainly is contained in dark, wall rock fragments. (*C*) Realgar and orpiment ore precipitated along bedding and shear planes that are preserved in ore (arrow). (*D*) Realgar ore filling mosaic or fractures in As-rich pyrite-mineralized rock.

Oxidized ore is present from the surface to a depth of 30 to 50 m in the south orebodies. Gold in the oxide ore mainly is associated with limonite. Primary ore lies below about 30 to 50 m, except in the north parts of the mine area where it is within 5 m of the surface. Hypogene Au ore is present as cataclastic and brecciated ore types. Cataclastic ore, where pyrite is the main Au carrier, contains disseminations, bedding parallel veinlets, bands, and networks in micro-joints and cleavage planes. Cataclastic ore consists of pyrite, marcasite, realgar, cinnabar, arsenopyrite, stibnite, and chalcopyrite in a gangue of quartz, clay, sericite, calcite, dolomite, chlorite, carbonaceous material, rare alunite, and gypsum.

Brecciated ore consists of fragments of sandstone, slate, and quartz vein material that are cemented by an argillaceous matrix high in Ca and Fe. Pyrite and zoned arsenical pyrite, arsenopyrite and stibnite are the dominant ore minerals (fig. 4-48) and are present as disseminations and veinlet-networks. Brecciated ore also contains realgar and orpiment. Gangue minerals are calcite, white mica, chlorite, sericite, calcareous material, and local kaolinite, pyrophyllite, biotite, anhydrite, and calcanthite.

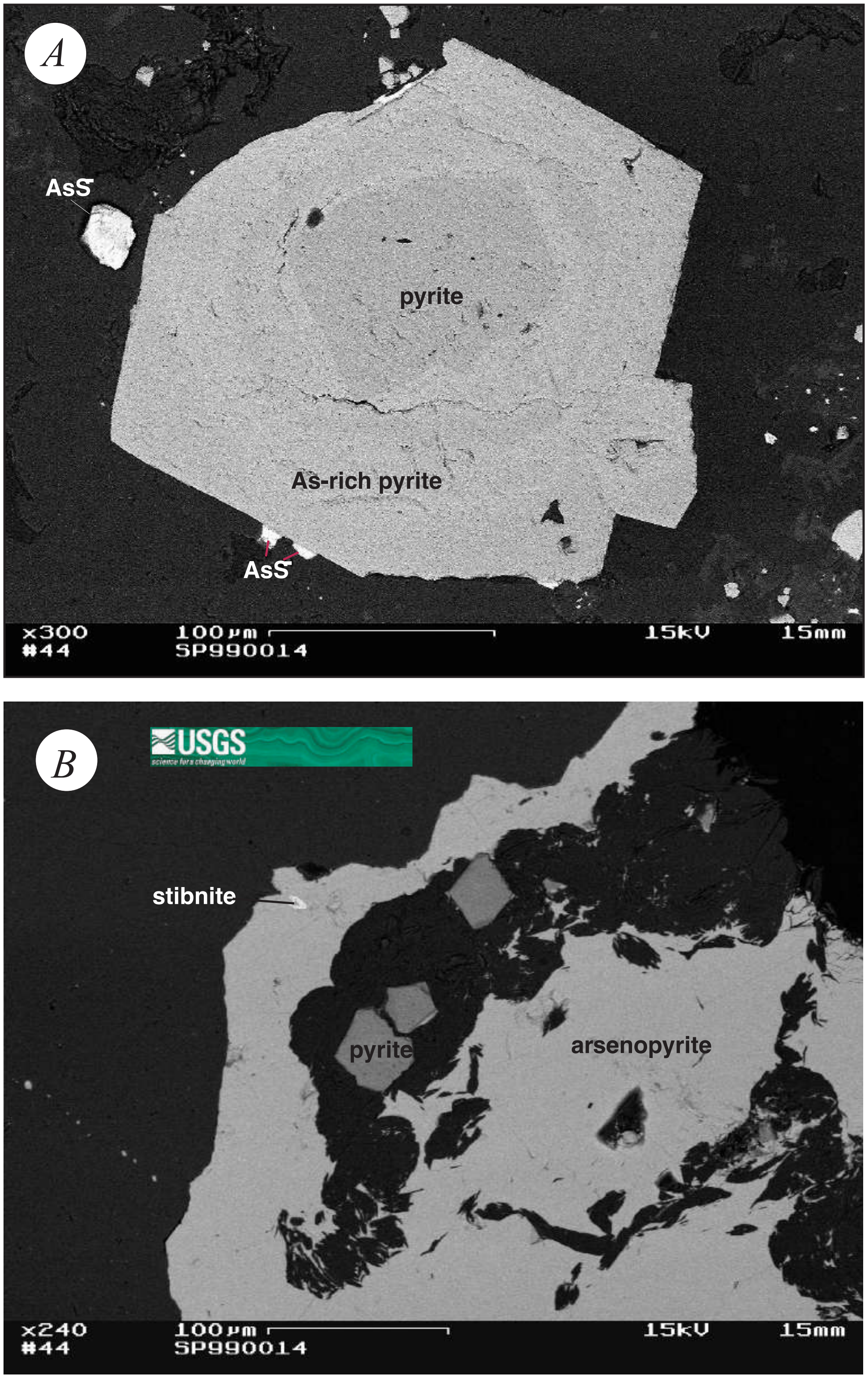



Figure 4-48. Scanning electron microscope back scatter images of Au ores from Qiaoqiaoshang Au Mine, Sichuan Province, West Qinling fold belt. (*A*) Zoned pyrite with As-poor core and growth rings of As-rich pyrite, contained in black, clay-rich inclusions in realgar-rich ores. (*B*) Stibnite, arsenopyrite, and pyrite in realgar-rich ores.

Geochemical signature of Qiaoqiaoshang Au deposit hypogene ores reflects the high-As sulfide mineralogy and the ore also contains anomalous concentrations of Hg as well as moderate concentrations of Cu, Pb, Zn, Ni, and Co (Appendix IV). This anomalous elemental suite also is common in most other Carlin-type Au deposits in the West Qinling fold belt area. The cataclastic and brecciated nature of the ores is similar to that found in the Songpangou Au deposit to the east, which is consistent with syndeformational Au deposition.

**Dongbeizhai Au deposit**

The Dongbeizhai Au deposit in Songpan County, Sichuan Province, northwest in a 335° direction 17 km from the Songpan County town at E. 103°33'25", N. 32°43'30 is a large (>50 tonne Au) sedimentary-rock-hosted Au deposit. It lies at 3,000 m elevation in the mountains of northwest Sichuan Province in the West Qinling fold belt (figs. 4-1, 4-33 and 4-34). The Dongbeizhai Au deposit consists of 30 layered, tabular, and lens-shaped orebodies in the foot wall of the controlling $F_1$ fault (fig. 4-49) The ore layers and lenses generally pinch and swell, branch, and merge with each other. The orebodies are 160 to 1,520 m long, 3.7 m thick, and are 90 to 813 m deep, trend north-south, dip west at angles of 16° to 30° and steepen to dips of 60° to 80° at depth. The reserve of the deposit is 52.8 tonne Au (by the end of 1997) with an average grade of 5.54 g/t Au. The deposit was not visited as part of this study and information is from Zheng, M.H. (1989, 1994) and Zheng, M.H. and others (1991) (see also, Li., X., 1993).

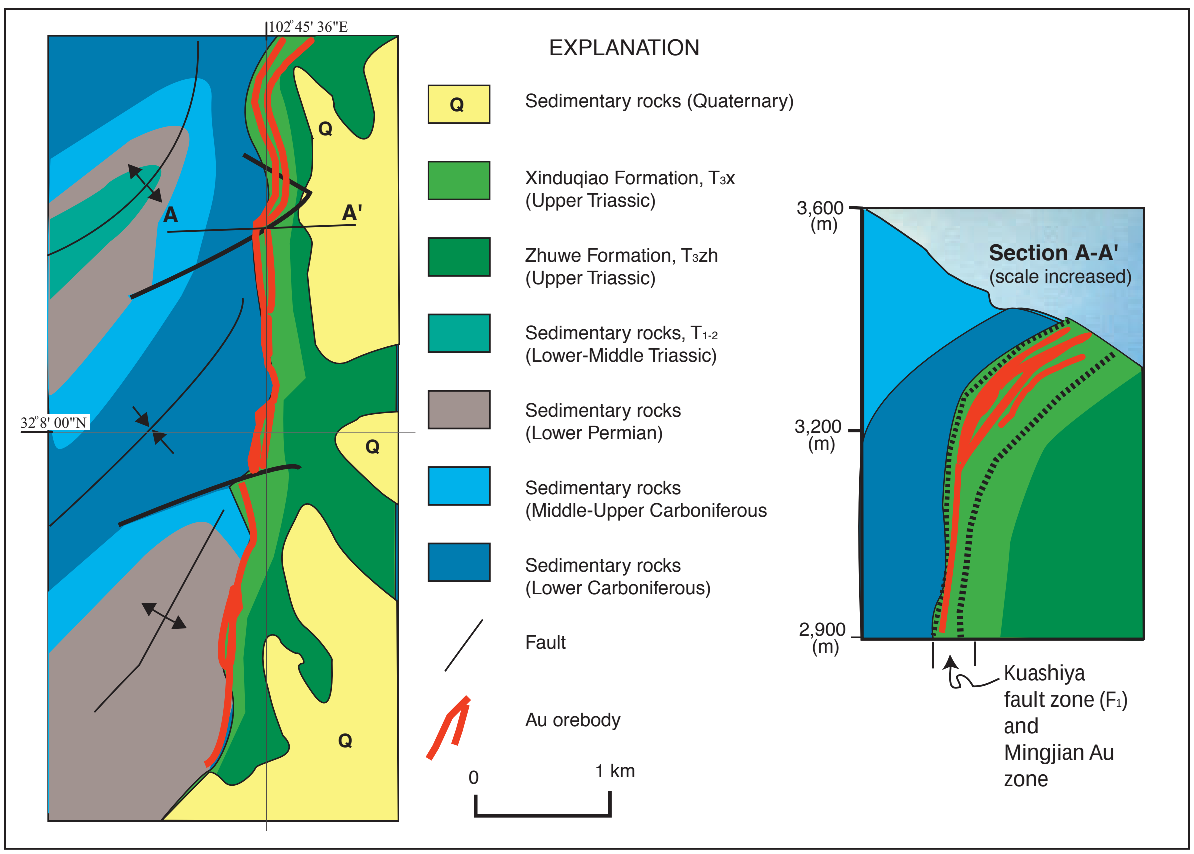



Figure 4-49. Geologic sketch map and typical cross section of the Dongbeizhai Au deposit, Sichuan Province, West Qinling fold belt. (Modified from Zheng, M.H., 1989, 1994). Coordinates are approximate.

The Dongbeizhai Au deposit is located along the Kuashiya fault zone at the west end of the Snow Mountain fault and the associated north -striking Xianglatai asymmetric anticlinorium (fig. 43). The Kuashiya fault zone separates northeast-trending broad folds of upper Paleozoic sedimentary rocks on the west from Triassic host rocks on the east (fig. 4-49). The Mingjiang Au zone that contains the Dongbeizhai Au deposit is in a north-trending, 130–km-long, 60–km-wide belt of nappes formed by west to east thrusting and is divided into two sub-belts. The east sub-belt contains the Minjiang Valley fault ($F_3$), Xianlietai-Kuashiya fault ($F_1$) and Yangdonghe-Zhagashan fault ($F_2$) (not shown on fig. 4-49). The Dongbeizhai Au deposit is situated in the middle of the $F_1$ fault that has a vertical displacement of more than 2 km. Gold mainly is present in a fracture zone in sandy slate approximately 15- to 140-m below the F1 fault plane (fig. 4-49).

The Dongbeizhai Au deposit area geology consists of low-grade metamorphosed Carboniferous and Permian limestone, dolomitic limestone, calcareous and phyllitic slate, and Triassic sandstone, siltstone, tuffaceous sandstone, and slate. The main host rocks are rocks the north-striking Upper Triassic Xinduqiao Formation ($T_3x$), which consists of C-bearing siltstone, slate, quartz greywacke, limestone, and tuffaceous sandstone (Zheng, M.H., 1989, 1994; Zheng, M.H. and others, 1991) (fig. 4-49). Organic C content in these rocks locally is high (average, 0.45 weight percent). The Au-ore host rocks are ferro-dolomitic argillite, calcareous argillite, fine-grained sandy dolomitic argillite, quartz–detritus-bearing fine-grained sandstone, and carbonate rock, which are metamorphosed and tectonized to low-grade sandy slates.

Magmatism is not directly associated with the ores of the Dongbeizhai Au deposit, although diabase dikes are present in the ore field and Yanshanian (Cretaceous to Early Tertiary) granite and diorite stocks are present over 10 km away from the mines area (fig. 4-33).

Orebodies of the Dongbeizhai Au deposit are present as en echelon lenses spaced 0 to 60 m apart in black, carbonaceous slate units (fig. 4-49). Ore minerals are pyrite, arsenopyrite, realgar, stibnite, native arsenic, pyrrhotite, chalcopyrite, sphalerite, cinnabar, native Au, marcasite, scheelite, famatinite, and zinc minerals. Gangue minerals are quartz, calcite, sericite, illite, kaolinite, and montmorillonite. Ore textures are relict bioclastic, relict colloform, girdle, crushed, replacement, granular, and pillar-like. The ore textures are banded, brecciated, disseminated, and stockwork. Two main ore types consist of: (1) pyrite cataclastic ores, and (2) realgar-orpiment-pyrite cataclastic ores. Gold usually is present as micron-sized inclusions in arsenical pyrite.

Hydrothermal alteration consists of silicification, and carbonatization. Silicification is typical of the early hydrothermal stages and is most intense within 2 m of the $F_1$ fault plane. Alteration minerals include illite, montmorillonite, kaolinite, sericite, quartz, calcite, and carbon. Carbonatization is typical of late hydrothermal stages, and is wide spread in the deposit area.

The paragenesis of the Dongbeizhai deposit is dominated by a main stage of quartz, arsenopyrite, and As-rich pyrite forming at between 150 to 236°C (average 180°C). This was followed by late-stage mineralization of realgar and orpiment between 110 and 180°C (average 150°C) (Zheng, M.H., 1989). This is similar to paragenetic sequences of most Carlin-type deposits (see also, Peters and others, 1998, 1999; Hofstra and Cline, 2000).

**Other Sedimentary Rock-Hosted Au Deposits**

The following descriptions of the Liba, Yinchanggou, Lianhechun, Laerma, and Manaoke sedimentary rock-hosted Au deposits in the West Qinling fold belt area in north Sichuan and south Gansu Provinces (figs. 4-1 and 4-33) demonstrate the variety of host rocks and deposit characteristics of the sedimentary rock-hosted Au deposits in the region (see also, Wang, X.C., 1992, 1994; Wang, K.R. and others, 1994). The deposits were not visited as part of this study and therefore information and descriptions are from literature sources as noted. Many of these deposits have characteristics that are similar to deposits along the Snow Mountain fault and the East Qinling fold belt area, but some deposits, particularly the Laerma, Liba, and Manaoke Au deposits have some different characteristics, which include local association with igneous rocks, or with deposits of Hg, W, or U.

**Liba Au deposit**

The Liba Au deposit, in Lixian County, Gansu Province, is 32 km from the Lixian County town at E. 105° 02' 36" and N. 34° 25' 06. The deposit was not visited as part of this study and information is compiled from'Liu, M. (1994) and Cheng, Y. and Zhang, W.D. (2001). The Liba Au deposit is one of several Au deposits that lie in a regional-scale cluster of other sedimentary rock-hosted Au deposits in Gansu Province in the west Qinling area (fig. 4-1). The deposit differs from other deposits in the region because it is hosted in low-grade metamorphic Devonian and Triassic meta-siltstone, phyllite, and slate in the contact aureole of the Zhongchwan granite intrusive (fig. 4-50), about 2 km northeast from the granite contact. The Liba Au deposit area contains more than 20 orebodies composed of complex vein lenses that branch, merge, swell, and pinch along steep-dipping faults that crosscut sedimentary bedding. The No. 5 and No. 6 orebodies are the main orebodies accounting for 80 percent of the total proven reserves of the deposit. The No. 5 orebody is 2,000 m long, 6 to7 m thick and 250 m deep; the No. 6 orebody is 600 m long, 5 to 6 m thick and 250 m deep. The average grade is 5 g/t and 4 g/t Au respectively.

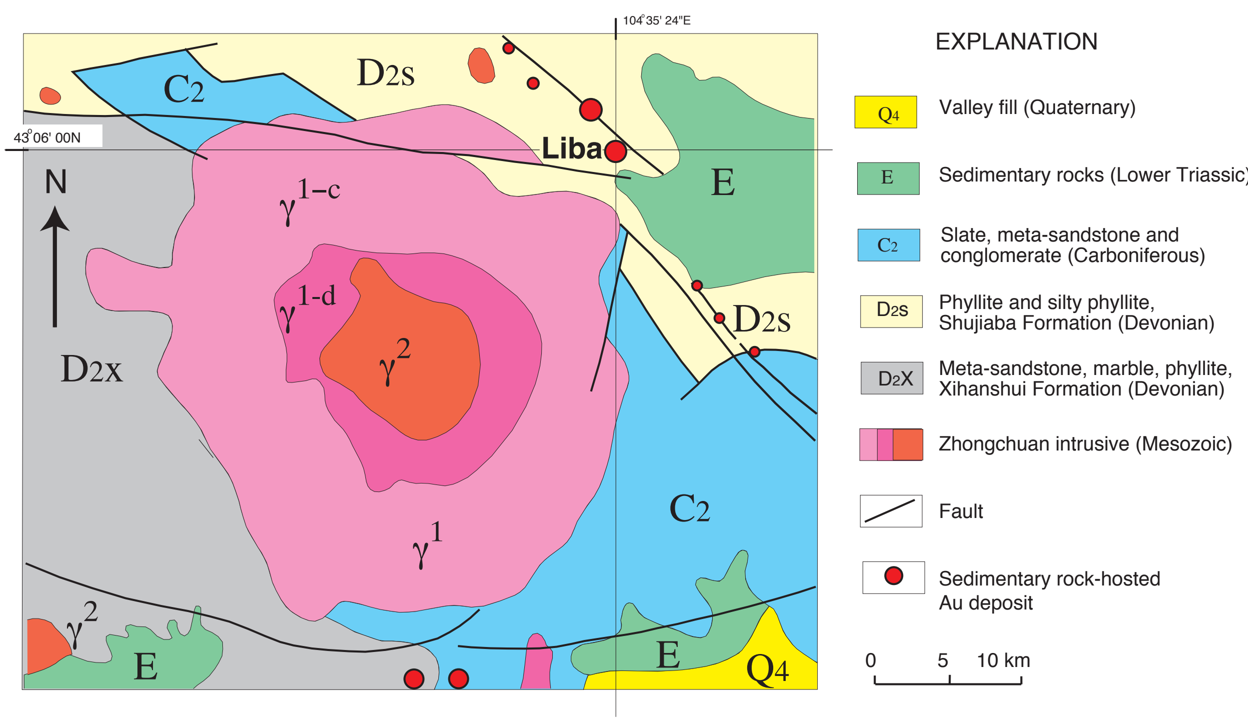



Figure 4-50. District-scale geologic map of the Liba Au deposit, Gansu Province, West Qinling fold belt area, showing a group of sedimentary rock-hosted Au deposits, which include the Liba, Sanrengou, and Jinshan deposits (see also, Li, Z.P., and Peters, 1998). They are located near the Zhongchuan granite intrusion and hosted in Devonian phyllite. Compiled from Liu, M. (1994) and Li, Z.P. and Peters (1998).

Geotectonically, the Liba Au deposit is located at the west end of the middle parts of the Qinling fold belt at the west end of the east-striking Lixian-Baiyun-Shanyang suture (fig. 4-1). On a regional scale, the deposit lies along the southwest limb of the west-northwest-trending Ding-Mawu anticline, which is contained along the north limb of the Shijiaheba anticlinorium (not shown on figures 4-1 or 4-50). Faults, small folds and more than 20 fractured zones are present in the Liba Au deposit area. The west-northwest-striking (320° to ~340°), southwest-dipping (65° to ~85°) main $F_1$ fault is interpreted as a reverse fault that is characterized by multi-staged activity and coeval ore fluid introduction. Adjacent and parallel northwest- and west-northwest-striking faults host Au ore and control the morphology, size, and grade of the orebodies. The main orebody is thickened and higher grade where northwest-striking faults intersect west-northwest-striking faults. This intersection zone is characterized by densely spaced fractures.

Sedimentary rocks in the Liba Au deposit area are Middle and Upper Devonian, Carboniferous, and Permian in age. The Upper Devonian Dachaotan and Xihanshui, and the Middle Devonian Sujiaba Formations are low-grade metamorphic molasses that consist of coarse-grained alternating marine and continental sediments. The orebodies of the Liba Au deposit are hosted in the 1,106–m-thick Sujiaba Formation mainly in the second layer that is dominated by silty phyllite (80 percent) and metasandstone. Ore–in silty phyllite accounts for 78 percent of the ore, whereas ore in metasandstone and phyllite accounts for 22 percent. Carboniferous rocks consist of carbonaceous, clastic rock interlayered with multi-layers of limestone, conglomerate, and siliceous rocks. Lower Permian and lower Triassic sedimentary rocks are composed of shallow marine argillite, and clastic rock with interlayers of carbonate rock, especially at the top.

The 210 $km^2$ Zhongchuan granite intrudes Middle Devonian to Middle Carboniferous sedimentary rocks south of the Liba Au deposit and is a multi-stage intrusion spanning the Hercynian (405 to 230 Ma), Indo-China (230 to 195 Ma), and early Yanshanian periods (fig. 4-50). The intrusive complex mainly is composed of six large late Mesozoic granitic intrusions, several small Middle Paleozoic basic rock stocks, and local andesitic porphyritic-dacite bodies, as well as Cenozoic alkalic to ultramafic volcanic rocks. Spessartite, diorite, oligoclase aplite, and granodiorite dikes also are present (Liu, M., 1994) (not all shown on figure 4-50). The contact thermal metamorphism zones around the granite are: (1) chlorite-sericite, (2) biotite, and (3) andalusite+ cordierite. Some dikes are mineralized by Au. Gold orebodies mainly are in the biotite zone, but are closely associated with the minerals muscovite and sericite in this zone. Other elevated geochemical elements in the Mesozoic granitic intrusions are Sn, W, Mo, and Bi, but these elements are not commonly enhanced near the sedimentary rock-hosted Au deposits.

Typical Carlin-type ore deposit minerals are absent in the Liba Au deposit, such as stibnite, cinnabar, realgar, and orpiment. Instead the deposit contains a mesothermal mineral assemblage of pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, galena, and sulfate minerals, which indicates ore minerals reached temperatures higher than in most sedimentary rock-hosted Au deposits. Sericitization is closely associated with Au, where the alteration pattern is observed from inner to the outer zones of the ore-bodies from pyrite-sericite, to sericite, to chlorite. Grade and thickness of orebodies directly correlate with the intensity of sericitization (Liu, M., 1994). Igneous rocks in Liba Au deposit may have provided a heat source for the ore-forming system (Liu, M., 1994), and account for this different mineralogy.

Most ores are disseminated, but also are present in stockworks and bands. Oxide ore displays replacement, corrosion, pseudomorphic, and crushed textures. Pyrite is the main ore mineral in the primary zone and is accompanied by chalcopyrite, sphalerite, arsenopyrite, galena, pyrrhotite, rutile, native Au, minor bornite, magnetite, marcasite, and electrum. Pyrite, arsenopyrite, sericite, quartz, and calcite are the main Au carriers. Gold in Au–Ag compounds accounts for 97 volume percent of the ore. Gold in crystal lattices of sulfide minerals, primarily pyrite, accounts for only 2.7 volume percent. Gold lies mainly along the contacts between pyrite, quartz, sericite, and limonite crystals. Some Au is present along partings in pyrite and in quartz inclusions of pyrite. Limonite, hematite, and jarosite carry Au in the oxide zone. Muscovite, sericite, and quartz are the main gangue minerals with lesser feldspar, chlorite, biotite, carbonate minerals, graphite, organic carbon, minor tourmaline, zircon, apatite, zeolite, and clay minerals.

Fluid-inclusion studies of ore minerals from the Liba Au deposit by Liu, M., (1994) indicate ore fluid salinities of between 6.9 and 11.6 (average 8.4) equiv. weight percent NaCl, and densities of 0.65 to 0.86 g/cm$^3$ (average 0.74g.cm$^3$), which are compatible with igneous-related ore processes, but also are consistent with thermally metamorphosed stratabound ore. The stratigraphic sequence near the Liba Au deposit in the Lixian-Mingxian area contains local horizons with anomalously high concentrations of Au (0.004 ppm), As (40 ppm), and Sb (2 ppm) (Liu, M., 1994). Although Li, Z.P. and Peters (1997) and Li, Z.P. and Peters (1998) included the Liba Au deposit as a sedimentary rock-hosted Au, this deposit may be intrusive-related and not a Carlin-type deposit. Cheng, Y. and Zhang, W.D. (2001), however, suggest that Liba-style Au deposits in the Zhongchuan area are remobilized deposits from late Paleozoic source beds during Yanshanian (Late Mesozoic to Early Tertiary) magmatism. The Au-associated alteration assemblage of biotite-sericite and lack of other typical mineralogical indicators of Carlin-type Au deposits, such as arsenically zoned pyrite and realgar and orpiment, however indicate that additional work is needed to understand the genesis of the deposit. The similarities to other sedimentary rock-hosted Au deposits in the area, however are the late Paleozoic host rocks and As geochemistry.

**Yinchanggou Au Deposit**

The medium-size (2 to 50 tonne Au) Yinchanggou Au deposit is about 40 km southwest of city of Pingwu in northern Sichuan Province (figs. 4-1, 4-33). The deposit consists of 5 layered Au orebodies, each of which is 30 to 70 m long and grades 3.25 to 5.34 g/t Au. Brecciated parts of the orebodies grade about 10 g/t Au. The area also contains two 80– to 400–m-long, and 1.67– to 7–m-wide Hg orebodies that are hosted in Permian limestone and contain 0.042 to 0.097 percent Hg (fig. 4-51). The Yinchanggou Au deposit was not visited during this study and information is compiled mainly from Zheng, M.H. (1994) and Wang, X.C. and others (1994).

The geology of the Yinchanggou Au deposit consists of Carboniferous carbonate rocks in the far northwest, a 800–m-wide section of Permian rocks that host most of the Hg ore, rocks of the Middle to Upper Triassic Zagunao Formation, and Lower Triassic rocks of the Bochigou Formation in the south, which hosts most of the Au orebodies (fig. 4-51). No igneous rocks are known (Wang, X.C. and others, 1994).

The orebodies are hosted along two 20– to 100–m-wide brecciated zones, one of which strikes northwest and the other strikes northeast (fig. 4-51). Gold ore also is localized along or adjacent to a northwest-striking fault. Local, narrow orebodies are present adjacent to these main structures and along sedimentary beds, particularly in the Zagunao Formation (fig. 4-51). No. 1 orebody is located at the intersection of a brecciated zone and the contact between the Bochigou and Zagunao Formations. No. 2 orebody is an elongated, narrow, nearly stratabound, curved spur to the east of No. 1 orebody that might be related to the curvature of bedding and may possibly connect with orebody No. 3. The No 3 orebody has three spurs, the longest of which is along a northeast-striking fault to the east of the breccia zone that hosts the No. 1 orebody (fig. 4-51). No. 4 orebody lies along probable stratigraphic zones approximately 100 m from a northwest-striking fault in the center of the deposit. No. 5 orebody is hosted in a northwest-striking breccia zone that intersections Permian limestone.

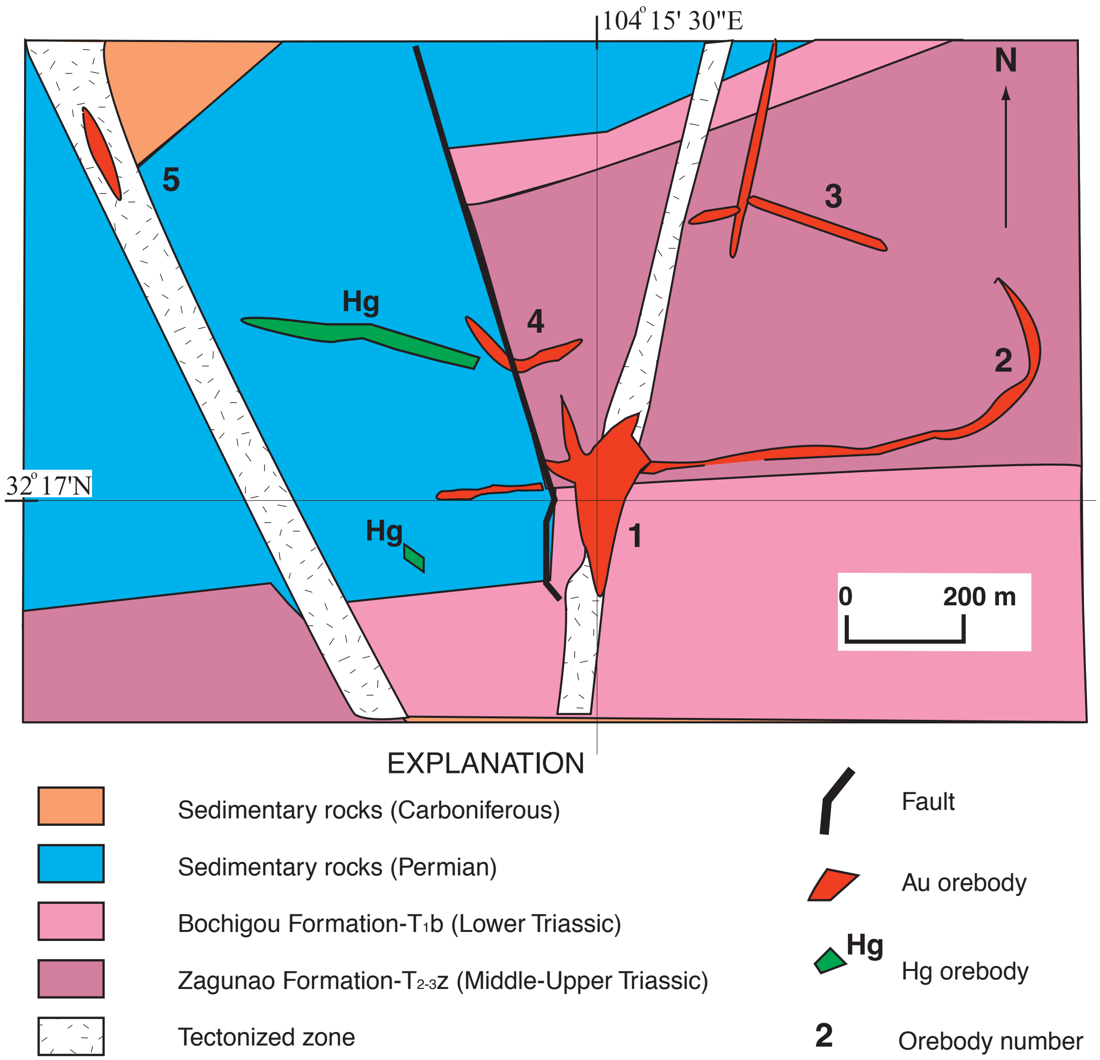



Figure 4-51. Geologic map of the Yinchanggou Au deposit, Sichuan Province, West Qinling fold belt. (Modified from Zheng, M.H., 1994). Ore controls are bedding planes and northeast striking faults and tectonized zones in the Zagunao Formation for Au depostios and bedding planes in the Permian sedimentary rocks for the Hg deposits.

Hydrothermal alteration and gangue minerals consist of quartz, calcite, and sericite. Ore minerals mainly are pyrite, arsenopyrite, cinnabar, and realgar. The geochemical signature of the ores is characterized by anomalous concentrations of As, Sb, Hg, and Ba along with Au. These characteristics are common in the sedimentary rock-hosted Au deposits in the "northern golden triangle" area of West Qinling fold belt and are similar to most Carlin-type deposits in Nevada, USA.

**Lianhechun Au deposit**

The medium-sized (20 to 50 tonne Au) Lianhechun Au deposit is located along the boarder of northern Sichuan and southern Gansu Provinces, south of the city of Jiushigou (figs. 4-1, and 4-33) in the Nanping-Maqu Au belt (not shown on fig. 4-33). The deposit consists of 13 east- and northeast-striking, layered and lensed Au orebodies that grade 3 g/t Au. The orebodies locally are spatially associated with Mesozoic granite porphyry dikes (fig. 4-52). The m-wide ore zones lie in multiple layers over a width of about 600 m that narrows locally to about 200 m. Average grade is 2 to 8 g/t Au. The deposit was not visited as part of this study and therefore information has been compiled from Zheng, M.H. (1994), Wang, X.C. (1994, 1998), and Li, Z.P. and Peters (1998).

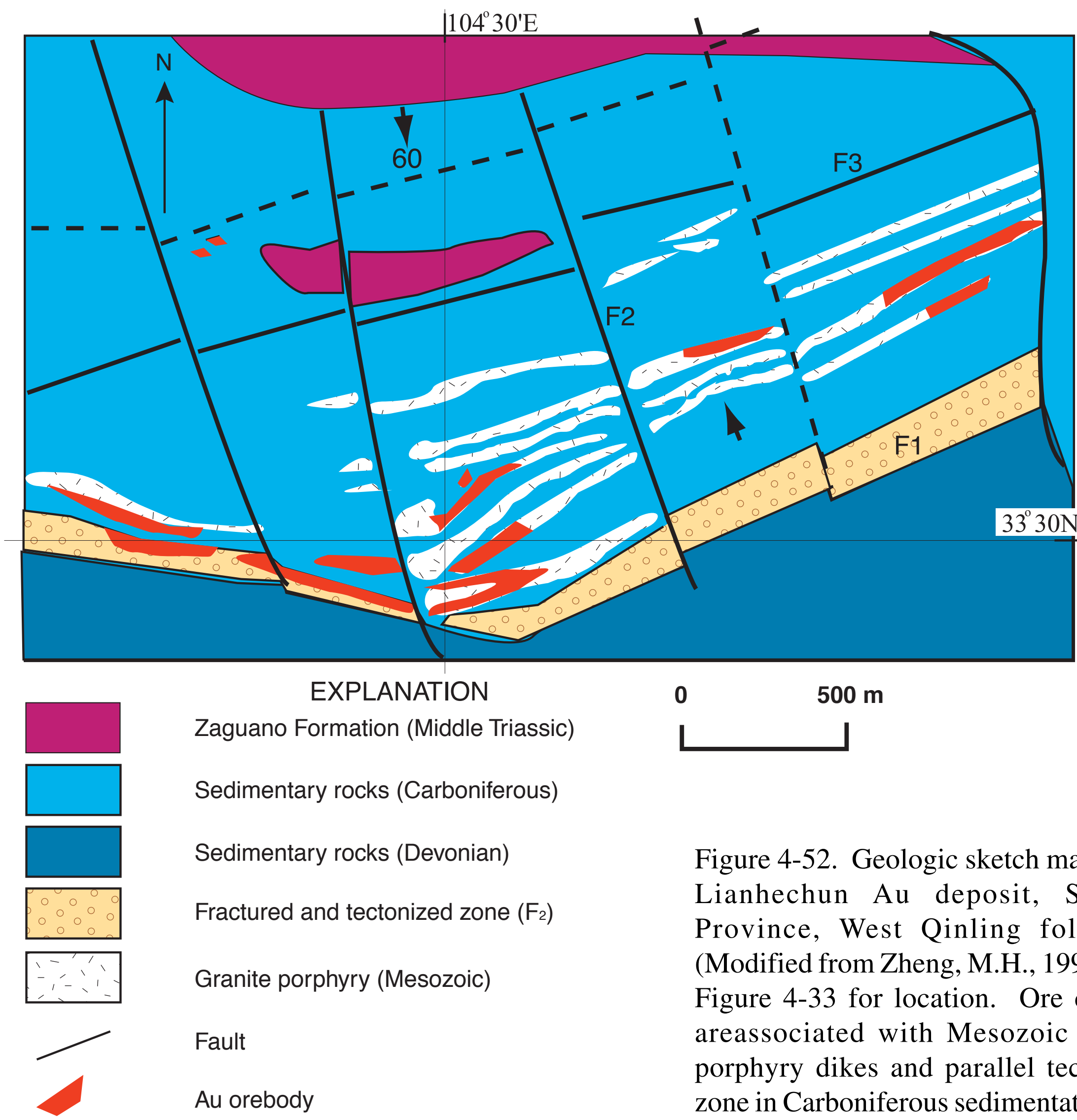



Figure 4-52. Geologic sketch map of the Lianhechun Au deposit, Sichuan Province, West Qinling fold belt. (Modified from Zheng, M.H., 1994). See Figure 4-33 for location. Ore controls areassociated with Mesozoic granite porphyry dikes and parallel tectonized zone in Carboniferous sedimentaty rocks.

The geology of the Lianhechun Au deposit area consists of east-striking rocks of the Middle Triassic Zagunao Formation to the north of the orebodies and Carboniferous and Middle Devonian sedimentary rocks to the south. The Zagunao Formation rocks lie conformably on top of Carboniferous sedimentary rocks (fig. 4-52). The main host rocks for the deposit are middle Devonian and Carboniferous slate and limestone and northeast-striking Mesozoic granite porphyry dikes.

Structural control in the area is related to a 50– to 150–m-wide fractured and tectonized zone ($F_2$) at the contact between the Devonian and Carboniferous sedimentary rocks (fig. 4-52). Fracture control also is parallel to and within granite porphyry dikes. North-northwest-striking cross faults also may localize the orebodies. Additional northeast-striking faults are present north of the main ore zones ($F_3$) and an east-striking, 60° south-dipping fault ($F_1$) is present at the contact between Middle Triassic and Middle Devonian rocks (fig. 4-52).

Hydrothermal alteration at the Lianhechun Au deposit consists of quartz, calcite, sericite, barite, kaolinite, and fluorite. Main ore minerals are pyrite, stibnite, arsenopyrite, pyrrhotite, cinnabar, and realgar. The deposit is geochemically anomalous in Tl, Ba, Hg, Sb, and As. These mineralogical and geochemical characteristics and the host rocks are similar to Carlin-type deposits and other similar deposits, such as Songpangou, and Qiaoqiaoshang Au deposits in the area.

**Laerma Au–U deposit**

The Laerma Au–U deposit is in Luqu County, Gansu Province, southwest or 168° and 50 km away from the Luqu County town at E 102° 35¨34¨, N 34° 09' 48" (figs. 4-33 and 4-53) approximately 100 km north of the city of Ruoergai, west of the Bailongjiang U–Au belt (not shown on figure) at the Sichuan–Gansu Province boundary. The deposit was not visited as part of this study and information has been compiled from Zhang, Z.A. (1993), Li, Y.D. and Li, Y.T. (1994), and Wang K.R. and others (1994, 2000).

The Laerma Au deposit mainly consists of 55, 50–to 300–m-long (maximum length 1,350 m), layered and lensed orebodies that grade between 1.0 and 24.7 g/t Au; however, up to 100 orebodies are present in a 5,600 by 350 m area. An auxiliary cluster of orebodies also is present about 10 km to the east (fig. 4-53). These orebodies grade >1g/t Au and form a fringe zone around a central 100– to 200–m-wide by 1,000–m-long, pod-shaped zone of orebodies with grades ≥3 g/t Au. Average grade is 2 to 8 g/t Au. The age of Au mineralization (49.5 to 12.7 Ma) in the Laerma Au-U deposit is on the basis of analysis of both whole rock and ore minerals (Li, Y.D and Li, Y.T., 1994). Uranium is enriched where the host rock contains between 5.19 and 15.50 ppm U and the U content of altered rocks ranges from 16.86 to 53.33 ppm U, and the average U content in ore is 28.41 ppm U.

Geotectonically, the Laerma Au deposit is in the middle of Maqu-Diebu nappe structural zone of the west Qinling fold system (not shown on figure 4-33). The deposit is located at the plunging western end of an east-plunging syncline. Faults in the mining district mainly trend east and west and interformational fractures and small structures trend northeast, northwest, and north-south (fig. 4-53). Structural control at the Laerma Au–U deposit is related to these faults, particularly at fault intersections. The faults and intersections also control alteration patterns (Wang, K.R. and–others, 1994, 2000).

Geology around the Laerma Au-U deposit consists of east-striking lower Paleozoic sedimentary and volcano-sedimentary rocks. The Au deposit is hosted in rocks of the Lower Cambrian Taiyangding Group and Laerma Formations at the core of the east-plunging syncline. Three horizons are present:

(1) the main ore host horizon composed of carbonaceous siliciclastics (chert), carbonaceous siliceous slate, silty slate and carbonaceous slate;

(2) the secondary host horizon, composed of carbonaceous slate, carbonaceous siliceous slate silty slate with layers of sericitic slate and phyllite; and

(3) carbonaceous slate, sericitic slate, silt slate and carbonaceous siltstone. The siliciclastic (chert) rocks are 94.2 weight percent $SiO_{2,}$ but also contain $Fe_2O_3$, $P_2O_5$ and bioclastic material.

These rocks are surrounded in the syncline by Lower Silurian rocks of the Yancangou Formation and Lower Silurian Xiadi Formation and Middle to Upper Ordovician Sulimutang Formation rocks. Early Yanshanian (Late Mesozoic to Early Tertiary) granite porphyry dikes locally are present and host some Au ore (Wang, K.R. and others, 2000).

There are more than 80 minerals associated with the deposit; the most prevalent ore minerals are: (1) sulfide minerals: pyrite, sphalerite, galena, chalcopyrite, chalcosite, pyrrhotite, marcasite, tetrahedrite, molybdenite, arsenopyrite, chalcomiclite, copper mica, gersdorffite,

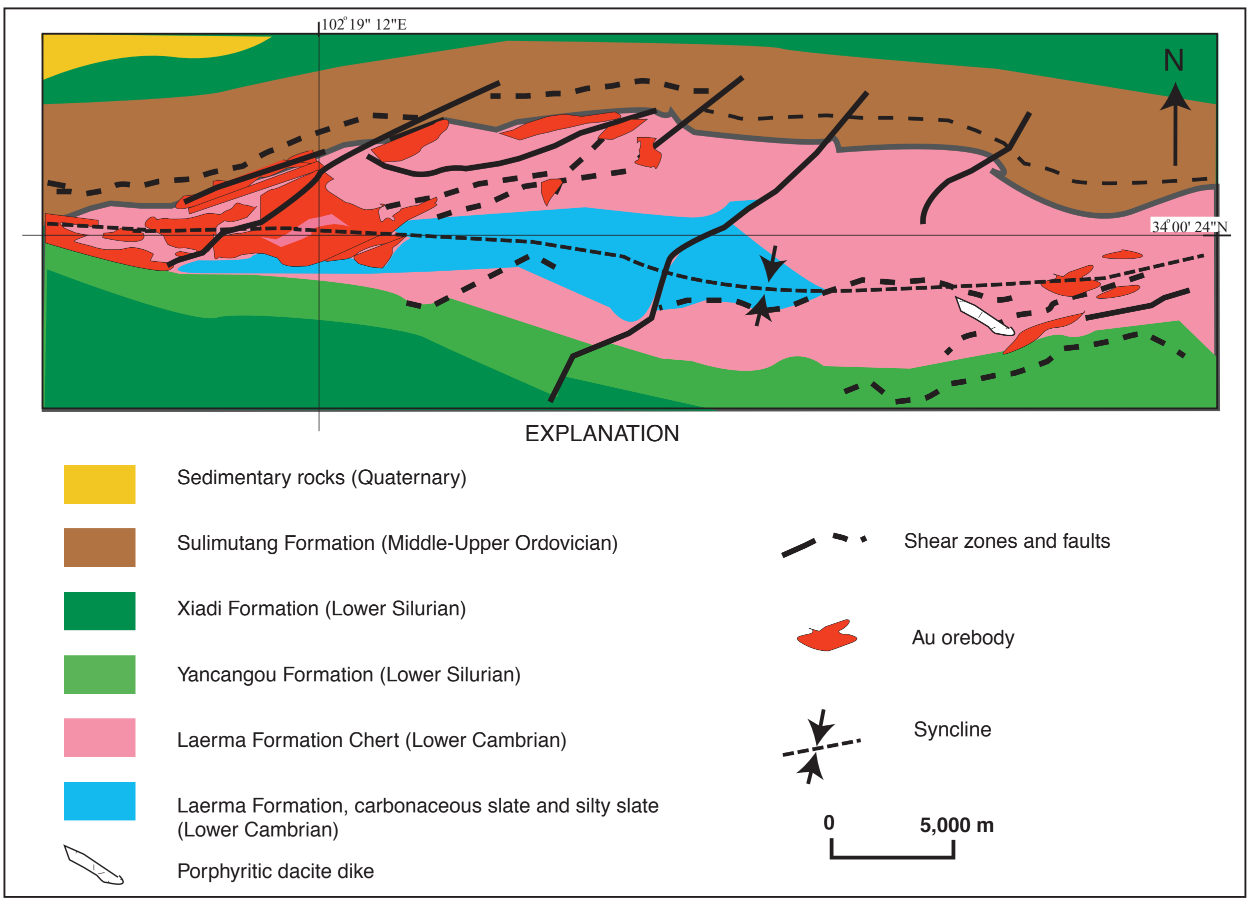



Figure 4-53. Geologic sketch map of Laerma Au deposit, on Gansu Province-Sichuan Province boundary, West Qinling fold belt (adapted from Zheng, M.H., 1994).

cinnabar, stibnite, realgar, orpiment, and stibnite; (2) selenide minerals, tiemannite, clausthalite, stibioselenium; (3) Au–Ag minerals, native Au, kustelite, electrum, selengold(?); and (4) uraninite. Common gangue minerals are quartz, sericite, dickite, hydromica, chlorite, montmorillonite, kaolinite, illite, bayite, gypsum, zeolite, chalcedonite, and dolomite.

Gold mainly is contained in pyrite, marcasite, quartz, barite, stibnite, and tiemannite, but also in realgar, orpiment, sphalerite, chalcopyrite, and siderite. Two types of pyrite, As-poor, and As-rich pyrite, with the same features as those in Carlin-type sedimentary rock-hosted Au deposits, are present in quartz-veinlets and in the host rock as disseminations. Most pyrite contains very low As and a corresponding low Au content, suggesting that the ability of pyrite to host sub-micron Au depends on its As content. Quartz also is a common host mineral of Au in the Laerma Au–U deposit (Zhang, Z.A., 1993), and contains 1 to 28 ppm Au, 13 ppm Hg, and elevated concentrations 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) high correlation of Au to high thermoluminescence values of quartz—a property of thermal analysis when quartz is heated. Barite contains between 1 to 98.56 ppm Au, and also has elevated values of Ag, Sb, Se, and Hg (Zhang, Z.A., 1993). Barite, together with quartz, is present 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 Au. Mircograin disseminations of Au are 1 to 30 mm-size and mainly present in or associated with quartz, barite, and dickite.

Alteration at the Laerma Au–U deposit consists of early pervasive silica with chlorite followed by fracture filling with quartz,–calcite, sericite, and barite. These are accompanied by the other ore minerals (Wang, K.R. and others, 2000). These fracture-fill minerals are accompanied by decarbonatization and the growth of dickite and allophane.

The ores are anomalous in As, Sb, Hg, Ba, Se, U, and Pt. Organic C is enriched in the host rock with a range of contents from 0.66 to 14.63 weight percent and an average of 3.24 weight percent C. Gold concentration is closely related to organic C, such that Au content is much higher in carbonaceous, silty slate than in silty slate. PGEs are enriched in the ore and in cataclastic carbonaceous siliceous slate on the basis of analysis of 20 ore samples: Pt content ranges from 0.01 ppm to 0.02 ppm, Pd content ranges from 0.001 ppm to 0.024 ppm; Os content ranges from 0.001 ppm to 0.005 ppm, and the maximum values of 10 ppm Os. PGEs locally are concentrated to form economic orebodies (Liu, J. and others, 2000).

This geochemical signature, the ore mineralogy, and host rock type have some similarities to Carlin-type deposits. The presence of the several base-metal minerals, uranium, and PGE minerals may indicate either an evolved Carlin-type system, access of the mineralizing system to additional minerals at depth, overprinting of two separate hydrothermal systems, or a hydrothermal process similar to but distinct from those which form Carlin-type deposits.

**Manaoke Au–W deposit.**

The large-sized (>50 tonne Au) Manaoke Au–W deposit is in northern Sichuan Province in Nanping County about 50 km east of the Nuoergai County town, approximately 60 km northwest of the city of Jiushigou along the Sichuan-Gansu Province boundary at E 104º 04' 00", N 33º 39' 15" (figs. 4-1 and 4-33). The deposit was not visited as part of this study and information was compiled from Ji, H.B. and others (1991) and Zhang, M.H. (1994).

The deposit consists of 18 northwest-striking stratabound mineralized layers that contain both W and Au. The Au orebodies are lens-like along the strike of the layers and are 80 to 1,100 m (average 350 m) long, 1.19 to 6.12 (average 3.08 m) wide, and grade 1.66 to 9, 64 g/t Au (average 3.55 g/t Au). There are approximately 8 major W orebodies (Ji, H.B., and others, 1991; Zhang, M.H., 1994). The Manaoke Au–W deposit consists of the No. 1 orebody as the main body, which is 480 m long, 20 to 360 m wide, 9.07 to 9.84 m thick and has a grade of 3.23 g/t Au. The ore reserve is more than 10 t Au.

Geology of the Manaoke area consists of five units of the Middle to Upper Triassic Zagunao Formation. The third unit ($T_{3-2-3}$z), consisting of turbiditic slate and sandstone, is approximately 400 to 500 m wide at the surface and hosts the ore horizons (fig. 4-54). North-dipping faults are present between the third and fourth units and juxtapose the third unit in the southwest part of the area against the fourth unit (fig. 4-54). Gold deposits locally appear to be enhanced and developed in fold hinges as illustrated in figure 4-54. No igneous rocks are known in the deposit area.

Hydrothermal alteration of the Manaoke Au–W deposit consists mainly of silicification and carbonatization, although chlorite and sericite also are part of the hydrothermal alteration assemblage. Overprinting of several alteration types is favorable for Au ore. Gangue minerals consist of quartz, calcite, sericite, and siderite. Skorodite is common in the oxide zone.

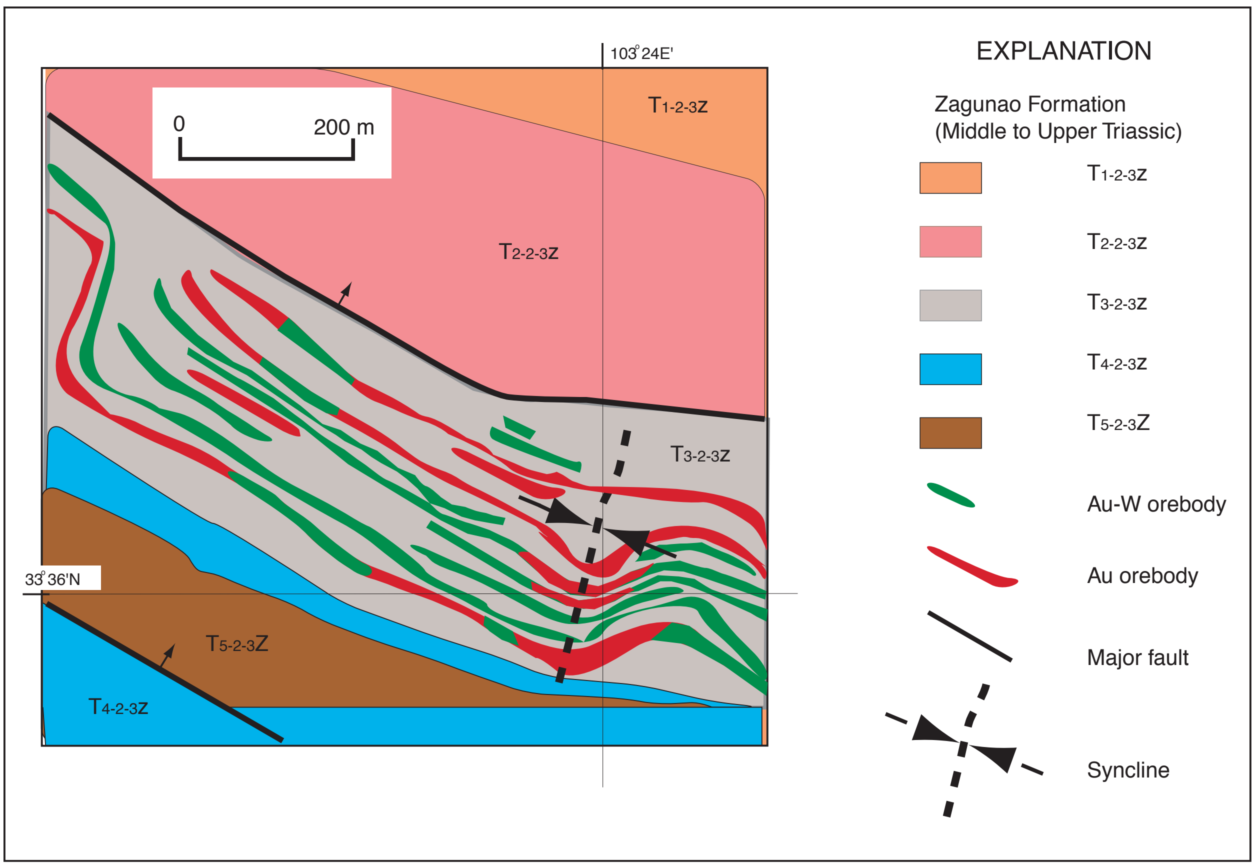



Figure 4-54. Sketch geologic map of the Manaoke Au-W deposit, Sichuan-Province, West Qinling fold belt. Adapted from Zheng. M.H. (1994). Note stratabound nature of orebodies in unit T3-2-3z and tendency fro Au orebodies to be aligned along structural zone in core or adjacent to axial plane of syncline in preference to W orebodie.

Ore minerals are pyrite, scheelite, tungstite, realgar, arsenopyrite, stibnite, and native Au. Ore mineral textures are euhedral, subeuhedral, and anhedral, and in the oxide zone psuedomorphic and replacement-relict texture are common. Ore is present in massive, disseminated, vein-network, cataclastic, and breccia bodies. Native Au is sub-micron- to micron-size within arsenopyrite, pyrite, clay mineral grains, and surrounding quartz grains. Local visible Au mainly is associated with quartz-stibnite intergrowth, commonly filling in the contact zone between the two minerals where it generally is 0.05 to 0.2 mm (the maximum, 1 mm) in size.

Geochemical signature of the Manaoke Au–W ores is characterized by anomalous concentrations of As, W, Sb, and Hg. Mineralogy of the ores is similar to most Carlin-type deposits, but the deposit is unusual because of the W-bearing horizons. The W-bearing horizons may have developed separately and possibly were over-printed as receptive hosts by the Au mineralization process. A late W mineral associated with quartz-pyrite veining also is developed in the large Carlin-type Betze Au deposit in Nevada (Peters and others, 1998, 1999), and scheelite is present in the Dongbeizhai deposit. Therefore, is possible that the W mineralization may possibly also be related to the Au mineralizing event in some Carlin-type deposits.

## Ore Deposits along the Luhuo-Daofu Fault Zone

A number of sedimentary rock-hosted Au deposits lie west of the Sichuan-Gansu boarder along the Luhuo-Daofu fault zone in a north-northwest-striking zone that also overlaps the Kokexili-Youjiang fold belt and the northwest-trending Youjiang fold belt to the south (fig. 4-33). The sedimentary rock-hosted Au deposits include the Pulongba, Qiuluo, Gala, and Xiaolongxi Au deposits. These deposits have many characteristics that are similar to Carlin-type deposits to the east in the main parts of the Qinling fold belt. Information about these deposits has been compiled from Wang, X.C. (1992, 1995, 1996), Zhang, F.X. and others (1998), and Li, Z.P. and Peters (1998).

### Pulongba Au deposit

The small-sized (<20 tonne Au) Pulongba Au deposit is located in north-central Sichuan Province about 60 km south of the City of Seda and 60 km northeast of the city of Ganzi. The deposit was not visited during this study

and information is compiled from Zheng, M.H. (1989), Wang, X.C. (1992, 1994, 1996) and Li. Z.P. and Peters, 1998). . The deposit lies along the Luhuo-Daofu fault zone that also contains the Qiuluo Au deposit to the northwest (fig. 4-33). The Pulongba Au deposit is one of several sedimentary rock-hosted Au deposits along this northwest-striking structural trend. The deposit contains two main elongated 400– to 600–m-long and 50–m-wide orebodies that are associated with northwest-striking faults. Ore grades range between 4 and 15 g/t Au. The northernmost orebody is associated with pyrolite (gabbro-diabase?) (fig. 4-55).

Geology of the Pulongba Au deposit consists of three upper parts of the Upper Triassic Runiange Formation that strike northwest and are bound by faults on the northeast. These faults expose the Upper Triassic Lianghekou Formation in the northeast, and the Middle Triassic Zagunao Formation in the southwest (fig. 4-55). The host rocks locally are composed of brecciated basalt that is interlayered with carbonaceous silty slate and thin-bedded sandstone, chert, limestone, and greywacke. Mesozoic granite porphyrite and Paleozoic(?) mafic pyroxene-olivine-bearing igneous rock (gabbro-diabase) also are part of the volcano-sedimentary sequence and locally host Au ore.

Faulting is predominantly northwest-striking and juxtaposes different sequences of Upper and Middle Triassic sedimentary and volcano-sedimentary rocks. Northeast-striking cross faults intersect the northern most orebody (fig. 4-55). A northwest-striking cross fault ($F_2$) lies close to the southern orebody.

Gangue mineralogy consists of quartz, calcite, sericite, and dolomite. Ore minerals are pyrite, arsenopyrite, chalcopyrite, tetrahedrite, marcasite, cinnabar, pyrrhotite, sphalerite, native Bi, and bismuthinite. The orebody is geochemically anomalous in As, Sb, Hg, Tl, Ba, and Bi. Mineralogy and the geochemical signature have similarities to most Carlin-type deposits, however native Bi and Bi minerals, as well as tetrahedrite, are not common minerals in most Carlin-type deposits, although the Liba Au deposit has Bi mineralogy and geochemistry. Late sulfosalt polymetallic minerals also are present in the polymetallic zones of the Betze Au deposit in Nevada (Peters and others, 1998, 1999) and argentiferous tetrahedrite and miargyrite are common minerals in northern parts of the Carlin trend, Nevada (T. Theodore, pers. communication, 2002). Bismuth minerals, as in the Liba Au deposit, may be associated with the granite porphyry bodies, similar perhaps to upper parts of distal-disseminated Ag–Au deposits in northern Nevada, USA. The basaltic host rock also has similarities to the Twin Creeks Au deposit in northern Nevada (Groff, 1996), and the Jinba Au deposit in Yunnan Province, Dian-Qian-Gui area (Chapter 3).

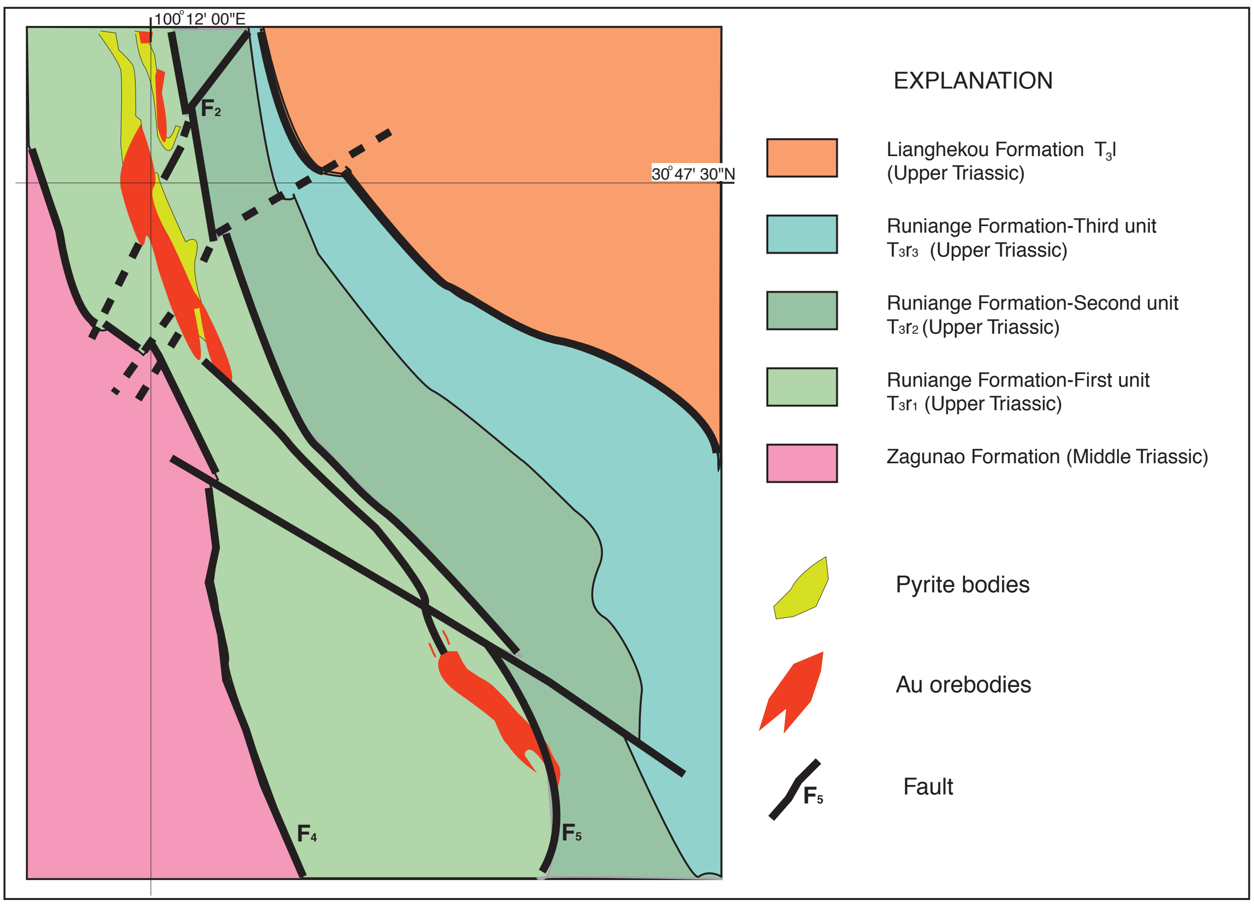



Figure 4-55. Geologic sketch map of the Pulongba Au deposit, Sichuan Province, West Qinling fold belt, Luhuo-Daofu fault zone. (Modified after Zheng, M.H., 1994). Placement of longitude and latitude is approximate.

**Qiuluo Au deposit**

The Quiluo Au deposit is in Ganzi County, Sichuan Province in a northwest, 48° direction and 30 km from the Ganzi County town at E. 100° 15'30", N. 31° 47'15". The deposit was not visited during this study and information is compiled from Wang, X.C. (1993) and Zheng, M.H. (1993). The medium-sized (20 to 50 tonnes Au) deposit is located approximately 20 km southeast of the Pulongba deposit about 80 km south of the City of Seda and 50 km northeast of the city of Ganzi along the Luhuo-Daofu fault zone (figs. 4-33, 4-56). Ore reserves are 10 tonne Au in an area of 2,500 by 800 m. The deposit consists of 4 northwest-striking, southwest-dipping, narrow, >800–m-long orebodies present in three horizons, two of which are separated from the other by a northeast-striking fault (fig. 4-56). The Quiluo Au deposit consists of 4 irregularly shaped orebodies. The main orebody is 240 m long, 3.80 to 38.62 m thick, and grades 15.3 g/t Au. Grades of all the orebodies range from 5 to 20 g/t Au (Wang, X.C., 1993).

Geotectonically, the Quiluo Au deposit is situated in the Bayankela fold belt. Faults in the mine district are the north-northwest-striking Quiluo and Lapu faults that are cut by northwest- and northeast-striking younger faults (not labeled on figure 4-56). The geology of the Qiuluo Au deposit area consists of Upper Triassic Runiange Formation host rock consisting of dark green basalt that is interlayered with limestone and sandstone, dark gray to black, thin-bedded carbonaceous slate that is, in turn, interlayered with sandstone, chert, and shaley

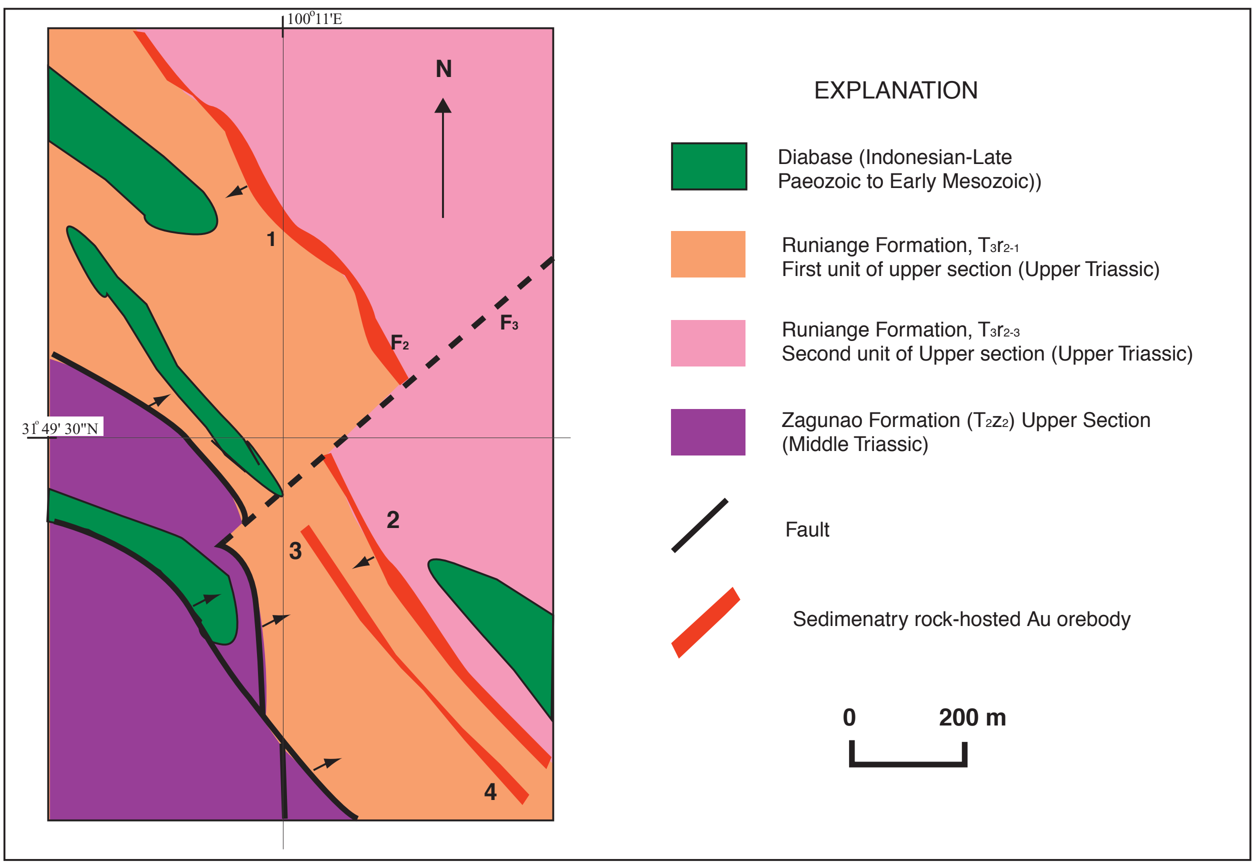



Figure 4-56. Geologic sketch map of the Qiuluo Au deposit, Sichuan Province, west Qinling fold belt, Luhuo-Daofu fault zone. (Modified after Zheng, M.H., 1994). Numbers refer to orebody numbers. Coordinates are approximate.

limestone. These rocks are bound on the northeast by a second upper unit of the Runiange Formation and an upper section of Middle Triassic Zagunao Formation in fault contact to the southwest (fig. 4-56). Throughout the deposit are northwest-elongate, up to 200–m-thick masses of Indonesian (Early Mesozoic) diabase (fig. 4-56).

The Quiluo Au deposit is hosted in carbonaceous slate, ferrodolomitic slate, silty slate, argillaceous siltstone, meta-basic volcanic rock and meta-tuff of the north-northwest-striking, southwest-dipping Upper Triassic Runiange Formation ($T_3r$) composed of three members (from the top to the bottom):

$T_3r^3$: detrital quartz sandstone, intercalated with silty slate, basalt and basaltic volcanic breccia.

$T_3r^{2:}$ carbonaceous slate, intercalated with siliciclastic rocks and local muddy limestone.

$T_3r^1$: spherulitic basalt sheared basalt, intercalated with carbonaceous-silt slate and meta-sandstone. $T_{3r}{}^1$ is the main ore host horizon.

These rocks ($T_3r$) were dynamically metamorphosed and are characterized by breccia, cataclasite and phyllonite.

Ore horizons favor the contact between the first and second units of the Runiange Formation ($T_3r^{2\text{-}1}$ and $T_3r^{2\text{-}3}$ on fig. 4-56). Although structural control mainly is stratigraphic, the orebodies also follow the general northwest strike of the Luhuo-Daofu fault zone. Northeast-dipping faults between the Zagunao and Runiange Formations may intersect the orebodies at depth. Cross faulting down drops the north orebody (fault $F_3$). The orebodies also are hosted along faults that separate the upper and lower sections of the Runiange Formation (fault $F_2$) and therefore this deposit is highly structurally controlled.

Hydrothermal alteration in the Quiluo Au deposit includes widespread Au-associated silicification, sericite, and carbonatization. Chlorite and muscovite also are common but may not be directly related to Au. Gangue minerals are quartz, calcite, sericite, and dolomite. Ore minerals consist of pyrite, abundant stibnite, arsenopyrite, native Au, marcasite, Ni-rich pyrite, tetrahedrite, native Bi, bismuthinite, and cinnabar. Ore textures are girdle, replacement, granular, euhedral, pillar-euhedral, and irregular anhedral granular textures. Ore is present in disseminated, veinlet, network, and brecciated forms. The deposit is geochemically anomalous in As, Sb, Hg, Tl, and Ba and this geochemical signature and mineralogy are very similar to the Pulongba Au deposit to the north-northwest, suggesting that these two deposits may be part of the same metallogenic event along the Luhuo-Daofu fault zone.

## CONCLUSIONS

The west-northwest-trending Hercynian-Indonesian (405 to 195 Ma) Qinling fold belt is one of the most important Au producing regions in China because it contains a variety of types of Au deposits. The sedimentary rock-hosted Au deposits along the complex fold belt cluster in several areas and are associated with specific lithotectonic zones or sutures, such as the Lixian-Baiyun-Shanyang or Luhuo-Daofu fault zones or along structural zones in the Ding-Ma Au belt in the eastern part of the fold belt, and the Nanping-Maqu Au belt in the west parts.

Sedimentary rock-hosted Au deposits in the Qinling fold belt are hosted in Middle to late Devonian and early Triassic clastic and carbonate sedimentary rocks. Host rocks typically are calcareous sandstone, siltstone micritic limestone, bioclastic limestone, carbonaceous and calcareous slate, and basalts. Although Mesozoic intrusive rocks are widespread in the Qinling fold belt area and a few small, late Paleozoic mafic intrusive bodies and some andesitic porphyry bodies are present, igneous rocks are not specifically exposed in or associated with most of the sedimentary rock-hosted Au deposits. Specific exceptions are the metamorphic contact zone in the Maanqiao Au and Liba Au deposits, and intermediate Mesozoic dike rocks along host structures at the Songpangou and Pulongba Au deposits.

Sedimentary rock-hosted Au deposits in the Qinling fold belt have many common features, such as their presence in bedding-parallel shear zones, in stratabound lenses, and in deformed or folded late Paleozoic to early Mesozoic sedimentary and volcanoclastic host rocks. Hydrothermal alteration mineralogy of the gangue and ore minerals in the deposits also have many similarities. The common minerals include illite-clay, quartz, local carbonation, decarbonatization, and many typical sulfide mineral assemblages, such as pyrite, arsenical pyrite, As sulfide minerals, and stibnite. Realgar and orpiment are abundant in many of the deposits. Local rare trace minerals containing Ni, Zn, and Hg also are common to many deposits. The high-As ores in the west Qinling fold belt have many textural and mineralogical similarities to high-As ores in Carlin-type deposits in Nevada.

Geochemical elements associated with these deposits are Au, Hg, Sb, and Ag and lesser amounts of Tl, U, PGEs, and W. PGE minerals are present in the Baguamiao, Laerma, Shuangwang, and other deposits. Mercury and Sb deposits are widely distributed in middle to lower Devonian strata and Au is associated with some of these deposits. Deposits of Hg and Sb are particularly abundant proximal to many Au deposits.

A wide range of possible mineralization ages from the Paleozoic to the Cenozoic may suggest long or multiple metallogenic Au events. This spread of possible genetic age is not uncommon from dating of Carlin-type sedimentary rock-hosted Au deposits, due to the mineralogy of the dated ore minerals, and a possible complex metallogenic history.

Deposits with syndeformational features include the Maanqiao, Baguamiao and Shuangwang Au deposits and these deposits are all hosted in Devonian marine sedimentary rocks and lie along the same lithotectonic zone as the sedimentary rock-hosted Au deposits to the east in the Ding-Ma Au belt, but display slightly different mineralogy and morphology. These deposits are associated with and usually are hosted in ductile shear zones or breccias, rather than brittle-ductile shear zone and may either be deeper equivalents of the deposits in the Ding-Ma Au belt or may represent a different metallogenic episode. These deposits may be a subclass of the Carlin-type sedimentary rock-hosted Au deposits or may be end members of orogenic vein or shear zone-hosted Au deposits.

The West Qinling fold belt contains many lower Triassic sedimentary rock-hosted Au deposits with high organic carbon content, such as the Songpangou, Qiaoqiaoshang, and Dongbeizhai, and Laerma Au deposits. Because the host rocks also contain a high Au background, 10 to 15 times higher than the regional background Au content, the host rocks also may be source-beds for the Au deposits. A similar source-bed hypothesis has been proposed by many workers for Devonian rocks along the Ding-Ma Au belt in the East Qinling fold belt and parts of the Dian-Qian-Gui area (see Chapter 3).

Some minerals not normally common to Carlin-type sedimentary rock-hosted Au deposits also are present in deposits in the Qinling fold belt. Scheelite and tungstite locally is present in some deposits, such as Manaoke. Uranium is common in the Laerma Au deposits. Albite- and titanium-rich zones are present in the Shuangwang, Ertaizi, Baguamiao and other sedimentary rock-hosted Au deposits in Qinling fold belt area, but are not common in most Carlin-type Au deposits.

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