CHAPTER 1
Introduction to and Classification of Sedimentary Rock-Hosted Au Deposits in P.R. China

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Abstract

Chinese sedimentary rock-hosted Au deposits are located along margins of the Precambrian Yangtze craton in the Qinling fold belt area in the north and northwest, the Dian-Qian-Gui area in the southwest, and the Middle-Lower Yangtze River area in the east. Regional-scale faults control their distribution, whereas secondary structures, such as short-axial anticlines (domes), district-scale high-angle faults, stratabound breccia bodies, and unconformity surfaces, control ore at the district and orebody scales. Deposits are hosted in Paleozoic to Mesozoic sedimentary rocks composed mainly of impure limestone, siltstone, and argillite. Alteration types are silicification, decalcification, argillization, carbonization, and locally albitization. Igneous intrusions usually are not present near most Chinese sedimentary rock-hosted Au deposits, except for local lamprophyre, granodioritic, and siliceous dikes. However, the Middle-Lower Yangtze River area contains many pluton-related Au deposits.

The main deposit types are Carlin-type, pluton-related, syndeformational, unconformity-hosted, and red earth and laterite Au deposits. Gold mainly is present as disseminations in most sedimentary rock-hosted Au deposits, although local accumulations of Au-bearing massive sulfide are present, especially in polymetallic replacement mantos in the Middle-Lower Yangtze River area. The main opaque minerals include Au, electrum, pyrite, arsenopyrite, stibnite, orpiment, realgar, and cinnabar. Gangue minerals are quartz, barite, organic carbon, carbonate and clay minerals, as well as some albite. Elements associated with Au in Nevada deposits, such as As, Sb, Tl, and Hg, also are closely associated with many Chinese deposits, but U, Sr, and some PGE elements also are associated with the Au deposits.

摘　要

中国沉积岩型金矿床主要分布于西北地区秦岭褶皱带的扬子前寒武纪克拉通边缘，西南的滇黔桂地区以及东部的长江中下游地区。这些矿床的分布受区域性裂谷控制，而次级构造如短轴背斜（穹隆），高角度断层，角砾岩层和不整合面也是有利的成矿构造。这类矿床主要赋存于古生代至中生代不纯灰岩，粉砂岩和泥岩中。蚀变类型有硅化、脱钙化、泥化、碳化　　，局部钠长石化。除了局部的煌斑岩和硅质岩脉，大多数沉积岩型金矿床周围一般都没有火成岩侵入体。长江中下游地区例外，产有与侵入体有关的金矿床。

主要的矿床类型为卡林型金矿床、与侵入体有关的金矿床、造山带金矿床、不整合面的金矿床和红土型金矿床。在大多数沉积岩型金矿床中，金主要呈浸染状产出，但在长江中下游地区局部金产在块状硫化物中，尤其是在层控平卧矿床中。不透明矿物有金、银金矿、黄铁矿、毒砂、辉锑矿、雄黄、雌黄和辰砂。脉石矿物有石英、重晶石、有机炭、碳酸盐和粘土矿物，局部有钠长石。美国内华达州金矿床具有 As、Sb、Tl 和 Hg 元素组合。中国许多沉积岩金矿也具有这种元素组合，而且铀、铊和铂族元素矿床也与金矿床有关。

INTRODUCTION

This is the introductory chapter of a six-chapter interim report on results of a joint project between the U.S. Geological Survey and the Tianjin Geological Academy to study sedimentary rock-hosted Au deposits in P.R. China and in Nevada, USA. The project began in 1998 and has involved joint field visits to deposits in China in 1997, 1999, and 2000, and in Nevada in 1999. The purpose of this chapter and Chapter 2 is to describe characteristics of sedimentary rock-hosted Au deposits in P.R. China and to provide a working classification for the deposits in three main areas, the, Dian-Qian-Gui (Chapter 3), Qinling fold belt (Chapter 4), and Middle-Lower Yangtze River (Chapter 5) areas (fig. 1-1). These later chapters describe a representative group of Chinese sedimentary rock-hosted Au deposits in areas that were visited in the field by the authors. When appropriate, the deposit characteristics are compared to similar deposits in Nevada. A final chapter (Chapter 6) provides a weights-of-evidence (WofE), GIS-based mineral assessment of favorable areas for sedimentary rock-hosted Au deposits in the Qinling fold belt and Dian-Qian-Gui areas. Appendices provide scanned aeromagnetic (Appendix I) and gravity (Appendix II) maps of south and central China, data tables of the deposits (Appendix III), and geochemical analysis of selected field samples (Appendix IV).

Figure 1-1. Location of three main areas of sedimentary rock-hosted Au deposits in China.

In an earlier report (Li, Z.P. and Peters, 1998), information about Chinese sedimentary rock-hosted Au deposits was collected, translated, and also summarized into a database, which consisted of over 160 occurrence records and 30 data fields organized in six subsets. They are: (1) deposit name and reference; (2) geographical location (Province, County, latitude and longitude); (3) commodity information (size, ore and gangue mineral); (4) tectonic setting (regional trend, structural environment); (5) ore-control structures; and (6) host rock and alteration. This database is available in Li, Z.P. and Peters (1998), CD-ROM version, and is updated on the internet (v.1.3) [http://geopubs.wr.usgs.gov/open-file/of98-466/]. Further database updates, particularly latitude and longitude locations and corrected pinyin spellings, are contained in Appendix III. This previous report also detailed a Au occurrence in Proterozoic sedimentary rocks of eastern Hebei Province (shortened to Jidong), northeast China.

Sources of information, in Chapters 1 through 6, about the Chinese sedimentary rock-hosted Au deposits are from 1980's and 1990's literature, both in English and in Chinese, and also is from data collected by the authors from field visits in 1997, 1999, and 2000. In addition, a number of Chinese government agencies provided data and information and are listed in the Acknowledgements at the end of this and subsequent chapters (fig. 1-2).

Figure 1-2. Photograph of geologists exchanging information and data at the 601 Geological Team Office in the Xiaojiapu Mine, Hubei Province, Middle-Lower Yangtze River area.

The P.R. China contains many sedimentary rock-hosted Au deposits of different types and sizes (fig. 1-1) (Zheng, M.H., 1984; 1989, 1994; He, L.X., and others, 1993; Cun, G., 1995; Gu, X.X., 1996; Kerrich and others, 2001). The country is well known for its large Au mines, many of which are from this deposit type. Gold is the main metal mined from sedimentary rock-hosted Au deposits in China, although some deposits contain significant amounts of As, Ag, Sb, and Hg, and lesser amounts of Cu, Pb, Zn, W, and PGEs. Sedimentary-rock-hosted Au deposits mainly are hosted in limestone, siltstone, argillite, and shale (Yang, K., 1996; Hu, R.Z. and others, 2001). Locally, igneous rocks also host Au in some of these deposits. Gold contained in most deposits, particularly of the Carlin-type, usually is micron-size, and is associated with As-rich pyrite. Locally, some deposits also may contain free Au (Liu, D.S., and Geng, W.H., 1987; Liu, D.S., 1992)

Mining of oxidized parts of sedimentary rock-hosted Au deposits increased world-wide in the 1970s and 1980s when it was recognized that these deposits could be economically mined using bulk-tonnage methods from open pit mines and that the ore could be processed with carbon-in-pulp or heap-leaching technologies. Recent discoveries in the USA, below the oxide zone, have proven that sulfide-rich ores also can be economically processed with large capital investments, using roasters and autoclaves to process hypogene ores. Exploration efforts between 1975 and 2000 resulted in the discovery of several large (50 tonne Au) and super-large (>50 tonne Au) deposits in mining districts in Nevada, and several large deposits also have been delineated in China.

Sedimentary rock-hosted (Carlin-type) Au deposits have been considered economically significant and geologically distinct since the early 1960s. Similar deposits have been discovered in P.R. China, Australia, Dominican Republic, Spain, Russia, Indonesia, Malaysia, Philippines, Yugoslavia, and Greece (Li, Z. P. and Peters, 1998) in addition to the Great Basin of Nevada. Similar deposits in P.R. China make it possible to apply comparative research on these Au deposits, and to develop a better understanding of the genesis of them.

Large, rich, sedimentary rock-hosted Au deposits in northern Nevada have made a large contribution to the economy of Nevada and the USA. In 1998, Nevada produced 74 percent of the nation's Au and has ranked first in USA Au production since 1981, the majority coming from Carlin-type deposits. Announced Au reserves of the Carlin-trend deposits alone are 70 million oz Au (Teal and Jackson, 1998) and production has exceeded 50 million oz. Au (Nevada Bureau Mines and Geology, pers communication). It has become important to understand their origin in order to assess the potential for future discoveries.

Although the origin of sedimentary rock-hosted Au deposits is incompletely understood, a number of features, including field relations at all scales, age relations, and geochemical and isotopic characteristics, enhance our understanding of these deposits. Previous genetic models have been developed from mining the oxide or weathered parts (supergene) of these deposits in the USA during the 1960s to 1980s. Recent exploitation has exposed sulfide (hypogene) parts of these orebodies and studies of these hypogene ores has increased knowledge of deposit genesis, because primary textures and geochemical signatures of the ores are not obscured by oxidation. Sedimentary rock-hosted Au deposits have become an important research topic and their origin has become much debated (Vikre and others, 1997; Hofstra and Cline, 2000).

A large number of sedimentary rock-hosted Au deposits have been discovered since the first Carlin-type Au deposit in P.R. China was identified there between 1964 and 1966 (see also, Liu, D.S. and others, 1994, Li, Z.P. and Peters, 1998). Several dozen of these deposits are of substantial grade and tonnage. Since the 1980s, Chinese geologists have devoted a large-scale exploration and research effort to the deposits; these studies have been sponsored by the Bureau of National Gold Administration, Ministry of Metallurgical Industry, Ministry of Geology and Mineral Resources, Chinese Academy of Sciences, Chinese Non-ferrous Metal Industrial General Company, and other Chinese government agencies. As a result, there are more than 20 million oz of proven Au reserves in sedimentary rock-hosted Au deposits in P.R. China. Additional estimated and inferred resources are present in over 160 deposits and occurrences (Appendix III), which are under-going exploration. This makes China second to Nevada in contained ounces of Au in Carlin-type deposits (see Liu, D.S, 1991).

Early comparative studies of Carlin-type Au deposits between Nevada and P.R. China have been done by Cunningham and others (1988), Dean and others (1988); Ashley and others (1991), Tu, G.Z. (1992), Mortensen and others (1993), Wang, J. and Du, L.T. (1993), Liu, D.S. and others (1994) and Li, Z.P. and Peters (1998). These studies have demonstrated that there are many similarities between the deposits on both continents that may be helpful in advancing our understanding of them (see also, Chapter 2).

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, formation names and names for structural features may differ because of old and new names and because of use of different names by different Provincial and Central Government 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.

Chinese names and terms used in this and subsequent chapters are translated from Chinese symbols to pinyin, but do not contain the Chinese tones. Different translators have use different forms of pinyin, but most names have been standardized throughout the texts. Chinese Provinces have long and short names, so areas of Chinese Carlin type deposits commonly are referred to as a combination of the abbreviated short province names. The southwest area, Dian-Qian-Gui (Chen, Y.M., 1987), is located in the Yunnan (short name Dian), Guizhou (Qian), and Guangxi (Gui) Provinces. The central area, Qinling fold belt (or Chuan-Shan-Gan), is in the Sichuan (short name Chuan), Shannxi (Shan), Gansu (Gan) Provinces. The term sedimentary rock-hosted Au deposit is used throughout this report and reflects a number of different types of Au deposits.

MINING, EXPLORATION, and METALLURGY

Compared to Nevada deposits, Chinese sedimentary rock-hosted Au deposits are smaller in size, generally contain a shallower oxidation zones, and thus consist of dominantly refractory ores. Most Chinese sedimentary rock-hosted Au deposits are in an undeveloped state or are being exploited by small-scale mining methods (fig. 1-3). This is because of the refractory nature of many of the ores, remote locations, and lack of infrastructure and financial capital. Mining, exploration, and metallurgical extraction of sedimentary rock-hosted Au deposits in China are conducted by conventional methods that are shaped by local economics and by the geologic character and location of the deposits.

Figure 1-3. Photographs illustrating mining methods used in various sedimentary rock hosted Au deposits. (***A***) Large, mechanized open-pit mining at the Xinqiao Au deposit, Tongling area, Anhui ProvInce, Lower Yangtze River area. (***B***) Open pit mining without blasting, Shewushan red earth deposit, Anhui Province, Lower Yangtze River area. (***C***) Hand tramming at the Gaolong Au deposit, Guizhou Province, Dian-Qian-Gui area. (***D***) Tractor and trailer haulage, Shewushan Au deposit, Lower Yangtze River Area.

Mining

Mining methods applied to sedimentary rock-hosted Au deposits in China are varied and depend on: land ownership, location, exploration stage, oxidation profile, orebody geometry, and local economic conditions. Production rates generally are less than 1,000 tonnes ore per day and commonly are in the 100s of tonnes per day or less. Many ore deposits or districts are mined by local villagers and farmers using small, open-cast, hand-mining methods, where parts of the ore districts are owned by Provincial- or County-level governments. Parts of the ore districts that are owned by the Central Government of the People's Republic generally employ more advanced exploration, mining, and metallurgy methods and are operated by a number of Ministries and Bureaus, or are joint ventured with private mining companies.

Underground exploration, development, and production in hilly, remote country in the Qinling fold belt and Dian-Qian-Gui areas is conducted by small adits and drifts, using hand tramming by sleds or by rail-driven ore cars (fig. 1-3). More advanced underground methods are common in the Middle-Lower Yangtze River area associated with Cu, Fe, and S mining, where shafts and hoists access deep gossanous and massive sulfide stratabound lenses.

Open pit operations commonly use a combination of undercut hand methods along toes of benches and hand-haulage by basket or wheel burrow and excavation by backhoe and small dump trucks, particularly in the Dian-Qian-Gui and Qinling fold belt areas. Conventional open pit methods with drilling, blasting, benching, and truck haulage is more common to mines in the Middle-Lower Yangtze River area (fig. 1-3).

Exploration

A traditional exploration method for Au deposits is prospecting by tracing particle Au in placers to their source by panning or loaming. This method has not worked in exploration for many sedimentary rock-hosted Au deposits, because the Au particles are so small that detectable Au in placers is not present downstream (Tu, G.Z., 1994; Liu, K.Y., 1991). Exploration and development of sedimentary rock-hosted Au deposits in P.R. China has taken advantage of various metallogenic (Tao, C.G., 1990; Liu, K.Y., 1991), mineralogic (Shao, J.L., 1989), geophysical, and geochemical (Shi, X.Q., 1990) characteristics of these deposits (see also Mai, C.G., 1989; Guo, Z.C., 1994). Metallogenic principles applied to these deposits are similar to those discussed by RamoviÊ (1968) and Shcheglov (1979). As a result, discovery and understanding of these deposits in China has grown.

Deposit-scale exploration commonly concentrates on empirical methods of orebody sampling and measurement. Chief techniques used are surface mapping, trenching, chip sampling, and underground tunneling by drift or cross cut, and rotary or diamond drilling (fig. 1-4). Ore measurement by these methods results in the identification of ore reserve and resource categories, on the basis of criteria similar to those described by Kuûvart and Bˆhmer (1978) and Kreiter (1968).

Drilling of sedimentary rock-hosted Au deposits in China is costly and not as common as drilling in Nevada. Optimization of drill targets commonly is accomplished by using standard structural geological techniques and geochemistry (fig. 1-5). Ground electrical and gravimetric geophysical exploration methods locally are applied to enhance drill targets and to search for concealed ore. Geophysical methods have been particularly successful in the high sulfide-bearing deposits in the Middle-Lower Yangtze River area.

Geochemical exploration, using regional-scale stream-sediment samples and district- and orebody-scale soil and rock-chip samples has proven to be a successful technique in the discovery and definition of sedimentary rock-hosted Au deposits in P.R. China. A well-documented example of this is the Lannigou Au deposits in the Dian-Qian-Gui area, where soil geochemistry has identified a number of mineralized Au systems associated with structures (Luo, X.H., 1994) (fig. 1-5) (Chapter 3). The Shewushan red earth (laterite-hosted) Au deposit was discovered by regional-scale stream-sediment sampling in the topographically low country of the Middle-Lower Yangtze River area (Chapter 5). Trace element geochemical sampling of the ores also has been helpful in defining the Carlin-type deposit class and distinguishing these deposits from deposits of other types (see also, Dean and others, 1988) (see also, Chapter 2).

Remote sensing exploration techniques, such as interpretation of LANDSAT images (fig. 1-7) and aeromagnetic and gravity geophysical methods (Appendices I and II) have been useful in identifying major deep faults that may have served as conduits for ore fluids. The methods have proven particularly useful in defining the Youjiang fault zone in the Dian-Qian-Gui area and the Lixian-Baiyun-Shayang rift in the Qinling fold belt area.

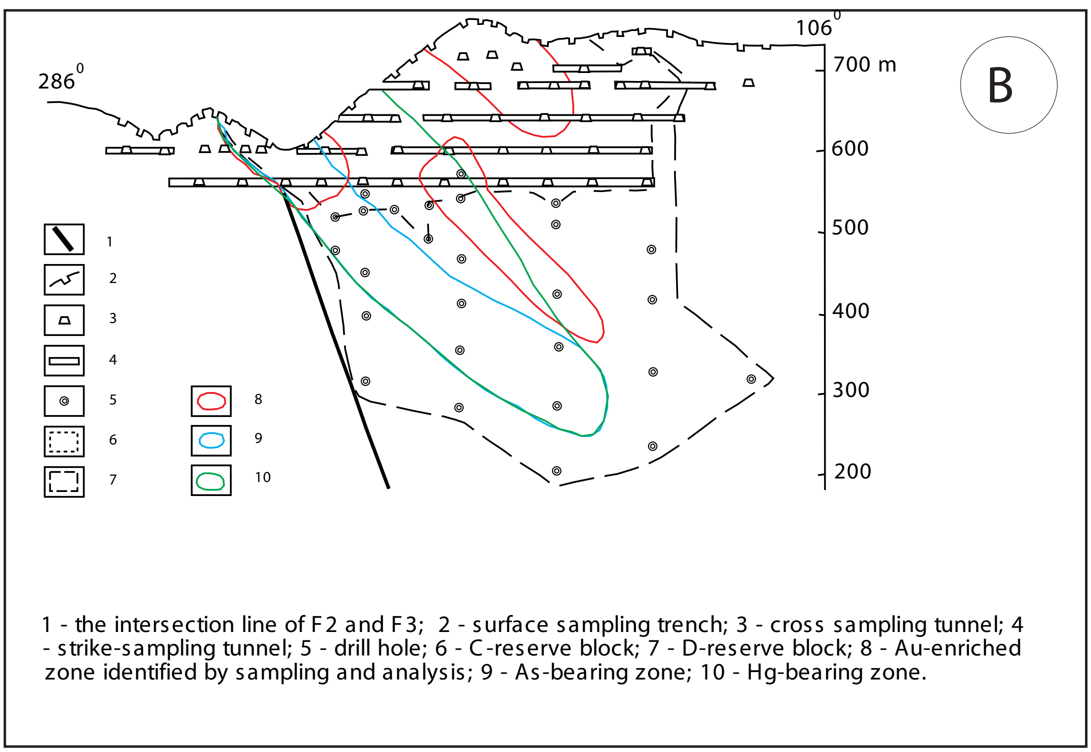


Figure 1-4. Exploration methods applied to the Lannigou Au deposit, Guizhou Province, Dian-Qian-Gui area. (A) Drilling exploration at the Lannigou Au deposit area. Covered towers of drill rigs are to protect drills from rain fall. (B) Geochemical analysis on the long section projection of the No. 1 orebody of the Huang-Chang-Gou block in the Lannigou Au deposit

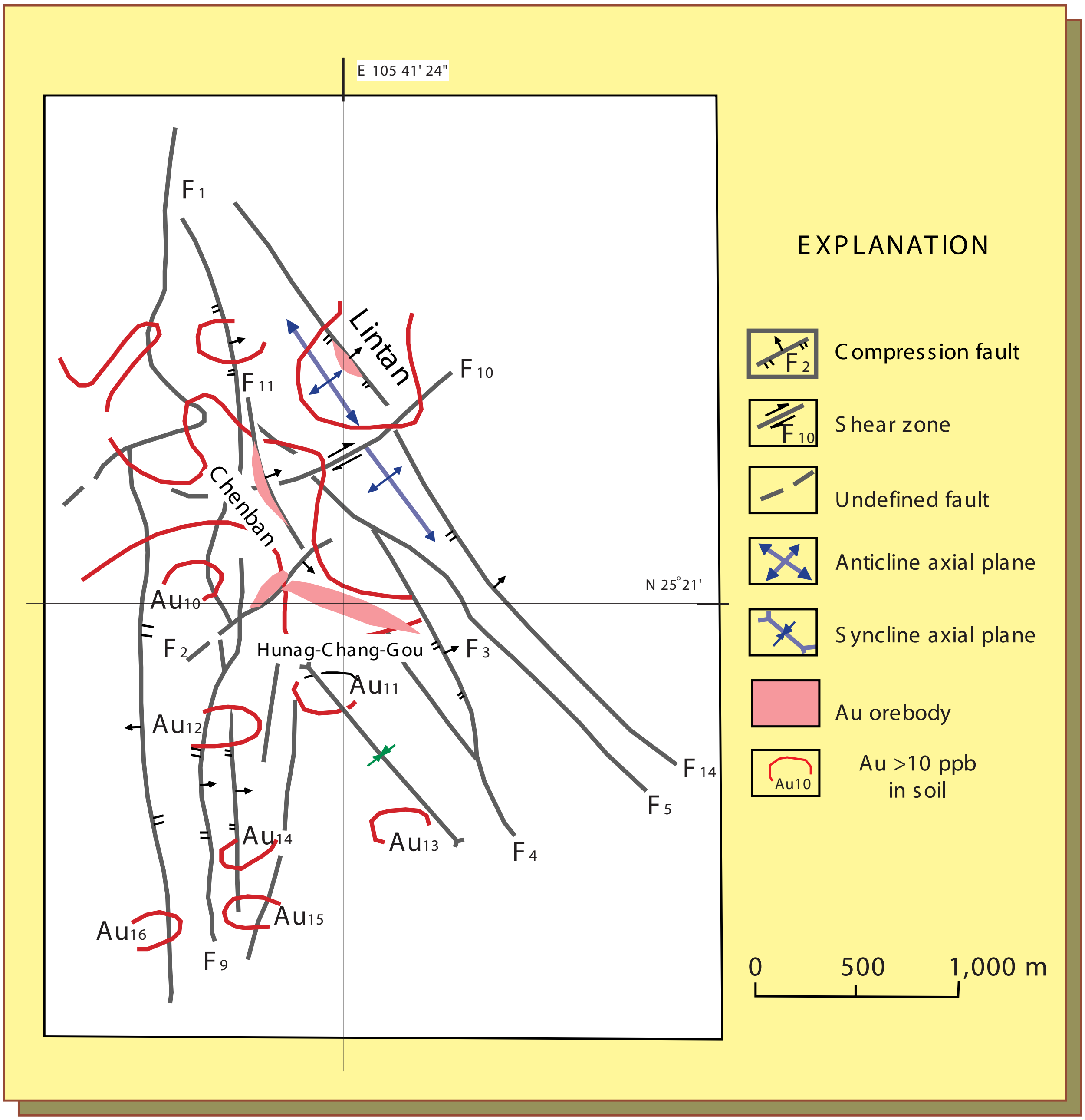


Figure 1-5. Distribution of soil geochemical anomaly in the Lannigou Au deposit, Guizhou Province, Dian-Qian-Gui area. Soil geochemistry has proven effective in defining broad areas of Au mineralized rock and in defining drill targets. From Lou, X.H. (1994).

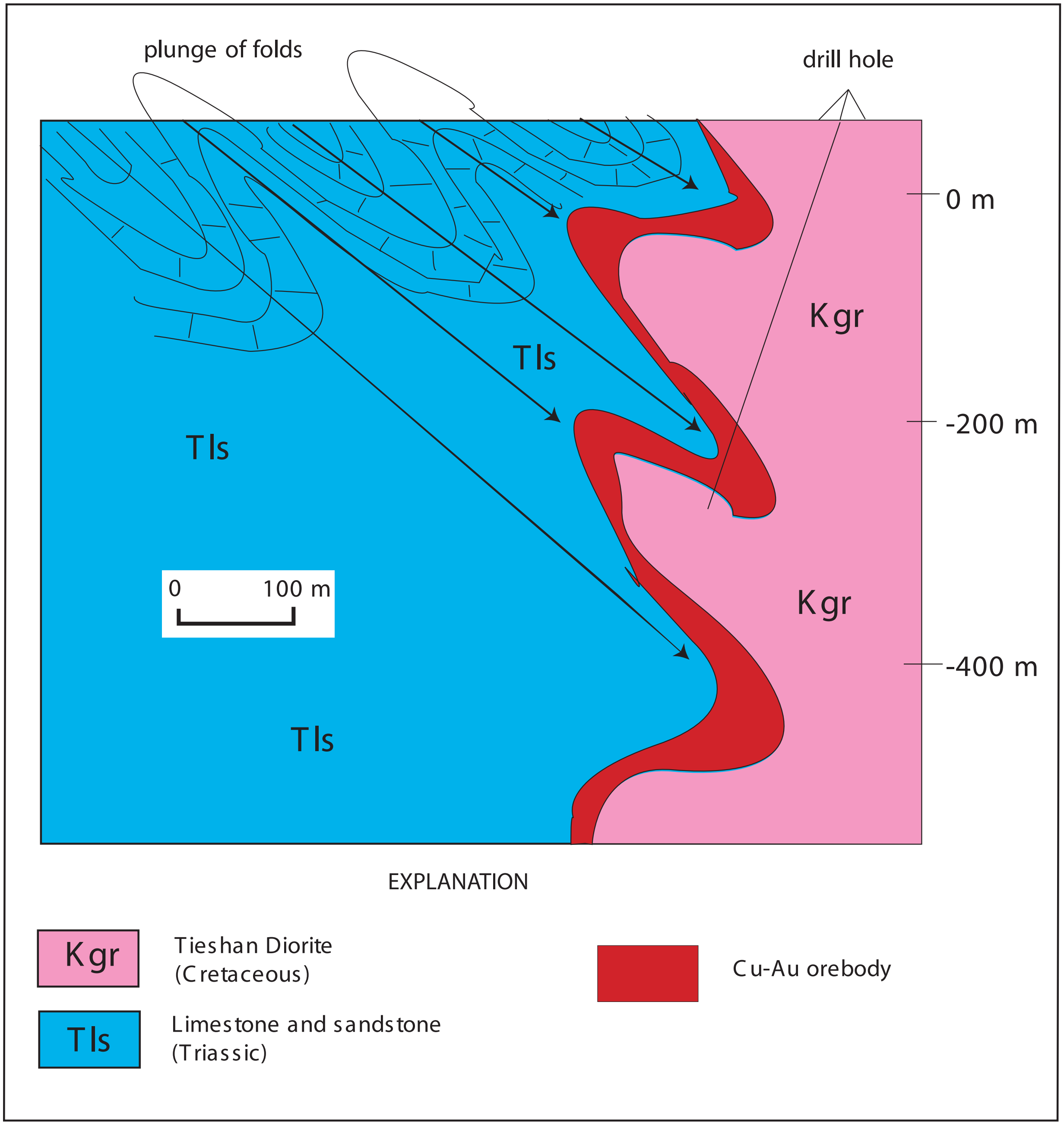


Figure 1-6. Diagrammatic exploration model for the Jilonghsan, Fengshandong, and Lijiawan deposits in southeastern Hubei Province, Lower Yangtze River area. This is an example of the use of structural geology for the targeting of drill holes in exploration. The thickest and richest part of the deposits is present along the contact with the 120 Ma granitic porphyry and noses of plunging folds in Triassic limestone. Folds are identified at the surface and projected toward the intrusive contact at an angle of 45 degrees and these targets are tested by drilling (see Chapter 5 for details).

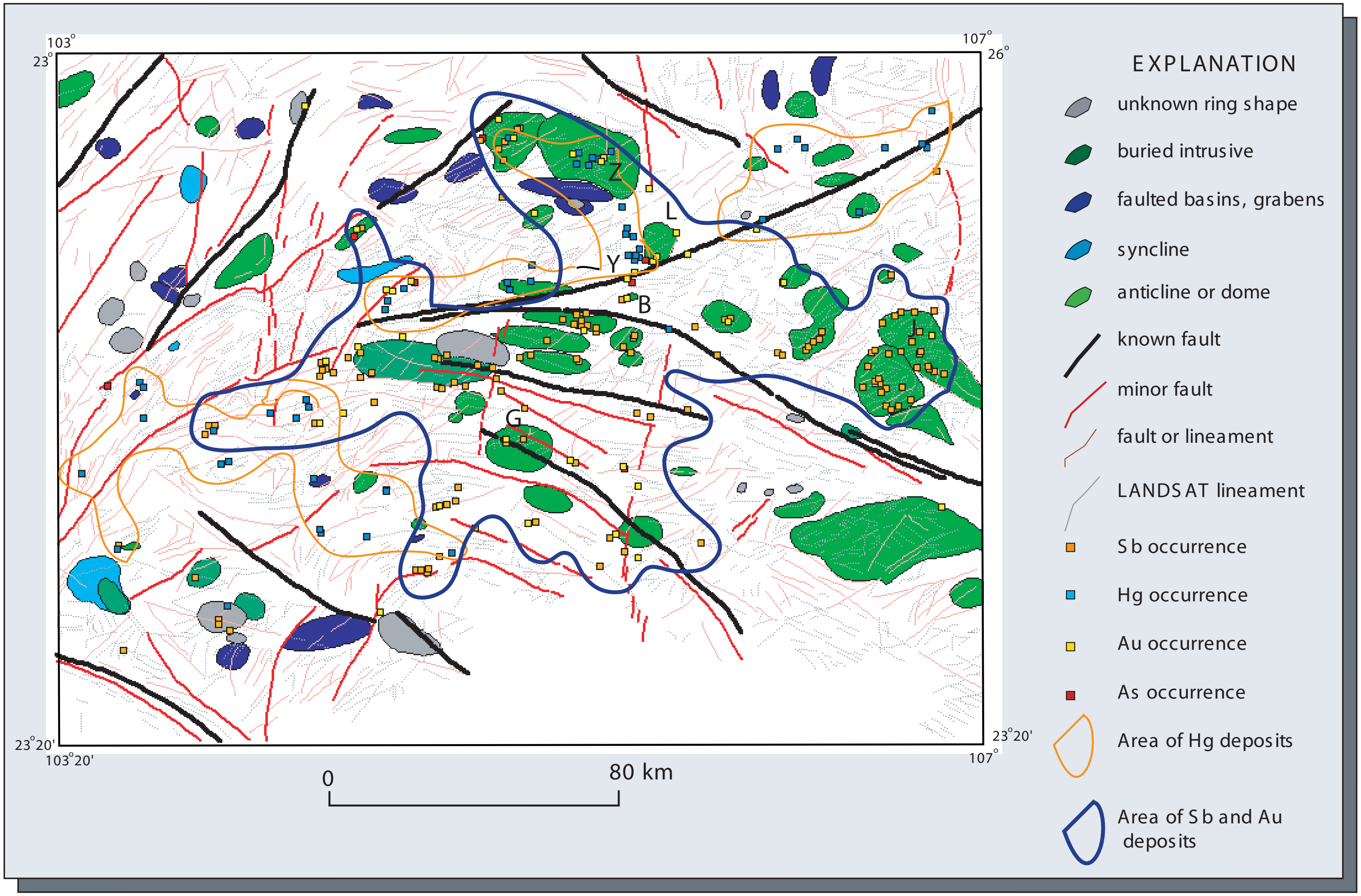


Figure 1-7. Example of use of LANDSAT interpretation for exploration and metallogenic analysis of sedimentary rock-hosted Au deposits in the Dian-Qian-Gui area. Interpretation of image shows a number of domal-shapes, faults, and lineaments. The Au occurrences are associated with these structural features and also have a spatial relation to Sb, Hg, and As prospects, mines, and mineral occurrences in the area. Mine areas are noted as: Z-Zimudang, L-Lannigou, Y-Yata, B-Banqi, J-Jinya, G-Getang.

Metallurgy

Processing of oxide ores from sedimentary rock-hosted Au deposits in P.R. China mainly is by cyanide leaching methods, either in heaps (Gaolong, Zimudang), vats (Hengxian, Zhanghai, Qiaoqiaoshang), or in carbon-in-pulp circuits (Maanqiao). Heaps usually are fed by small hand-powered or motorized dump trucks (fig. 1-8A). Most vats contain about 100 to 500 tonnes and are fed and emptied by hand methods usually on weekly or bi-weekly cycles (fig. 1-8B). Gossanous and sulfide ores in the Xinqiao and Mashan Au deposits in the Middle-Lower Yangtze River area are processed by ball mill and flotation methods (fig. 1-8C, D), as well as by non-cyanide leach methods. Hypogene Carlin-type Au ores in the Qinling fold belt and Dian-Qian-Gui areas have proven to be a metallurgical problem, because of the physical remoteness of the orebodies and capital and infrastructure needs required for autoclaves and roasters. Bioleach bench-scale testing has been conducted on the Lannigou Au deposit and other ores and could prove to be more economic.

Figure 1-8. Photographs of processing techniques used in various sedimentary rock-hosted Au deposits in China. (*A*) Heap leach pads below open pit mine at Gaolong Au deposit, Guangxi District, Dian-Qian-Gui area. (*B*) Vat leach pits operated by local villagers, Zhanghai Au deposit, Anhui Province, Middle-Lower Yangtze River area. (*C*) Flotation Mill for sulfide polymetallic ores at Xinqiao Mine, Hubei Province, Lower Yangtze River area. (*D*) Mill and smelter at Mashan Au mine for gossanous and polymetallic sulfide ores, Hubei Province, Middle-Lower Yangtze River area.

A good example of metallurgical approaches to extraction of micron-size Au is from the Lannigou Au deposit, Dian-Qian-Gui area (Chapter 3) where 81.89 volume percent of Au is enclosed in pyrite and arsenopyrite, and the rest is present between minerals. Pyrite contains 123.05 g/t Au and arsenopyrite contains 115.32 g/t Au; and 52.4 volume percent of the Au is submicroscopic Au. Currently, only Au is of interest, but if the milling methods were to be improved, As, Hg, C, and S may also be beneficiated. Most ores at the Lannigou Au deposit are refractory with little oxide reserves. Most Au is native Au, with a fineness greater than 90. On the basis of these characteristics, the Lannigou Au ore is classified as an As-bearing, low-sulfide, refractory ore. Results of bench-scale testing indicate recovery rates between 84 and 94 percent using flotation and leaching methods (Luo, X.H., 1994).

LOCATION of SEDIMENTARY ROCK-HOSTED Au DEPOSITS

Chinese sedimentary rock-hosted Au deposits discussed in this and subsequent chapters are distributed in three main areas in southwest and central China. Each of these main clusters of deposits lies in several provinces (figs. 1-1, 1-9). Most of the Au deposit occurrences are mines or prospects (Li, Z.P. and Peters, 1996; 1998) in the Dian-Qian-Gui, Qinling fold belt, and the Middle-Lower Yangtze River areas (fig. 1-9). Other sedimentary rock-hosted Au deposits are mainly in the Guangdong, Hunan, Hubei, and Liaoning Provinces (Liao, J.L., 1987; Shi, X.Q., 1990; Cai, G.X, 1991; Xu, A.J., 1991; Liu, B.G. and Yeap, E.B., 1992; and Cheng, Q.M., and others, 1994; Du, J.N. and Ma, C.K., 1994). Size of these Au occurrences is detailed in Li, Z.P. and Peters (1998) in subsequent chapters, and in Appendix III. A few sedimentary rock-hosted Au deposits, such as the Greatwall deposit, were recently discovered in the Proterozoic Lengkou basin in the eastern Hebei Province of north China (Qiu, Y.S. and Yang, W.S., 1997) and are discussed in Li, Z.P. and Peters (1998).

Chinese sedimentary rock-hosted Au deposits mainly are present in Paleozoic to early Mesozoic rocks in sedimentary basins around the Yangtze Precambrian craton (fig. I-9). The Qinling fold belt area is located on the northwestern margin of the Yangtze craton (Chapter 4). The Dian-Qian-Gui area is located along the southwest margin of the Yangtze craton (Chapter 3), and the Middle-Lower Yangtze River area is located on the eastern margin of the craton (Chapter 5) (fig. 1-9). Geology and tectonic history of the three areas have many similarities; however, each area has some local, unique geologic structures and lithofacies that influence the style of the Au deposits (Yao, Z.Y., 1990; Wang, Y.M. and others, 1996).

GEOLOGICAL SETTING of SEDIMENTARY ROCK-HOSTED Au DEPOSITS

Geologic setting of sedimentary rock-hosted Au deposits is necessary to understand their genesis, control, and potential. Tectonic and sedimentary environments, in relation to the metallogenic epochs of these deposits, allow evaluation of the spatial geological environment in which they occur. Although each mining district has Paleozoic and early Mesozoic host rocks that contain the bulk of the sedimentary rock-hosted Au deposits (see also, Zheng, Z.M., and others, 1984; Ji, X. and Coney, 1985; Yang, Z. and others, 1986; Deng, S. and others, 1986; Hsu, K.J. and others, 1990; Dong, S.B., 1993; Deng, Y.Q, 1994; Wang, Y. and others, 1996), these rocks and some igneous rocks have been structurally deformed and locally metamorphosed. Individual geologic histories in each terrane represent events that define a metallogenic setting in each area (see also, Sengor and Natal'in, 1996; Yin, A., and Nie, 1996).

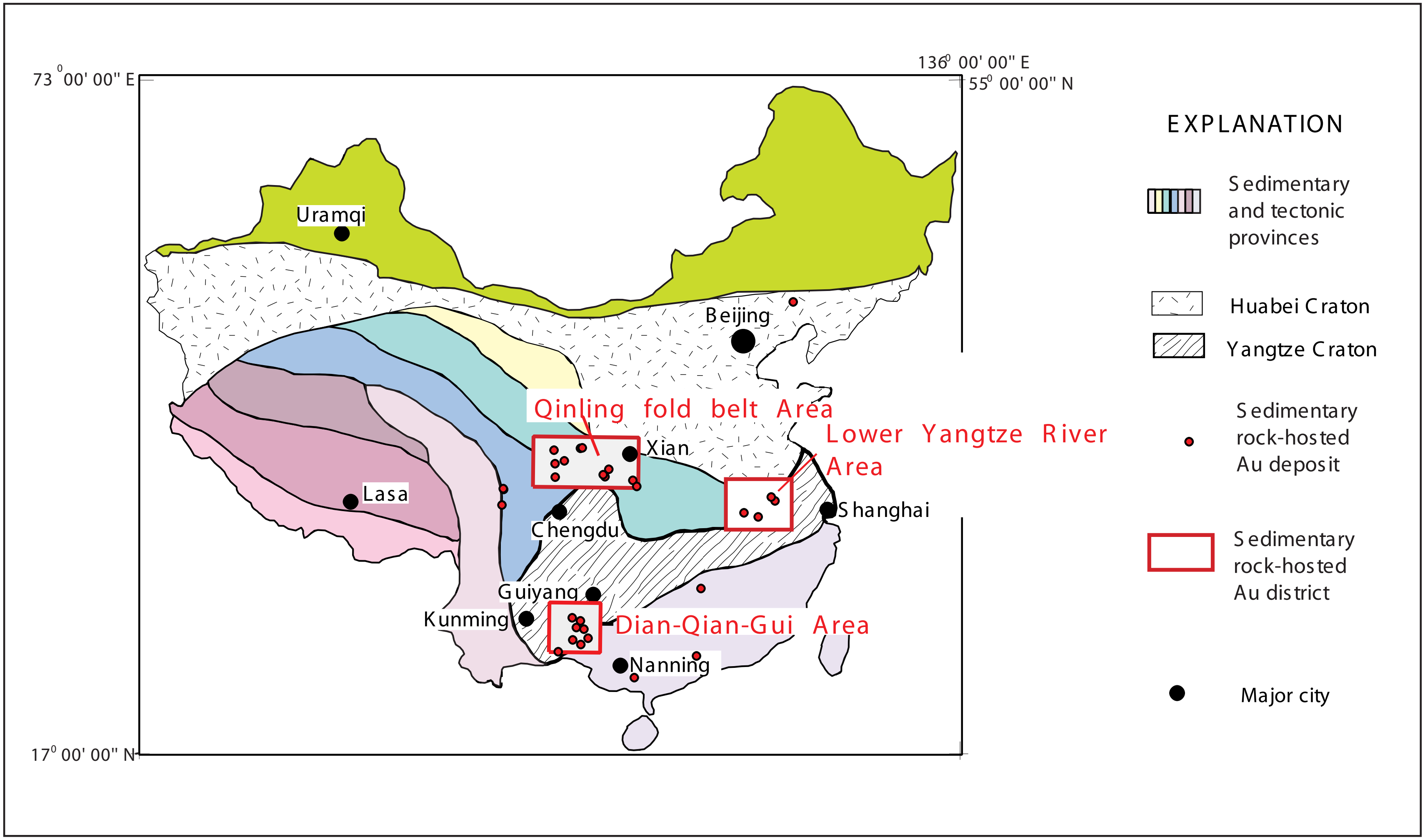


Figure 1-9. Location of sedimentary rock-hosted Au deposits in China in relation to generalized tectonic provinces. and the Yangtze Craton The deposits are located in three areas: the Dian-Qian-Gui area in the south, at the southwestern margin of the Yangtze Craton, the Qinling fold belt area on the northern margin of the Yangtze Craton, and the Lower Yangtze River area on the east side of the craton. Major cities are noted with large circles Compiled from Li, D.S. (1994) and Wang, J. (1993) and modified from Li, Z.P. and Peters (1998).

Sedimentary rocks

Sedimentary host rocks of most sedimentary rock-hosted Au deposits in Nevada contain sedimentary and tectonic breccia bodies, which serve as host rocks for most of the larger orebodies, but also serve as conduits for migrating fluids (Peters and others, 1997). Most Chinese sedimentary rock-hosted Au deposits are hosted in marine carbonate- and clastic-rich sedimentary rocks that locally are interbedded with volcanic flow rock or tuff. These rocks typically formed in abyssal, bathyal, and turbidite environments and consist of limestone, argillite, siltstone, sandstone, and shale. Low-grade metamorphic rocks, such as spotted phyllite, slate, and crystalline limestone—from carbonate and clastic sedimentary protolith—host some deposits. These Paleozoic and early Mesozoic rocks lie at the margins of the Precambrian crust of the Yangtze craton and have been affected by Paleozoic and Mesozoic tectonic and local igneous events, which have produced crustal thickening and deformation.

In the Dian-Qian-Gui area (Chapter 3), mainly late Paleozoic impure locally carbonaceous limestone, silty argillite, and siltstone (carbonate-clastic units) host Au–Hg–Tl-type Au deposits; Au–Sb–pyrite-type deposits also are present in silty argillite, siltstone interbedded with basaltic lava, breccia, and tuff, (terrigenous or volcanoclastic units). Turbidite deposits, including siltstone, argillite, greywacke, and carbonate-bearing rocks (micritic and bioclastic limestone) also host Au–As–(Sb)-type Au deposits in the Dian-Qian-Gui area (Hu, J.P, 1991).

In the Qinling fold belt area (Chapter 4), Paleozoic and early Mesozoic argillaceous limestone, bioclastic limestone, argillite, siltstone, carbonaceous calcareous slate, and shale host most sedimentary rock-hosted Au deposits. However, some carbon-rich black clastic sedimentary rocks (black shale) host both large and extra-large sedimentary rock-hosted Au deposits as well as Sb, Hg, U and PGE deposits (Li, Z.P. and Peters, 1998). Low-grade metamorphic rocks (see also, You, Z.D. and others, 1993) and some igneous dikes host some Au deposits, but a direct connection of Au mineralization to igneous activity usually is lacking.

In the Middle-Lower Yangtze River area (Chapter 5), stratabound replacement deposits are hosted in specific horizons of Triassic and Carboniferous silty limestone. Plutonic rocks and skarn also locally host some of these deposits. Local Carlin-type deposits in the Middle-Lower Yangtze River area, such as the Zhanghai Au deposit, are hosted in slaty, black Silurian siltstone and shale.

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

Igneous and metamorphic rocks

Igneous rocks are associated with some sedimentary rock-hosted Au deposits in the Qinling fold belt and the Middle-Lower Yangtze River areas. Recent research in Nevada on Carlin-type deposits suggests that intrusive activity may be an important component in the formation of these deposits by supplying regional heat flow and possibly may be the source of some of the metals in the deposits (Henry and Boden, 1997; Henry and others, 1998; Ressel and others, 2000a, b; Henry and Ressel, 2000a,b). Igneous rocks are essential to the formation of the distal-disseminated Ag–Au sedimentary rock-hosted deposits in Nevada (Sillitoe and Bonham, 1990; Margolis, 1997; Theodore, 2000).

The Qinling fold belt area (Chapter 4) contains widespread igneous rocks consisting of early Mesozoic intermediate stocks and plutons (Liu, M., 1994; Fan, S.C., and Jin, 1994) and some Paleozoic plutons. Some of the igneous bodies may be genetically related to Au deposits, according to Xie, Y.H. and others (1996). The Maanqiao Au deposit is located in the metamorphic aureole of Mesozoic granite, as is the Liba Au deposit (Chapter 4). Granodioritic dikes are present near or in host structures in the Songpangou-Qiaoqiaoshang Au deposit areas near the Snow Mountain fault (Chapter 4) and in the Pulongba Au deposit. Some of these Au deposits contain elevated values of Bi and other elements compatible with igneous activity in their ores (Appendix IV, Chapter 4). Field and laboratory relations are not definitive as to whether hydrothermal activity that formed the Au deposits overprinted or was part of the igneous events.

Igneous activity generally is lacking and not considered related to deposits in the Dian-Qian-Gui area (Chapter 3). Therefore, the Dian-Qian-Gui area is important because non pluton-related theories of ore genesis for sedimentary rock-hosted Au deposits must be considered. Igneous rocks in the Dian-Qian-Gui area show little expression of deep intrusive activity according to regional-scale geophysical data (Appendices I and II). Small alkalic and ultramafic intrusive bodies are reported by Luo X.H. (1994) near the Lannigou Au deposit, Guizhou Province. The Jinba Au deposit, Yunnan Province, is partly hosted in bodies of gabbroic diabase that either serve as hosts for ore or may have a genetic relation to Au and other metals (Chapter 3).

Sedimentary rock-hosted Au deposits in the Middle-Lower Yangtze River area (Chapter 5) are associated with 160– to 180–Ma diorite plutons in the Tonglushan (Daye) area, 140– to 150–Ma porphyry plutons in the Jilongshan-Fengshandong-Lijiawan area, and 80–Ma stocks at the Jinjinzui porphyry Au deposit in southeast Hubei Province. Many of these deposits have similarities to porphyry-related Au deposits as described by Sillitoe (1988). In Anhui Province, most stratabound ores, such as the Xinqiao and Mashan Au deposits, are thought to be associated with Cretaceous stocks. Mesozoic diorite dikes at the Carlin-type Zhanghai Au deposit in the Middle-Lower Yangtze River area fill structures, but do not appear to be associated with Au deposition (Li, Z.P. and Yang, W.S., 1989).

Structural controls

Four main host-structure types control Chinese sedimentary rock-hosted Au deposits: (1) short-axial anticlines (domes); (2) stratabound and crosscutting breccia bodies; (3) unconformity surfaces; and (4) joints associated with faults and anticlines (Li, Z.P. and Peters, 1998). Shear zones with ductile-brittle deformation textures of ore and host rocks also are observed in some deposits (Liu, D.S. and others, 1994; Wang, G. and others, 1994).

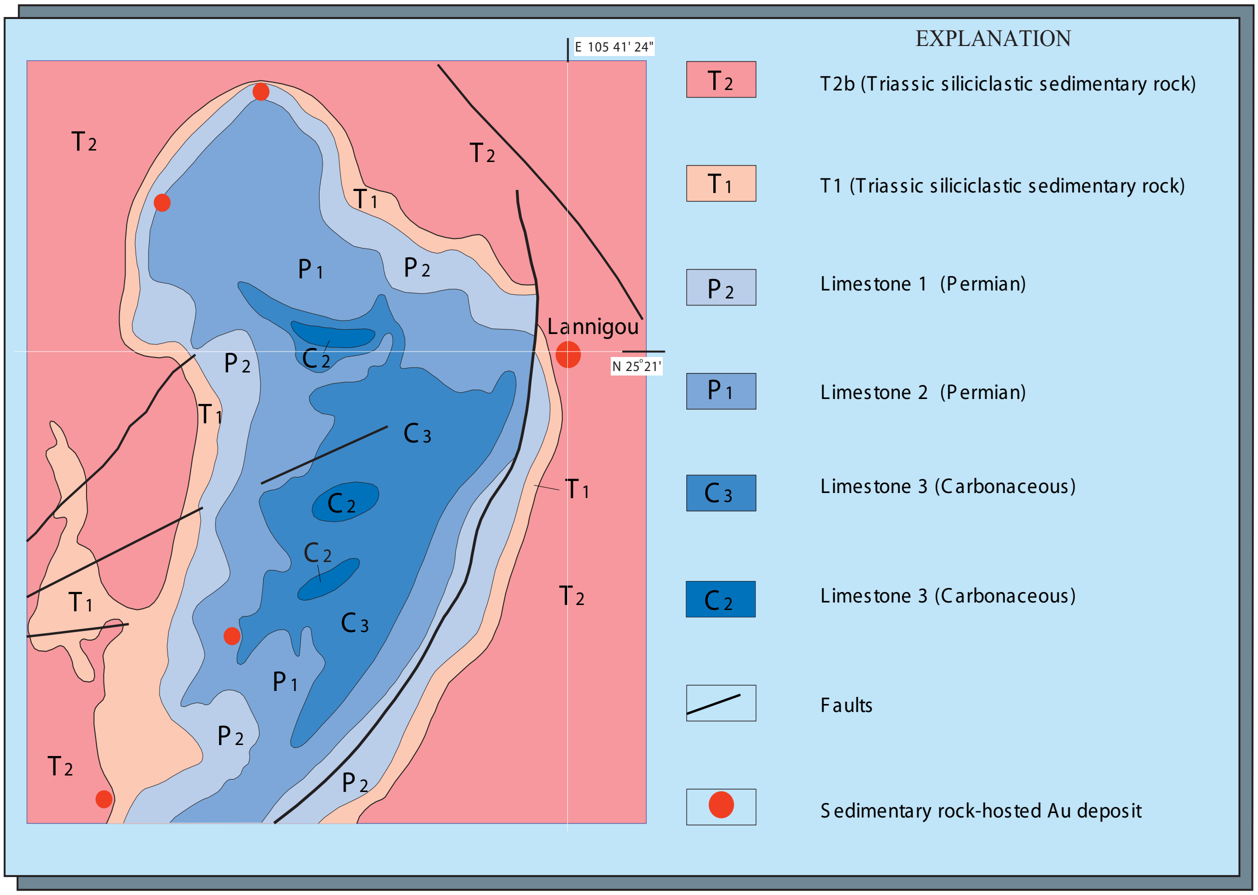


Figure 1-10. Laizishan short-axial anticline structure (dome) at the Lannigou Au deposit, Guizhou Province, Dian-Qian-Gui area.

Structural domes are common and important ore-controlling structures in the Dian-Qian-Gui area (fig. 1-10) and domal folds are associated with most sedimentary rock-hosted Au deposits there (Zheng, Q. and Zhang, M., 1989; Luo, X.H., 1994). Gold deposits in the Dian-Qian-Gui area typically cluster along shear or fault structures on the outermost parts of the domes near the contact between Paleozoic carbonate and Triassic siliciclastic rocks (Chapter 3). The Laizishan dome, associated with the large Lannigou Au deposit, is a well-documented, typical example in the Dian-Qian Gui area (fig. 1-10). Here, faults surrounding the Laizishan dome are well-developed, and are associated with Au, As, Hg, and Sb mineral occurrences. Elongate domes and folds also host ore in southwestern Hubei and in Anhui Provinces in the Middle-Lower Yangtze River area (Chapter 5). Complex folding also influences the location of some sedimentary rock-hosted Au deposit clusters in the Qinling fold belt area.

Stratabound and crosscutting breccia bodies also are ore-controlling structures that typically host many sedimentary rock-hosted Au deposits. Many breccia bodies are conformable with stratigraphic units in the host rock. A good example of breccia host bodies is in the Shuangwang Au deposit (Fan, S.C. and Jin, Q.H., 1994) (Chapter 3), which is a large Au deposit in the Qinling fold belt area, hosted in breccia that is both conformable or cross cuts bedding at low-angles. Crosscutting fault breccias are common hosts for ore along structures in the Zimudang Au deposit (Guo, Z.C, 1994) (Chapter 5), Lannigou (Luo, X.H., 1996), and Hengxian Au deposits in the Dian-Qian-Gui area (Chapter 3) and also are common in the Nevada Carlin-type deposits (see also, Peters and others, 1997).

Unconformity surfaces or bedding planes, and bedding plane faults often serve as ore-control structures in Dian-Qian-Gui area (Chapter 3). Karst caves and paleo-erosional surfaces are common near these unconformities, and some Au orebodies take the shape of karst pots. Sedimentary rock-hosted Au ore bodies with this style of mineralization are the Changkeng, Getang, Lubuge, Beyin, Maxiong, Kagou, Dachang, and Shaziling Au deposits (Appendix III) or prospects (Deng, X.N., 1993; Li, Z.P. and Peters, 1998). These features also are more easily subjected to weathering and laterite development and commonly are the sites of local oxidized (ìred earthî) orebodies in the Dian-Qian-Gui and Middle-Lower Yangtze River areas.

Joints associated with folds and faults are important local ore-control structures in the Chinese sedimentary rock-hosted Au deposits where folds usually control the overall distribution of the deposit and joints, local faults, and structural breccia zones control the local shape of the orebodies. The Zimudang and Yata Au deposits in the Dian-Qian-Gui area (Chapter 3) serve as typical examples, where joints associated with folds and faults exert a strong control on the breccia-hosted Au mineralization.

Metallogeny

Various deposit models for sedimentary rock-hosted Au deposits used in Nevada are applicable to those in P.R. China and call upon a number of mineralizing processes, various sources of metals, and hydrothermal fluids (fig. 1-11). The striking alignment of sedimentary rock-hosted Au deposits in Nevada along trends (fig. 1-12) suggests that these trends are deep-seated structures that served as traps or conduits for the Au fluids (see also, Arehart, 1996; Hofstra and Cline, 2000).

Deposit-scale geologic characteristics, such as host-structure, host-rock, hydrothermal alteration, and ore minerals are clues to the metallogeny of the sedimentary rock-hosted Au deposits in each region (Liu, D.S. and others, 1994; Wang, Y.G., 1994; Xie, Y.H. and others, 1996). Because most deposits are hosted in Paleozoic or Mesozoic sedimentary basins along the margins of Precambrian cratons, local distribution of the deposits is closely related to the local structural responses to tectonic events in these sedimentary basins. Several large tectonic structures and associated faults are spatially related to the Au deposits: the Baiyun-Lixian-Shanyang rift in the Qinling fold belt area (Chapter 3), the Youjiang deep-crustal fault zone in the Dian-Qian-Gui area (Chapter 4), and the Changjiang (Yangtze River) fold and fold depression zone in the Middle-Lower Yangtze River area (Chapter 5).

Regional structural and tectonic fabrics associated with sedimentary rock-hosted Au deposits contain ore-stage minerals, which are consistent with Au-bearing solutions that were transported along the regional-scale conduits—an idea supported by petrology of rocks in the ore deposits and their associated fluid conduits that are of regional extent (see also, Peters, 1997, 2000a,b). These regional-scale structures or lineaments serves both as conduits and host-structures for sedimentary rock-hosted Au deposits. In the northern Nevada, these structures are high-angle brittle-ductile faults, with folds, or tectonic windows that are oriented parallel or perpendicular to the main trends (Roberts, 1960, 1966; Shawe, 1991) (fig. 1-12). High-angle faults are considered to play a key role in ore-control in many sedimentary rock-hosted deposits in Nevada (Togashi, 1992).

Carlin-type Au and some distal-disseminated Ag–Au deposits, both in Nevada and in China, contain many conflicting characteristics and relations that contribute to controversies of

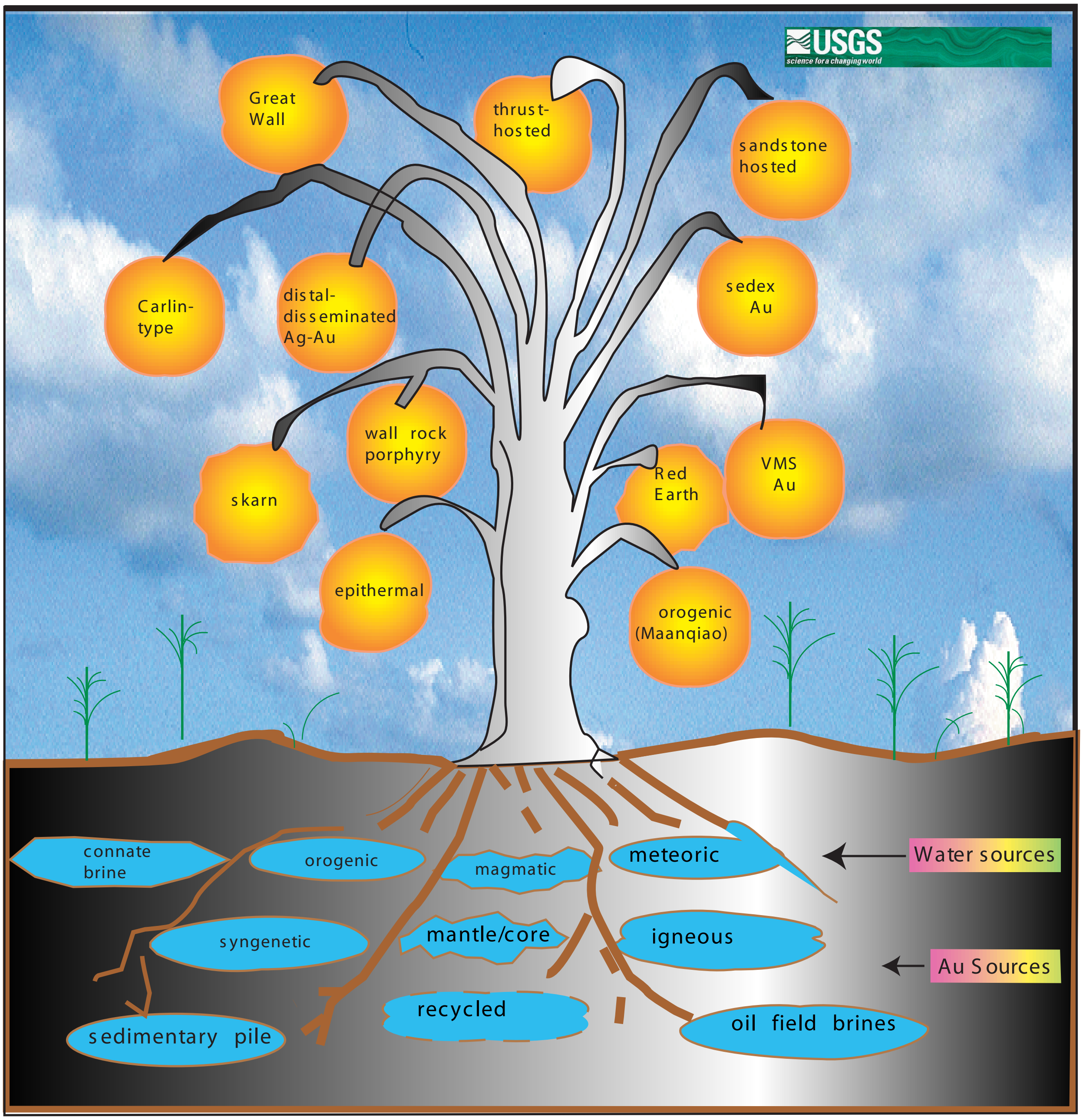


Figure 1-11. Diagram of family tree of different classes of sedimentary rock-hosted Au deposits. The main feature that these deposits have in common is sedimentary host rock; however, the deposits may have genetic water associated with plutonic or sedimentary rocks, or be related to diagenetic, hydrothermal, or orogenic processes. Similarly, Au may be derived from plutonic rocks, from deep-crustal or mantle sources, from the sedimentary pile, or from syngenetic and stratiform processes.

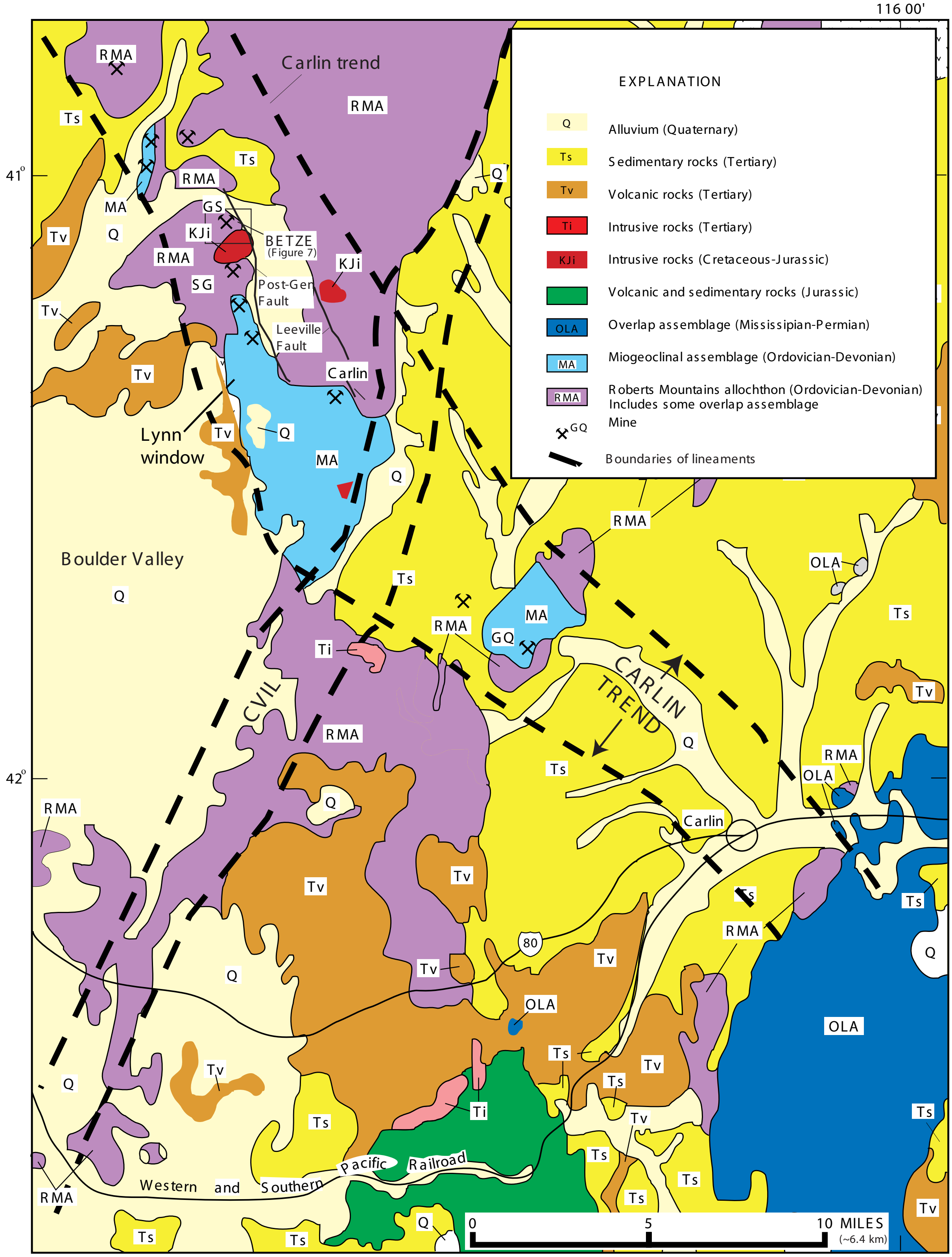


Figure 1-12. Gold deposits and schematic geologic map showing the distribution of allochthons and tectonic windows in northern Nevada. The Carlin trend lies along the Lynn-Carlin window where several Au deposits are exposed. Other windows through the Roberts Mountains allochthon also have exposed Au deposits. Trace of Roberts Mountain thrust (RMT) shown schematically. The Crescent-Valley-Independence lineament (CVIL) may have similarities to the Youjiang fault system in the Dian-Qian-Gui area, China, such that both fault zones may have served as regional-scale fluid conduits for the sedimentary rock-hosted Au deposits.

their genesis and age (Li, W.K. and others, 1989; Ji, H.B. and others, 1999). Stratigraphic chronology can only give a maximum age. The orebodies commonly are controlled by structures that cross cut a number of stratigraphic units and display geologic features, which may represent processes that span long periods of geological time. Radiometric dating methods require robust syn-ore alteration minerals, which usually are lacking. Illite and kaolinite are the most common alteration minerals, and these have not given wide-spread reproducible ages in individual deposits or in ore districts in Nevada (Arehart and others, 1993a; Folger and others, 1996; Groff, 1996; Phinisey and others, 1996; Fleet and Mumin, 1997; Parry and others, 1997; Henry and Ressel, 2000a,b; Hofstra and Cline, 2000).

Chinese Carlin-type Au deposits, with the same geologic characteristics as those in Nevada, exhibit a similar controversy regarding their age (see also, Kerrich and others, 2001). Chinese deposits are hosted in sedimentary formations ranging from Paleozoic to early Mesozoic in age (Li Z.P. and Peters, 1998), and are particularly abundant in rocks between Devonian and Lower Triassic age. Locally, however, early Paleozoic rocks also host similar deposits in the Qinling fold belt at Laerma Au deposit (Chapter 4). Early Paleozoic carbonaceous sedimentary rocks also host deposits in the Dian-Qian-Gui area, such as Sixianchang (Zhang, F., and Yang, K.Y., 1993, Chapter 4), and in the Middle-Lower Yangtze River area, at Zhanghai (Chapter 5). Some deposits, such as Yata, Sanchahe, Ceyang, and Banqi Au deposits, are present in or near high-angle reverse or normal brittle-ductile faults, which were formed in the Yanshanian (185 to 67 Ma) orogeny, suggesting that the age of Au mineralization may be less than 100 Ma (see also, Ashley and others, 1991), but radiometric dating of these deposits is not available. Ages of Au mineralized rock derived from radiometric isotope methods (K/Ar, $^{40}Ar/^{39}Ar$ and U-Th-Pb) give ages ranging from >300 Ma to <15 Ma (Li, Z.P. and Peters, 1978).

In general, interpretive ages of sedimentary rock-hosted Au deposits in P.R. China span an interval between the age of the host rocks and the age of the post mineralization cover. Many of the dates are compatible with known metallogenic events and coincide with tectonic or magmatic activity in the region. The spread of ages is due to the limits of the analytical methods and to unique features of the sedimentary rock-hosted Au deposits, which generally lack datable minerals. It is likely, using some of the minimum age dates from the Chinese Carlin-type deposits that some deposits may have formed as late as the Tertiary. As discussed below, possible evidence for syngenetic (Paleozoic and Early Mesozoic) formation of the Chinese deposits also is present.

CLASSIFICATION of SEDIMENTARY ROCK-HOSTED Au DEPOSITS

Classification of sedimentary rock-hosted Au deposits is important because large, rich, Au deposits along the Carlin trend, Nevada, a major elongate cluster of deposits, are a significant contributor to the United States' resource-based growth (fig. 1-12). Deposits of a similar type in other parts of the world may also have significant economic values. The discovery of very large, high-tenor, hypogene sedimentary rock-hosted Au deposits in Nevada (Teal and Jackson, 1997) have significantly changed the grade-tonnage curves of this deposit type from those originally reported in Cox and Singer (1986).

A grade-tonnage curve for a group of genetically similar deposits implies that additional deposits, formed by the same processes, would statistically be of a similar size and grade. Although origin of sedimentary rock-hosted Au deposits is incompletely understood, a number of features, including field relations at all scales, age relations, and geochemical and isotopic characteristics, bear on the origin of these deposits (see also, Chapter 2). Previous genetic models have been developed from mining the oxide or weathered parts of these systems in Nevada over the last two decades. Recent extensive exposures of unoxidized parts of the deposits provide new evidence that leads to consideration of additional hypotheses of their origin, particularly those that: (1) incorporate the role of nearby magmatic activity; (2) consider small- and large-scale deformation textures of ores and surrounding rocks; and (3) examine the high geochemical thresholds of ore-related elements in the host stratigraphic column.

Geologic characteristics of some deposits in P.R. China, not necessarily identified in Nevada, allow a refined classification of distinct deposit types. Characteristics of a deposit also suggest genetic processes that can be linked to local- and regional-scale geologic parameters. Sedimentary rock-hosted Au deposits have many styles; they may be stratabound, structurally-controlled, or complex—as noted along the Carlin trend in Nevada by Christensen (1993, 1996). Carlin-type deposits generally are characterized by relatively uniform, low Au grades that are exploited by surface, bulk mining methods (Bagby and Berger, 1985; Tooker, 1985; Berger and Bagby, 1991; Arehart, 1996), but some hypogene deposits contain high-grade oreshoots that are zoned complexly (Peters and others, 1998, 2000), and are mined by underground methods. In addition, a class of pluton-related, distal-disseminated Ag–Au and polymetallic replacement deposits are present in Nevada (Peters and others, 1996; Theodore, 2000) and have similarities to deposits in the Middle-Lower Yangtze River area (Chapter 5).

Hydrothermal minerals commonly characterize mineral deposit types and there are a number of common mineral species in most Chinese sedimentary rock-hosted Au deposits (Shao, J.L. and others, 1982; Xu, G.F. and others, 1982; Zhang, Z.G., 1984; Geng, W.H., 1985; Liu, D.S. and Geng, W.H., 1985; Shao, J.L., 1989; Wang, K.R. and Zhou, Y.Q., 1992; Wang, X.C., 1993; Wang, K.R. and others, 1994; Li Z.P. and Peters, 1998; Wang, K.R. and others, 2000; Mao, J.W. and others, 2001). Typical ore minerals in the Carlin-type Au deposits are pyrite, arsenopyrite, As-rich pyrite, and some base-metal sulfide minerals, such as chalcopyrite, sphalerite, and galena. Many deposits in the Dian-Qian-Gui and Qinling fold belt areas also contain stibnite, realgar, orpiment, and Hg and Ni sulfide minerals as well as PGE-bearing minerals. Gangue and alteration minerals of many sedimentary rock-hosted deposits typically are quartz, calcite, barite, fluorite, and sericite (illite)–clay. These mineral associations differ in subtypes of deposits.

Geologic investigations of sedimentary rock-hosted Au deposits in northern Nevada have been numerous (Teal and Jackson, 1997; Hofstra and Cline, 2000), but the origin of these deposits is still debated (see also, Hofstra and others, 1991a,b; Ilchik and Barton, 1997; Arehart, 1996; Henry and Boden, 1998; Tosdal, 1998; Ressel and others, 2000). Genetic hypotheses call for: (1) possible connections to igneous activity at depth, (2) complex evolution of tectono-thermal events, (3) inherent host rock permeabilities, and (4) evolved meteoric or metamorphic fluids, oil brines or orogenic fluids, as well as other factors (fig. 1-11). Different genetic hypotheses call for different sources of hydrothermal fluids and different sources of Au, S, and other metals. Different genetic hypotheses can account for the variation in types of sedimentary rock-hosted Au deposits, but they may be considered to form a common family due to their host rocks, although genesis of each deposit type may have been different (fig. 1-11).

The type of sedimentary rock-hosted Au deposit, such as pluton-related or classic Carlin-type Au deposit typeØthat is inferred to be present in a regionØis critical for metallogenic analysis, for exploration methodology, and for regional-scale mineral resource assessment. For instance, Carlin-type Au systems are either: (1) products of far-traveled fluids that ultimately owe their origins to magma (Sawkins, 1983; Sillitoe and Bonham, 1990), or (2) are products of orogenic or connate fluids derived from devolatilization reactions at deep crustal levels driven by heat supplied by magma (Ilchick and Barton, 1997), or (3) are products of convecting meteoric waters also driven by magmatism (see also, Hofstra and others, 1997, Chapter 2). If classic Carlin-type Au deposits were products of plutons, then they would most likely be present ìoutboardî of distal-disseminated Ag–Au deposits. The complex geologic setting of most sedimentary rock-hosted Au districts does not provide this definitive spatial link between plutons and the deposits.

The following sections of this chapter address six main types of sedimentary rock hosted Au deposits in China: (1) Carlin-type, epigenetic, or sediment-hosted Au–Ag deposits; (2) distal-disseminated Ag–Au and polymetallic replacement, or pluton-related deposits; (3) stratiform, syngenetic sedimentary rock-hosted Au deposits; (4) unconformity-hosted deposits; (5) syndeformational sedimentary rock-hosted Au deposits; and (6) red earth or laterite-hosted Au deposits. These deposit types are part of the family of sedimentary rock-hosted Au deposits (fig. 1-11), but may owe their origin to different processes. Deposit type designations have been made on the basis of mineralogy, geochemistry, host rock type, and other geologic characteristics of individual deposits. Although classification is not perfect, these classifications were designed for metallogenic analysis and to compliment description of deposit characteristics in later chapters dealing with the Dian-Qian-Gui, Qinling fold belt, and Middle-Lower Yangtze River areas.

Carlin-type Au deposits

Carlin-type Au deposits are described as ‘carbonate-hosted Au–Ag deposits’ in USGS model 26a of Berger (1986) and Cox and Singer (1986) on the basis of descriptions of these deposits along the Carlin trend (fig. 1-12) and other areas in Nevada. Characteristics of Carlin-type Au deposits are those indicated by Percival and others (1988), Peters and others (1996), Arehart (1996), and Hofstra and Cline (2000). These characteristics are: (1) presence of submicron-sized Au, commonly in the crystal structure of disseminated arsenical pyrite (Hausen and Kerr, 1968; Liu, D.S., and Geng, W.H., 1985; Bakken and others, 1989; Mao, S.H., 1991; Arehart and others, 1993b; Hu, R.Z. and others, 2001) (fig. 1-13); and (2) variably silicified, decalcified, and argillized host rocks that include calcareous or siliceous sedimentary rocks, as well as skarn, mafic metavolcanic, and felsic intrusive rock. The most abundant host rocks are thin-bedded, flaggy, mixed carbonate-siliciclastic rocks. Deposition of ore minerals was most likely at moderate depths of approximately 1 to 3 km (Rytuba, 1985; Kuehn and Rose, 1985; Kuehn, 1989; Lamb and Cline, 1997), in contrast to shallow paleodepths of epithermal deposits (see also, Peters, 2001). Alteration types associated with Au-mineralized rocks in sedimentary rock-hosted Au (Carlin-type) in Chinese deposits are decalcification (decarbonatization), argillization (illite–clay), and silicification and jasperoid development, similar to alteration types described in Nevada Au deposits by Radtke (1985); Bakken and Einaudi (1986); Bakken, 1990; Kuehn and Rose (1992, 1995), Ferdock and others (1996); Arehart (1996); and Li, Z.P. and Peters (1998). Pre-Au alteration assemblages include syngenetic or diagenetic minerals in Paleozoic sedimentary rocks, as well as contact metamorphic and metasomatic mineral assemblages spatially associated with local thermal aureoles of stocks. Post-Au alteration effects are related to supergene processes and locally to young epithermal or hot-spring related events associated with extension. Silicification, decalcification, and carbonization in Chinese Carlin-type Au deposits are described by Lin, B.Z. and others (1994), and Hu, J.M. and Zhang, H.S. (1994) as three main Au-associated alteration stages of Au ore formation. Decalcification (decarbonatization) and the addition of sericite, barite, and carbon are common. Carbonation as pre-Au carbon is commonly present in large masses of black, sooty sedimentary rocks that surround and lie in the orebodies, and is common in Carlin-type Au deposits

Most Carlin-type Au deposits are related to silicification and to quartz veining and silicification has been reported in most sedimentary rock-hosted Au deposits in P.R. China (Liu, D.S. and others, 1994). Multiple episodes of silicification often are observed. Two to five episodes of silicification are described in the Pingding Au deposit (Lin, B.Z. and others, 1994); three episodes of silicification are known at Lannigou (Luo, X.H., 1994) (Chapter 3) and Jilongshan Au deposits (Hu, J.M. and Zhang, H.S., 1994) (Chapter 4). Li Z.P. and Peters (1998) discuss three types or stages of silicification in the Chinese Carlin-type deposits: (1) cryptocrystalline silica and jasperoid, such as in the Gaolong Au deposit: (2) stockwork veining; and (3) late-stage silicification with quartz-calcite-(stibnite-barite) (see also, Peters and others, 1998, 2000, and Chapter 4). This three-stage silicification pattern is similar to multiple silicification stages in the Betze Au deposit in the Carlin trend, Nevada (Leonardson and Rahn, 1996).

Decarbonatization is common in the Pingding, Jilongshan, and Gaolong Au deposits (Appendix III) where it has a direct spatial relation to Au mineralization. In the Changkeng Au deposit, only 20.80 to 22.47 wt. percent CaO remains in the siliceous carbonate ore, which means that more than half of the carbonate in the limestone has been leached (Du, J.E. and Ma, C.H., 1994). Carbonate rocks in the Pingding and Gaolong Au deposits are decalcified and altered to jasperoid that is composed of fine-grained, gray quartz (or chalcedony), and which may contain Au. Decarbonatization leads to significant volume loss in some deposits and this change in rock shape may be accompanied by tectonic strain.

Carbonization increases host rock carbon content and is widespread in most Carlin-type Au deposits (Ballantyne, 1988; Berger and Bagby, 1991; Lu, G.Q. and others, 1992; Huang, Y., 1993; Arehart, 1996; Zeng, Y.F. and Yin, H.S., 1994). A metallogenic process may have transported organic materials and Au together and re-precipitated them in the hydrothermal, ore-forming systems. Graphite and pitchblende are common products of carbonization in some Chinese deposits (Peng, D.Q., 1992). Carbonization has been reported in the Dongbeizhai, Laerma, and Jinya Au deposits (Liu, D.S. and others, 1994) (Chapters 3 and 4). Carbonization increases the carbon content of source beds, and promotes leaching of Au that may have been associated with the carbon and is therefore considered favorable for Au mineralization, according to Wang, J. and Du, L.T. (1993). Carbon commonly is mobilized in Carlin-type Au systems and is moved by hydrothermal fluids, or in the case of the Betze Au deposit, Nevada, by contact metamorphism (Leonardson and Rahn, 1996; Ferdock and others, 1997). Rock masses with high carbon contents have lower tensile strengths than the surrounding rocks and commonly are areas of intense tectonism.

Total sulfide mineral content in Carlin-type Au deposits usually is <4 volume percent, but local massive accumulations of pyrite are not uncharacteristic (Bagby and Berger, 1985; Percival and others, 1988; Berger and Bagby, 1991). Carlin-type ores are characterized by low-sulfide mineral content, for instance, about 4 vol. percent of ore minerals are contained in ores of the

Banqi Au deposit, and 4.8 volume percent are present in the Yata Au deposit (Tao, C.G., 1990). Minerals in the ore zones include Au-bearing arsenian pyrite, marcasite, stibnite, realgar, orpiment, cinnabar, Tl–sulfide minerals, rare Ag–Sb and Pb–Sb sulfosalt minerals, Hg-bearing minerals, sphalerite, and Ni sulfide minerals (fig. 1-13).

Stibnite is reported as a host mineral for Au in some Chinese Carlin-type Au deposits (Zhang, Z.A., 1993; Liu D.S. and Geng, W.H., 1987). The highest Au content of stibnite reported in the Laerma Au–U deposit is 233.40 ppm Au, and this stibnite also contains 135 ppm Hg. Lower Au values also are found in stibnite of the Miaolong deposit 2.87 ppm, and in the Banqi Au deposit where stibnite contains up to 10 ppm Au. Stibnite also is abundant in the Hengxian Au deposit (Li, Z.P. and Peters, 1998) (Chapter 3). Sedimentary rock-hosted Au deposits, in which stibnite is present as the main Au host mineral, are present in Hubei Province, P.R. China (Liu, D.S. and Geng, W.H., 1987). Antimony deposits also are common in the Ding-Ma Au belt in East Qinling fold belt area (Chapter 4), described by Zhang, F.X. (1997a,b).

Clay minerals also host Au in the Banqi, Yata, Getang, Shixia, and Changkeng Au deposits. X-ray diffraction analysis indicates that clay minerals contain very fine-grained pyrite and arsenopyrite, which may contain micron-sized Au particles. A dissolution experiment (Geological Institute, Chinese Academy of Science, 1992) showed that 90 weight percent of Au in clay minerals is enclosed in this fine-grained pyrite (arsenopyrite), whereas, only 5 to 10 weight percent of the Au is contained on the surface of clay minerals (Liu, D.S. and others, 1994).

Chinese Carlin-type Au deposits contain some minerals not commonly found in the Nevada deposits (Liu, D.S. and others, 1994; Li, Z.P. and Peters, 1998); for example, pyrrhotite is present in the Baguamiao and Maanqiao Au deposits as one of the main Au host minerals. Albite is present in the Shuangwang and Ertaizi Au deposits and is spatially associated with Au mineralization, although it may be paragenetically earlier. Carbon and U-bearing minerals, including pitchblende and graphite, are more common in some Chinese sedimentary rock-hosted Au deposits such as the Laerma, Banqi, Yata, Jinya and Dongbeizhai deposits. In addition, several native elements are present in Chinese sedimentary rock-hosted Au deposits, such as native S (Qinlong Au deposit), native Cu, Zn, Fe, Al (Getang Au deposit), and As (Yata and Jinya Au deposits). Tungstite also is present in some deposits in the Qinling fold belt area (i.e. Manaoke, Chapter 4) and is present in the Betze Au Deposit in Nevada (Peters and others, 1998, 2000).

Christensen (1993, 1996) placed orebody styles of Carlin-type Au deposits into three structural types, which form a spectrum between undeformed stratabound replacement bodies, more structurally controlled, orebodies with high-grade vein-like ores, and massive breccia- or stockwork-types.

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

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

Studies of Carlin-type deposits in Nevada suggest that many deposit subtypes identified in China may be parts of larger systems. Geochemical modeling of ores in the Betze Au deposit by Woitsekeskaya and Peters (1998) suggest that the paragenetic sequence pyrite–(Au)–realgar–stibnite is the result of a single fluid that traveled through and titrated with the wall rock (fig. 1-14). This paragenetic sequence is documented in the Betze Au deposit in Nevada by the presence of discrete oreshoots that reflect quartz-clay-pyrite-Au, to realgar-orpiment-calcite, to

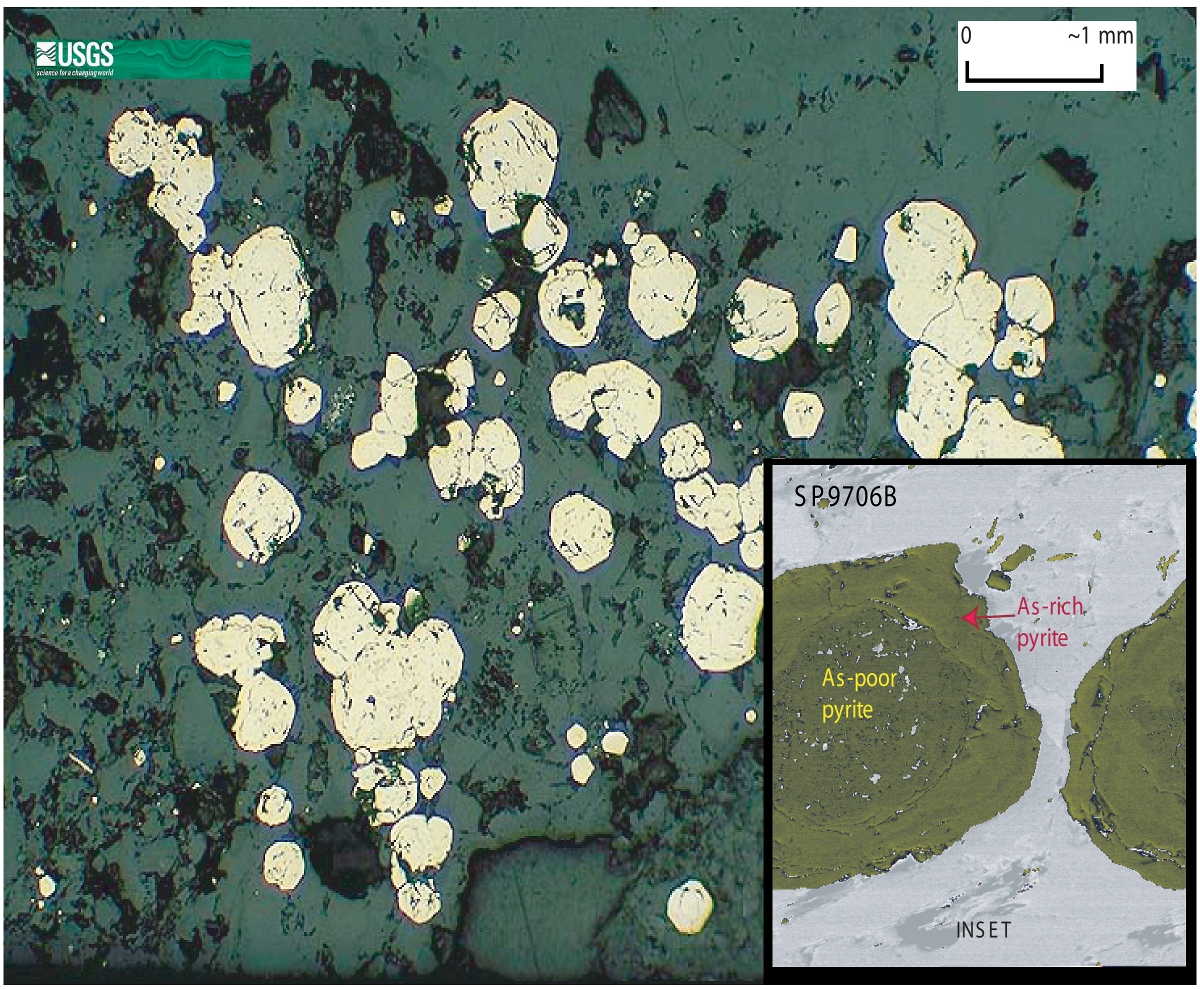
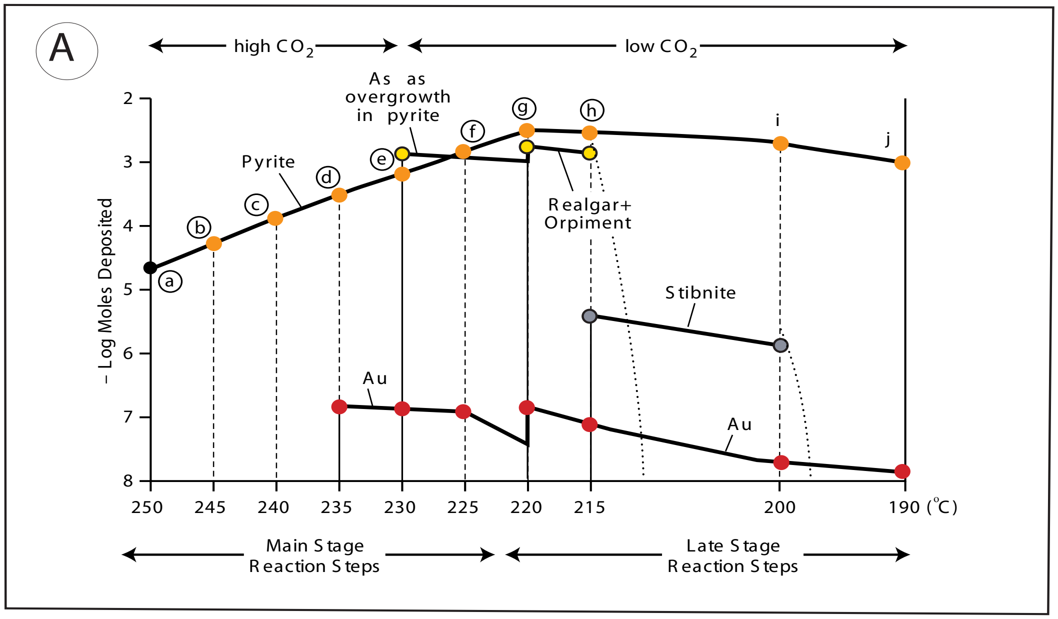


Figure 1-13. Examples of arsenically-zoned pyrite, typical in many Carlin-type deposits in the Dian-Qian-Gui and Qinling fold belt areas. These images show examples from the largest deposit, the Lannigou deposit in Guizhou Province. The larger photograph is a polished section of bright pyrites, which show round rimming. The inset shows a SEM back scatter image of these pyrites and a As-poor, old core and a younger As-rich rim, which most likely carried micron-sized Au. Field of view of inset is approximately 100 microns.

stibnite-quartz, to polymetallic, high sulfide-bearing ores rich in Hg and base-metals (Peters and others, 1998, 2000) (fig. 1-15). These paragenetic mineral assemblages in a single deposit are similar to subtypes of Au ores described and classified in the Dian-Qian-Gui and Qinling fold belt areas and this suggests that the high As, Sb, or Hg ores in these areas may all be part of a single, regional-scale, metallogenic process.



B

Field Mapped Zones	Modeled Mineral Zones	pH	°T C
illite+pyrite+quartz+ graphite+Au	illite+pyrite+quartz+ graphite+Au	6.75	250
illite+pyrite+calcite+ quartz+realgar+Au	illite+pyrite+calcite+ quartz+realgar+Au	6.68	225
kaolinite+quartz+ pyrite+stibnite	illite+pyrite+ quartz+realgar	6.49	200
	illite+pyrite+ quartz+stibnite	6.31	175
	kaolinite+quartz+ pyrite+stibnite	6.25	150

Figure 1-14. Geochemical modeling of fluids in Carlin-type deposits showing one fluid is capable of producing ores rich in Au, As, and Sb. (A) Quantitative depositional curves for sulfide minerals and Au; quantity of minerals is shown in log moles/kg fluid for each temperature and pressure increment. Letter annotations refer to sequential events of reaction progress steps. (B) Table of alteration and mineral assemblages calculated in a cooling hydrothermal event for a Carlin-type deposit. From Woitsekhowskya and Peters (1998). These diagrams demonstrate that As and Sb ores are part of the Au stage and not a separate ore type or metallogenic stage.

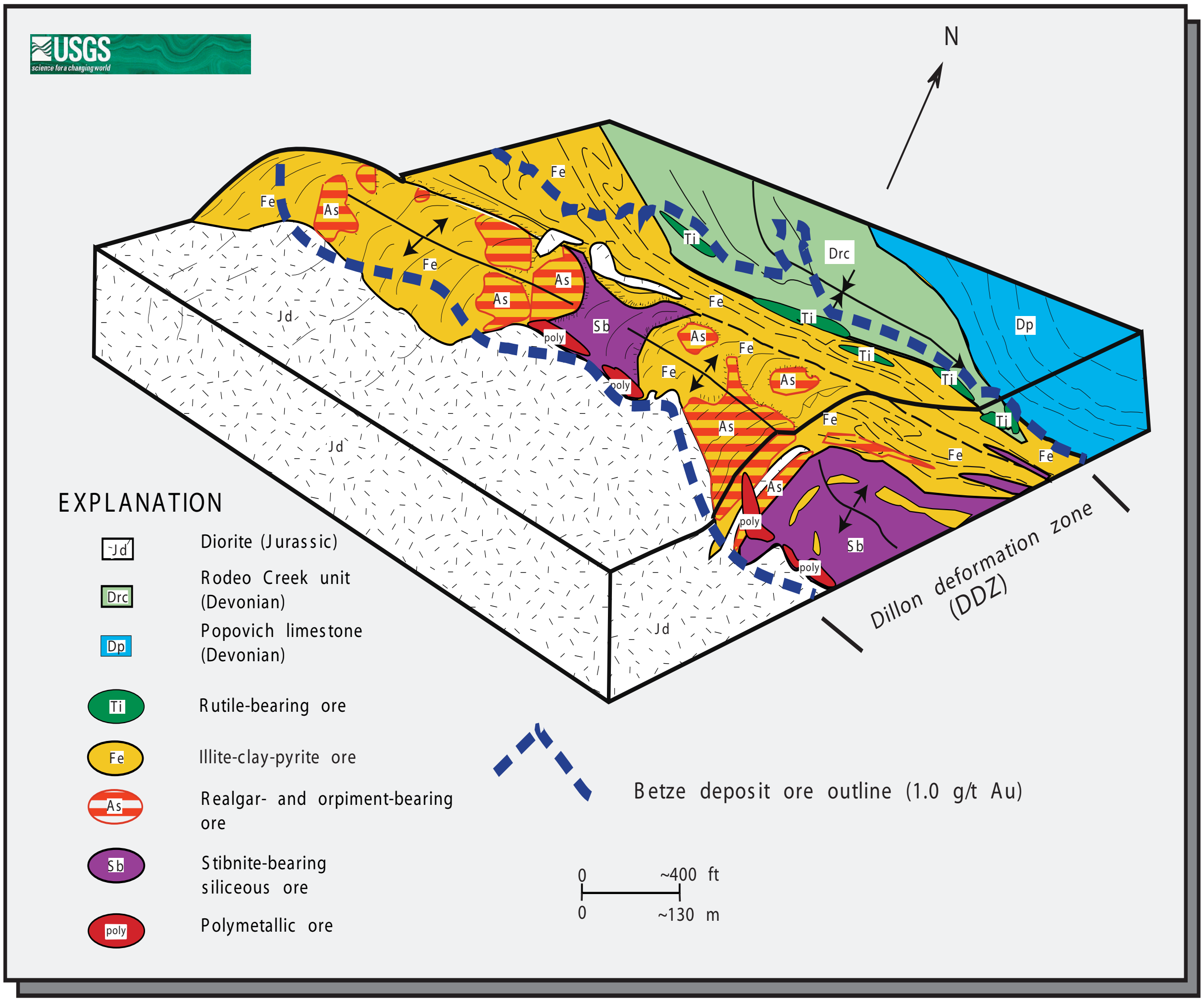


Figure 1-15. Block diagram of the Betze Au orebody, Goldstrike Mine, Carlin trend area Nevada at about 4,600 to 5,000 ft elevation. Shows the spatial distribution and zoning of types of ore and their relation to structures and local geology. The As and Sb ores, as well as the Hg-rich polymetallic and rutile-bearing ores are all part of a single system. Adapted from Peters and others (1998, 2000).

Pluton-related Au deposits

Pluton- or porphyry-related sedimentary rock-hosted Au deposits applicable to are described in the distal-disseminated Ag–Au deposit model 19c of Cox and Singer (1992) and Cox (1992) and the polymetallic replacement model 19c of Morris (1986) and Mosier and others (1986). These deposits differ from the Carlin-type Au deposits, but are part of the sedimentary rock-hosted Au deposit family (fig. 1-11). They contain Ag and Au in disseminations, replacements, and stockworks of narrow quartz-sulfide veinlets and (or) Fe oxide-stained fractures in sedimentary rock, and they contain some diagnostic trace elements—specifically Zn, Mn, Cu, and Bi—which are consistent with many pluton-related deposits (Cox and Singer, 1992). Ores in the Middle-Lower Yangtze River area contain these minerals and elements and locally also contain celestite, fluorite, pyrrhotite, and arsenopyrite. Fluids involved in the generation of these deposits include a significant magmatic component (Li, Z.P. and Yang, W.S., 1989) (fig. 1-16). The Middle-Lower Yangtze River area Au deposits have strong characteristics typical of polymetallic replacement or manto deposits, which are massive lenses of dense sulfide minerals in limestone, dolomite, or other soluble rocks near igneous intrusions (see also, Morris, 1986; Mosier and others, 1986).

Although many distal-disseminated Ag–Au and polymetallic replacement deposits are hosted by sedimentary rocks, they contain distinct features that differentiate them from Carlin-type Au deposits. For instance, pluton-related deposits show significant potassium metasomatism, which is comparatively rare in Carlin-type Au deposits. In addition, many distal-disseminated Ag–Au deposits contain more Ag and base-metals than most Carlin-type Au deposits (Peters and others, 1996).

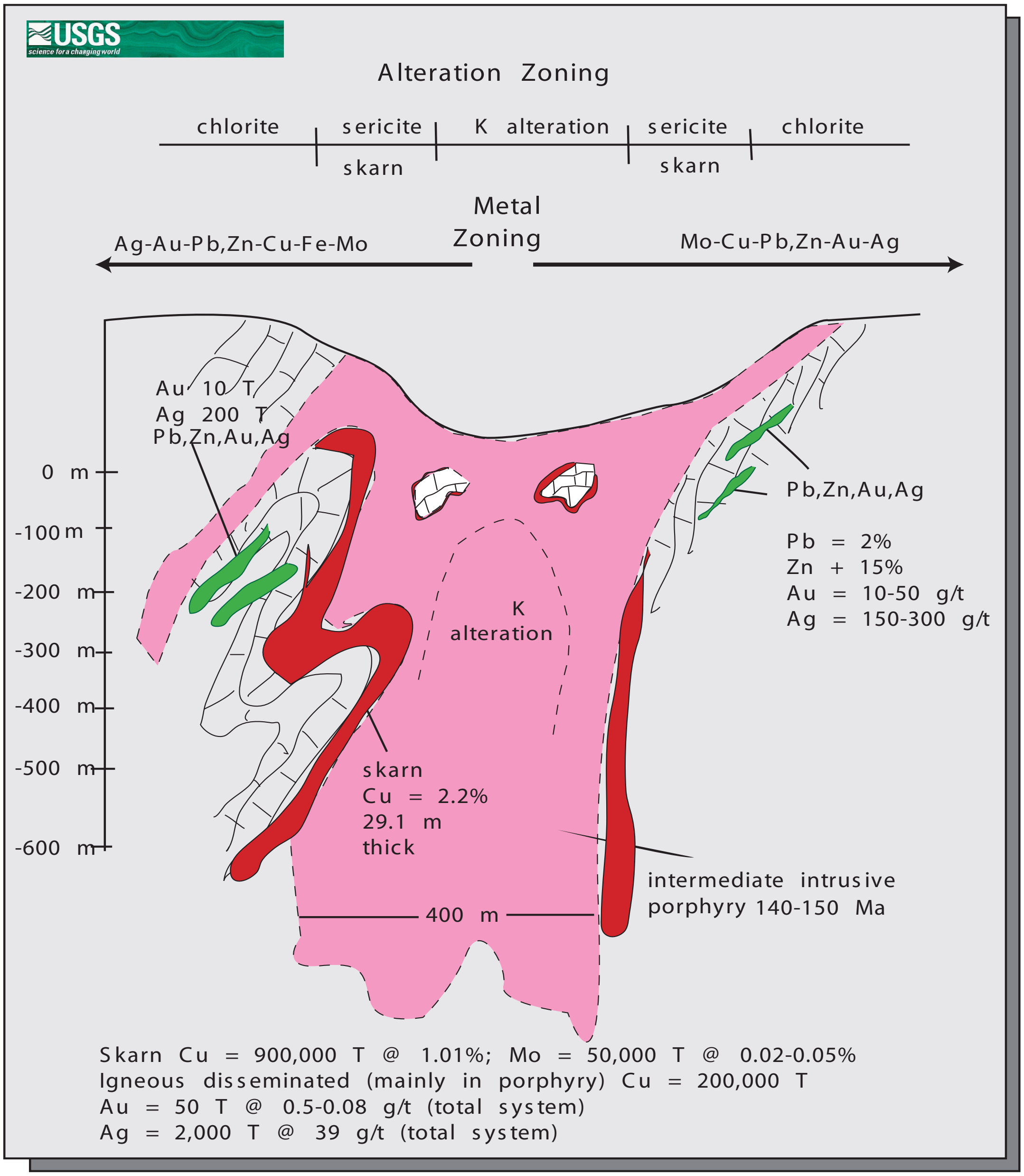


Figure 1-16. Diagrammatic cross section and model of the Fengshandong skarn-porphyry deposit, Hubei Province, Middle-Lower Yangtze River area. The model also is similar to the Jilongshan and Lijiawan deposits. Deposits on the outside of the intrusive are sedimentary rock-hosted Au deposits of the distal-disseminated Ag-Au type, and near the intrusive are skarn and polymetallic replacement deposits.

Some sedimentary rock-hosted Au deposits are not known to be genetically or spatially associated with intrusive rocks, but truly are distal in nature and are located over 1 km from the causative intrusives. Due to complex tectonism and extension after mineral precipitation, the deposits contain different geometric relations to the intrusive centers and also are hosted in different parts of the stratigraphic succession. The distal-disseminated Ag–Au and polymetallic replacement deposit models belong to the porphyry Cu or pluton-related mineralizing environment (fig. 1-16), which has a strong affiliation with upper crustal magmatism. The Carlin-type Au deposits, by comparison, cannot be definitively tied to magmatism. An underestimation of base-metal contents of mineralized systems, particularly from oxide ores, also has contributed to problematic classification between Carlin-type and pluton-related Au systems (Hitchborn and others, 1996; Theodore, 2000).

Porphyry systems consist generally of large volumes of rock that are characterized by disseminated concentrations of pyrite, chalcopyrite, bornite, molybdenite, or Au and a number of other prograde and secondary sulfide minerals. These minerals form in intensely fractured rocks that are filled by stockwork veins or disseminated grains in hydrothermally altered porphyritic intrusions and (or) in their hydrothermally altered adjacent wall rock (Peters and others, 1996; Theodore, 2000). The deposits may be directly related to porphyry Cu systems that contain relatively high concentrations of Au compared to porphyry Cu systems that are deficient in Au. Much mineralized rock in these systems owes its origin to fluids that were expelled during the process of crystallization of genetically associated magma. Some intrusive centers are composites of a number of closely associated igneous phases and associated ore-types, such as Au skarns and polymetallic veins (Doebrich and Theodore, 1996; Margolis, 1997; Theodore, 2000).

Alunite and albite are specific and common alteration minerals diagnostic of some Chinese sedimentary rock-hosted Au deposits near plutons (Wang, J. and Du, L.T., 1993; Fan, S.C. and Jin, Q.H., 1994; Liu, D.S. and others, 1994). Sericitization is closely associated with Au mineralization in the pluton-related Liba Au deposit (Chapter 4), where the alteration pattern is observed as zones grading from pyrite-sericitization, sericitization, to chloritization (from inner to the outer zones of ore-bodies). Orebodies are present in the sericitization zone, and the grade and thickness of orebodies directly correlate with the intensity of sericitization (Liu, M., 1994). Albitization has been observed in the Shuangwang, Ertaizi, Baguamiao, and other sedimentary rock-hosted Au deposits in the Qinling fold belt area (Chapter 4), but is not common in Dian-Qian-Gui area and in the Nevada deposits (Li, Z.P. and Peters, 1998).

The link between Carlin-type Au deposits, such those in the Dian-Qian-Gui and Qinling fold belt areas and plutonic rocks is not demonstratable, but a direct relation of the deposits to igneous rocks is present in the Middle-Lower Yangtze River area. In Nevada, igneous activity followed and accompanied tectonic events in the Mesozoic and Tertiary and produced plutons and Tertiary volcanic rocks around many of the known areas of sedimentary rock-hosted Au deposits. Early Tertiary igneous activity in Nevada may have had a direct role in the genesis of some sedimentary rock-hosted Au deposits there (Henry and Ressel, 2000a,b). Sedimentary rock-hosted Au deposits along the Carlin trend and in most of north-central Nevada are interpreted to be either Late Cretaceous or Early Tertiary, (Arehart and others, 1993a; Teal and Jackson, 1997; Henry and Boden, 1997; Tretlear and others, 2000; Ressel and others, 2000a,b), indicating that Au deposition was synchronous with or post dated magmatic activity and heat flow during the Sevier-Laramide tectonic event. This implies that there could be a link between distal-disseminated Ag–Au deposits and Carlin-type Au deposits.

Stratiform, Syngenetic Au deposits

Many sedimentary rock-hosted (Carlin-type) Au deposits in the Dian-Qian-Gui (Chapter 3) and the Qinling fold belt (Chapter 4) areas are stratabound, and this has led several workers to suggest that specific sedimentary or volcanic horizons be considered as source-beds for the Au in the deposits, even suggesting that the Au deposits could be syngenetic (Tan, Y.J., 1994; Huang, Y., 1993). The deposits also have been theorized to be directly related to carbonaceous material in the sedimentary pile (Lu, C.Q. and others, 1992; Huang, C.S and Du, Y.Y, 1993; and Zheng, Y.F and Yin, H.S., 1994). Similar theories have been proposed for organic-rich Au deposits in the Qinling fold belt (Li, Y.D. and Li Y.T., 1994; Mao, Y.N. and Li, X.Z., 1994; Zheng, Y.F. and Yin, H.S., 1994; Zhang, X.F., 1997a,b; see also, Giordono and others, 2000) and for carbonate-hosted deposits in Nevada along the Carlin trend (Emsbo and others, 1997).

Three kinds of sedimentary formations in the Dian-Qian-Gui area serve as good source bed examples; they were formed in different geologic environments and are related to different types of Au deposits according to Tan, Y.J. (1994):

(1) Terrigenous clastic or volcanic-terrigenous siliceous clastic rocks formed in a littoral environment, including the lower Devonian Pojiao (Yujiang) units and the Longtan unit (including the upper Permian Dachang Group). The lower Devonian Yujiang Assemblage, consists of greenish gray to dark gray, silty argillite, and interbedded siltstone, and has an average Au content of 4.6 ppb. The upper Permian Longtan Assemblage consists of argillite (1.92 ppb Au, locally averaging 8 ppb Au, with some horizons up to 19 ppb Au), siltstone (2.67 ppb Au), coal layers (1.63 ppb Au), basalt (44.7 ppb Au), and pyroclastic rock (54.33 ppb Au). These rocks host Au–Sb–pyrite occurrences (Tan, Y.J., 1994) in the northwest part of the Dian-Qian-Gui area that include the Gedang, Maxiong, Getang, and Dachang Au deposits (Appendix III and Chapter 3).

(2) Carbonate-bearing, fine-grained clastic rocks deposited in a platform shallow sea environment, including the upper Permian Changxing unit and lower Triassic Yielang Assemblages. The upper Permian Changxing unit and lower Triassic Yielang Assemblages, consist of argillite, siltstone, and impure limestone averaging 8 ppb Au. Of these, silty argillite contains Au values up to 15 ppb. These rocks host Au–Hg–Tl mineralized occurrences in the northwest Dian-Qian-Gui area, including the Zimudang Au deposit (Chapter 3) (Tan, Y.J., 1994).

(3) Turbidites deposited at the continental slope and in a deep-sea environment, including the Late Triassic Xinyuan Formation (local name: Xuman, Baifeng and Banna Groups). The middle Triassic Xinyuan Formation rocks, including 70 volume percent siltstone and argillite, 10 volume percent greywacke, and 20 volume percent carbonate (micritic limestone, bioclastic limestone). Their Au content ranges from 2 to 12 ppb, averaging 6.73 ppb Au. These rocks contain Bouma sequences consisting of rhythmic-bedded calcareous, fine-grained sandstone, siltstone, and calcareous argillite. There also are inter-beds and lenses of argillaceous limestone and limestone. Gold–As–(Sb)-mineralized occurrences are typically related to these turbidite-hosted Au deposits in the southeast part of the Dian-Qian-Gui area (Tan, Y.J., 1994).

The Au occurrences in the Lannigou Au district are hosted in lower Permian to middle Triassic sedimentary rocks deposited on a continental slope at continental platform and deep-sea basin margin. These rocks formed in a transition environment between a margin slope and chasm-basin during lower to middle Triassic (especially, the middle Triassic) and may have source bed Au-bearing potential, according to Zheng M.H. (1989) who documented that the siltstones in the strata have an average of 20.37 ppb Au, and 17.40 ppb Au in the argillite. These geochemical concentrations are much higher than those concentrations in adjacent or similar rocks and indicate that the possible ore-forming materials most likely existed in this area prior to structural disruption and hydrothermal alteration.

Stratabound Au ores also are present in the Jinlongshan (Zhenan) Au deposits in the Qinlong fold belt and have locally been remobilized during tectonism (Peters, 2001) (Chapter 4). In the East Qinling fold belt, the Ding-Ma Au belt is hosted in an early Devonian to late Permian sedimentary sequence that is characterized by a basin with 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 for the 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: (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).

The West Qinling fold belt contains many sedimentary rock-hosted Au deposits with high organic carbon content. The Laerma, Songpangou, Qiaoqiaoshang, Dongbeizhai, Pingding, Jiuyuan, and Heidousi Au deposits (Chapter 4 and Appendix III) all are hosted by fine-grained, black clastic rocks. These rocks contain high Au contents that are 10 to 15 times higher than the regional background Au content (Zeng, Y.F. and Yin, H.S., 1994; Li, Y.D. and Li., Y.T., 1994; Mao, Y.N. and Li, X.Z., 1994). Some geologists consider that these carbonaceous rocks are the source-beds for both petroleum and Au deposits (Zeng, Y.F. and Yin, H.S., 1994) and they also suggest that organic carbon was involved in the Au mineralization process. These theories are compatible with those of Parnell and McCready (2000), Simoneit (2000), and Taylor (2000), who discuss the migration of organic matter in hydrothermal systems and the association of Au- and hydrocarbon-bearing fluids on regional and ore deposit scales.

Unconformity-hosted Au deposits

Sedimentary rock-hosted Au deposits are formed in some locations along unconformity surfaces, usually in carbonate rocks. These surfaces have served to localize fluid flow and tectonism and commonly contain dissolution, paleo karst, and deformation fabrics. Examples are the Changkeng, Getang, and Gedang Au deposits (Chapter 3) (Appendix III).

Orebodies of the Changkeng Au deposit in Gaoming County in Guangdong Province are controlled by an unconformity surface between late Triassic rocks and early Carboniferous rocks where karst caves are present in the bioclastic limestone at the footwall of the orebodies (fig. 1-17) (Du, J.E and Ma, C.H., 1994). Siliceous carbonate ore in the Changkeng Au deposit contains between 20.80 and 22.47 weight percent CaO, and more than half of the carbonate minerals in the altered limestone have been leached out during decalcification. Two Au orebodies and three Ag orebodies are present along the same brecciated, northeast-trending fault zone. In vertical section, the Au orebodies are located at the top and the Ag orebodies are present at the bottom of a fault zone. The Au orebodies in the Changkeng Au deposit contain high As, Sb, Bi, Hg, Ba, and S contents; in particular, the values of As, Bi, and Hg are one to two times higher than in those in the Ag orebodies. The Ag orebodies contain one to two times more Zn, Pb, and Cu than the Au orebodies. The Au/Ag. ratio is 1/0.8 in Au orebodies, and 1/644 in Ag orebodies.

In the Getang Mining District sedimentary Permian and Triassic rocks are siliceous, brecciated argillite, and siliceous limestone breccia. Breccia bodies containing Au are present along the unconformity surface between the Upper Permian Longtan and Maokou Formations (Chapter 3) (Tao, C.G., 1990; Cheng, J.H., 1994). Anastamosing, northeast-striking, several km-long faults intersect the unconformity surface that contains tensional and sheared zones in mineralized paleo-karst, and Au-bearing breccia. The ores mainly are present in breccia, veins, and disseminations. Ore minerals include native Au, native Cu, native Zn, pyrite, pyrrhotite, chalcopyrite, arsenopyrite, stibnite, realgar, orpiment, cinnabar, galena, sphalerite, molybdenite, and magnetite. Gangue minerals are quartz, calcite, kaolinite, hydromica, muscovite, biotite, epidote, hornblende, garnet, barite, apatite, zircon and rutile. Oxide ores are fine-grained and have pseudomorphic and colloform textures and carry significant goethite, limonite, and jarosite. Alteration at the Getang Au deposit mainly is silicification with introduced stibnite, kaolin, dickite, and fluorite, as well as minor chlorite, calcite, and gypsum. The Getang Au deposit in Guizhou Province has many similarities to the Gedang Au deposit in Yunnan Province, such as control by an unconformity or paleo-erosional surface that has been over printed-by faulting and shearing (Chapter 3).

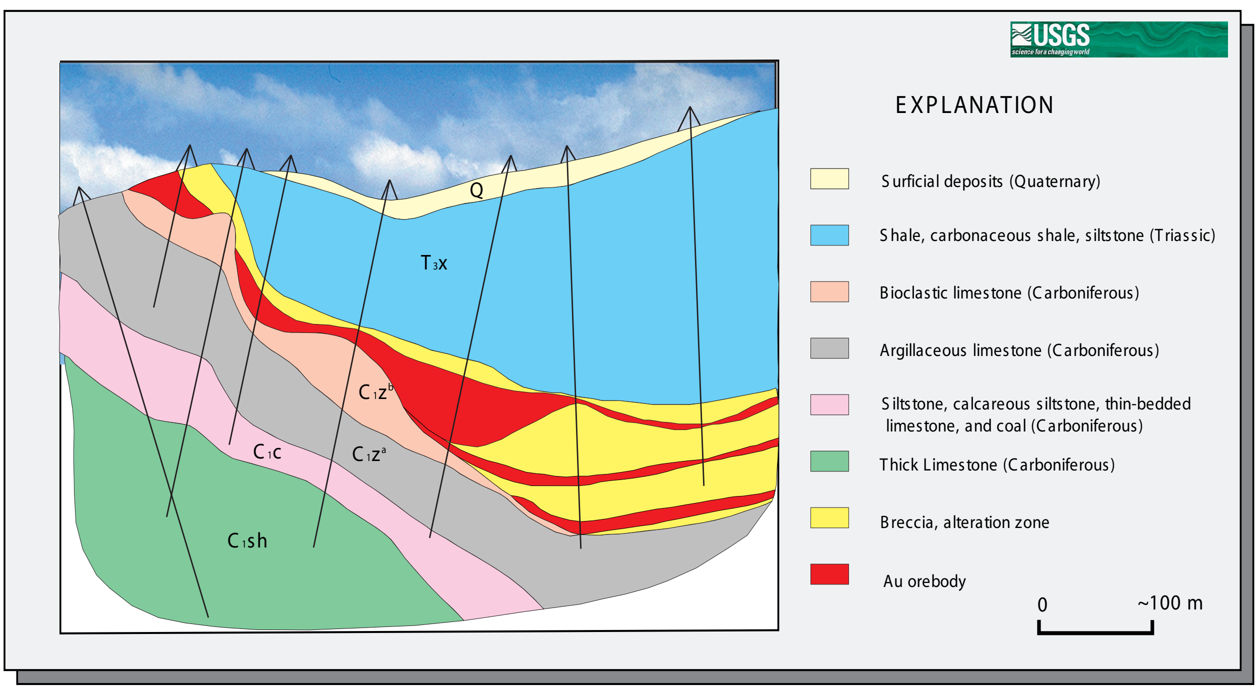


Figure 1-17. Sketch of geologic cross section of the Changkeng Au deposit, Guangdong Province, showing ore control on an unconformity surface between between units T_3x and C_2Zb. Compiled from Du, J.E. (1994).

The Gedang Au deposit is controlled by shallow-dipping, interformational fracture zones that are present mainly along an unconformity (palaeo-erosion surface). The Au ore zones are layer- or lense-shaped that coincide with the bedding and with conformable deformation planes in the host rocks. Locally, the orebodies have acute orientations to the host rock bedding planes. Hydrothermal alteration consists of silicification and the addition of pyrite and other sulfide minerals, as well as calcite, barite, and local melanterite. Mineralogy of the Gedang Au deposit ores mainly consists of pyrite, arsenopyrite, stibnite, As-bearing pyrite, pyrrhotite, sphalerite, chalcopyrite, magnetite, and ilmenite. Hematite and limonite are common in the supergene zone. Gangue minerals are quartz, hydromica (sericite-illite), calcite, dolomite, barite, and fluorite. Gold mainly is present in the Gedang Au deposit in hydromica and in sulfide minerals as micro- to submicron-sized grains. Gold is colloform-shaped in hydromica and is present as inclusions in pyrite, arsenian pyrite, and in arsenopyrite.

These unconformity-hosted Au ores contain many mineralogical and geochemical characteristics typical of Carlin-type ores, but also have minerals and geochemical pathfinders, such as Bi and base metals, that may indicate igneous or other genetic influences.

Syndeformational Au deposits

The close relation among sedimentary rock-hosted Au deposits and their host structures implies that they may be genetically related to each other. Structural and hydrothermal events in both the regions and in the deposits are derived from similar tectonic mechanisms that have undergone similar evolutionary processes. In these systems, potential for a Au occurrence in a fault with multiple stages of activity is significantly greater than that of a fault with a single stage of activity (Luo, X.H., 1994).

Many regional-scale lineaments, including district-scale faults and shear zones, appear to have been active before, during, and after the Au event that formed the deposits. In addition to mineral belts and their accompanying folds and faults, examples of probable regional-scale hydrothermal fluid conduits are: (1) permeable Paleozoic carbonate-rich stratigraphic units; (2) the Paleozoic-Mesozoic (carbonate-siliciclastic) boundary and other unconformities; and (3) regional-scale tectonic zones and associated faults. Fluids may have traversed more than 10 km along some permeable or structurally prepared horizons, especially in or adjacent to district-scale tectonic lineaments that cross many of the lithostratigraphic terranes. Fluid flow accompanied by deformation along structures has produced jasperoidal rocks, silicified breccia, gouge, and phyllonite along or adjacent to these structures.

Peters (1998, 2000a,b) has suggested that shear folding of pre-existing regional folds was a major ore-control in the large Betze Au deposit in the Carlin trend, Nevada and that some of the brittle-ductile deformation present in these zones was synchronous with ore deposition (fig. 1-19). Syn-deformational genesis has also been documented in the Lannigou Au deposit, Guizhou Province, by Luo, X.H. (1993, 1996) (Chapter 3) and also is suggested from ore textures in the Maanqiao and Jinlongshan deposits in the East Qinling fold belt area (Chapter 4). At the Lannigou Au deposit and other deposits in the Dian-Qian-Gui region (Chapter 3), structural movement and deformation is not only a mechanical process, but also is a chemical process, in that it directly and indirectly affects the ore fluids and formation of the deposits. According to Chen Y.M (1987) and Zhang X.F. (1997a,b) these processes also altered a proto orebody and cause enrichment or impoverishment of metals and concentrated scattered ore-related chemical elements from source beds into the Au ore deposit.

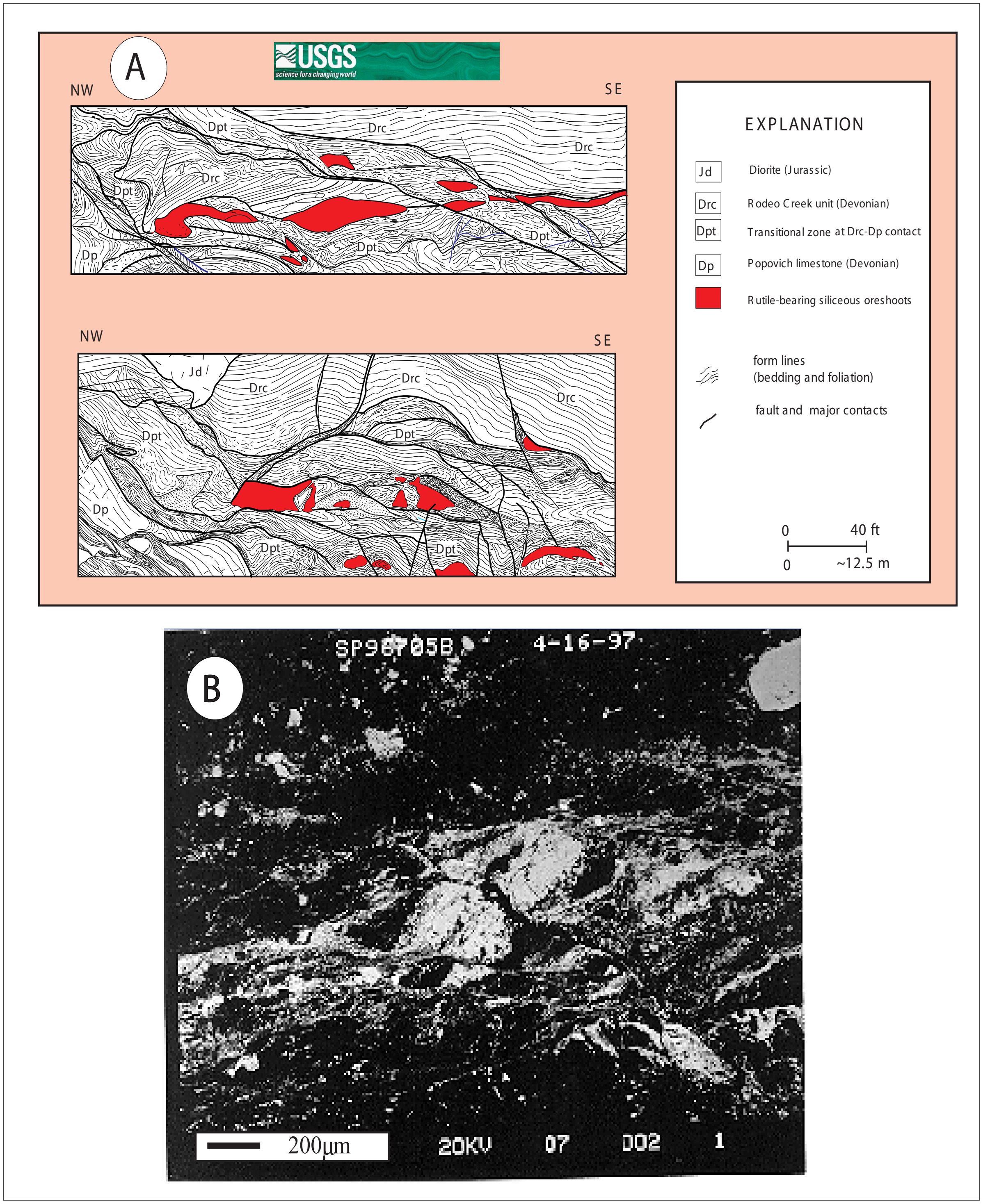


Figure 1-18. Examples of orogenic, syn-deformational textures in sedimentary rock (Carlin-type) Au deposits. (***A***) Bench sketches of the transitional contact between the Devonian Rodeo Creek unit and Popovich limestone, upper central Betze orebody, Nevada between 4,800 and 4,900 ft levels, showing location of rutile-bearing siliceous breccia oreshoots. Sketches are roughly parallel with the WNW strike of the orebody. Dark pods are rutile-bearing siliceous breccia pods, which contain Ti, P, REE, and U minerals. Modified from Peters and others (1998, 2000). (***A***) Scanning electron microscope back scatter image of sheared texture in As-rich, brecciated pyrite. Multiple As-rich pyrite grains, accompanied by Au, have grown during shearing and microbrecciation, Betze orebody, northern Nevada.

If a 50-tonne Au deposit, such as the Lannigou deposit, were formed from source rocks containing 20.37 ppb Au, and 90 percent of the Au were leached from these source rocks, then about 1 km^3 of source rock (see Fig. 1-17) would supply the required Au for the deposit. Since the stratigraphic section in the Dian-Qian-Gui region is over 1,000 m thick, there is plentiful potential source rock. The Nanpanjiang orogenic fold zone in the Dian-Qian-Gui area has undergone regional low-grade metamorphism and therefore the tectono-thermal event may have remobilized Au and transported and precipitated it in favorable structures (Chapter 3). The ore-forming temperature of sedimentary rock-hosted Au deposits in the Dian-Qian-Gui area is between 172° and 265°C. Therefore, the thermal event could have provided the heat source, and also may have provided the environment for local traps and space for the orebodies (Luo, X.H., 1993, 1994, 1996).

The Maanqiao Au deposit in the Qinling fold belt also has characteristics of syndeformational, orogenic origin (Chapter 4). The deposit is hosted in late Devonian to late Carboniferous fine-grained clastic, carbonaceous slate and limestone, the upper parts of which are in contact with early Mesozoic granite. Contact metamorphism locally has converted the limestone to marble. Intense post-intrusive ductile shear zones that have dismembered many marble pods along phyllite and quartz-sericite shears locally have disrupted bedding planes. The stratabound, shear zone-hosted Au ore zones are surrounded by disseminated haloes of sulfide minerals in the undeformed strata around the shear zones. These halos generally are thicker than the shear zones and Au grade is less than in the shear zones. Alteration consists of intense quartz-sericite-pyrite along the strands of the shear zones and is accompanied by biotite, plagioclase, ankerite, dolomite, apatite, and calcite. Disseminated non-texturally destructive growths of these minerals lie adjacent to the intensely deformed parts of the shear zones. Gold ore zones contain pyrrhotite, pyrite, with lesser magnetite, arsenopyrite, chalcopyrite, sphalerite, galena, native Au, local stibnite, and Ni–Sb, Pb–Cu–Zn, and Pb–Sb sulfide minerals. Gold is present as grains of native Au at boundaries of metal and non-metal minerals and locally in the alteration matrix along the strands of the shear zone.

The Maanqiao Au deposit ores, contain elevated concentrations of As and Sb, which is similar to other Carlin-type sedimentary rock-hosted Au deposits in the Qinling fold belt (Chapter 4, Appendix IV). Elevated geochemical values of Cu, Pb, Zn, Ni and Co in the Maanqiao ores also is compatible with those found in Carlin-type deposits, but this elemental suite also is 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 (with the exception of the Liba and Pulongba Au deposits), which may reflect proximity of the Mesozoic intrusive to the north.

The Maanqiao Au deposit has many 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. There also are some features, such as host rock, geochemistry, and geologic setting that are similar to Carlin-type deposits. The 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 (see also, Phillips and Powell, 1993; Goldfarb and others, 1998; Groves and others, 1998).

Red earth and laterite-hosted Au deposits

Oxidation of sedimentary rock-hosted Au deposits directly affects mining and milling costs and methods. For instance, surface oxidation of some distal-disseminated Ag–Au deposits can result in supergene bonanza Ag ore bodies that are enriched in Ag chloride minerals (figs 1-19, 1-20). Oxidation of sulfide minerals allows low-cost heap-leach processing methods to be employed and also reduces blasting costs because the rocks commonly are softer and can be directly excavated. The level of oxidation positively affects Au concentrations in the ore. Oxidation level also may provide structural and tectonic information about the level of exposure of some deposits. Unfortunately, oxidation may obscure textural, mineralogical, and geochemical characteristics of sedimentary rock-hosted Au deposits thus hindering proper classification.

Laterite-hosted Au or red earth deposits are formed in South China where Au-bearing carbonate rocks, clastic rocks, contact zones of granite, volcanic, and metamorphic rocks are

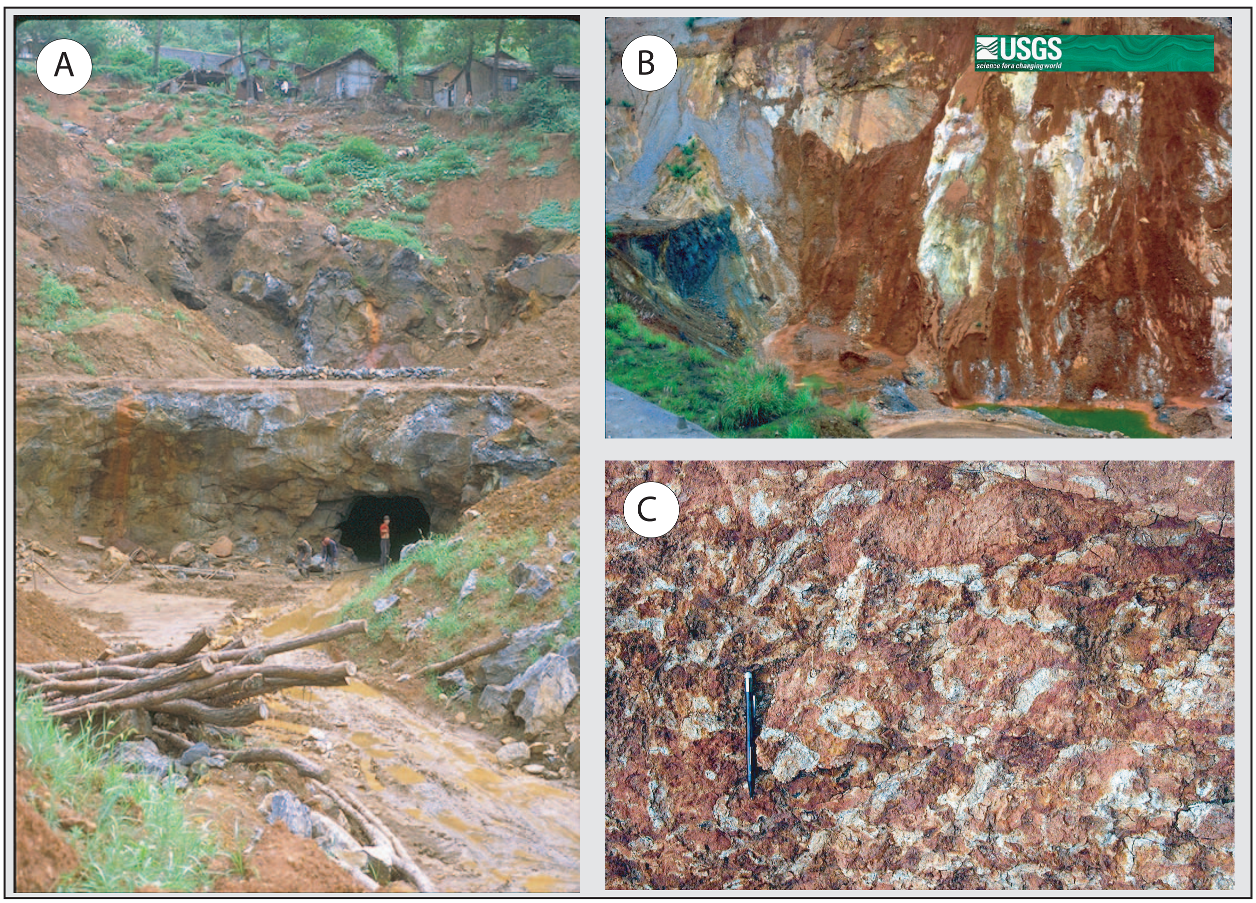


Figure 1-19. Photographs of intensely weathered sedimentary rock-hosted Au deposits. (***A***) Gossanous outcrops of main ore horizon at Mashan Au deposit, Anhui Province, Middle-Lower Yangtze River area. (***B***) Gossanous iron oxides on footwall of open pit at the Xinqiao Au deposit, Anhui Province, Middle-Lower Yangtze River area. White areas are bleached intrusive rock. (***C***) Mottled saprolitezone in the Shewushan red earth (laterite-hosted) deposit, Hubei Province, Middle-Lower Yangtze River area.

exposed to tropical climate weathering. Characteristics of these deposits have similarities to those described by Webster and Mann (1984) and Butts (1989). Red earth deposits are located in topographically low areas of low hills and plains that have undergone extensive erosion. The areas of Nanling, the southeast coast of China, Guizhou, Yunnan Provinces, and Middle-Lower Yangtze River area, for example at the Shewushan Au deposit (Chapter 5, Appendix III) (fig. 1-19), are the main locations of lateritic Au deposits.

Karst caves and paleo-erosional surfaces are common near unconformities, and some Au orebodies along these zones take the shape of karst pots (fig. 1-20). Unconformity surfaces also are more easily subjected to weathering and laterite development and are the sites of local oxidized ("red earth") orebodies (fig. 1-19). Orebodies in the Changkeng Au deposit, for example, are controlled by the unconformity surface where karst caves in the bioclastic limestone form the footwall of the orebodies (Du, J.E and Ma, C.H., 1994).

A common feature of highly oxidized deposits is the obscuring of diagnostic hypogene features. Oxidation of distal-disseminated Ag–Au deposit ores indicate that these high-level, pluton-related occurrences can mimic Carlin-type Au deposit geochemical signatures in the oxide zone. Albino (1993) points out that enrichment of As, Sb, and Hg is common in both Carlin-type systems and in distal-disseminated Ag–Au deposits, and that this partly results from these elements having the ability to be transported as bisulfide complexes. In addition, Albino (1993) points out that many distal-disseminated Ag–Au deposits are enriched in Mn, whereas some Carlin-type deposits, in fact, may be leached of Mn.

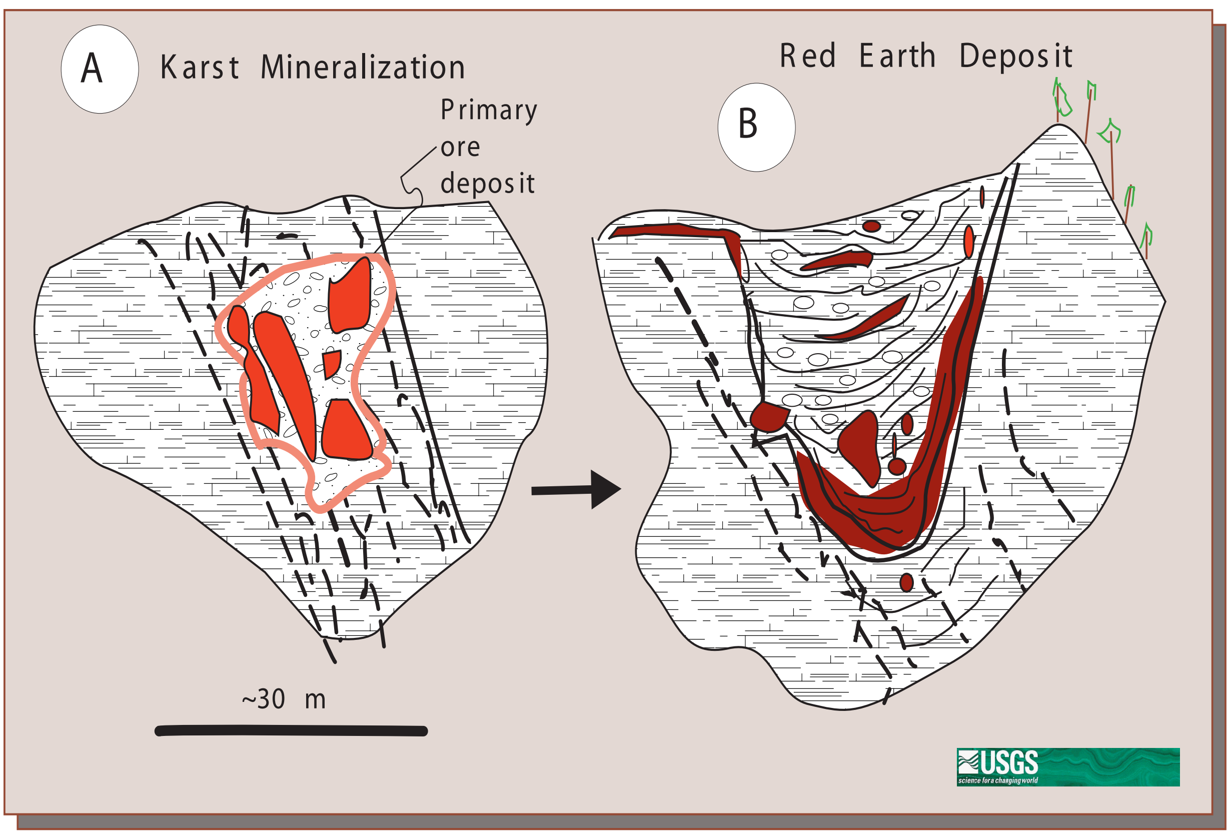


Figure 1-20. Hypothetical formation of red earth deposit in karst terrane. A hypogene deposit is formed along steep-dipping structural zone. Oxidation of and acid generation by sulfide minerals in primary ore enhanced karst development and collapse in supergene zone, forming a red earth deposit, commonly in karst pots.

GEOCHEMISTRY of SEDIMENTARY ROCK-HOSTED Au DEPOSITS

Carlin-type Au deposits in P.R. China are called "look-like-rock" or in Chinese Xiang shi tou, because there is no clear visible boundary between the orebody and the unmineralized host rock. Gold assays commonly are the only means to distinguish between rock and ore; therefore, an important geochemical feature of these deposits is the inheritance of minerals and geochemical components from the unmineralized host-rocks. Another geochemical feature of sedimentary rock-hosted Au deposits is the introduction of large amounts of SiO_2 and the formation of jasperoid that accompany Au mineralization. In addition, CaO and MgO in the host rocks commonly are dissolved and removed. Basic geochemical characteristics of Chinese sedimentary rock-hosted Au deposits, such as composition of host rock, and of ore, trace elemental assemblages, and fluid inclusion and isotope studies have been summarized by Li, Z.P. and Peters (1998) (see also, Chapter 2). Additional geochemical analysis has been conducted in the Qinling belt fold area and the Middle-Lower Yangtze River area in this report (see also, Appendix IV).

Trace element characteristics

The main trace elements associated with the ores from many sedimentary rock-hosted Au deposits are As, Sb, Hg, Zn, and Ba. Trace amounts of Tl, Pb, Cu, Co, Ni, P, and some rare earth elements also are present (Hill and others, 1986; Dean and others, 1988) (Appendix IV) (see also, Chapter 2). High Fe and S are associated with most of the ores and are represented mainly as pyrite or other sulfides. Thallium is anomalously high in some deposits, but is absent in others. Tellurium and Bi usually are absent or very low, except in deposits with igneous rocks present.

The Ag/Au ratios generally are less than 1 in most Carlin-type Au deposits, but the reverse is true in the distal-disseminated Ag–Au and polymetallic replacement deposits. A Au/Ag ratio of between 9.2 to 66.9 in the Lannigou Au deposit may reflect local variations in the amount of Ag there, which is not uncommon in these deposits. Pluton-related Au deposits have much higher Ag/Au ratios (Li, Z.P. and Peters, 1998). In the Changkeng Au deposit there are two Au orebodies and three Ag orebodies, which are separated from each other along the same brecciated northeast-trending fault zone. The Au/Ag. ratio in this deposit is 1/0.8 in Au orebodies, and 1/644 in Ag orebodies (Du, J.E. and Ma, C.K. 1994). Silver, Cu, Pb, Zn, Bi, and Mo are present in low concentrations in most deposits, except in the distal-disseminated Ag–Au and polymetallic replacement, pluton-related, deposits in the Middle-Lower Yangtze River area. Uranium is enriched in the Laerma, Pingding, and nearby deposits in the Qinling fold belt area, P.R. China (Chapter 4). Platinum group elements (PGE) also may be enriched up to ore levels in some Chinese Carlin-type Au deposits, such as Laerma Au deposit in Qinling fold belt area (Chapter 4).

Arsenic is one of the main elements that characterize most sedimentary rock-hosted Au deposits (Chapter 2). Geochemically Carlin-type deposits bear some similarities to distal-disseminated Ag–Au (pluton-related) deposits (Peters and others, 1996). In some Chinese sedimentary rock-hosted Au deposits, As has been enriched to economic levels. At the Jinya Au deposit (fig. 1-21) (As: 0.44 to 1.89 wt. percent), the Pingding Au deposit (As: 3.99 to 15 wt. percent), and the Qiaoqiaoshang Au deposit in the Qinling fold belt area (Chapter 4), realgar ore has been mined for As along with Au ores (Liu, D.S. and others, 1994). Massive arsenopyrite is common in the Xinqiao, Mashan, and Huangshilaoshan Au–polymetallic replacement deposits of the Middle-Lower Yangtze River area (Chapter 5)

Antimony prospects have played an important role in the history of exploration for Carlin-type Au deposits in China. For example, the Banqi Au deposit was found in 1978 by investigation of an Sb prospect. Later, a group of Au prospects associated with Sb, As, and Hg were discovered around the Banqi deposit, and the Getang, Zimudang, Xiongwu, and Ceyang sedimentary rock-hosted Au deposits were found nearby in the Dian-Qian-Gui area (Mai, C.R., 1989) (see also, fig. 1-7).

Mercury also is associated with Au in many Carlin-type Au deposits. Most Hg-rich Chinese Carlin-type Au deposits are present in or near zones of economic Hg orebodies (Liu, D.S. and Geng, W.H., 1987). For example, the Sando-Danzhai Hg mineralized zone (Huang, G.S. and Du, Y.Y., 1993), located in the southern Guizhou Province, is a north-striking, 50 km long, 7 km wide zone present in Cambrian silty and argillaceous limestone. There are 3 large, 1 medium and 11 small Hg deposits in this zone and also 1 medium and 6 small sedimentary rock-hosted Carlin-type Au deposits (Chapter 3). Some of them, such as the Sixiangchang and Miaolong deposits were old Hg mines. Gold prospects associated with Hg also are found at Baxi, Tuanjie, Qilicun, and Jiawuchi (Sichuan province) Au deposits, as well as the Nima Hg–(As) prospect. The Ding-Ma Au belt contains many Hg deposits (Zhang, X.F., 1997a,b), and the Laerma to Pingding sedimentary rock-hosted Au trend in the Qinling fold belt area (Chapter 4) overlaps an extensive Hg–Sb–U province, and Hg is enriched up to economic levels (0.01 wt. percent) in the Laerma Au deposit (Li, Z.P. and Peters, 1998).

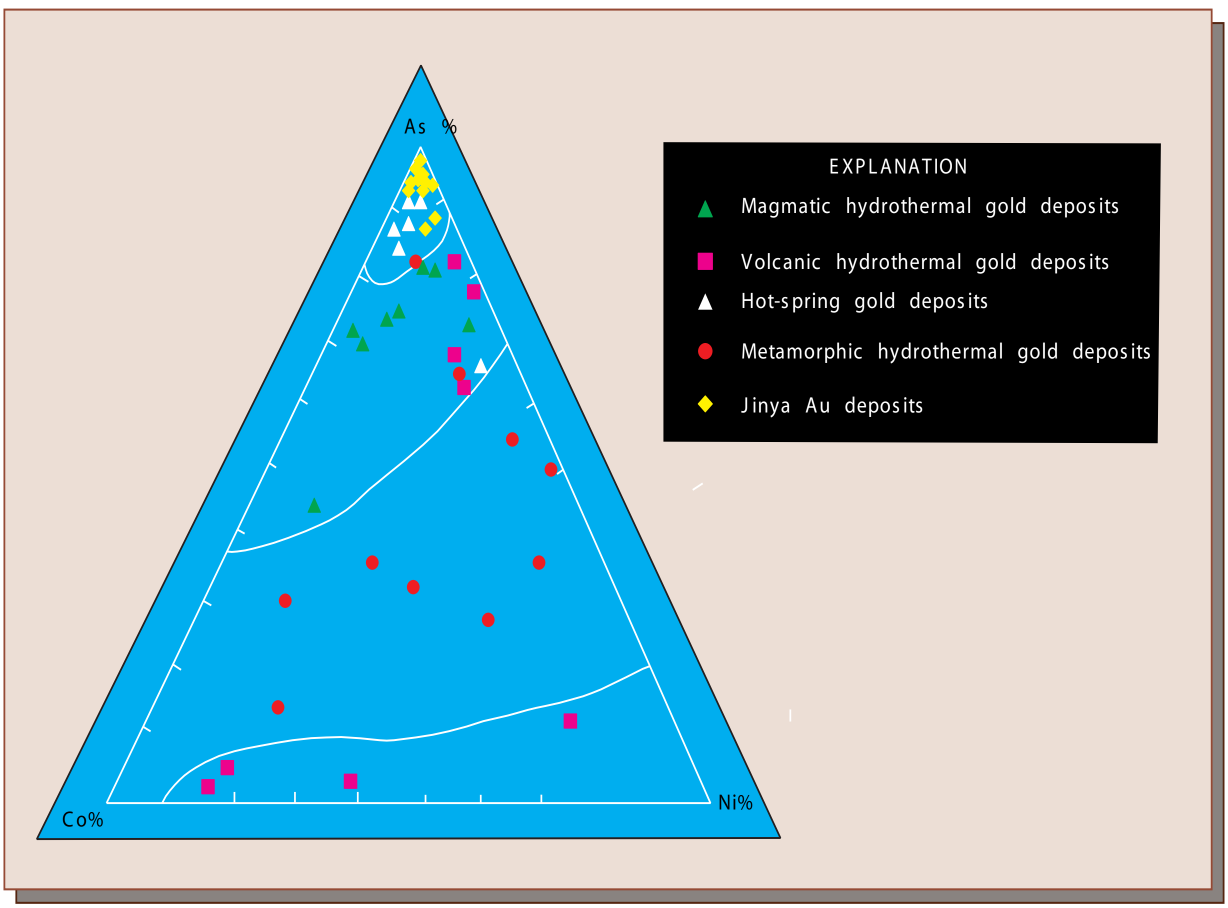


Figure 1-21. Triangular diagram of Co, Ni, and As in pyrite from Jinya Au deposit, Guangxi District, Dian-Qian-Gui area. Pyrites of Jinya Au deposit fall in the area of hot-spring Au deposits. This indicates that some Chinese Carlin-type Au deposits have affinities to hot-spring hydrothermal fluids, according to Li, Z. H. and others (1994).

Thallium is a common trace element in many Carlin-type Au deposits in Nevada; at the Carlin Mine, Nevada, the ore contains between 40 to 50 ppm Tl in mostly unoxidized ores, about 150 ppm in arsenic ores, and about 3 ppm in unaltered rock (Togashi, 1992). Deposits in the Dian-Qian-Gui area typically are anomalous in Tl; for instance, the Zimudang Au deposit (Chapter 3) is reported as a Au–Hg–Tl Carlin-type Au deposit, and an unidentified red thallium mineral was found in the Lanmuchang deposit near the Zimudang Au deposit (Li, Z.P. and Peters, 1998). The Lannigou Au deposit (Chapter 3) contains an elevated Au–As–Tl–Cr–Cu element assemblage, and the Shuangwang Au deposit in the Qinling fold belt (Chapter 4) also contains elevated concentrations of Tl, Li, Ti, Ba, Sn, V, and Cr. The Zhanghai Au deposit in the Middle-Lower Yangtze River (Chapter 5) also contains elevated values of Tl (Appendix IV).

Barium usually is present as barite, a very common mineral in alteration or late stage barite-calcite veins. It commonly is associated with many sedimentary rock-hosted Au deposits, but does not usually positively correlate with Au. In the Laerma Au deposit in the Qinling fold belt area, barite together with quartz is present in veinlets and veins, which lie in alteration zones on the flanks of orebodies where gray to gray-white quartz-barite veins contain 0.39 to 2.46 ppm Au (Li, Y.D and Li, Y.T., 1994) (Chapter 4).

Uranium is present in many sedimentary rock-hosted Au deposits in the Qinling fold belt area. The Laerma Au–U deposit is a typical Au deposit containing enriched U, where the host carbonaceous siliceous slate, siliciclastic rock, and carbonaceous silty slate contain between 5.19 and 15.50 ppm U. 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 (Li, Y.D. and Li, Y.T., 1994). Separate, economic U deposits are present peripheral to sedimentary rock-hosted Au deposits in the Laerma area.

Platinum group elements (PGE), including Os, Pd and Ru, are enriched in several Chinese sedimentary rock-hosted Au deposits, including the Laerma and Shuangwang deposits. In the Laerma Au–U deposit, analysis of 20 samples of carbonaceous siltstone, contained 0.02 to 0.022 ppm Pt, 0.001 to 0.005 ppm (highest 10 ppm) Os, and 0.001 to 0.024 ppm Pd. A few small orebodies rich in PGE also have been found. In the Shuangwang Au deposit, electron microprobe analysis of pyrite and ankerite grains show a Pt value of 2.66 wt. percent and a Pd value of 0.34 wt. Percent (see also, Peng, D.Q., 1992; Xu, E.S. and others, 1992). Sedimentary rock-hosted Au deposits in the Qinling fold belt (Chapter 4) and Dian-Qian-Gui areas (Chapter 3) partially lie along metallogenic belts of Pt–Mo–Ni ores in black shales describe by Coveney and others (1992), Lott and others (1999), and Coveney (2000).

Geochemistry of the host rock lithology of sedimentary rock-hosted Au deposits varies from one deposit to another. For instance, in the Dian-Qian-Gui area the geochemical characteristics of host mudstone, siltstone and argillaceous limestone can be distinguished as shelf facies rocks in the northwest part of the area, with lower SiO_2, higher TiO_2 compositions, and Fe_2O_3+FeO, MgO/CaO ratios than those in abyssal facies in the southeast part (Chapter 3) (Tan, Y.J., 1994; Li, Z.P. and Peters, 1998).

Similar geochemical classification of ore types is used both in Nevada and in the P.R. China (see also, Dean and others, 1988; Tan, Y.J., 1994)—such as siliceous, pyritic, arsenic, and oxidized ore types. Sedimentary rock-hosted Au deposits have characteristic elemental assemblages that reflect the mineral association found in these ores. These element assemblages vary from one deposit to another, but usually contain several common elements.

A good example of the use of geochemical exploration using soils is from the Lannigou Au deposit discussed by Luo, X.H. (1994) and translated in Li, Z.P. and Peters (1998). The ores are anomalous in As, Hg, C, and S with lessor amounts of Au; Ag, Cu, Pb, and Zn, and soil geochemistry was used to delineate mineralized zones in the Au deposit area. Soil samples were analyzed for 34 elements: Si, Fe, K, Ca, Al, Mg, Na, Ti, As, Sn, Cr, V, Ba, Zr, P, Mn, Mo, Pb, Sb, Cu, Ni, Co, Sc, Zn, Y, Ga, Sr, Be, Ag, Yb, Nb, W, Au, Ag, Hg. Of these elements, Au concentrations in soil varied from 1 ppb to greater than 3,000 ppb, averaging 1.26 ppb. The average Au concentration for stream sediments in the drainage system, which are within the whole southwest Guizhou Province, a total area of 31,128 km^2, is 2.1 ppb. Seventeen anomalies were delineated using 20 ppb as the threshold concentration (fig. 1-5).

Correlation analysis shows that As, Tl, and Cr have a positive relation to Au; Ba, U, Pb, and Zn have a clear negative relation to Au, while the relation among Sb, Hg and Au is not clear. The assemblage Au–As–Tl–Cr–Cu, an element assemblage similar to the Jinya Au deposit in the Guangxi District, characterizes the element association of the Lannigou Au deposit on the basis of R-mode factor analysis. However, this assemblage is different from the Banqi and Yata Au deposits that have an assemblage of Au–As–Sb–Ag–Hg (Li, Z.G. and others, 1994). The Au–As–Tl–Cr–Cu elemental assemblage reflects characteristics of fine-grained clastic rocks of terrigenous origin (Zhang, Z.N., 1993). In general, Au, As, Sb, and Hg make up the typical elemental assemblage in both Nevada and Chinese sedimentary rock-hosted Au deposits (Togashi, 1992; Tu, G.Z., 1992; Liu, D.S. and others, 1994; Li, Z.P. and Peters, 1998).

Fluid-inclusion and stable isotopes

Fluid-inclusion and stable isotope data from sedimentary rock-hosted Au deposits have been studied in Nevada and in the P.R. China (Lu, H.Z., 1988; Li, W.K. and others, 1989; Hofstra and others, 1991a,b; Bagby and Cline, 1991; Zheng, M.H. and others, 1991; Lu, G.Q. and others, 1992; Arehart and others, 1993c; He, L.X. and others, 1993; Liu, D.S. and others, 1994; Cline and others, 1996; He, M.Y., 1996; Gao, Z.B. and others, 1996; Hofstra, 1997; Hofstra and Cline, 2000) (see also, Chapter 2). Although fluid-inclusion and isotope data vary from one deposit to another, an epithermal to mesothermal hydrothermal environment is suggested for Carlin-type deposits.

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

Stable isotope data from sedimentary rock-hosted Au deposits show a wide range, and vary from one deposit to another. In Nevada, there is a wide range of $‰\delta^{34}S$, from –5 to +20 per mil, in Au-associated minerals (see also, Radtke, 1985). Hydrothermal fluids are considered to be dilute (between approximately 0.5 to 10 wt. percent NaCl equivalent) and are dominantly from fluids with isotopic signatures similar to evolved meteoric water (Hofstra and others, 1991a, b; Hofstra, 1997; Hofstra and Cline, 2000), except at Getchell and Twin Creeks (Cline and others, 1996) where either magmatic or metamorphic water is suggested by D and O isotope signatures (see also, Chapter 2). Fluid characteristics in Carlin-type Au deposits suggest an environment below the epithermal zone but the fluid source and the source of the Au is still equivocal.

In the P.R. China, Zheng, M.H. and others (1991) conducted systematic isotopic research on the Dongbeizhai Au deposit, Qinling fold belt area, using S, H, O, C, Pb, and Rb–Sr stable isotopes, and concluded that the ore-formation fluids mainly were derived from meteoric water; the S was derived from the host rock; and that carbonate-bearing sedimentary units are the main source of many of the metallic elements in the deposits (see also, Wang, X.C. 1996) (fig. 1-22). Interpretation of isotope data from sedimentary rock-hosted Au deposits in the Dian-Qian-Gui area suggest that there may have been several fluid sources, including hydrothermal fluids arising from the deep crust or from distal magmatic bodies (fig. 1-22) (see also, Chapter 2). The field of H and O isotopes of these deposits has some similarities with those in the Getchell trend, Nevada (Cline and others, 1996).

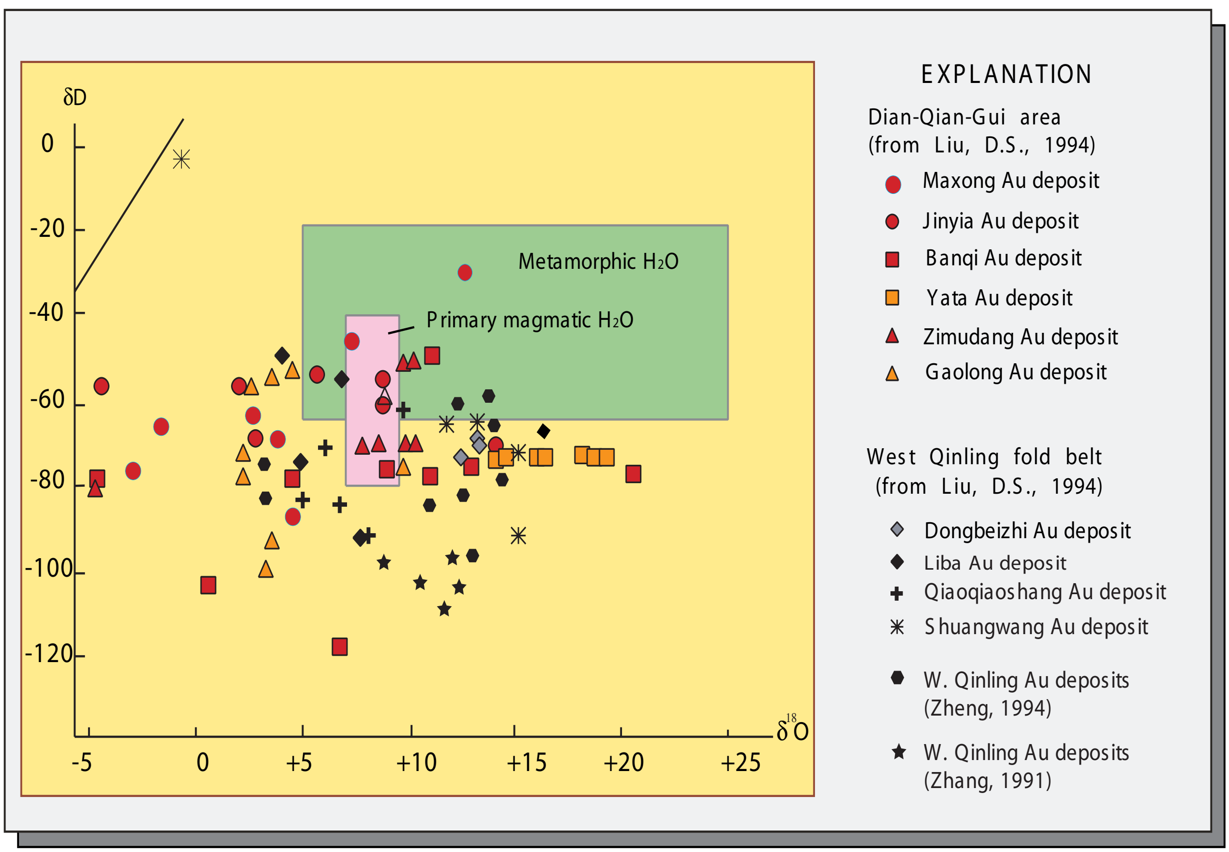


Figure 1-22. δD vs. $\delta^{18}O$ diagram showing that H and O data of Chinese Carlin-type Au deposit are scatted over a large area. This implies that metallogenic fluids may have been derived from different sources or that different assumptions and fractionation curves were used to caslculate fluid values.. Adapted from Liu, D.S. and others (1994), Zhang (1991), and Zheng (1994).

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

CONCLUSIONS

The purpose of this chapter has been to introduce and characterize the general geological and geochemical characteristics of Chinese sedimentary rock-hosted Au deposits. Additional characteristics are detailed in Chapter 2 and in subsequent chapters. Characteristics of sedimentary rock-hosted Au deposits are expanding as research continues. The family of Carlin-type deposits has sometimes included some pluton-related, skarn, metamorphic rock-related, and orogenic Au deposits, as well as those related to porphyry systems. The following are some geological similarities and differences of the Au deposits in the Qinling fold belt, Dian-Qian-Gui, and Middle-Lower Yangtze River areas.

Sedimentary rock-hosted Au deposits in P.R. China are located in three main areas around the Precambrian Yangtze craton and commonly are hosted by Paleozoic to early Mesozoic marine carbonate strata and shale, whose overall porosity and permeability have been enhanced by dissolution and tectonism. Some deposits are hosted, in places, by early Paleozoic sedimentary and basaltic rocks.

Carlin-type Au deposits generally contain sub-micron sized particles of Au, although some deposits—particularly the distal-disseminated Ag–Au, polymetallic replacement, or syndeformational Au deposits—contain free Au particles as large as 3 mm. Geochemical association of Au with Carlin-type deposits is: (1) As (strong positive correlation); (2) Sb (Sb generally was introduced later than Au); and (3) Hg. The Au/Ag ratio is usually ≥ 1; As/Au $\approx$ 1,000; Sb/Au $\approx$ 50. Pluton-related deposits have higher concentrations of Ag, as well as Bi and base metals.

Chinese sedimentary rock-hosted Au deposits have some similar regional sedimentary and tectonic features to many Carlin-type Au deposit s in Nevada: (1) all deposits are present near the margin of one or more Precambrian cratons, or in areas where craton-scale tectonic units join; (2) deposits are hosted in Paleozoic or Mesozoic sedimentary basins, which contain both shallow-water cratonic shelf and sedimentary rocks from the adjacent deeper basins; (3) tectonically, there is a history of both compressional and extensional deformation; and (4) there is evidence of alignment of geologic features that reflect regional deep-crustal rifts or zones that were developed by major orogeny. It is likely that many or all of these features contribute to the localizing and formation of clusters of sedimentary rock-hosted Au deposits.

Sedimentary rock-hosted Au deposits are hosted by carbonate and siliciclastic sedimentary rocks, especially rocks formed in shelf transitional zones of sedimentary facies, such as argillaceous limestone, calcareous siltstone, and silty argillite. A high content of organic material is common in or near most sedimentary rock-hosted Au deposits, although the role of C in Au mineralization is not yet clear. Organic matter may have preceded Au-bearing fluids or may have been introduced or remobilized by the hydrothermal Au event. Minera-lization of carbonaceous matter is evident in many deposits, and the worldwide correlation with these Au deposits suggests there may be a genetic link. Some of the Chinese carbonaceous ores have syngenetic characteristics.

Lack of evidence for distinct temporal links between Au mineralization and igneous rocks in the Qinling fold belt and Dan-Qian-Gui areas contrasts with a direct link in the Middle-Lower Yangtze River area. A few deposits, such as at the Liba, Pangjiahe, Maanqiao, and Qiuluo Au deposits, are present near igneous intrusions.

Common hydrothermal alteration types are silicification, argillization, and decalcification. Pyrite, arsenopyrite, stibnite, realgar, orpiment, quartz, barite, calcite, and illite-clay minerals are the common minerals associated with Carlin-type sedimentary rock-hosted Au deposits. The combination of minerals is different in each deposit depending on the host rocks. Chalcopyrite, sphalerite, and galena are present in trace amounts in some deposits, particularly in pluton-related distal-disseminated Ag–Au deposits in the Middle-Lower Yangtze River area. Different mineral assemblages may also be the result of zoning in individual deposits. Pyrrhotite, tungstite, albite, and several native metals are special features in some Chinese deposits. Illite-clay minerals, quartz, barite, and pyrrhotite also act as host minerals in some deposits.

The Au–As–Sb–Hg–Ba elemental assemblage is common in sedimentary rock-hosted Au deposits, but Tl seems to be more common in the Nevada deposits and is only found in a few Chinese deposits, such as the Zimudang Au deposit in the Dian-Qian-Gui area and the Zhanghai Au deposit in the Middle-Lower Yangtze River area. Uranium and PGEs are uniquely related to some Chinese deposits and are not known in the Nevada Carlin-type deposits.

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

Oxidation zones in Nevada sedimentary rock-hosted deposits are deeper than in Chinese deposits. This has had a negative economic impact on the development of such deposits in the P.R. China. The exception is the red earth deposits and gossanous deposits in the tropically weathered parts of the P.R. China.

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