GEOLOGICAL SURVEY OF CANADA

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Report on the Sino-Canadian Gold Project 1987-1990

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1992

REPORT

ON

THE SINO-CANADIAN GOLD PROJECT

1987-1990

by

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PREFACE

This report summarizes the results of a co-operative gold project conducted under the terms a Canada - China Memorandum of understanding. The contents have not been extensively edited and the report contains some repetition from chapter to chapter. Portions of the text were produced at various stages during the project and have been reproduced here with minimum revision to the original versions. The figures in Chapter 2 have been reproduced from various Chinese journal papers and reports and some of these lack a conventional bar scale.

COVER: The Erdaogou Gold Mine, Liaoning Province, China

Photo By:
B.E. Taylor

Kim Nguyen and Richard Lancaster prepared several figures for the report.

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Chapter 1

OVERVIEW OF THE SINO-CANADIAN GOLD PROJECT 1987-90: GOLD DEPOSITS IN NORTH CHINA PLATFORM AND THEIR CANADIAN ANALOGUES

K.H. Poulsen

INTRODUCTION

As part of the commitment by both sides to the Memorandum of Understanding (1985) between the Geological Survey of Canada and the Ministry of Geology and Mineral Resources P.R.C., a co-operative research project on Chinese and Canadian gold deposits was established in October, 1987. The objectives of the project were:

1. To compare the methods of research on gold deposits in China and Canada.
2. To gain further understanding of the geology of Precambrian rocks which host important gold deposits in both countries.
3. To test models of gold deposit genesis in both countries to assist in effective exploration.

Geologists from the Ministry of Geology and Mineral Resources, Peoples Republic of China, visited Canada in August, 1988, examined gold deposits and their host rocks in southern British Columbia and northwestern Ontario and participated in field work in the Rice Lake greenstone belt in southeastern Manitoba. A jointly prepared progress report entitled "Contrasts in setting and style of gold deposits in two Archean terranes: Rice Lake District, Canada, and Western Liaoning District, China " (Chapter 8 of this report) was published in Current Research, Part C, 1989 (English version) and in the Bulletin of the Shenyang Institute (Chinese version).

Geologists from the Geological Survey of Canada visited China in May-June, 1989, conducted field work in the Liaoxi area with Chinese colleagues and examined gold deposits in the eastern Shandong area. The general impressions gained by the Canadian team, in the form of a progress report entitled "Observations on gold deposits in North China Platform", were published by the GSC in Current Research, Part A, 1990, and is reproduced in part as Chapter 5 of this report.

Representatives of the Chinese team visited Canada in August, 1990 to prepare final reports, to examine Archean gold deposits in the Abitibi greenstone belt and to participate in the IAGOD Symposium at Ottawa. Mr. Lin Baoqin made an oral presentation on the results of the joint project at the IAGOD meeting. The companion manuscript (Chapter 3 of this report) will be subsequently published in the 1990 IAGOD Proceedings Volume.

As fully illustrated in subsequent chapters, the distribution of gold deposits in the North China Platform correlates remarkably well with the distribution of uplifts of Archean basement rocks and, at the deposit scale, a large number are hosted directly by Archean rocks.

This raises two valid questions, that have been posed by many geologists in China. Are these gold deposits Archean in age and of the "greenstone" type that are common in Canada, and, are these Archean host rocks analogous to those in Canadian greenstone belts? These themes are central to this project and have been addressed through direct comparison and contrast of Canadian and Chinese examples.

CANADIAN GREENSTONE BELTS

Greenstone belts are well known components of Archean terranes throughout the world. In the past, they have also been termed "schist relicts", "schist belts", and "gold belts" in recognition of their metamorphosed state and the fact that they contain a significant proportion of the world's gold resources.

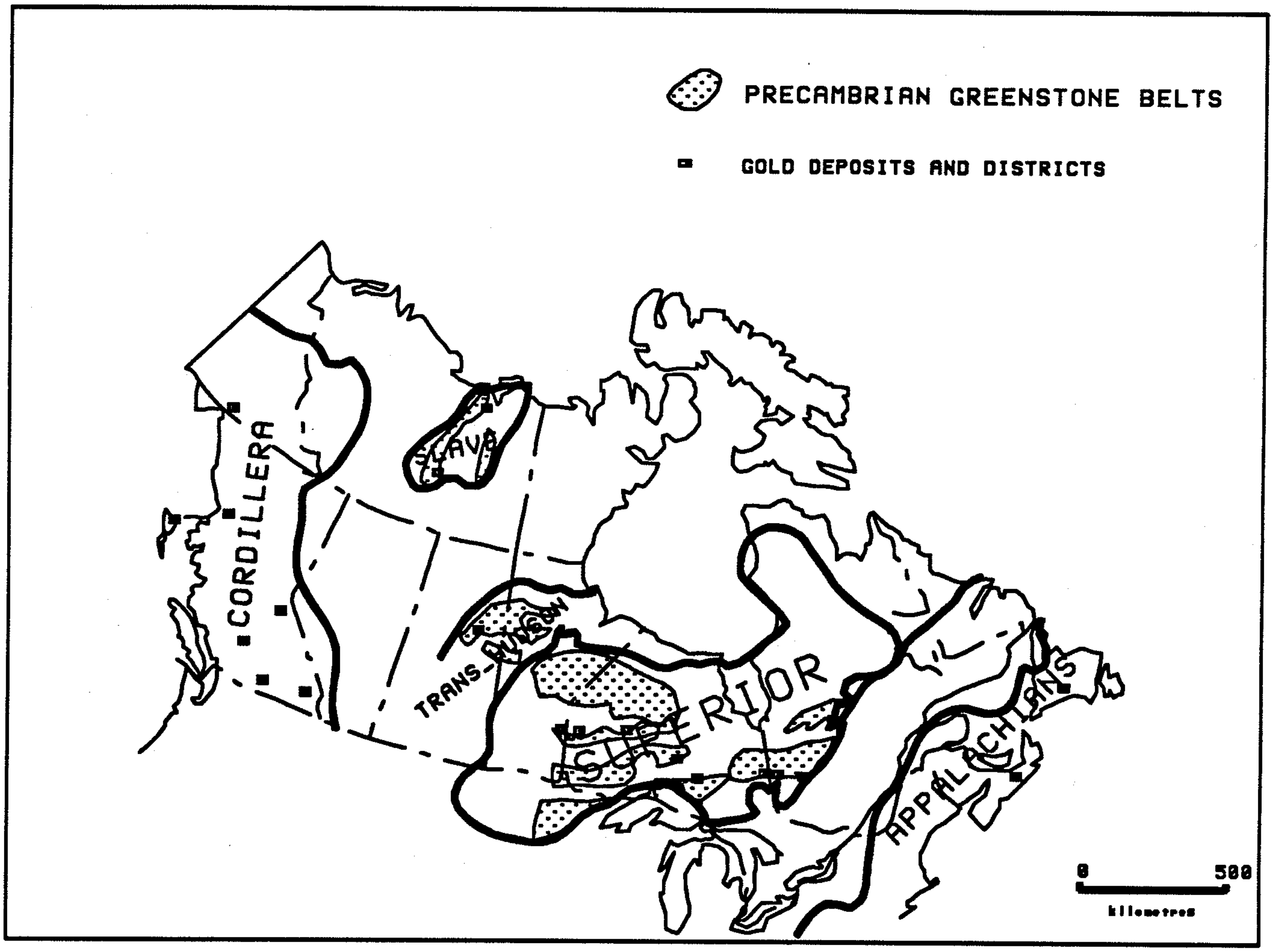


Figure 1: Major geological domains, greenstone belts and gold deposits of Canada.

Historically, there has been a tendency to regard greenstone belts solely as features of Archean terranes but with the advent of precise U-Pb geochonological methods, it has become evident that there are many examples of greenstone belts in Early Proterozoic terranes. For example, the greenstone belts of the Trans-Hudson Orogen of the Canadian Shield (Fig.1) were once thought to be of Archean age because of their many similarities with those of the adjacent Superior Province. The Superior Province greenstone belts were known to be of Archean age because of numerous potassium-argon ages in excess of 2500 Ma but the abundant 1750 Ma K-Ar ages in the Trans-Hudson Orogen were thought to have resulted from overprinting by Early Proterozoic (Hudsonian) metamorphism. However, numerous recent U-Pb zircon age determinations have verified that the greenstone belts of the Trans-Hudson actually formed at approximately 1870 Ma.

The Appalachians in eastern Canada and the western Canadian Cordillera (Fig.1) are composed primarily of Phanerozoic rocks. Although it was well known that both orogens contain some rocks that are similar to the Precambrian greenstone belts, the historical view has been that these are not greenstone belts because of their assumed continuity with platformal sedimentary rocks and their common tectonic history with those rocks. Modern terrane analysis refutes that view, however, and both orogens are now viewed as collages of "suspect terranes" that have been accreted to the North American continent; many of these terranes have no primary continuity with their neigbours and have independent tectonic histories. There are, therefore, no compelling reasons to continue to regard the greenstone components of these orogens to be substantially different from those of the Canadian Shield.

Definition

There is no fully satisfactory definition of what makes a greenstone belt unique. The English term "greenstone" implies but one thing, rocks of relatively mafic composition metamorphosed to assemblages containing any or all of epidote, actinolite and chlorite; such assemblages tend to be diagnostic of the prehnite-pumpellyite, greenschist and low to middle amphibolite facies of Turner. Indeed, most Canadian greenstone belts conform to this rule. Komatiites were once cited as diagnostic of greenstone belts but their importance has generally been over-estimated and the majority of Canadian greenstone belts, even those of Archean age, lack komatiites. Banded iron formation is a common component of greenstone belts but its abundance is variable from belt to belt and many greenstone belts lack significant banded iron formation. The only recurring feature of Canadian greenstone belts is their abundant quantities of metabasalt which is most commonly pillowed, and most workers consider this to be the only essential ingredient of a greenstone belt. However, rather than defining what a greenstone belt is, it is perhaps more useful to review their common components and compare these components in greenstone belts of different ages.

Metavolcanic Rocks

As noted above, basaltic rocks are the most abundant component of greenstone belts, particularly in their lowermost portions. Tholeiitic basalts predominate and are commonly pillowed and variolitic and record subaqueous deposition. Magnesian basalts are relatively common in the lower parts of greenstone belts and calc-alkaline basalts dominate the upper parts of some belts. Although calc-alkaline andesites, dacites and rhyolites form significant proportions of the metavolcanic successions, their abundance has been over-estimated in the past because many whole rock chemical analyses recorded the effects of hydrothermal alteration rather than primary composition. Komatiitic volcanic rocks occur in some Archean greenstone belts. They have also been reported in a few Proterozoic greenstone belts as have less magnesian rocks of the bonninite suite. Paleozoic greenstone belts in Newfoundland contain komatiitic basalts but no komatiites. This progression towards less magnesian lithologies with decreasing age of greenstone belts is thought to represent secular cooling of the mantle rather than a difference in tectonic setting among greenstone belts of different age.

Metasedimentary Rocks

The metasedimentary components of greenstone belts fall into four categories:

1) Most common are metamorphosed greywacke-mudstone successions that contain normally graded beds, rare cross-bedding of ripple drift type and locally complete Bouma seqences. These have been interpreted by most sedimentologists to represent turbidites originating in oceanic accretionary wedges. Most rocks of this type are concordant to metavolcanic rocks in greenstone belts but also are commonly separated from them by tectonic contacts.

2) Polymictic conglomerate and trough cross-bedded sandstone of local derivation is commonly found above angular unconformities that formed in the late stages of greenstone belt development. These sedimentary rocks are interpreted to be of alluvial-fluvial origin and, in some cases, are intercalated with alkaline volcanic rocks to form the Temiskaming-type sequences of Archean greenstone belts and the Missi-type of the Early Proterozoic belts of Canada.

3) Least common are the mature orthoquartzite-dolomite successions which are found locally in the oldest (¢2800 Ma) greenstone belts in Canada. These sequences also contain komatiites and banded iron formation and typically are preserved above angular unconformities developed on older Archean tonalite. The dolomites contain algal stromatolites and fossil gypsum casts suggesting a shallow marine environment. Most workers consider these poorly preserved rocks to represent the early rifting of ancient continental crust.

4) Banded iron formation and chert are well known chemical sedimentary products in greenstone belts. Such rocks are particularly well developed in Archean greenstone belts but also occur in Canadian greestone belts of early Proterozoic and Paleozoic age. They, like komatiites, are less common in younger greenstone belts, possibly because of secular changes in the composition of the Earth's atmosphere and oceans.

Intrusions

Intrusive rocks comprise over 50 percent of the volume of granite-greenstone terranes. Intrusions internal to greenstone belts form a small fraction of this volume and occur as synvolcanic layered sills ranging in composition from peridotite, through gabbro and anorthosite, to tonalite and trondhjemite and also as syn- to late tectonic stocks of a potassic suite containing monzonite, granite and syenite. Intrusions external to greenstone belts form larger batholithic bodies, typically composed of tonalite-trondhjemite-granodiorite with the relative age of the various phases ranging from synvolcanic to syntectonic. Only in local cases have batholithic rocks been shown to be older than the greenstone belts that they surround.

Structure

The structure of greenstone belts has, in the past, been interpreted to be rather simple and involve the formation of large upright synclines and anticlines. Many recent studies have shown their structure to be more complex with the local development of early thrusts and nappes prior to upright folding and major shear zones (tectonic slides) at the same time as and after folding. The latest stages of shearing invariably involved strike-slip faulting. Diapiric emplacement of batholiths was once thought to be an important mechanism of greenstone belt deformation but this is now regarded to be only of local importance and it is now recognized that many of the structures in greenstone belts are controlled by tectonic axes at scales much larger than any single belt.

Metallogeny

Apart from the iron resources contained in the Archean banded iron formations, greenstone belts of all ages are characterized by three important metallogenic components:

1) volcanogenic massive sulfide deposits which formed by seafloor volcanic processes;

2) lode gold deposits which typically are composed of quartz-carbonate veins formed during the orogenic stages of greenstone development;

3) Ni-Cu and Cu-Au deposits hosted by layered ultramafic/ mafic sills, internal plutons, and komatiites. Layered or zoned ultramafic/mafic intrusions in greenstone belts also contain minor concentrations of Ti,Cr,V and Pt but these rarely occur in commercially exploitable amounts.

Origin

The most popular models of the 1960's and 1970's portrayed greenstone belts as ensialic rift basins that were deformed by diapiric reactivation of the sialic basement. The numerous precise ages obtained from Precambrian greenstone belts now refute many aspects of such a model and many North American geologists now propose that greenstone belts are accreted remnants of oceanic island arcs, seamounts and ocean floor (e.g. Card,1990). Recent comparisons have also been made between greenstone belts and Phanerozoic ophiolites and, although most greenstone belts are somewhat different from ophiolites, it is possible that these two tectonic features have some common elements of origin.

AN OVERVIEW OF CANADIAN GOLD DEPOSITS

Gold is a commodity that occurs in a wide variety of geological settings and ore deposit types in Canada. *Byproduct* gold from volcanogenic massive sulphide deposits, nickel-copper deposits, porphyry copper-molybdenum deposits and the Chibougamau copper deposits accounts for approximately one-third of Canadian resources. The remainder occurs in *gold-only* deposits which comprise *placers*(5%) and bedrock sources(60%) which are termed *lode gold* deposits. Lode gold deposits are present in all of the major tectonic subdivisions of the Canadian landmass but occur dominantly in terranes with an abundance of volcanic and clastic sedimentary rocks of low to medium metamorphic grade. Economically viable deposits are concentrated primarily in the Archean greenstone terranes of Superior and Slave Provinces, with lesser numbers in the Mesozoic/Cenozoic rocks of the Cordillera, the Proterozoic greenstone sequences of the Trans-Hudson Orogen and the Grenville Province and the Paleozoic sequences of the Appalachians.

Models

Models are conceptual constructions that typify a group of deposits with broadly similar characteristics. Ideally, models should not coincide in detail with any one single deposit but should attempt to accomodate the common characteristics of the group. There are many types of ore deposit models including:

a) DESCRIPTIVE MODELS - tectonic setting, host rocks, structure, hydrothermal alteration, ore composition, relative age of ore;

b) GENETIC MODELS - source, transport, and deposition mechanisms; key geological processes related to ore;

c) TONNAGE - GRADE MODELS - the size, shape amd metal concentrations that are economically viable;

d) EXPLORATION MODELS - key geological, geochemical and geophysical parameters of deposits that can be used in a practical way in the search for additional mineral resources;

Genetic Models

The <u>genetic</u> classification of hydrothermal gold deposits in Canada, as is the case elsewhere in North America, is still largely influenced by the classification of Lindgren who divided hydrothermal ore deposits, including those of gold and silver, into "thermal" types such as *epithermal*, leptothermal, now termed *transitional* (Panteleyev, 1986), and *mesothermal*. Ore deposit geologists now fully appreciate that thermal conditions for gold and silver deposition are rather similar (200-400 degrees C) for all of these thermal types so that Lindgren's choice of terms was unfortunate. Nonetheless, Lindgren also recognized that his scheme also applied in a qualitative way to the <u>depths</u> in the earth's crust at which various types of deposits form (Fig. 2) and it is this concept from his classification scheme which has persisted to the present day. Thus, *epithermal* gold deposits are those for which there is evidence of a shallow crustal origin (less than 1 or 2 km), *transitional* deposits are those inferred to have formed at 1 to 4 km and *mesothermal* deposits at 3-10 km.

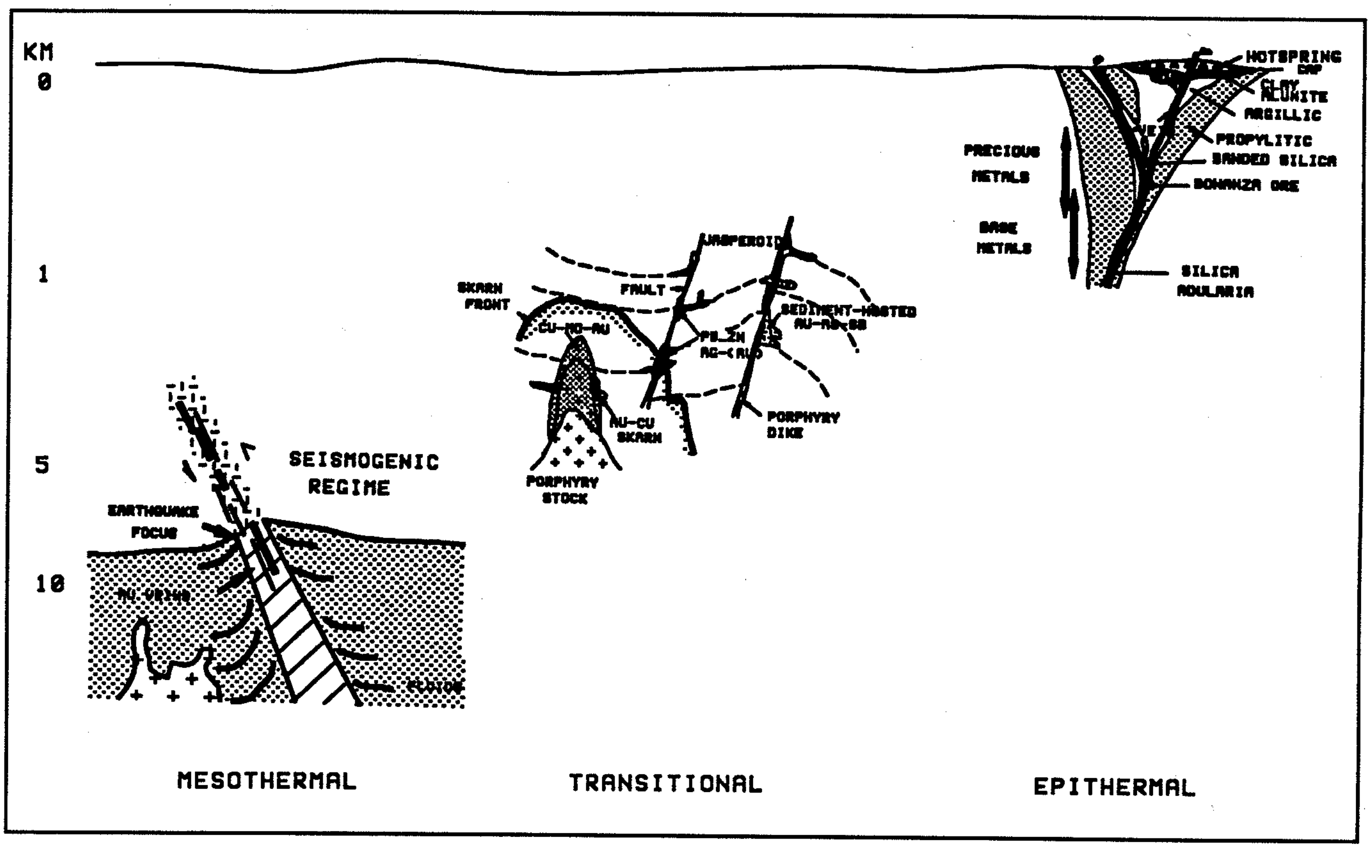


Figure 2: Schematic models of the crustal settings of gold deposits. Mesothermal after Sibson et al.,1988; Transitional after Sillitoe and Bonham, 1990; Epithermal after Buchanan as reproduced in Panteleyev, 1986.

The depth ranges implied for each of the three types are not firmly fixed but are guidelines that reflect variations in the following process-related parameters:

i) lithostatic pressure
ii) fluid pressure
iii) crustal temperature and metamorphic facies transitions
iv) availability of meteoric fluids
v) brittle-ductile fields of deformation and seismicity

For example, in areas of high heat flow such that both the brittle-ductile transition and metamorphic facies boundaries occupy elevated positions in the crust and, where a reduced permeability permits establishment of high fluid pressures, it is theoretically possible that the depth interval between the epithermal and mesothermal could be substantially compressed to 2 or 3 km. Burial and uplift histories are also important factors in assigning the gold deposits to a particular depth zone because they can result in the superposition of mineralization that characterizes one zone onto another.

Descriptive Models

Canadian lode gold deposits, as a group, possess such a diversity of geological characteristics that there is little consensus among geologists as to their division into genetic types. There are, however, four commonly used descriptive models for Canadian gold deposits based on their geological setting and the nature of the ore comprising the deposit.

Of paramount importance are the abundant **quartz-carbonate vein** deposits that typify greenstone terranes of all ages; because their inferred conditions of formation are compatible with the low to medium metamorphic grade of their host rocks, these deposits are also commonly referred to as mesothermal vein deposits. Such deposits typically contain ubiquitous but low concentrations of sulphide minerals(1-10%) within or adjacent to veins. Where the proportion of wall-rock sulphides to vein material are high, orebodies take on the appearance of the "silicified, sheeted, or veinlet zones" that are a common component of many gold deposits of vein type.

Quartz-carbonate vein deposits account for approximately 80% of the production from Canadian lode gold deposits. The Canadian Shield, the Superior Province in particular, contains the most significant producers. Typical examples of these deposits include Goldenville, Nova Scotia; Sigma-Lamaque, Quebec; Dome and Campbell Red Lake, Ontario; San Antonio, Manitoba; Star Lake, Saskatchewan; Bralorne-Pioneer and Cariboo-Island Mountain, British Columbia. The deposits consist of simple to complex vein systems with significant vertical extent (in some cases greater than 2 km), hosted by folded and metamorphosed volcanic and clastic sedimentary sequences. The veins are typically distributed adjacent to faults of regional scale and occupy shear zones, faults, stockwork zones and extensional fractures, or are associated with folds. The veins are generally discordant to their host rocks, except for those hosted by shear zones and faults that are parallel to lithological contacts. The veins are composed mainly of quartz, with less abundant carbonate and pyrite. Commonly associated minerals include tourmaline, scheelite, fuchsite and arsenopyrite. Hydrothermal alteration of wallrocks is dominated by carbonatization, accompanied by alkali metasomatism and sulfidation of the rocks immediately adjacent to the veins. Genetic models for these "mesothermal" veins are still the subject of much debate; these include orthomagmatic, metamorphic, deep meteoric circulation, mantle degassing, lower crustal granulitization, and mixed fluid models. Despite the great uncertainty about the source of gold and fluids, it is clear that these veins are a product of collisional orogenesis.

Stratabound sulphide-rich lode gold deposits, unlike most quartz-carbonate veins, are particularly rich in sulphide minerals (10-70%) and these sulphides do not show any particular relationship in their distribution to associated veins. Such deposits have been termed "replacement" deposits in the past but, because of the inherent genetic implications, it is preferable to regard these gold sulphide deposits as belonging to one of two sub-types: those hosted typically by mica schists and those hosted by iron formation.

Schist-hosted sulfide gold deposits represent approximately 15 percent of Canada's historical production and reserves. Typical examples include the Chetwynd deposit in Newfoundland, the Bousquet River and Montauban deposits in Quebec, the Hemlo and Madsen deposits in Ontario, the McLellan deposit in Manitoba and the sulfide lodes of the Island Mountain Mine in British Columbia. These deposits comprise stratabound, auriferous bodies of disseminated to massive sulfides, typically pyrite, that are hosted by micaceous and/or aluminous schists derived most commonly from tuffs, volcanic sandstones or sandstones. They are sulfide-rich gold deposits in which ore distribution is not dictated by vein quartz and, with few exceptions they have low contents of base metals and a gold content exceeding that of silver. The deposits are stratabound at the district and deposit scale but they occur in metamorphic terranes affected by a transpositional style of deformation so that it is difficult to determine whether the stratabound nature is primary. Orebodies are closely associated with zones of potassium silicate alteration and locally with peripheral aluminous alteration assemblages. Genetic models for these deposits are poorly established and two contrasting opinions prevail. One is that the deposits predate deformation and are exhalative or epithermal deposits that have been remobilized by overprinting deformation and metamorphism. The other is that they are related to the quartz-carbonate vein type of deposit and differ only in that the ores have formed by wallrock replacement rather than vein filling. Some sulfide-rich gold deposits are hosted by banded iron formation and these represent approximately 5 percent of total lode gold production and reserves. These deposits occur only within the Canadian Shield and important Canadian examples include the Agnico Eagle deposit in Quebec, the Hardrock and Central Patricia deposits in Ontario, the Farley deposit in Manitoba and the Lupin deposit in the Northwest Territories. All of these deposits occur in complexly folded iron formation containing quartz veins but the ore consists primarily of massive sulfides that are developed adjacent to the veins. Pyrite, pyrrhotite and arsenopyrite are the typical sulfide minerals and carbonate alteration is common in the vicinity of orebodies. The host iron formation is typically of the chert magnetite type and at many deposits it is clear that the sulfide ores have formed by replacement of magnetite by sulfur-bearing fluids that are related to vein formation. Because of this, most geologists do not regard these deposits as exhalative in origin even though the iron formation itself is a chemical precipitate of volcano-sedimentary origin. At some deposits such as Lupin, however, the distribution of gold is not strictly related to veins and an argument can be made in favour of an exhalative origin for the sulfides.

Epithermal gold deposits, by virtue of their formation at or near a paleosurface, possess chemical, mineralogical and structural characteristics that serve to distinguish them from the other three types. They can occur in both continental and island arc environments, typically in volcanic sequences but also can be found to extend into the basement below volcanic units (Sillitoe, 1989). Deposits of epithermal type account for approximately 5 percent of Canada's lode gold production and reserves. Most deposits of this type occur in Mesozoic and Tertiary rocks in the Canadian Cordillera and important examples include Mt. Skukum in the Yukon Territory, and the Blackdome, Cinola and Toodoggone deposits in British Columbia. These deposits occur in non-metamorphosed volcanic and sedimentary terranes. Following conventional nomenclature (i.e Heald et al.,1987) these deposits are divisible on the basis of their mineralogy and geological setting into acid-sulfate, adularia-sericite and hotspring types. Epithermal gold deposits typically occur in steeply dipping brittle faults and fractures that may also have served to localize intrusions.

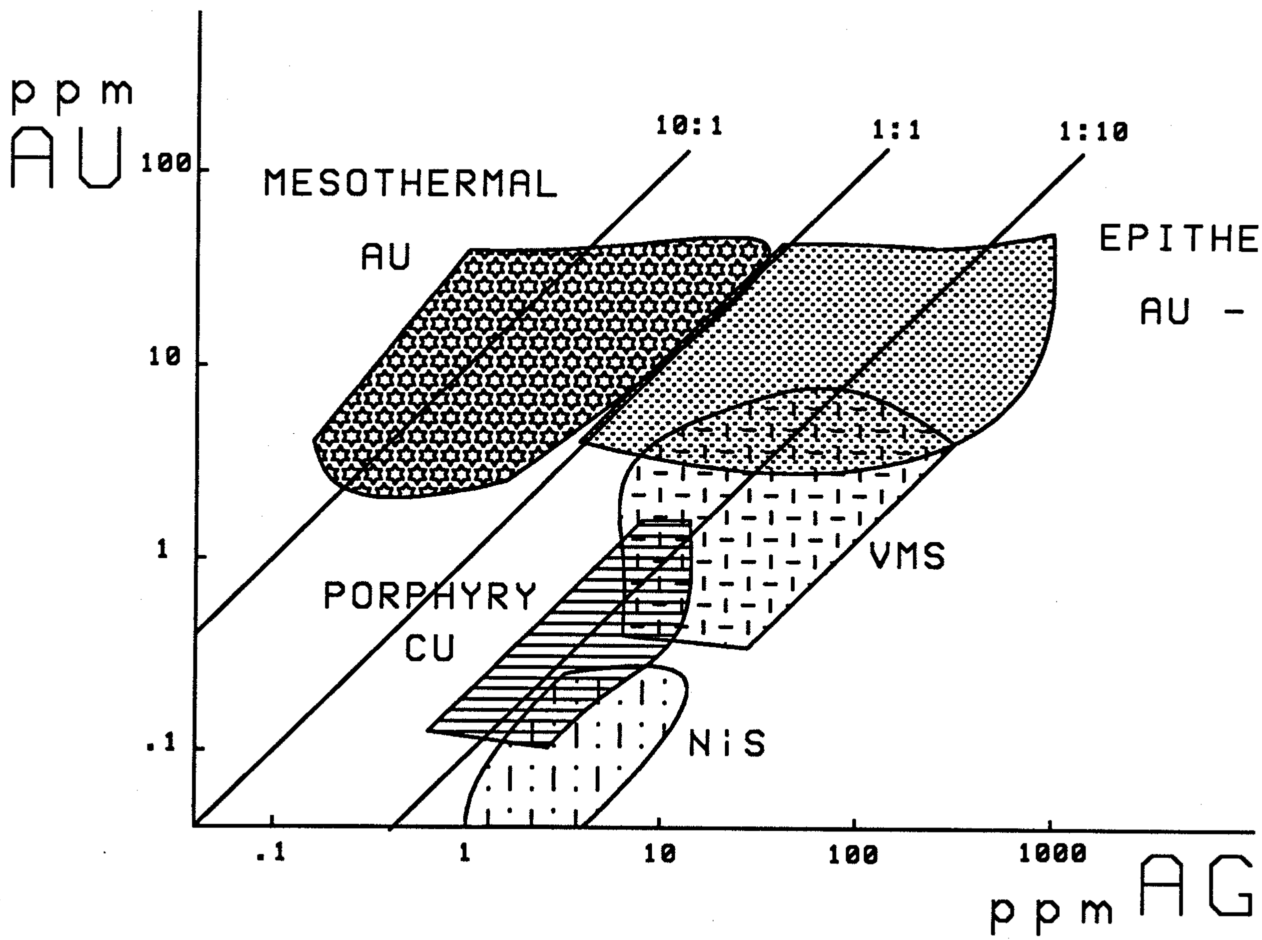


Figure 3: Gold versus silver concentrations in a variety of gold-bearing mineral deposit types.

Such fractures include intrusion-related structures such as caldera ring fractures, radial fractures, as well as faults and fractures related to regional fault systems. Quartz is the predominant gangue mineral in all epithermal deposits but calcite, chlorite, adularia, barite and cinnabar are common; alunite is important in acid sulfate and hotspring deposits. Common ore minerals include native gold, electrum, sulfosalts, tellurides and bismuthinite. Silver contents commonly exceed that of gold in epithermal deposits by contrast with mesothermal deposits (Fig 3). By contrast with the mesothermal gold deposits in greenstone belts, epithermal deposits commonly are zoned vertically and laterally with respect to the abundance and species of minerals containing gold, silver and base metals; epithermal systems rarely contain deep (¢500 metres) orebodies but these are commonly persistent along their strike. Mineralogical and textural evidence, isotopic data and geologic reconstruction all support a shallow crustal origin of epithermal deposits in association with magmatic centres, both extrusive and intrusive. Both magmatic and wallrock sources are thought to contribute the chemical constituents of epithermal gold deposits.

Transitional (Panteleyev, 1986) gold deposits include skarns, mantos and Carlin-type sediment-hosted gold-arsenic-antimony deposits (Sillitoe and Bonham, 1990). These deposits are thought to have formed at one to three kilometres of crustal depth in association with felsic intrusions, some parts of which may contain porphyry copper-molydenum mineralization. They also occur in terranes containing fine grained carbonate and siliclastic rocks that commonly host orebodies away from intrusive centres. Canadian examples of transitional deposits include Cinola (Carlin-type?), Hedley (skarn) and Ketza River (manto). Intrusion-associated vein deposits possessing some characteristics of porphyry systems and included in the transitional category are Equity, Zeballos and Rossland (Panteleyev, 1986).

APPLICATION TO NORTH CHINA PLATFORM: THE MAIN CONCLUSIONS OF THIS REPORT

By comparison with the characteristics of Canadian gold deposits and their settings, as outlined above, the following chapters contain information on the Archean rocks and their spatially associated gold deposits in North China Platform. Based on this information it is possible to conclude that:

1) The Archean rocks exposed in the uplifts within North China Platform are substantially different from those in the Archean greenstone belts of the Canadian Shield. The Archean rocks in NCP belong to high grade gneiss belts with local relict roots of greenstone belt material; most of the rocks in NCP are felsic and mafic orthogneisses of TTG type (Chapters 2,8).

2) Gold deposits in NCP are different from the mesothermal greenstone gold deposits of the Canadian Shield and therefore exploration programs that are designed on the basis of greenstone gold models are likely to fail. The gold deposits in the Liaoxi area (Chapters 3,4) have great similarity to the adularia-sericite type (bonanza)

epithermal deposits of the North American Cordillera (i.e. Blackdome, B.C. and Creede, Colorado). The large "Linglong"- and "Jiaojia"-type deposits in Eastern Shandong Province are hosted by large Mesozoic granitoid intrusions and don't have any direct Canadian analogues; they do however, have characteristics that are analagous with transitional geological environments and granite porphyry systems (Chapter 5).

3) The most important geological controls on the gold deposits of North China Platform are Mesozoic magmatic and hydrothermal activity coeval with Mesozoic upper crustal brittle faulting. The role of Archean gneiss is indirect - the Archean rocks are exposed only in basement uplifts created during the Mesozoic (Chapters 3,5).

4) Based on preliminary geochronological studies by J.K. Mortensen (Chapter 6), it appears that the gold deposits in the Liaoxi and Jiaodong uplifts formed in Early Cretaceous time.

5) Preliminary light stable isotope determinations by B.E. Taylor (Chapter 7) show that meteoric fluids were involved in the formation of the deposits so that recognition of the Cretaceous paleosurface will be important for future exloration.

6) Future research on the gold deposits in North China Platform should include the preparation of metallogenic maps for individual gold districts. Such maps should portray not only the distribution of gold deposits but also known occurrences of porphry Cu-Mo, vein W-Mo, base metal skarn and polymetallic vein mineralization. Such a metallogenic approach (see for example, Sillitoe, 1989) may reveal large-scale patterns of metal zonation that would be useful in identifying gold potential at the regional scale.

REFERENCES

Heald, P., Foley, N.K. and Hayba, D.O.
1987: Comparative anatomy of volcanic-hosted epithermal deposits: acid-sulfate and adularia-sericite types; Econ. Geol., v.82, p.1-26.

Panteleyev, A.
1986: A Canadian Cordilleran model for epithermal gold-silver deposits; Geoscience Canada, v.13, p.101-111.

Sibson R.H., Robert, F. and Poulsen K.H.
1988: High-angle reverse faults, fluid pressure cycling, and mesothermal gold-quartz deposits; Geology, v.16, p.551-555.

Sillitoe, R.H.
1989: Gold deposits in western Pacific island arcs: the magmatic connection; Economic Geology Monograph No.6, p.274-291.

Sillitoe, R.H. and Bonham H.F. Jr.
1990: Sediment-hosted gold deposits: Distal products of magmatic hydrothermal systems; Geology, v.18, p.157-161.

Chapter 2

A REVIEW OF THE GEOLOGY OF GOLD DEPOSITS IN NORTH CHINA PLATFORM

Lin Baoqin and Shen Ershu

INTRODUCTION

North China Platform is one of the most important areas of gold production in China. Its gold deposits commonly occur in Archean terranes which contain mainly metamorphic rocks of the amphibolite facies with granulite facies rocks nearby. They also occur in post-Archean anatectic granites, in syntectonic granites which include the Yanshan type and in Mesozoic volcanic rocks. About two thirds of China's endogenic gold deposits and about 80 percent of its gold reserves are in the North China Platform, particularly in Archean rocks.

There are two zones of Archean rocks in the northern part of North China Platform. The northern one parallels its northern margin and contains the Baishanzhen and Anshan Groups in Jilin Province, the Jingjiagou Formation and Anshan Group in the Fushun Area in Eastern Liaoning Province, the Jianping Group in Western Liaoning, the Wudaohe and Dantazi Groups in northern Hebei and the Jining and Wulashan Groups in Inner Mongolia and so on. The southern or inner zone contains the Qianxi and Badaohe Groups in Eastern Hebei, the Wutai and Fuping Groups in Shanxi Province, the Anshan Group in Eastern Liaoning Peninsula and the Jiaodong Group in Shandong Peninsula.

There is only one zone of Archean rocks in the southern part of North China Platform and this consists of the Taihua Group in Xiaoqinling district on the border between Henan and Shaanxi Provinces and the Dengfeng Group in Henan Province (Fig. 1).

Early Proterozoic supracrustal rocks are distributed marginal to, and in down-warped belts within, the Archean craton.

In the northern part of North China Platform post-Archean anatectic granites and syntectonic discordant granites of various ages occur within the Archean rocks and many of the Archean rocks are overlain by Mesozoic volcanic and sedimentary rocks.

The Archean rocks typically comprise TTG complexes (50 to 70% of total) and supracrustal rocks (30 to 50%). The TTG complexes are most commonly composed of trondhjemite, tonalite and granodiorite with subordinate quartz monzonite, monzonite and monzonitic granite. The supracrustal rocks, the protoliths of which may be volcano-sedimentary rocks, are typically gneiss, leptynite, amphibolite and magnetite quartzite with minor pyroxenite. Primary textures are rarely preserved. The Jining Group in Inner Mongolia, in part, is dominated by a khondalite series, the protoliths of which may be claystone and siltstone with volcanic rocks.The metamorphic grade of the Archean rocks is typically up to the granulite and amphibolite facies. A granulite belt 1500 kilometres long and 200 kilometres wide parallels the northern margin of NCP (Cui Wenyuan et al., 1988).

Qin Nai et al. (1988) divided the Archean supracrustal rocks into three volcano-sedimentary megacycles, termed A, B and C. Megacycle A is older than 2900-3000 Ma. The supracrustal rocks in the Baishanzhen Group and Jinjiagou Formation of the Huadian-Fushun area and the Qianxi Group of Eastern Hebei can be assigned to this megacycle. Thus, Megacycle A is distributed mainly in the northern part of the North China Platform. The metamorphic rocks of this megacycle are generally of granulite facies or upper amphibolite facies. The age range of megacycle B is between 2900-3000 Ma and 2700-2800 Ma. The supracrustal rocks of the Shipengzi and Tongshicun Formations in the Huadian-Fushun area and of the Xiaotazigou Formation in Western Liaoning partly belong to this megacycle and the Badaohe Group in Eastern Hebei probably also belongs to it. The metamorphic rocks of this megacycle are generally of amphibolite facies and locally of granulite facies. The age range of megacycle C is between 2700-2800 Ma and 2500 Ma. The supracrustal rocks assigned to this megacycle are the Anshan Group in Huadian County of Jilin Province, the Taihua Group in Xiaoqinling district, the Jiaodong Group in Shandong Peninsula. The metamorphic rocks of this megacycle are generally in the amphibolite facies, and locally in the granulite facies.

Qin Nai et al. (1988) pointed out that the Archean terranes of North China Platform have undergone multiple phases of intrusive activity and the TTG complexes can be divided accordingly. Rb-Sr and Pb-Pb ages of 2830-2860 Ma obtained from the Tiejiashan granite in Anshan (Zhong Fudao, 1984), a K-Ar age of 2800 Ma from the soda granite in Qingyuan County (Yan E et al., 1981), and a Rb-Sr age of 2971+/-65 Ma from tonalite in Jiapigou, Huadian County (We Jiahon et al., 1986) can be assigned to the first phase. U-Pb ages of 2690 Ma from tonalite in Dongshibapan, Eastern Shandong (Yu Hanmao et al., 1985), of 2700 Ma from tonalite in Taishan, Shandong (Jahn Borming, 1987) and of 2565 Ma from trondhjemite in Shandaogou, Huadian County (Lin Baoqin, 1986), are representative of the second phase and Rb-Sr ages of 2446+/-23 Ma and 2443+/-55 Ma from tonalite in Eastern Hebei (Wang Kaiyi, 1987) of the third phase.

North China Platform also experienced intense mobilization in Mesozoic Era with magmatism resulting from subduction of the Pacific Plate beneath the Asian Plate. The Mesozoic granites can be assigned to two phases: the Indo-China and Yanshan phases. Six magmatic suites such as the gneissic granite, syenite, monzonite, biotite granite, alkali-granite and megacrystic granite series have been recognized (Mu Kemin et al., 1989). For example, in Shandong Province the Kunyushan and Linglong intrusions belong to gneissic granite series and Guojialing intrusion, to the megacrystic granite series.

Mesozoic volcanic and sedimentary rocks in North China Platform are mainly found in Western Liaoning and may be divided into five cycles in ascending order as follows: Xinglonggou (J1), Lanqi (J2), Yixian (J3), Jianchang (K1), and Zhaoduba (K2). The Yixian and Jianchang cycles are the most extensive and volcanic eruptions of both cycles were intense. Rocks of the five cycles are predominantly intermediate, with minor basic and acid compositions.

Mu et al. (1981), after studying the genesis and distribution of the main gold deposits in China, advanced the new concept of "gold concentration areas" and recognized seven such areas in the Archean of the North China Platform (Fig. 1), and named them the Huadian-Fushun area, the Yanshan area, the Zhangjiakou-Chifeng area, the Lingbao (Xiaoqinling) area, the Zhaoyuan-Rushan area, the Wutai area and the Dandong-Yinkou area. Mu Ruishen emphasized that these are merely spatial divisions that do not imply a mode of genesis. The seven areas of concentration of gold mineralization, according to Mu Ruishen's scheme, are described individually in the following sections.

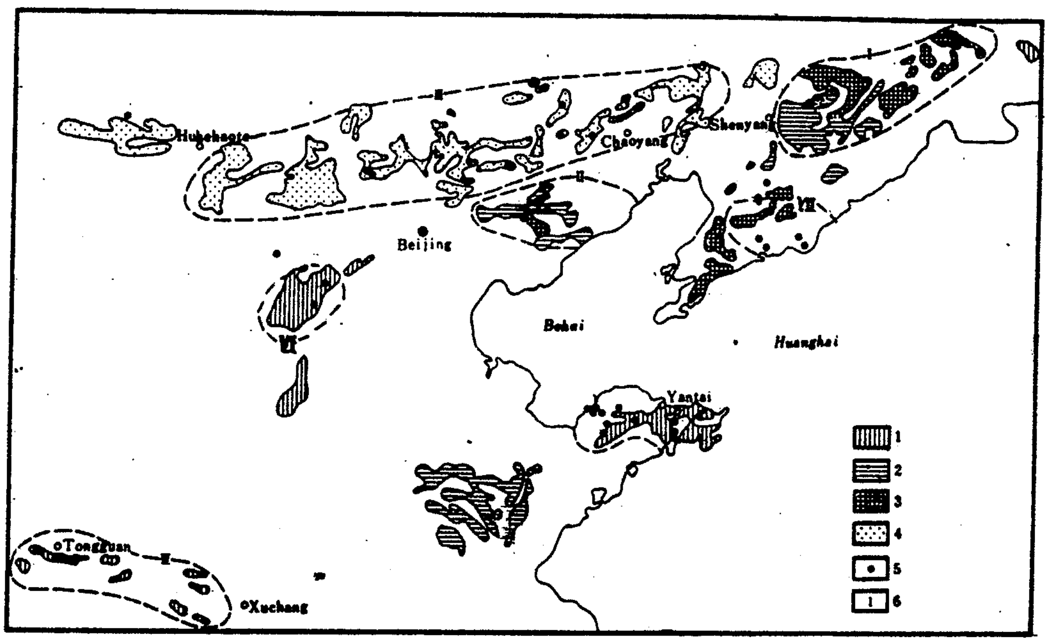


Figure 1: Distribution of Archean rocks and their related gold deposits in North China Platform.
1.Megacycle C 2.Megacycle B 3.Megacycle A 4.Archean undivided
5.Gold Deposits 6.Concentration area of gold mineralization (I-Huadian-Fushun, II-Yanshan, III-Zhanjiakou-Chifeng, IV-Lingbao, V-Zhaoyuan-Rushan, VI-Wutai, VII-Dandong-Yinkou).

HUADIAN-FUSHUN AREA

This area is bounded by a line between Huadian and Tieling in the north and by a line through Jian and Benxi in the south. The Chifeng-Kaiyuan Break passes through this area and divides the area into two parts: the north one belongs to the southern margin of Zhangguancailing Eugeosyncline and the south one belongs to the Tieling-Jingyu Kern of North China Platform. Therefore, it is located at the conjunction of two major tectonic units (Fig. 2).

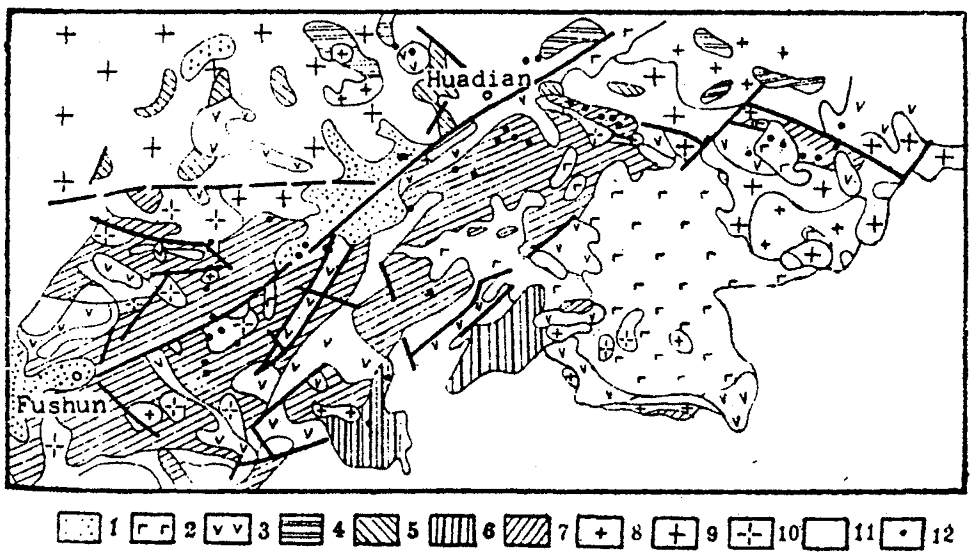


Figure 2: Geology of the Huadian-Fushun Area
1.Quaternary System 2.Quaternary basalt 3.Mesozoic volcanics 3.Carboniferous metamorphic rocks 5.Hulan Group 6.Proterozoic metamorphic rocks 7.Archean metamorphic rocks 8.Yanshanian granite 9.Hercynian granite 10.Archean/Proterozoic granite 11:other 12:gold deposits/occurrences.

The area is underlain by the Archean Anshan and Baishanzhen Groups, the Proterozoic Laoling Group, the Paleozoic Hulan Group and the Carboniferous Luquantun Formation. Proterozoic, Hercynian and Yanshanian intermediate acidic stocks occur in the southern part whereas Hercynian granites are well developed in the northern part of the area.

This is one of the most important areas of gold production in North China Platform. More than ten gold mines of large-medium size occur in this area, as well as several small deposits that are hosted by metamorphic rocks of the Anshan Group. Subordinate numbers of gold deposits are hosted by metamorphic rocks of the Laoling Group, as well as by the Hulan Group, the Carboniferous system and granite of different ages. The Tieling-Jingyu Kern is about 500 kilometres long, from Helong of Jilin Province in the east to Fushun of Liaoning

Province in the west. In Jilin Province, the Jinchengdong gold deposit in Helong County, the Haigou gold deposit in Antu County, the Jiapigou gold camp in Huadian County, the Shipangou gold deposit in Huinan County , and, in Liaoning Province, the Xianjincheng gold deposit in Qinyuan County are all located within the Tieling-Jingyu Kern which coincides spatially with the occurrence of Archean plagioclase amphibolite of the Anshan Group.

Jiapigou Gold Camp

This district is located at the northern part of the concentration area and of the Tieling-Jingyu Kern. The camp (Fig.3) is approximately 50 kilometres long and one to three kilometres wide and includes more than ten gold deposits such as Jiapigou, Banmiaozi, Sandaocha, Bajiazi, Erdaogou, Miaoling, Sidaogou, Xiaobeigou, Caichangzi, Laoniugou and Daxiangou gold deposits which are all hosted by Archean plagioclase amphibolite of Anshan Group. Three episodes of deformation and two metamorphic cycles have been recognized in these rocks. The regional tectonic trend strikes NW and an intense dynamic metamorphic zone striking NW also passes through the area (Fig.3). Trace element geochemical data (Lin et al., 1986) show that the abundances of gold are approximately thirty time higher than Clark Value in some of these host rocks. The gold deposits mentioned above are clustered in the proximity of the dynamic metamorphic zone.

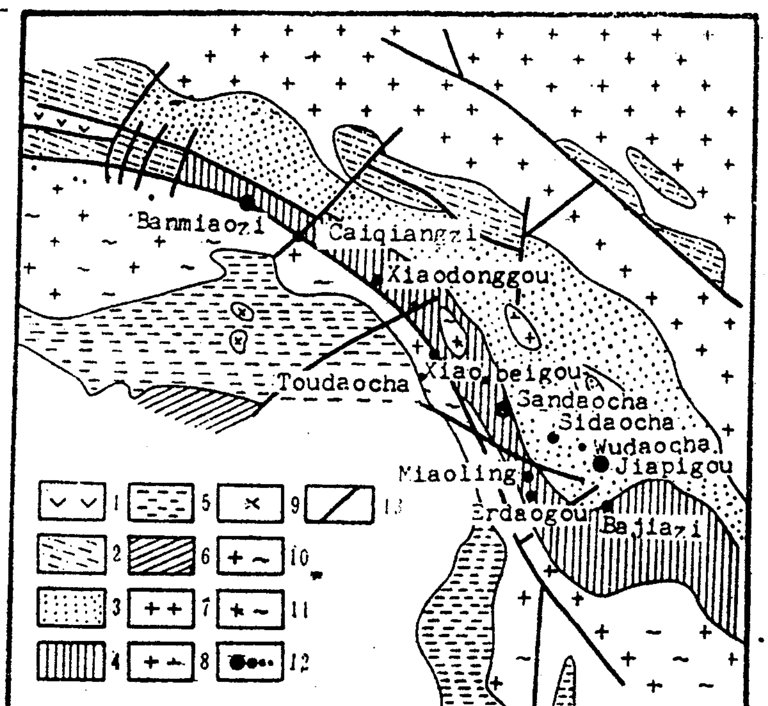


Figure 3: Geolgy of the Jiapigou gold camp
1.Jurassic volcaniclastic rocks 2.Hulan Gp 3. Sandaogou Fm of the Anshan Gp 4.Jiapigou Fm of the Anshan Gp 5.,6. high grade metamorphic rocks 7. Hercynian granite 8.Hercynian granodiorite 9.Hercynian mafic rocks 10.migmatitic granite 11.Archean granite 12.gold deposits 13.faults

The gold-bearing geological bodies comprise gold-bearing quartz veins, silification zones, cataclasite zones, foliated zones and some intermediate-acidic dikes. Of the seventy odd gold veins, single veins are in the majority. Alteration can be divided into three associations: 1. sericitization, silification, chloritization, pyrophyllitization; 2. Chloritization, silification, sericitization, carbonatization and 3. Silification, chloritization, carbonatization, talcitization (talc).

The **Jiapigou** deposit is located at the town of Jiapigou in the southeastern part of the camp and it is the largest one in the camp. Three ore veins have been opened: New No. 1-3 vein, New No. 4 and New No. 6 vein. The New No. 1-3 vein is a big blind ore body 500-600 metres long and deep and hosted by amphibolite. The New No. 4 vein extends to surface and is about 17 metres wide and hosted by amphibolite. New No. 6 vein is a big blind vein ore body with an alteration zone 70 to 90 metres wide in the hanging wall and 15 to 20 metres wide in the footwall. Two types of ore, gold-bearing pyrite ore and gold-bearing polymetallic ore, contain native gold, electrum, calaverite, argentite, pyrite, retzbanyite, chalcopyrite, galena, sphalerite, pyrrhotite, magnetite, scheelite, wolframite and siderite. Gangue minerals include quartz, chlorite, sericite and calcite.

The **Erdaogou** gold deposit is situated several kilometres to the south of the town Jiapigou and is the site of a large scale gold mine. The ore vein is tabular and its depth is double its length. The boundary of ore vein with the wall rock is sharp and regular. The ore types are the same as that of Jiapigou gold deposit. Metallic minerals comprise native gold, pyrite, galena, sphalerite, scheelite and magnetite. Gangue minerals include quartz, chlorite, sericite and calcite.

The **Sandaocha** gold deposit, another large scale mine, is located several kilometres northwest of the town of Jiapigou. The ore body is hosted by amphibolite and amphibole-plagioclase gneiss (Fig. 4). The No. 1-3 vein is a big blind vein that, on surface, is a limonitic breccia zone which contains thin and stable clay lines. Above the fifty metre level, it is predominately a single vein and below that, compound veins. Ore types are the same as that of Jiapigou Gold Mine. Metallic minerals comprise native gold, electrum, silver-bearing native gold, retzbanyite, pyrite, sphalerite, galena, chalcopyrite, marcasite, magnetite, pyrrhotite, scheelite and bismuthinite. Gangue minerals include quartz, chlorite, sericite and calcite (Fig. 4).

Although most mines in this district are hosted by Archean gneiss, it must be pointed out that the Mesozoic porphyritic diorite has also been mineralized, but it is of lower grade. Mesozoic magmatic activity here is generally weak. Therefore, the genesis of these gold deposits has been controversial for many years. Most Chinese geologists believe that they belong to a class of metamorphic hydrothermal gold deposits.

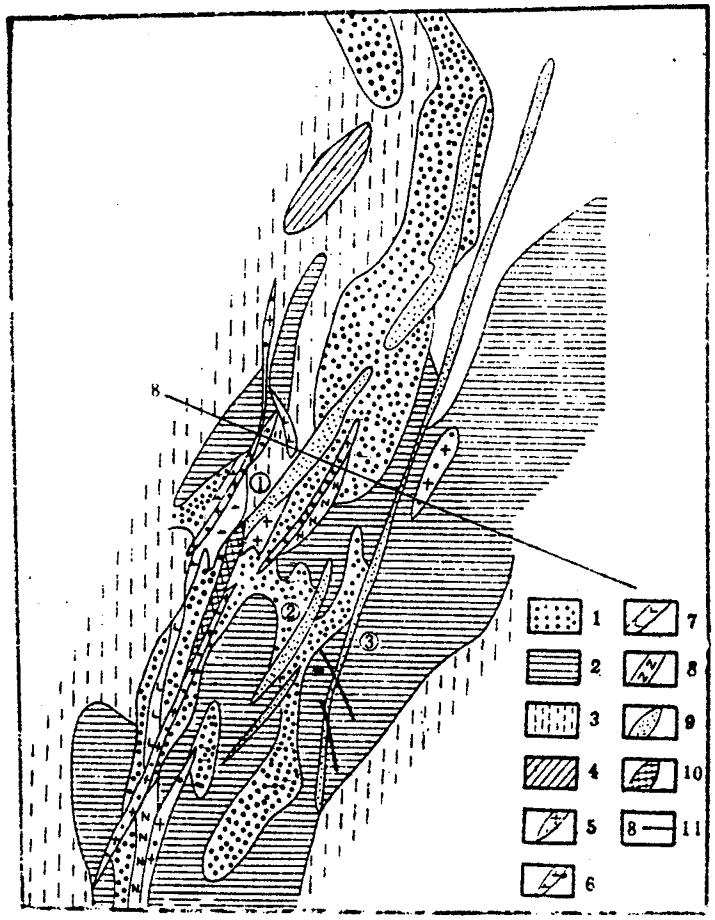


Figure 4:
Geology of the Sandaocha gold deposit
1.,2.,3.Archean gneiss 4.amphibolite 5.feldspar porphyry 6.diorite 7.lamprophyre 8.sericitic zone 9.altered breccia zone 10.gold-quartz vein 11.prospecting line.

Antu gold district

To the east of Jiapigou Camp, the **Haigou** deposit is of large size and hosted by Archean metamorphic rocks. It is situated in Antu County of Jilin Province and at the northern edge of North China Platform. The mine area is underlain by Archean hornblende-plagioclase-gneiss and rocks of a TTG complex. Hercynian granite is exposed in the northern part of the mine and a Yanshanian granite stock intrudes the Archean rocks (Fig. 5). NE faults are well developed. Seven gold-bearing quartz veins occur in the phyllonitized TTG complex rocks and are controlled by faults striking 30-60 degrees NE. They are mainly single veins, with a few zones that are veined and lenticular. The No. 28 ore vein is the main one and consists of No. 28-1, 28-2 and 28-3 veins that are, in total, approximately 1000 metres long, 18 wide and several hundreds of metres deep. Metallic minerals are native gold, calaverite, pyrite, henkelite, galena, chalcopyrite, sphalerite, molybdenite and crystalline uranniobite.

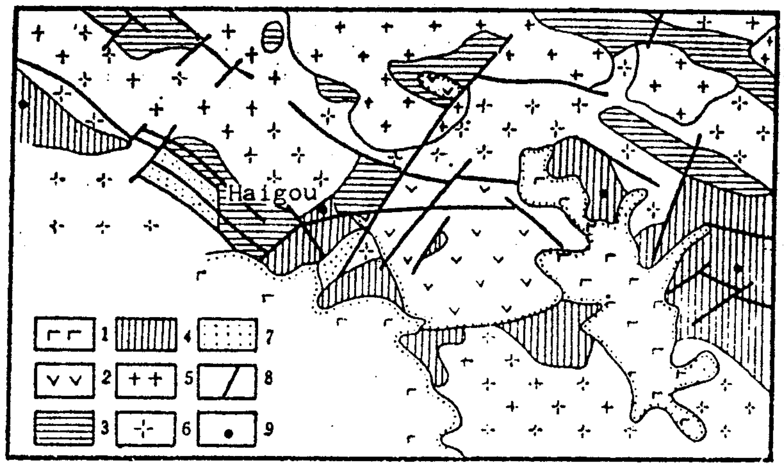


Figure 5: Geology of the Haigou gold deposit
1.Quaternary basalt 2.Mesozoic volcanics 3.Paleozoic metamorphic rocks 4.Anshan Gp 5.Yanshanian granite 6.Hercynian granite 7.Other 8.faults 9.gold occurrences

Other districts

Apart from the large deposits that are hosted principally by Archean metamorphic rocks in the Huadian-Fushun area, gold-bearing quartz-calcite veins and breccia zones can be found in carbonate members of the Zhenzhumen Formation of the Laoling Group as is the case at the **Jinchang** deposit at Tonghua City in Jilin Province. Gold also is associated with polymetallic deposits that occur in the Jian Group. To the north, in the geosynclinal area, some gold mineralization has been found at the Erdaodianzi Gold Deposit in Huadian County which is hosted by the Hulan Group, the Taodaochuan Gold Deposit of Yonji County and the Jinchanggou Gold Deposit of Jian County.

The mine area at the **Jinchanggou** gold deposit is underlain by Jian Group which is intruded by Yanshanian diorite and granite stocks. Skarn was formed in an external zone of the diorite stock. Gold and polymetallic mineralization occur in diorite, in skarn and in granulite, amphibolite and gneiss of the Jian Group which occurs in the periphery of the stocks. Mineralization bodies consist of brecciated zones of carbonatization, silification and pyritization. No. 1 ore zone is composed of the No. 1, No. 1-1, No. 1-2, No. 1-3 and No. 5 ore veins. To the west of the diorite stock, the ore zone extends southwards for a length of approximately 1600 metres with a width of 400 metres. Gold occurs in quartz calcite veinlets (Fig. 6).

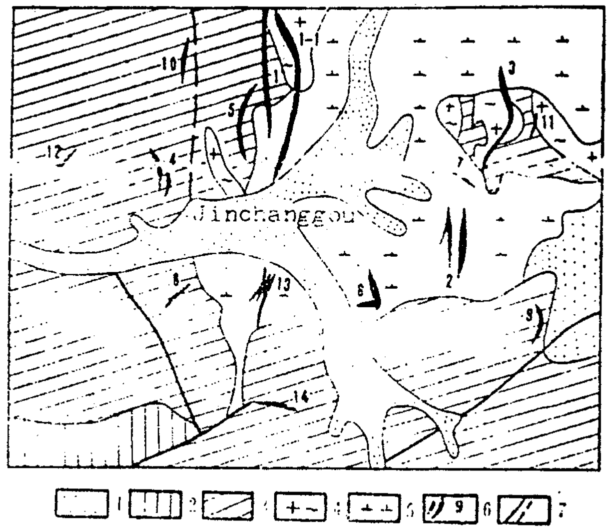


Figure 6: Geology of the Jinchanggou gold deposit, Jian County.
1. Quaternary 2.marble and amphibolite 3.biotite granulite, amphibolite and gneiss 4.TTG complex 5.diorite 6.ore vein 7.fault.

The **Erdaodianzi** gold deposit is located to the northeast of Huadian County and it is large scale. The mine area is underlain by Hulan Group (?) consisting of biotite gneiss and quartz-feldspar gneiss in the lower part, and feldspar-hornblende hornfels, carbonaceous mica-quartz hornfels, garnet-mica-quartz hornfels and mica-quartz hornfels in the middle part. The upper part of the Hulan Group is not exposed in the mine area. The strata strike NWW and dip S or N at angles 60 to 80 degrees. Biotite granite intruded the strata and related dikes include garnet-bearing granite, granite aplite, lamprophyre and gabbro.

The orebodies are hosted by carbonaceous hornfels and feldspar hornfels. The mineralized zone, consisting of three swarms of quartz veins, is about two kilometres long and 300 to 400 metres wide. The No. 1 swarm consists of 23 veins and strikes 290-340 degrees. The No. 2 swarm consists of 72 quartz veins and strikes 290-340 degrees. The No. 3 swarm consists of 24 quartz veins. Among them, the No. 1 swarm is particularly important. The New 1 ore vein is part of this swarm and it is approximately 500 metres long and 450 metres deep. Gold is associated with arsenopyrite, chalcopyrite, pyrite, galena and sphalerite. Two ore types are a quartz-magnetite type and a quartz-pyrite type. The alteration of wallrocks includes silification, pyritization, chloritization, carbonatization, sericitization and skarn. Among them, silification and pyritization are closely related genetically with gold.

To the northwest of Liuhe structural basin in Hailong County, **Xiangluwanzi** is a small gold deposit hosted by Upper Jurassic volcanic rocks that uncomformally overlie the Anshan Group. The Upper Jurassic volcanic rocks are composed mainly of rhyolitic crystal tuff containing fragments of breccia and rhyolitic tuff-lava and are intruded by subvolcanic plagioclase granite. Ore veins occur in the tuff and are controlled by NW trending faults. One hundred and ten ore veins are known and these can be divided into two types: the quartz-sulfide veins and the carbonate-sulfide veins. Generally, they are tens of metres long and the longest are 100 to 200 metres and have depths similar to their lengths. The quartz-sulfide veins are the most abundant and formed earlier than the carbonate-sulfide veins. Gold is associated with pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, and bornite. The deposit contains more silver than gold. Quartz and calcite are gangue minerals. The alteration of the wallrocks includes silification, pyritization, carbonatization, pyrophyllitization and seritization. The first three are closely related with gold in their genesis. This deposit is closely related to Mesozoic volcanic rocks in space and genesis.

YANSHAN AREA

Yanshan is one of the important regions of gold production in China and, geographically, includes Chanping, Miyun, Pinggu, Jixian, Xinglong, Zunhua, Qianxi, Kuancheng and Qinglong Counties in Hebei Province in an area extending 280 kilometres latitudinally and 80 kilometres wide. Suizhong and Jinxi Counties in Liaoning Province may be part of the eastern extension of this area. Geotectonically, it is located in the hinterland of the Yanshan Synclinorium of North China Platform. Upwarped and downdropped segments were controlled by E-W and NW trending faults. In space, the Yanshan Area coincides with an upwarped segment (Fig. 7).

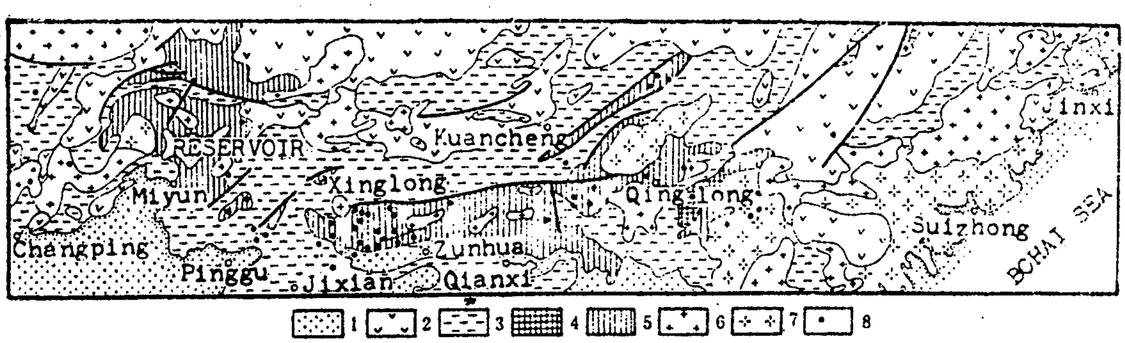


Figure 7: Geology of the Yanshan area.
1.Cenozoic rocks 2.Mesozoic volcanic and clastic rocks 3.Paleozoic and mid- to late-Proterozoic rocks 4.Early Proterozoic rocks 5.Archean rocks 6.Yanshanian granite 7.Precambrian granite 8.gold deposit/occurrence

The Precambrian here includes Archean (seventy percent), Lower Proterozoic (five percent) and Middle-Upper Proterozoic (twenty five percent) rocks (Fig. 8).

The Archean sequences contain both supracrustal rocks and those of TTG complexes. The supracrustal rocks in Eastern Hebei may be divided into two groups, the Qianxi Group, composed of Shangchuan and

Santunying Formations, and the Badaohe Group, consisting of Wangchang, Wanzhanzi and Sanmendian Formations in ascending order. Based on the

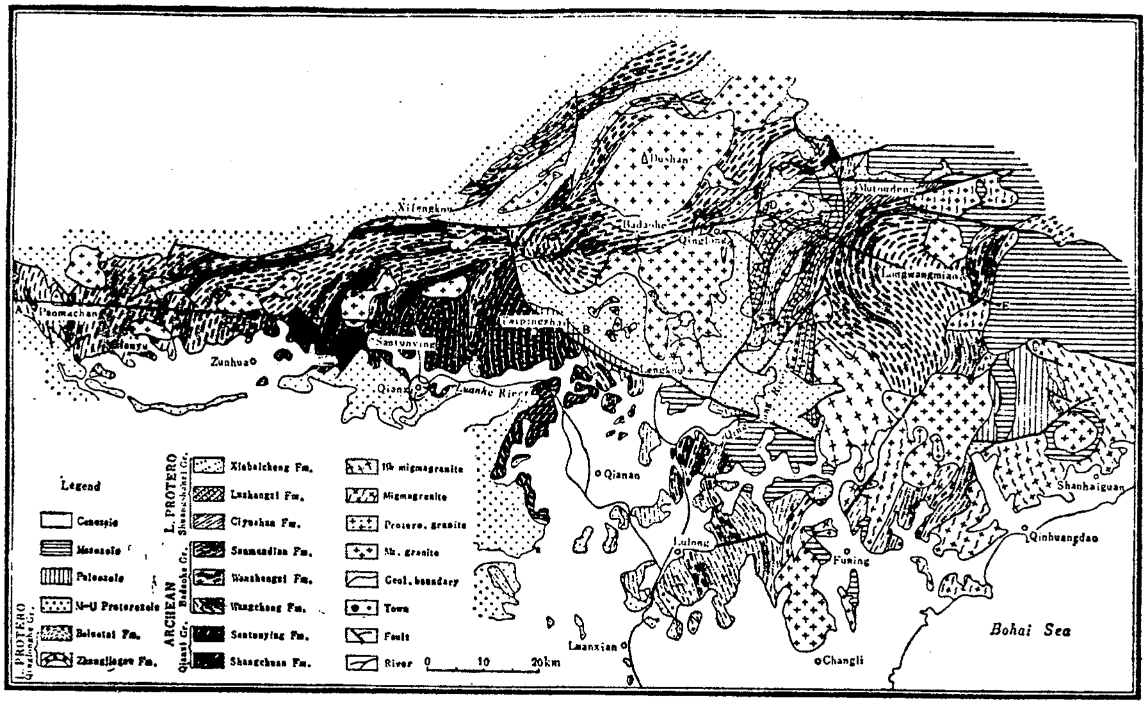


Figure 8: Geology of the Early Precanbrian of Eastern Hebei.

distribution of rocks, tectonic characteristics and the relationships among the rock units, Sun Dazhong et al. (1984) have compiled a table showing details of their scheme of stratigraphic classification (Table 1). In the Miyun area, the Archean supracrustal rocks are divided into two groups, the older Miyun Group composed of gneiss and granulite and the younger Zhangjiafen Group consisting of gneiss, schist with marble and quartzite. The TTG complexes that correspond to tonalite-granodiorite in composition include light coloured gneiss and some charnockite. The distribution of these rocks has not been clearly defined. However, the ratio between supracrustal rocks and TTG complexes is between 1:8 and 1:6 in the Qianxi Group and between 1:4 and 1:3 three in the Badaohe Group. During the Anshan movement (around 2500 Ma), regional metamorphism took place. The metamorphic grade of Qianxi and Badaohe Groups is mostly up to the granulite and amphibolite facies. As shown in Figure 9, the Miyun and Zhangjiafen Groups correspond to metamorphic facies belt of high and lower grade metamorphism respectively.

Rocks of the Changcheng, Jixian and Qingbaikou Systems of the Middle-Upper Proterozoic Subera are dispersed around the margins of the Archean terrane and those of the Palaeozoic Erathem and of a Mesozoic volcanic system are scattered throughout the area.

Table 1 The stratigraphic features of Early Precambrian of Eastern Heboi

Chrono. Unit	Group	Formation and Lithology (Thickness, meter)	Metamorphic Facies	Original Rocks	Migmatization	Ages (b.y.)
M. Proterozoic	Changcheng System	Changchougou Fm.: Conglomerate, sandstone				Pb-Pb 1.92
Early Proterozoic	Qinglonghe Group	Boluotai Fm.: Mica granulitite gar-mica-qz schist, BIF(888) Zhangjiagou Fm.: Metaconglomerate (170)	Lower amphibolite facies -greenschist facies	Siltstone, semipelite & BIF Conglomerate with siltstone	Banded felsic	Rb-Sr isoch. 2.08
	Shuangshanzi Group	Xiabaicheng Fm.: Mica granulitite with mica schist (879) Luzhangzi Fm.: Metabasic intermediate-acid volcanics (1626) Ciyushan Fm.: Bi-pl granulitite (882)		Siltstone & semipelite Basic-intermediate volcanics Intermediate-acid volcanics & silts		Rb-Sr isoch. 2.19
Archean	Badaohe Group	Sanmendian Fm.: Bi-pl granulitite with pl amphibolite & BIF (3350) Wanzhangzi Fm.: Pl amphibolite with bi-pl granulitite & leuco-granulitite (1600) Wangchang Fm.: Pl amphibolitJ with hornblendite	Upper amphibolite facies	Greywacks, silts & BIF Basic volcanics with some Mg-rich basalt in lower part	Gneissic felsic	Rb-Sr isoch. 2.55
	Qianxi Group	Santunying Fm.: Bi-hyp-pl gneiss & pyx granulite with BIF (1250) Shangchuan Fm.: Pyx granulite with pyx-pl amphibolite(1500)	Lower granulite facies	Various volcanics, tuff-sedimentaries & BIF Basic volcanics & tuff-sedimentaries	Charnockitic	Rb-Sr isoch, 2.52 U-Pb 2.48

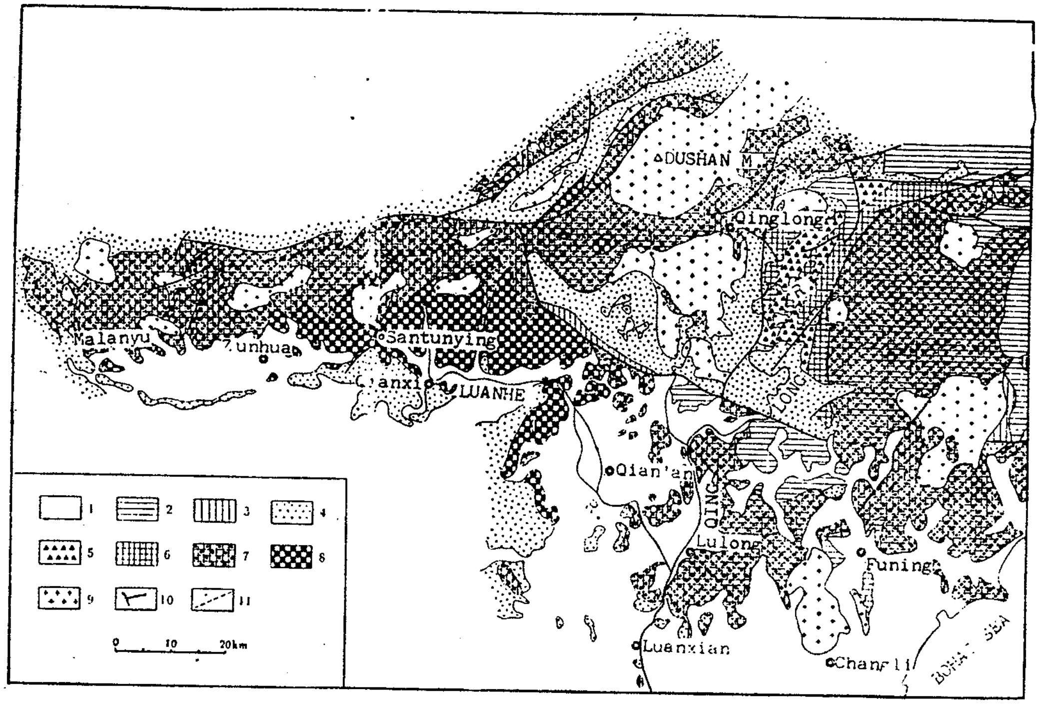


Figure 9: The distribution of Early Precambrian metamorphic facies in Eastern Hebei.
1.Cenozoic 2.Mesozoic 3.Paleozoic 4. mid- to late Proterozoic 5.epidote-amphibolite facies 6.lower amphibolite facies 7.upper amphibolite facies 8.amphibolite-augite granulite facies 9.Phanerozoic intrusion 10.fault 11.facies boundary

Mesozoic magmatism was intense in this area. The Mesozoic magmatic rocks are mostly of intermediate to acidic composition and extend along an E-W direction. Mesozoic granites in the form of stocks can be found intruded into various rocks, chiefly the Badaohe Group.

More than 100 gold occurrences and 49 gold deposits, some of them large scale like the Jinchangyu Mine in Qianxi County, and medium size like the Huajian Mine in Kuancheng County and the Sanjia Mine in Qinglong County, form ore zones extending along an E-W direction. However, the majority of the gold deposits are concentrated in the central-southern part of the area, including Xinglong Zunhua and Qinglong Counties. Gold deposits are mainly hosted by the Badaohe Group, especially Wangchang Formation (80%), and only a few by Mesozoic granite as the Yu'erya Mine in Qianxi County. Therefore, two types of gold deposits are distinguished in this area, depending on the characteristics of the host rocks: the Jinchangyu type hosted by Archean metamorphic rocks and the Yu'erya type hosted by Mesozoic granite. Yu Changtao et al. (1989) argue that the Jinchangyu and Yu'erya types are of similar genesis and that both of them are a magmatic type of deposit that formed in Mesozoic time. However, most Chinese geologists hold different views. On account of the close spatial relation between the Jinchangyu-type of deposits and the Badaohe Group (approximately ninety percent of gold deposits and about eighty-six percent of gold reserves are hosted by the Wanchang Formation), they interpret the Jinchangyu-type to be stratabound metamorphic hydrothermal gold deposits.

The Jinchangyu Type

The Jinchangyu-type gold deposits are concentrated in the middle part of Zunhua-Qianxi area, which is geotectonically called the Malanyu Kern and is underlain mainly by the Wanchang Formation of the Qianxi Group. In this region are many famous gold deposits, such as Jinchangyu, Malanyu, Huashi, Sanyi, Niuxianshan, Huajian and Luojiaggou gold mines.

The **Jinchangyu** gold deposit is located in the central section of Malanyu Kern. The Wangchang Formation here can be divided into five rock members as follows: 1. hornblendite, 2. diopside amphibolite, 3. garnet-diopside amphibolite, 4. banded iron formation and 5. garnet amphibolite. The last two are important hosts for gold. All of the rock types have been metamorphosed to upper amphibolite facies assemblages. Yanshanian granites occupy the western part of the mine area and are represented by the Qinshankou and Jiajiashan granites (Fig. 10).

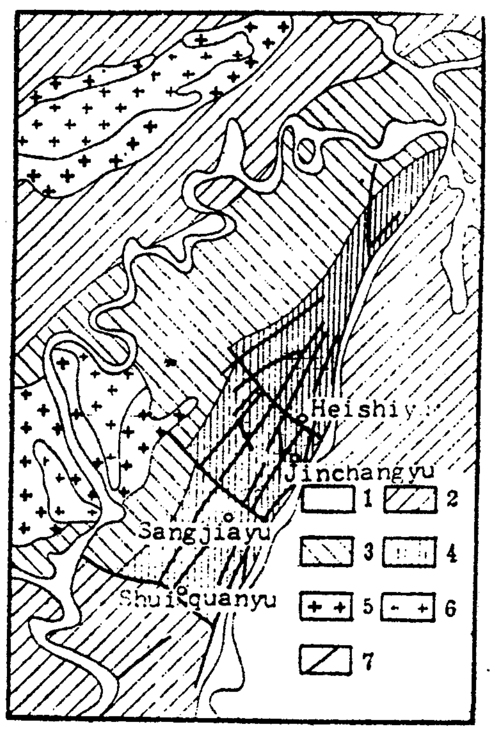


Figure 10: Geology of the Jinchangyu
1.Quaternary 2.augite granulite, upper member of Wangchang Fm
3.amphibolite/augite granulite, middle member of Wangchang Fm
4.amphibolite/magnetite quartzite, lower member of Wangchang Fm
5.Yanshanian granite 6.Yanshanian plagioclase granite 7.fault

The Jinchangyu deposit is controlled by a structural zone about six kilometres long and 700 metres wide, extending southward from Heishiyu to Sanjiayu. This belt contains mainly sericite schist and minor chlorite schist and may be divided into six schist zones (Fig. 11). Structural lenses of remnant amphibolite are common. The sericite schist is gradually changed into chlorite schist and than schistic amphibolite from the central part of the schist zone outwards when the schist zone well developed. The Jinchangyu member of the structural belt is about 1300 metres long and 700 metres wide. Among the six schist zones, the 'II' Zone that links with Heishiyu member is the largest and it varies from twenty metres to seventy metres wide. It contains eighty percent of the total gold in the mine, so it is the most important.

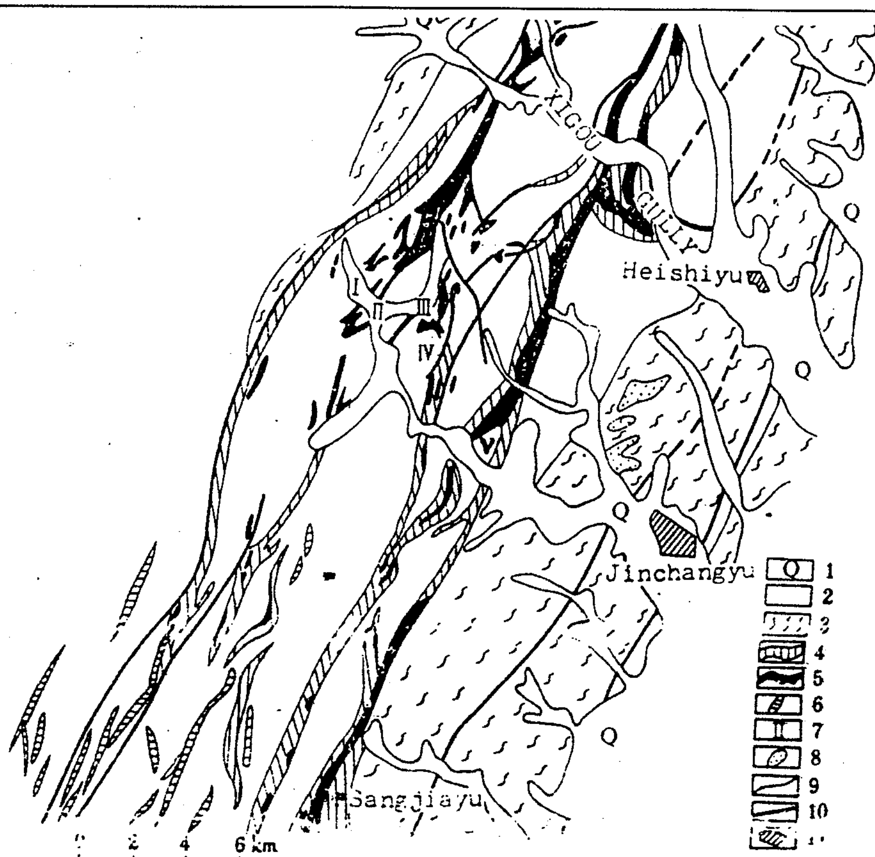


Figure 11: Geology of the Jinchangyu gold camp.
1.Quaternary 2.amphibolite 3.augite granulite 4.foliated amphibolite 5.gold-bearing compound vein zone 6.dike 7.ore zone 8.magnetite quartzite 9.fault 11.village

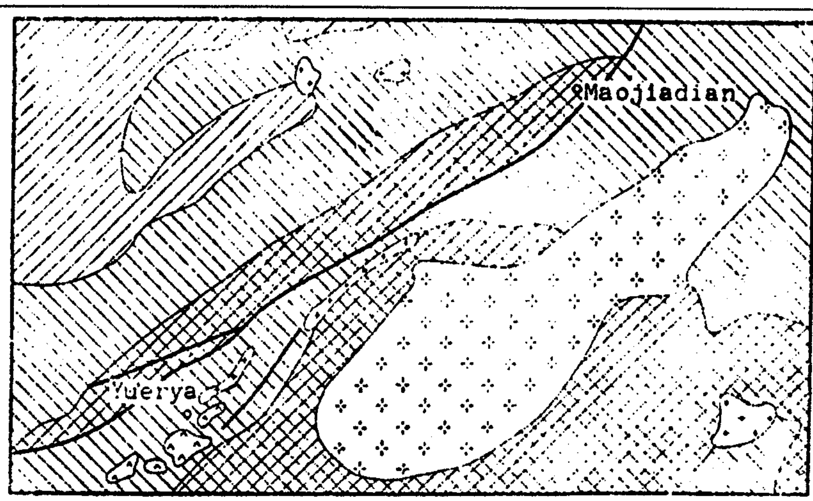
There are two types of gold-bearing bodies, single veins (greater than one metre thick) and compound veins (less than one metre thick). The single veins, as a rule, are composed of quartz and contain high grade gold. The sizes of single veins are variable, the largest being up to ten metres thick and 50 metres long and, on average, two to eight metres thick and 15 to 35 long. The long axes of the quartz lenses are commonly parallel to schistosity. Compound veins are classified by their mineral composition into three types, quartz,

quartz-feldspar and feldspar compound veins. Metallic minerals include pyrite, galena, chalcopyrite, sphalerite, chalcocite, molybdenite, magnetite, pyrrhotite, bornite and hematite. Pyrite makes up ninety-five percent of the ore minerals and is mainly dispersed in quartz veins, sericite schist and other altered rocks. Native gold, kustelite and calaverite are the principal gold minerals. Non-metallic minerals include quartz, albite, dolomite and calcite with rare sericite and chlorite. Twenty-seven chemical elements, mainly Au, Ag, Mo, and Bi have been analysed in the ore. The common alteration types are sericitization, chloritization, silicification, carbonatization, pyritization and albitization.

Hydrothermal activity was multistaged. Stage I comprised the development of veined and silified bodies, Stage II, the formation of albite and carbonate-albite veins, Stage III, the formation of gold-bearing quartz veins, and Stage IV, the development of late quartz and carbonate veins.

The Yu'erya Type

The Yu'erya type of gold deposits such as Maojiadian, Yu'erya and Baizhangzi gold mines are concentrated in the Maojiadian-Yu'erya region, in the northern part of Malanyu Kern which is mainly underlain by the Gaoyuzhuang Formation of the Changcheng System. The Gaoyuzhuang Formation, which consists of dolomitite with shale and marl, is in fault contact with the Archean rocks of the Wangchang Formation of Badaohe Group on the southeast side and of the Qianxi Group on the northwest side of the fault. There are many acidic intrusions such as the Yu'erya, Shuangahuting and Maojiadian bodies (Fig. 12) along the fault.



1 2 3 4 5 6

Figure 12: Geology of the Maojiadian - Yu'erya District
1.Jurassic volcanic and clastic rocks 2.Proterozoic carbonate and clastic rocks 3.Archean gneiss 4.Precambrian granite 5.Yanshanian granite 6.Yanshanian ultramafic rock

The **Yu'erya** gold deposit is hosted by the Yu'erya granite that was intruded into the Gaoyuzhuang Formation. Archean rocks are distributed on the periphery of the mine area (Fig. 13). NE Faults that strike 55-65 degrees in this area control not only the Mesozoic granite but also the gold mineralization. The Yu'erya deposit was first discovered in 1887 and it has been mined since then to the present. Ore bodies are mainly distributed near the inner contact zone and over the yellowish-pink granite.

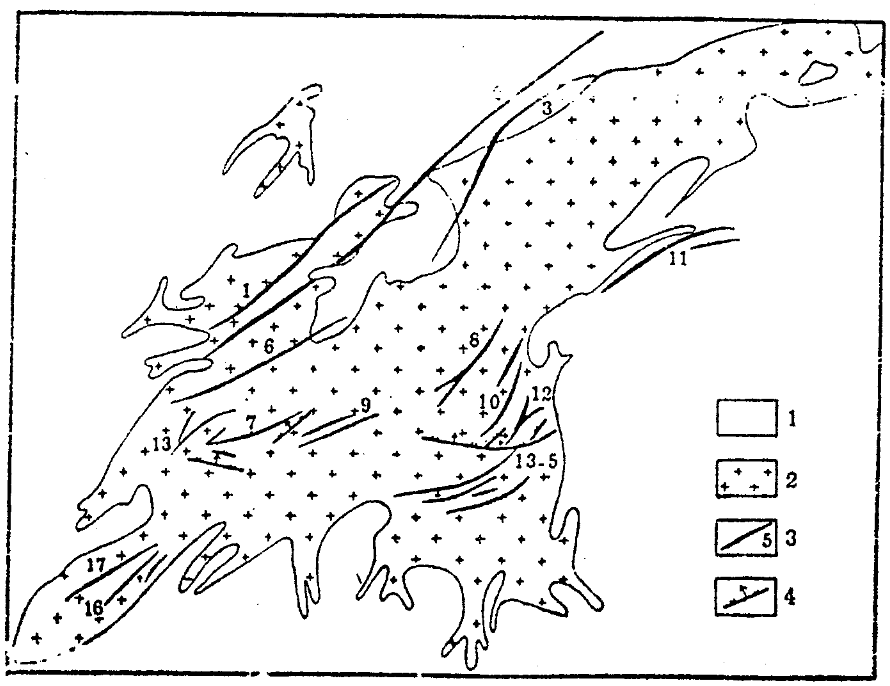


Figure 13: Distribution of ore veins in the Yu'erya gold mine.
1.dolomite, Gaoyuzhuang Fm 2.Yanshanian granite 3.ore vein 4.fault

Three kinds of ore bodies, many of them blind, have been recognized: I. pyrite quartz veins; II. pyrite quartz veinlet zones and III. mineralized altered granite. The rocks that host gold exhibit intense alteration of four types: pyritization, sericitization, silification and albitization with weak chloritization and kaolinization. Native gold is predominant and locally visible with lesser electrum and calaverite. The most important metallic mineral is by pyrite which is followed in abundance by chalcopyrite, galena, sphalerite, and pyrrhotite. Nonmetallic minerals include quartz, sericite, chlorite, carbonate minerals, tremolite and garnet. Native gold is hosted predominantly in pyrite and in cracks in quartz .

The <u>**Shuiquan**</u> deposit in Western Liaoning may be within the extension of the Yanshan concentration area. It is of medium size and hosted by a dioritic body which intruded into the Gaoyuzhuang Formation. Gold mineralization occurs in an E-W striking zone of alteration within the dioritic body and in a contact zone between granite porphyry and the diorite (Fig. 14).

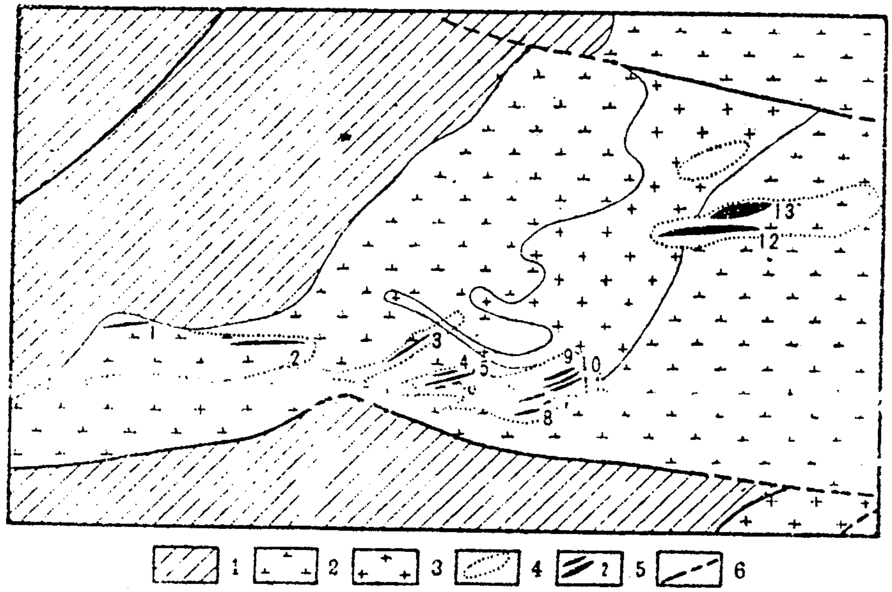


Figure 14: Distribution of ore veins in the Shuiquan gold mine. 1.limestone, Gaoyuzhuang Fm 2.Yanshanian diorite 3.Yanshanian granite porphyry 4.alteration zone 5.ore veins 6.fault

ZHANGJIAKOU - CHIFENG AREA

This includes the area bounded by the Kangbao-Weichang-Chifeng-Kaiyuan Break in the north (its northern border) and Zhangjiakou-Chengde-Pingquan-Ningcheng-Beipiao Break in the south (its southern border) or by the line of between the cities of Kangbao, Taipusi, Weichang, Chifeng and Aohan in the north and between the cities of Zhangjiakou, Chicheng, Luanping Chengde, Pingquan, Chaoyang and Beipiao in the south. Geotectonically it belongs to the eastern part of the Nei Mongol Axis of North China Platform (Fig. 15).

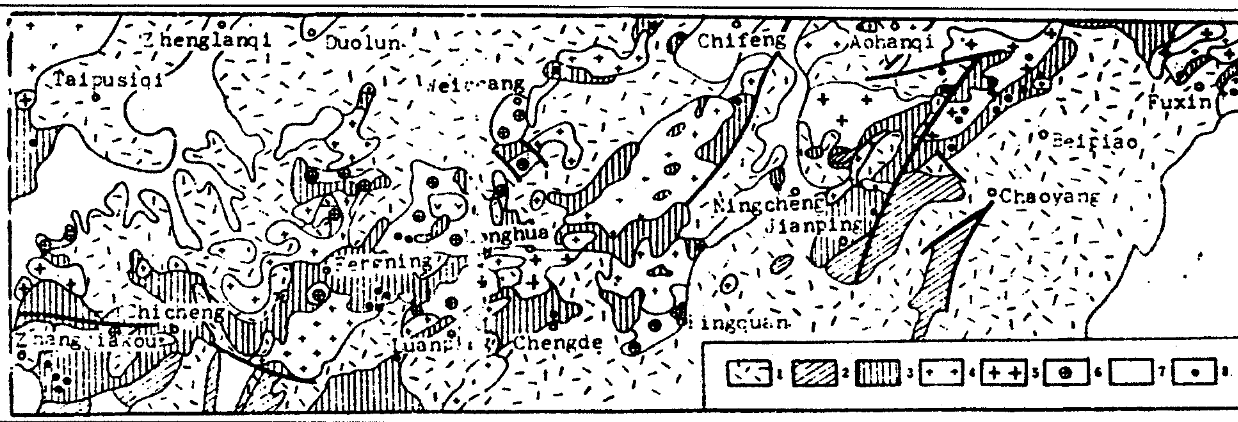


Figure 15: Geology of the Zhangjiakou-Chifeng concentration area 1.Mesozoic volcanic and clastic rocks 2.mid- late-Proterozoic carbonate and clastic rocks 3. Archean/Proterozoic metamorphic rocks 4.Yanshanian granite 5.Hercynian granite 6.Precambrian granite 7.other 8. gold deposits

The metamorphic rocks in this region are classified according to the scheme of Tang Yingjia et al. (1990). The Wudaohe Group is divided in ascending order into: 1) the Yaoshang Formation, which consists of clino- and ortho-pyroxene amphibolite intercalated with garnet-plagioclase diopsidite and garnet-augite-plagioclase amphibolite; and 2) the Dashanju Formation, which consists of thickly layered hornblende-plagioclase gneiss and biotite-hornblende-plagioclase gneiss, intercalated with plagioclase amphibolite and augite amphibolite. The Dantazi Group is divided in ascending order into: 1) the Yanwopu Formation, which consists of plagioclase amphibolite with hornblende-plagioclase gneiss and biotite-plagioclase gneiss in its lower part, and biotite-hornblende gneiss, hornblende-biotite-plagioclase gneiss with plagioclase-amphibolite and iron formation in its upper part; 2) the Baimiao Formation which consists of biotite-plagioclasegneiss with garnet-plagioclase amphibolite; and 3) the Hexi Formation which consists of garnet-bearing biotite granulite, biotite-hornblende granulite and leptite with amphibolite. In some areas, the Dantazi Group contains marble and graphitic marble. Proterozoic rocks of the Changcheng System, the Jixian System, and the Qinbaikou System and those of Palaeozoic Erathem occur in Chicheng, Pingquan and to the east of Jianping County. Mesozoic rocks are distributed in fault basins and consist of intermediate-acidic volcanics, epiclastics and coarse sedimentary clastics. It is an area where there is evidence of intense magmatism, particularly related to the Yanshanian phase.

There are several hundred gold deposits and occurrences in the area. They are clustered in the Zhangjiakou district in the west and the Chaoyang-Beipiao district in the east part of the area. In the Fengling-Chengde district, the middle part of the area, gold associated with other deposit types is dominant. In general gold-bearing geological bodies in this area are primarily hosted by high grade metamorphic rocks which have a mafic component, and are predominantly single quartz veins, whereas veinlet and network zones are rare. This is a peculiarity of this area by comparison with other concentration areas of gold mineralization in North China Platform.

Zhangjiakou District

The Xiaoyinpan (large size), Zhangquanzhuang (medium size) and some small size gold deposits and occurrences comprise this district. It is underlain by Archean metamorphic rocks includeing hornblende-plagioclase granulite, clinopyroxene-orthoyroxene-plagioclase granulite, hornblende-plagioclase gneiss, impure marble and iron formation. The E-W trending Chongli-Chifeng Break with a breccia zone up to a kilometre wide passes through the northern part of the district. The Luojiaying-Hanjiagou Fault controls the distribution of gold deposits. Archean or Proterozoic biotite granite and related dikes, Yanshanian megacrystic granite, syenite and related dikes are locally present. Seven anticlines and synclines have been outlined, the axial traces of which are N-S to NWW in the west, but which change gradually eastwards to NW. A total of approximately 200 gold-bearing quartz veins are distributed in the district occupying 350 square km.

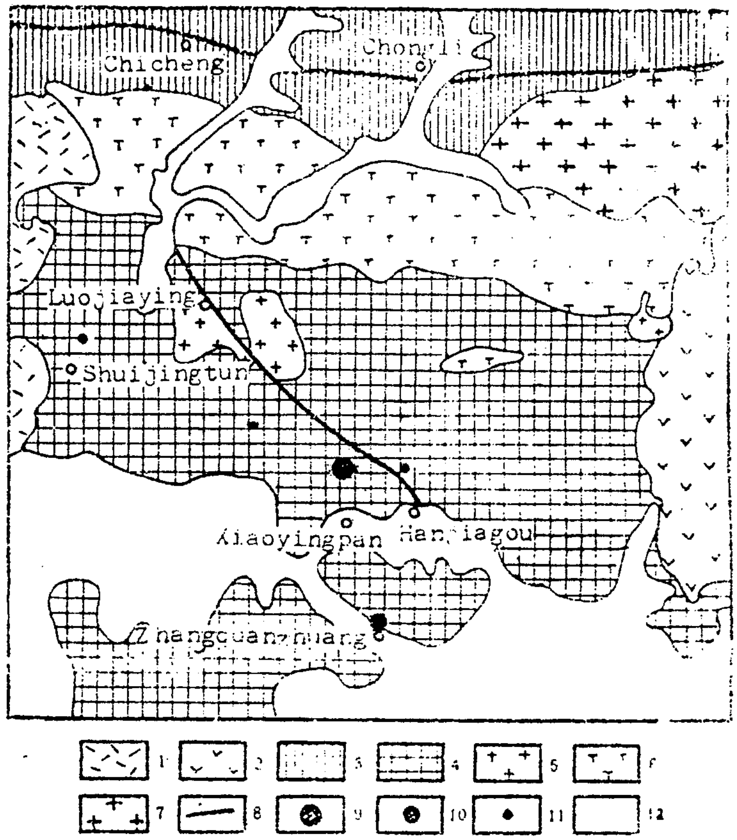


Figure 16: Geology of the Xiaoyinpan gold deposit
1.Upper Jurassic volcanic and volcaniclastic rocks 2.Middle Jurassic volcanics 3.Upper Archean metamorphic rocks 4.Lower Archean metamorphic rocks 5.Yanshanian K-spar granite 6.Yanshanian aegerine-augite syenite 7.Precambrian biotite granite 8.fault 9.large gold deposit 10.medium gold deposit 11.small gold deposit 12.other

Most quartz veins extend along an E-W trend parallel to the gneissosity of the metamorphic rocks in general.

The **Xiaoyinpan** gold deposit is located in Xuanhua County, Hebei Province and geotectonically is near the northern margin of Yanshan Settling Zone, south of the Chongli-Chicheng Fault (Fig. 16). The mine area is underlain by Archean metamorphic rocks including hornblende-plagioclase gneiss and granulites which form an anticline striking NW and dipping SW. Four sets of fault are as present: near N-S, near E-W, NE20-40 degrees and NW 300-340 degrees which cut ore veins and thus, obviously, are post-infilling structures. The only igneous bodies that outcrop in the mine area are dikes of diabase and feldspar-quartz porphyry. The ore structure is approximately two kilometres long, several metres wide and quite deep and is the only one found in the mine. Quartz veins in the ore structure are hundreds of metres deep and several metres wide, the widest one being up to eight metres thick. It is the largest ore vein in the Zhangjiakou district, and therefore Xiaoyinpan is a large scale mine. Quartz veinlets and alteration occur between the lenticular quartz veins. The types of alteration include sericitization, carbonatization and silification. Economic ore bodies are in the middle to lower part of the gold-bearing quartz veins. Gold-bearing minerals comprise native gold, electrum and calaverite. Metallic minerals include predominant pyrite, galena, chalcopyrite and subsidiary henkelite and sphalerite. The gangue minerals are quartz, feldspar, ankerite and calcite. Native gold occur in fissures and as inclusions in pyrite, galena and quartz.

The **Zhangquanzhuang** gold mine is near Xiaoyinpan and its geological setting is also similar. However, the orebodies here are hosted mainly by rocks of a TTG complex and only in a few cases by augite granulite and amphibolite. Gold-bearing quartz veins are related closely in space with dikes of porphyritic diorite that are widespread in the mine area and that have been alterated and mineralized at the contacts with quartz veins. There are forty-one gold-bearing quartz veins in the mine. No. 12 vein is the best one followed by No. 4, 5, 8, 13 and 14. The No. 12 ore vein strikes NW, dips NE, is thirteen hundred and sixty metres long and six to one-half metres wide. It consists of many lenses, of which ten lenticles are economic targets. These gold-bearing sulfide quartz veins can be divided into two types: a gold-bearing quartz type and a gold-bearing altered type with disseminated veined and massive ore. The wall-rocks exhibit mainly carbonatization, silification, pyritization and chloritization with subsidiary sericitization and baritization. Pyrite veins occur in the better mineralized sections. The ore mineral assemblage is mainly electrum, native gold, pyrite, chalcopyrite, galena and some bornite, chalcocite, lead carbonate and limonite.

Chifeng-Beipiao District

This includes the area from Chaoyang-Beipiao in the east to Chifeng in the west. Honghuagou and Jinchanggouliang deposits are important in the area. Nearly a hundred occurrences and small scale deposits such as Dongwujia, Erdaogou, Shajingou, Dongfeng and Daheshan, are distributed over the long rectangular district with a NE trend. Gold-bearing geological bodies are hosted by Archean rocks, granite and Mesozoic volcanic rocks (Fig. 17).

The **Honghuagou** gold camp is situated in the western part of the Chifeng region and includes tens of occurrences and gold deposits like Honghuagou and Lianhuashan. The camp is underlain by Archean rocks and Jurassic volcanic and volcaniclastic rocks. Yanshanian granite outcrops in the southern part of the area. Honghuagou (Fig. 18) is a large deposit at Chifeng City, Inner Mongolia. The mine area is predominantly underlain by Archean TTG gneiss and supracrustal rocks of the Xiaotazigou Formation, which consists mainly of amphibolite, with minor marble and leptite. The supracrustal rocks are commonly residual masses in TTG gneisses. Jurassic andesite breccia and andesite rest unconformably on Archean rocks and are overlain, in turn, by Jurassic conglomerate, pebbly sandstone and greywacke, Lower Cretaceous rhyolite tuff and rhyolite tuff-breccia and Tertiary basalt. A stock of quartz porphyry is the only small pluton but there are many dikes in the mine area. These are compoposed of hornblendite, diabase, diorite, porphyritic diorite, basaltic andesite, andesite, granodiorite, lamprophyre, syenite porphyry and quartz porphyry.

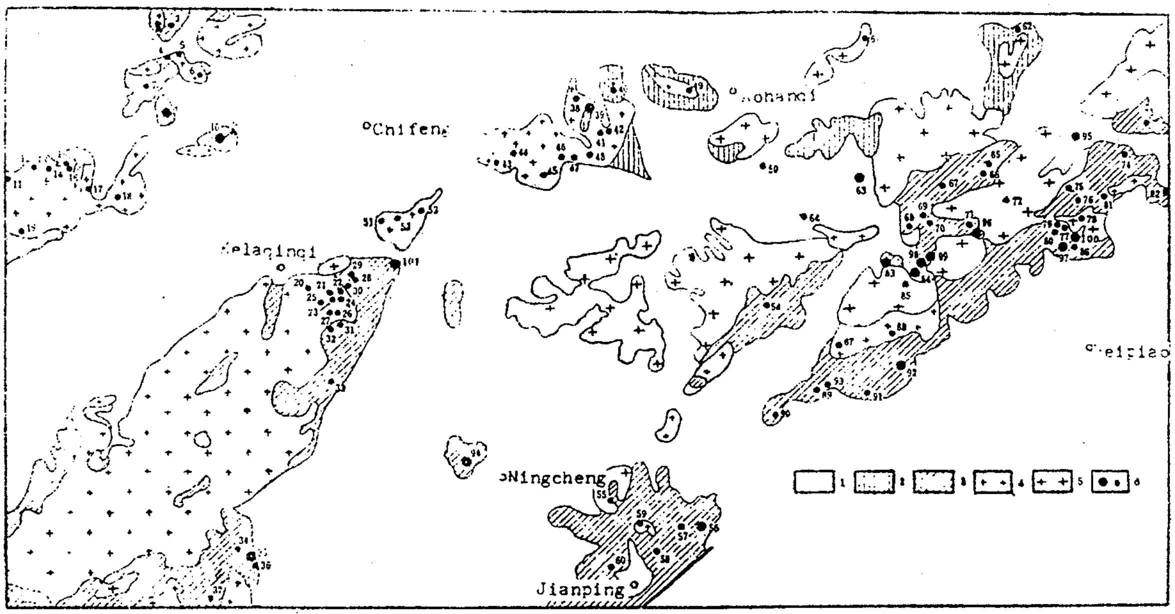


Figure 17: Gold deposits and occurrences in the Chifeng - Beipao area.
1.other 2.Paleozoic metamorphic rocks 3.Archean Xiaotazigou Fm 4.Yanshanian granite 5.Hercynian granite 6.gold deposit/occurrence

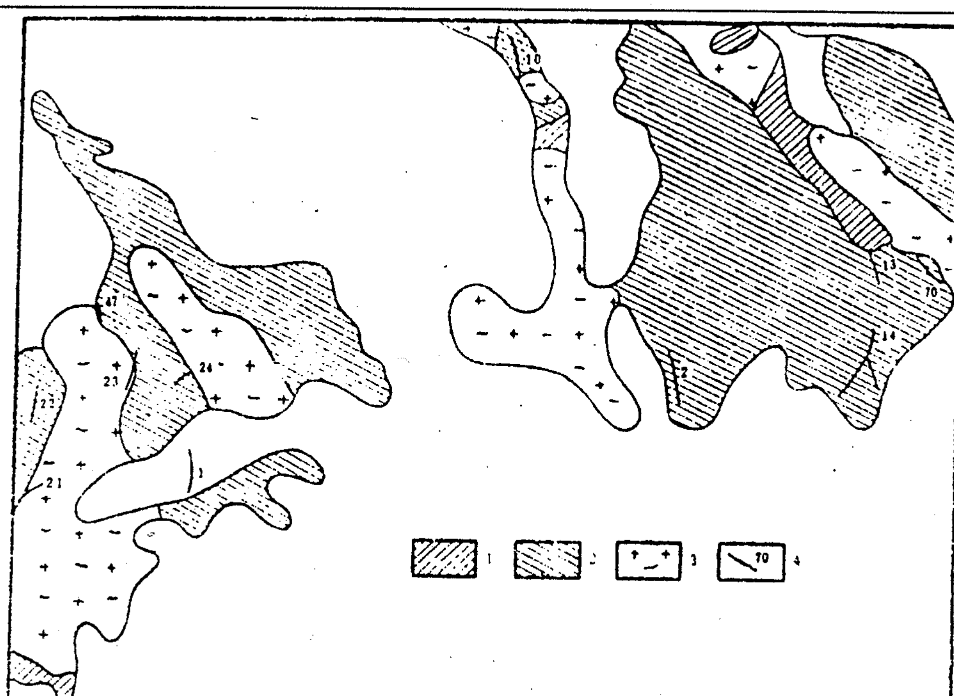


Figure 18: Geology of the Honghuagou gold deposit.
1.amphibolite, Xiaotazigou Fm 2.gneiss, Xiaotazigou Fm 3.TTG complex 4.gold-quartz vein

Four sets of faults, NE-NEE, NNW, NNE and NW-NWW have been identified, the last one, exemplified by the Sidaogou Fault, being best developed. Gold-bearing quartz veins are controlled by the NNE faults. Among the approximately seventy quartz veins, the No. 15, 3 and 6 ore bodies are the largest and of medium grade. No. 15 quartz vein is several hundred metres long, ten cm to three metres wide, strikes NE 5-15 degrees, and is a single ore vein. It is divided into three ore blocks, the southern one being the most important and consisting of both quartz vein and alteration zone material. Sericitization is the chief type of wall-rock alteration, silification and pyritization are subordinate, and carbonatization and chloritization are weak. The ore mineral association includes native gold, electrum, pyrite, chalcopyrite, galena, sphalerite, quartz, sericite, chlorite and carbonate minerals.

The **Jinchanggouliang** camp, including Jinchanggouliang, Erdaogou and Xiaochanggao Gold Mines and other occurrences, is located in the northwestern margin of Nuluerhushan Kern, to the north of the Beipiao-Chengde Break. Archean metamorphic rocks, Mesozoic granitoids and Mesozoic volcanic and sedimentary rocks crop out in the camp area. The Jinchanggouliang Gold Mine, hosted by Archean rocks, the Erdaogou deposit, hosted by Mesozoic volcanic rocks, and the Xiaochanggao occurrence, hosted by a granitoid, are all distributed around the Xiduimiangou Stock. There are no significant differences in the features among all of these deposits. Nearby Jinchanggouliang, the Xiaotazigou, Dongwujia, Changgao and Miliyinzi gold mines are are all hosted by Archean gneisses and situated near small Mesozoic stocks. Shajingou gold mine occurs in both Archean gneiss and Mesozoic diorite. Ore-bearing quartz veins cut by Mesozoic intermediate acidic dikes may be a common phenomenon at those mines described above.

ZHAOYUAN-RUSHAN AREA

The Zhaoyuan-Rushan Area, extending eastwards from the shore of the Bohai Gulf and including Yexian, Zhaoyuan, Qixia, Muping and Rushan Counties in Eastern Shandong, is the largest gold camp in China (Fig. 19). The area is geotectonically a portion of Jiaoliao Block in North China Platform. It is approximately 120 kilometres long and 30 to 50 kilometres wide. The west margin of the uplift is marked by the Tancheng-Lujiang Break, a great sinistral strike-slip structure, that transects the eastern part of North China Platform.

The central part of this area is underlain by Archean rocks of the Jiaodong Group composed in ascending order of the Pengkuan, Minshan and Fuyan Formations, by lower Proterozoic Fenzishan Group and by upper Proterozoic Penglai Group. Granitoid rocks, distributed on both sides of the Precambrian supracrustal rocks, consist of the Linglong, Guojialing and Luanjiahe phases in the west and the Kunyushan phase in the east. The Jiaodong Group is composed mainly of gneiss, granulite, amphibolite, marble and quartzite. Some primary features in these metamorphic rocks are preserved and indicate that the protoliths of the Jiaodong Group are mainly volcanic and sedimentary rocks. The Fenzishan and Penglai Groups are composed predominantly of

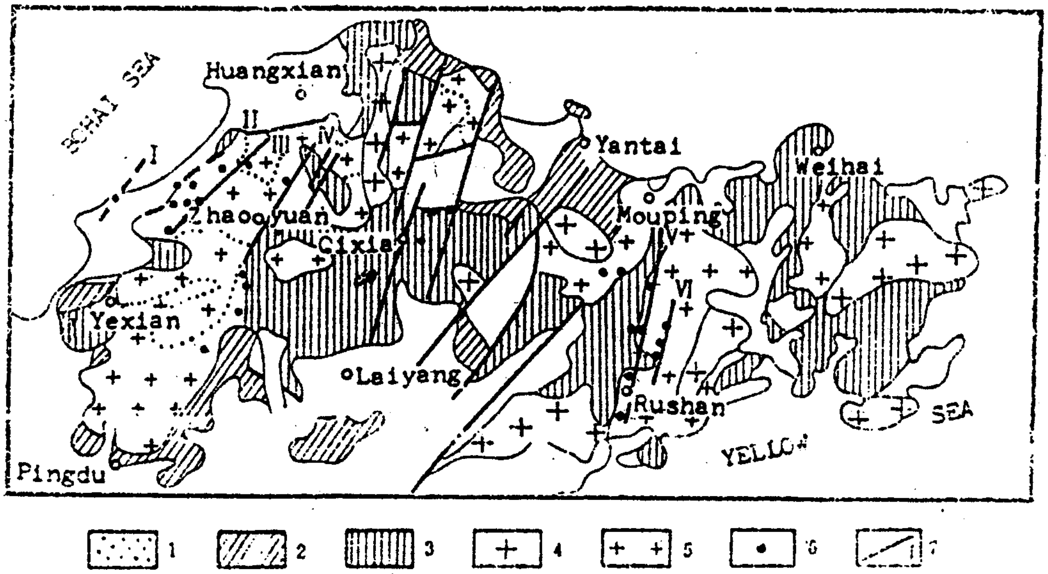


Figure 19: Geology of the Zhaoyuan - Rushan area
1.Tertiary conglomerate 2.mid-Proterozoic Fengshishan Gp 3. Archean Jiaodong Gp 4.Mesozoic granite 5.Proterozoic(??) granite 6.gold deposit 7.faults (I.Sanshandao II.Huangxian-Yexian III.Bei-Jie IV.Zhaoyuan-Pingdu V.Jinniushan VI.Jiangjunshi-Quhezhuang.

metamorphosed sedimentary rocks with a minor volcanic component. The granitoid rocks are represented mainly by biotite granite of the Linglong phase; hornblende granite of the Guojialing phase; potassium feldspar granite of the Luanjiahe phase and (normal) granite for Kunyushan phase. The ages of the granitoid rocks are controversial but most Chinese geologists believe that they are younger than the Precambrian and that they were emplaced during Mesozoic time. In this area, the Qixia Anticlinorium, occupied by the Jiaodong Group is a major fold structure with an axis trending nearly E-W. It is superimposed by structures with a NE trend such as the Zhaoyuan-Pindu Fault and Mupin-Jimo Fault.

To the west of Qixia County, more than a hundred gold deposits such as Sanshandao, Jiaojia, Xianchen, Lingshan, Wan'ershan, Xishan, Lingshangou, Jinchiling, Linglong, Dakaitou and Jiuqu gold deposits, which are large or medium in scale, have been found and developed. They are distributed over north limb of Qixia Anticlinorium as a "zone" that coincides with the occurrence of the Pengkuan Formation of the Jiaodong Group in space, from Sanshandao in the west to Zhaoyuan County in the east, an area approximately 70 kilometres long and 15 kilometres wide (Fig. 20). The gold deposits here are called "Zhaoye type" and furthur divided into two types, the "Linglong" type and the "Jiaojia" type. To the east of the Mupin-Jimo Fault, approximately seventy gold deposits (or occurrences) have been discovered and are scattered over Mupin-Rushan area (Fig.21), of which two are large in scale , the Denggezhuang and Dongzhuang gold deposits and tens of deposits like Jinliushan and Tongjiashan mines are medium scale. Gold deposits in the Mupin-Rushan area can be separated into two zones, one

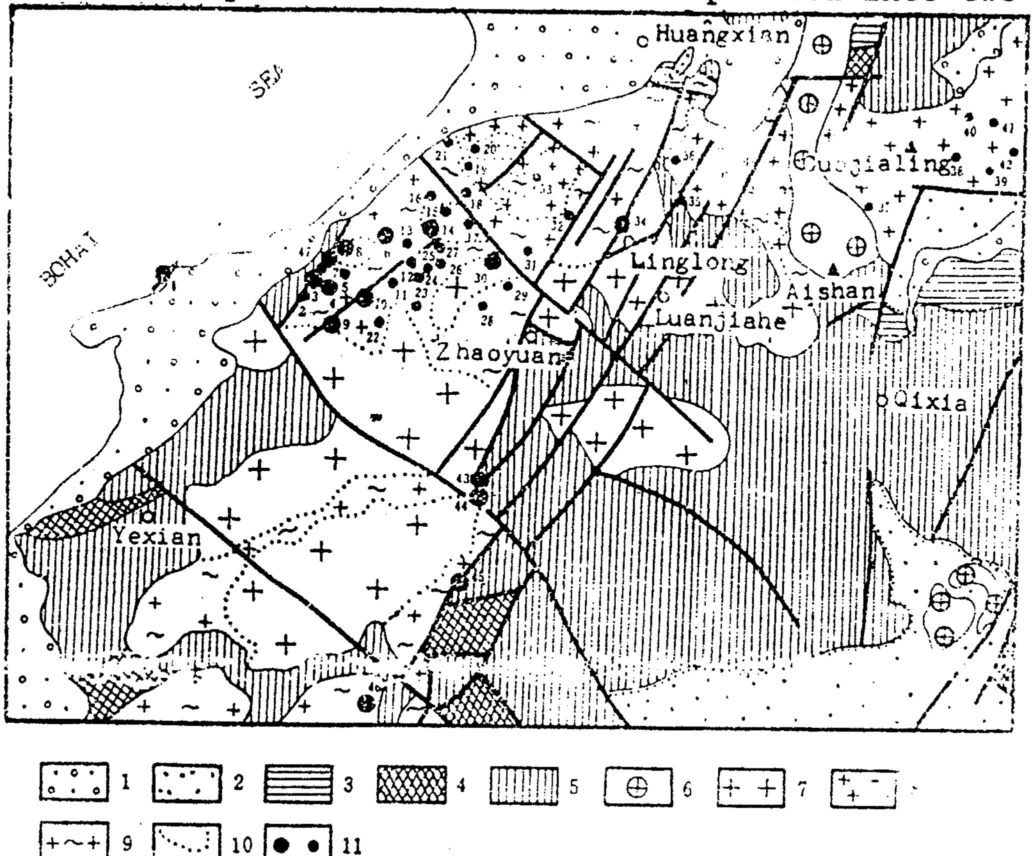


Figure 20: Gold deposits of the Zhaoyuan-Yexian area
1.Quaternary 2.Mesozoic volcanic and sedimentary rocks 3.Penglai Gp 4.Fenzhishan Gp 5.Jiaodong Gp 6.Yanshanian granite porphyry 7.Luanjiahe granite 8.Guojialing granite 9.Linglong granite 10.internal subdivisions of Linglong granite 11.gold deposits/occurrences

is called the Anjicun zone and the other the Jinliushan zone. The Anjicun zone extends eastwards and is controlled by the Qixia Anticlinorium. The Jinliushan zone is situated on the northwestern limb of the Kunyushan Anticlinorium and is controlled by a north trending fault. The Rushan and Tangjiagou gold camps occur in this zone. The gold deposits that are distributed over both the zones also coincide spatially with the Pengkuan Formation of Jiaodong Group. However, some of them are hosted by granite and occur in faults, just as the gold deposits in Zhaoyuan-Yexian area (Fig. 20).

As mentioned above, this area is known for the occurrence of two distinct ore types, "Linglong type" and "Jiaojia type". In fact, they have similar features and a common genesis. Therefore the so-called "Zhaoye type" simply means the combination of the "Linglong type" and "Jiaojia type". It is a special type of gold deposit in China. The features of "Zhaoye type" may be summarized as follows:
1) The gold deposits are hosted mostly by Linglong phase granite and partly by Guojialing phase granite. One of the chemical features of

these granites is that their Na/K is greater than one. 2) Intermediate temperature hydrothermal alterations is intense, but

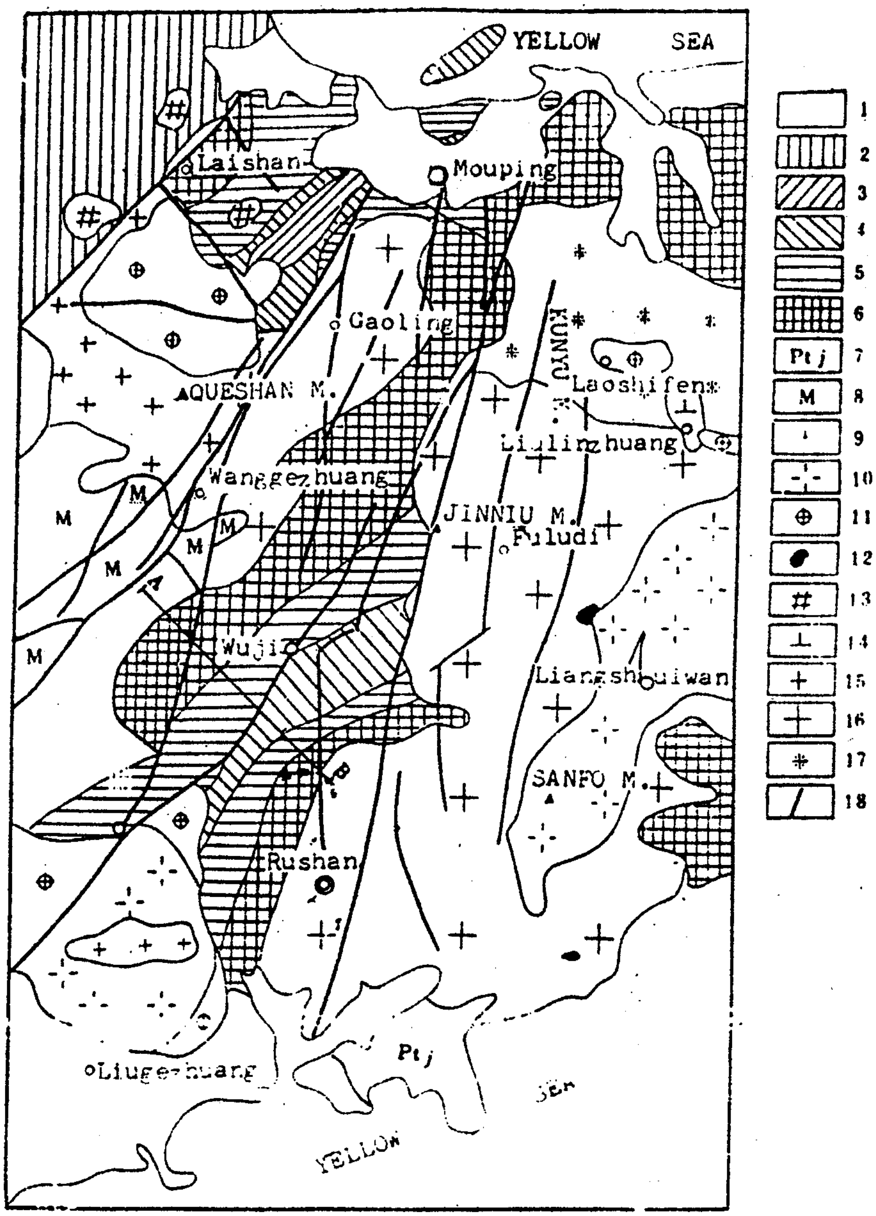


Figure 21: Geology of the Muping - Rushan district
1.Mesozoic-Cenozoic 2.Fenzishan Gp 3,4,5,6,7.Jiaodong Gp 8.mylonitic granite 9.Yanshanian granite 10,11.porphyritic monzonite 12.augite diorite 13.pegmatite 15,16,17.Proterozoic(?) granite 18.fault

there are some difference between the "Linglong type" and "Jiaojia type". The alteration in the "Linglong type" is rather weak beside infilling quartz veins whereas in the "Jiaojia type" it is strong on both sides of veinlets and disseminations. The wall-rocks exhibit silification, seritization and potash feldspathization with clear zonation. The potash feldspathization is a special alteration of "Zhaoye" type; 3) A swarm of intermediate-basic dikes, such as diorite-porphyry, lamprophyre and diorite is closely related genetically and spatially with gold veins and is consistent in orientation with ore zones.

Sanshandao District

The **Sanshandao** gold deposit is located in the western margin of the area, on the shore of the Bohai Gulf and controlled by the Sanshandao Fault which strikes NE 40 degrees and dips southeast. The Sanshandao Fault transects the Linglong granite near the contact between the granite and the Jiaodong Group. Five alteration zones have been recognized and two gold-bearing quartz veins have been found. Of them, the No. 2 quartz vein joins with the No. II alteration zone in some fractures. The No. I alteration zone is controlled by a major fault about two kilometres long and up to two hundreds metres wide. The alteration zone is symmetrical in cross-section i.e. from regular lenticular ore body in the interior, outward to a pyritized sericite-quartzite zone, a granite zone with pyritization-seritization-silification and a granite zone with sparse single quartz veins. In fact, the ore bodies are gold-bearing altered rocks with different composition and fabric. Six economic bodies that occur in the No. 1 alteration zone are simple veins than 1000 metres long, on average two metres wide and nearly 1000 metres deep. Gold occurs mostly in electrum. The gold deposit is large in scale and of medium gold grade.

Jiaojia District

To the east of the Sanshandao Fault, the Huangxian-Yexian Fault controls the Jiaojia, Xinchang, Hedong and Wang'ershan gold deposits. The Hedong gold deposit occurs in the contact zone between the granite bodies of Linglong and Guojialing phases and all of the rest occur in the Linglong phase (Fig. 22).

The ore bodies of **Jiaojia** gold deposit are hosted by Linglong granite or occur in the contact zone between the granite and plagioclase amphibolite of Jiaodong Group, and are controlled by the Jiaojia Fault. The gold ore bodies are situated in the foot-wall of the major fault and have the same strike of the fault. No mineralization has been found in the hanging-wall. Economic ore bodies have good continuity but are variable in grade (Fig. 23). This deposit is the largest one in China at present and is the type example of the so-called "Jiaojia" type of ore which is characterized by veinlets and disseminations in cataclastic altered granite. Of the six economic ore bodies, the largest one is more than 1000 metres long and

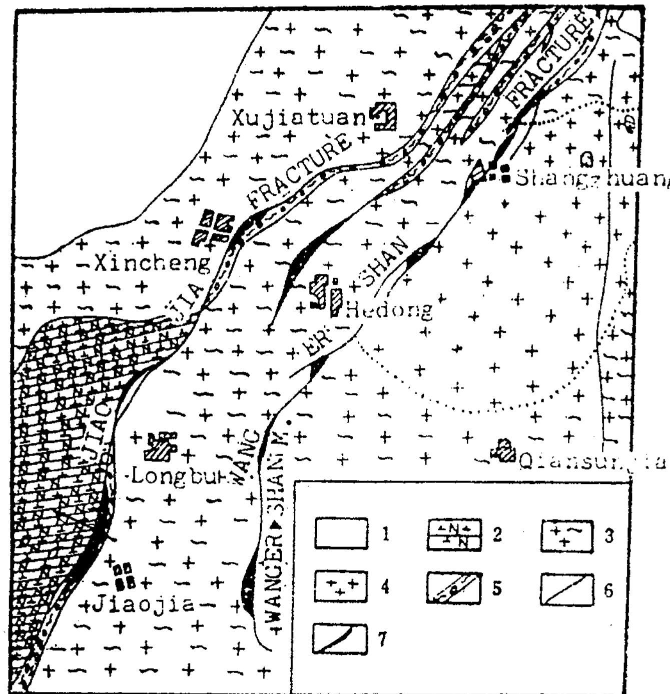


Figure 22: Geology of the Jiaojia - Hedong district
1.Quaternary 2.amphibolite, Jiaodong Gp 3.Linglong granite 4.Guojialing granite 5.cataclastic zone 6.fault 7.gold orebodies.

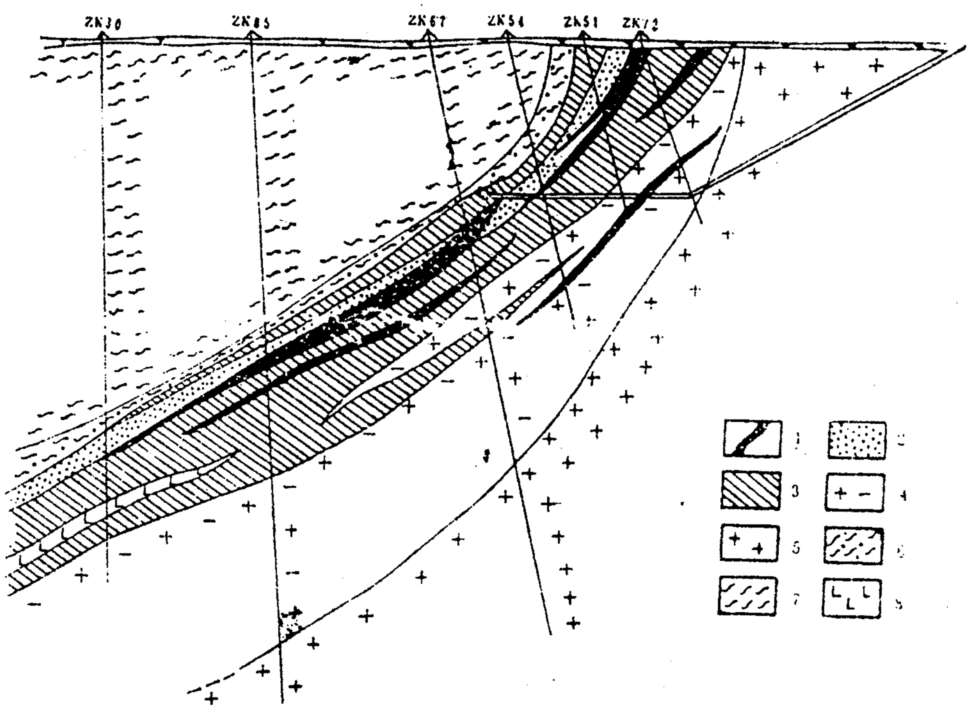


Figure 23: Cross-section along a prospecting line, Jiaojia district
1.orebodies 2.sericite-quartz cataclasite 3.sericitized granite 4.silicified granite 5.granite 6.sericitized amphibolite 7.amphibolite 8.diorite dike

500 metres deep and is the largest single orebody in China at present. Jiaojia is therefore a large scale mine. The ore bodies strike NE17-38 degrees and dip NW at an angle of 40-60 degrees. Veinlets are hair like and occur in pyritic and sericitic quartzite or in cataclastic rocks. Fine-grained pyrite is disseminated in the intensely altered granite. The ore grades are high and consistent. However, the No. 6 ore bodies are veinlet stockwork zones hosted by potash granite and are variable in their gold grade.

Several kilometres to the north of the Jiaojia deposit, another large mine is called the **Xincheng** deposit which also is of the "Jiaojia " type. There are two economic ore bodies here, the largest one being 300 metres long and nearly 1000 metres deep. The Hedong and Wang'ershan deposits are controlled by Wang'ershan Fault which is a subsidiary structure of Huangxian fault (Fig. 22). The features of **Hedong** deposit are the same as that of Jiaojia. Alteration is predominated by silicification and seritization and, rarely, potash metasomatism. The mine is large in scale with ore bodies more than 100 metres long on surface and 400 metres deep. However, the **Wan'ershan** deposit is different. It is of Linglong type and gold-bearing quartz veins comprise the major ore bodies. They are arranged *en echelon* with individual quartz vein more than 100 metres long and ten metres wide. Metallic sulfides are predominantly pyrite, chalcopyrite, sphalerite and galena. The ore bodies grade laterally into silified rocks and quartz stockworks. The deposit is medium in size.

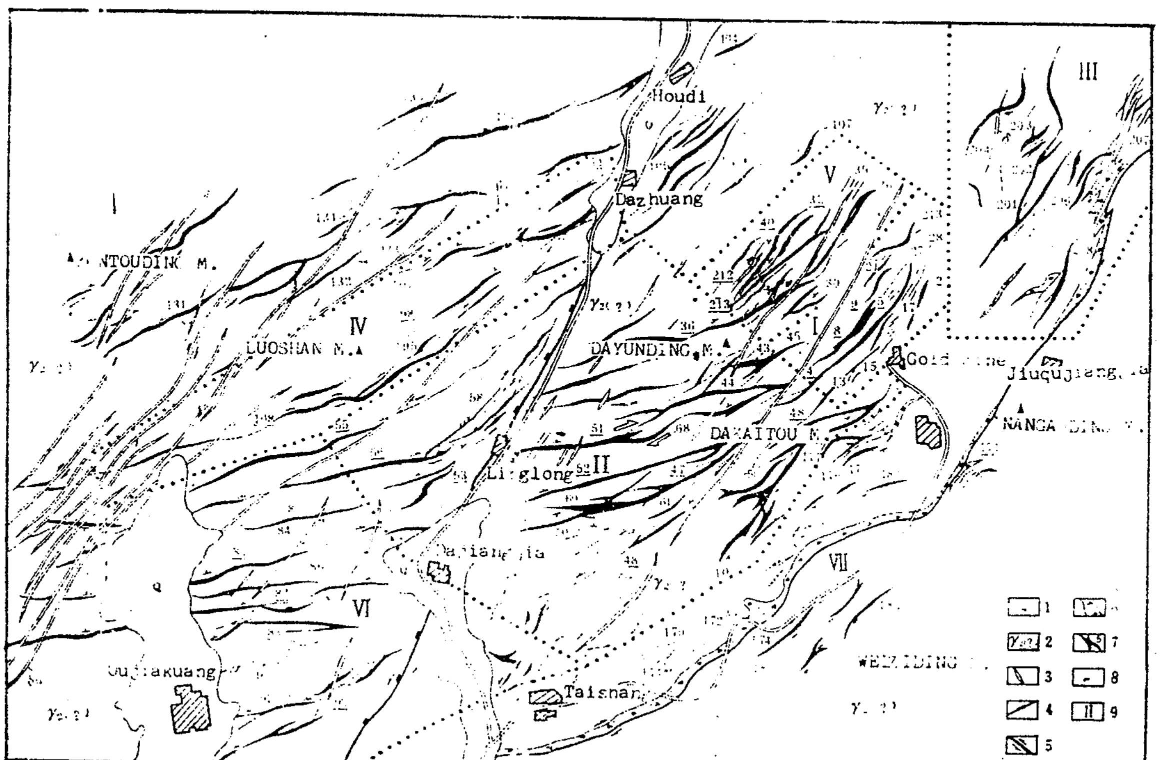


Figure 24: Geology of the Linglong gold camp
1.Quaternary 2.Linglong granite 3.dikes 4.Linglong fault 5.fault 6.Potouqing fault 7.veins 8.occurrences 9.ore sections

Linglong District

The Linglong gold camp is located in the eastern part of Zhaoyuan-Yexian ore zone and is contolled by the Zaoping fault. The Linglong fault, which cuts the Zaoping fault, transects the central part of the area. The camp is divided into seven sections i.e. I.Jiuqu, II.Linglong-Dakaitou, III.Dongfeng, IV.No. 108 vein, V.Shuangding, VI.Oujiakuang and V.Potouqin (Fig.24). The camp contains hundreds of gold-bearing quartz veins and, in fact, there is a swarm of gold-bearing quartz veins occupying fifty square kilometres around the centre of the Linglong Mine (Fig. 24). Among them, the No. 108 ore vein is the largest, just less than five kilometres long and locally more than ten metres wide. All of the quartz veins strike NE and mostly dip NW at an angle of 50-75 degrees. The ore bodies within the quartz veins are discontinuous. The largest one is less than one metre wide and hundreds of metres long.

Most ore bodies are of quartz vein type and some of them, like those in the Potouqin section are brecciated and altered rocks infilled by quartz veinlets and sulfide veinlets. Gold-bearing sulfide-quartz veins in the Jiuqu section occur in the centre of pyrite-sericite-quartzite and grade lateraly into altered rocks with pyritization, sericitization and silification along strike and down dip. Therefore there is no significant difference between the "Linglong type" and "Jiaojia type" ores in that they grade into one another. Native gold and electrum are major sources of gold and these are associated with pyrite, chalcopyrite, sphalerite, galena and pyrrhotite. The gold minerals are present in quartz, pyrite and chalcopyrite.

Jinniu District

The **Denggezhuang** gold deposit is located in the central part of the Muping-Rushan region to the east of Mupin-Jimo Fault. The gold deposit is a portion of the Jinniushan ore zone and occurs in a second- order fault, west of the Jinniushan Fault (Fig. 25). The gold deposit is composed of a gold-bearing sulfide-quartz vein of the "Linglong type". The country rock is medium grained biotite granite. Locally the ore vein is parallel to, and is cut by a lamprophyre dike of dark colour. A swarm of quartz veins is controlled by NNE trending faults and shows an *en echelon* arrangement. Economic veins are No I-IV ore veins. No. I vein is approximately 2500 metres long, a single vein two to three metres wide or a compound vein up to 80 metres wide. It is more than 350 metres deep, strikes NE at 15-25 degrees, dips NW but locally SE at an angle of 40-89 degrees. The gold grades are rather high. No. II is a single vein about 1400 metres long, .8 to 3 metres wide and 350 metres deep. The grade of ore is also rather high. The major types of alteration are silification, sericitization (sericite-quartzite), carbonatization and pyritization and minor potash feldspathization, albitization, chloritization and clay gouge. The No. I-IV vein of Denggezhuang gold deposit contains pyrite, chalcopyrite, pyrrhotite, sphalerite, magnetite, goethite, hematite, arsenopyrite, galena, kustelite-electrum and native gold.

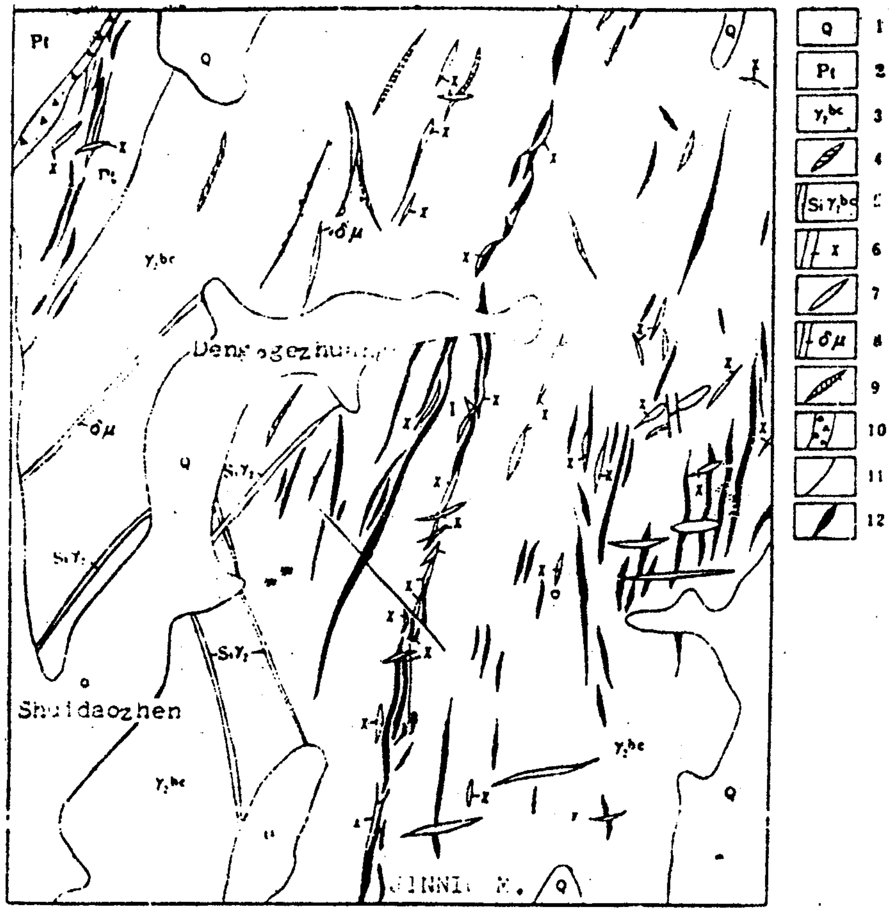


Figure 25: Geology of the Jinniu Mountain area
1.Quaternary 2.gneiss and amphibolite, Jiaodong Gp. 3.granite 4.serecicitized granite 5.silicified granite 6.lamprophyre 7.diorite dike 8.porphyritic diorite dyke 9.quartz vein 10.cataclastic zone 11.fault 12.quartz-pyrite vein

Rushan Gold Camp

This district contains four gold deposits which are medium scale and more than ten ore occurrences. These gold deposits and occurrences are distributed on the northwest limb of the Kunyushan Anticlinorium and are limited by the Jinniushan Fault in the west and the Jiangjunshi fault in the east. The deposits are hosted by Kunyushan phase granite. To the southwest of the camp relicts of the Minshan Formation of the Jiaodong Group are enclosed in the granite and some relicts of marble also occurin the area. The stratigraphic relicts strike NE 40-60 degrees in coincidence with that of regional tectonic trends. A major fault of NNE trend extends through the area and diabase and diorite porphyry have a close spatial relationship with the gold veins in that they are intersect each other. Economic ore bodies are made of gold-bearing pyrite-quartz veins and are lenticular. Three types of ore body have been classified as follows: 1) veins that have clearly defined boundaries with wall-rocks; Gold-bearing sulfides are disseminated, massive and/or irregular veins in the quartz vein; 2) networks that have little gold; such pyrite-quartz networks occur in altered granite adjacent to quartz veins. 3) veinlets that are rare and are present only in the margins of sericite-quartzite. In these ore types gold occurs in electrum only and is associated mainly with pyrite with lesser chalcopyrite, galena, sphalerite, rare fahlite, bornite pyrrhotite and arsenopyrite. Gangue minerals include quartz, sericite, feldspar, calcite, epidote, chlorite and dolomite. Alteration minerals are potash feldspar, sericite, quartz, epidote, chlorite and pyrite. Four alteration zones have been recognized: 1) Potash feldspar granite zone; 2) Sericite-quartzite granite zone; 3) Sericite zone and 4) Silification zone.

Tangjiagou Gold Camp

The Tangjiagou Camp is located to the west of Rushan Gold Camp and includes the **Tangjiagou** deposit and several small scale mines and occurrences. The camp area is underlain mainly by the Minshan Formation of the Jiaodong Group. Porphyritic diorite and lamprophyre dikes that cut the ore bodies are rare. The Tangjiagou Fault, which strikes NE 10-15 degrees and dips SE at 60-75 degrees, extends through the area and controls the ore bodies. Gold-bearing pyrite-quartz veins occur in a fault zone containing parallel compound veins. The minerals and ore textures are similar to those in the Rushan Gold Camp. However, the wall-rocks at Tangjiajou are mainly carbonates so that it displays different alteration which is weak and represented by silification and sericitization only. Although the types of the wall rocks in the two deposits, carbonate for the "Tangjiagou type" and granite for the "Rushan type" are different from each other, the genesis of both the gold deposits is thought to be similar.

LINBAO-XIAOQINLING AREA

Xiaoqinling, the eastern extension of the Huashan Mountains lies on the north slope of the Qinling Mountains and on the border between Henan and Shaanxi Provinces. The area from Huaying County in Shaanxi Province in the west, to Lingbao County in Henan Province in the east, is ninety kilometres long and ten kilometres wide. Geotectonically, it is located on the southern border of North China Platform and the west end of the Xiaoqinling-Songshan Rise, which extends westwards. The area is underlain predominantly by the Archean Taihua Group, whereas the Gaoshanhe Formation of Jixian System is exposed in the southwestern part. In addition, there are scattered exposures of Tertiary sedimentary rocks (Fig. 26). The Taihua Group can be divided into two subgroups: a Lower Subgroup consisted of grey gneiss of a TTG complex and dark amphibolite to form the so-called Lujiayu Bimodal Suite and an Upper Subgroup, composed of metasediments resembling khondalite. Two episodes of deformation and one penetrative S1 foliation have been recognized. A representative of D2 fold structure with S1 as its form surface, the Laoyacha-Jinluoban Anticline, underlies the whole area, except for the northern portion which is occupied by the Wulicun Anticline. Two metamorphic cycles and three

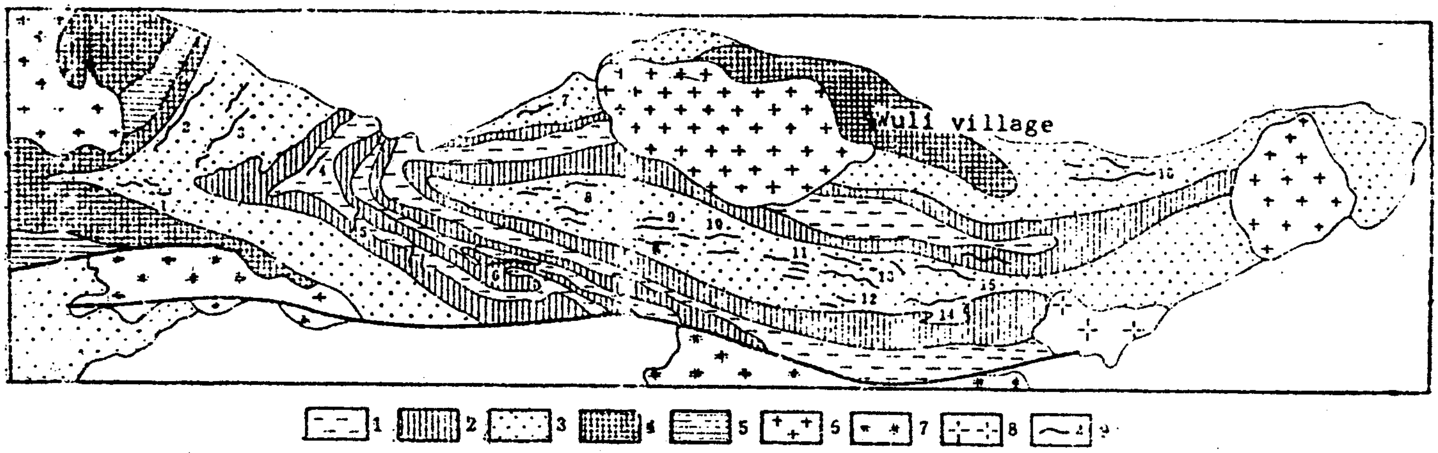


Figure 26: Geology of the Xiaoqinling district
1.Quiangmayu Fm, Taihua Upper Subgroup 2,4.Guanyintang Fm, Taihua Upper Subgroup 3.Lujiayu Fm, Lower Taihua Subgroup 5.Sanguanmiao Fm of Taihua Upper Subgroup 6.Mesozoic granite 7.Proterozoic granite 8.Archean granite 9.major gold deposits.

metamorphic belts are recognized. The metamorphic grade is up to amphibolite facies with local granulite facies.

This is one of the main gold producing regions in China. Approximately 1100 quartz veins (600 in Henan and 500 in Shaanxi) have been found. Of them, two quartz veins are more than 4000 metres long, and 41 are more than 1000 metres in length, and these all have been prospected for gold. According to available data (Wan Hengzhi, 1983), economic ore bodies have been found in 18 veins in Henan Province. Generally, ore veins extend down-dip approximately 300 metres. The deepest, the No. 505 ore vein in the Wenyu Mine, reaches 500 metres in its down dip continuation and it has not pinched out. Ore veins in this area can be divided into five sections based on depth, the head section, upper section, middle section, lower section and bottom section. The best economic ore bodies occur in the upper section and some in the middle section. Accordingly, some prospective targets can be forecast. Most of ore veins occur in the lower subgroup Lujiayu Bimodal Suite and the rest in the upper subgroup. Three clusters of ore deposits can be defined as follows: 1) a Central zone, the major part of the gold camp, containing the Tonyu, Wanpaigou, Sanchayu, Dongchuang, Laoyacha, Qiangmayu, Jindongcha, Yangzhaiyu and Dongtongyu gold deposits which are distributed in the core of Laoyacha Anticline. 2) a Northern zone, containing the Linghuyu, Dahuyu, Huanciyu and Wulicun gold deposits in the core of Wulicun Anticline and 3) a Southern zone containing the Dushuyu and Xiangshudian gold deposits. Some of these gold deposits are large in scale.

Five types of gold-bearing quartz veins have been recognized in this area based on associated minerals: 1) a quartz type in which milky quartz is the major mineral with negligible or rare sulfides and other minerals; 2) a pyrite-quartz type in which pyrite and quartz are the major minerals and the pyrite is coarse-grained and locally massive in the quartz; 3) a pyrite-polymetallic quartz type which is characterized by pyrite and polymetallic sulfides with the latter predominantly galena with subsidiary sphalerite and chalcopyrite, and which is the most significant type for gold; 4) a pyrite-carbonate-quartz type, characterized by carbonate minerals and only minor metallic minerals and of lesser importantance and 5) a barytocelestite-calcite-quartz type, containing barytocelestite, calcite and quartz with minor aegerine-augite, feldspar and pyrite. Gold occurs predominantly in native form and also in electrum and calaverite. Ninety-five percent of the metallic minerals are sulfides, predominantly pyrite, galena, chalcopyrite and sphalerite, with some tellurides. The common types of wall-rock alteration are sericitization, pyritization and carbonatization, with lesser K-feldspathization, biotitization, chloritization and epidotization. The presence of pyrite and sericitization is the chief criterion for the locallization of ore. Four metallogenic stages have been recognized as follows: Stage I) pyrite-quartz, Stage II) quartz-pyrite; Stage III) quartz-pyrite-polymetallic sulfides, and Stage IV) quartz-pyrite-carbonate.

The **Laoyacha** gold deposit in Linbao County, Henan Province, is situated in the middle of the central ore zone. The Jindongcha deposit is to the east and the Dongchuang deposit to the west. Ore veins are hosted by the TTG complex of the Lujiayu Formation of the lower subgroup (Fig. 27). The earlier faults that strike NNE, NNW and EW were infilled by intermediate-basic dikes, whereas the ore veins occupy faults that strike EW, NWW-SEE. The ore zone comprises nineteen veins that parallel the regional tectonic trend. The longest vein in the mine is approximately 2000 metres long, and the veins are generally several hundreds metres long although some are as short as

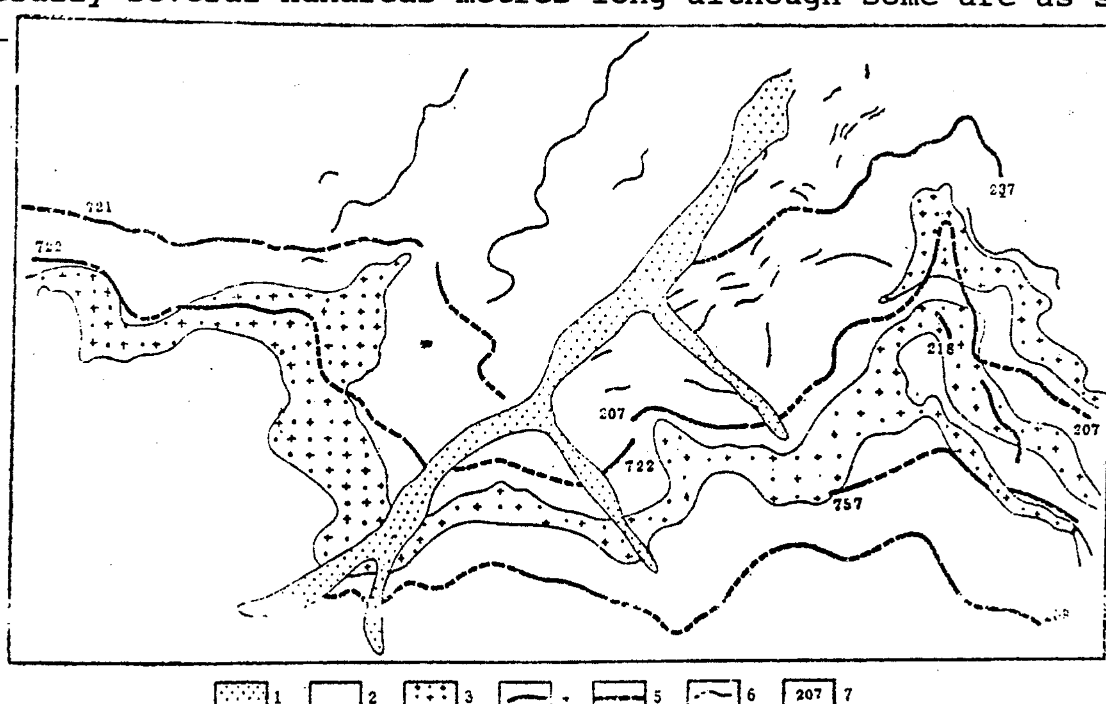


Figure 27: Geology of the Laoyacha gold deposit
1.Quaternary 2.Archean TTG 3.granite dike 4.gold-quartz vein 5.Mylonite zone 6.quartz vein 7.vein number

ten metres. Each lode is composed of a quartz vein, a tectonic mylonitic zone and alteration as exemplified by the major lodes, No. 721, 722, 207, 237, 757 and 209. Single quartz veins bearing gold are lenticular and tens of metres long. The maximum width, in the middle of the lenses is one to three metres. The mylonitic zones are approximately fifty to sixty metres long is and are occupied by quartz veins at their ends. The alteration is typically only one metre wide and includes pyritization, sericitization, silification and chloritization. Six economic ore bodies are all in the quartz veins but locally ore bodies occur in mylonitic zones and alterated rocks but these are far less important. Native gold is associated closely with pyrite. There are two generations of pyrite. One is coarse grained, two to four millimetres, and is disseminated, not only in quartz veins, but also in mylonitic zones and alteration zones where grades of gold are lower. Another type is fine grained and commomly associated with galena, sphalerite and chalcopyrite. This type occurs in orebodies with high grades of gold.

The **Wenyu** gold deposit is situated in Lingbao County near the boundary between Henan and Shaanxi provinces, in the middle section near the core of Laoyacha-Jinluoban Anticline. The mine area is underlain by Lower Taihu Subgroup composed of TTG. Mesozoic dikes of various compositions, but mainly mafic, are widespread in the mine area. Gold ore veins occur on the south limb of the Laoyacha-Jinluoban Anticline. Gold-bearing quartz veins are few and of low grade within 200 metres of the core of LJ Anticline. However, large quartz veins bearing high grades of gold occur from 200 to 2000 metres outward from the core of LJ Anticline. The economic significance of ore bodies is influenced by the types of host rocks, rocks of the TTG complex being most favourable for good gold grades. There are two types of mineralization, polymetallic sulfides and the gold-bearing quartz veins, both of them occurring as single veins controlled by WNW-trending faults with SSW dip. The No. 505 lode consists of quartz veins and mylonites and is controlled by a thrust fault striking 270-310 degrees and dipping 37-55 degrees S. It extends on surface for 4200 metres from the Daxiyugou to the Dongchuang mine area. Economic ore bodies occur within it in the Xilujiang-Xiyugou district and are approximately 1400 metres long and ten metres wide. Locally, the ore vein is wider where its strike changes direction. Native gold is associated mainly with pyrite and galena and locally with chalcopyrite, pyrrhotite, magnetite, sphalerite and wolframite. Quartz is the main gangue mineral. Native gold is 0.02-0.05 millimetres in grain size and occurs in fissures in pyrite and in the intergranular space, or within grains, of siderite and quartz. Wall rocks exhibit sericitization, carbonatization, biotitization, K-feldspathization and chloritization. The higher grades of gold correlate with stronger alteration.

The **Jindongcha** gold deposit is located in Lingbao County of Henan Province in the middle section of LJ Anticline and in the central zone of the Xiaoqinling Gold Camp. The mine area is underlain by a lower subgroup TTG complex. There are 89 gold-bearing quartz veins in the mine and these occur in four bands:

Band I consists of a major ore vein, its branching lodes and veinlets which are adjacent to the major vein which strikes E-W. The veins are distributed in the core and north limb of LJ Anticline.
Band II is parallel to Bands I and III and is composed of the No. 50 lode, No. 31 lode and their branches and veinlets which are parallel to the major veins and strike E-W.
Band III is contains the No. 183 lode and veinlets and strikes NE.
Band IV is composed of the No. 136, 135 and 137 lodes and strikes N-S.

No. 9 is a single lode, consisting of quartz veins and mylonite, that strikes E-W and dips S. It extends westwards from Dongtizigou to Fanghucha for 1680 metres. Ore consists of a pyrite type, a polymetallic type and an altered-rock type. Alteration of wall rocks includes pyritization, sericitization, silification, carbonatization, K-feldspathization and biotitization. Among them, the first four types are closely related with gold. Metallic sulfides are clustered in the quartz vein near its contact with the hangingwall and footwall where they coincide with high grades of gold. Native gold is associated mainly with pyrite and galena, with subordinate sphalerite and rare scheelite, magnetite and native silver. Gangue minerals are mainly quartz with lesser calcite and dolomite.

The **Tongyu** gold deposit is located in Tongguan County, Shaanxi Province, in the west part of the Xiaoqinling Gold Camp, and on the west end of the LJ Anticline. The mine area is underlain predominantly by rocks of the lower subgroup TTG complex. Dikes include granite porphyry, diabase and fraidronite. The No. 505 lode is the major one in the mine and is 4630 metres and 1000 metres deep. It strikes NE-SW and dips NW at angle 18-20 degree. The lode is hosted by TTG complex and consisted of lenticular quartz veins and an alteration zone. Economic ore bodies only occur in the middle part of the lode. Ore bodies are typically 10 to 200 metres long, the longest being 350 metres long and .8 to 2 metres wide, and the widest one, 9.45 metres wide. Native gold and silver occur with pyrite and lesser chalcopyrite, galena, molybdenite, sphalerite and proustite. The gangue minerals are dominantly quartz with feldspar, calcite and fluorite. The alteration of rocks, one to five metres wide, is mainly sericitization, silification and lesser pyritization, carbonatization and chloritization.

WUTAI AREA

The Wutai area of gold concentration is located in Shanxi Province from Wutaishan in the west to Taihangshan in the east including Yuanping, Wutai, Daixian, Fuping, Fanshi, Laiyuan, Lingqiu and Hunyuan Counties. Geotectonically it belongs to Wutai Kern of Shanxi Uplift, North China Platform. The area is underlain predominantly by Precambrian metamorphic rocks and by patches of rocks belonging to the Proterozoic Changcheng and Jixian System, as well as Palaeozoic and Mesozoic rocks (Fig. 28). The Fuping Group is distributed mainly in the northeast part of the area and is composed of various gneisses, bedded plagioclase amphibolite, granulite and marble. U-Pb ages of 2800 Ma and 2700-2900 Ma have been obtained from

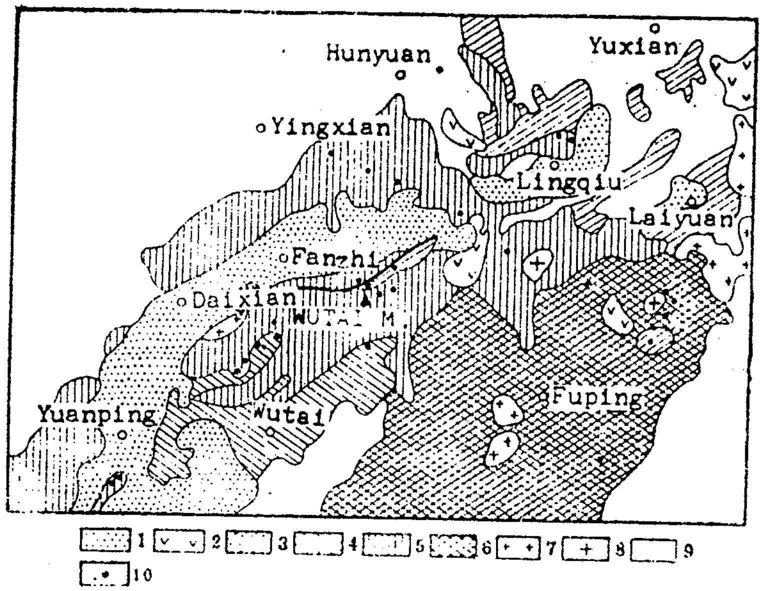


Figure 28: Geology of the Wutai gold concentration area
1.Cenozoic 2.Jurassic volcanics and clastics 3.carbonate and clastic rocks, Changcheng and Jixian Systems 4.Hutuo Gp 5.Wutai Gp 6.Fuping Gp 7.Yanshanian granite, granodiorite 8.Precambrian granite 9.other 10.gold deposit

it. The Wutai Group, constituting the main body of Wutai Mountain, is dispersed in the centre and northern part of the area and is divided into three subgroups, in ascending order, I) the Shiju Subgroup consisting of quartzite, biotite granulite with marble, plagioclase amphibolite, iron formation and gneiss, II) the Taihuai Subgroup composed of metaconglomerate, schist with iron formation, feldspar quartzite with marble and schist, and III) The Gaofan Subgroup consisting of quartzite, metasiltstone, phyllite and carbonaceous phyllite. Metamorphic rocks of the Shiju Subgroup at Dongshandi in Fanshi County have been dated at 2508 and 2557 Ma by the U-Pb zircon method and granulite of Shiju Subgroup at 2522 Ma by the Rb-Sr method. The Hutuo Group occurs in the southern part of the area and is a thick sedimentary cycle consisting of clastics (29.4 percent), argillaceous rocks (25.7 percent), carbonate rocks (42.5 percent) and basic volcanic (2.4 percent). The group can be divided into three subgroups: the Doucun, Dongye and Guojiazhai Subgroups in ascending order. U-Pb ages of 2366 Ma have been obtained from metamorphosed mafic volcanic at the Dongjiao Apatite Mine.

The granitoids of Wutai Area are greatly varied and widespread and they cover one third of the late Archean terrain. They are assigned to the Wutaiian and Luliangian phases. The Wutaiian phase granitoids were emplaced during Archean time and the Guangmingsi, Ekou, Shifo and Lanjishan bodies which intruded Shiju and Taihuai Subgroups, have been dated at 2500, 2520, 2507 and 2560 Ma respectively by the U-Pb zircon method.

There are tens of gold deposits and occurrences in the area.

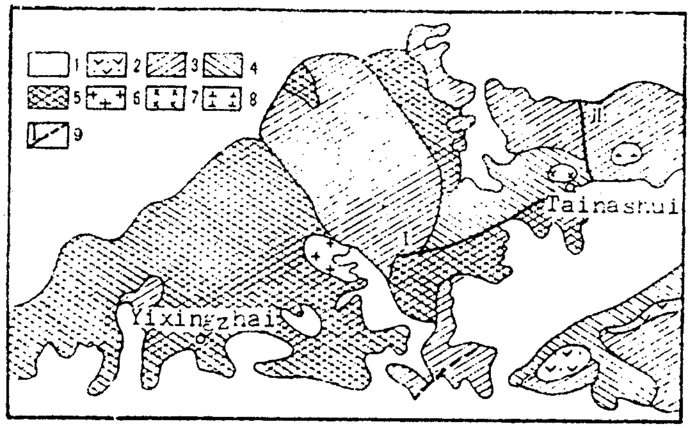


Figure 29: Geology of the Yixingzhai - Tainashui district
1.Cenozoic 2.Mesozoic volcanics and clastics 3.Cambro-Ordovician carbonates and clastics 4.carbonates and clastics, Changcheng and Jixian Systems 5.Wutai Gp 6.Yanshanian granite, granodiorite 7.Yanshanian dacite porphyry 8.Yanshanian diorite 9.fault 10.Dalugou-Jiaozhuang Fault 11.Niejiagou Fault.

Economic ore bodies are concentrated mainly in Fanshi-Lingqin District such as Yixingzhai and Tainashui Gold Mines, and then Fupin-Laiyuan District such as Daomaguan and Sanliwan Gold Mines. These mines are characterized in geological setting by widespread metamorphic rocks in Wutai and Hutuo Groups into which were intruded by Mesozoic hypabbysal and subvolcanic intermediate-acidic intrusions. Quite good gold mineralization occur in dolomitite of Gaoyuzhuang Formation of Changcheng System. Mu et al. (1985) have divided the gold deposits in the area into six types. They are 1) the metamorphic hydrothermal type, controlled by metamorphic rocks of Wutai and Hutuo Groups; 2) the infiltration hydrothermal type, controlled by carbonate rocks of the Changcheng System; 3) the volcanic hydrothermal type 4); the granite type, controlled by Yanshanian intermediate-acidic intrusions; 5) the conglomerate type; and 6) the placer type. Superimposed metallization may be of distinctive feature here.

The **Yixingzhai** gold deposit is representative of metamorphic hydrothermal type and is situated in the northern part of the Wutai Area (Fig. 29, 30), south of Hengshan. The area is underlain by biotite-hornblende-plagioclase gneiss with plagioclase amphibolite and Mesozoic intermediate-acidic intrusions. There are four Mesozoic volcanic vents in the south-central part of the mine area. Three sets of fractures transect the mine area. The NNE trending set controls the distribution of volcanic vents and, in part, quartz porphyry. The NS set cuts through the mine area and controls the distribution of gold-bearing quartz veins. The NW trending set cuts the gold-bearing quartz veins.

It has been recognized that there are two types of ore-bearing geological bodies, the gold-bearing single and compound quartz veins of N-S strike, hosted by the Wutai Group and the gold-bearing polymetallic quartz veins and stockwork veins, controlled by Mesozoic volcanic structures. Orebodies of the first type are better than those of the second type. Basically, the gold-bearing quartz vein are of single vein type. Eight ore veins have been mined and these are of

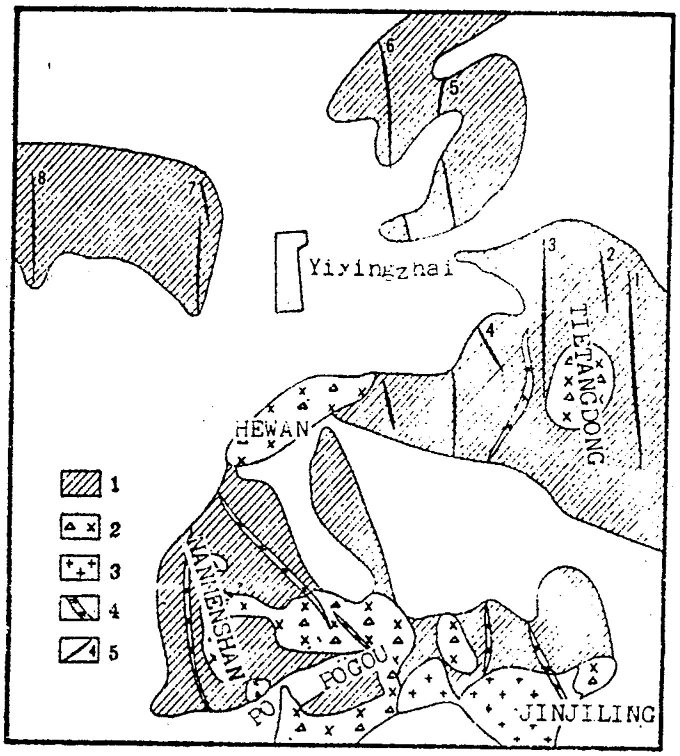


Figure 30: Geology of the Yixingzhai gold deposit.
1.Wutai Gp 2.Yanshanian rhyolite 3.Yanshanian monzonite 4.Yanshanian dikes 5.gold-quartz veins

medium size and grade. The host rocks exhibit silicification, carbonatization and chloritization. Gold is associated with argentite, cerargyrite, pyrite, chalcopyrite, sphalerite, galena, quartz, calcite, adularia and chalcedony. Gold minerals are native gold and electrum. Native gold occurs in pyrite and other metallic sulfides. In the four volcanic vents of the southern mine area, gold mineralization was superimposed by gold-bearing polymetallic quartz veinlets and networks that were influenced by Mesozoic volcanism. Gold is associated with silver, iron, molybdenum and copper.

The **Tainashui** gold deposit is located at the intersection of Niejiagou fault with Dalugou-Jiaozhuang fault (Fig. 29). To the south lies the Wutai Group, and to the north, the Gaoyuzhuang Formation of Changcheng System and the Wumishan Formation of Jixian System. The country rocks of the volcanic vents that host gold ore are mainly the dolomitic limestone of Gaoyuzhuang Formation of Changcheng System and, to a lesser extent, the limestone of the Wumishan Formation of the Jixian System. The volcanic neck is elliptical on surface and funnel-shaped in section and contains predominantly dacitic volcanic breccia. Dacite porphyry occurs along the eastern margin of the vent (Fig. 31). Gold-bearing quartz veins are controlled by fractures and tectonic breccia in the dacite porphyry (Fig.32). The gold mineralization occurs at the footwall contact zone between the dacite porphyry and carbonate rock. Fifteen ore bodies are mostly blind bodies 10 to 100

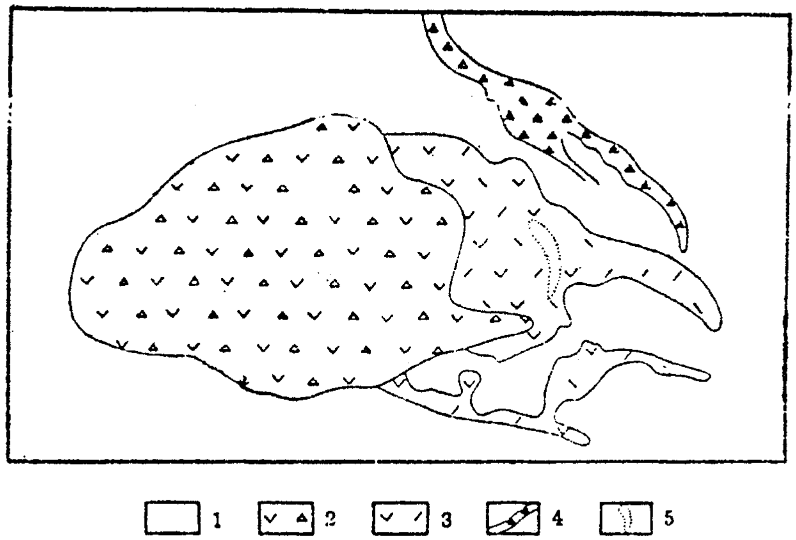


Figure 31: Geology of the Tainashui gold deposit.
1.Gaoyuzhuang Fm, Changcheng Gp and Wumishan Fm, Jixian Gp 2.dacite breccia 3.dacite porphyry 4.breccia zone 5.gold ore zone

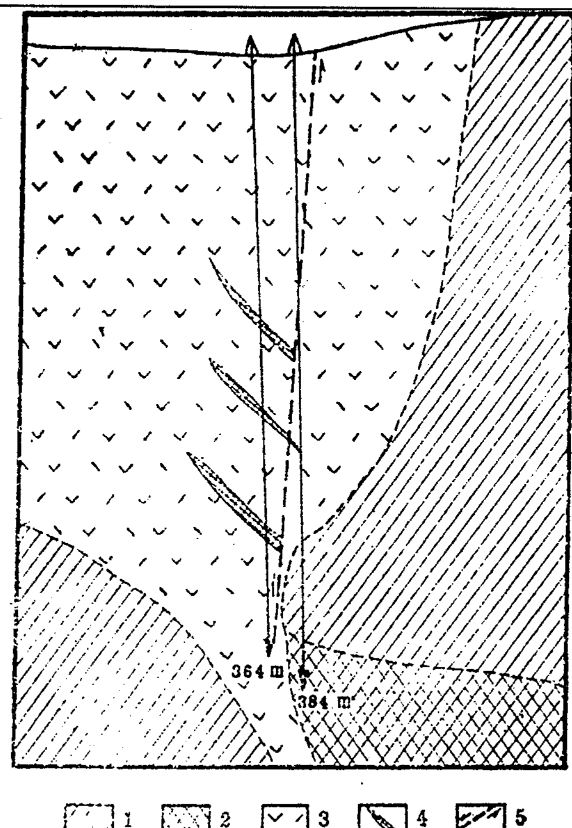


Figure 32: Cross-section along a prospecting line, Tainashui deposit
1.limestone, Gaoyuzhuang Fm, Changcheng Gp 2.gneiss, Wutai Gp 3.dacite porphyry 4.gold orebodies 5.fault

metres long and less than one metre wide. The deposit is medium size and low-medium grade. Gold is associated with coper, lead, zinc, molybdenum and silver. Native gold is enclosed in pyrite. The rocks in the interior of the vent exhibit primarily sericitization and kaolinization with some then silicification and potash-feldspathization.

The **Santiaoling** gold deposit is located on the border between Yingxian, Fanshi and Laiyuan counties. The mine area is underlain dominantly by metamorphic rocks of the Wutai Group and some small patches of rocks of the Changcheng System, Jixian System and Palaeozoic rocks. Magmatism is represented by Mesozoic granite porphyry and diorite which were intruded into the Wutai Group. There are four sets of fractures developed in the mine area: on NW, NE, NNW and NEE trends. A fracture zone, 1000-1500 metres long and 10-300 metres wide is coincides with the contact between the intrusion and the Muge Formation of Wutai Group and with the intersections of NNW and NW fractures. Sixteen economic ore bodies have been recognized, but the mine is small in scale and medium in grade. Gold is associated with chalcopyrite, pyrite, sphalerite and galena, and gangue of quartz and calcite. The wall rocks exhibit pyritization, silicification, chloritization and carbonatization.

The **Huangcao**, **Chafang** and **Shittanggou** occurrences, not of economic significance, are distributed in the northern slope of Wutai Mountain (Fig. 33). These occurrences are hosted by the Gaoyuzhuang Formation of Changcheng System, primarily shallow marine carbonates. They have been divided into four members and gold mineralization occurs in the first and third members which consisted of bedded dolomite although there are few economically viable bodies. Gold is associated with magnetite, pyrite, galena, sphalerite, pyrrhotite, chalcopyrite, native silver, brown hematite, quartz, calcite, dolomite and liverstone.

The basal conglomerate of the Hutuo Group also contains gold but no economic ore bodies have been found.

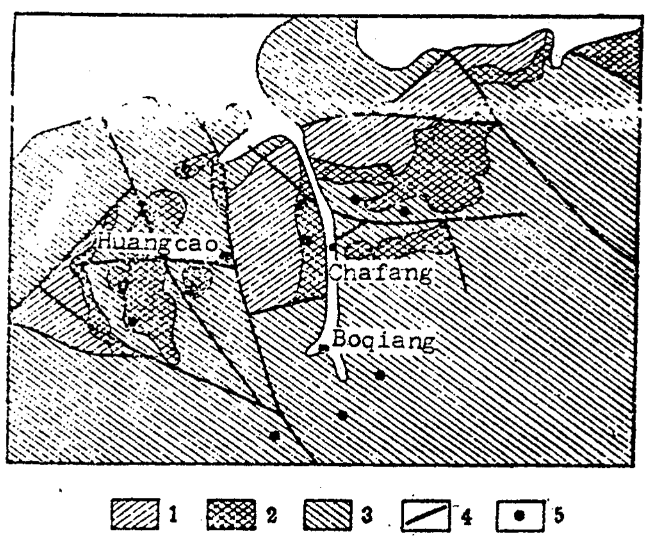


Figure 33: Gold occurrences on the northern slope of Wutai Mountain.
1.limestone,C-O 2.limestone, Prot. 3.Wutai Gp. 4.fault 5.occurrence

DANDONG-YINKOU AREA

This is an area of gold concentration located on the Liaodong Peninsula in Dandong, Kuandian, Benxi, Zhuanghe, Xiuyan and Yinkou Counties and Cities. Geotectonically it is part of the Yinkou-Kuandian Kern of Jiaoliao (Eastern Shandong and Liaoning Peninsula) Anteklise (Fig. 34). The traditional metamorphic rock classification is used here. Archean rocks are poorly exposed in the area and are found only in certain districts. The Archean rocks comprise grey orthogneiss (more than ninety percent), of quartz dioritic and biotite granitic composition, and bedded supracrustal (less than ten percent) correlated to Anshan Group which is composed of lower Chengzitan and upper Dongjiagou Formations. The bedded supracrustals form enclaves occupying an area less than ten square kilometres within the grey orthogneiss. Early Proterozoic rocks of the Liaohe Group are distributed throughout the area with a sequence of Langzishan, Lieryu, Gaojiayo, Dashiqiao and Gaixian Formations in ascending order. Some remnants of Middle Proterozoic Yushulazi Group and Upper Proterozoic Sinian System are scattered in the area. Syntectonic Proterozoic granite dated at 2.06 Ga intruded into the earier bedded rocks and may be assigned to acidic granite system. Mesozoic igneous rocks are the most important and comprise seventy percent of the outcrop in the area. According to Yao Fengliang (1988), the Mesozoic igneous rocks can be classified into three series. They are: 1) gneissic granite series (being deep-seated and dated at between 220-198 Ma); 2) granite complex (moderate- to deep-seated and dated at 180-140 Ma); and 3) amphibole (hornblende)-perthite granite series (shallow seated and dated at 120 Ma).

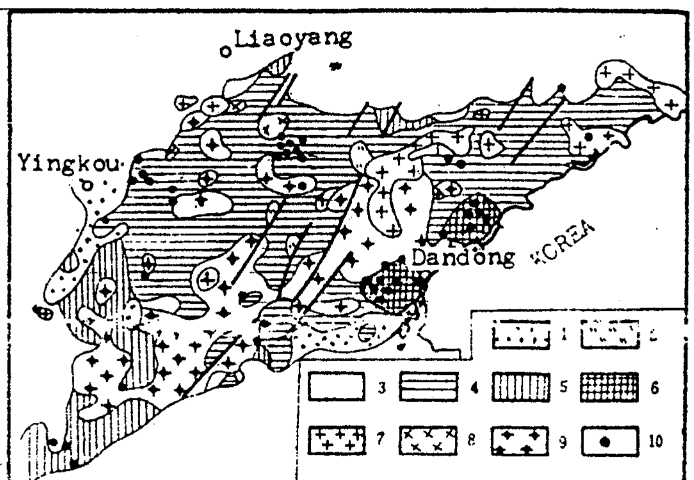


Figure 34: Geology of the Dandong -Yinkou Area
1.Quaternary 2.Jurassic volcanics and coal-bearing strata 3.other 4.Liaohe Gp 5.Anshan Gp 6.Proterozoic metamorphic rocks 7.Yanshanian granite 8.Precambrian ultramafic rock 9.Precambrian granite 10.gold deposits/occurrences

More than one hundred gold deposits and occurrences in the area are clustered in discrete districts and form several NE-trending ore axes i.e. the Dandong Zone in the east, the Zhuanghe-Xiuyan and Guiyunhua zone in the middle and the Sunjiagou zone in the west. The Dandong zone localizes approximately fifty percent of the gold deposits in the area including Wulong and Sidaogou which have been developed into large scale mines. In addition, tens of small gold deposits and occurrences have been found in this zone. Mesozoic granites such as the Sanguliu and Dabu intrusions are widespread over the Dandong zone. The NE-stiking Yalujiang Break also is closely related to gold mineralization. The Zhuanghe-Xiuyan zone extends in a NNE direction, in which Xiuyan and Shimiao Intusions represent the major Mesozoic granites. More than twenty gold deposits and occurrences have been found in this zone, including the medium-sized Weizi Gold Mine and the small-scale Shimiaozi, Koubangou, Xinfen, Sanjiazi and Wangjiadonggou Gold Mines. The Zhuanghe and Xiuyan Breaks may control the distribution of gold deposits. Thus, the Zhuanghe-Xiuyan zone can be divided into two subzones, the Zhuanghe subzone, which is 130 km long and 15 kilometres wide, and the Xiuyan subzone about 80 kilometres long and 20 kilometres wide. The gold deposits in the Dandong zone can be classified, according to their geological setting, into two types: the Wulong type, where the gold deposits are hosted by granitic complex or gneissic granite, are controlled by fault structures and are closely associated with dikes; and the Sidaogou type, where the gold deposits are hosted by intercalated beds of metasandstone, carboaceous slate and marble of the Early Proterozoic Liaohe Group, and are controlled by fold structures and fracture within beds.

The **Wulong** deposit is situated to the north of the Sanguliu granite complex. The mine area is occupied by gneissic granite and several hundreds of dikes including corcovadite, fine grained diorite, lamporphyre and diabase (Fig. 35). According to Pen Jingqi (1988), 90 percent of the gold-bearing quartz veins here are associated with intermediate dikes. NS and NW trending fractures are related to gold mineralization and are in proximity to the major NNE trending fault so that they may be second order structures. Ore bodies are veined, most of them are regular gold-bearing quartz veins and only a few are ore-bearing altered tectonoclastic zones. Massive and prismatic-granular types of ore-bearing quartz veins have been recognized. The massive quartz veins make up 70 percent of the ore-bearing bodies and is poor in gold by comparison with the prismatic-granular quartz veins which make up 30 percent and which are rich in gold. Altered zones, two to three metres wide, are common, but not well-developed, with silicification, sericitization, pyritization and carbonatization being the main alteration types. Biotitization and chloritization may be present where diorite dikes are host rocks. In the mine area, there are three types of ore structure, including network veins, veinlet-disseminated and single veins. There are mineralogically four types of ore bodies, 1) a gold-quartz-pyrite, pyrrhotite type; 2) a gold-quartz-bismuthinite type; 3) a golg-polymetallic sulfide type and 4) a gold-quartz-chlorite type. Except for the second, these types of ore bodies are widespread. The metallic sulfide minerals in the quartz veins are mainly pyrite and pyrrhotite with accessary bismuthinite, native bismuth, chalcopyrite, sphalerite and galena, with rare scheelite and arsenopyrite. Gangue minerals are predominantly quartz alone or with rare calcite, chlorite and fluorite. Gold is found mainly as native metal and electrum, locally as kustelite.

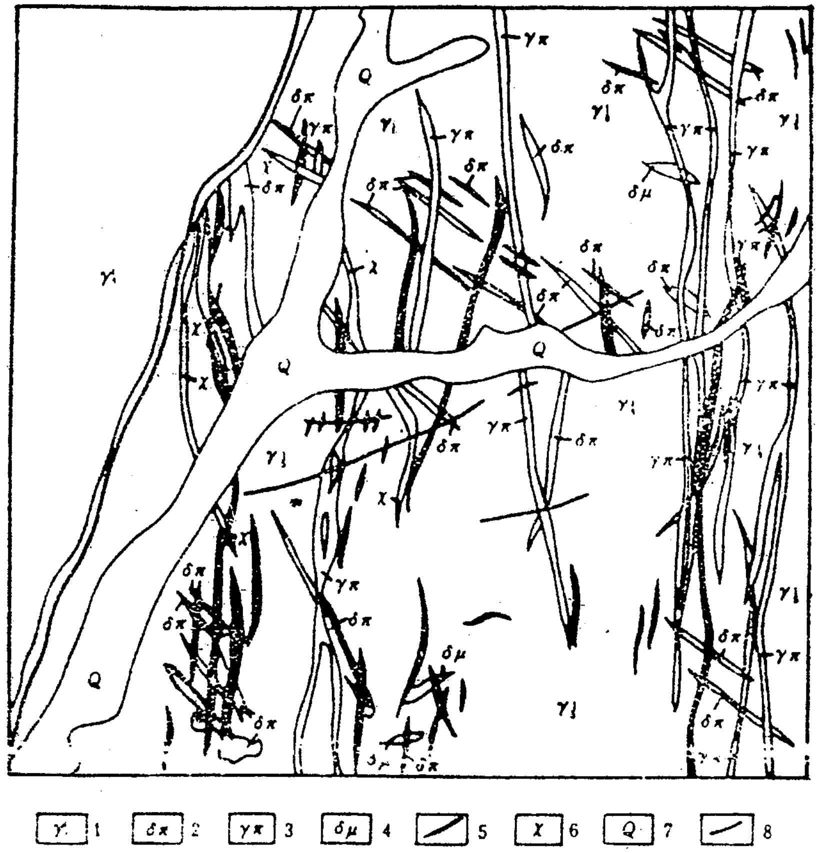


Figure 35: Geology of the Wulong gold deposit.
1.gneissic granite 2.diorite dike 3.granite porphyry 4.foliated diorite dike 5.orebodies 6.lamprophyre 7.Quaternary 8.fault

The **Sidaogou** gold deposit is located southwest of Dandong City in the middle section of the 15 km long zone of mineralization from Jingiangshan in the northeast to Jielishu in the southwest. It occurs adjacent to the Yalujiang Break and to the east of Sanguliu intrusion. The mine area is underlain by the Gaixian Formation of Liaohe Group of metamorphosed quartz sandstone, feldspar quartz-sandstone with graphite sericite schist in the lower part and schist in the upper part, covered with psephyte. These rocks are overlain by strata of the Sinian System and tuffaceous arenaceous shale of Jurassic System.A NE-trending schistose fault zone contains series of lower order faults and drag folds. Economic bodies of gold mineralization are limited by intercalated band of quartz sandstone and are controlled by interstratified fractures and minor folds. The orebodies are stratabound and lenticular, containing veinlet and disseminated ores. Five gold-bearing zones are arranged in an *en echelon* fashion, the largest one being 600 metres long, 10 to 80 metres wide and 500 metres downdip. The ore bodies have extremely complicated and, commonly irregular, shapes. They have several different relationships with their host rocks (Fig. 36): 1) orebodies consisting of compound veins are controlled by interstratified fractures and are therefore statabound but composed of sulfide veins that cut across beds;

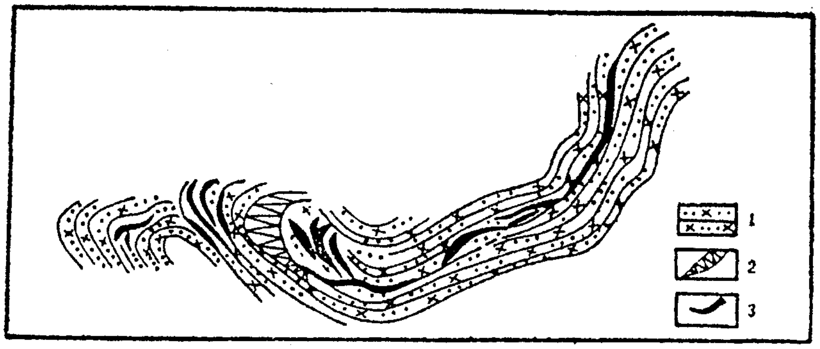


Figure 36: Geometry of oebodies, 1st Level, Sidaogou gold deposit
1.metasandstone 2.quartz vein 3.gold orebodies

2) orebodies that are controlled by fractured zones consist of veins that obliquely cut the bedding of the host rock, but with branches that are concordant with the bedding; and 3) orebodies that are controlled by minor folds or the secondary fold structure contain veins that are generally concordant with the host rock, but, that may cut the strata to form a "puncture" structure. In all cases, the orebodies are accompanied by silicification, pyritization and sericitization. Mineralization consists dominantly of pyrite with lesse pyrrhotite, chalcopyrite, quartz and sericite. Arsenopyrite and scheelite are rare.

The **Weizi** gold deposit in the Xiuyan Break is representative of the Zuanghe-Xiuyan zone. The mine area is underlain by the upper part of Liaohe Group, of which the lower biotite plagioclase gneisses are scattered in the west of the mine area; the middle, hornblende-plagioclase gneisses occur as xenoliths in gneissic granite; and the upper, biotite granulite is intercalated with biotite schist and hornblende schist. Most of gold-bearing quartz veins in the mine area are hosted by biotite schist (Fig. 37). Economic reserves are in the axial area of an overturned syncline and gold-bearing quartz veins are strictly controlled by interstratified parallel and *en echelon* fractures. The boundaries between quartz veins and their host rocks are obscure; locally the contacts of the quartz veins are gradational and contain many xenoliths of banded and podiform mica schist. Vein, veinlet-disseminated and network vein mineralization has been recognized and classified into two types of mineral association, the Au-quartz-pyrite and the Au-quartz-pyrite-polymetallic types, the second being the most productive for gold. Gold is associated dominantly with pyrite (70%), subordinate pyrrhotite, galena, sphalerite, and chalcopyrite and rare scheelite and electrum. Gangue minerals are quartz with calcite, biotite, muscovite, sericite, chlorite and feldspar. Electrum and silver-bearing native gold are the major gold minerals. The rocks around the orebodies exhibit silicification, pyritization, oligoclase-albitization and chloritization.

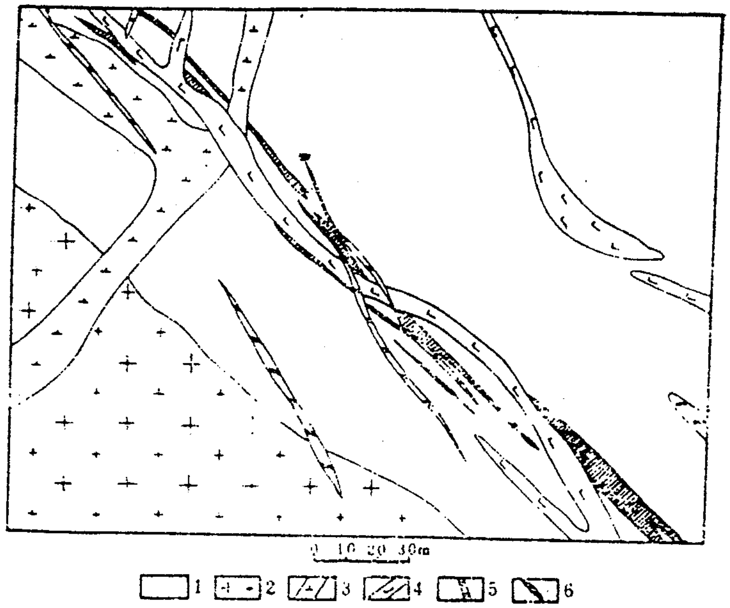


Figure 37: Geology of the 6th Level, Weizi gold deposit
1.biotite gneiss, biotite schist 2.porphyritic granite 3.diorite porphyry 4.andesite porphyry 5.lamprophyre 6.gold orebodies

The **<u>Sunjiagou</u>** deposit is representative of Sunjiagou zone (Fig. 38) and occurs in contact between granite and metamorphic rocks. Perhaps the most striking feature of this gold deposit is the presence of potassium metasomatism to various degrees with silicification and carbonatization of the rocks in the area. Some Chinese geologists believe that Wulong, Sidaogou and Weizi gold deposits are of metamorphic hydrothermal type, but some consider that all the deposits, including the Sunjiagou Mine, are of magmatic hydrothermal type with their metallogenetic epoch of Mesozoic Era.

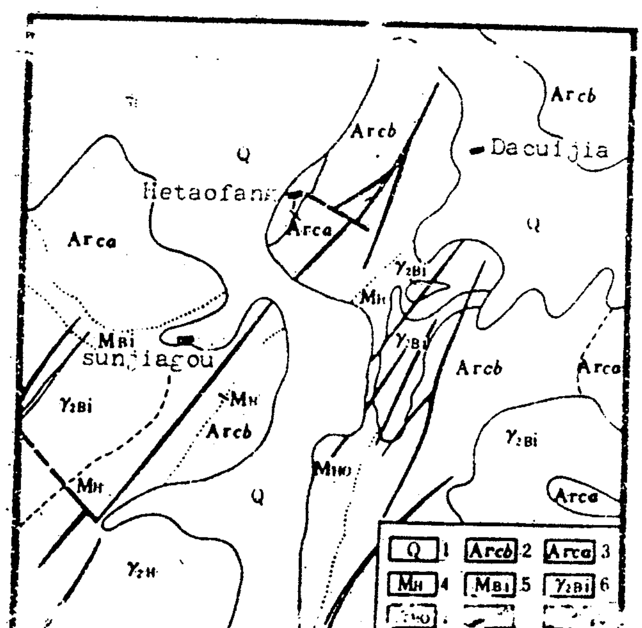


Figure 38: Gold deposits of the Sunjiagou-Hetofan district.

1.Quaternary
2,3.Chengzitan Fm
4,5,6,7.TTG complex
8.rhyolite dike
9.gold-quartz vein

GOLD METALLOGENY

It is clear from the above descriptions that there are essentially three types of settings for gold deposits in North China Platform, in Mesozoic volcanic rocks, in or adjacent to Mesozoic granitoid rocks and in Archean metamorphic rocks.

There is no controversy concerning the age of mineralization for two of these types of gold deposits in North China Platform. The first of these occurs in Mesozoic volcanic rocks and is therefore at most of Mesozoic age. At the Erdaogou gold mine, the gold-bearing veins cut Jurassic rhyolites and Mesozoic diorites although the basement is composed of Archean greenstone belt lithologies. The Xiangluwanzi deposit in Hailong County, Jilin Province occurs in brecciated tuff capping late Jurassic plagioclse porphyry underlain by Archean metamorphic rocks. At the Tainashui deposit in Shanxi Province, ore is related to porphyritic dacite which forms a subvolcanic intrusion that is underlain by metamorphic rocks of the Wutai Group.

The second type of deposit for which the age is well constrained occurs in Mesozoic granite. This is commonly referred to as the Yu'erya type of deposit and is represented by deposits such as Yu'erya, Maoshan, and Huajian-Niuxinshan. Potassium argon ages of 149 Ma, 169 Ma and 234 Ma have been obtained from the Yu'erya granite. The Maoshan granite has yielded a K-Ar age of 138 Ma and an age of 133.9 Ma has been obtained from sericite formed as part of the hydrothermal alteration at Maoshan. In addition, Yu Changtao(1986) obtained a lead model age of 230 Ma for the ore at Yu'erya. Collectively these ages indicate that the metallogenic epoch of the Yu'erya type of deposit is constrained between the early Triassic and the late Cretaceous, corresponding to the interval from the Indosinian Movement to the Yanshanian Movement.

Despite the concensus on gold deposits in Mesozoic volcanic rocks and granite, the question of the appropriate metallogenic epoch for deposits in the Archean metamorphic terrains of North China platform has been a contoversial topic for many years. In the past, these gold-bearing vein deposits were assumed to be medium to low temperature hydrothermal deposits, largely due to the influence of Lindgren's theory of magmatic hydothermal metallogeny, and hence they were assigned to the Mesozoic metallogenic epoch. Since the 1960's, however, the theory of metamorphic hydothermal metallogeny has gained prominence, primarily on the basis of much new isotopic data. This theory has gained new ground and has been joined by the theory of lateral secretion but the origin of these deposits remains problematical. When the ideas of a metamorphic hydothermal origin for the Jinchangyu deposit in Eastern Hebei and of a Precambrian metallogenic epoch became dominant, Yu Changtao(1986) raised several points to refute them. He suggested a granite-related magmatic hydrothermal origin and a Mesozoic metallogenic epoch for this type of deposit based on the following facts:

1) Most of the Jinchangyu-type deposits are distributed in the Wanchang Formation around Mesozoic granites or between neighbouring granites.
2) The isotopic ages for the mineralization are mostly Yanshanian.

3) Study of the temperatures and compositions of fluid inclusions shows that the characteristics of the hydrothermal solutions are similar for Jinchanyu-type and Yu'erya-type deposits.
4) The initial temperature of the fluid in each case was greater than 390 degrees C and the fluid was in a supercritical state.
5) The delta-D-H2O and delta-O-H2O data for vein mineralization plot in the field of magmatic water.
6) Lead isotope data show that the constituents of the ores are derived from granites.

Therefore the debate on the age and genesis of this type of gold deposit continues as new evidence is gathered.

REFERENCES

An Jiatong et al.
1988: Study on the Factors Controlling the Formation of Gold Deposits in the Muping-Rushan Region, Shandong Province; Contributions to the project of regional metallogenetic conditions of main gold deposit types in China. V. Jiaodong Area in Shandong Province. pp. 1-45.

Chao Yuan et al.
1989: Assessment Criteria for Quartz Vein and Ore-controlling Condition of Gold Deposits in Xiaoqinling District of Shaanxi Province; Contributions to the project of regional metallogenetic conditions of main gold deposit types in China, III. Xiaoqinling area in Henan and Shaanxi Province, pp. 87-145.

Jahn, B.M. et al.
1987: Archean Granitoids from the Taishan Complex; in Petrogenesis and Crustal Evolution of the Taishan Complex, Abstracts of the International Symposium on Petrogenesis and Mineralization of Granitoids (ISPMG), Guangzhou, China.

Lin Baoqin et al.
1986: The Early Precambrian geology and mineralization of gold in the Jiapigou area, South Jilin Province. Bulletin of the Shenyang Institute of Geology and Mineral Resources, CAGS No.13 pp. 1-116. Scientific and Technical Press of Liaoning Province, Shenyang(in Chinese with English abstract).

Lin Baoqin et al.
1989: Research on the Main Gold-bearing Strata, Xiaoqinling District on the Borderland between Henan and Shaanxi Provinces; Contributions to the project of region metallogenetic conditions of main gold deposit types in China. III. Xiaoqinling area in Henan and Shaanxi Provinces, p.1-46. Geological Publishing House, Beijing.

Lu Zuoziang et al.
1988: On Characters of Fault Controlled Ores and Regularities of Mineralization Enrichment of Jiaojia Gold Deposits, Eastern Shandong, China; Contributions to the project of regional metallogenetic

conditions of main gold deposit types in China. V. Jiaodong Area in Shandong Province. Geological Publishing House. pp. 85-119.

Mu Ruishen, Han Zhongwen, and Xu Qingguo
1981: On the regional minerogenetic regularity of gold deposits in China; Annual Report of the Chinese Academy of Geological Sciences, Geological Publishing House, Beijing.

Peng Jingqi et al.
1988: The Controlling of Magmatic Rocks and Regional Structure over Gold Deposits in Southern Liaoning Province. Contributions to the project of regional metallogenetic conditions of main gold deposit types in China. IV. Southern Liaoning Province, p.91-132.

Qin Nai et al.
1988: Metallogeny of Gold Deposits in the Archaean of the Sino-Korean Paraplatform; Metallogeny of Gold Deposits, Bulletin of the Chinese Academy of Geological Sciences, p. 123-132. Geological Publishing House, Beijing.

Qin Nai et al.
1988, Regional metallogenetic conditions of main gold deposit types in China, People's Republic of China; Ministry of Geology and Mineral Resources, Geological Memoirs Number 11, Series 4. Geological Publishing House, Beijing.

Qiu Youshou et al.
1988: Auriferousness of Metamorphic Rocks and Granite in Muping-Rushan Area of Shandong and Their Relation with Minerogenesis; Contributions to the project of regional metallogenetic conditions of main gold deposit types in China. V. Jiaodong Area in Shandong Province. pp. 120-177.

Sun Dazhong et al.
1989: Studies on Auriferous Rock Series of the Archaean in Eastern Hebei; Contributions to the project of region metallogenetic conditions of main gold deposit types in China, II. Eastern Hebei Province, pp. 49-98.

Wang Dinggou et al.
1989: Main Gold Ore-controlling Conditions and Prediction of Blind Orebodies in Xiaoqinling Area of Henan Province; Contributions to the project of region metallogenetic conditions of main gold deposit types in China. III. Xiaoqinling area in Henan and Shaanxi Provinces, pp. 47-86.

Wang Kaiyi et al.
1987: Rb-Sr Age of the Shanghaiguan polyphase granitic gneisses; Scientia Geologica Sinica, No. 2 pp. 148-159.

Wang Konghai et al.
1988: Auriferousness of the Metamorphic Rocks and Granite in Southern Liaoning Province and Its Relation with Metallogenesis; Contributions

to the project of regional metallogenetic conditions of main gold deposit types in China. IV. Southern Liaoning Province. pp. 1-44.

Yan E et al
1981: The geological character of the Archeozoic greenstone zone in Qingyuan area, Liaoning Province; Bulletin of the Geological Society of Liaoning, No.1, p.158-177. (in Chinese, with English abstract).

Yao Fengliang et al.
1988: Evolution of the Mesozoic Granites in the Southern Liaoning Province and Genesis and Prediction of Related Gold Deposits; Contributions to the project of regional metallogenetic conditions of main gold deposit types in China. IV. Southern Liaoning Province. pp. 45-84.

Yu Changtao et. al.
1989: Study on the Genesis of Major Types of Gold Deposits and its Mechanism of Formation in Eastern Hebei. Contributions to the project of region metallogenetic conditions of main gold deposit types in China. II. Eastern Hebei Province pp.1-48. Geological Publishing House, Beijing.

Yu Hanmac
1985: On a study of the isotopic age of the Linglong granite in Shandong Province. Bulletin of the Geological Society of Liaoning Province, No. 1, pp. 74-85 (in Chinese, with English abstract).

Yu Runlin et al.
1989: Metallogenetic Conditions of Major Gold Ore Type and Ore-searching Orientation in Eastern Hebei: Contributions to the project of region metallogenetic conditions of main gold deposit types in China. II. Eastern Hebei Province. pp. 99-146.

Zhong Fudao
1984: Geochronological study of Archaean granite-gneisses in the Anshan area, Northeast China. Geochemical, No. 3 pp. 195-205 (in Chinese, with English abstract).

Chapter 3

VEIN GOLD DEPOSITS OF LIAOXI UPLIFT, NORTH CHINA PLATFORM

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B.E. Taylor, F. Robert, J.K. Mortensen, K.H. Poulsen

ABSTRACT

Liaoxi Uplift is one of a series of basement uplifts with vein gold deposits that comprise the Nei Mongol Axis of North China Platform. It contains Archean gneiss, Mesozoic granitoid rocks and Mesozoic sandstone and subaerial volcanic rocks. Twenty deposits, each containing from one to twenty tonnes of gold, occur within Archean gneiss as well as the Mesozoic volcanic and granitoid rocks. Major ENE faults define the limits of the Archean gneiss as well as the gold deposits. Numerous NE and NW secondary faults are the primary loci for orebodies which commonly comprise fault gouge, vuggy polymetallic quartz veins, hydrothermal breccia and ribbon quartz veins. The deposits are silver-rich (Ag/Au = 7:1 to 1:1) and, in the Jinchanggouliang-Erdaogou area, ore minerals are zoned about the Xiduimiangou quartz monzonite stock from an inner Sb-Cu zone, to an intermediate pyrite (+/- Pb-Zn) zone and an outer Zn (+/- Pb) zone. Host rocks to ore zones exhibit evidence of hydrothermal alteration types including i) sericitic (sericitization, silicification, pyritization) in felsic rocks, ii) propylitic (chloritization, carbonatization, pyritization), dominantly in mafic rocks, and iii) argillic, which is primarily present in vein-bearing faults in both rock types.

The relatively late timing of formation of these deposits, their overall distribution, structural style,and the lead, oxygen and hydrogen isotopic compositions of minerals and rocks are consistent with an epithermal origin. Their composition and hydrothermal alteration, despite the diversity of their host rocks, indicate that these deposits belong to the adularia-sericite class of epithermal ores and are, in part, of magmatic hydrothermal origin. Magmatic heat, volatiles and perhaps metals were added to meteoric geothermal fluids localized by active faults that were eventually sealed by veins. Many of the alteration-, ore- and vein-forming constitutents were probably redistributed from the gneissic, volcanic and plutonic host rocks. The dual correlation of these deposits with Precambrian basement and Mesozoic plutonic rocks illustrates the important tectonic control of basement uplifts on the distribution of gold in North China Platform.

INTRODUCTION

Approximately two-thirds of China's endogenic gold deposits and approximately 80 percent of its gold reserves are in the North China Platform, particularly in association with Archean rocks (Fig. 1). The deposits are hosted by Archean metamorphic rocks, by post-Archean anatectic granites, and by syntectonic Mesozoic (Yanshanian) granites and Mesozoic volcanic rocks. The Archean rocks comprise trondhjemite-tonalite-granodiorite complexes (50-70 percent of total) and amphibolite to granulite grade supracrustal rocks (30-50% of total) including paragneiss, leptynite, amphibolite, magnetite-quartzite (iron formation ?) and pyroxenite, the protoliths of which may be volcanic and sedimentary rocks. The Archean rocks of North China Platform exhibit evidence of multiple episodes of Precambrian intusive activity (Qin Nai et al., 1988) and, in addition, have experienced intense magmatism in the Mesozoic as a result of subduction of the Pacific Plate beneath the Asian Plate.

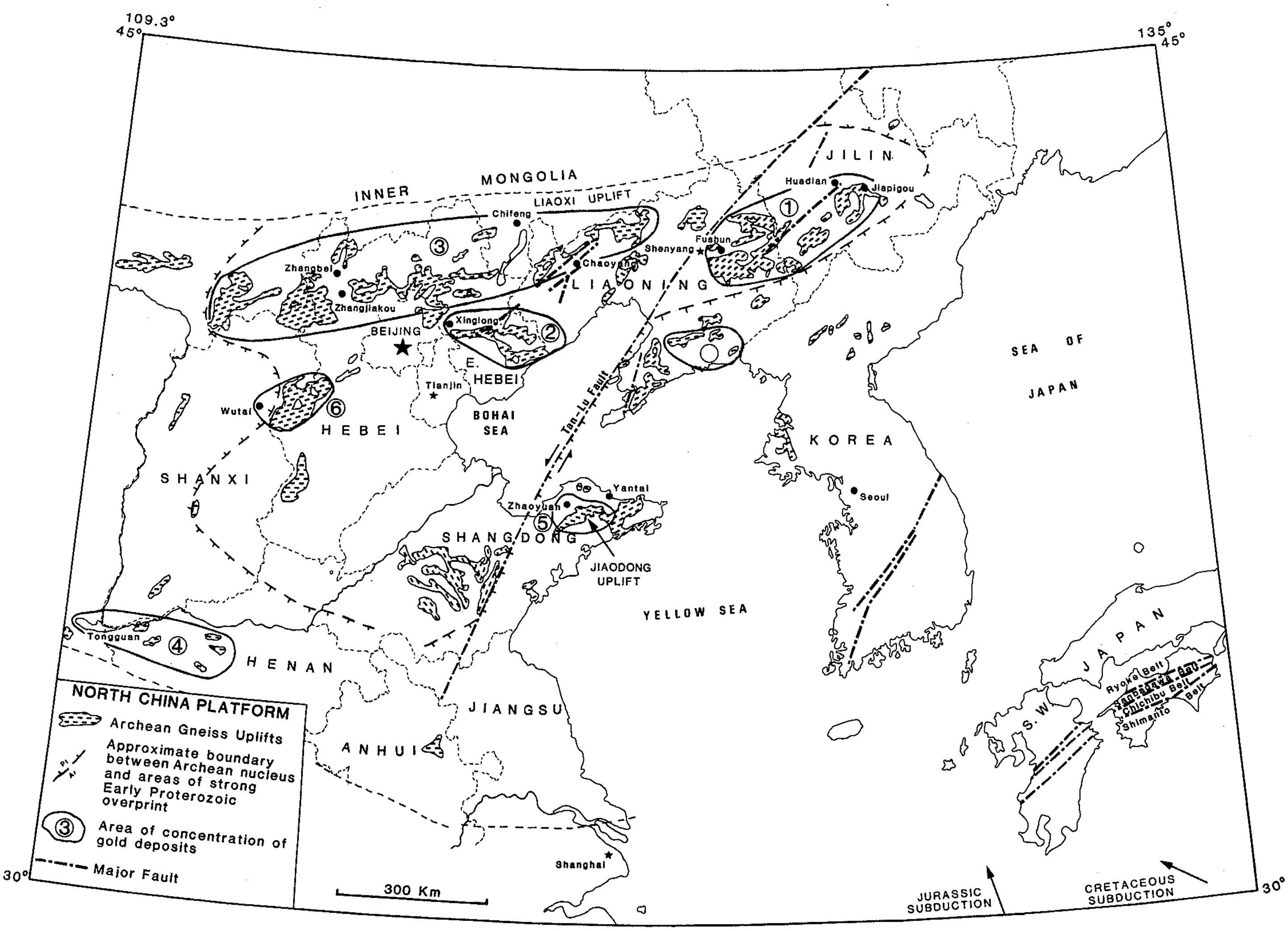


Figure 1: Distribution of areas of concentration of gold deposits in North China Platform (adapted after Mu Ruishen et. al.). The numbered areas of gold concentration are (1) Huadian-Fushun, (2) Yanshan, (3) Zhangjiakou-Chifeng, (4) Lingbao, (5) Zhaoyuan-Rushan, (6) Wutai, (7) Dandong-Yinkou.

Most Chinese geologists regard the relationship between uplifts of Precambrian metamorphic rocks and gold to favour genesis of the deposits from Precambrian source beds, either by remobilization of existing Precambrian deposits or by extraction of gold from geochemically enriched source rocks of the amphibolite facies during younger hydrothermal events (Qin Nai et al., 1988). There is nonetheless an increasing awareness of the importance of Mesozoic magmatic activity as a focussing mechanism for many deposits (see for example, Guo Wekui,1989) in the uplifts. In this paper we document the setting and geology of the vein gold deposits in Liaoxi Uplift which occurs within in the Zhangjiakou-Chifeng area of gold concentration.

GENERAL GEOLOGY

The Liaoxi Uplift (Fig.2) covers an area of approximately 1500 sq. km along the border of Liaoning Province and Inner Mongolia Autonomous Region and is one of a series of uplifts that comprise the Nei Mongol Axis.

The inner part of the uplift is dominated by Archean gneisses and Mesozoic granitoid rocks. The Archean rocks are predominantly plagioclase-biotite-hornblende gneisses with subordinate amounts of amphibolite, feldspar megacrystic orthogneiss, granite pegmatite, hornblendite, metapyroxenite and laterally extensive sheets of quartz magnetite rocks which appear to be metamorphosed oxide iron formations. Apart from the iron formations, which are mined on a small scale for iron ore, there is little preserved evidence to reveal the original protoliths of the gneisses. The Mesozoic granitoid rocks are equally abundant as the Archean rocks and, on existing geological maps, they are subdivided into several suites of which there are predominantly three types(Fig. 2). The largest masses, 25 to 50 km in diameter, are composed of relatively homogeneous, coarse grained quartz monzonite. These bodies are designated to be of Hercynian age on most geological maps but recent geochronological studies (J.K. Mortensen, unpublished data) suggest that some of these are Late Triassic in age. Smaller masses, 10 to 25 km in diameter, composed of granite and quartz monzonite occur as scattered bodies that define the central axis of the uplift. The smallest plutons, 1 to 10 kilometers across, are composed principally of medium grained granodiorite, diorite and quartz monzonite and are locally porphyritic.

Jurassic and Early Cretaceous cover rocks occur in the interior of the uplift but are most abundant on its flanks. In both cases these cover rocks are predominantly terrestrial sandstone and subaerial volcanic flow, breccia and tuffs. There are two notable features concerning the disposition of the cover rocks. First, on the flanks of the uplift, they overlie a 2km thick sequence of Sinian (Late Proterozoic) quartzite and dolomite that is absent from the interior of the Uplift, whereas, in the interior of the uplift, similar Mesozoic cover rocks rest directly on Precambrian basement. Second, the Mesozoic sedimentary and volcanic rocks in both cases, like the Sinian, everywhere dip moderately to steeply despite the absence of penetrative deformation and recognizeable metamorphism. These observations suggest that the uplift occurred prior to, or during Mesozoic magmatism and that uplift and tilting were achieved by fault-block rotation.

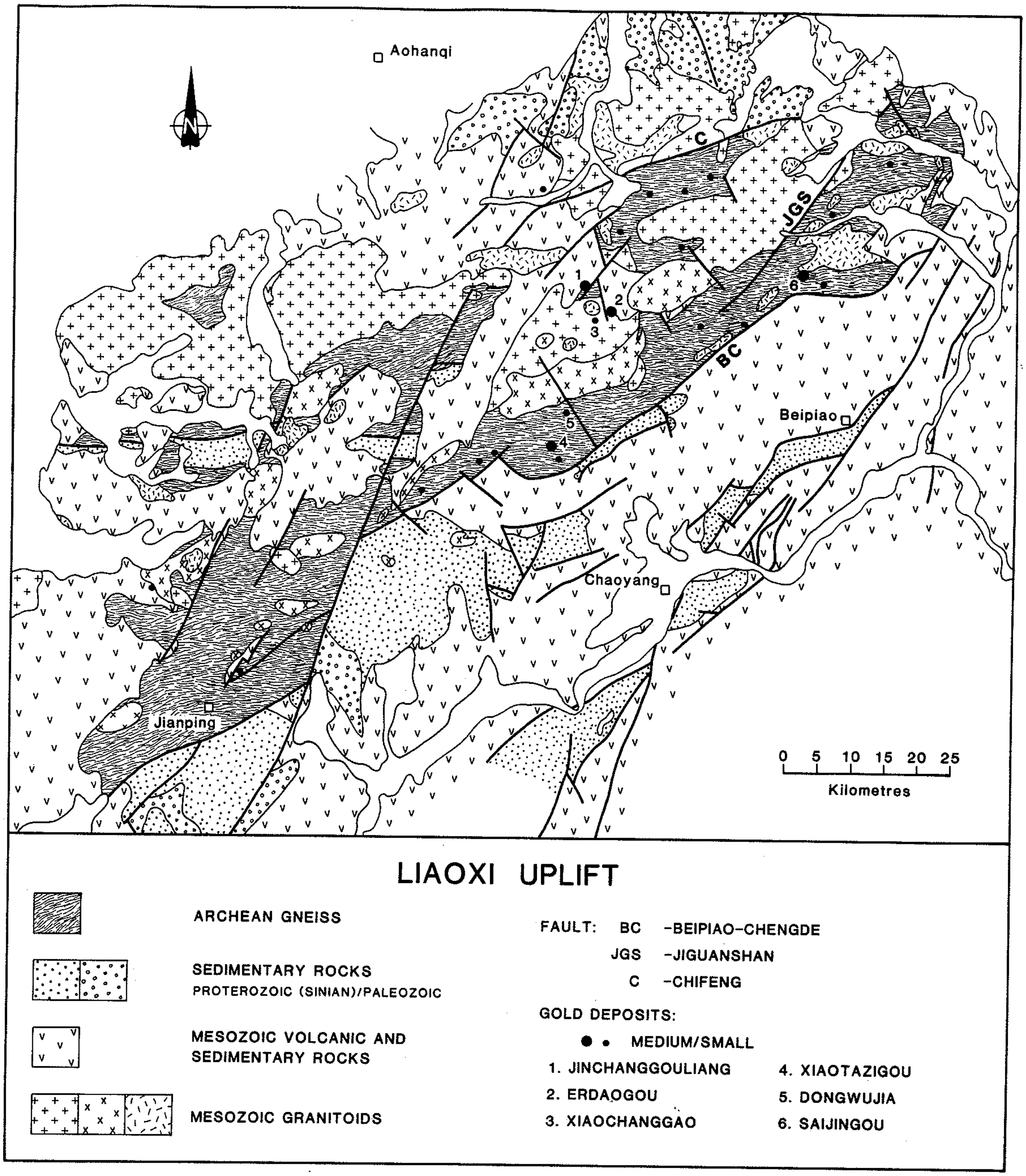


Figure 2: Geology and gold deposits of Liaoxi Uplift.

There are a number of elements that contribute to the overall structure of the uplift. The northeasterly striking Beipiao-Chengde Fault is a ten metre wide zone of fault gouge and breccia that, like its northern counterpart, the Chifeng Fault, is a reverse fault that establishes the limits of exposure of the Archean gneisses as well as the structural grain of the uplift as a whole (Fig.2). The long axes of many of the Mesozoic granitoid bodies also are parallel to this trend, as is the mean strike of gneissosity in the Archean rocks. Numerous northeasterly and northwesterly striking faults are transverse to this structural trend, however, and the most prominent member of the northeasterly set has a sinistral offset of 25 km (Fig.2). All of these structural elements are compatible with a north-northwesterly compression across the uplift.

GEOLOGICAL SETTING OF GOLD DEPOSITS

Polymetallic vein gold deposits are distributed throughout the central core of Liaoxi uplifts (Fig.2). The authors studied six small to medium sized mines in the Jinchanggouliang-Erdaogou, Xiaotazigou-Dongwujia and Shajingou areas.

The gold deposits of the Jinchanggouliang area (Fig.3) are centred around the Xiduimiangou Stock, an Early Cretaceous zoned pluton with a margin of equigranular granodiorite and a core of porphyritic quartz monzonite. The stock intrudes Archean gneiss and a large mass of Late Triassic medium to coarse grained quartz monzonite. In the eastern part of the area, a sequence of Early Jurassic rhyolitic to andesitic flows, tuff and breccia, with intercalated immature sandstone, dips moderately to steeply ENE, away from the gneissic and granitoid rocks. Except for the depositional contact between Archean gneisses and Early Cretaceous crystal tuff at the Jinchanggouliang Mine, exposed contacts between the volcanic rocks and the gneissic and granitoid rocks elsewhere are commonly occupied by faults and small intrusions. Local lenses of conglomerate at the base of, and low in, the volcanic sequence contain abundant boulders of gneiss. A small stock of granodiorite to diorite at the Erdaogou Mine, the Laoshang intrusion, cuts both the volcanic rocks and the large quartz monzonite mass. Dykes, which have a wide range in composition from diorite and porphyritic rhyolite to dacite and biotite trachyte (bt, Fig.3), are ubiquitous throughout the area and most commonly strike N to NW. A "T-shaped" dyke east of Jinchanggouliang (qp, Fig. 3) is notable because it varies along strike from homogeneous quartz-phyric rhyolite, to flow-banded rhyolite, to a breccia of porphyritic rhyolite fragments in an aphanitic matrix, and thus likely is, in part, an intrusive breccia, perhaps a near-vent facies. Although they show complex cross-cutting relationships with one another, the dykes collectively represent the youngest magmatic activity in the area in that they were observed to cut all other rock units including the Xiduimiangou Stock. The dykes are cut by the numerous faults in the area, but in many cases occupy the same structural sites as faults, including those faults which host veins. The **Jinchanggouliang** deposit (20 tonnes Au) occurs in Archean gneiss within the hanging-wall of the northerly dipping Toudaogou Fault (Fig. 3). The orebodies occur in faults that cut across the gneissic grain of the Archean rocks and that locally offset Mesozoic dykes. Numerous individual orebodies have been mined over a vertical interval of 300 metres. The **Erdaogou** deposit (5 tonnes Au) is hosted by faults cutting Late Jurassic flow-banded rhyolite, diorite dykes and a granodiorite stock (Fig. 3). The orebodies are being mined over a vertical interval of 200 metres. On a large scale, the **Xiaochanggao** deposit (2 tonnes Au) appears to be hosted by a large

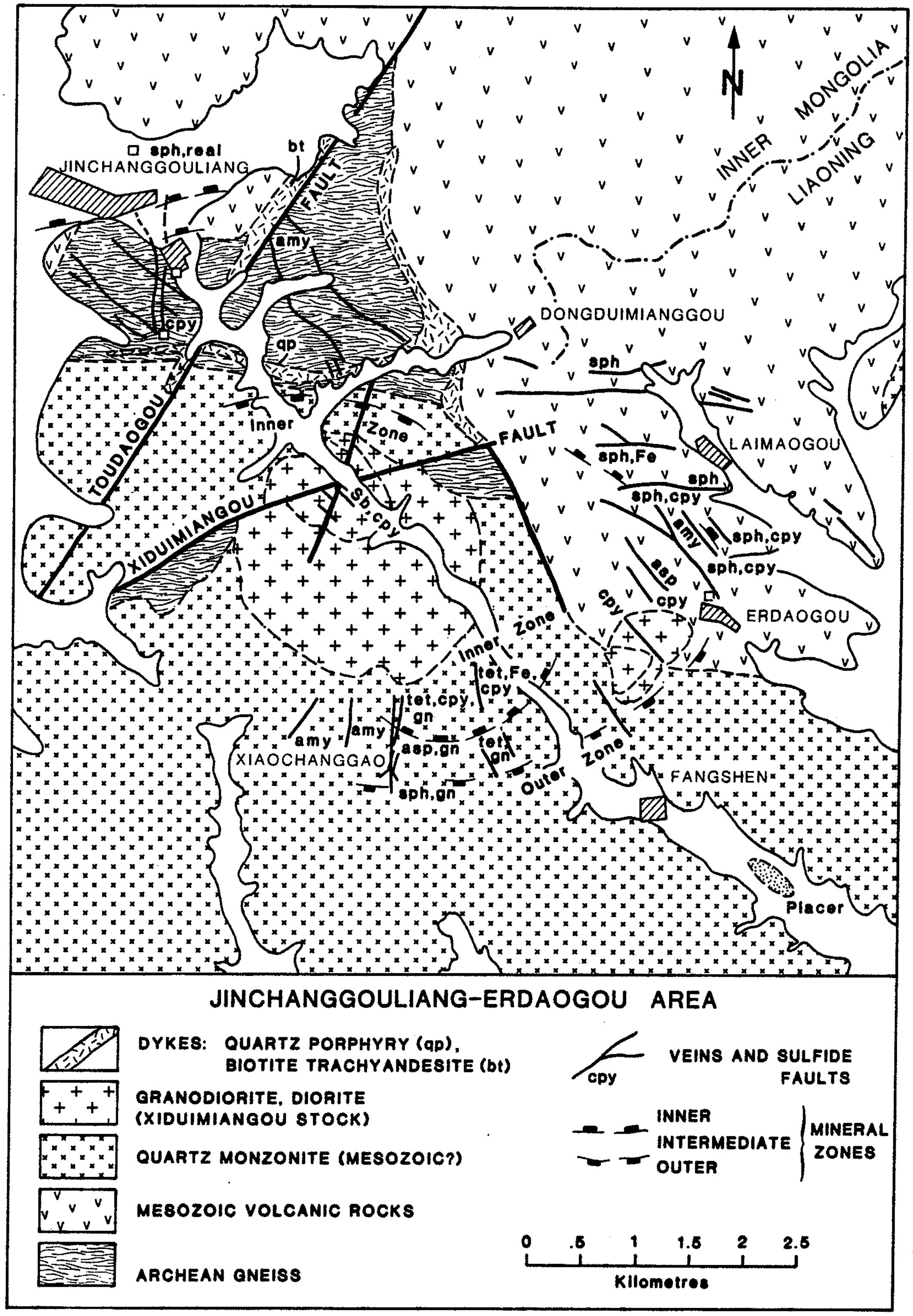


Figure 3: Geology and gold deposits of the Jinchanggouliang-Erdaogou area. Note the zonal distribution of ore minerals about the Ziduimiangou Stock. The Inner Zone is enriched in copper, the Outer Zone in Pb-Zn. Mineral abbreviations are amy (amethyst), Fl (fluorite), tet (tetrahedrite), cpy (chalcopyrite), asp (arsenopyrite), sph (sphalerite), gn (galena), sb (stibnite) and real (realgar).

mass of Late Triassic equigranular quartz monzonite (Fig. 3) but, in detail, the orebodies are associated with dykes composed of diorite and porphyritic andesite parallel to, and cut by, vein faults. The largest orebody within this deposit is 800 metres long and 300 metres deep.

The Xiaotazigou and Dongwujia deposits are located seven kilometres apart in an area dominated by Archean gneisses of the Xiaotazigou Formation (Fig. 2). Narrow stratiform magnetite iron formation units are prominent in this area and are generally parallel to the dominant ENE gneissosity. Mesozoic intrusions include a small stock of quartz monzonite, numerous dykes of diorite and porphyritic dacite, and a large mass of quartz monzonite that flanks the area on the north. Quartz veins that cut this quartz monzonite body, as well as Archean gneiss (Fig. 2), contain wolframite and molybdenite and are sites of small-scale tungsten mines. The gold deposits occur to the north of the Beipiao-Chengde Fault and to the west of the Eastern Fracture Zone, a northerly striking brittle fault, in minor faults that are parallel to both of these major structures. The **Xiaotazigou** deposit (2 tonnes Au) consists of an array of quartz veins that are parallel to faults composed of gouge. The chalcopyrite-arsenopyrite-pyrrhotite-gold ore is typically located in the gouge zones rather than the adjacent ribboned quartz veins. The **Dongwujia** deposit (2 tonnes Au) contains ribboned quartz veins as much as three metres wide. Gold occurs in the veins within shoots containing high concentrations of chalcopyrite and galena, and in sulphide-rich gouge and breccia adjacent to veins. The largest orebody is 300 m long and 200 m deep.

At Shajingou (Fig.2), an extensive quartz vein system is hosted by an apophysis of a Mesozoic granodiorite-diorite stock that has intruded Archean gneiss. The apophysis is composed mainly of diorite that contains abundant gneissic xenoliths and that is cut by an amygdaloidal breccia dyke, 250 m wide, and by numerous dykes of aplite. The Shajingou deposit (2 tonnes Au) is centred on a northwesterly-striking, northeasterly-dipping fault zone. Arrays of northwesterly- and easterly-dipping quartz veins containing gold and minor sulphides extend up to one kilometre away from the fault into its footwall rocks. However, most production has come from veins that are in the immediate hanging-wall of the fault and parallel to it.

CHARACTERISTICS OF THE OREBODIES

All of the deposits that we examined have points of similarity and difference with regard to their structure, mineralogy, hydrothermal alteration and in the isotopic composition of lead in galena and of oxygen and hydrogen in vein minerals and altered rocks.

Structure

At Erdaogou, Jinchanggouliang, Xiaochanggao, Xiaotazigou and Dongwujia much of the ore occurs in veins controlled by sinuous, anastomosed, gouge-rich faults. The faults are generally less than a few metres wide and consist of a variety of fault rocks which include cataclasite, fault breccia, clay gouge and sulphide gouge. These fault rocks are typical of brittle faults formed at a high crustal level. The faults generally consist of anastomosing and branching, interconnected segments (Fig. 4a) along which occur several textural types of ore. These include: (1) quartz-sulphide and sulphide veins, typically a few metres long and generally less than 10 cm thick; (2) sulphide replacements and disseminations along fractures; (3) sulphide gouge, and (4) mineralized tectonic breccia. Small extensional veins at a high angle to the faults are locally developed between overlapping fault segments (Fig. 4b). The restriction of the veins to the faults, the truncation of mineralized veins by fault segments (Fig. 4a, b), the occurrence of quartz vein fragments in tectonic breccia cut by later mineralized veins and the presence of sulphide gouge collectively indicate that the mineralization was emplaced in active faults.

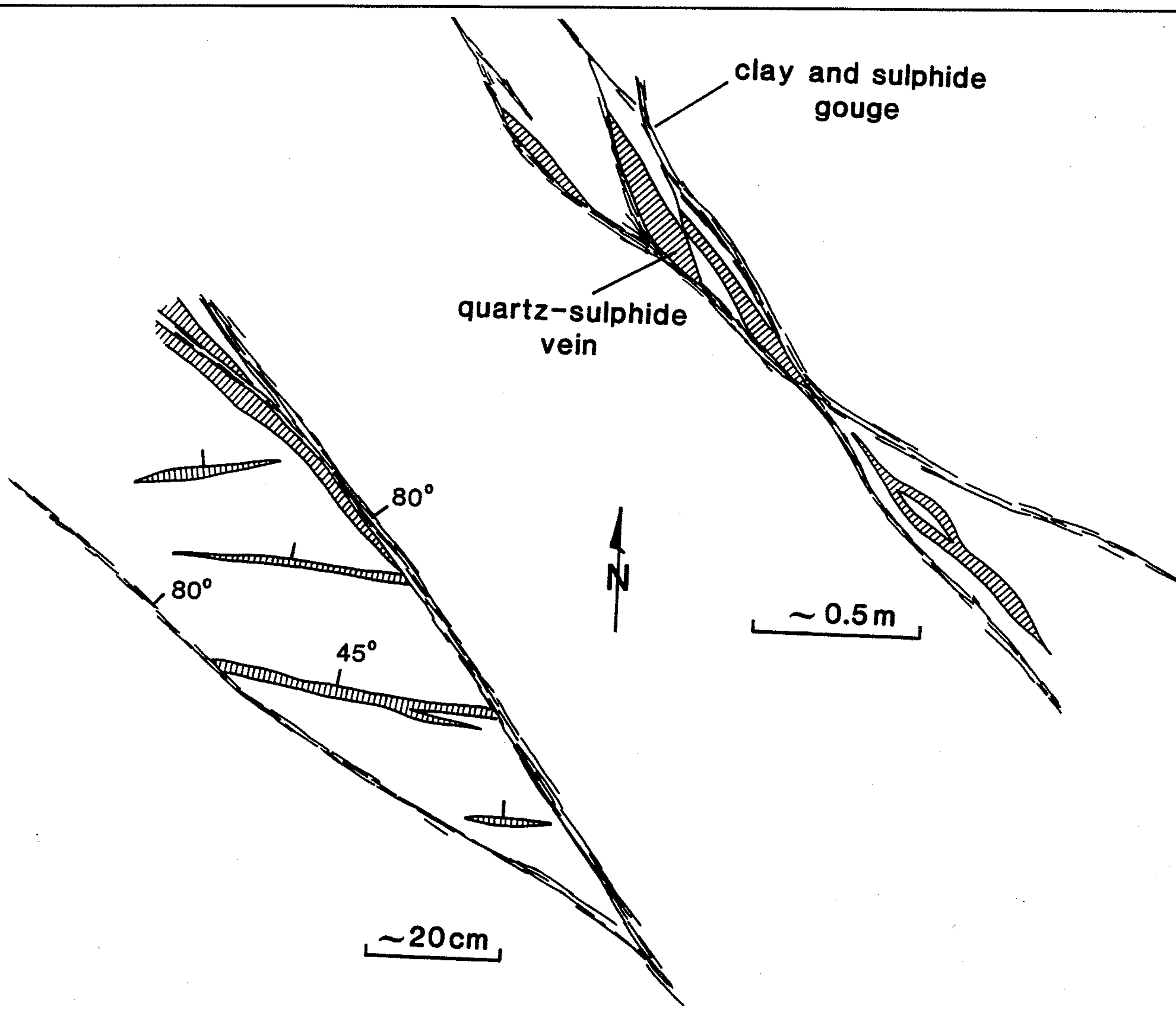


Figure 4: Sketches of ore structure of the No. 3 vein, Erdaogou Gold Mine.

The dominant set of faults at the Erdaogou Mine strikes NW-SE and dips steeply, either to the northeast or to the southwest (Fig. 5a). The other set strikes E-W and dips steeply to the north. Striations were locally observed on both sets of faults. As shown in Figure 5, the E-W set is characterized by rather shallowly plunging lineations, pitching between 20 and 40^{o}, suggesting that these faults are essentially strike slip. However, the presence of striations plunging both to the east and to the west points toward multiple episodes of movement. The NW-SE faults contain moderately to steeply plunging striations, with most pitches between 60 and 70^{o}. Again, the fact that striations plunge in two opposing directions in these faults indicates multiple periods of movement. The only information on the sense of displacement at Erdaogou comes from the No. 3 vein. There, small extensional veins at a moderate angle to the fault between two overlapping fault segments indicate a sinistral horizontal component of displacement (Fig. 4b). The moderate northerly dips of the extensional veins, combined with the steep northeasterly dip of the fault, indicate a reverse vertical component of displacement.

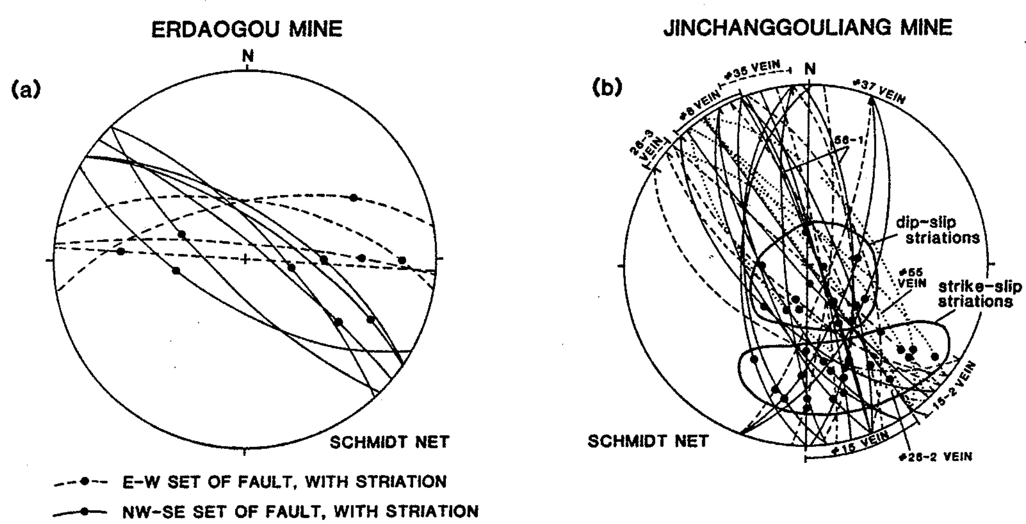


Figure 5: Equal area stereo net plots of ore faults and fault plane striations for a) the Erdaogou Mine b) the Jinchanggouliang Mine.

The Jinchanggouliang deposit is characterized by a complex network of mineralized and post-ore faults (Fig. 5b). Within these networks, four orientations of mineralized faults can be distinguished: (1) NW-SE faults that dip NE; (2) NW-SE faults that dip SW; (3) N-S faults that are near vertical; and (4) NE-SW faults. Of these the N-S set is the oldest and is cut by the two NW-SE sets which, in turn, are cut by the NE-SW set. All sets of faults except the NE-SW one, contains two populations of fault striations (Fig. 5b), locally preserved on the same surface. One population, observed to be the older, has a moderate to shallow south to southeasterly plunge whereas younger striations are steeper. These relationships suggest formation of the faults in a srike-slip regime followed by dip-slip reactivation.

Metre-wide quartz veins were observed at Xiaotazigou, Dongwujia and Saijingou. The veins commonly have a ribbon texture and are composed of massive, vitreous quartz with minor sulfide minerals. Where sulfides are abundant, they occupy fractures that cut the quartz. Gouge and cataclasite are well developed along vein margins and appear to have formed after the veins.

Ore Mineralogy

All of the deposits contain the same suite of ore minerals, including electrum, pyrite and chalcopyrite. Galena and sphalerite are also common but have a more restricted distribution. The content of silver exceeds that of gold at all deposits (7:1 to 1:1), and, although most of the silver is accounted for by electrum, tetrahedrite occurs at some deposits, notably at Xiaochanggao. Rarer ocurrences of associated sulfide minerals include arsenopyrite at Xiaotazigou, Xiaochanggao, Jinchanggouliang and Erdaogou, realgar and orpiment at Jinchanggouliang, stibnite in a vein south of Jinchanggouliang, and pyrrhotite at Xiaotazigou.

The type and abundance of the ore minerals were noted to differ from vein to vein in a given district. Accordingly, data were collected in an attempt to establish whether there were patterns of mineral zoning. This was done most thoroughly in the Jinchanggouliang-Erdaogou area where many veins were examined in underground workings and in surface exposures. Three apparently concentric zones are indicated from this compilation (Fig. 3). An inner Sb-Cu zone is characterized by the presence of tetrahedrite and stibnite and abundant chalcopyrite, an intermediate pyrite zone characterized by sparse base metal content but with common pyrite and local chalcopyrite, arsenopyrite and amethyst, and an outer Zn zone where sphalerite is particularly abundant and is locally accompanied by realgar and orpiment. Galena is present in all of the zones and fluorite was noted at a few localities in the inner zone. Gold has been extracted from veins within all of the zones, but it is perhaps significant that most of the productive orebodies at the larger deposits are contained in the intermediate zone. Although not fully established, the zones appear to be centred about the Xiduimiangou quartz monzonite stock (Fig.4).

A similar distinction between copper-bearing and zinc-bearing zones can be made in a qualitative way for the Xiaotazigou-Dongwujia area. Here, the main gold orebodies contain abundant chalcopyrite, but veins south of Xiaotazigou mine (Fig.5) also contain substantial sphalerite.

Hydrothermal Alteration

In all of the mines examined, host rocks to veins and breccia zones exhibit evidence of hydrothermal alteration in varying amounts. Hydrothermal alteration was mapped in detail in only a few locations, but could be generally useful in documenting the paleo-geothermal systems in which ore was deposited. The alteration mineralogy and its distribution reflect both the chemical composition and permeability of the host rock. The general types of alteration include i) sericitic alteration (sericitization, silicification, pyritization) in felsic rocks, ii) propylitic alteration (chloritization, carbonatization,

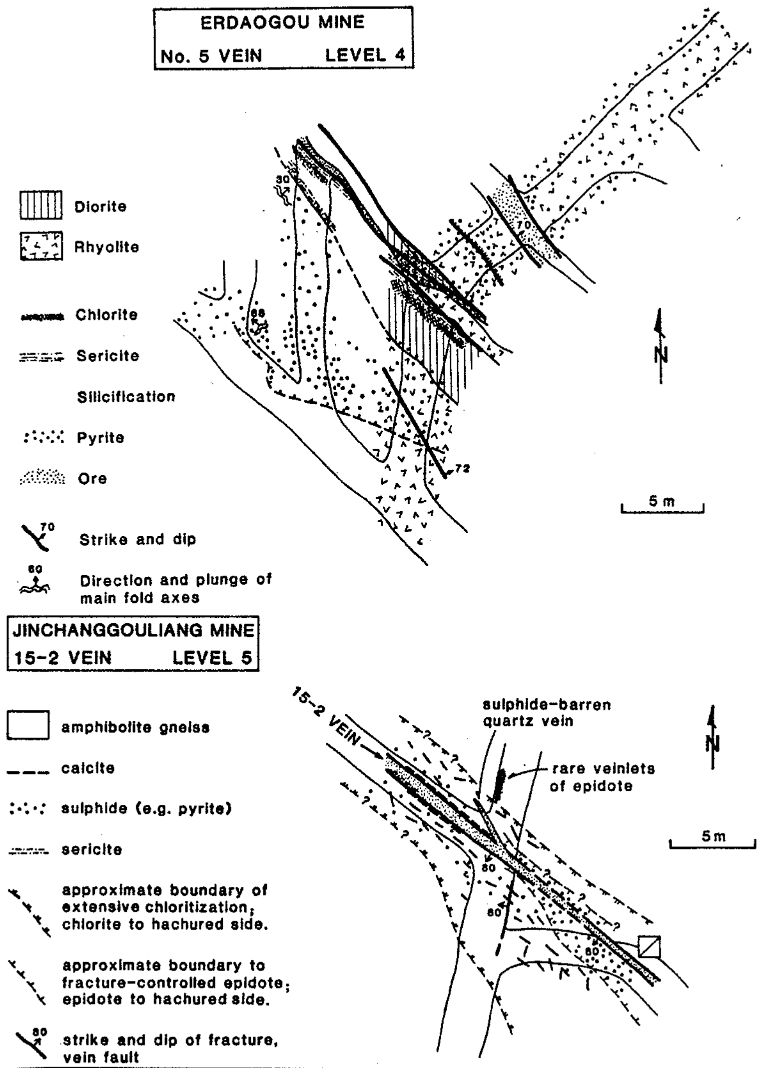


Figure 6: Underground maps of the disribution of alteration minerals adjacent to a) the No. 5 Vein, 4th. level, Erdaogou Mine and b) the 15-2 Vein, level 5, Jinchanggouliang Mine.

pyritization), dominantly in mafic rocks, and iii) argillic alteration, which is primarily present in vein-bearing faults in both rock types. Presumably argillization of wallrock fragments in (or adjacent to) vein-bearing faults occurred as the geothermal systems in each area cooled; clay gouge may have eventually sealed fluid pathways. Broadly similar mineral assemblages developed in several deposits, although physico-chemical conditions of alteration and mineralization may have differed in detail. Except for an apparent tendency for epidote to occur in rocks where veins contain chalcopyrite at Jinchanggouliang, no obvious variation in alteration mineral assemblages with sulphide mineral assemblages were observed. Ore grade, however, appears to vary directly with the sulphide (especially pyrite) contents of veins and altered wall rocks.

The most striking example of silicification was examined in rhyolite wall rocks at Erdaogou (Fig. 6a). Here, medium-gray zones as wide as two metres are developed about veins, preserving the overall texture of the rhyolitic rocks (welded ashflows, in part). Within the zone of silicification, and for several metres beyond its abrupt limit, 0.5 to 1.0 mm pyrite cubes comprise about 3 - 5% of the altered rocks. In other mines, silicification is less pronounced, and consists primarily of closely-spaced veins and/or veinlets of quartz rather than pervasive replacement of groundmass.

Sericite, pyrite and quartz, the principal components of sericitic alteration, are typically restricted to: wallrock fragments in vein-bearing faults; vein selvedges, one to several cm-thick: or coatings on vein walls or along fractures through veins. Although developed farther from the vein-bearing faults in the felsic rocks, diorite dykes in Erdaogou and Jinchanggouliang mines were replaced by sericite (+ pyrite) as far as 10 cm from veins. Where zoning developed (e.g., Erdaogou), pyrite and sericite occurs farther from veins than zones of marked silicification.

Chloritization of wallrocks, and the occurrence of chlorite as a vein mineral, is predominant at Jinchanggouliang (Fig. 6b) where wallrocks (largely amphibolite and biotite-hornblende schist) contain abundant mafic minerals. Pyrite and calcite, and, locally, epidote (chalcopyrite) accompany the chlorite. In rocks of intermediate composition, chlorite is found with sericite.

Calcite accompanied the alteration of mafic and intermediate rocks, and locally comprises the sole vein mineral in subsidiary veinlets adjacent to the principal vein-bearing faults. Pervasive carbonatization of mafic dykes which occupy vein-bearing faults was noted at both Erdaogou and Jinchanggouliang, and ferroan dolomite was noted locally as an alteration mineral at Dongwujia and Saijingou.

Lead Isotopic Composition of Galena

Lead isotopic compositions were determined at the laboratories of the Geological Survey of Canada for 27 samples of galena from veins at Erdaogou, Jinchanggouliang, Xiaochanggao, Shajingou, Dongwujia and Xiaotazigou. The data (Fig. 7) define a remarkably linear array on a $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ plot that is best interpreted as a mixing line between lead derived from the Precambrian gneisses and from the Mesozoic igneous rocks. Whereas each deposit contains lead from both sources no matter what immediate rocks host the ore, there is a general correlation between the proximity of a sampled vein to Mesozoic rocks and the measured isotopic composition of lead in galena from the vein. The Erdaogou deposit is hosted by Mesozoic volcanic rocks, whereas Jinchanggouliang and Xiaochanggao are inferred to be located directly beneath a Mesozoic unconformity. Similarly, although the Xiaotazigou, Dongwujia and Saijingou deposits are more isolated from volcanic rocks, the isotopic composition of galena from these veins appears to require a Mesozoic source component in the hydrothermal system. The presence of Mesozoic dykes and stocks in these areas is further evidence that such Mesozoic igneous activity existed. Furthermore, the reproduceability of measurements for multiple samples from some of the deposits (Fig.7) suggests that mixing of the lead took place by hydrothermal activity at a relatively large scale rather than at the local vein site.

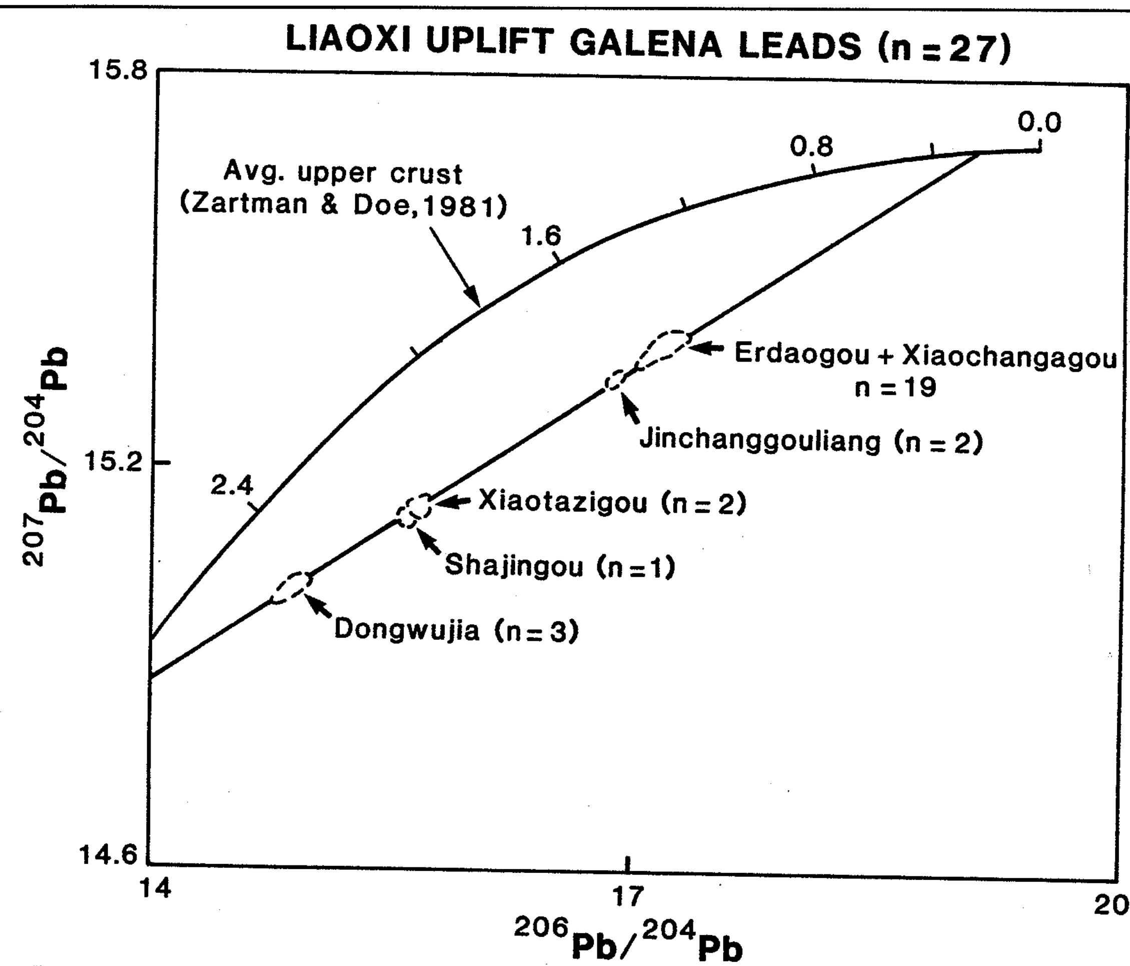


Figure 7: Lead isotopic compositions of galena from veins at six gold deposits in Liaoxi uplift. The data define a mixing line between Precambrian Basement (averaging approximately 2450 Ma) and Mesozoic (approximately 125 Ma) components.

Light Stable Isotopes

The oxygen isotope composition of 26 samples of "fresh" and altered wallrocks from Jinchanggouliang were determined at the laboratories of the Geological Survey of Canada. Coupled with three isotopic determinations of the hydrogen isotope composition of whole rocks (δD=-98.2, -113.2, -121.8) these data (Fig. 8) indicate that meteoric water played a substantial role in the alteration process at these deposits. It appears that there is a more pronounced and perhaps widespread shift in the isotopic composition of altered versus unaltered samples from Jinchanggouliang by comparison with those at Erdaogou. This suggests that, although the host rocks at Jinchanggouliang are much older than those at Erdaogou, Jinchanggouliang represents a structurally higher level in the hydrothermal system than Erdaogou. Furthermore, the relatively unaltered nature, both mineralogically and isotopically, of sulfide-bearing rhyolite dykes at Erdaogou suggests that some metal introduction may have been from a magmatic source because the data would permit only very small water/rock ratios if meteoric water were the only fluid source.

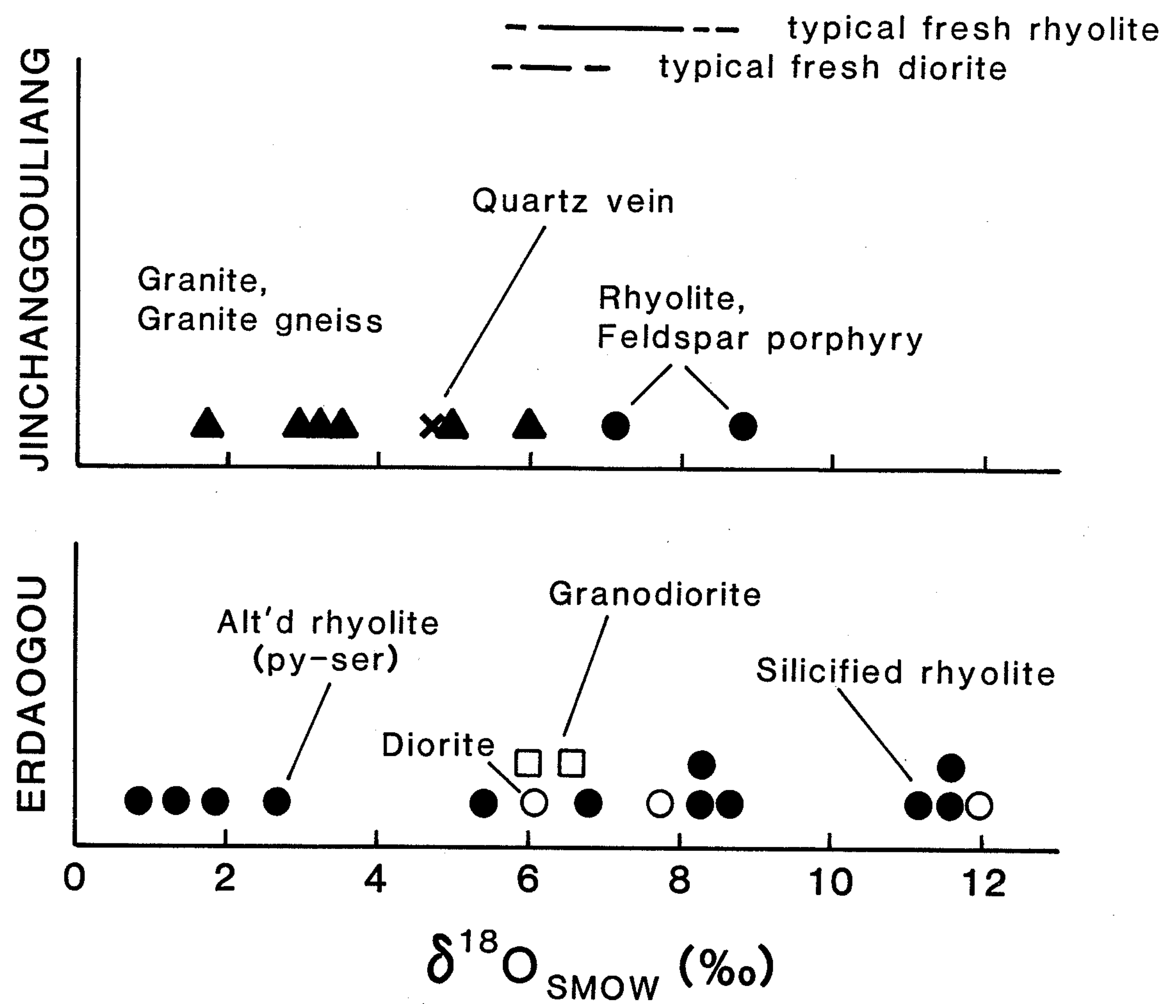
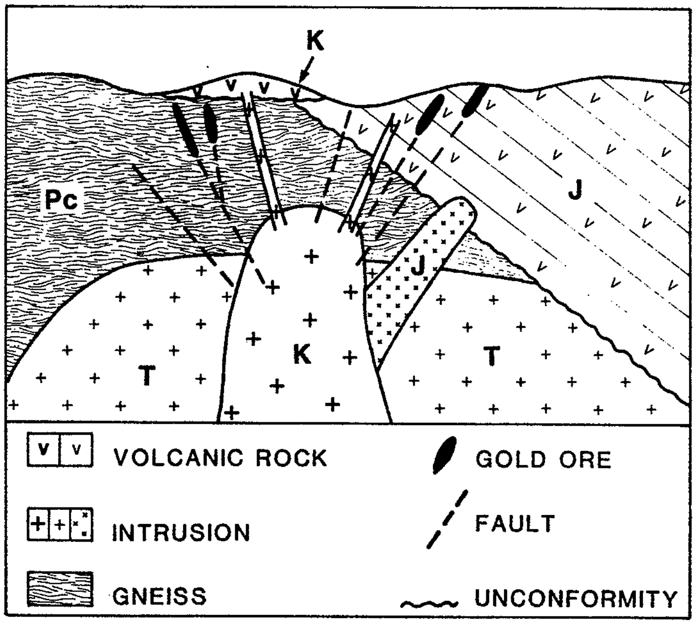


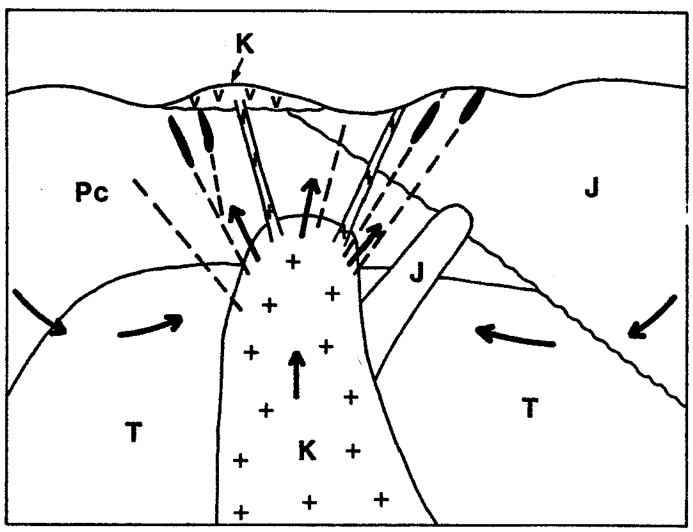
Figure 8: Plots of ^{18}O for whole rocks and a quartz vein from Jinchanggouliang and Erdaogou gold mines indicate a range in dO^{18} of at least 11 permil. The low $\delta^{18}O$ values for altered sericitized rhyolite and for granite gneiss are due to high water-rock alteration by meteoric waters. Silicified rhyolite at Erdaogou with high δO^{18} values may indicate a lower temperature, lower water-rock ratio alteration.

GENETIC MODEL

The essential geological characteristics of the gold deposits of Liaoxi Uplift are summarized in Figure 9. These Early Cretaceous deposits are similar in many respects to Tertiary adularia-sericite type epithermal deposits in Colorado and New Mexico which are hosted by Precambrian rocks, or for which Precambrian rocks comprise the principal basement rocks. These include, among others, deposits in the so-called Colorado Mineral Belt, which extends from Central City, in



(a)



(b)

Figure 9: Schematic diagrams illustrating: a) the geological model of the Liaoxi gold deposits (T-Triassic, J-Jurassic, K-Cretaceous). Note that different erosional levels through this structure can yield surfaces that expose vein gold deposits that appear to be restricted to one of: Precambrian basement, Mesozoic plutons or Mesozoic volcanic rocks. b) the most probable genetic model for the deposits. Arrows

indicate the hypothetical movement of meteoric water for potential mixing with magmatic fluids.

the Colorado Front Range, to the San Juan volcanic field in southwestern Colorado. In these instances, as in the Chinese deposits, Mesozoic (to Tertiary) gold vein deposits formed about high-level intrusions in uplifts of Precambrian basement. Largely because of their young age, many of the Tertiary deposits in the Southwest U.S. are less deeply eroded than those examined in China, and are clearly of epithermal affinity (e.g., Hayba et al., 1986). Polymetallic gold vein systems explored in the Lake City caldera, Colorado (e.g. Slack, 1980), reflect a base metal and precious metal zoning generally similar to that described here for the Jinchanggouliang-Erdaogou area.

The Liaoxi deposits are of probable magmatic hydrothermal origin. Magmatic heat, volatiles (e.g, H_2O, S and C), and perhaps metals were added to meteoric geothermal fluids localized by active faults that were eventually sealed by veins (Fig. 9). Many of the alteration-, ore- and vein-forming constitutents, as illustrated by the lead isotopic data, were probably also redistributed from the sedimentary, volcanic and plutonic host rocks. The oxygen and hydrogen isotopic data support the importance of meteoric water in the mineralizing system but also allow for a direct magmatic contribution of fluids and metals. It is important to note that the magmatic system that drove the ore-forming hydrothermal fluids was probably of Early Cretaceous age. The relative position of the Cretaceous paleosurface with respect to the present erosional surface is thus a critical factor in the interpretion of the Liaoxi deposits. Contributions from buried intrusions other than those presently exposed can not be discounted.

The role of Precambrian basement in the formation of the deposits is still problematic. The presence of basement rocks is a useful first-order parameter for the location of gold deposits in North China Platform, a fact that is best explained by the evidence that the basement uplifts were generated in the Mesozoic in conjunction with the emplacement of large volumes of Mesozoic magma. Clearly, the basement rocks have contributed some ore components (e.g. Pb) via their interaction with circulating meteoric fluids but, given that epithermal deposits of this type occur universally with a wide variety of "basement" lithologies, it seems unlikely that the nature of the basement is critical for the localization of ore.

REFERENCES

Guo Wenkui
1989: Significant geological features of vein gold metallogeny in China; Global Tectonics and Metallogeny, v.3, p.91-100.

Hayba, D. O., Bethke, P. M., Heald, P., and Foley, N. K.

1986: Geologic, mineralogic, and geochemical characteristics of volcanic-hosted epithermal precious-metal deposits: Rev. Econ. Geol., v. 2, p. 129-167.

Mu Ruishen, Han Zhongwen and Xu Qingguo
1981: On the regional minerogenetic regularity of gold deposits in China; Annual Report of Chinese Academy of Geological Sciences. Geological Publishing House, Beijing.

Qin Nai, Wang Konghai, Pang Qingbang, Qiu Youshou, Mu Ruishen, Yu Changtao, Wei Yongfu, Li Wenkang and Lu Yingie
1988: Regional metallogenic conditions of main gold deposit types in China, Shenyang Institute of Geology and Mineral Resources Publishing House, 127 p.

Slack, J. S.
1980: Multistage vein ores of the Lake City district, western San Juan mountains, Colorado: Econ. Geol., v. 75, p. 963-991.

GEOLOGIC SUMMARY OF THE ERDAOGOU MINE, LIAONING PROVINCE AND THE JINCHANGGOULIANG MINE, INNER MONGOLIA

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Shang Ling and Zhang Lidong

INTRODUCTION

The Erdaogou and Jinchanggouliang mines in Liaoning Province and Inner Mongolia, respectively, presently exploit polymetallic vein deposits for gold. This summary of the geologic features of these mines derives largely from (1) the results of collaborative surface and underground mapping and observations by Shang Ling (Liaoning Bureau of Mineral Resources), Zhang Lidong (Shenyang Institute of Geology), and by Francois Robert and Bruce E. Taylor (Geological Survey of Canada) during the period May 8-25, 1990; (2) geologic investigations of Zhang Lidong as part of his graduate studies (MSc); and (3) additional information obtained from discussions with the mine staffs. The purpose of these investigations was to develop a geologic-based occurrence model(s) which would prove useful in exploration and mine development.

The geologic features observed in the Erdaogou and Jinchanggouliang mines share many similarities; differences are largely due to variation in host rock lithology. The Jinchanggouliang mine is developed in a much larger deposit (ca. 30 Tonnes Au) than that presently defined at the younger Erdaogou mine (ca. 5 Tonnes Au). Despite the difference in size, similar geological features in both of these mines indicate a common mode of origin for the gold deposits; veins formed in active faults within a magmatically-heated hydrothermal system. Investigations to provide a more detailed understanding of origin of the veins, associated igneous rocks, and hydrothermal system (e.g., stable and radiogenic isotopic systematics, mineralogy, geochemical characteristics, fluid inclusions) are in progress and will be the subject of subsequent papers.

GEOLOGIC SETTING

The gold deposits of the Jinchanggouliang and Erdaogou mines occur, respectively, to the north and southeast of the Xiduimiangou Stock, a zoned pluton with a marginal facies of equigranular granodiorite and a core of porphyritic quartz monzonite (Fig. 1). The pluton has a reported K-Ar feldspar age of 126 Ma., and is one of several Mesozoic granitic bodies comprising the central areas of the Liaoxi Uplift. The mines exploit portions of polymetallic mineralized veins which trend generally N to NW. Vein-mineral zoning patterns recognized during mapping (described below) are distributed concentrically with respect to the exposed contact of the Xiduimiangou Stock.

To the immediate south of the Jinchanggouliang mine, the Xiduimiangou stock intrudes Archean gneisses and a large mass of medium to coarse grained granite. To the east, a sequence of Jurassic rhyolitic to andesitic flows, tuffs and breccias, with intercalated immature sandstones, dips steeply ENE, away from the gneissic and granitoid rocks. Faults and small intrusions occupy the contact between the volcanic rocks and the gneisses and granitoids. Local conglomerate within, and near the apparent base of the volcanic sequence contains abundant boulders of gneiss and suggests the presence of an erosional unconformity.

A small stock at the Erdaogou Mine cuts both the volcanic and plutonic rocks (Fig. 1). Flow-banded rhyolite to dacite, and (apparently) highly welded tuffs are common host rocks in the mine. Dykes of a wide range in composition including diorite and porphyritic rhyolite to dacite and biotite trachyite are common, and show complex cross-cutting relationships with one another. They strike N to NW and are cut by the numerous faults in the area. In many cases, the dykes occupy the same structural sites as faults, including those faults which host the veins. Collectively, the dykes represent the youngest magmatic activity in the area. A "T-shaped" unit southeast of Jinchanggouliang (Fig. 1) varies along strike from homogeneous quartz-phyric rhyolite, to flow-banded rhyolite, to a breccia of porphyritic rhyolite fragments in an aphanitic matrix. In places this unit resembles a pebble dyke, and probably fills the vent of a fissure eruption.

Other volcanic to sub-volcanic rocks of alkaline affinity (including trachytes and pyroxene-hornblende syenites) occur as flows, welded tuffs, dykes, and small intrusions. Volcaniclastic rocks (water-laid tuffs, air-fall tuffs), arkose, and conglomerates occur E and NNE of Erdaogou, but were not closely examined.

ERDAOGOU MINE

The Erdaogou mine includes underground workings on a number of gold-bearing pyrite-base metal sulphide-quartz veins exposed at surface. Local numerical designations for the veins (e.g., veins No. 5, No. 21, etc.) are used herein (Fig. 2). Although known and locally prospected and mined from surface since the end of the 19th century (Quin Dynasty), concerted exploration and underground mining activity are recent. Exploration from 1967-70 led to installation of a mill in 1976, and gold production in 1981. Since 1988, the mining rate is reported to be on the order of 150 Tonnes/day. Veins No. 3, 5, 5-1, 6 and 21 are currently exploited by the Erdaogou Mine (Fig. 2).

Lithology

Wall rocks within the mine include both plutonic and volcanic varieties. A stock of porphyritic to equigranular, medium grained granodiorite to diorite, that is zoned from a dark coloured marginal facies to a light-coloured core, is the dominant host rock to vein No. 21 and a portion of vein No. 6 (Fig. 2). This subrounded stock lies just to the west of Erdaogou mining village, and has an exposed

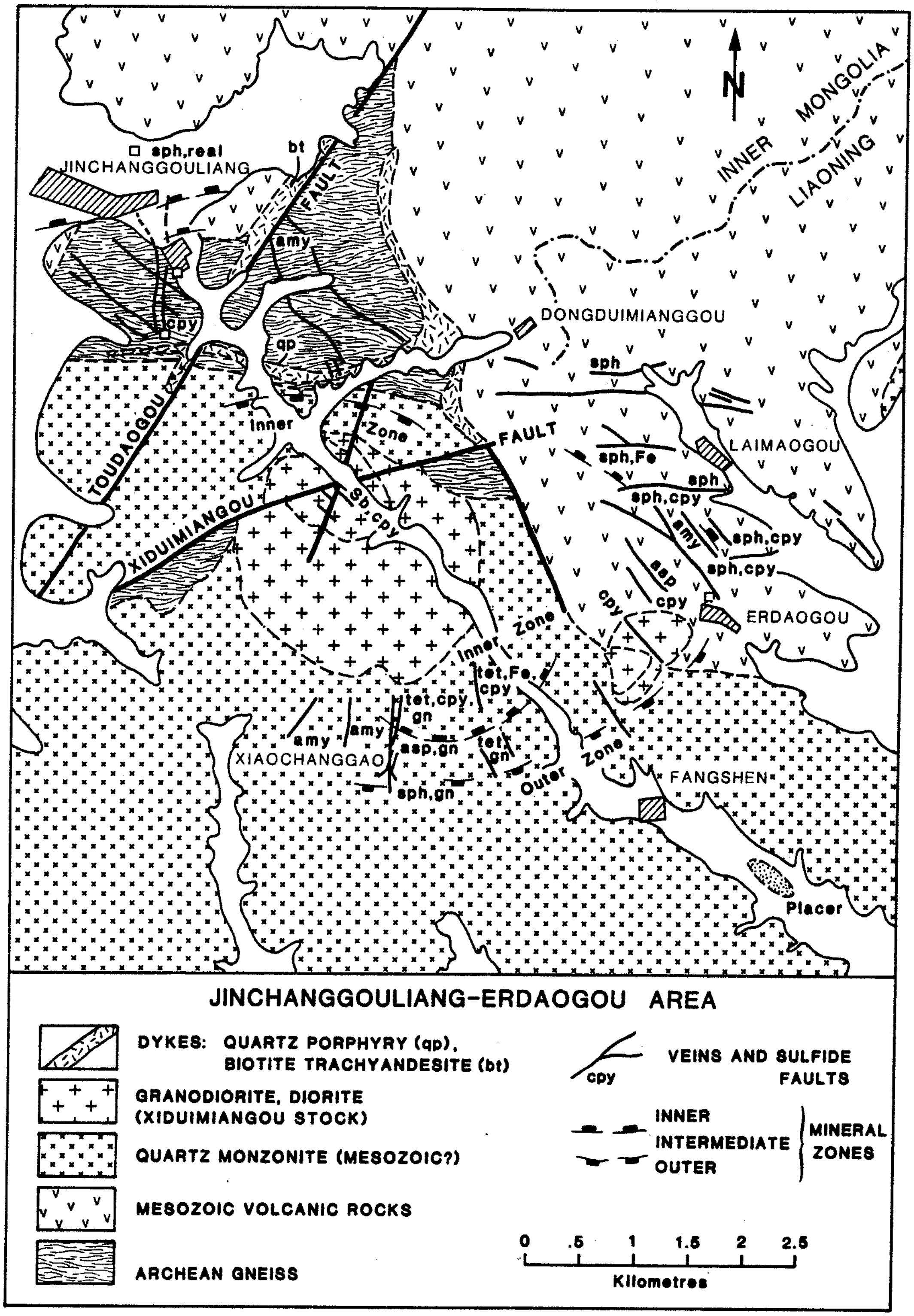


Figure 1: Map of the geology and gold veins in the Jinchanggouli-ang-Erdaogou area showing the approximate boundaries to sulphide mineral occurrence zones. Mineral abbreviations are: amy, amethyst; Fl, fluorite; tet, tetrahedrite; cpy, chalco-pyrite; asp, arsenopyrite; sph, sphalerite; gn, galena; sb, stibnite; and real, realgar. The "Inner Zone" is enriched in Cu relative to the "Outer Zone" which is enriched in Zn and Pb.

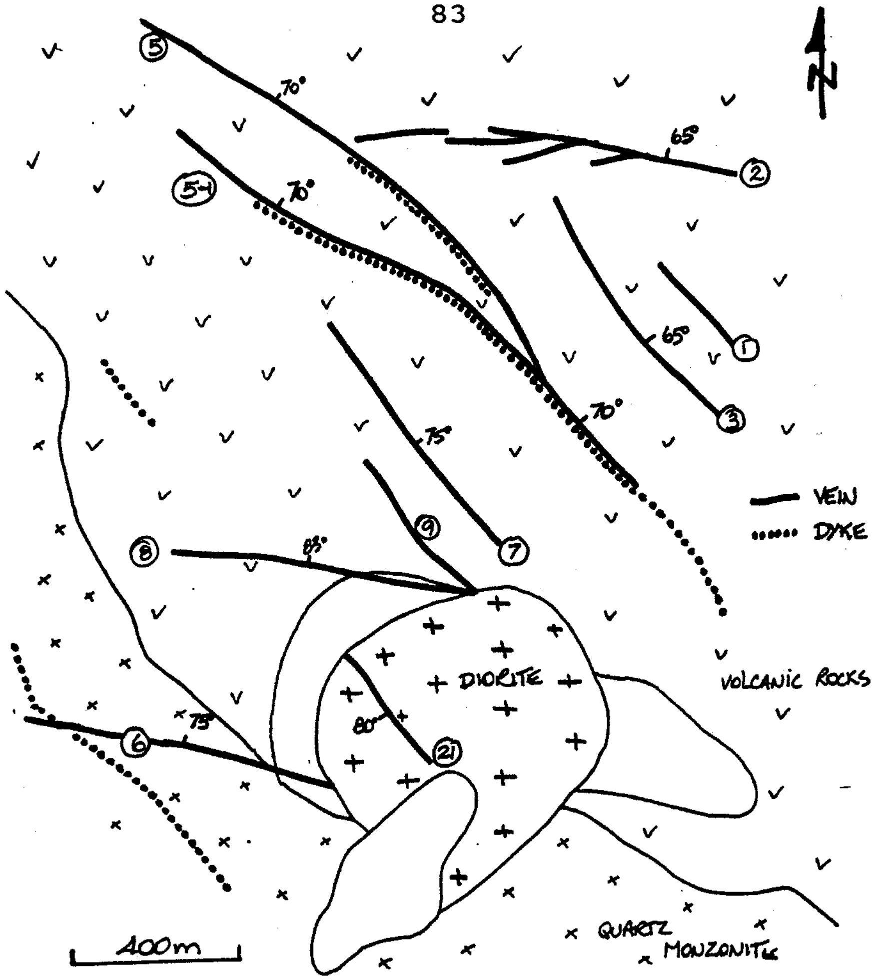


Figure 2: Simplified geological map of the Erdaogou mine area showing orientations of significant mineralized fault veins.

diameter of approximately 1200 metres. Except for the plagioclase phenocrysts and the somewhat darker colour of the porphyritic marginal facies, the texture of the rock is equigranular and otherwise rather featureless in hand specimen.

Massive to flow-banded rhyolite is a common host to many of the veins in the Erdaogou mine and immediate area. In places, felsic volcanic wall rocks have the appearance of highly welded ignimbrites, although this identity is less certain than the flows and subvolcanic intrusions. Spherulites were found underground and in several surface exposures as evidence of the devitrification of one-time glassy rocks. A reddish colouration is evident in some rhyolite, especially in the general vicinity of veins. Whether this is a feature related to hydrothermal activity is uncertain. Trachytic (also syenitic) rocks were observed in the field, and a columnar jointed neck-like body several hundred metres ESE of the mine village may represented a local vent. The chemical compositions and more accurate decriptions of the mineralogy of each of the types of volcanic rocks encountered remain to be determined.

Numerous dykes cross-cut the plutonic and volcanic rocks and, especially in the case of diorite dykes, generally follow the vein faults and may, themselves, be faulted. The felsic dykes typically have a porphyritic-aphanitic or equigranular-aphanitic texture; phenocrysts are either quartz (less common) or feldspar. Porphyritic, very fined-grained diorite is thought to indicate potential for good ore grades, but detailed mapping suggests that any such relationship may be to due to reaction of the diorite with the hydrothermal fluids (see below). All dykes may be variously hydrothermally altered, along with the other lithologies encountered, but the diorite dykes were particularly susceptible to hydrothermal alteration, and felsic dykes were less so. Fresh, sulphide-bearing (pyrite and chalcopyrite) rhyolite dykes observed in a cross-cut between veins No. 5-1 and 21 suggest that felsic magmas related to these dykes may have been of particular importance to the origin of the gold deposits.

Dark-coloured, biotite-amphibole schist and gneiss waste rock was found on the dump of a small adit on vein No. 17, some 2000 metres NNW of Erdaogou, east of the contact of Jurassic volcanic and volcaniclastic rocks with the granitic intrusive rocks (Fig. 1). Thus, Archean basement rocks may not be far beneath some of the volcanic rocks which lie north of Erdaogou, although no Archean metamorphic rocks were observed to crop out on the surface, or were exposed in any of the underground workings examined.

Breccias of apparent hydrothermal origin and intrusive origin, in addition to tectonic breccias described below, were locally found in surface exposures and underground. Intrusive breccias were typically monolithologic, and occurred both as felsic dykes, and as zones of limited extent at intrusive contacts. Hydrothermal breccias were found in local,less well defined areas, generally associated with dense rhyolitic wall rocks.

Structural Geology

Mineralized rocks at Erdaogou are localized along two sets of steeply dipping faults, striking WNW and NW (Fig. 2). These faults are also the locii of dykes, essentially of dioritic composition. The faults range in strike length from 0.5 to 2 km and are generally less than a few metres wide. They consist of a variety of fault rocks which include cataclasite, fault breccia, clay gouge and sulphide gouge. These fault rocks are typical of brittle faults formed at a high crustal level.

The faults generally consist of anastomosing and branching, interconnected segments (Fig. 3a) along which occur several textural types of ore. These include: (1) quartz-sulphide and sulphide veins, a few metres long and a generally less than 10 cm thick; (2) sulphide replacements and disseminations along fractures; (3) sulphide gouge, and (4) mineralized tectonic breccia. Small extensional veins at high angle to the faults are locally developed between overlapping fault segments (Fig. 3b). The restriction of the veins to the faults, the truncation of mineralized veins by fault segments (Fig. 3a, b), the occurrence of quartz vein fragments in tectonic breccia cut by later mineralized veins and the presence of sulphide gouge collectively indicate that the mineralization occurred in active faults. The

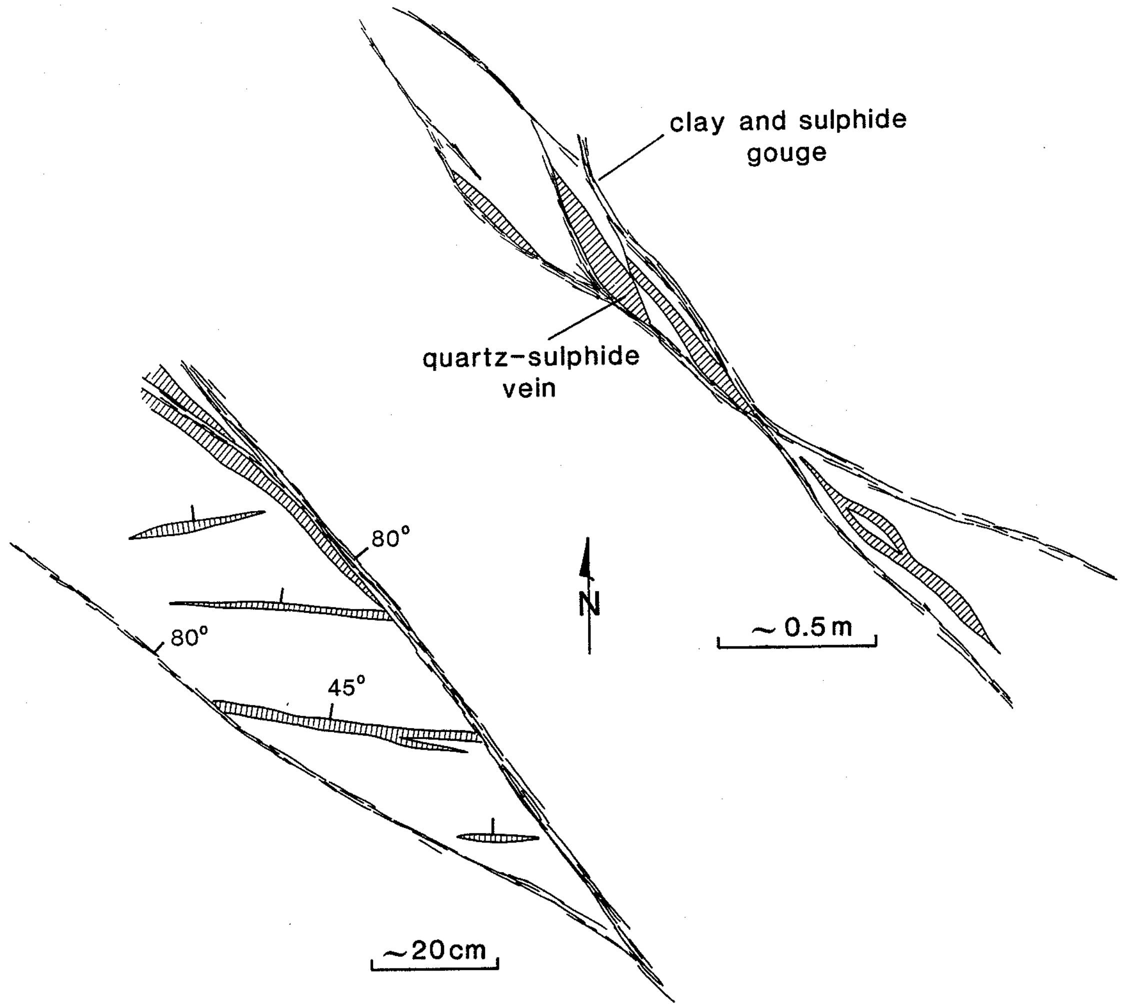


Figure 3: Sketches of principal fault traces and vein-filling, linking structures made from photographs of vein No. 3, Erdaogou mine.

nature, mineralogy and textures of the ore zones are described in detail in a following section.

Structural analysis of the mineralized faults to understand their history and kinematics was hampered by the scarcity of indicators of the direction and sense of displacement along these faults. The dominant set of faults strikes NW-SE and dips steeply, either to the northeast or to the southwest (Fig. 2). The other set strikes E-W and dips steeply to the north. Striations were locally observed on both sets of faults. As shown in Fig. 4, the E-W set is characterized by rather shallowly plunging lineations, pitching between 20 and 40^{o}, suggesting that these faults are essentially strike slip. However, the presence of striations plunging both to the east and to the west points toward multiple episodes of movement. The NW-SE faults contain moderately to steeply plunging striations, with most pitches between 60 and 70^{o}. Again, the fact that striations plunge in two opposing directions indicates multiple periods of movement.

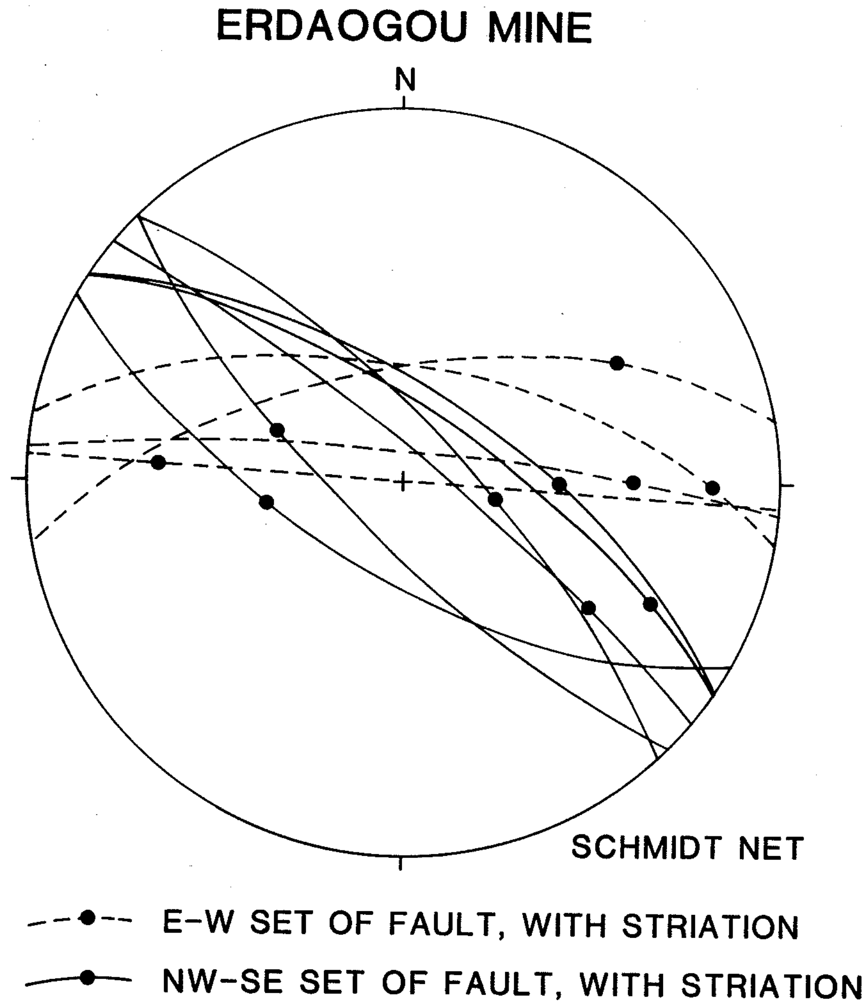


Figure 4: Stereographic (Schmidt net) projection of the traces of fault planes and of striations from the Erdaogou mine area.

The only information on the sense of displacement comes from the No. 3 vein. There, small extensional veins at moderate angle to the fault between two overlapping fault segments indicate a sinistral horizontal component of displacement (Fig. 3b). The moderate northerly dips of these veins, combined with the steep northeasterly dip of the fault, indicate a reverse vertical component of displacement. In addition to the above structural analysis, a very good surface exposure of the diorite intrution hosting the No. 21 vein (Fig. 2) was mapped in detail at the scale of 1:250. It was noted that there was a well developed fracture network within the the intrusion and that the orientations of the different fracture sets were very similar to those of the mineralized faults in the area. It was hoped that detailed mapping of these fractures would provide structural information that could help interpreting age relations and kinematics of the mineralized faults.

The detailed map is reproduced in Figure 5. It shows three main fracture sets: a dominant NW-SE set; a moderately well-developed E-W set, and a poorly developed N-S to NNE-SSW set. Despite some local conflicting cross-cutting relationships, the NW-SE set generally cuts the E-W set and is probably younger. Offset of earlier fractures indicates systematically a sinistral horizontal component of displacement along both the E-W and NW-SE fractures (Fig. 5).

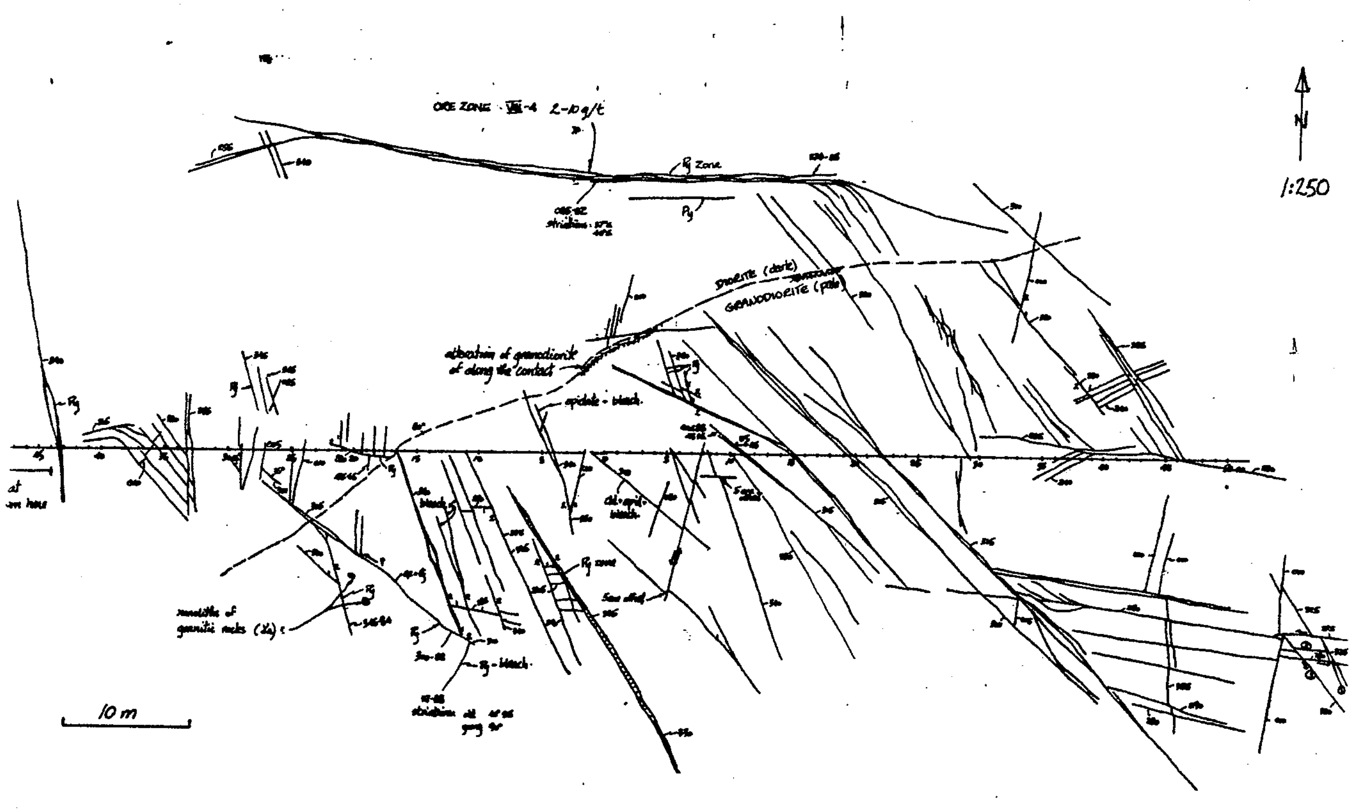


Figure 5: Detailed map showing the fracture network in diorite intrusion hosting No. 21 vein (see Fig. 2) at Erdaogou mine. Numbers in circles near fracture intersections give ages relative to one another.

In summary, the structural analysis at Erdaogou indicated that both sets of mineralized faults experienced more than one period of movements. If the fracture network in the diorite intrusion (Fig. 5) is considered to represent a microcosm of the mineralized fault network, then it can be suggested that the E-W faults predate the NW-SE faults and that the net displacement along both sets has a sinistral horizontal component.

Alteration Facies

Hydrothermal alteration of the wall rocks adjacent to the veins in the Erdaogou mine produced five principal alteration types, or facies: (a) silicification, (b) sericitization, and (c) argillization in felsic rocks, and (d) propyllitization and (e) carbonatization in mafic rocks. Some minor supergene argillization may be superposed on that caused by hydrothermal waters, but this is not known at present. The type of alteration minerals and their distribution are largely a direct consequence of the chemical composition of the wallrocks and their primary and secondary (fault-induced) permeability.

Silicification is a common form of alteration of the felsic rocks such as the flow-banded rhyolite (-dacite?) and felsic tuffs encountered northeastward of the zoned granodiorite stock, but was not apparent from (megascopic examination) in diorite dykes. Silicified rocks are found immed-iately adjacent to the quartz veins, and are characterized by preservation of some primary textures of the wall rocks in spite of replacement of groundmass by very fine-grained, white to light grey quartz. Silicification may also take the form of multiple mm-thick veinlets of quartz. The width of silicified zones about quartz veins varied from a few tens of centimetres to as much as ten metres. Silification of flow-banded rhyolite exposed along portions of the No. 3 vein on the 2 Level is evident in Plate IA. Flow-banding in the rhyolite locally controlled replacement of the groundmass. The outer margin of extensive silicification of groundmass is typically abrubt, whereas silification controlled, or characterized by quartz veinlets may grade to unsilicified rocks over several metres. The quartz veinlets have numerous orientations, depending in some instances on local fracture patterns, and generally less on the orientation of primary fabric (e.g., flow-banding) in the wall rocks. The width of the silicified zones in rhyolite may be as much as 2-4 m wide where massive, and as much as 10-15 m wide where characterized by quartz veinlets. An example of such distribution is shown in Figure 6.

Sericitization of felsic rocks occurs generally within a metre, but may extend up to ten metres or so, of the quartz veins, and produced sericite-pyrite-quartz mineral assemblages. Where quartz veinlets are present, cream-coloured zones of sericite a millimetre or so thick, may be found adjacent to wall of each veinlet. The relative distribution of silification and sericitization is shown about the No. 5 vein, 4th level, in Fig. 6. Calcite is but a very minor constituent of altered felsic rocks, if present at all, but may occur in the adjacent ore vein. It is typically a "late" mineral in the veins themselves. Sericite and pyrite are also common accessory minerals in silicified rocks, and may be found further from the veins than is evidence of silicification. This is especially true for pyrite, which occurs as disseminated euhedral grains a millimetre or less in diametre, and comprise as much as 5 vol. % (estimated) of felsic rocks, and locally higher in mafic rocks. The abundance of pyrite decreases further from the veins to less than 1 vol. %. Larger grains of pyrite, to 5 mm in diametre may be found in altered diorite. Because pyrite is easily recognized, its presence might be used to

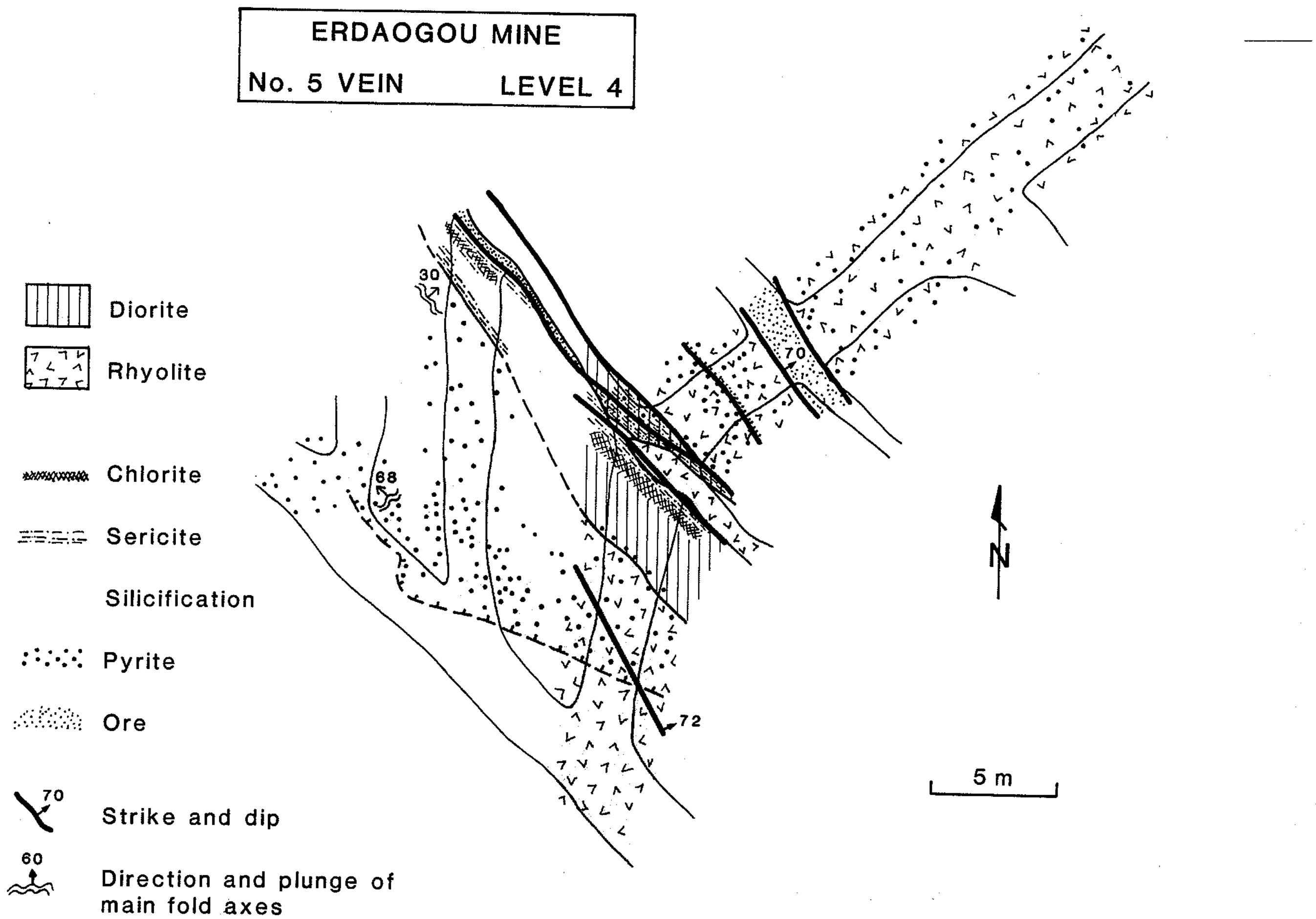


Figure 6: Geologic map of a portion of the No. 5 vein, 4th level in the Erdaogou mine showing the distribution of important alteration minerals.

advantage in underground exploration drilling to recognize altered wall rocks in the vicinity of veins.

Propyllitization is characterized in the zoned granodiorite stock and in diorite dykes by the mineral assemblage calcite-chlorite-pyrite, distributed throughout the groundmass, or in veins and veinlets. Relative to the occurrence of sericite, chlorite is found further from the vein. In chloritized diorite or granodiorite adjacent to vein No. 6, or the trace of the vein fault which hosts this vein (e.g., 2 Level), calcite veinlets are prominent in addition to quartz veins. Epidote may occasionally occur as a trace consitituent in mafic rocks, and is more common at Jinchanggouliang (Plate IB).

Carbonatization of diorite dykes within 5-10 cm of an immediately adjacent quartz vein is indicated by an abruptly defined tan-coloured zone (Plate IC). This light-coloured zone contrasts with the dark gray-green colour of the chloritized diorite which occurs further from the vein. Sericite and/or clay may also occur within this zone, but this re-quires additional confirmation.

Argillic alteration of felsic (and mafic) rocks was generally restricted to gouge zones within and along the vein faults. These faults remained active during and after vein formation; vein breccia can be found in places. Pyrite also precipitated along fractures in clay-rich wallrocks (especially diorite; Plate ID) which probably records the last stages of mineralization during cooling of the hydrothermal system.

Veins, Ore Mineralogy, Ore Grade and Tonnage

As presently defined, ore consists of gold-bearing quartz-sulphide veins typically 10-20 cm in width, and locally as much as 50 cm. Calcite and locally potassium feldspar are additional gangue accessory minerals in the veins hosted by intermediate to mafic rocks. The quartz is typically translucent where undeformed, and white-coloured in appearance where multiply fractured. Amethyst is common in some places (e.g, No 5-1 vein, 4 Level), and is typical of zoned, open-space filling veins. Cockscomb structure can readily be seen with both handlens and microscope.

Sulphide minerals may comprise as much as 75% of the vein in places, but in others, sulphides make up a minor portion of the vein. These sulphides include: pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, bornite (?), and arsenopyrite. Chalcocite may also be present; positive identification remains to be made. Veins often have centres dominated by sulphide, and the vein walls by quartz (e.g., the zones, amethyst-bearing cockscomb quartz - sulphide structure of No. 3 vein). A massive, intergrowth of quartz (calcite) and sulphides appears to be most common. Whereas the quartz and calcite gangue may be coarse-grained, the grain size of the sulphide minerals is typically less than 5 mm. Grain-size reduction of all sulphides (see Plate IE), and especially galena, as a result of continued fault movement is evident in a few places. This has resulted in a very-fine grained galena mylonite (so-called "steel galena").

A mineralogical zonation across the Erdoagou mine area was made apparent through mapping and observation of vein mineral assemblages. This zonation is illustrated in Figure 1. Pyrite-(tetrahedrite-chalcopyrite) are common in veins WNW of Erdaogou (e.g, Nos. 6, 9, and 21), whereas veins NW and N of the mine (e.g, Nos. 3, 5, and 7) have mineral assemblages characterized by pyrite-sphalerite-galena in addition to minor chalcopyrite. Thus, there appears to be a Cu-Pb-Zn zonation across the mine area. This zonation will be further discussed in relation to the veins at Jinchanggouliang. It is not known whether there is a distinct relationship between metal zonation and gold occurrence and/or gold grade. However, more extensive mining has taken place along veins in which galena and sphalerite figure prominently in addition to chalcopyrite and pyrite.

Despite the fact that the distribution of galena, sphalerite, and chalcopyrite within and along a particular vein is often irregular (e.g, they may occur as monomineralic pods or lenses), mineralogical zonation of the type noted above was not apparent on the scale of a single vein. A possible exception is vein No. 7, in which arsenopyrite appears to be absent, or significantly less abundant at the southern extent of the vein.

Petrographic observations can be interpreted to suggest the following relative depositional sequence: (1) quartz + pyrite; (2) sphalerite; (3) galena; (4) tetrahedrite; (5) chalcopyrite; (6) quartz; and (7) calcite. Gold (i.e., electrum) has been documented as inclusions in pyrite, chalco-pyrite, and tetrahedrite (see Plate IF). Electrum must also occur intimately associated with galena, based on assay data (Lifuyuan et al., written commun., 1990). The assay data further suggest that pyrite and galena are principal sulphides with which gold is associated. The latter association may also be reflected in the apparently preferential devel-opment of mining of galena and sphalerite-bearing veins. The gold content of pyrite-bearing wall rocks is unknown, but should be determined in order to assess the potential of larger-tonnage, lower grade ore in the wall rocks. Silver also occurs (in tetrhedrite and galena), and the Ag/Au ratio of the ore is on the order of 4-6, based on reported average grades. Indeed, silver might be recovered economically as a by-product of gold mining.

Some 3 km to the NW of Erdaogou, stibnite is found with chalcopyrite in a several minor veins (Fig. 1). Fluorite also was found in veins cutting a large Mesozoic (?) pluton of quartz monzonite shown in the map on Figure 1. Thus, there appears to be a district-scale metal zonation reflected in the veins which may be indicative of the distribution and temperature of the once-active hydrothermal system(s) responsible for gold mineralization. The stibnite occurrence in the Xiduimiango stock and the realgar in the Jinchanggouliang mine suggest that these areas may be among the uppermost in the geothermal system, and indicate that gold-bearing veins may occur below.

Ore grades on the order of 10-20 g/Tonne (e.g, 13.59 g/Tonne average for the No. 5-1 vein) are reported. The No. 5-1 vein is said to constitute 50% of proven reserves (thought to total approximately 10 Tonnes Au). Estimates for unproven ore reserves for Erdaogou are difficult to make based on present data.

JINCHANGGOULIANG MINE

The Jinchanggouliang mine exploits 10 principal gold-bearing quartz-sulphide veins and related offshoots which are hosted for the most part in mafic Archean gneisses (e.g., amphibolites) within the hangingwall of the northerly dipping Toudaogou fault. Access is by one of three shafts. The ore bodies occur in faults that cut across the gneissic grain of the Archean rocks and that have locally offset Mesozoic dykes. Numerous individual orebodies have been mined over a vertical interval of 300 m, but ore of similar grade is known to exist over 500 m.

Lithology

Massive, dark green amphibolite and biotite-hornblende gneisses are the most common wallrocks hosting veins of the Jinchanggouliang mine, along with some minor biotite schists and feldspathic gneiss. The rocks are massive to well-foliated, and are locally cross-cut by granitic pegmatite-aplite dykes up to approximately 1.0 m thick.

Two principal types of felsic dykes are present in the mine (Fig. 7): biotite trachyte and a quartz porphyry (rhyolite?), and biotite-hornblende diorite (or andesite). The latter is less abundant than in the Erdaogou mine where emplacement of diorite dykes pre-dated hydrothermal altera-tion. One surface exposure of a biotite-bearing diorite (an-desite) dyke near the Jinchanggouliang mine suggests that the dyke cross-cuts (i.e., is younger than) vein No. 17 (Fig. 1).

Structural Geology

From a structural point of view, the Jinchanggouliang deposit shares many characterisitics with Erdaogou. Mineralized rocks occur in similar, high-level faults of similar dimensions, characterized by the same types of fault rocks. The faults are also composed of smaller anastomosing and branching segments. Textures and structures of the ore zones also suggest active faulting during mineralization.

The Jinchanggouliang deposit is characterized by a complex network of mineralized and post-ore faults (Fig. 7). Essentially four sets of mineralized faults can be disting-uished: (1) NW-SE subvertical faults represented by veins No. 15-2, 236, 54; NW-SE faults dippoing to the southwest represented by vein No. 8; (3) N-S, subvertical faults represented by veins No. 15, 35, 55, 56; and (4) NE-SW, southeasterly dipping faults represented by vein No. 37 (Fig. 7). According to the mine geologists (Mr. Liu, pers. comm., 1988) and to our observations, the age relationships among the four sets of veins are as follows: the N-S set is the oldest, cut by the two NW-SE sets, which are in turn cut by the NE-SW set, as can be seen at the northern limit of the mine workings (Fig. 7).

Striations were commonly observed along the faults, al-lowing a more complete structural analysis than at Erdaogou. The structural data are reported on the stereonet of Fig. 8. All sets of faults, except the younger one (vein No. 37), contain two populations, or orientations, of striations, locally observed on the same fault surface. One set of striations has moderate to shallow, south to southeasterly plunges, whereas the other set has steeper plunges. At two localities, the shallow to moderately plunging set was the best developed and was clearly overprinted by a weaker, more steeply plunging set. The three oldest sets of faults have therefore been reactivated. These relationships suggest that along these three sets, the first movements were dominantly strike-slip and were followed by dominantly dip-slip movements. It is interesting to note that only the youngest, down-dip striations have been observed along the younger

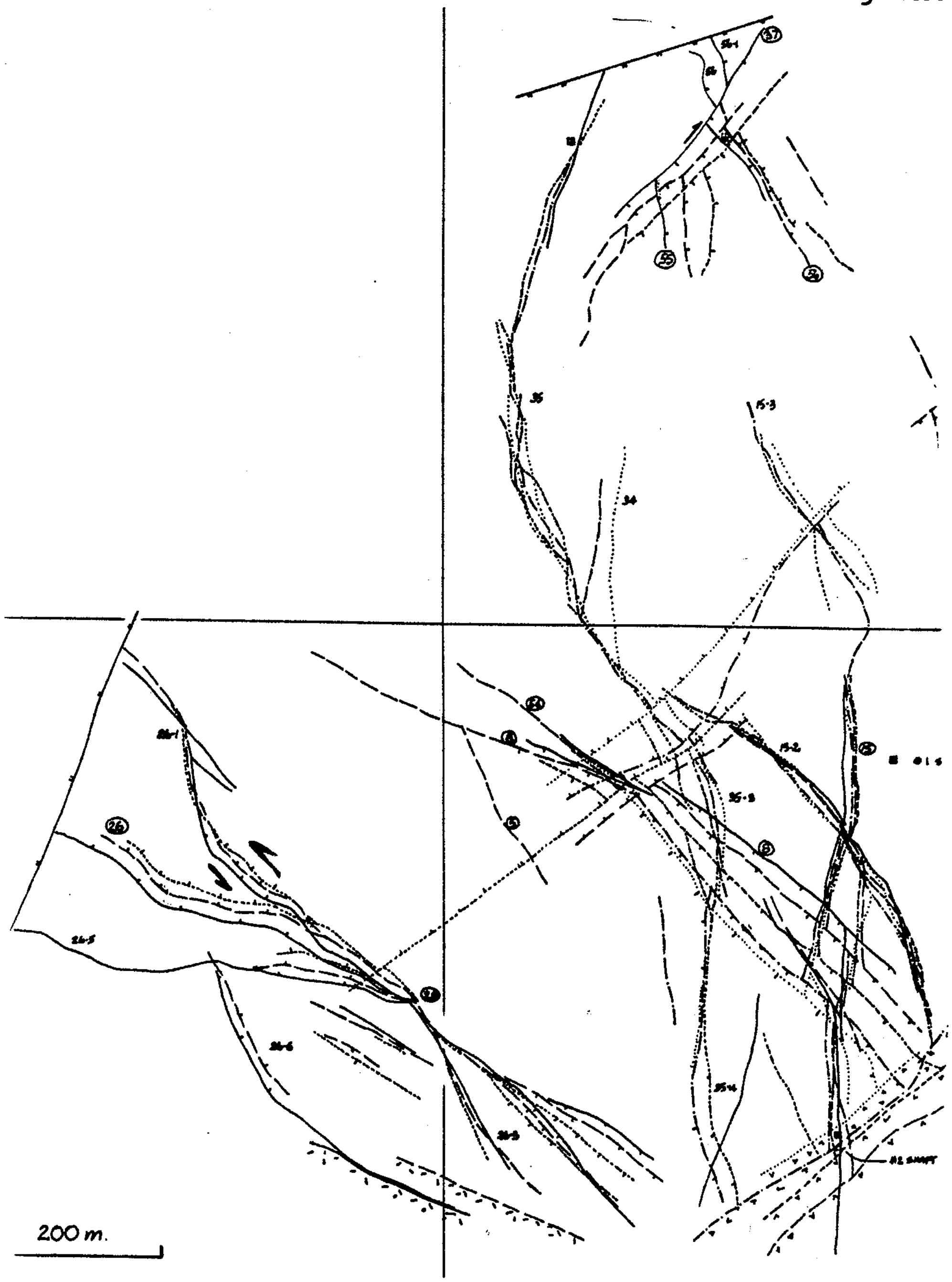


Figure 7: Simplified composite level plan of the Jinchanggouliang mine showing the traces of the significant fault veins.

set of faults and that perhaps it developed after the strike-slip event. However, additional observations would be required to verify this hypothesis.

The presence of striations, as well as common offsets of dykes and mineralized faults, allow determination of the net sense of displacement along several mineralized faults. The No. 37 vein, which belongs to the youngest set and offsets veins No. 55 and 56 in the northern part of the mine (Fig. 7), is a normal, dip-slip fault. Net

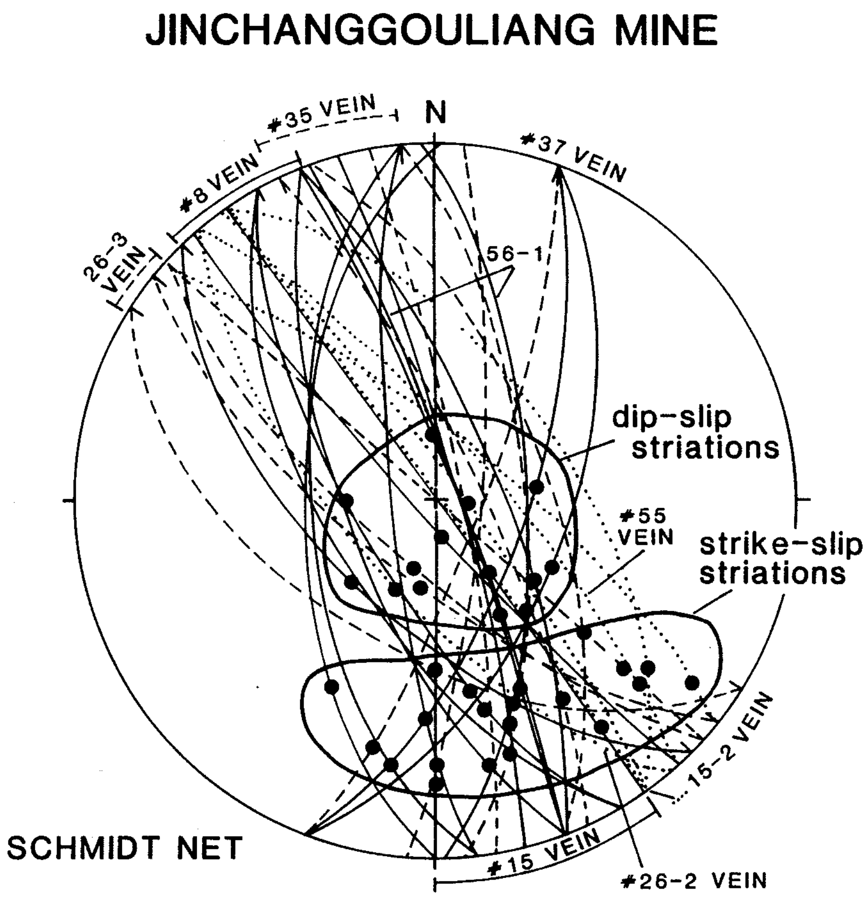


Figure 8: Stereographic (Schmidt net) projection of the traces of faults along veins No. 8, 15, 15-2, 26-2, 26-3, 35, and 37 in the Jinchanggouliang mine, and the piercing points of striations from striations on these faults indicating dip-slip and strike-slip movement.

dextral displacement (with a small normal component) is indicated for the N-S set, based on the offset of a dyke along the No. 15 vein, whereas conficting displacements are obtained for the No. 8 vein of the NW-SE, southwest-dipping set. Both normal (-dextral) and sinistral movements are indicated by the offsets of a dyke and the No. 15 vein, respectively. These conflicting interpretations probably reflect the fact that the mineralized faults are not all of the same age and that they have been reactivated.

Post-ore faults are particularly important at Jinchanggouliang, because they offset mineralized veins. As can be seen in Fig.7, there are at least two sets of port-ore faults. However, veins have not been found on the other side of these faults at the western, northern and southern limits of the mine workings, with which to document the magnitude and nature of fault movement. Their (unknown) offsets remain of prime importance.

In summary, the structural analysis at Jinchanggouliang shows that the gold mineralization occurs in faults of different ages. Most of them record evidence of early strike-slip movements and have been reactivated as dip-slip faults.

Alteration Facies

There is comparatively little variation in alteration mineral assemblages in the Jinchanggouliang mine relative to that described at Erdaogou due to the dominance of mafic gneisses as wall rocks. The alteration minerals include: calcite, chlorite, epidote, pyrite, and (apparently) potassium feldspar.

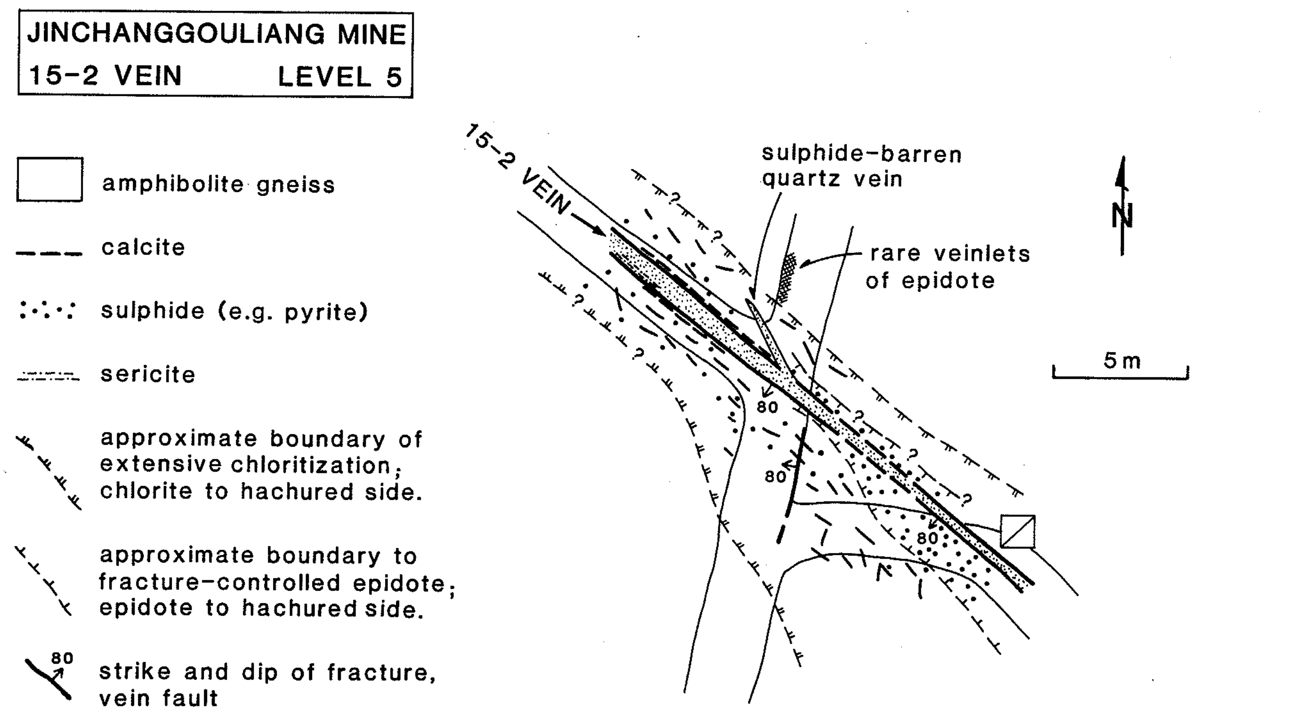


Figure 9: Geologic map of a portion of the No. 15-2 vein, 5th level in the Jinchanggouliang mine showing the distribution of important alteration minerals.

Epidote occurs primarily as fracture coatings, along with calcite and quartz within a few centimetres to 2 m of the vein (e.g, No. 15-2 vein, Level 5; Fig. 9). Local patch-replacement of plagioclase and amphibole by epidote was also noted. The presence of epidote close to the vein is largely the result of the reaction of the H_2O-CO_2 hydrothermal fluids with plagioclase in the amphibolite wall rocks. As indicated in Figure 9, the thickness of the abundant epidote zone is not everywhere the same, and this may be due to the effect of the minor variations in wall rock composition. The zone also appears to be associated with a higher concentration of pyrite.

Calcite occurs as veinlets in a zone which may extend beyond the limits of abundant epidote, as shown about a portion of the No. 15-2 vein in Fig. 9. The zone of calcite veinlets is, in this instance, as much as 4 m wide, but is of variable thickess. The occurence of the calcite veinlets is apparently influenced by the abundance of fractures in the wall rocks.

Chlorite is the most abundant and readily recongized mineral which resulted from hydrothermal alteration about the veins. As Plate IB illustrates, the chlorite-bearing zone about the veins may be variable in thickness, but as much as 6 m. The abundance of chlorite decreases in the wall rocks with distances from the vein, and is fracture-controlled at the outer limits. Because of its significance as an indicator of hydrothermal alteration of the amphibolite, careful documentation of the presence of chlorite in drill core should aid in underground exploration.

Veins, Ore Mineralogy, Ore Grade and Tonnage

Sulphide-rich quartz veins are typically 0.20 to 0.30 m thick. Limited exploration by drilling below level 7, plus assay data from levels 1-7, suggests that the quartz veins thicken slightly with depth (to greater than 0.70 m), without any apparent significant change in grade with depth.

There is no apparent zoning of sulphide minerals in the mine (see Fig. 1). Chalcopyrite is more abundant in the southern portions of the mine, including veins No. 26, 26-1, 26-5 and 8. Veins in the northern portion of the mine (veins No. 55, 56, 57) contain galena and sphalerite. In addition, the presence of realgar/orpiment in the northern portion of the mine may suggest a temperature gradient, with slightly cooler temperatures to the north and/or a change in the relative fugacity of arsenic. Arsenopyrite was also noted in the veins at Jinchanggouliang.

Average gold grades are 10-30 g/Tonne, although local, individual assays can be much higher, to several hundred g/Tonne. The highest gold grades are found within a block bounded to the south by rhyolite-porphyry and to the ESE by biotite trachyte. There is no apparent consistent variation of grade with distance northward in the mine area, despite the fact that the vein sulphide mineral assemblage appears to change from pyrite-chalcopyrite (10-15 g/Tonne); to principally pyrite (18 g/Tonne); and, finally, to pyrite-galena-sphalerite-realgar/orpiment (11 g/Tonne).

SUMMARY

Based on their hydrothermal characteritistics and their geologic setting, the gold deposits of the Erdaogou-Jinchanggouliang area may be classified as adularia-sericitie type. Although adularia is not presently recognized as a principal gangue mineral, the lack of sulphate minerals (e.g., alunite) is an important distinction of the generally smaller, acid-sulphate type of deposits. Metal zoning and vertical limits to the mineralized rocks are typical characteristics of adularia-sericite type of deposits, and evidence discussed above suggests that zoning is indieed present and can be mapped in the field. Our work suggests that presence of a centre to the hydrothermal system: beneath the Xiduiminagou stock. Stable isotope investigations presently being carried out by the GSC should result in an oxygen-isotope map which will better document the regional extent of hydrothermal activity, and will, it is hoped, provide additional information to support the zoning pattern mapped in the field.

The presence of stibnite at a small prospect in the Xi-duiminagou stock and of realgar at Jinchanggouliang suggest vetical mineral zoning, and that these areas represent rela-tively higher structural levels in the deposit. The presence of similar vein structures and amethyst in both Erdaogou and Jinchanggouliang, however, suggests that there are not very large differences in their respective levels of erosion.

Although the mines are at present exploited for gold within the veins, this type of deposit may have associated lower-grade, large tonnage ore associated with the veins. Successful mining and extraction of gold at lower concentra-tions (should they exist) would depend upon machinery and extraction techniques available. Silver is apparently not recovered at present, but this may prove to be a valuable by-product.

The high-level, brittle nature of the mineralized faults both at Jinchanggouliang and Erdaogou is also compatible with such a model. Structural analysis of these faults reveals that they belong to sets of different ages that have been variable reactiviated. As indicated above and as revealed by a comparison of Figures 1 and 5, the fracture pattern in the Jurassic diorite intrustion at Erdaogou mimics the mineralized faults patterns in both mines. This suggests that the fault network in the Archean rocks at Jinchanggouliang developed during Jurassic times, or younger, and were not controlled by any pre-exisiting, reactivated Archean faults.

Furthermore, as is shown in Figure 1, some mineralized faults appear to be radially distributed around the Xiduimiangou intrusion. If this is the case, then the mineralized fault pattern observed at Jinchanggouliang-Edraoguo is probably the result of superimposed sets of faults: (1) regional faults of a well-developed set oriented at 310-340^{o}, and (2) a set of radial fracturers related to emplacement of the Xiduimiangou intrusion.

RECOMMENDATIONS FOR EXPLORATION AND FUTURE POTENTIAL

Considering past production, the magnitude of the 20 Tonne Au reserves at Jinchanggouliang, and the fact that the Erdaogou deposit appears to have been formed at essentially the same time by the same or related hydrothermal activity, the potential for additional gold production at Erdaogou appears to be very good. There is no indication of loss of grade with depth, and the vein faults are of the same general magnitude as those mined at Jinchanggouliang. The potential appears good for deeper mining. The abundance of grade and tonnage of ore, although not well-defined, are known to vary along strike of the principal veins. Therefore, the chief exploration targets should be faults with evidence of veining and/or hydrothermal alteration. Considerable potential may also exist both NW and SE of the Erdaogou mine village. This may include as yet undiscovered (buried) veins.

Further, the ore potential of altered wall rocks has not been extensively tested, perhaps owing to the recovery methods used. Pyrite clearly precipitated beyond the veins during hydrothermal alteration, and gold is known to occur as inclusions in vein pyrite. Thus, some potential for pyrite-bearing wall rocks as low-grade ore, perhaps bulk mineable from surface, may exist.

During exploration of mineralized faults, it is very important to keep in mind that mineralized rocks are not continuously or uniformly distributed within the vein faults, either along strike or down-dip. As a result, along any particular fault segment, several drill holes may be required to adequately assess whether a particular fault segment is barren or mineralized. Similarly, apparently small occurrences of mineralized rock explored by local inhabitants should not be disregarded; they may lead to larger mineralized veins at depth.

Recommendations include the following:

1. Continue exploration (perhaps by cross-drilling) of all faults with NNW trends. Particularly encouraging would be evidence of hydrothermal alteration. Veins apparently pinch and swell, and the absence of vein material does not necessarily preclude eventual discovery of ore along strike, or at depth.

2. Exploration should be extended horizontally, to the SE of Erdaogou. Areas along strike of present veins, and beneath alluvial cover are potentially good targets. Particular note should be made of the presence or absence of galena (in addition to pyrite); presence of galena is encouraging.

3. Exploration should be conducted north of the present Jinchaggouliang mine site, beneath alluvium and Cretaceous volcanic rocks. Attempts should be made (as in 2 above) to identify the presence of NNE-trending faults. These should be explored in detail. Efforts should be made to understand the displacements and offsets along the port-ore faults, in order to find the extension of known mineralized faults.

4. Consideration should be given to assaying the gold content of altered wall rocks (most especially the granitic and rhyolitic wall rocks at Erdaogou) to determine whether they could represent ore-grade material.

5. Exploration by drilling and assay should be conducted in the area of the stibnite occurrence in the Xiduimiangou stock. Mineral

zoning mapped elsewhere suggests that gold-mineralized veins may exist at depth in this area.

PLATE I

a. Photograph of partially silificied rhyolite adjacent to vein No. 5, 4th level in the Erdaogou mine. Abbreviations: S, silificied rhyolite; R, rhyolite.

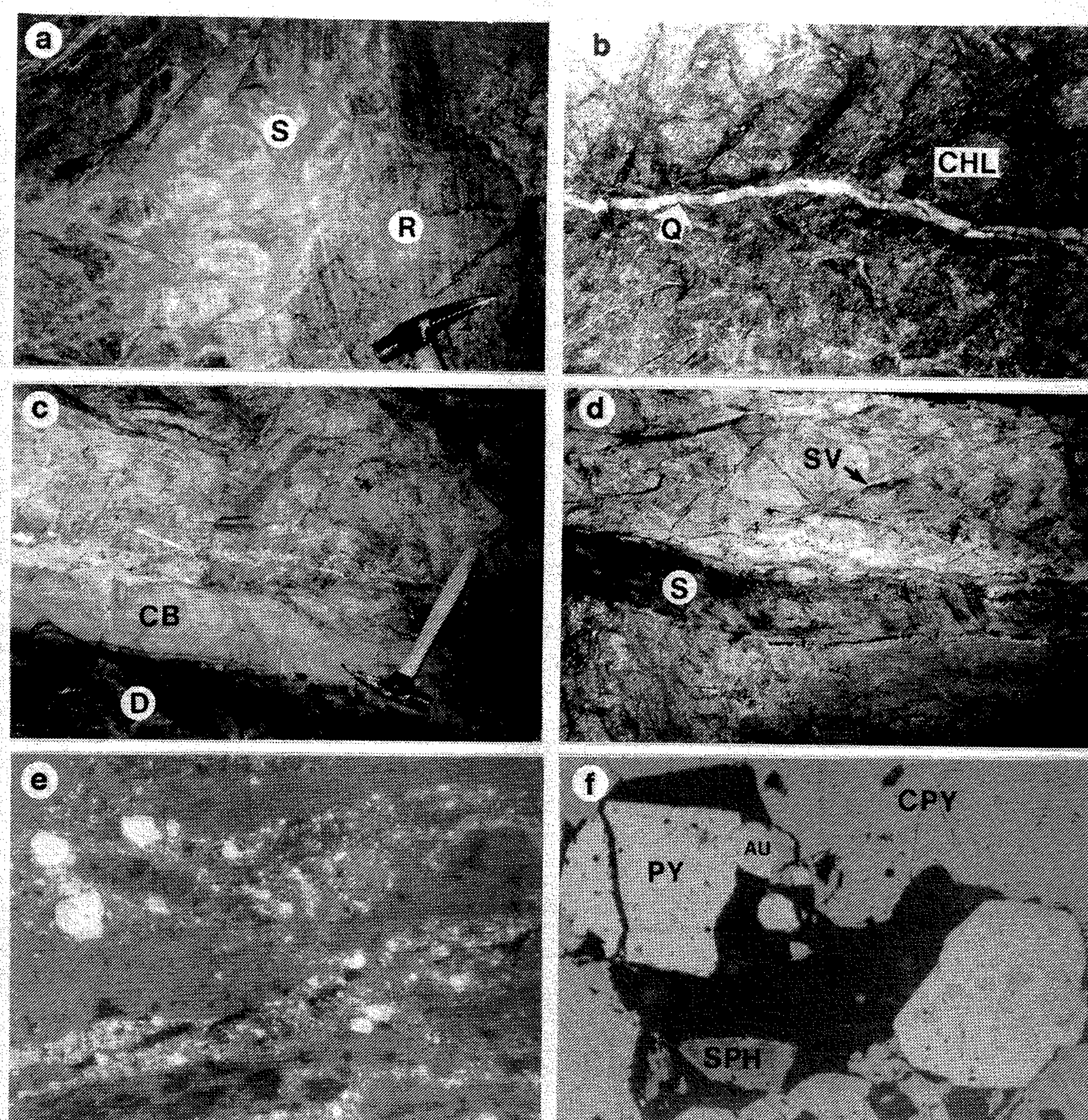
b. Photograph of quartz (+ sulphide) vein and chlorite-rich vein envelope cross-cutting granitic and aphibolitic gneisses; Jinchanggouliang mine. Abbreviations: CHL, chlorite-rich vein envelope; Q, quartz vein.

c. Photograph of diorite dyke (D) emplaced in vein fault through rhyolite (partially silicified adjacent to vein), Erdaogou mine, shows carbonatized zone (CB; sericite) adjacent to vein; vein No. 5, 4th level.

d. Photograph of clay-altered (supergene ?) dyke, sulphide-rich zone (S), and sulphide veinlets (SV) along vein No. 5-1, 4th level in the Erdaogou mine.

e. Photomicrograph of sulphide-bearing (dominantly pyrite) vein breccia illustrating evidence for recurrent movement during and after vein formation; Erdaogou mine.

F. Photomicrograph of gold (Au; electrum), pyrite, sphalerite (SPH), and chalcopyrite (CPY) illustrating grain-to-grain relationships; Erdaogou mine.


a
S
R
b
CHL
Q
c
CB
D
d
SV
S
e
f
CPY
AU
PY
SPH

Chapter 5

OBSERVATIONS ON GOLD DEPOSITS IN THE ZHAOYUAN AREA OF NORTH CHINA PLATFORM

K.H. Poulsen, B.E. Taylor, F.Robert and J.K. Mortensen

JIAODONG UPLIFT

The Jiaodong uplift occupies the central part of the Shandong Peninsula (Fig.1) The western part of the uplift is marked by the Tan-Lu Fault, a major sinistral strike-slip structure, that transects NCP. In this area the uplift is 50 km wide.

Precambrian schists and gneisses comprise approximately 50 percent of the exposure in the uplift and these consist primarily of Archean rocks of the Jiaodong Group. Primary features in these metamorphic rocks are better preserved than those in the rocks of the Liaoxi Uplift and indicate that the Jiaodong Group is composed mainly of biotite schist of metasedimentary origin, with minor amphibolite representing metamorphosed dykes. Some of the metamorphic rocks in Jiaodong Uplift are reported to be biotite gneiss and metamorphosed granite of Early Proterozoic age, but they are not present near the main gold district and were not examined.

The Mesozoic granitoid rocks of this uplift occur mainly in a single batholithic complex comprising the voluminous biotite quartz monzonite of the Linglong Phase and the younger K-feldspar-porphyritic biotite-hornblende granodiorite of the Guojialing Phase. The Linglong Phase is commonly described as "migmatite", but this designation appears to be based on the presence of abundant xenoliths of schist and gneiss near its contacts with the Precambrian rocks. Small stocks of Mid-Mesozoic (Yanshanian) granodiorite and granite occur throughout the uplift and comprise the youngest granitoid phase. Mesozoic volcanic and sedimentary rocks occur on the flanks of the uplift but these were not examined.

The structure of the uplift is defined primarily by the NE axis of the Linglong and Guojialing granitoid rocks, by the ENE distribution of, and strike of foliation within, the Precambrian schists and gneisses, and by a set of NNE brittle faults that are parallel to the Tan-Lu Fault. Older faults such as the Zaoping and Jiaojia faults follow a sinuous course but strike, on average, ENE, whereas a younger set strikes NW (Fig.1).

Gold deposits are distributed throughout the central core of Jiaodond uplifts (Fig.1). The authors had the opportunity to examine two large gold deposits in the Linglong and Jiaojia areas of Zhaoyuan gold district in the Jiaodong Uplift.

Linglong Area

This area (Fig.2) is underlain entirely by the Linglong Phase biotite quartz monzonite which is cut by a swarm of NE striking diorite and lamprophyre dikes. More than 100 quartz veins, ranging from 10 cm to 5 m wide, dip steeply NNW and occur in the footwall of

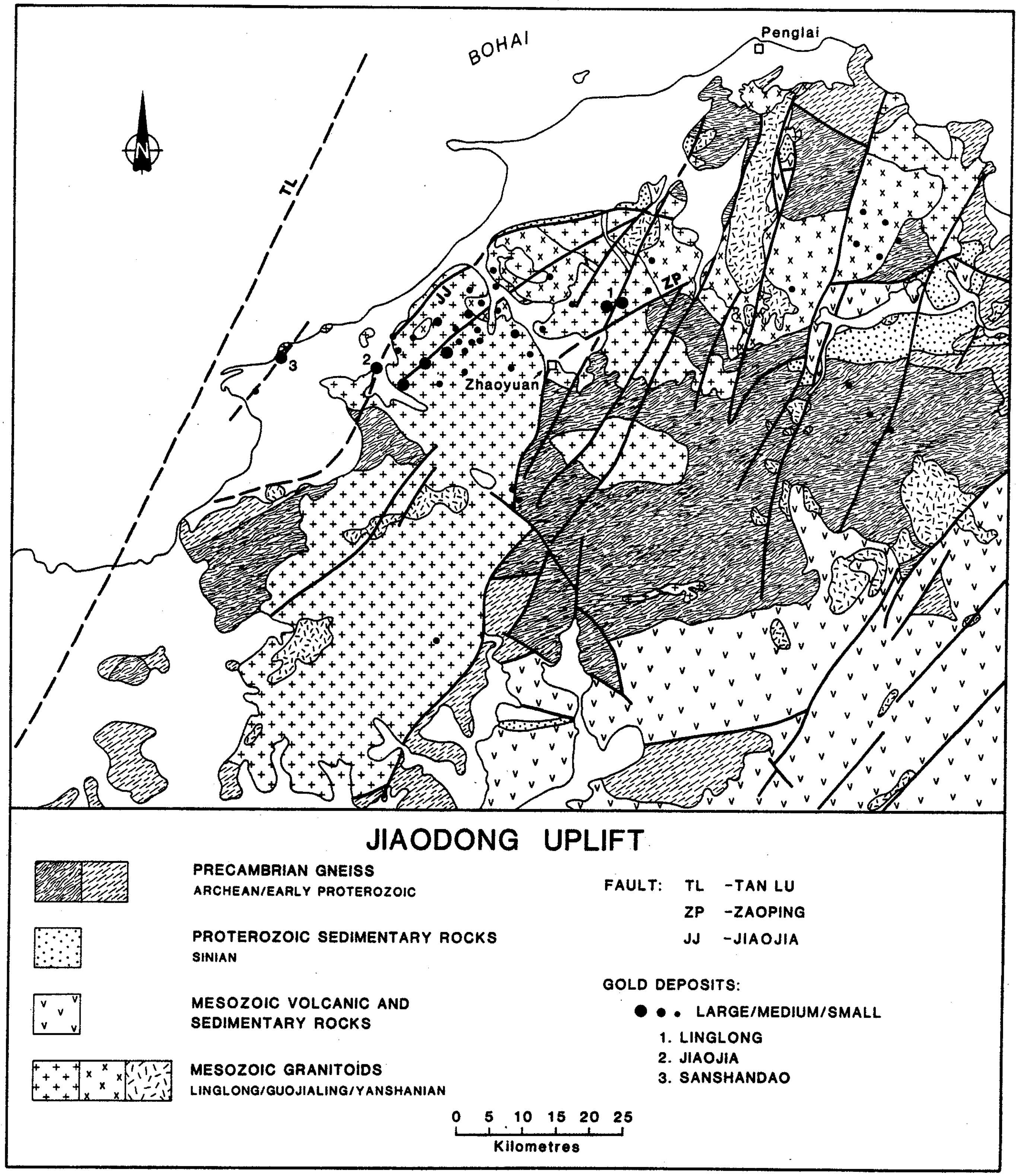


Figure 1: Geology of the Jiadong Uplift. After an unpublished compilation map by the No. 6 Geological Team of Shandong Province.

the SE-dipping Zaoping Fault (Fig. 2). The veins and dikes are offset 30 metres sinistrally by the Linglong Fault which appears to be related to the larger Tan-Lu system.

At the Linglong deposit, there are two centres of production, Linglong and Lingshan. Gold is mined over a vertical interval of 400 metres and is known to extend to 1000 metres below surface. Ore from upper elevations is of quartz vein type, whereas non-vein disseminated ore ("alteration-" or "Jiaojia-type") occurs at greater depth. The Zaoping Fault is mineralized with Jiaojia type ore at depth and individual vein structures, depending on vertical position, may contain barren quartz grading downward to quartz vein ore and ultimately to Jiaojia type ore.

Metre-wide quartz veins were observed at Linglong. The veins commonly have a ribbon texture and are composed of massive, vitreous quartz with minor sulfide minerals. Where sulfides are abundant, they occupy fractures that cut the quartz. Gouge and cataclasite are well developed along vein margins and appear to have formed after the veins.

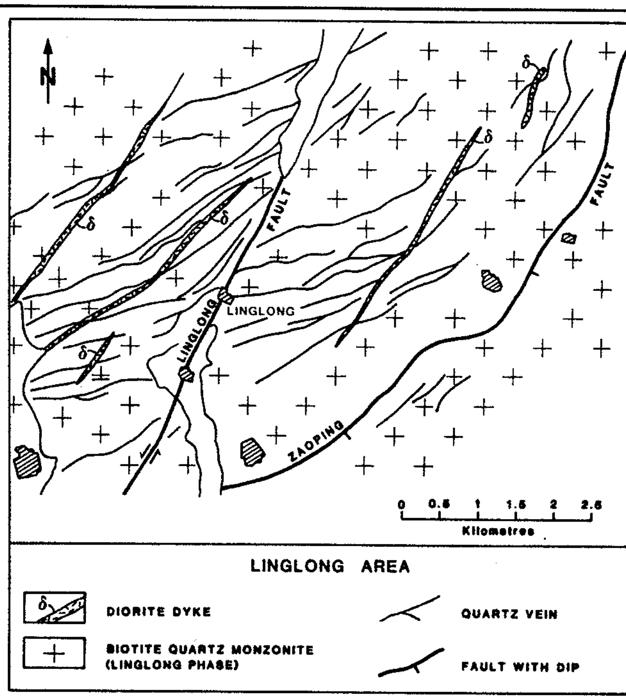


Figure 2: Map of the geology and veins in the Linglong area. From a map by Li Shi Xian (pers. comm., 1989).

Jiaojia Area

The Jiaojia area (Fig.3) is underlain in part by granitoid rocks of the Linglong Phase, and these are cut by a stock composed of Guojialing Phase granodiorite with feldspar phenocrysts up to 10 cm long. Archean gneisses occupy the hanging wall of the northwesterly-dipping Jiaojia Fault, a sinuous zone of fault gouge, up to 3 m wide, that merges with several smaller splay faults.

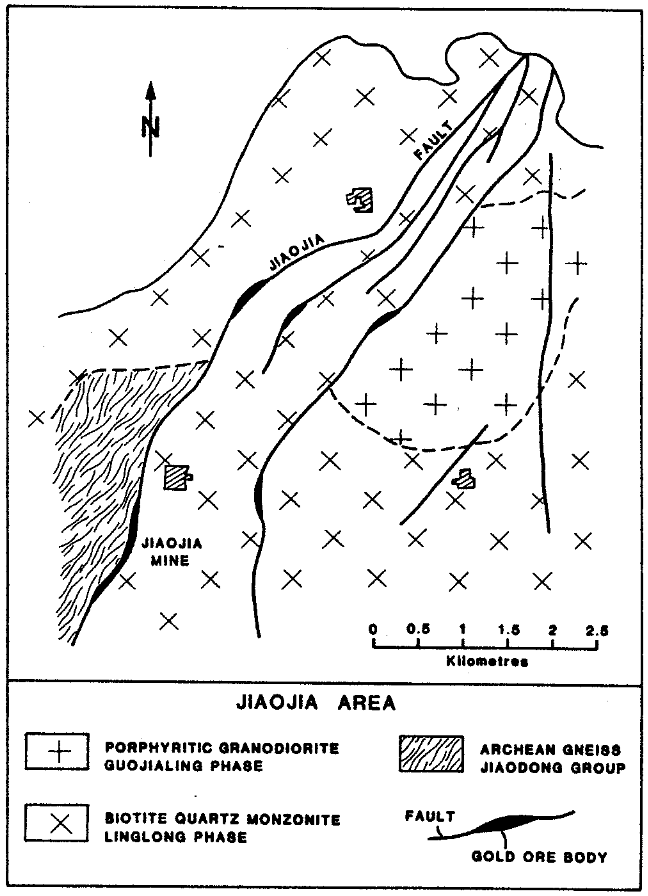


Figure 3: Map of the geology and gold deposits in the Jiaojia are. From a map by Li Shi Xian (pers. comm., 1989).

The Jiaojia deposit, the largest of six of this type in the area, occurs within the footwall of the Jiaojia Fault. It is composed of "Jiaojia-type" ore, disseminated pyrite, gold and minor base metals in a sericitized cataclastic matrix of Linglong Phase quartz monzonite. The deposits are composed of several *en echelon* lenses adjacent to and parallel with the Jiaojia Fault. The largest lens is 1300 m long and is, on average, four metres wide, although locally it is as wide as 30 m. Farther from the fault, lenses contain increasing amounts of vein quartz.

The cataclastic ores at Jiaojia and Linglong are fine grained, non-foliated, dark-coloured rocks containing disseminated fine-grained sulphide minerals and gold. A continuous progression was observed outward, from fine- grained ore to less-mineralized, sericitized coarse quartz monzonite, to fresh quartz monzonite that is neither altered nor deformed. Given the shape and distribution of the orebodies, it is likely that they represent incipient cataclastic zones that did not develop into faults, but that were favourable loci for fluid movement.

Discussion

Chinese geologists employ a host rock classification for gold deposits. The deposits described above are therefore thought to be representative of a migmatite type (Jiaojia, Linglong). However, if we consider all of the characteristics of the deposits, including their relative time of formation, overall distribution, structural style, mineralogical composition and hydrothermal alteration, we must conclude that all these deposits belong to a single class transitional in their geological attributes between the conventional epithermal and mesothermal types. Furthermore, it seems inescapable that the deposits that we examined in the Zhaoyuan area are of probable magmatic hydrothermal origin and in some ways resemble porphry deposits.

The "Jiaojia-type" is the most unique of all of the styles of mineralization that the authors examined in China. It is similar in some respects to a type of cataclastic ore that is found at some Abitibi gold deposits (Eldrich in the Rouyn area, McDermott in the Harker-Holloway area). The potential of material of this type (i.e., diseminated gold in mineralized wall rocks) to be ore might easily be overlooked in districts where gold has been traditionally extracted from quartz veins. Furthermore the grade-width-tonnage characteristics of the Jiaojia type deposits are such that they would be viable in the North American economic context.

Chapter 6

GEOCHRONOLOGICAL AND ISOTOPIC STUDIES IN NORTH CHINA PLATFORM: PROGRESS REPORT

J.K. Mortensen

INTRODUCTION

Studies of gold deposits in the Liaoxi and Jiaodong uplifts of the North China Platform (NCP) are hampered by a lack of reliable age data for many of the rock units associated with the gold mineralization. In the Liaoxi Uplift, a very small number of mainly K-Ar ages was available prior to the present study. Although a considerable amount of previous geochronological data is available for the Jiaodong Uplift, the data set is incomplete, and results are in some cases contradictory. In order to clarify age relationships in these two important regions, detailed sampling for geochronology was carried out during field work in the Liaoxi Uplift, and several critical rock units were sampled for dating purposes during a field excursion to the Zhaoyuan-Yexian area of the Jiaodong Uplift in eastern Shandong Province. These and other samples collected during the field work were also intended for radiogenic isotope tracer studies.

PREVIOUS DATING STUDIES IN NORTH CHINA PLATFORM

Much of the previously available age data for the NCP consists of K-Ar ages (often on whole rock samples) or Rb-Sr ages. A K-Ar age provides at best only the time at which a sample cooled through the blocking temperature of the K-Ar system in the particular material being analysed (Table 1). For igneous rocks, K-Ar mineral ages may therefore be much younger than the actual crystallization age of the rocks, especially if the area has experienced later thermal events (younger magmatism or metamorphism). Similarly, K-Ar ages for metamorphic minerals yield only the time that a body of metamorphic rocks cooled, rather than the time of peak metamorphism. K-Ar whole rock ages are particularly unreliable, and can generally only be interpreted as minimum ages for a rock unit.

Rb-Sr whole rock isochrons commonly yield misleading ages, due mainly to a lack of initial Sr isotopic homogeneity in the sample suite. This is especially common for felsic igneous rocks generated in a continental environment such as the NCP, or for rocks that have been strongly altered and/or metamorphosed and in which Rb and/or Sr mobility has occurred. U-Pb and Sm-Nd techniques provide more reliable crystallization ages for igneous and metamorphic rocks. These methods have been used in a number of studies in the NCP, but have been applied almost exclusively to the Archean basement rocks of the region. Sm-Nd isochron ages are generally relatively imprecise, however, and U-Pb zircon dating in the NCP are complicated by the presence of abundant inherited and/or xenocrystic zircon in many rock units.

PURPOSE OF STUDY

The main goals of this study were a) to establish the crystallization age and isotopic character of each of the main rock suites in the two study areas in order to better understand processes of crustal evolution in the NCP; b) to constrain as closely as possible the age of gold mineralization in each area; and c) to use the isotopic signature of the mineralization to evaluate the relationship(s) between the mineralization and its host rocks. The data generated in the present study will be integrated with existing age and isotopic data for the NCP, and outstanding questions and recommended lines of future research will be identified.

PRELIMINARY RESULTS

Liaoxi Uplift

<u>Sampling</u>. Detailed sampling for geochronology and isotopic studies was carried out in the Liaoxi Uplift during the 1989 field work. A total of 27 samples were collected for U-Pb (K-Ar) geochronology and Nd and Pb isotopic study, 15 samples were collected for K-Ar dating only, over 25 samples were collected for Nd and Pb isotopic study only, and over 50 sulfide samples were collected for isotopic studies of the mineralization itself. Mineral separates have been prepared from most of these samples, and a large number of analyses have been completed.

<u>Geochronological Results</u>. The large body of weakly to moderately foliated, porphyritic quartz monzonite/granite mapped as 4 and assigned a Hercynian (Late Paleozoic) age (Sample 1, Fig. 1) was dated using both U-Pb zircon and K-Ar biotite methods. The zircon data indicates a crystallization age of 220 +/- 4 Ma, and the presence of a considerable amount of inherited zircon with an average age of 2.43 Ga. Biotite yields a K-Ar age of 207 +/- 3 Ma. This unit is therefore not Hercynian in age but is actually Late Triassic (Late Indosinian or Early Yanshanian), and should be designated γ51. The earliest Jurassic biotite age reflects cooling of the body after regional deformation.

Two samples of quartz-feldspar (biotite, hornblende) -phyric, flow-banded rhyolite were collected for U-Pb dating (Samples 2 and 3, Fig. 1). The rhyolite sample at the Erdaogou mine (Sample 2) yields a concordant U-Pb zircon age of 145 +/- 1 Ma, and contains abundant inherited zircon with an average age of 2.40 Ga. The second rhyolite sample (Sample 3), collected near the village of Dongduimianggou, also yields an age of approximately 144 Ma, and contains inherited zircon with an average age of 2.48 Ga. Both of these units are therefore latest Jurassic (J3) in age.

A subvolcanic quartz-feldspar porphyry body which locally contains flow-banded phases, and passes into a pebble dyke, was sampled for U-Pb dating near the village of Dongduimianggou (Sample 4, Fig. 1). Four zircon fractions were analysed, and all yielded ages ¢2.0 Ga. They are therefore all considered to be xenocrysts, and the emplacement age of the body remains unresolved.

A large body of hornblende-biotite diorite (Laoshang diorite) was sampled at the Erdaogou mine (Sample 5, Fig. 1). This body intrudes

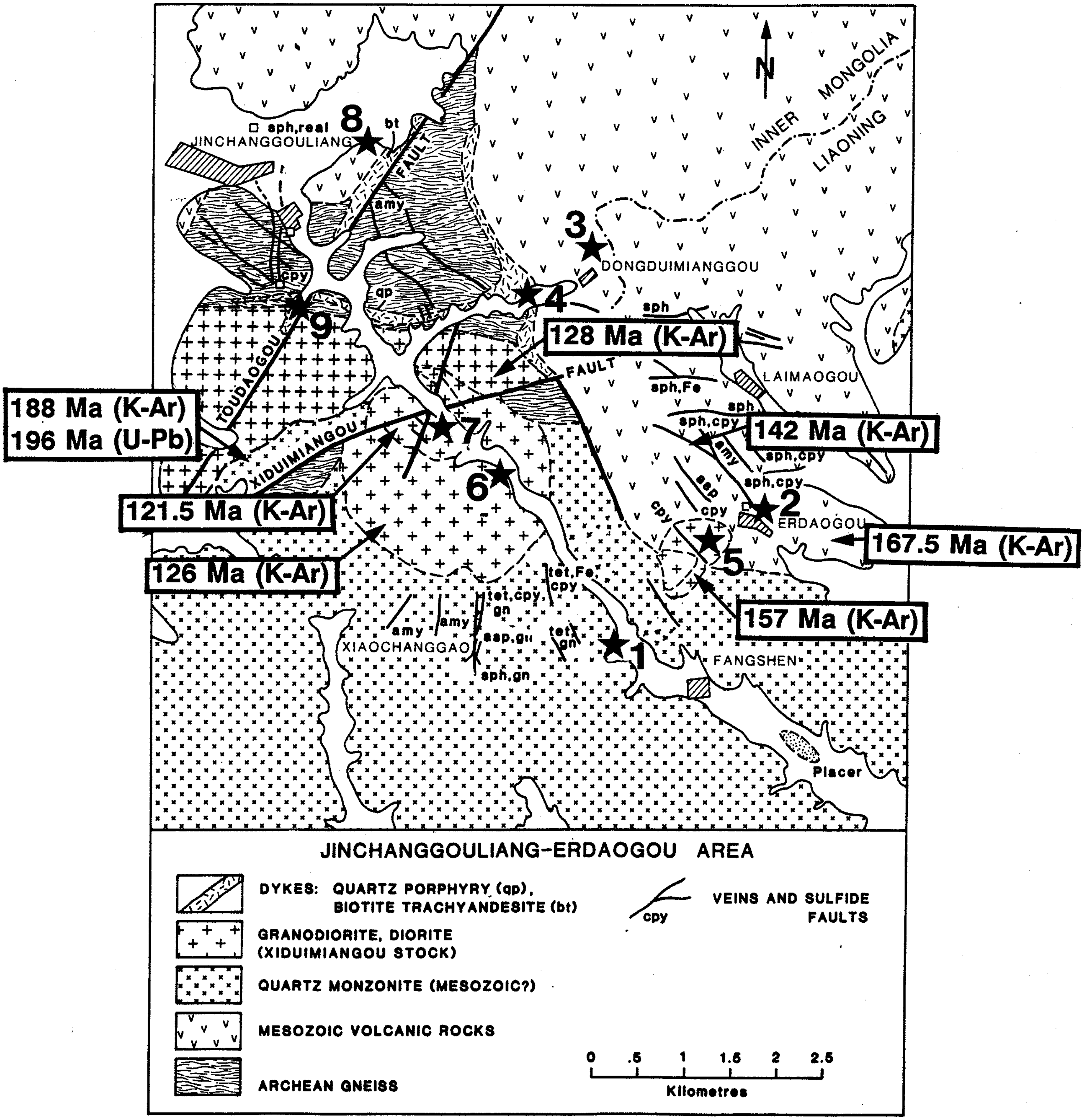


Figure 1: Map of the geology of the Jinchanggouliang-Erdaogou area showing units dated and isotopic ages obtained by the No.3 Geological Team of Chaoyang (boxes) and the location of samples dated in this project (stars).

rhyolites at the base of the volcanic section which are only slightly lower stratigraphically than rhyolites dated at 145 Ma (Sample 2 above). No zircon was recovered; however the sample yields a K-Ar biotite age of 147 +/- 3 Ma, which indicates that the diorite is a subvolcanic equivalent of some of the extrusive rocks in the area.

Zircons and biotite from the main phase (equigranular quartz diorite) of the Xiduimiangou pluton (Sample 6, Fig. 1) were dated. Three U-Pb zircon analyses are nearly concordant at 131 +/- 2 Ma, and the biotite yields a K-Ar age of 128 2.0 Ma. The body is therefore Early Cretaceous in age, and the K-Ar age reflects cooling soon after intrusion.

A sample of the porphyritic core phase of the Xiduimiangou pluton (Sample 7, Fig. 1) contains abundant inherited zircon (average age of 2.01 Ga). The preliminary data indicates an age of approximately 128 Ma, consistent with this being a slightly younger phase of the pluton.

Zircon and biotite from a poorly consolidated quartz-feldspar-biotite (hornblende) crystal tuff exposed in a roadcut northwest of the Toudaogou fault near Jinchanggouliang (Sample 8, Fig. 1) were dated. A range of ages of zircon (mostly Early Cretaceous in age) are present in the sample; however the maximum possible emplacement age is estimated to be 129 +/- 1 Ma. The K-Ar biotite age of 120 +/- 2 Ma for this unit is probably the best estimate of its crystallization age.

A biotite-feldspar-phyric trachyandesite dyke which crosscuts gold-bearing veins was sampled underground at the Jinchanggouliang mine (Sample 9, Fig. 1). A K-Ar biotite age of 124 +/- 2 Ma was obtained. Zircons from this sample give a range of ages, but the best estimate is 123 Ma.

<u>Discussion of Preliminary Dating Results</u>. Preliminary isotopic ages have recently been obtained for 7 rock units from the Erdaogou-Jinchanggouliang area by the No. 3 Geological Team of Chaoyang. These results, together with dates produced in the present study, are shown in Figure 1, and listed below (ages shown with an asterisk are samples also dated in this study).

Table 1

-Xitaizi porphyritic granite.......188 Ma (K-Ar)
...........196 Ma (U-Pb zircon?)
*-Laoshang quartz diorite...........157 Ma (K-Ar)
-rhyolite, Erdaogou area...........167.5 Ma (K-Ar whole rock?)
-diorite dyke (wall rock of No. 5-1 vein)
...........142 Ma (K-Ar)
*-Xiduimiangou pluton, main phase...126 Ma (K-Ar feldspar)
...........126 Ma (U-Pb zircon?)
*-Xiduimiangou pluton, porphyritic core
...........121.5 Ma (K-Ar)
-Xiduimiangou pluton, adamellite...128 Ma (K-Ar)

Taken together, the data indicates that Mesozoic magmatism in the Erdaogou-Jinchanggouliang area occurred in three main episodes, in Late Triassic-Early Jurassic time (220-196 Ma), Late Jurassic time (168-145 Ma), and Early Cretaceous time (131-120 Ma). Gold mineralization is clearly related only to the youngest magmatic event, and the age of mineralization can be tightly constrained between 128-120 Ma (late Early Cretaceous).

Galena Pb Isotope Studies of Liaoxi Uplift. Pb isotopic compositions were determined for galena from 27 veins from the Erdaogou, Jinchanggouliang, Xiaochangagou, Shajingou, Dongwujia, and Xiaotazigou deposits. The preliminary results are summarized in Figure 7 of Chapter3. The data define a remarkably linear array, and there is a clear correlation between the proximity of a sampled vein to Mesozoic igneous rocks and the measured Pb isotopic composition of galena in the vein. Galenas from veins hosted entirely by Late Jurassic rhyolites (Erdaogou) or Late Triassic granite (Xiaochangagou) have the most radiogenic isotopic compositions; galenas from veins hosted by Archean gneisses but closely associated with Mesozoic dykes (Jinchanggouliang) yield intermediate isotopic compositions; and galenas from veins in Archean gneisses where Mesozoic intrusions are rare or absent (Dongwujia and Xiaotazigou) yield very non-radiogenic isotopic compositions (Fig. 7, Ch.3). The preliminary interpretation of the data array is that it represents a mixing line between Pb derived from Mesozoic igneous rocks and Pb derived from Archean gneisses, rather than a secondary isochron. The Pb/Pb age calculated from this array (2450 Ma) therefore has little meaning.

Jiaodong Uplift

Sampling. A number of samples were collected during a visit to the Zhaoyuan-Yexian area of East Shandong Province to try to resolve some of the outstanding problems regarding the age and origin of the main lithological units in this important part of the Jiaodong Uplift. All mineral separations are complete, and preliminary U-Pb and K-Ar dates, as well as Nd and Sr isotopic compositions, have been obtained from 5 samples thus far.

Geochronological Results. U-Pb dating of zircon and monazite from a sample of weakly to moderately foliated biotite granite of the Linglong phase (Sample 1, Fig. 2) indicate an age of 154 +/- 1 Ma (Late Jurassic). Zircon and monazite from a sample of Luanjiahe granite (Sample 2, Fig. 2) yield an identical U-Pb age of 154 +/- 1 Ma. A sample of porphyritic quartz monzonite of the Guojialing phase (Sample 3, Fig. 2) yields a U-Pb zircon age of 123.5 +/- 4.0 Ma, a U-Pb sphene age of 125 6 Ma, and a K-Ar biotite age of 123.7 +/- 2.5 Ma. A second sample of a very coarsely part of the Guojialing phase (Sample 4, Fig. 2) yields a U-Pb zircon age of 127.1 +/- 0.2 Ma and a K-Ar biotite age of 125.3 1.8 Ma. The Linglong granite and Luanjiahe granite samples yield K-Ar biotite ages of 122.8 +/- 2.1 Ma and 126.9 +/- 4.6 Ma, respectively. All 4 samples of granitic rocks contain abundant inherited zircon with average ages in the range of 2.4 to ¢3.0 Ga.

A sample of biotite-garnet-cordierite-sillimanite schist (metapelite) from near the top of the Pengkuan Formation (Sample 5, Fig. 2) yields U-Pb monazite ages which average 1849 +/- 4 Ma. Biotite from the same sample gives a K-Ar age of 988 +/- 13 Ma.

Isotopic Results. Sm-Nd and Rb-Sr results for the 4 granitic samples, and for 3 samples of Pengkuan Formation metapelite have also been completed. The results confirm the high initial Sr ratio for the granitoids in this area that had been reported in earlier studies, and indicate that all of the granitic rocks in this area (including the S-

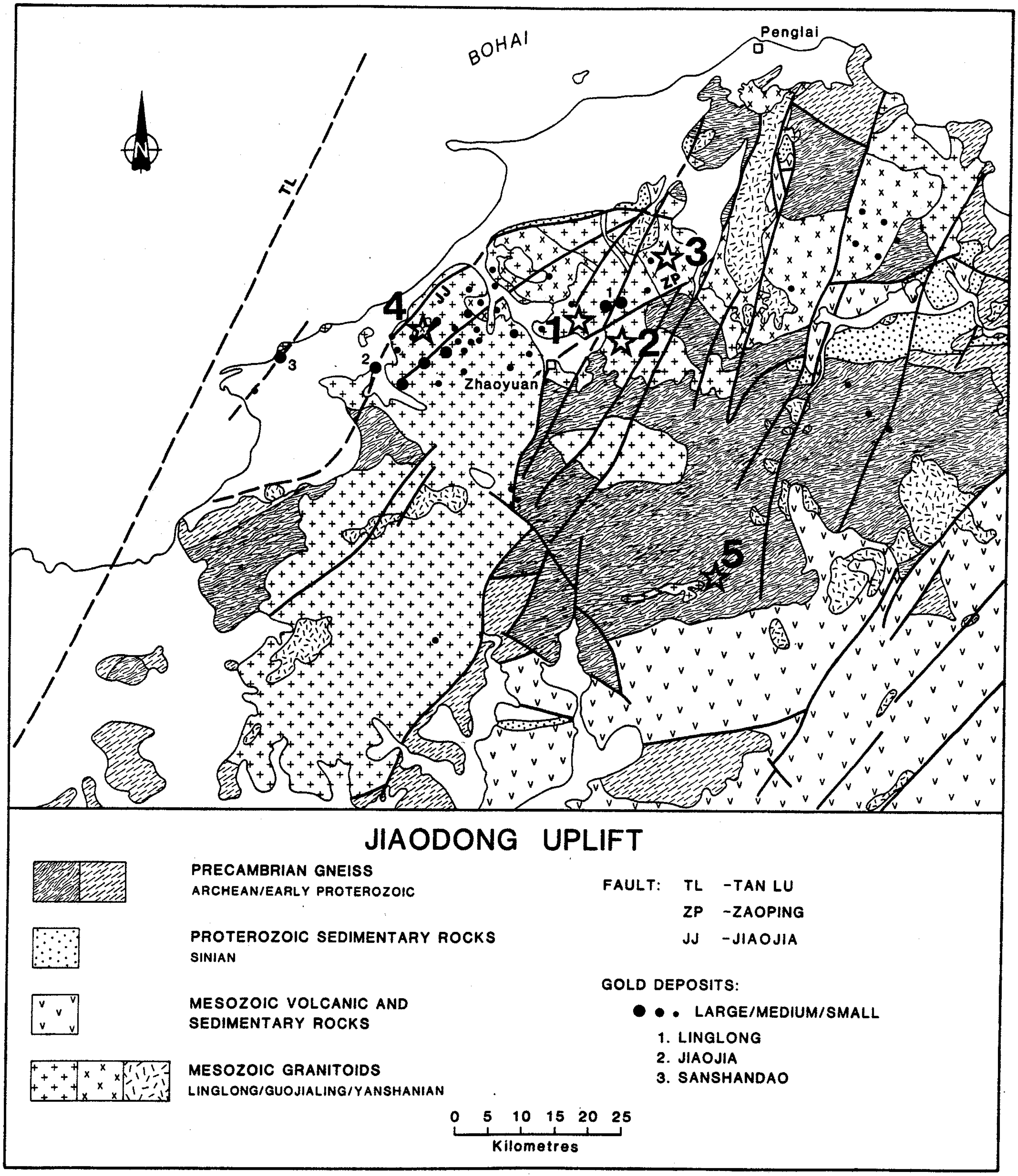


Figure 2: Map of the geology of the Zhaoyuan-Yexian area of the Jiaodong Uplift, eastern Shandong Province. Sample localities referred to in the text are shown by stars.

type Linglong and Luanjiahe phases, and the I-type Guojialing phase) are crustally derived.

The Pb isotopic composition of galenas from the Linglong and Jiaojia deposits has been measured, and found to be identical within error. This confirms that the two deposit types are closely related, and likely of the same age.

Discussion. The preliminary results reported here indicate that two separate intrusive events occurred in Mesozoic time in the Zhaoyuan-Yexian area. One of these occurred in Late Jurassic time (≈154 Ma) and resulted in the emplacement of the Linglong and Luanjiahe granites. The second intrusive event occurred about 25-30 Ma later, in Early Cretaceous time (≈125 Ma), and is marked by intrusion of the Guojialing phase. Emplacement of the Guojialing intrusions also thermally reset the K-Ar biotite system in the older Linglong and Luanjiahe granites. Gold mineralization in this area is thought to be closely related to the Guojialing phase plutons, and therefore probably occurred at about 125-120 Ma.

U-Pb monazite ages for the Pengkuan Formation metapelites indicate that peak metamorphism occurred at about 1850 Ma. This is quite consistent with a K-Ar muscovite age for an undeformed pegmatite that crosscuts the Pengkuan Formation gneiss in this area. The K-Ar muscovite age represents only a cooling age through 350 C, and the pegmatites may therefore represent small-volume anatectic melts produced during the Early Proterozoic metamorphism at 1850 Ma, and emplaced following the main deformation.

The young crystallization age of the Linglong granite, and the fact that Proterozoic K-Ar ages are preserved within Jiaodong Group metamorphic rocks and contained pegmatites in the Zhaoyuan-Yexian area, indicates that the high-grade metamorphism and local migmatization that has been documented for much of the Jiaodong Group was not responsible for the formation of the Linglong granite magma. The Linglong and closely related Luanjiahe granites were likely generated by a separate and much younger phase of crustal anatexis, which is not recorded, or has not been recognized, at the present erosion level.

CONTINUING RESEARCH

Liaoxi Uplift

All U-Pb and K-Ar ages reported here will be finalized. U-Pb dating of other Mesozoic igneous rock units will also be done, along with K-Ar dating as appropriate. As well, several orthogneiss units that form part of the Archean gneissic basement in this area will be dated by U-Pb methods. Several of these orthogneiss samples come from within the type section of the Xiaotazigou Formation of the Jianping Group, and these ages will be critical to establishing correlations within the Archean of the NCP.

Whole-rock Sm-Nd and feldspar Pb isotopic analyses will be carried out on a suite of approximately 25 samples ranging from Archean gneisses to the youngest Mesozoic igneous rocks in the Liaoxi Uplift. These data will contribute to a better understanding of the overall crustal evolution of this region, and will help place constraints on both the possible age(s) of Archean gneiss units that cannot be dated directly, and on the genesis of the widespread and abundant Mesozoic igneous rocks.

Muscovite from greisen zones associated with wolframite- and molybdenite-bearing quartz veins northwest of the Dongwujia deposit will be dated. Field relationships suggest that these veins may be a higher temperature manifestation of the same hydrothermal system that produced the Au veins in this area. The W and Mo bearing veins are spatially and probably genetically related to a suite of felsic intrusions that are monazite-bearing and likely peraluminous in composition (5; includes Lao Lin Shan and a large unnamed body farther to the northeast). A similar age for these veins and the Au-bearing veins farther away from the 5 intrusions would have important implications for regional metallogenic zoning in the Liaoxi Uplift.

Feldspar Pb isotopic data for various rock units in the Liaoxi Uplift will be integrated with the galena Pb isotopic data reported above, and additional Pb isotopic analyses of other sulfide minerals from both the Au- and the W- and Mo-bearing veins. Taken together, this data should permit a very detailed analysis of the source of metals for the vein systems.

Jiaodong Uplift

Hornblende from two samples of hornblende-plagioclase gneiss of the Jiaodong Group will be dated using K-Ar to better constrain the thermal history of this unit. Zircons have also been recovered from two units within the Jiaodong Group. Zircons from the metapelitic gneiss in the upper Pengkuan Formation are euhedral to subhedral in shape, do not show morphological features considered typical of metamorphic zircons, and are interpreted to be detrital grains incorporated into the sedimentary protolith of the rock. Several single grains will be dated to determine the provenance of this unit. Zircon and sphene were recovered from a hornblende-plagioclase gneiss unit that is considered to be a pre-metamorphic mafic intrusion into the upper Pengkuan Formation. Although the sphene is clearly metamorphic in origin, the zircon is igneous. Both zircon and sphene from the sample will be dated, to determine both the intrusive age of the body, and to provide another constraint on the metamorphic and subsequent thermal history of the Jiaodong Group.

Muscovite from a zone of intense alteration adjacent to a Au vein in the Linglong mine will be dated by K-Ar to help constrain the age of mineralization.

Sm-Nd analysis of additional samples of the Jiaodong Group gneisses, and Pb isotopic analysis of feldspars from all of the granitic samples dated in this study, together with various pegmatitic and aplitic veins which intrude the granites, are now in progress. Several samples of pyrite from various veins in the Linglong and Jiaojia mines will also be analysed for their Pb isotopic compositions. These data will be integrated with the large amount of isotopic data already available from this area. Together with the precise and consistent set of ages that have been produced for the main granitic phases, the Pb isotopic data will be used to place constraints on the nature and origin of Au mineralization in the area.

CONCLUSIONS

Preliminary dating and isotopic results obtained for the Liaoxi and Jiaodong uplifts have already shed considerable new light on the nature and timing of magmatism, and on the age and origin of gold mineralizationin these regions. In both areas, gold mineralization occurred at about 125-120 Ma (Early Cretaceous), and was associated with some of the youngest felsic magmatism. Pb isotopic studies suggest that some of the Pb in the deposits was derived from Archean gneisses; it remains uncertain how much, if any, of the gold was derived from the gneisses. It is anticipated that when completed (estimated mid-1991), this study represent a major contribution to understanding both the Archean through Mesozoic crustal evolution of the NCP in the Liaoxi and Jiaodong uplifts, and the nature and age of gold and possibly related tungsten-molybdenum mineralization. The success of the project thus far underscores the importance of close integration between field mapping, petrographic studies, careful sampling, and selection of the appropriate isotopic system to answer specific problems.

Chapter 7

PROGRESS REPORT ON LIGHT StABLE ISOTOPE STUDIES IN THE LIAOXI UPLIFT

Bruce E. Taylor

INTRODUCTION

Since collaborative field studies of gold deposits in the Liaoxi Uplift and Shandong area, during May-June 1989, stable isotopic studies have been initiated on the hydrothermal and gold-mineralizing processes which were at one time active in these areas. The purpose of the isotopic studies differs in each of these areas. The on-going study of the O-H-C-S isotope systematics of wall rock alteration and mineralization in the Erdaogou-Jinchanggouliang area was un-dertaken, among other reasons, to document and, if possible, map the effects of hydrothermal alteration in wall rocks associated with gold-bearing veins in the Erdaogou-Jinchanggouling area. At Shandong, isotopic studies are aimed at providing additional evidence regarding possible alteration of samples selected for mineral age determination. It is well-known that hydrogen and oxygen isotopic data provide an important measure of the "freshness" of minerals, and, hence, the reliability of certain mineral ages. In addition, we wish to address any evidence for the origin of the igneous rocks and test for the presence of meteoric waters in these large deposits.

This report details the results of a relatively small number of whole-rock oxygen and hydrogen isotope analyses of veins and wall rocks from the Erdaogou-Jinchanggouling area.

ERDAOGOU-JINCHANGGOULIANG AREA

Geologic examination of the Erdaogou-Jinchanggouliang area (see Chapter 4) indicated that the hydrothermal system in which the gold veins developed was probably magmatically-heated, and has the characteristics of the audularia-sericite type of epithermal deposits. Such systems typically bear evidence of two hydrothermal fluids, a dilute fluid of clearly meteoric origin, and a more saline (sometimes CO2 - bearing) fluid whose origin is often disputed. In some deposits, the saline fluid is resembles a magmatic fluid, and in other systems, a "formation water" or evolved fluid. Oxygen isotope studies have generally demon-strated that the effects of hydrothermal alteration, especially by dilute meteoric waters, can be mapped, and can illustrate the "paleo-hydrology" in such systems. Because oxygen-isotope shifts in wall rocks may be detected in the absence of obvious, or pronounced hydrothermal alteration, a "paleo-hydrologic map" of the Erdaogou-Jinchanggouliang area could be of use to determine (1) the general relationship of gold-mineralizing processes in each of these two mine areas to each other; (2) the general location of heat source(s); (3) regions of maxium fluid movement; and, perhaps (4) provide targets for further exploration.

In addition, isotopic analysis of sulphur, carbon, oxygen, and hydrogen of vein-forming minerals and fluid inclusions will provide information on the sources these elements and, possibly, on temperatures of vein formation. By analogy with modern magmatic-geothermal systems, gaseous components such as CO2 and sulphur gases (SO_2 and H_2S), and possibly some metals may be of magmatic origin. This will form a hypothesis to be investigated.

PRELIMINARY RESULTS AND COMMENTS

Selected results of whole-rock oxygen isotope analysis are listed in Table 1, and presented graphically in Figure 8 of Chapter 3. There is clearly a large variation in $\delta^{18}O$ evident for otherwise similar rocks. This can best be explained as the consequence of alteration by meteoric waters. Indeed, δD values for three samples (-98.2; -113.2; -121.8) indicate that the meteoric waters had hydrogen isotope compositions sufficiently distinct from magmatic waters to permit recognition of a meteoric hydrothermal system, even at relatively low values of an integrated water/rock ratio.

Several points can be made at this time:

(1) It appears that there is more pronounced and perhaps wide spread $\delta^{18}O$-shift in the rocks in the Jinchanggouling area. This suggests the possibility that altered in this area were structurally higher in the hydrothermal system.

(2) The rocks at Erdaogou display a more restricted $\delta^{18}O$ shift than is evident at Jinchanggouling, perhaps because of a somewhat deeper relative position in the hydrothermal system.

(3) The unaltered nature (either mineralogically or isotopically) of the sulphide-bearing rhyolite dikes sampled in the cross-cut betwen veins #6 and #21 at Erdaogou strongly suggest that some metal introduction may have been magmatic. The present data would permit only very small water/rock ratios if meteoric water were the only water source.

Table 1. Oxygen isotope analyses of whole-rock samples collected from the Erdaogou-Jinchanggouling area.

Sample No.	Brief Description	$\delta^{18}O$
Erdaogou Area		
TAA-89-20	rhyolite, weakly silicified	+ 8.28
TAA-89-21	rhyolite, vein-silicified	+ 8.30
TAA-89-22	rhyolite, pervasively silicified	+ 8.58
TAA-89-23	diorite, "fresh"	+ 6.05
TAA-89-24	diorite, "chloritized"	+ 7.75
TAA-89-25	diorite, "sericitized/carbonatized"	+11.75
TAA-89-26	rhyolite, pervasively silicified	+11.02
TAA-89-27	rhyolite, vein-silicified	+11.45
TAA-89-28	rhyolite, with qtz. vnlts, sericite	+11.56
TAA-89-48	rhyolite, chloritized	+ 5.40
TAA-89-49	rhyolite, chloritized	+ 0.95
TAA-89-50	granodiorite, near fault contact	+ 6.15
TAA-89-52	granodiorite, "fresh"	+ 6.48
TAA-89-64	rhyolite	+ 1.35
TAA-89-65	rhyolite; py.-ser. alt'd breccia	+ 1.82
TAA-89-67	rhyolite porphyry	+ 2.69
TAA-89-70	rhyolite dyke, pyrite-bearing	+ 6.84
Jinchanggouling Area		
TAA-89-13	granitic gneiss	+ 1.74
TAA-89-12	quartz vein x-cutting porph. dyke	+ 4.89
TAA-89-11	hornblende-feldspar porph. dyke	+ 3.23
TAA-89-13	foliated granitic dyke	+ 3.02
TAA-89-133A	biotite trachyte; 0.5 m from fault	+ 4.97
TAA-89-134C	chloritized wall rock; vn. ft.wall	+ 6.06
TAA-89-158	feldspar porphyry	+ 7.13
TAA-89-169	rhyolite	+ 8.83
TAA-89-176	granite, chloritized	+ 3.50

Chapter 8

CONTRASTS IN SETTING AND STYLE OF GOLD DEPOSITS IN TWO ARCHEAN TERRANES: RICE LAKE DISTRICT, CANADA AND WESTERN LIAONING DISTRICT, CHINA

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INTRODUCTION

This chapter emphasizes comparisons and contrasts in the settings and styles of mineralization in the Archean terranes of both countries. In Canada, gold deposits of Archean age, as exemplified by the Rice Lake District in southeastern Manitoba, are hosted by Archean granite-greenstone terrains of low metamorphic grade. In China, gold deposits of Mesozoic age, as exemplified by the Western Liaoning District, are typically hosted by Archean gneisses of medium to high metamorphic grade. These fundamental differences are further reflected in the composition, structure, alteration and nature of ore fluids in the two districts. In 1987 the senior author and D.C. Findlay of the Mineral Resources Division visited the western Liaoning gold district located in the North China Platform, three hundred and sixty kilometers northeast of Beijing. A five week visit to Canada by a team of Chinese scientists in the summer of 1988 included tours of gold deposits in southern British Columbia with Dr. B. E. Taylor and of the Archean greenstone belts of northwestern Ontario with Drs. J.M. Franklin and F. Robert. The Chinese team subsequently spent three weeks mapping the geology of gold deposits with Canadian colleagues in the Rice Lake gold district, southeastern Manitoba. This report contains a preliminary account of points of contrast and comparison between Rice Lake and western Liaoning Districts and their gold deposits.

REGIONAL SETTING

The Rice Lake District is located in the western part of the Uchi Subprovince of Superior Craton (Fig. 1). Rice Lake District shares many of the attributes of Superior Province greenstone belts. Well preserved volcanic lithologies predominate principally in the form of basaltic flows and porphyritic dacitic volcaniclastic rocks. Metasedimentary rocks fall into two categories: turbiditic metagreywackes that are conformable with volcanic rocks in the southeastern part of the district, and cross-bedded arenites which unconformably overlie the volcanic rocks near the town of Bissett, in the western part of the district. Layered synvolcanic sills containing fine to medium grained gabbroic rocks are a common feature in all parts of the volcanic succession and a large tonalitic intrusion, the Ross River Pluton, is also thought to be synvolcanic (Turek et al., 1987). All major rock units within the district are

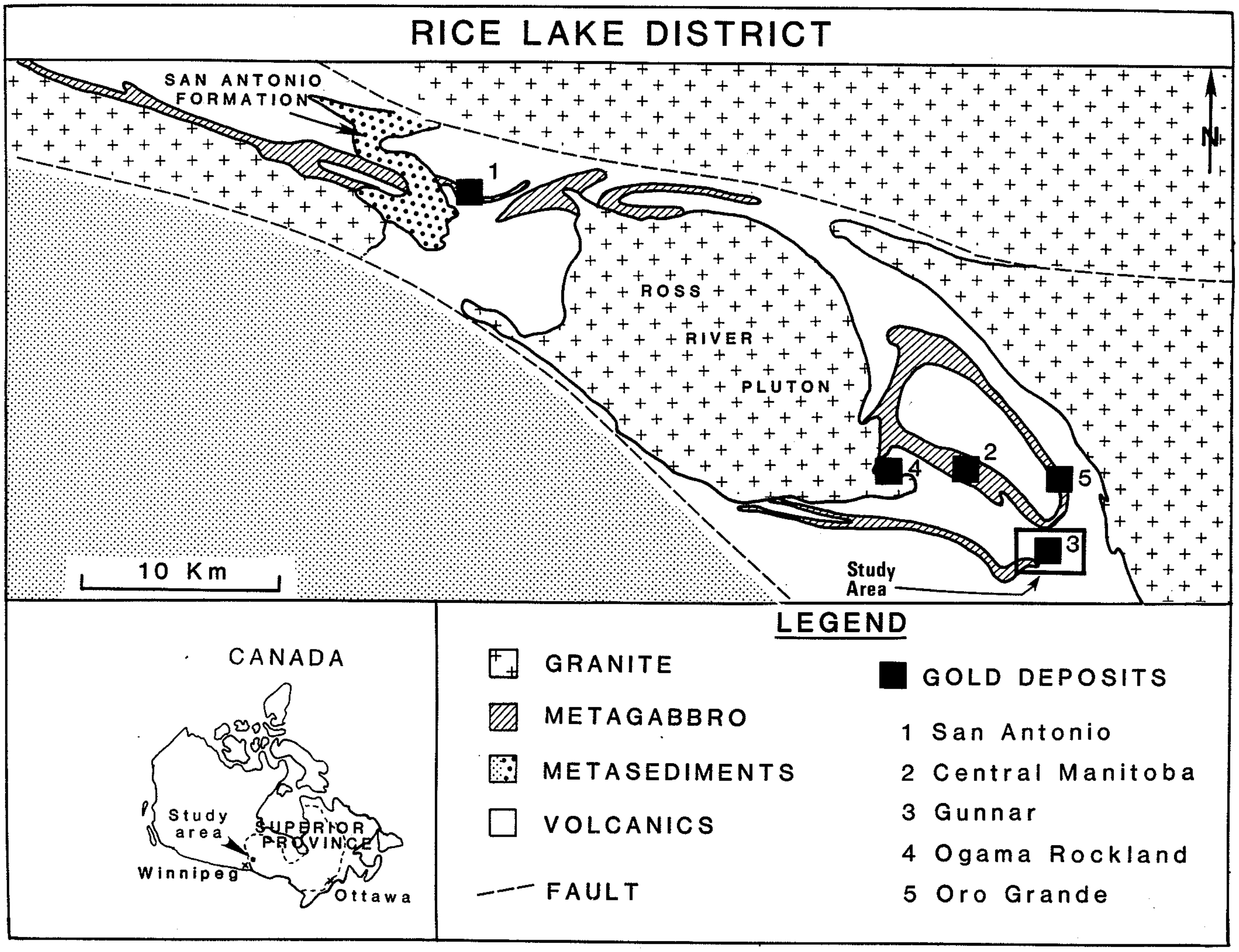

Figure 1: Geology and Gold Deposits of the Rice Lake Greenstone Belt, southeastern Manitoba, Canada.

of Archean age and have been affected by late Archean (2700 Ma) low grade metamorphism, although, medium grade metamorphic rocks are encountered northward and southward in the Wanipigow and Manigotagan gneissic belts respectively. Upright to reclined folds and several generations of low grade cleavage developed in conjunction with metamorphism.

The Western Liaoning District is located in the eastern part of the Yanshan uplift of the North China Platform (Fig. 2). Like many of the uplifts of the North China Platform, it contains a wide variety of medium to high grade gneissic lithologies. Most common are plagioclase-hornblende-biotite gneisses and orthogneisses composed of tonalite, trondjhemite and granodiorite (TTG). Remnants of possible greenstone belt rocks are locally preserved in the form of amphibolites, layered metapyroxenite enclaves and oxide iron formation. All of the mafic and felsic gneisses in Western Liaoning district are of Archean age and have been affected by late Archean medium to high grade metamorphism (Anshan Movement) and locally by early Proterozoic medium grade metamorphism (Zhong tiao Movement).

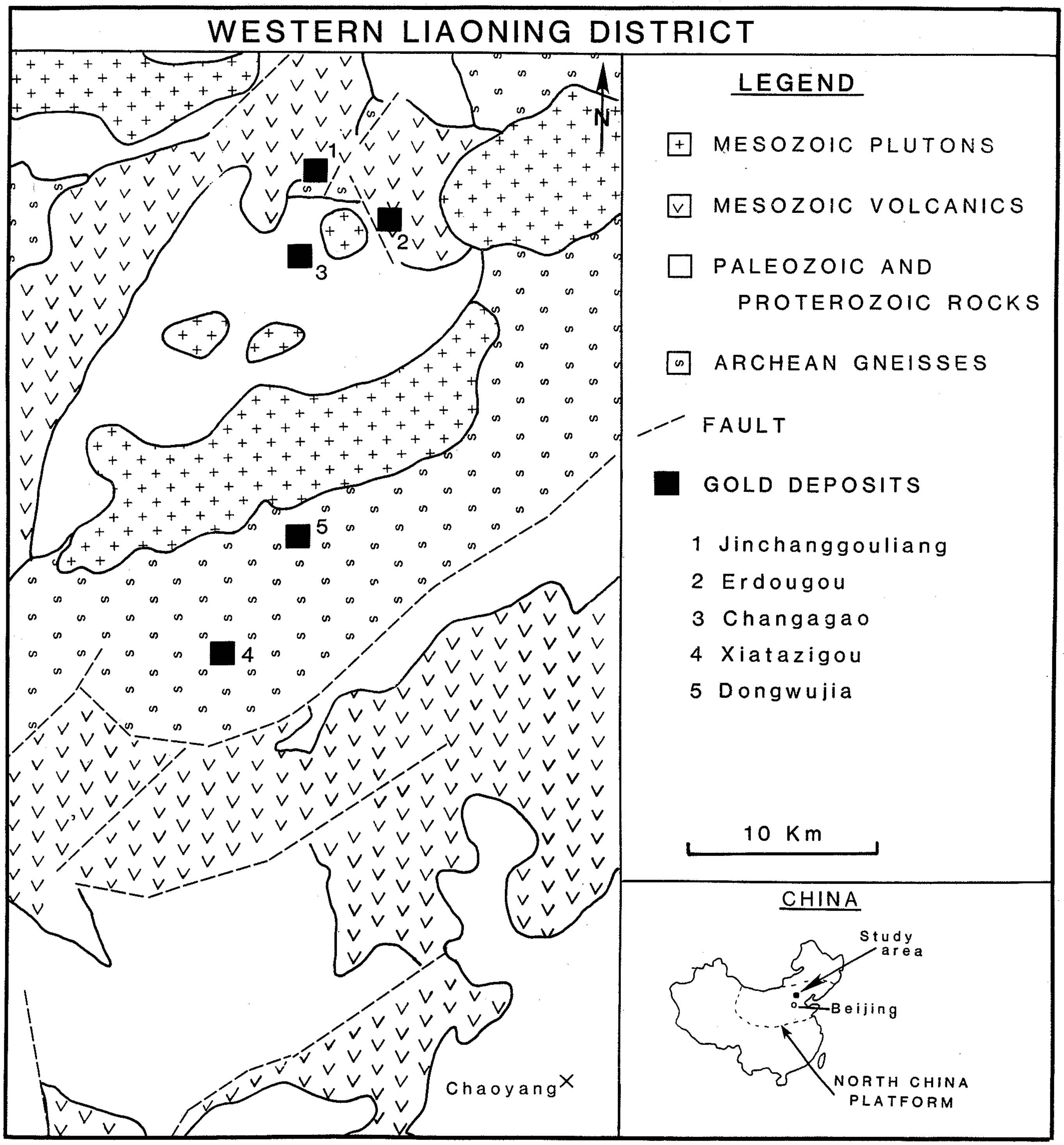

Figure 2: Geology and gold deposits of the Western Liaoning area, northeast China.

Successive generations of complex folds and foliations accompanied the two metamorphic events. Paleozoic and Mesozoic magmatic activity has been imprinted on much of the Archean terrain in Western Liaoning district. Porphyritic granitoid bodies of Permian age intrude the Archean rocks and both are overlain unconformably by a gently to moderately dipping sequence of unmetamorphosed volcanic flows (principally flow banded rhyolite), tuffs and epiclastic rocks of

Jurassic to Cretaceous age. These rocks, as well as their basement, are intruded by late Jurassic to early Cretaceous dioritic to granodioritic stocks and plugs.

Table 1: Comparison of size, setting and composition of veins in Rice Lake and Western Liaoning gold districts.

RICE LAKE DISTRICT

deposit	approximate size (Tonnes Au)	host rocks	vein composition
San Antonio	> 40T	fine grained leucogabbro	quartz-ankerite-pyrite-albite
Central Manitoba	> 5T	quartz gabbro and cherty siltstones	quartz-chalcopyrite-pyrrhotite-pyrite-albite
Gunnar	> 3T	metabasalt and quartz-feldspar porphyry dyke	quartz-ankerite-pyrite-chlorite
Ogama-Rockland	2T	tonalite	quartz-pyrite-chalcopyrite-ankerite
Oro Grande	< 1T	quartz gabbro	quartz-pyrite-pyrrhotite-chlorite

WESTERN LIAONING DISTRICT

deposit	approximate size (Tonnes Au)	host rocks	vein composition
Jinchanggouliang	> 20T	plagioclase-hornblende-biotite gneiss and Mesozoic dykes	pyrite-chalcopyrite-sphalerite-galena-tetrahedrite-quartz-calcite
Erdougou	> 10T	Mesozoic rhyolite and diorite dykes	pyrite-chalcopyrite-galena-tetrahedrite-quartz
Changagao	> 2T	porphyritic Paleozoic granite	pyrite-chalcopyrite-galena-tetrahedrite-quartz
Xiatazigou	2T	plagioclase-hornblende-biotite gneiss	pyrite-arsenopyrite-pyrrhotite-chalcopyrite-quartz
Dongwujia	2T	meta-iron formation and lamprophyre dykes	pyrite-arsenopyrite-chalcopyrite-quartz-ankerite

DISTRIBUTIONS OF GOLD DEPOSITS

The major gold deposits of Rice Lake District are distributed around the margins of the Ross River Pluton within the mafic parts of the volcanic succession (Fig. 1). In particular, three of the deposits considered (Table 1) occur within or near the top of differentiated gabbroic sills, the fractionated portions of which are characterized by modal quartz, granophyric texture and pegmatoid segregations. One deposit, the Gunnar, occurs at the intersection between pillowed basaltic flows and a quartz feldspar porphyry dyke; another, the Ogama-Rockland occurs entirely within the Ross River Pluton.

The major gold deposits of the Western Liaoning District are distributed in two clusters (Fig. 2). In the northern part of the area, Jinchanggouliang, Erdaogou and Xiaochanggao deposits occur around the periphery of the Jurassic/Cretaceous Xiduimiangou granodiorite and are hosted by Archean gneisses, Mesozoic volcanic rocks and Permian granite, respectively (Table 1). Xiatazigou and Dongwujia deposits occur in the southern parts of the area and are hosted principally by plagioclase-hornblende-biotite gneisses and iron formation.

DYKES

Although hypabyssal dykes are a common feature of both districts, they have a different tectonic significance.

In the Rice Lake District, dykes are ubiquitous (Stockwell, 1945) and cut all lithologies except the cross-bedded arenites of the San Antonio Formation. As such, they are common features in the vicinity of gold deposits and tend to be cut by ore-bearing structures. Most varieties are of felsic composition and commonly are quartz- and/or feldspar-phyric. Lamprophyre dykes locally cut and are cut by quartz veins at the Gunnar deposit.

In Western Liaoning District, dykes are principally of Mesozoic age and cut Archean gneisses, Paleozoic granites and Mesozoic volcanic rocks. Diorite, granodiorite and lamprophyre compositions are common and among the felsic varieties, some are quartz- and feldspar-phyric. Ore structures commonly cut or follow Mesozoic dykes.

ORE STRUCTURES

Structural controls on the specific location of ore veins are important in both districts, but the structures are of different styles.

In Rice Lake District, gold-quartz veins are typically hosted by shear zones comprising phyllonitic schists which cut all lithologies, including dyke rocks. Brittle fracturing and veining within and adjacent to competent rocks is commonly observed, and combined with the ductile nature of the host shear zones, suggests formation at moderate crustal depths. Shear zones are arranged into northwest and northeast striking sets and typically have dextral reverse and sinistral reverse movements, suggesting development in a compressive tectonic environment.

In Western Liaoning District, the structures which control the location of ore veins are faults and fractures that cut all rock types including some Mesozoic dykes. Ore-bearing faults commonly contain fault gouge and breccia, suggesting a shallow level of development. Normal faults are the rule and indicate development in an extensional tectonic environment.

VEIN COMPOSITION

In both districts, veins are the principal source of ore, although considerable differences exist in their composition.

In the Rice Lake District, veins contain gold in excess of silver in a ratio of approximately 7:1. Vein mineralogy of deposits is dominated by quartz with lesser and variable amounts of ankerite and albite. Principal sulphide minerals, in decreasing order of abundance, are pyrite, pyrrhotite, chalcopyrite and sphalerite, with rare galena and tellurides. Tourmaline, chlorite and sericite are common accessory minerals. Native gold commonly occurs within pyrite or chalcopyrite and a second generation occupies fractures in quartz or chloritic slickensides (Stephenson, 1971).

In Western Liaoning District, veins contain silver in excess of gold in a ratio of approximately 4:1 and are rich in sulphides by comparison with quartz. The vein mineralogy at different deposits shows a temporal progression through four assemblages:

1) pyrite - quartz - biotite - K-feldspar
2) pyrite - Sb sulphides - quartz - electrum - sericite and minor K-feldspar - minor gold
3) galena - sphalerite - tetrahedrite - chalcopyrite - electrum
4) marcasite - chalcopyrite - bornite - chalcocite - quartz - calcite - sericite - clay minerals and rare native silver.

ALTERATION AND ORE FLUIDS

Effects of hydrothermal alteration adjacent to veins are well recorded in both districts, but these are of substantially different types.

In the Rice Lake District, hydrothermal alteration is dominated by deposition of carbonate minerals. Near quartz veins, hydrous metamorphic assemblages are progressively replaced by calcite and chlorite, ankerite and sericite, and locally albite and pyrite. Such alteration typically extends one to ten meters from ore veins and is dominantly controlled by faults and fractures. The importance of CO_2 as a constituent of ore- forming fluids is further reflected by fluid inclusion compositions in vein quartz. Inclusion fluids were trapped in the temperature range of 250^{o}-$350^{o}C$, are of low salinity (5 Wt% NaCl equivalent) and contain approximately ten mole percent of CO_2 (Diamond, unpublished data).

In Western Liaoning District, wall rock minerals are progressively replaced by high temperature biotite - K-feldspar and pyrite, by medium temperature sericite - chlorite - pyrite and minor K-feldspar and by low temperature calcite - sericite - adularia and clay minerals. The superimposed alteration envelopes extend laterally up to twenty-five to thirty meters on either side of individual veins and fractures. Fluid inclusion analyses (Zhang, unpublished data) support the observed variations in veins and alteration mineralogy. As at Rice Lake, salinities are low (5 Wt% NaCl equivalent) but inclusion trapping temperatures range from 450°C down to less than 200°C and inclusion fluids contain low mole fractions of CO_2, typically one percent.

DISCUSSION

It is evident from the foregoing descriptions that, although there are some points of comparison, there are many points of contrast in setting and style of gold deposits in these two Archean terrains.

The contrasting points can be attributed to two main factors: the inherent differences in metamorphic grade of the Archean rocks between the two areas and the superposition of Mesozoic magmatic activity on the Archean rocks in Western Liaoning District. There is little doubt from the weight of the evidence presented that the formation of the gold deposits in Western Liaoning District is largely related to upper crustal Mesozoic magmatic activity, but there remains the important question as to the role of the Archean basement terrain. In Western Liaoning District, as in other parts of the North China Platform, there is as strong a spatial correlation of gold deposits with Archean gneisses as there is with centers of Mesozoic magmatism. One explanation put forward by Chinese geologists for this dual correlation, is that in the North China Platform, as in other parts of the world, preferential concentration of gold took place in Archean greenstone belts and their metamorphosed remnants, and that they provide a source for reconcentration of gold by Mesozoic magmas and their fluids. In many respects, such a "source bed" or "lateral secretion" concept is not unlike many current models proposed for gold deposits of strictly Archean age requiring preconcentration of gold in exhalative or felsic magmatic deposits for subsequent remobilization into quartz veins by metamorphic fluids. The essential unresolved question in all of these cases is which of the ore forming constituents are derived from host rocks and which are inherent to the primary fluid.

REFERENCES

Stockwell, C.H.
1945: Maps 809A (Beresford Lake), 810A (Rice Lake) and 811A (Gem Lake); Geological Survey of Canada.

Stephenson, J.
1971: Gold Deposits of the Rice Lake - Beresford Lake Greenstone Belt, Southeastern Manitoba, Manitoba Mines Branch Publication 71-1, p. 337-385.

Turek, A., Keller, R., Weber, W., and VanSchmus, W. R.,
1987: U-Pb Zircon Geochronology of the Rice Lake Greenstone Belt, p. 119-121 in Report of Field Activities 1987, Manitoba Energy and Mines, Minerals Division.