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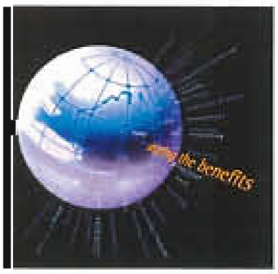
REPORT NO. 2

Geological, Tectonic and Metallogenic Relations of South China

P603

CODES SRC
Centre for Ore Deposit Research

University of Tasmania
Australia



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Geological, tectonic and metallogenic relations of SE China

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AMIRA project P603

Report 2

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Appendices

Executive Summary

This report presents progress for GIS compilation of geology and mineral deposits in South China up to November, 2000. At the time of writing of this report, compilation of the geology database for Yunnan, Sichuan and parts of Guizhou and Guangxi provinces have been completed. A CD-ROM for the GIS compilation of the geology of Yunnan was delivered to sponsors at the last project review meeting, and a new CD-ROM including Sichuan and parts of Guizhou and Guangxi provinces is presented to the sponsors with this report. Mineral deposit database for Yunnan and Sichuan are being compiled in this quarter.

More than 700 mineral occurrences have been recorded for Yunnan. At Least five different styles of lead-zinc-silver mineralisation occurs in Yunnan: (1) sedimentary exhalative (Sedex) deposits (e.g., famous Tertiary Jingding/Laping deposit), (2) with copper in volcanic-hosted massive sulphide (VHMS) deposits (e.g., Carboniferous Laochang deposit, and recently discovered Carboniferous Dapingzhang deposit), (3) with copper and tin in lead-zinc skarn deposits (e.g., Triassic Hongshan deposit), (4) with precious metals in veins and porphyry deposits (e.g., Beiya deposit), and (5) with tin and copper in Sn-W vein and skarn deposits (e.g., Mengzimao). Yunnan also has potential for Carlin type and Mesothermal gold, porphyry and sedimentary copper and mafic-ultramafic-hosted Ni-Cu deposits.

During this quarter, a considerable amount of time has been spent establishing the Geological legends to incorporate the lithological and stratigraphic characteristics. Descriptions of geological units of Yunnan have been refined, and integrated into the GIS digital database. Consistent colour schemes for the maps have been established to correlate lithological and geological units across the provincial borders and to correlate with the stratigraphic units in mainland SE Asia. Compilation of geology coverage for the remaining parts of Guizhou and Guangxi is progressing well, and a mineral deposit database for these provinces will follow shortly.

1. Introduction and background

This report presents progress on the P603 project "Geological, Tectonic and Metallogenic Relations of Mineral deposits in South China" up to November, 2000. The P603 project has two programs: (1) GIS compilation of geological and mineral deposit data and (2) stratigraphic, tectonic and metallogenic studies. This program builds on the AMIRA P390A project which was completed in 1999. Under the AMIRA P390A project, a digital database of mainland SE Asian mineral deposits and geology has been successfully established. The mineral deposit database includes over 3730 mineral deposit locations across the SE Asian region compiled from various literature sources. The GIS database allows independent SE Asian geoscience and mineral deposit data to be displayed at a variety of different scales and as integrated overlays for metallogenic interpretation and evaluation. The P603 project is to establish a similar and compatible GIS, digital geoscience data set and mineral deposit database for South China. At the last two sponsors' meetings in December 13, 1999 and June 16, 2000, the three aims of the P603 project have been presented to the sponsors and herein reinstated.

(1) To establish a GIS (ARC/INFO, ArcView and MapInfo) integrated, comprehensive digital geoscience data set and mineral deposit database for south China focussing on the distribution of ore deposits building on the successful AMIRA project P390A for mainland SE Asia.

(2) To undertake a tectonic and metallogenic analysis of the selected mineralised belts in the region, with particular emphasis on geological features, structural relationships, and regional metal zonation based on the GIS database, field observations and geochronological data.

(3) To develop a geotectonic and metallogenic model for the evolution and origin of mineralised belts in these regions.

The South China is a very resource-rich region just north of Myanmar, Lao PDR and Vietnam, and includes the largest metallogenic provinces in China with world-class base and precious metal deposits. The Sanjiang region along the western part of South China covering Yunnan and Sichuan is notable for its mineralised accreted island arcs, back-arcs and rift basins, and contains a diversity of mineral resources. Mineralisation styles in these provinces and adjacent parts of Myanmar, Laos and Vietnam show similarities. For instance, the VHMS Pb-Zn-Ag-Cu type Laochang deposit in Yunnan and the Gacun deposit from Sichuan (e.g. Sun Haitian, 1992; Yang and Mo, 1993; Hou and Mo, 1993; Yang et al., 1993) are comparable with the Bawdwin deposit in NE Myanmar (Khin Zaw, 1990, 1992; Khin Zaw and Burrett, 1997) and the Tesek Chini deposit in Malaysia (Khin Zaw et al., 1999a).

Other copper-gold bearing skarn and porphyries and mesothermal gold deposits are also known to exist (e.g., Beiya, Yangla, Jinchang deposits). Cu-Fe type VHMS deposits and sandstone-hosted SEDEX type deposits (e.g., Jinding in Yunnan) are also found in the Sanjiang Region. Carlin-type gold deposits are also widely distributed at the northern Golden Triangle (Sichuan, Gansu and Shaanxi) and the southern Golden Triangle (Guizhou, Guangxi and Yunnan).

Significant Devonian to Carboniferous base- and precious-metal mineralisation also occurs in the eastern part of the South China Terrane covering Guangdong, Fujian, Jianxi, Anhui and Jiangsu provinces along the margin of Yangtze craton (e.g., Gu Lianxing et al., 1993; Yu-sheng Zhai et al., 1996). Different metal associations are also recorded (e.g., Pb-Zn type Fankou deposit in Gaungdong province, and Cu-Fe type Wushan and recently discovered Yongping deposits in Jiangxi province) (e.g., Gu Lianxing et al., 1993; Nie Pi, pers. comm., 2000).

2. GIS compilation

The P603 project area is shown in Figure 1. This is a contiguous with the P390A project area for the GIS compilation of the SE Asian geology and mineral deposits. SE Asia and mainland China is composed of major crustal terranes (Fig. 2). The P390A project covers the two geological terranes: the Shan-Thai terrane (Myanmar, Laos, western Thailand and SW Yunnan south of the Red River suture zone) and the Indochina terrane (Laos, Cambodia, eastern Thailand and Vietnam), and this P603 project will focus on the South China terrane. The provinces to be covered by GIS in the South China Terrane are shown in Figure 3. Although mineral resource data are available for South China, no comprehensive geoscience and mineral deposit data sets in digital format and in English have been established.

Data capture and establishment of digital databases for South China are undertaken using ARC/INFO. The detailed methodology for GIS compilation was comprehensively described in the previous AMIRA reports (Khin Zaw and Rice, 1996a, 1996b, 1997; Khin Zaw et al., 1997, 1998, 1999a, 199b). Additional information on the data capture is presented by Dr. Eleanor Bruce later in this report. Geological maps of the provinces at 1:500,000 or 1:1,000,000 scales have been digitised. These scales are useful for depicting regional deposit groupings and large-scale structures while the geological setting of individual deposits can be displayed.

In this quarter, we spent a considerable amount of time revising, refining and updating the geological data in the GIS database for Yunnan. Other work completed is as follows:

Colour Scheme: The following colour scheme has been adopted:

Epoch	*Colour*
Quaternary	Yellow
Tertiary	Orange
Mesozoic	Green
Paleozoic	Blue
Precambrian	Purple
Intrusive and volcanic rocks	Red
Mafic and ultramafics	Black

The different shading and patterns may be used to describe different stratigraphic and lithological units for a particular geological period (e.g. Cenozoic, Mesozoic, Paleozoic etc) but retains the original colour of the geological period (e.g. green for Mesozoic). A similar colour scheme has been also used for the SE Asian P390A database.

GEOL_LEG: We have also established the Arcview Legend (avl. file) for Geological Legend (GEOL_LEG) incorporating the lithological and stratigraphic characteristics. We documented and defined the polygon ID numbers and description for each geological and stratigraphic-lithologic unit for Yunnan Province. These polygon ID numbers and description are important as these data can be extensively applied for future regional geological correlation across individual provincial boundaries. Progress on the GIS compilation of geology and mineral deposit database will be reported for each province as below.

2.1. Yunnan

At the last meeting, we provided a CD-ROM incorporating the first version of the digital compilation of the geology of Yunnan province to the sponsors. We also reported a preliminary account of metallogenic relations of South China and a brief account of mineral deposits in Yunnan province. Yunnan province has a total land area of 394,000 km^2 and a population of 40.94 million. It is bounded on the east by Guangxi and Guizhou, on the north by Sichuan, and on the northwest by Tibet. It has a total boundary of 4000 km with Myanmar on the southwest, Laos PDR and Vietnam to the south. Yunnan province has potential for recoverable mineral resources of lead, zinc, silver, copper, gold, nickel, cobalt, tin, the platinum group, thallium, indium and cadmium.

Dr. Khin Zaw visited Bureau of Geology and Mineral Resources (BGMR), Yunnan province and met with Dr. Ding Jun who is in charge of the GIS section of BGMR. He discussed with Dr. Ding about a collaborative project for GIS compilation of mineral resources in Yunnan province. Dr. Ding mentioned the current status of the Bureau GIS compilation of geological, geophysical (gravity and aeromagnetics), geochemical (stream sediments) and remote sensing (e.g., TM and SPOT) data on scales of 1:50,000 to 1:1,000,000 for the Yunnan province. The Bureau has PC Arc/Info, MAPGIS, Arcview, MapInfo and TNTmips.

BGMR is also involved in the project "Integrated Assessment and Development of Mineral Resources within the Greater Mekong Subregion" organised by UN-ESCAP, Bangkok covering Myanmar, Cambodia, Yunnan, Lao PDR, Thailand and Vietnam, and they have presented a report to the UN-ESCAP about the mineral resource potential of Yunnan. BGMR also applied GIS techniques to the resource assessment and mineral evaluation in parts of Yunnan province. The GIS section at BRGM has 22 staff but has a lack of expertise in deposit database development and there is also no mineral deposit database in English.

Although the Yunnan BRGM has the established a GIS section to produce digital geological maps, there are also no well-qualified economic geologists or ore geologists to establish the mineral deposit database or inventory. The Bureau is interested in training their geologists in database development and Economic Geology to establish a mineral deposit inventory of Yunnan in conformity with modern ore genesis theory and nomenclature. Geologists from Yunnan BGMR have contributed to the Yunnan MINDEP database development for this project. Mr. He Jiaxue from BRGM, Yunnan also plans to visit CODES SRC early next year.

2.1.1. GIS coverage of geology for Yunnan

Geological studies in Yunnan province date back to the mid-19th Century, and the best English source of geological data for Yunnan is in geological memoir Series 1, No. 21 on the Regional Geology of the Yunnan province. Geological investigation was started after 1911 and well-developed during the war of resistance against Japan (1937-1945). The Bureau of Geology and Mineral Resources for the Yunnan province was established in 1958 and systematic geological mapping was undertaken since then, and they have completed a geological map of 1:1,000, 000 scale in 1965 and also reported on the geology of ore deposits in Yunnan. The Bureau also produced geological maps of 1:200, 000 scale covering Yunnan in 1985 and mapping on 1:50, 000 scale was started in 1980 and 137 map sheets have been completed in 1999 and mapping to fill the gap is in progress.

For this P603 project, the 1:1,000, 000 scale geological map of Yunnan has been digitised. A detailed digitised geological map of the Yunnan province is shown in Fig. 4 together with polygon ID for each stratigraphic and lithologic unit. These data can be also integrated with the P390A geology database of SE Asia region. Fault lines from the 1:1,000, 000 scale geological map of Yunnan have been also digitised and shown in Fig. 5 and the fault data are shown together with previous SE Asia fault database in Fig. 6.

2.1.2. MINDEP database for Yunnan

More than 700 mineral occurrences have been recorded for Yunnan including 560 lead-zinc-copper ± silver, 75 iron, 15 tin-tungsten, 16 gold, and 17 nickel-copper-platinum-paladium occurrences (Fig. 7). Many base metal deposits are widely distributed in Yunnan and there is a potential for world class base metal discoveries in Yunnan.

Lead-zinc-silver deposits: The relationships of geology and lead-zinc-silver deposits are shown in Fig. 8. At least five different styles of lead-zinc-silver mineralisation occur in Yunnan:

(1) With copper in sedimentary exhalative (Sedex) deposits (e.g., famous Tertiary Jingding/Laping deposit),

(2) With copper in volcanic-hosted massive sulphide (VHMS) deposits (e.g., Carboniferous Laochang deposit, and the recently discovered Carboniferous Dapingzhang deposit),

(3) With copper and tin in lead-zinc skarn deposits (e.g., Triassic Hongshan deposit),

(4) With precious metals in veins and porphyry deposits (e.g., Beiya deposit), and

(5) With tin and copper in Sn-W vein and skarn deposits (e.g., Mengzimao).

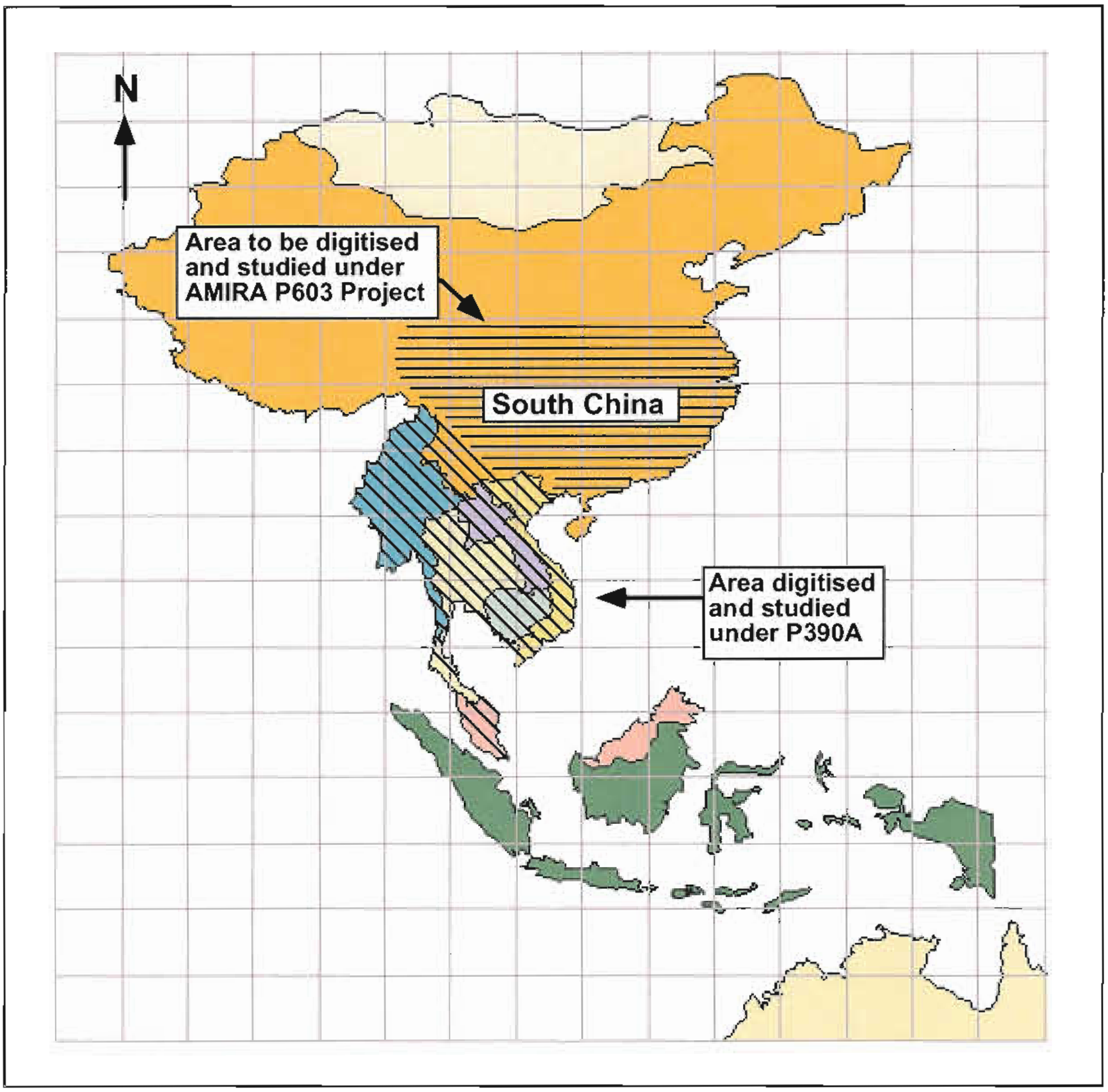

Fig. 1. Map showing the area to be digitised and studied under the AMIRA P603 project.

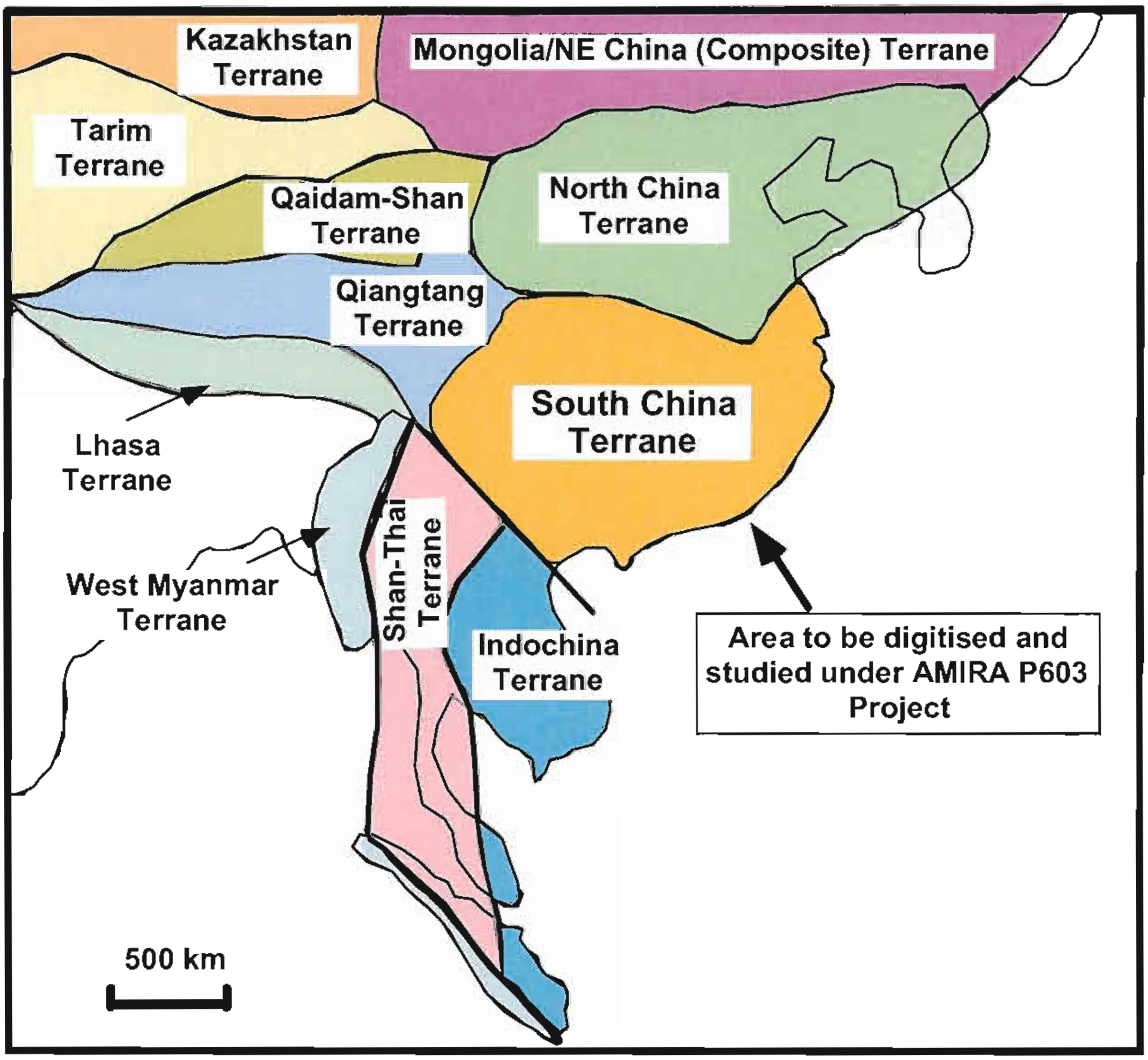

Fig.2. Map showing major crustal terranes in SE Asia and China and the area to be digitised and studied under the P603 project. West Myanmar, Shan-Thai and Indochina teranes have been digitised and studied under the P390A project.

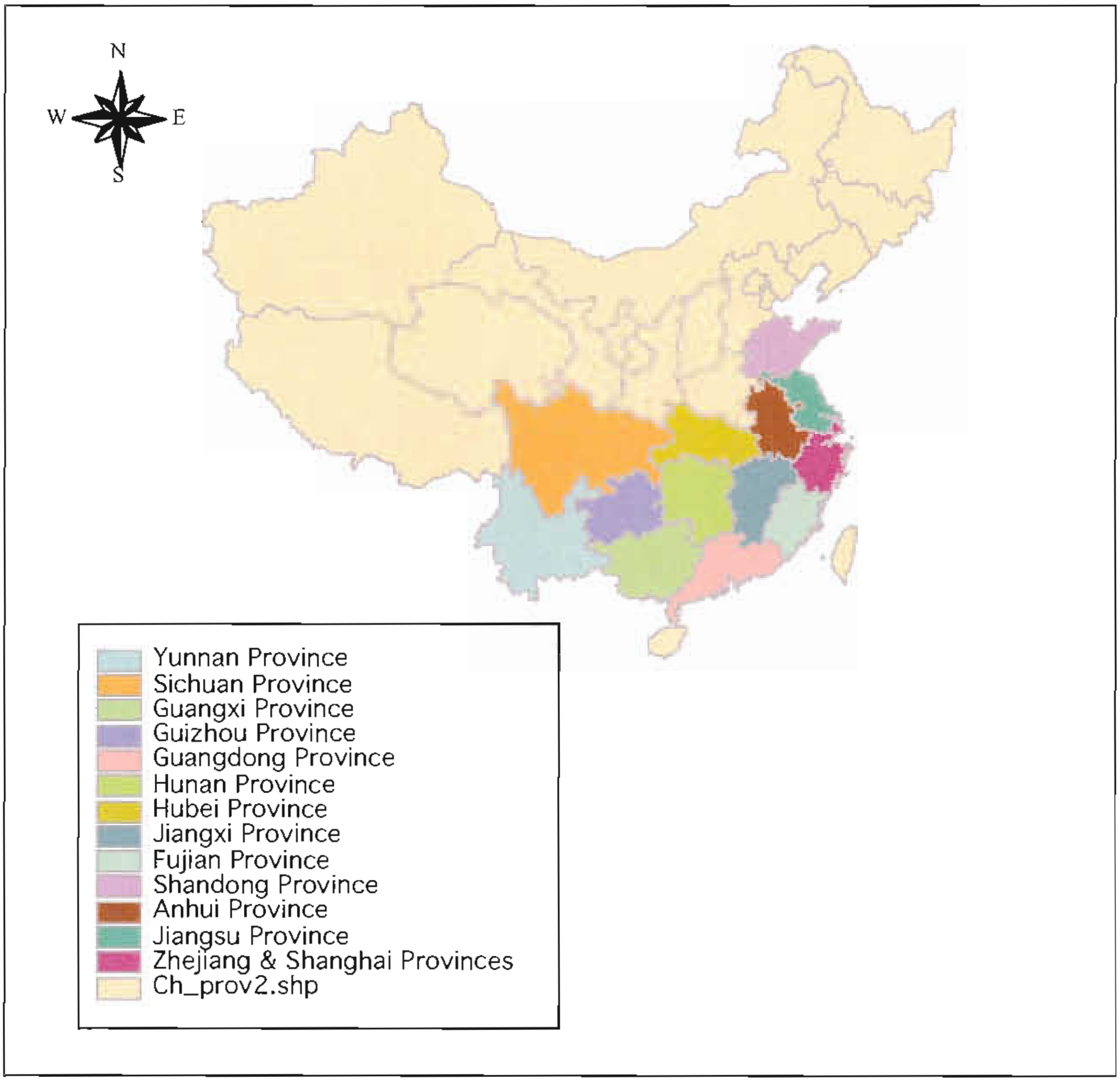

Fig. 3. Map showing provinces in South China to be covered by this AMIRA P603 project.

Sedex deposits: The Jinding deposit is the largest Sedex type deposit in China (Fig. 9) and contains at least 100 Mt grading 1.73% Pb and 7.51% Zn. The deposit is hosted in Eocene Yunlong Formation consisting of sandstone, siltstone and limestone (Fig. 10). These rocks form the upper section of Lanping-Simao basin developed during Permian to Tertiary. The deposit occurs in the northern part of the Lanping-Simao basin (e.g., Qingtong et al., 1992; Shangqing and Sanchuan, 1993; Junlie et al., 1994; Ning Li and Kyle, 1997). The ores were deposited in a smaller sub-basin (probably a rift basin) rich in gypsum. The mineralisation is stratabound with enrichment of celestite ($SrCO_3$) at the base and followed by barite, then sphalerite and galena. The deposit area is characterised by thrusting of Upper Triassic limestone and Jurassic sandstone.

VHMS deposits: Major VHMS deposits in Yunnan occur in the Upper Palaeozoic Island-arc related Changning-Menglian felsic volcanic belt which is 20-60 km wide and 250 km long and extends south into Myanmar. The volcanics are mafic tholeiitic, felsic and alkaline and host both Pb-Zn-Cu-Ag and Cu-Zn types. The Laochang is a Pb-Zn-Cu-Ag type VHMS deposit and the mining activity at Laochang dates back to the 14th Century. The geological ore reserves of the deposit is at least 15 Mt grading 3.8% Pb, 3.5% Zn, 1.9% Cu and 113 g/t Ag (Yang and Mo, 1993; per. comm., Kaihui Yang, 2000). The deposit is hosted in Upper Carboniferous volcaniclastic rocks of basaltic-andesitic composition with alkaline affinities (Yang and Mo, 1993; Yang et al., 1993) (Fig. 11) and the volcanic units are in fault contact with limestone (Fig. 12). Major faults striking N-NW occur in the vicinity of the deposit. The ore is generally massive, fine-grained and banded but the sedimentary features such as graded-bedding, ripple marks and sulphide clasts are also reported. The ore minerals are sphalerite, galena, chalcopyrite, pyrite, pyrrhotite, arsenopyrite, minor sulphosalts, bornite, magnetite, hematite and cassiterite. Carbonate minerals are relatively abundant and realger and orpiment also occur at the top of the ore lenses.

The Dapinzhang deposit is a recently discovered Cu-Zn type Upper Carboniferous VHMS deposit in Yunnan (Fig. 9) and similar to the Laochang deposit. The deposit was discovered in 1996 by Chinese geological team after following up a regional 1:200,000 scale Cu anomaly and the geologists found that local people had already started digging for copper within the Cu anomaly area. The deposit occurs within two small isolated Carboniferous felsic volcanic inliers near the southwest margin of the Simao basin. The mineralisation occurs along a strike length of 3000m and the width of sulphide zone is 10-70m thick and the extent of the sulphide mineralisation has not been closed off towards the SE. The mineralisation consists of banded sulphides of chalcopyrite, sphalerite, galena and pyrite grading 6.2% Cu, 3% Zn, 0.7% Pb, 3.5 g/t Au and 110.6 g/t Ag and the stringer chloritic sulphide zone grading 1.5% Cu and 1.92% Au (per. comm., Paul Chromie, 2000). The other VHMS deposits are Cu-Zn type Tongchangie and cupriferous Sandashan deposits which are also hosted in Upper Carboniferous to Permian volcanics.

The presence of thick carbonate sequences of Late Proterozoic (Sinian) to Palaeozoic age and the tectonic setting suggest that there is a potential for MVT type base metal deposits in Yunnan. MVT deposits are reported to the north in the Sichuan province (e.g. Daliangzi deposit). The Daliangzi deposit is hosted in a Sinian carbonate sequence and contains 40 Mt grading 10.4% Zn, 0.8% Pb and 43 g/t Ag (e.g., Zheng and Wang, 1991). These deposits are similar in styles with the MVT deposits of the Lennard Shelf, western Australia. BHP also discovered a new MVT deposit in the Sinian carbonate units in Sichuan but sold to a third party. The Sinian is regarded as a local chronostratigraphic (time-rock) term for the pile of sediments deposited on the unconformity caused by the collision of Yangtze and Cathaysian terranes in South China at about 850 Ma. The Sinian sequence ranges in age from about 850 Ma to about 545 Ma (base of Cambrian) and is fairly widely distributed in Yunnan. The Middle Proterozoic to Sinian carbonate sequence in the Janning-Anning county area of Yunnan hosts discordant Zn-Pb mineralisation in cavity-fill, veins and breccia (e.g., Liaocaoba) but the nature of mineralisation is not well understood to be discordant Sedex type mineralisation or MVT type mineralisation.

Copper deposits: Yunnan province has important copper mineralisation styles (Fig. 13). As described above, copper occurs in association with Zn-Pb-Ag-Au type VHMS, Cu-Zn type VHMS (e.g., Permo-Carboniferous Tongchangjie deposit), and Sedex deposits. Yunnan is also known to host Cu-Fe type Proterozoic deposits (e.g., Dahonshan and Dongchuan type deposits) but many of these deposits are still poorly documented.

In addition, copper-dominant Sedex deposits (sediment-hosted stratiform copper deposits) may be present in Yunnan. Brown (1997) indicates that this type of copper deposits is an important, economically attractive, world-class mineral deposit type, traditionally represented by supergiants such as the Kupfershiefer of north-central Europe and the copper belt of Central Africa. They tend to be high-tonnage deposits because of their wide lateral extent along preferred stratigraphic units. As well, their copper grades frequently surpass those of 'competitive' deposit types such as porphyry copper ores and they may contain significant amounts of other highly desirable metals such as cobalt and silver. The presence of copper-cobalt and copper-silver occurrences is also noted in Yunnan (e.g., Niren deposit). The Niren (Tuoding) deposit of copper-silver±cobalt association occurs in the Devonian "Red bed" strata along a strike length of 2 km with a thickness of 2 to 4 meter. The ore minerals are chalcopyrite, bornite, chalcocite, galena and tetrahedrite. The mineralogy and the lateral continuity of the deposit show similarity to a typical of a sediment-hosted copper deposit.

Copper is also associated with epigenetic vein-type and epithermal/porhyry deposits in Yunnan (e.g., Beiya deposit) or porphyry deposit (Xuejiping deposit). Copper bearing vein and skarn (?) deposits are also present. Copper is also associated with intrusive-related nickel-platinum deposits in ultramafic-mafic rocks (see below).

Gold deposits: Yunnan has small-scale gold and silver mining, and the province remains largely unexplored for precious metals. Although Yunnan is not a significant gold producer, its geological and tectonic setting suggest that the province will become a gold producing region in China. The relationships of gold deposits, faults and granitoid intrusions in Yunnan are shown in Fig. 14. Four distinct primary gold mineralisations can be recognised: (1) Carlin-type gold deposits in SE Yunnan adjacent to Guizhou and Guangxi provinces (e.g., Kuzhubao, Bashishan, Dihei and Miluo) (2) epithermal ? vein, and breccia gold deposits (e.g., Beiya deposit), (3) porphyry copper±gold deposits (e.g., Yangla deposit) and (4) medium to high-grade metamorphic rock-hosted, structurally controlled gold deposits along Ailaoshan belt (e.g., Jinchang and Daping deposits). Presently available geological information suggest possible three other gold mineralisation styles: (1) skarn (?) copper±gold deposits, (2) Cyprus type copper±gold deposits and (3) gold-platinum-pladium in mafic-ultramafic intrusives.

Nickel deposits: Yunnan has potential for Proterozoic ultramafic-hosted Voisey's Bay type Ni-Cu-Co±PGE mineralisation styles. The Voisey's Bay contains 136 Mt grading 1.59% Ni and significant Cu-Co credit (Naldrett, 1997; Naldrett and Li, 2000). It is interesting to note that the Ni-Cu-Co-PGE deposit also occurs at Jinchuan in the Gansu province and mineralisation is hosted in Proterozoic mafic-ultramafic bodies (e.g., Guo and Dentith, 1997; Naldrett , 1997; Barnes and Tang, 1999). The Jichuan deposit hosts more than 500 Mt of ore grading 1.2% Ni and 0.7% Cu. Similar Proterozoic mafic-ultramafic bodies are also distributed in Yunnan and Sichuan. Pt-Pd-Ni-Cu-Co occurrences are also recorded in Yunnan in association with these mafic and ultramafic rocks (Fig. 15). There are also potential for the Noril'sk type Pt-Pd-Cu-Ni deposit which are associated with the Permian to Triassic basaltic volcanic rocks and has 900 Mt grading 2.7 Ni (e.g., Naldrett, 1997) and BHP had explored for these styles in Yunnan and Sichuan (per. comm., Paul Chromie, 2000).

The Jinbaoshan Pt-Pd-Ni-Cu deposit which is located approximately 134 km south of Dali in Mindu county, Yunnan province may be an example. The mineralisation includes platinum group metals, chalcopyrite and pentlandite forming as magmatic segregations into conformable layers within ultramafic sills composed principally of late Carboniferous-Permian ? peridotite intruding Devonian siltstone and dolomite. The deposit was discovered in 1971 by the Third Geological Brigade and further exploration work included geological mapping, magnetic surveys, trenching, aditing and diamond drilling. Chinese geologists estimated geological resource of 31 Mt grading 1.49 g/t combined Pt+Pd with 0.15% Cu, and 0.17% Ni using 0.5 g/t Pt+Pd cutoff value. The other new sedimentary exhalative Ni-Mo mineralisation style in Cambrian black shale is also reported at Deze, in related to a deep fracture zone extending from Yunnan, through Guizhou, Hunnan, to Zhejiang provinces (Fig. 16).

3. Sichuan, Guizhou and Guangxi

Sichuan province lies between 97° 21″-110° 12′E and 26° 03′-34° 19′N and it is bordered by Yunnan at the south, Tibet at the west, Qinghai, and Gansu at the northwest, Shaanxi and Hubei at the northeast and Guizhou and Hunnan at the southwest. Several major orogenic belts in SE Asia and Yunnan pass through the Sichuan province and extend into Tibet, Qinghai and Gansu. For Sichuan, we digitised the 1:1, 000, 000 scale geological map in geological memoir Series 1, No. 23 on the Regional Geology of the Sihuan province. For Guizhou, 1:500, 000 scale geological map in geological memoir Series 1, No. 7 on the Regional Geology of the Guizhou province and for the Guangxi province, 1:1, 000, 000 scale geological map in geological memoir Series 1, No. 3 on the Regional Geology of the Guangxi province are digitised. All the completed digital data are presented to the sponsors with this report.

A preliminary mineral deposit compilation on the Sichuan province has been undertaken. Dr. Khin Zaw visited Chengdu and met with Prof. Luo Yaonan and group from Sichuan Bureau of Geology and Mineral Resources (SBGRM) and also with Prof. Liu Rong and group from SW Institute of Metallurgical Mineral Resources Exploration. Both groups are willing to assist for the development of mineral deposit database for the Sichuan province. Mr. Luo Yaonan of SBGRM provided a metallogenic map of the Sichuan province which includes 458 mineral occurrences. Dr. Wang Xiaocun from the SW Institute of Metallurgical Mineral Resources Exploration also plans to visit CODES SRC in year 2001. Detailed deposit database for Sichuan, Guizhou and Guangxi are deferred until GIS geological compilation have been completed for these provinces, and metallogenic relation will be presented to the sponsors at the next meeting.

4. Future program

The program for the next six months is herein presented. In this quarter, geology coverages for Yunnan, Sichuan and parts of Guangxi and Guizhou have been completed, and we provided the preliminary CD-ROM for these data. Compilation of extensive and voluminous information on geology for Yunnan and Sichuan consumes considerable time to include detailed stratigraphic and lithologic units.

Further work for GIS compilation includes completion of the geology database for parts of Guizhou and Guangxi provinces in 2000. The digital data for mineral deposits in Yunnan, Sichuan, Guizhou and Guangxi provinces will be integrated. The geology maps of different provinces are to be fitted onto the Digital Chart of the World, which is to be used as a base map for the project.

In this project, emphasis will be given to the regional correlations of the broader tectono-stratigraphic units in South China and also the database will be used to correlate geological units in SE Asia. Development of a geological mosaic for the Yunnan, Sichuan, Guangxi and Guizhou is in progress. Similarly structural and tectonic analysis of fault history in South China will be undertaken. Detailed correlation and structural study are deferred until digital data entry for these provinces are completed, and will be presented to the sponsors by Drs. Clive Burrett and Ron Berry in next review meeting.

The digital database will be utilised to produce geological and mineral deposits maps of south China to understand the metallogenic, tectonic and genetic aspects of mineralised belts in the area. The following Table 1 shows progress and future plans for the GIS program.

We have also communicated with the researchers from other provinces from South China for International collaboration. We have collaborated with the following institutions: (1) Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, Guizhou Province, (2) Institute of Geology and Karst Geology, Ministry of Land and Resources, Guilin, Guangxi Province and (3) Guangzhou Institute of Geochemistry, Guangzhou, Guangdong Province. They are in return interested in gaining expertise from CODES SRC/Earth Sciences for training their local geologists.

Table 1. Program for GIS module showing progress for the GIS studies.

Province	Proposed program	1999-2000	2000-2001	2001-2002
Yunnan & Sichuan	Geology coverage	———		
	Deposit database	———	———	
Guangxi & Guizhou	Geology coverage	———	———	
	Deposit database		———	
Guangdong & Hunan	Geology coverage		———	
	Deposit database		———	
Hubei & Jiangxi	Geology coverage		———	
	Deposit database		———	
Fujian & Shandong	Geology coverage		———	———
	Deposit database			———
Anhui & Jiansu	Geology coverage		———	———
	Deposit database			———
Zhejing & Shanghai	Geology coverage		———	———
	Deposit database			———

Note: The red line denotes completed program and black line for ongoing and future program.

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Fig. 4. Geology of Yunnan Province
(AMIRA P603 Project)

Geology Legend

Geology Legend

🟨	100 Qh Sand, pebble, clay and volcanics-Holocene
🟨	101 Qp Sand, pebble, clay and minor volcanics-Pleistocene
🟨	102 Q Sand, pebble and clay-Quaternary
🟧	103 N2 Sandstone, conglomerate and mudstone-Pliocene
🟧	104 N1 Conglomerate, sandstone, mudstone, marl and coal-Miocene
🟧	105 N Sandy conglomerate, mudstone, marl and coal-Miocene
🟧	106 E3 Conglomerate, sandstone and marl-Oligocene
🟧	107 E2-3 Conglomerate, sandy marl and minor volcanics-Oligocene
🟧	108 E3^2 Conglomerate, sandstone and mudstone-Eocene
🟧	109 E1-2^2 Sandstone, siltstone and mudstone-Eocene
🟧	110 E1 Siltstone, mudstone, marl and salt-Paleocene
🟧	111 E Sandstone and shale-Tertiary
🟥	200 gh6 Granite porphyry-Eocene to Neogene
🟥	201 g61 Granite-Eocene
🟥	202 gh61 Adamellite-Eocene
🟥	203 gp61 Granite porphyry-Eocene
🟥	204 lp61 Quartz porphyry-Eocene
🟥	205 zp61 Dacite porphyry-Eocene
🟥	206 dm6 Diorite porphyry-Eocene to Noegene
🟥	207 dom6 Quartz diorite porphyry-Eocene to Neogene
🟥	208 nodu6 Quartz monzodiorite porphyry-Eocene to Neogene
🟥	209 hop6 Quartz monzonite prophyry-Eocene to Neogene
🟥	210 hp61 Monzonite porphyry-Eocene
🟥	211 hop61 Quartz monzonite porphyry-Eocene
🟥	212 x6 Syenite-Eocene to Neogene
🟥	214 t6 Subtrachyte-Eocene to Neogene
🟥	216 xo61 Quartz syenite-t6 Subtrachyte-Eocene
🟥	217 xp61 Orthophyre-Eocene
🟥	219 c61 Undivided alkaline rocks-Eocene
🟩	300 K2 Mudstone, sandstone and marl-Upper Cretaceous
🟩	301 K2^1 Conglomerate, sandstone and mudstone-Lower Cretaceous
🟩	302 K1^1 Mudstone and sandstone-Lower Cretaceous
🟩	303 K1 Sandstone, mudstone and conglomerate-Lower Creaceous
🟩	304 J1 Mudstone, siltstone and marl-Upper Jurassic
🟩	305 J2-3 Mudstone, shale and sandstone-Mid to Upper Jurassic
🟩	306 J2 Sandstone, shale and minor limestone-Middle Jurassic
🟩	307 J1+2 Sandstone, mudstone and conglomerate-Lr. to Middle Jurassic
🟩	308 J1 Mudstone, sandstone and conglomerate-Lower Jurassic
🟩	309 T2b^3 Sandstone, mudstone and coal-Upper Triassic
🟩	310 T2a^3 Conglomerate, sandstone and coal-Upper Triassic
🟩	311 T2^3 Sandstone, mudstone and coal-Upper Triassic
🟩	312 T1^3 Sandstone, shale, limestone and minor volcanics-Upper Triassic
🟩	313 T3 Limestone and volcanics-Upper Triassic
🟩	314 T2^2 Limestone, mudstone and volcanics-Middle Triassic
🟩	315 T1^2 Dolomite, metasandstone and volcanics-Middle Triassic
🟩	316 T2 Carbonate, sandstone and volcanics-Middle Triassic
🟩	317 T1+2 Sandstone, shale and volcanics-Lr. to Middle Triassic
🟩	318 T1 Sandstone, shale and carbonate-Lower Triassic
🟥	400 g53 Granite-Cretaceous
🟥	401 g53(3) Granite-Cretaceous
🟥	402 g53(2) Granite-Middle Cretaceous
🟥	403 rg53(1) Granite-Cretaceous
🟥	404 hg53 Adamellite-Cretaceous
🟥	405 hg53(3) Adamellite-Cretaceous
🟥	406 hg53(2) Adamellite-Cretaceous
🟥	407 hg53(1) Adamellite-Cretaceous
🟥	408 gp53 Granite prophyry-Cretaceous
🟥	409 gp53(3) Granite porphyry-Cretaceous
🟥	410 gp53(2) Granite prophyry-Cretaceous
🟥	411 gd53 Granodiorite-Cretaceous
🟥	412 lp53 Quartz porphyry-Cretaceous
🟥	413 d053 Quartz diorite-Cretaceous
🟥	414 Bm53 Diabase-Cretaceous
🟥	415 g52 Granite-Jurassic
🟥	416 hg52 Adamellite-Jurassic
🟥	417 gp52 Quartz porphyry-Jurassic
🟥	418 d052 Quartz diorite-Jurassic
🟥	419 d52 Diorite-Jurassic
🟥	420 dm52 Diorite porphyry-Jurassic
🟥	421 n52 Gabbro-Jurassic
🟥	422 Bm52 Diabase-Jurassic
🟥	423 s52Ultramafics-Jurassic
🟥	424 g4-g51 Granite-Late Palaeozoic to Triassic
🟥	425 hg4-hg51 Adamellite-Late Paleozoic to Triassic
🟥	426 gd4-gd51 Granodiorite-Late Paleozoic to Triassic
🟥	428 hg43-hg51 Granite-Permian to Triassic
🟥	429 gd43-gd51 Granodiorite-Permian to Triassic
🟥	430 g51 Granite-Triassic
🟥	431 hg51 Adamellite-Triassic
🟥	432 gd51 Granodiorite-Triassic
🟥	433 gp51 Granite porphyry-Triassic
🟥	434 lp51 Quartz porphyry-Triassic
🟥	435 zp51 Dacite porphyry-Triassic
🟥	436 do43-do51 Quartz diorite-Permian to Triassic
🟥	437 d51 Diorite-Triassic
🟥	438 d051 Quartz diorite-Triassic
🟥	439 d0m51 Quartz diorite porphyry-Triassic
🟥	440 h-n51 Monzonite to gabbro-Triassic
🟥	441 n51 abbro-Triassic
🟥	442 bm51 Qiabase-Triassic
🟥	443 s51 Ultramafics-Triassic
🟥	444 En3^5 Orthophyre-Cretaceous
🟥	452 hg4-hg51(a) Adamellite-Late Paleozoic to Triassic
🟥	453 hg4-hg51(b) Adamellite-Late Paleozoic to Triassic
🟥	454 gd4-gd51(a) Granodiorite-Late Paleozoic to Triassic

🟥	456 g43-g51(a) Granite-Permian to Triassic
🟥	457 g43-g51(b) Granite-Permian to Triassic
🟥	458 hg43-hg51(a)-Granite-Permian to Triassic
🟥	460 gd43-gd51(a)-Granodiorite-Permian to Triassic
🟥	461 gd43-gd51(b) Granodiorite-Permian to Triassic
🟦	500 Pz Carbonate, sandstone, coal and volcanics-Upper Permian
🟦	501 P1-2 Mafic volcanics-Lr. to Upper Permian
🟦	502 P1 Limestone, dolomite and felsic volcanics-Lower Permian
🟦	503 P Siltstone, mudstone and marl-Permian
🟦	504 C3 Limestone, shale and volcanics-Upper Carboniferous
🟦	505 C2+3 Carbonate, sandstone and volcanics-Mid to Up Carboniferous
🟦	506 C2 Carbonate intercalated with volcanics-Middle Carboniferous
🟦	507 C1+2 Carbonate and volcanics-Lr. to Middle Carboniferous
🟦	508 C1-2 Mafic volcanics-Lr. to Middle Carboniferous
🟦	509 C1 Nodular limestone with mafic volcanics-Lower Carboniferous
🟦	510 C Undivided sandstone, shale and limestone-Carboniferous
🟦	511 D3 Carbonate and volcanics-Upper Devonian
🟦	512 D2+3 Sandstone, shale and carbonate-Mid to Upper Devonian
🟦	513 D2-3 Sandstone, shale and carbonate-Mid to Upper Devonian
🟦	514 D2 Limestone, sandstone and shale-Middle Devonian
🟦	515 D1+2 Carbonate, sandstone and shale-Lr. to Mid Devonian
🟦	516 D1 Carbonate rocks-Lower Devonian
🟦	517 D Carbonate, sandstone and shale-Devonian
🟦	518 S3 Argillaceous carbonate, shale and sandstone-Upper Silurian
🟦	519 S2+3 Carbonate, siltstone and shale-Mid to Upper Silurian
🟦	520 S2-3 Limestone and siltstone-Mid to Upper Silurian
🟦	521 S2 Argillaceous limestone-Middle Silurian
🟦	522 S1+2 Carbonate, shale and sandstone-Lr. to Middle Silurian
🟦	523 S1 Graptolitic shale-Lower Silurian
🟦	524 S Shale, limestone and sandstone-Silurian
🟦	525 O3 Shale, sandstone and carbonate-Upper Qrdovician
🟦	526 O2+3 Marl, shale and sandstone-Mid to Upper Qrdovician
🟦	527 O2 Marl and mudstone-Middle Ordovician
🟦	528 O1+2 Limestone, mudstone and marl-Lr. to Middle Ordovician
🟦	529 O1-2 Limestone-Lr. to Middle Ordovician
🟦	530 O1 Limestone-Lower Drdovician
🟦	531 O Carbonate, siltstone and shale-Ordovician
🟦	532 C1 Dolomite, limestone and shale-Upper Cambrian
🟦	533 C2+3 Dolomite, limestone and siltstone-Mid to Upper Cambrian
🟦	534 C2-3 Dolomite and limestone-Mid to Upper Cambrian
🟦	535 C2 Dolomite, limestone and shale-Middle Cambrian
🟦	536 C1+2 Sandstone, dolomite and siltstone-Lr. to Middle Cambrian
🟦	537 C1 Sandstone, shale and carbonate-Lower Cambrian
🟦	538 C Schist, phyllite and marble-Cambrian
🟦	539 Pz1 Schist, phyllite and marble-Lower Palaeozoic
🟦	540 Z-C2 Sandstone, slate and limestone-Sinian to Mid Cambrian
🟥	600 g4 Granite-Late Palaeozoic
🟥	601 hg4 Adamellite-LatePalaezoic
🟥	602 d43 Diorite-Permian
🟥	603 h043 Quartz monzonite-Permian
🟥	604 n-d43 Gabbro-diorite-Permian
🟥	605 n43 Gabbro-Permian
🟥	606 bm43 Diabase-Permian
🟥	607 N43 Undivided mafic rocks-Permian
🟥	608 n4 Gabbro-Late Palaezoic
🟥	609 Bu4 Diabase-Late Palaeozoic
🟥	610 N4 Undivided mafic rocks-LateProterozoic
🟥	611 s43 Ferruginous ultramafics-Permian
🟥	612 s4 Ferruginous ultramafics-Late Palaeozoic
🟥	613 E Ultramafics-Unknown age
🟥	615 hg3 Adamellite-Early Palaeozoic
🟪	701 AnCsh Schist, quartzite with mafic volcanics-Precambrian
🟦	702 Zb Carbonate, sandstone and minor conglomerate-Upper Sinian
🟦	703 Za Sandstone and volcanics-Lower Sinian
🟦	704 Z Slate, siltstone and conglomerate-Sinian
🟪	705 Pt2g1 Migmatite, gneiss, granulite and quartzite-Mid Proterozoic
🟪	706 Pt2ch Migmatite, gneiss, schist and marble-Mid Proterozoic
🟪	707 pt2xm Migmatite, gneiss and schist-Mid Proterozoic
🟪	708 Pt2ln Schist and marble with mafic volcanics-Mid Proterozoic
🟪	709 Pt2dm Migmatite, gneiss and marble-Mid Proterozoic
🟪	710 Pt2dy Slate and calc-phyllite-Mid Proterozoic
🟪	711 Pt2lz Dolomite and stromatolithic limestone-Mid Proterozoic
🟪	712 Pt2& Slate and carbonate-Mid Proterozoic
🟪	713 Pt2l Stromatolithic dolomite-Mid Proterozoic
🟪	714 Pt2y Slate, dolomite and siltstone-Mid Proterozoic
🟪	715 Pt2m Slate, siltstone and limestone-Mid Proterozoic
🟪	716 Pt2d Stromatolithic limestone-Mid Proterozoic
🟪	717 Pt2hs Quartzite, sandstone and slate-Mid Proterozoic
🟪	718 Pt2h Phyllite, slate and siltstone-Mid Proterozoic
🟪	719 Pt1cn Gneiss, schist and marble-Lr Proterozoic
🟪	720 Pt1al Migmatite, gneiss and amphibolite-Lr Proterozoic
🟪	721 Pt1dh Metavolcanics, quartzite and marble-Lr Proterozoic
🟪	722 Pt1jl Schist, gneiss and amphibolite-Lr Proterozoic
🟪	723 Pt1ys Migmatite, granulite and gneiss-Lr Proterozoic
🟥	800 g23 Granite-Late Proterozoic
🟥	801 nhg23 Adamellite-Late Proterozoic
🟥	803 hg22 Adamellite-Middle Proterozoic
🟥	804 gd22 Granodiorite-Middle Proterozoic
🟥	805 n2 Gabbro-Early to Middle Proterozoic
🟥	806 bm22 Diabase-Middle Proterozoic
🟥	807 n22 Gabbro-Middle Proterozoic
🟥	808 g21 Granite-Early Proterozoic
🟥	809 d21 Diorite-Early Proterozoic
🟥	810 d021 Quartz diorite-Early Proterozoic
🟥	811 bm21 Diabase-Early Proterozoic
	900 Water

Fig. 5. Faults in Yunnan
(P603 project)

Fig.6. Faults in Yunnan together with faults in mainland SE Asia
(P603project)

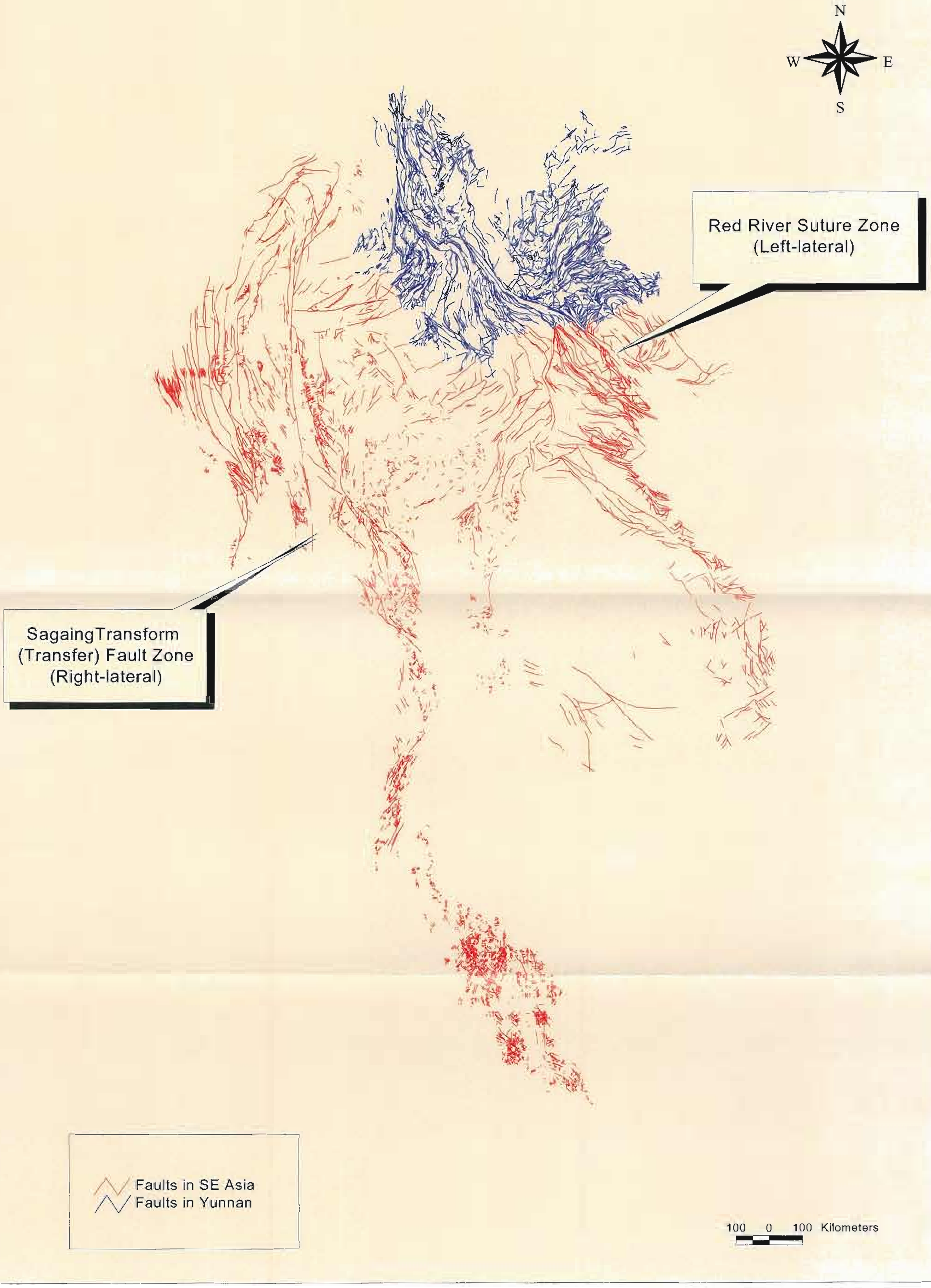
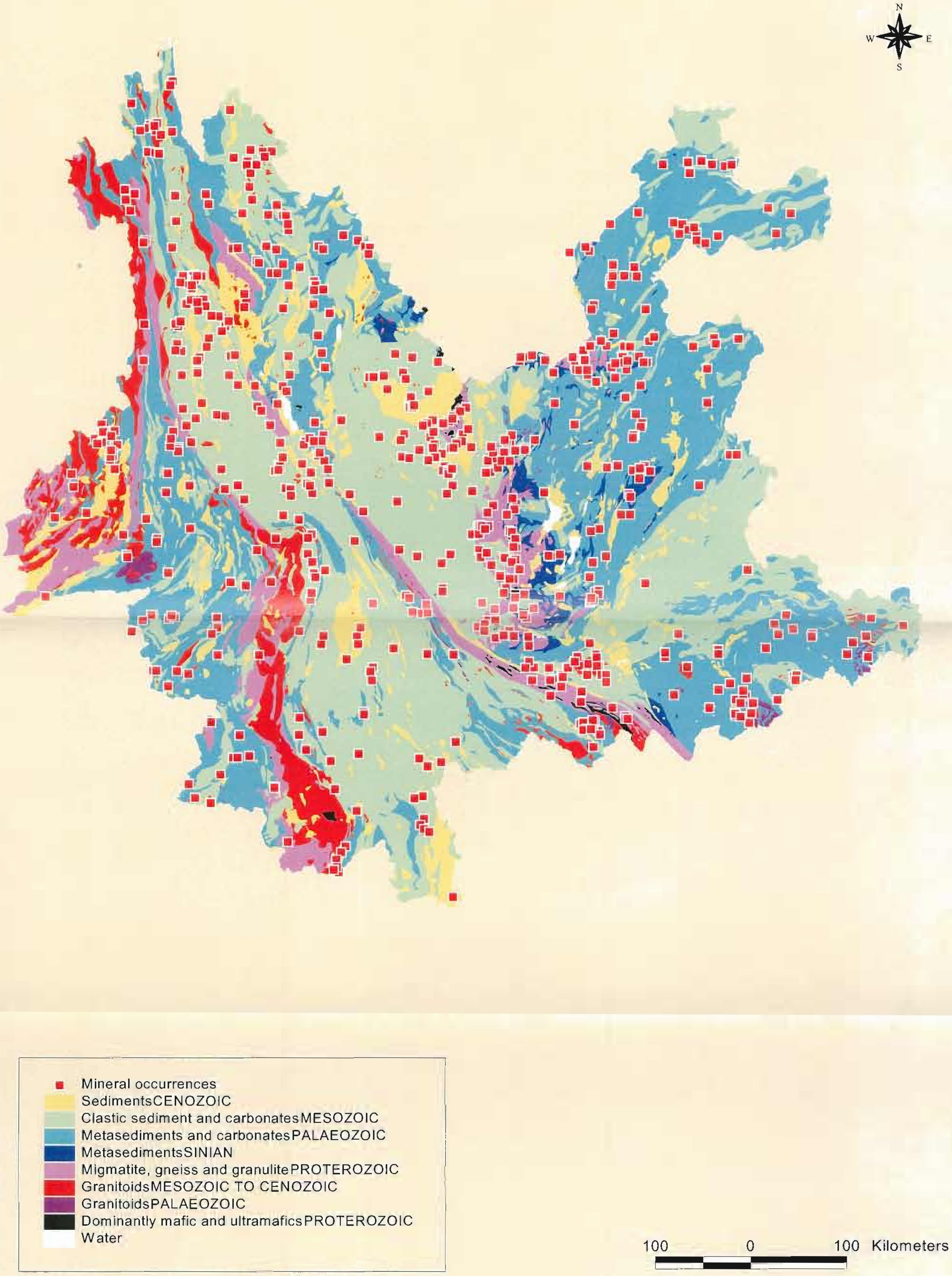


Fig.7. Mineral occurrences in Yunnan
(P603 project)



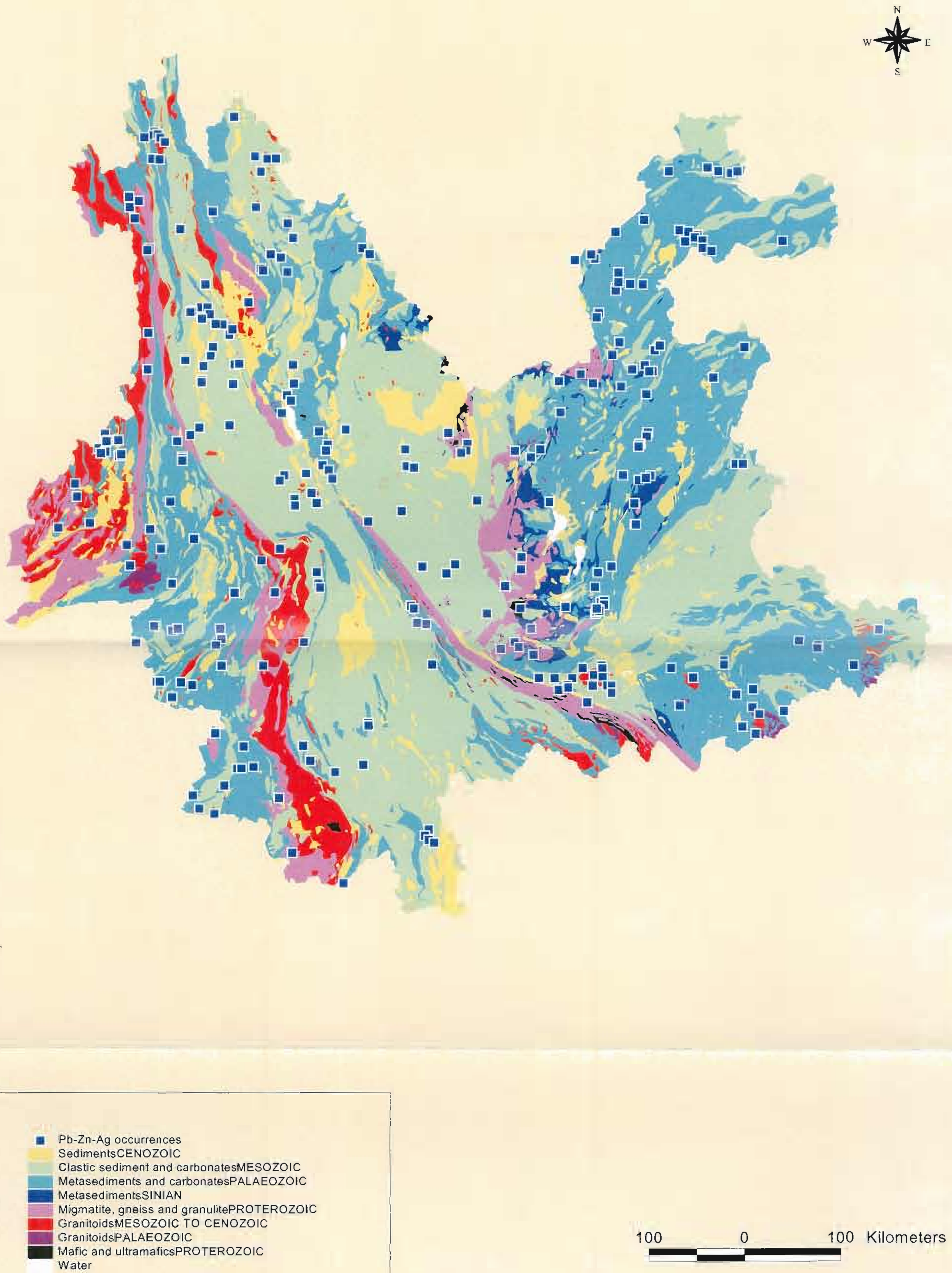
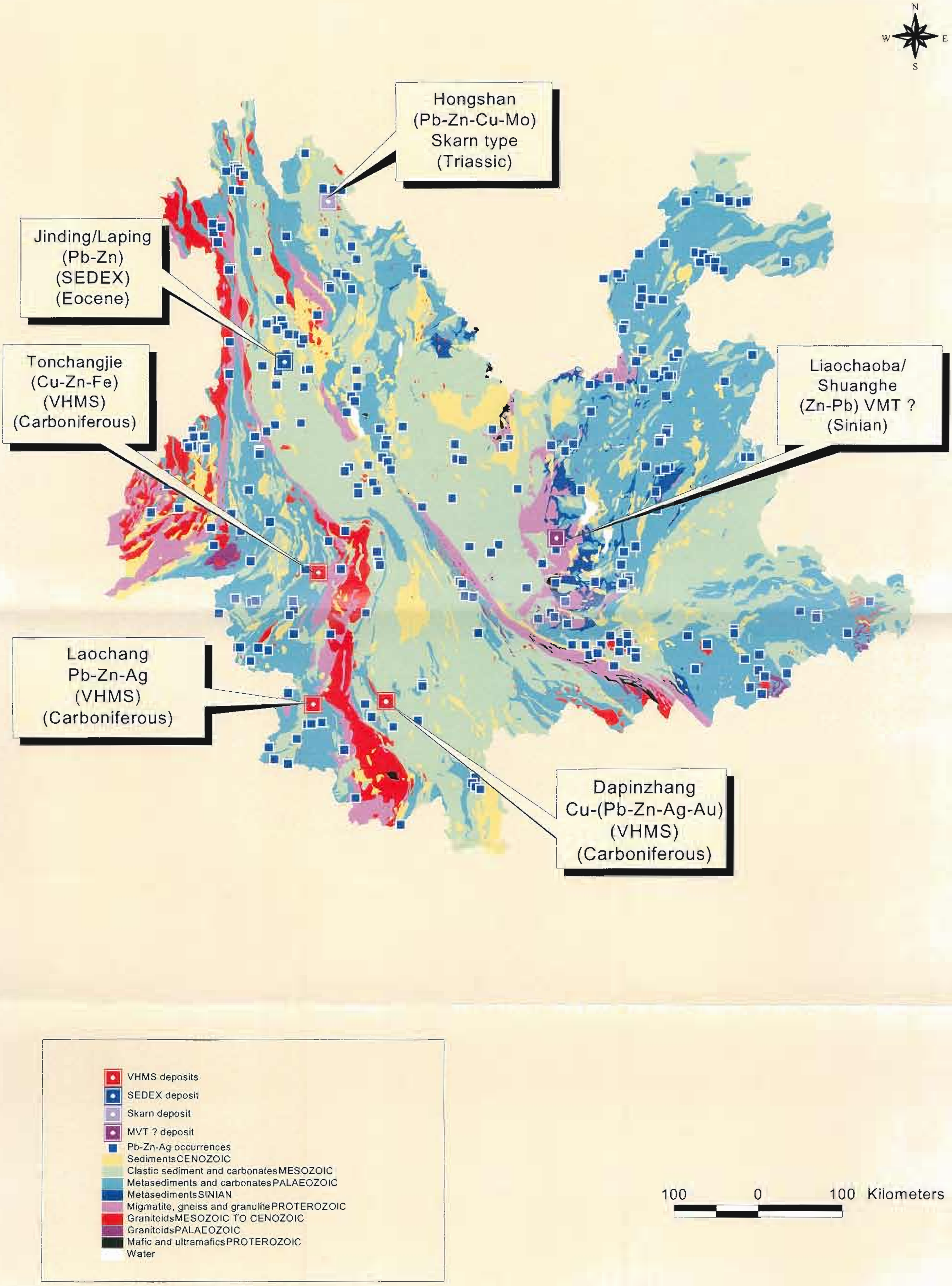


Fig. 8. Map showing geology and lead-zinc-silver occurrences in Yunnan (AMIRA P603 Project)

Fig. 9. Map showing geology and selected lead-zinc-silver occurrences in Yunnan (AMIRA P603 Project)



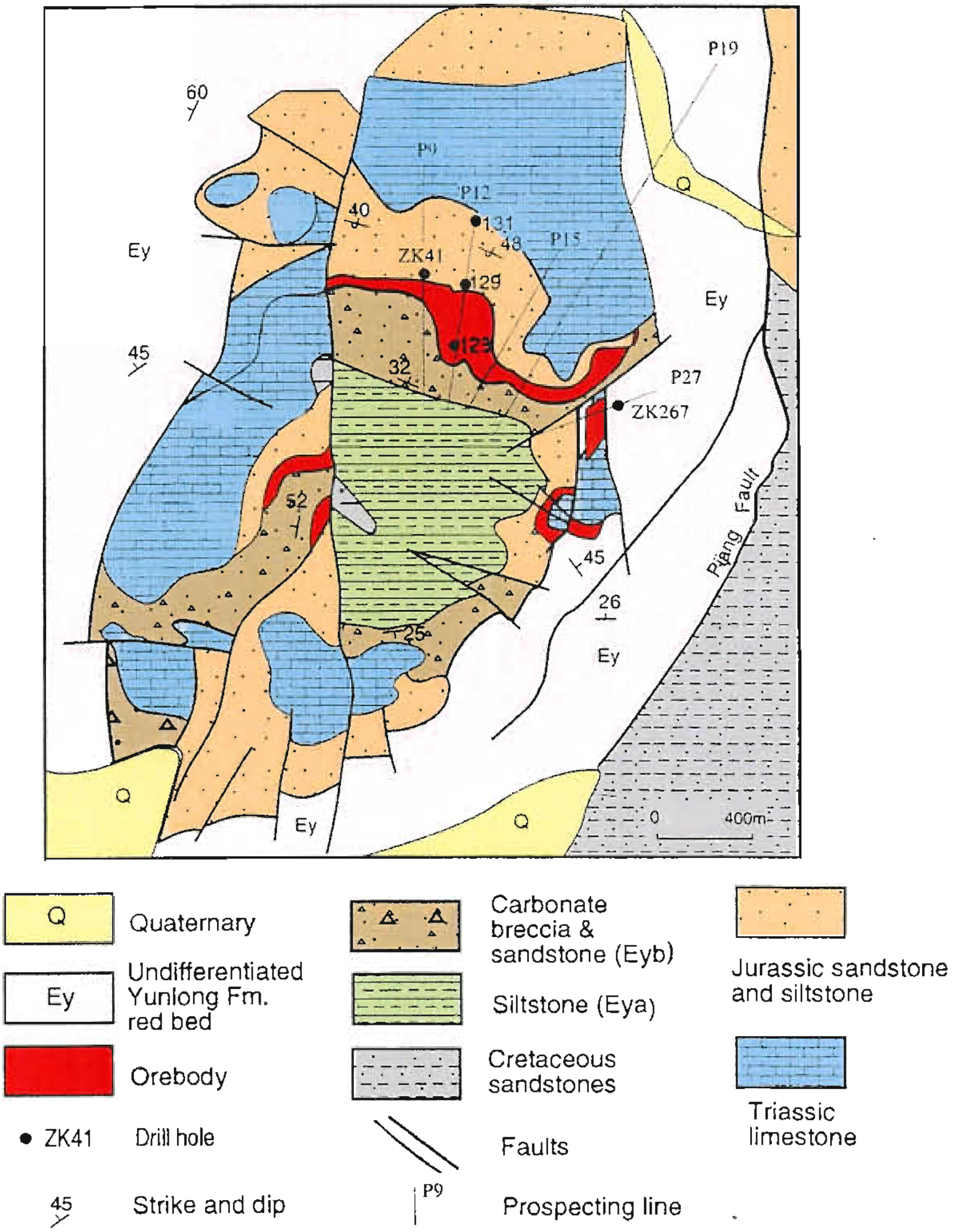


Fig. 10 Geological setting of the Jinding Pb-Zn deposit (after Ningli and Kyle, 1997).,

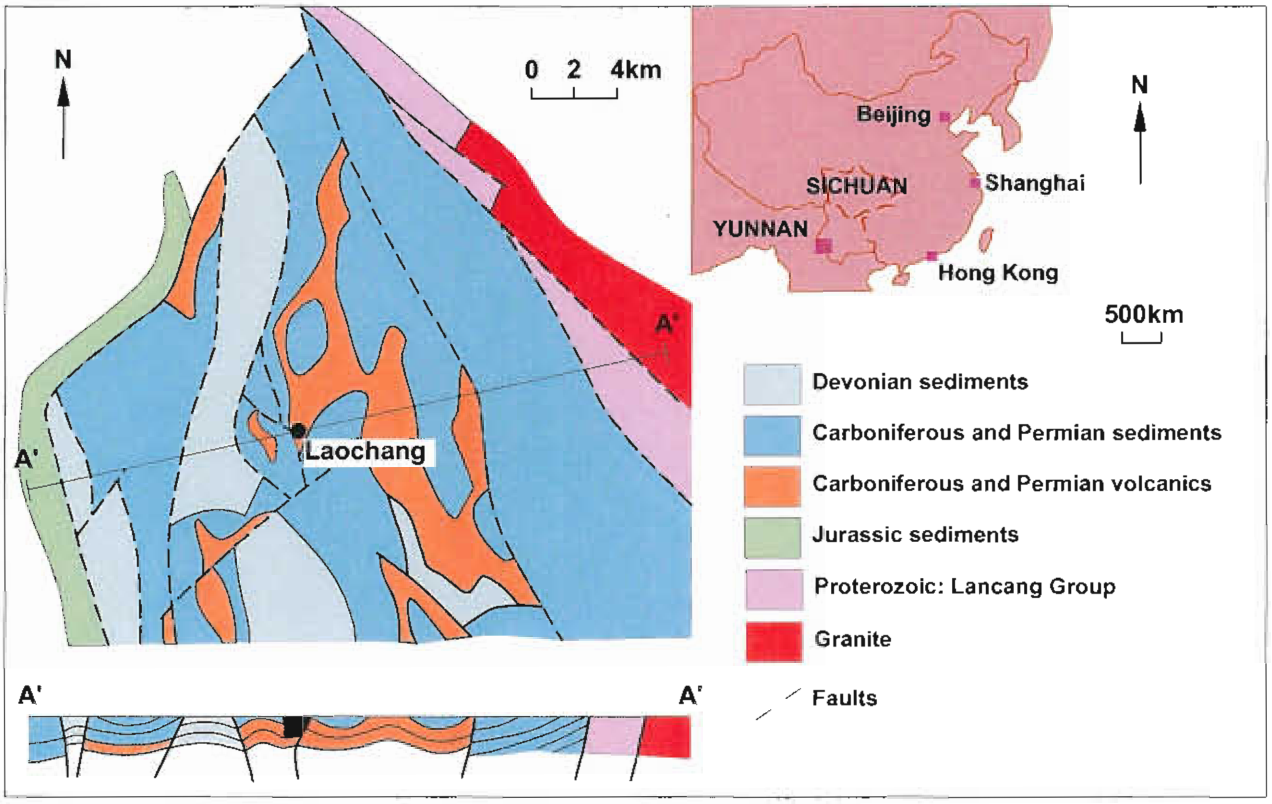


Fig. 11. Map showing regional geological setting of the Laochang deposit (after Yang and Mo, 1993).

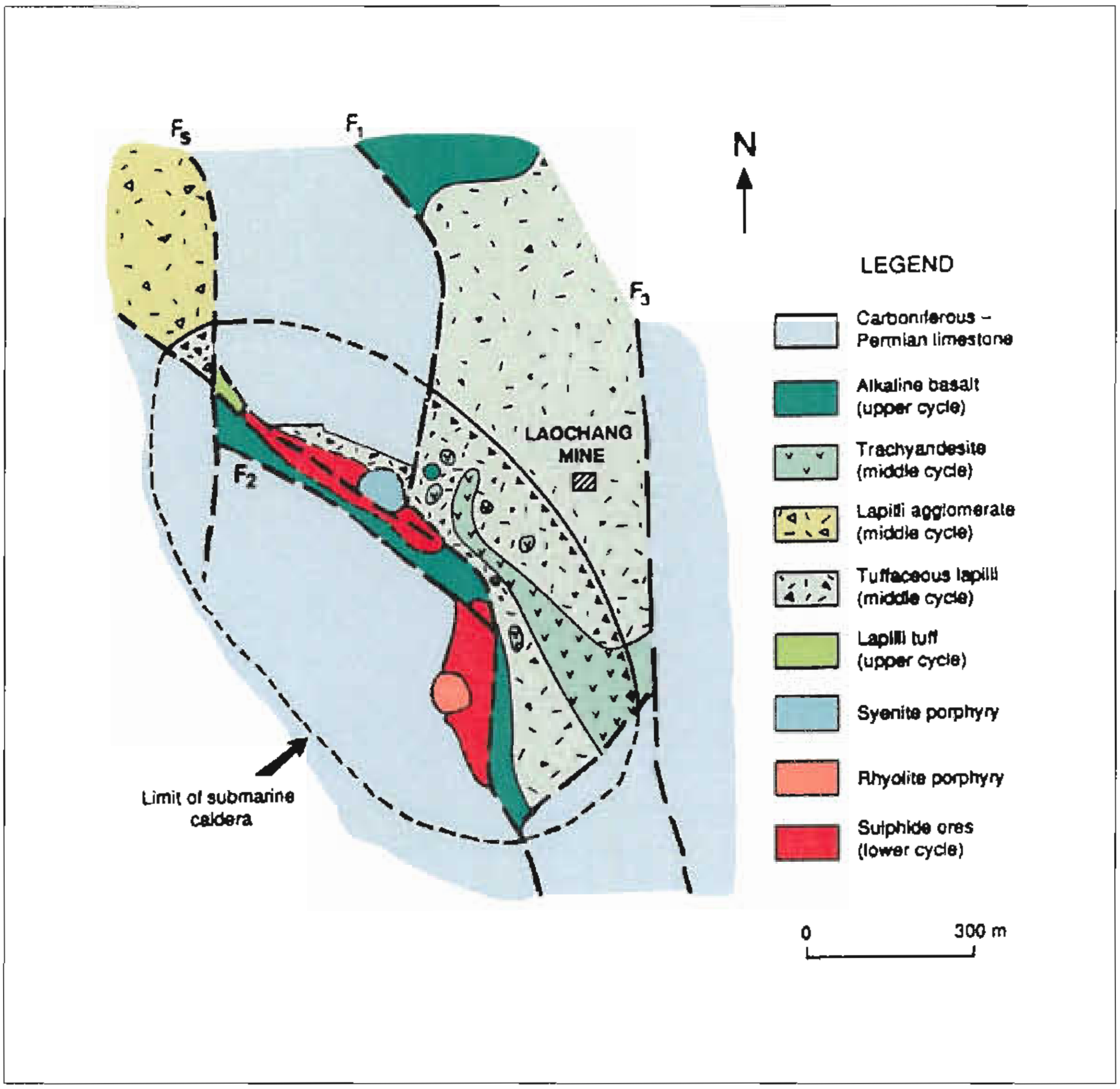


Fig. 12. Map showing geological setting of the Laochang deposit, Yunnan (After Yang and Mo, 1993).

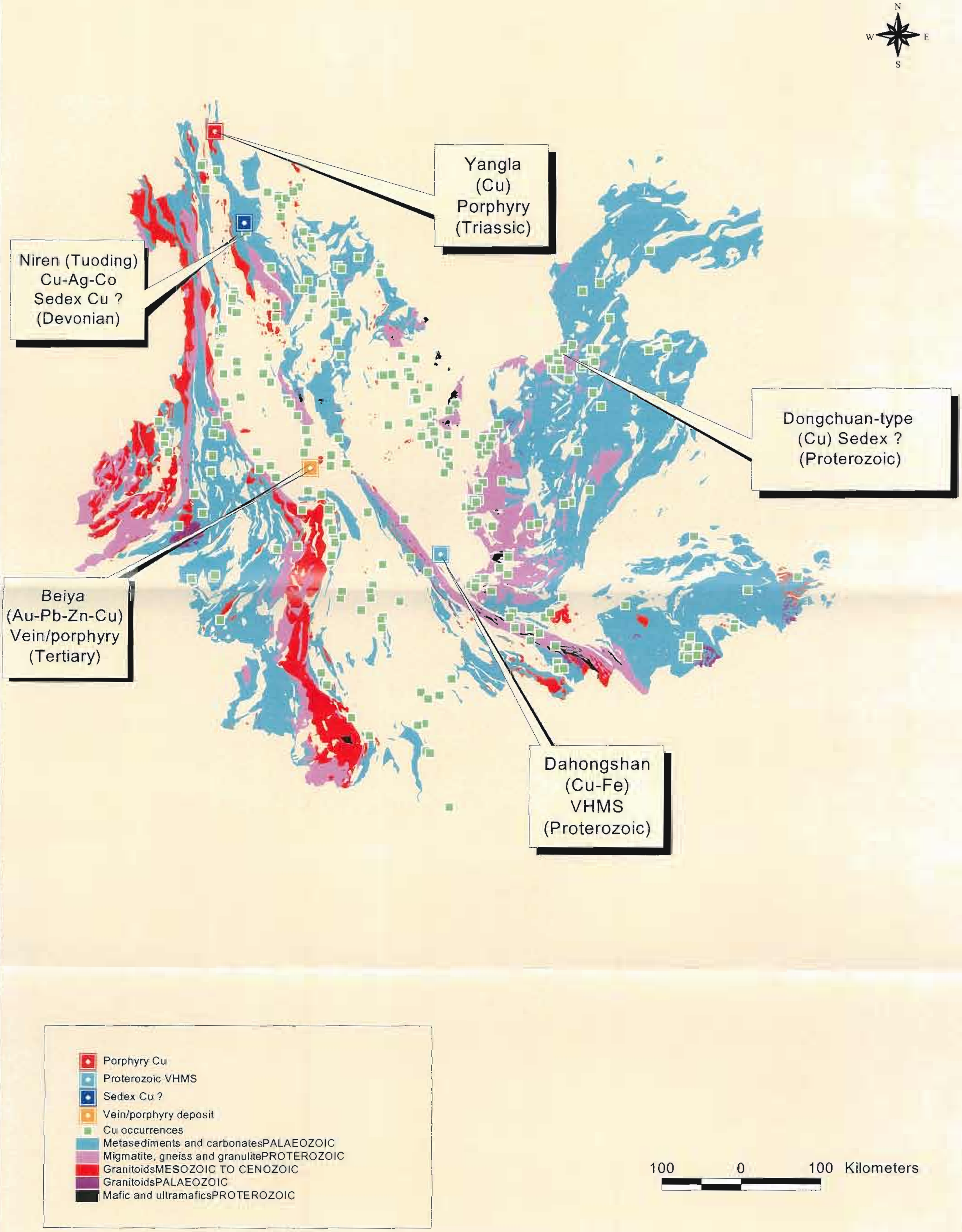


Fig. 13. Map showing geology and selected copper occurrences in Yunnan (AMIRA P603 Project)

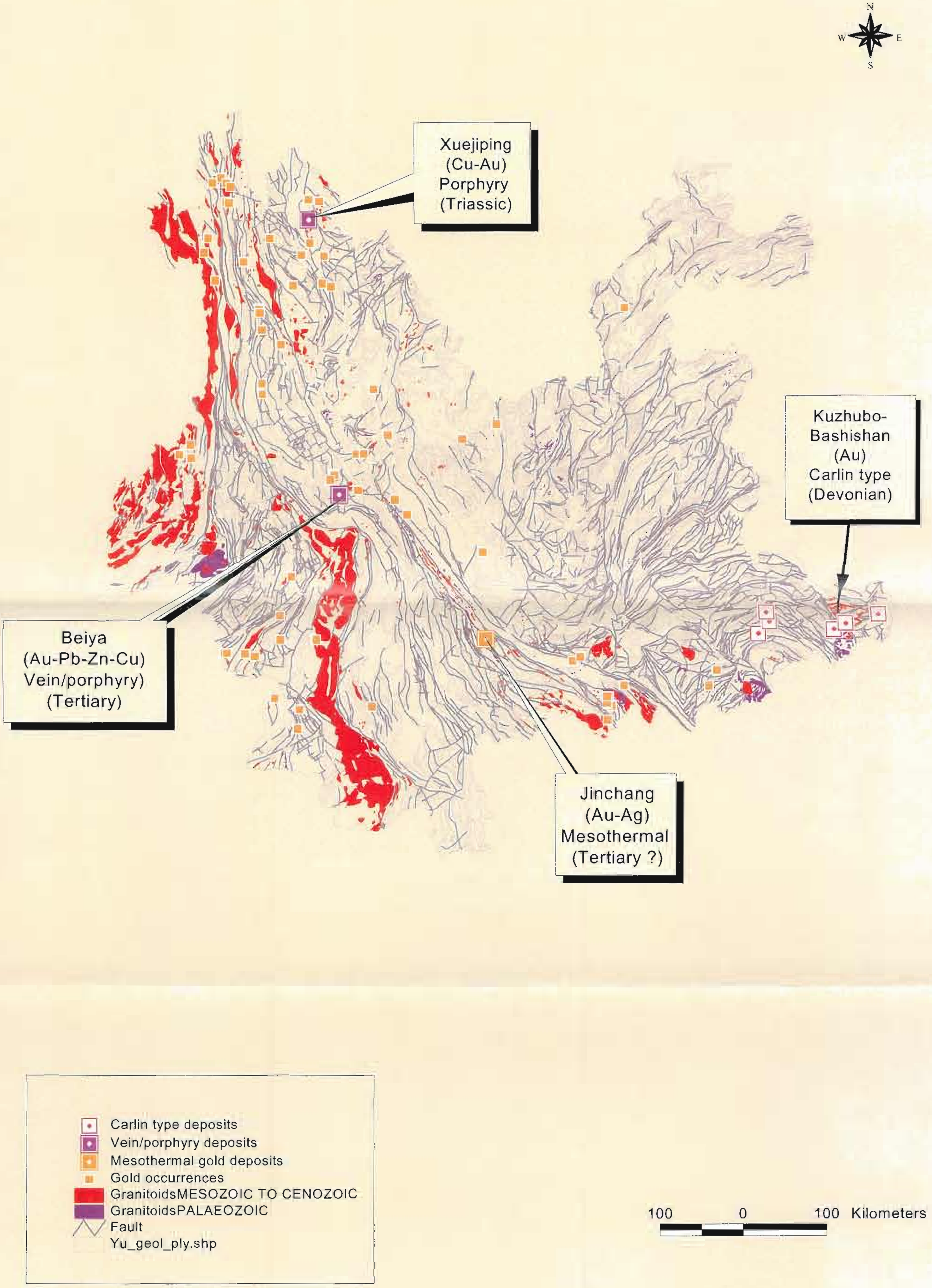


Fig. 14. Map showing gold deposits, granitoids and faults in Yunnan
(P603 Project)

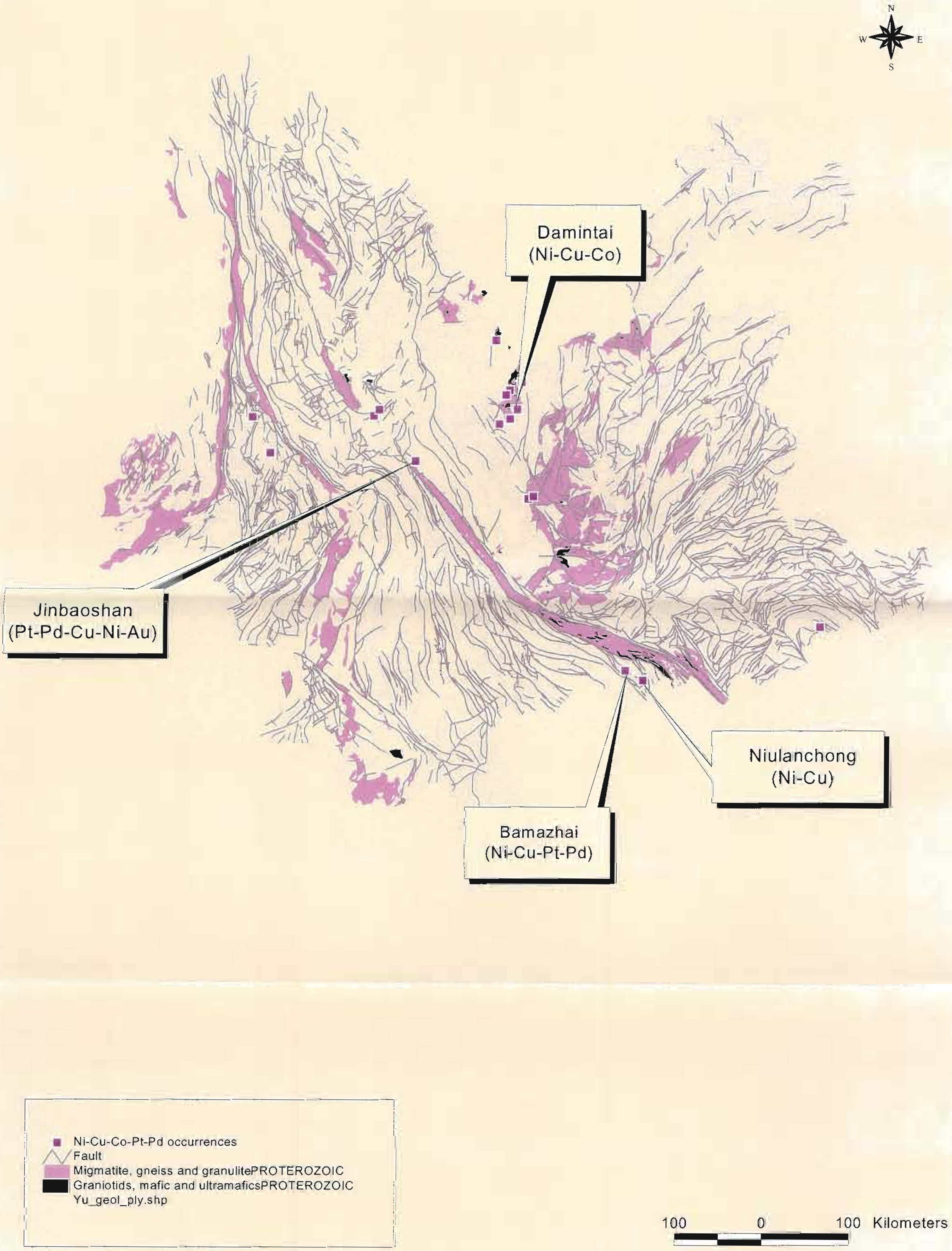
Xuejiping
(Cu-Au)
Porphyry
(Triassic)

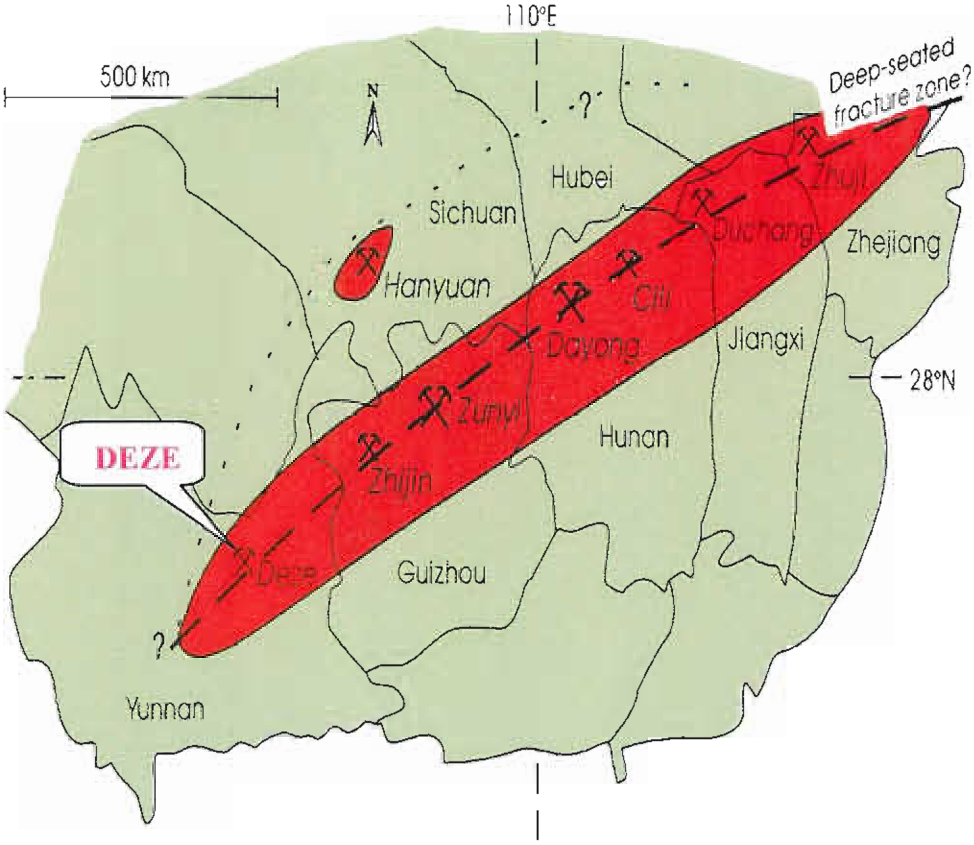
Kuzhubo-
Bashishan
(Au)
Carlin type
(Devonian)

Beiya
(Au-Pb-Zn-Cu)
Vein/porphyry)
(Tertiary)

Jinchang
(Au-Ag)
Mesothermal
(Tertiary ?)

Fig. 15. Map showing nickel-copper-cobalt-platinum-pladium occurrences in Yunnan (P603 Project)





Ni-Mo Ore Bed Locations

Yunnan: Deze
Sichuan: Hanyuan (Fulin)
Hunan: Cili & Dayong (Yongling Zhangjiajie) at Daping, Houping, Sansha & Ganziping
Guizhou: Zhijin & Zunyi at Tianeshan, Xintuguo, Tuanshanbao & Songlin
Jiangxi: Duchang
Zhejiang: Zhuji, Fuyang & Tonglu

Fig. 16. Map showing distribution of sedimentary exhalative Ni-Mo deposits in South China. Note location of the Deze deposit in Yunnan (After Lott et al., 1999).

GIS Database Compilation

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The GIS Database for South China is currently being designed to provide broadscale geological data across 13 provinces. The framework for the database compilation is based on the following thematic components:

Geological Units
Faultlines
Deposits
Geochronology
Lithology
Cultural and Physical Features

The primary sources of both spatial and attribute information include hardcopy maps and research data. A significant amount of the source data has been provided at a provincial level resulting in mapping and descriptive inconsistencies across boarders. Due to the disparity in source data and differences in mapping scales and techniques, documentation of data capture procedures and data lineage is a major requirement of the database compilation.

During the initial 12 months of the project the main focus of the spatial data capture has been on the geological and fault line mapping. Digital capture of the geological mapping for the provinces of Yunnan and Sichuan has been completed and coverage of the adjacent provinces of Guizhou and Guangxi is over 50% complete. In this time a review of existing CD-ROM based geological mapping products was also conducted to assist in the design of the deposit database. Metadata documentation for all completed data sets has been prepared.

Data Formats

GIS data are currently captured using a combination of ArcInfo 8 and ArcView software. Digitising of hardcopy mapsheets is conducted in ArcInfo to ensure consistency in the internal data structure and construction of feature topology. The original data sets will be converted to ArcView shapefile and MapInfo table format using Feature Manipulation Engine (FME) data conversion software.

Reference Data

The reference data set used to adjust the captured mapsheets to a common spatial location is the *China Administrative Regions GIS Data 1:1M* (CIESIN, 1990) which is described in the metadata documentation.

Geological and Fault Line Data

Several data capture procedures were adopted to increase digitising efficiency, ensure data reliability and maintain consistency between provinces. Each province is covered by a different mapping series which vary in scale from 1:500,000 to 1:1,000,000. The number of mapsheets within the series covering each province varies according to map scale. For example, although similar in aerial size the province of Guizhou, at a scale of 1:500,000, is covered by four mapsheets while the province of Guangxi, at a scale of 1:1,000,000, is covered by two map sheets.

Each mapsheet is scanned at a pixel resolution between 80 and 100 metres and registered to geographical coordinates using ERDAS Imagine software. The geological unit, rock and fault line descriptions provided in the map legend are coded with a unique identification number that is used to assign geological attributes to the mapped feature. The scanned map images are digitised using "heads-up" screen digitising which ensures a positional accuracy of approximately 100 metres. A series of Arc Macro Language (AML) programs was developed to facilitate feature labelling and error checking.

Following the digitising, labelling and editing process the mapsheets are built for topology and systematically checked for attribute errors. The individual sheets are then combined to adjacent sheets through a process of "edgematching" and the resulting provincial data set is "rubber sheeted" using an adjustment function to the political boundary dataset.

In their current format the geological mapping and fault line data sets contain all information provided on the hardcopy map version. The next stage will involve assigning new mapping codes to provide both positional and descriptive consistency across provincial boundaries.

Documentation

Metadata is a description of the characteristics of data that has been collected for a specific purpose (ANZLIC, 1996). In this project metadata documentation will be prepared for each GIS data set. The structure of the metadata files is based on the Australian and New Zealand Land Information Council (ANZLIC) Standards. Information will include data collection methods, accuracy of source data, processing history, content descriptions, data quality, geographic extent and other details required for potential users to assess the suitability of the data set for their intended application.

November 2000 CD-ROM Contents

The CD-ROM will contain the completed geological and fault line mapping for Yunnan and Sichuan provinces and the adjacent mapsheets in the Guangxi and Guizhou provinces. Associated metadata documentation is also provided. A second CD-ROM will be disseminated in late December 2000 containing the completed coverage for Guangxi and Guizhou.

Table 1. Completion status of geological data sets (November 2000)

Province	**Data Source**	**Map Scale**	**No of Map sheets**	**Geological Units and Fault lines Digitised**	**Adjusted to the Political Boundary Dataset**	**New Geological Codes Assigned**
Yunnan	Geological Map of Yunnan Province, PRC, 1986	1:1,000,000	4	C	C	x
Sichuan	Geological Map of Sichuan Province, PRC, 1986	1:1,000,000	4	C	C	x
Guangxi	Geological Map of Guangxi Zhuang Autonomous Region, PRC	1:1,000,000	2	P	P	x
Guizhou	Geological Map of Guizhou Province, PRC, 1984	1:500,000	4	P	P	x

C – Complete
P – In progress
x – To be completed

APPENDIX

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A general review of volcanogenic massive sulphide deposits in China

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ABSTRACT

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Volcanogenic, massive sulphide deposits in China have, for the past forty years, been an important source of Cu, Zn, Pb and sulphur, and of a number of associated elements such as Au, Ag and Co. The areal distribution of the deposits is determined by the different geological settings in which they occur and which range in time from Archean to Triassic. Host-rock lithologies comprise felsic, mafic and ultramafic metavolcanic rocks, with or without subsidiary, intercalated metasedimentary rocks; four groups of ore associations, based on chemical composition, have been distinguished: Cu, Cu–Zn, Cu–Fe and Pb–Zn–Cu.

Only one deposit of economic significance (Hongtoushan) has been recognised so far in an Archean greenstone belt. This ore is hosted by metafelsic volcanic rocks of a calc-alkaline suite.

The Proterozoic was an important period for the formation of two groups of volcanogenic massive sulphide deposits in China. Early Proterozoic Cu–Fe deposits, such as Dahongshan and Lalachang, are predominantly distributed in graben-like depressions within cratons. Late Proterozoic Cu–Zn deposits, e.g., Xiqiu and Liujiaping, occur mainly along the edges of the craton. The ores of all Proterozoic deposits are hosted by quartz keratophyre.

The most important metallogenic epoch for this type of ores in China was the Lower Palaeozoic and is represented by a number of deposits situated in the northern Qilian Caledonian orogenic belt. Within this belt, the various groups of deposits can be related to specific plate-tectonic settings. Cu–Zn or Pb–Zn–Cu ores occur in quartz-keratophyric tuffite, with or without intercalated sediments, of island-arc environments (Houyanshan, Zheyaoshan, Xiaotieshan); Cu ores are hosted by spilite, generated probably in back-arc basin settings (Honggou); while Cu–Zn ores presumably occur in metabasalts of oceanic ridge or off axis settings (Yendonggou).

Volcanogenic, massive sulphides are relatively unimportant in the Late Palaeozoic, both with regard to size and numbers, but a rather unusual and important Cu–Zn deposit, hosted by ultramafic rocks (Deerni) is ascribed to this epoch.

An important Pb–Zn–Cu deposit (Gacun) that is comparable with the Kuroko deposits was formed in the Early Mesozoic Yidun orogenic belt, which is considered to represent a mature arc environment. The ores are hosted by rhyolites within calc-alkaline volcanites of dominantly andesitic and rhyolitic composition.

The very important sedex-type stratabound and stratiform base-metal deposits in China seem to have occurred mainly at times when the volcanogenic massive sulphide deposits became relatively unimportant. For instance, the Early Proterozoic, Early Palaeozoic and Early Mesozoic, are the main periods for the formation of volcex-type massive sulphides, while the Middle Proterozoic and Middle–Late Palaeozoic are most important for sedex-type, stratiform base-metal sulphides.

Introduction

Volcanogenic, massive sulphide deposits in China have, for the past 40 years, been an important source of Cu, Zn, Pb and sulphur and of a number of associated elements such as Au, Ag, Co and Se. Large-scale production from this type of ores began in the early 1950's, though exploitation can be traced backwards historically for over 600 years (Song Shuhe, 1982). However, ideas on the genesis of the ores have gradually changed and matured as development and exploitation of the deposits have taken place. For example, the massive

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Geology and genesis of Upper Palaeozoic massive sulphide deposits of South China

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Synopsis

The Devonian–Carboniferous massive sulphide deposits of South China occur in post-Caledonian marine basins and are hosted by clastics, shales and carbonates that are intercalated with thin layers of basaltic and/or acidic volcanic rocks. The ores are composed mainly of sulphides of iron, copper, lead and zinc, together with scheelite, wolframite and cassiterite and some gold. They have relatively high arsenic contents and Co/Ni ratios, lower S/Se ratios and variable δ^{34}S, and the lead isotope ratios are somewhat anomalous. Footwall mineralization is weakly developed in clastics and shales but can be important in carbonate rocks. Alteration characteristically includes silicification, kaolinization, sericitization and K-feldspathization. During late Jurassic and early Cretaceous times the deposits were intruded, transformed and superimposed by granitoids, resulting in the coexistence of massive sulphide deposits with late-stage skarn- and/or porphyry-type ores in the same district.

The most important base-metal reserves in South China are provided by more than 20 major strata-bound deposits, examples being Mashan, Wushan, Chenmenshan, Dongguashan, Xinqiao, Dongxiang, Yongping, Dabaoshan and Fankou (Fig. 1). The deposits occur within the sequences of several Hercynian–Indosinian marine basins and were at one time regarded as typical skarn-type or hydrothermal ores. Meng Xianmin[71] was the first geologist to recognize the strata-bound character and submarine sedimentary origin of these deposits, but, because he mistook the Mesozoic intrusions for Carboniferous lavas, his conclusions were not widely accepted by other geologists. Xu Keqin (Hsu Kechin) and Zhu Jinchu[97] proposed that the deposits were formed primarily by submarine sedimentation and were then intruded, transformed and superimposed by Mesozoic granitic magma and related hydrothermal fluids. Since then the origin of these deposits has been the subject of many studies.[14,38,60,95,110]

It has been suggested elsewhere that the deposits are typical of the massive sulphides that are formed on continental crust and, hence, they have been termed the 'South China type'.[23] The geological features of the deposits were also compared with those of the Cyprus and Kuroko types.[24] The aim of the present contribution is to summarize advances in the research on these deposits and to provide a comprehensive description of their geological features together with a comparison of these features with those of Sullivan-type deposits.

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Geological setting

The South China-type massive sulphide deposits (SCMSD) are distributed over a large area that is bounded by the Yangtze River to the north and by the coastline to the east and south. The western part of the area extends off the western margin of Fig. 1 into Guangxi Province.

According to Guo Lingzhi and co-workers,[31] the Dabie craton, which is located to the north of the Yangtze River (Fig. 1), is composed of late Archaean to early Proterozoic metamorphic rocks and belongs to the southern part of the North China plate. During the Mid-Proterozoic the South China oceanic plate was subducted northwards beneath the North China plate, resulting in the northeast-trending island-arc system that forms the Changsha–Leping belt, which is represented by thick sequences of calc-alkalic and spilitic–keratophyric volcanics and flysch sediments with fragments of ophiolite. The Lower Palaeozoic subduction zone is marked by the northeast-trending fault that passes through Zhenghe and Dapu in Fujian Province (Fig. 1). The late Proterozoic to early Palaeozoic flysch with spilitic–keratophyric intercalations northwest of this fault was formed in arc–trench–basin environments. As a result of back-arc extension a contemporaneous sedimentary basin developed on the Mid-Proterozoic basement along the Yangtze River belt (Fig. 1).

A northeast-trending Mesozoic volcanic belt (Fig. 1), which is part of the circum-Pacific magmatic zone, extends along the southeast coast of China. There has been heated debate regarding the tectonics of the basement beneath the volcanic cover. In the opinion of Guo Lingzhi and co-workers[31] the basement rocks, which have suffered greenschist- to amphibolite-facies metamorphism, may represent an active Hercynian–Indosinian continental margin. However, on the basis of isotope dates of 1000–2000 m.y. most researchers[65,84,102] are inclined to consider it an exotic Precambrian terrane.

Towards the end of the early Palaeozoic (Caledonian orogeny) the continental crust of South China stabilized. Subsidence of the crust during the late Palaeozoic resulted in a marine transgression from the southwest to the northeast. On the basis of their relationship to the basement on which they were initiated Shi Yangshen *et al.*[83] distinguished two types of fault-bounded sedimentary basin: inherited and superimposed. The Xinjiang, Pingxiang–Leping, west Fujian and north Guangdong basins (Fig. 1) are the superimposed type, in which Hercynian sediments are separated by a sharp unconformity from either folded Lower Palaeozoic sequences or metamorphosed Mid-Proterozoic basement. The Lower Yangtze basin, on the other hand (Fig. 1), was inherited—i.e. it was formed by the continued development of a pre-existing Caledonian basin. In this case there is no angular unconformity between the Lower and Upper Palaeozoic sequences.[97] During the Hercynian–Indosinian cycle both the superimposed and inherited basins generally received several thousand metres of sediments—predominantly, carbonates and clastics.[97] Volcanic intercalations have been identified in these sequences in many places; examples are

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Metallogeny of copper and iron deposits in the Eastern Yangtse Craton, east-central China

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Abstract

The Eastern Yangtse Craton of central to eastern China is an important Fe–Cu metallogenic province. Based on studies of the regional geology and tectonic evolution, this metallogenic belt is controlled by faults and aulacogens in the continental plate. In the Early Yanshan Epoch (Jurassic), the dominant west–northwest and east–west lithospheric faults controlled the distribution of Cu (Mo, and Au) mineralization, whereas in the Late Yanshan Epoch (Cretaceous) the north–northeast and northeast lithospheric faults controlled Cu–Fe mineralization. In a mineral district, the distribution of ore-fields is under the dual control of basement fault(s) and near-surface fault(s). Based on the relation of ring and lineament faults to intrusions, a 'three-level' model of vertical zonation is proposed. Systematic petrochemical studies of Mesozoic igneous rocks and mineralization identify three subseries: (1) a calc-alkaline, intermediate to silicic subseries rich in potassium; (2) a calc-alkaline, intermediate to felsic subseries rich in sodium; and (3) a calc-alkaline, intermediate to mafic subseries rich in sodium. Genetic types of ore deposits are diverse, including Fe and Cu skarns, Cu porphyries, Fe ore magma injections, Ningwu-Luzong Fe deposits (from late orthomagmatic to pegmatitic–pneumato-hydrothermal, and to mesothermal–epithermal) associated with subvolcanic rocks, and remobilized sedimentary Fe and/or Cu deposits. The genetic types of ore deposits form two metallogenic series: (1) a sedimentary metallogenic series (active mainly in the Paleozoic), and (2) a magmatic–hydrothermal metallogenic series consisting of three subseries (active predominantly in the Jurassic and Cretaceous), with the latter being more important in this region. The superposition and compounding of these two metallogenic series contribute to many styles of mineralization in this mineral province.

1. Introduction

The middle and lower reaches of the Yangtse River extend from Wuhan to Shanghai (Fig. 1) and cover an area of about 30,000 km^2. Tectonically, this region is in the eastern part of the Yangtse Craton (Yang et al., 1986). Metallogenically, this region is rich in iron, copper, and gold deposits (Jiangsu Provincial Geological Bureau, 1984; Jiangxi Provincial Geological Bureau, 1984; Anhui Provincial Geological Bureau, 1987) (Fig. 2). The ore deposits in this region are controlled by tectonics, sedimentation, and magmatism (Zhai et al., 1981; Chang and

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Metallogenic Model of Dongchuan–type Sedimentary Copper Deposits In China

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Abstract

Dongchuan–type copper deposit are a major type of sedimentary copper deposits in China. They occur in a transgressive copper–bearing rock series of the Middle Proterozoic Kunyang Group. The rock series is marked by variegated sandshales of the Yinmin Formation in the lower part, dolomites of the Luoxue Formation in the middle part and carbonaceous shales and marls of the Heishan Formation in the upper part. The formation of this type of deposits occurred in four stages. (1) The stage of formation of copper– and iron–bearing weathering crust: In the early Middle Proterozoic the crust was uplifted and the copper–bearing rock series in the uplifted area underwent weathering and erosion and then copper–and iron–bearing weathering crust was formed at a dry–hot climate and in an oxiding and alkaline environment. (2) The stage of formation of copper–bearing source beds: In this stage the uplifted crust sank, and at adminantly dry–hot transitional climate, the copper– and iron–bearing weathering crust on old land was denuded, transported rapidly as fragments and in suspension and deposited in hollows on sea basin margins. Meanwhile, erosion of bottom currents resulted in leachng of copper and iron from copper– and iron–bearing weathered materials on the bottom of the sea basin, thus producing copper–bearing source beds (copper–bearing argillaceous–arenaceous dolomite) in the Yinmin Formation and the Luoxue Formation. (3) The stage of formation of stratiform copper orebodies: During the process of diagenesis, copper–bearing minerals having originally occurred in sediments were dissolved and entered intergranular fluids of the sediments. As a result of filter pressing, evaporation and crystallization dehydration, the copper–bearing intergranular fluids migrated upward and laterally toward sediments with a high porosity and good pore permeability and portions with structural fractures and then were entrapped and concentrated below impermeable barriers, thus forming stratiform copper orebodies in sediments with appreciable amounts of reducing agents. (4) The stage of formation of metamorphosed ore veins and pockets: The

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Geologic Controls of Sandstone-Hosted Zn-Pb-(Sr) Mineralization, Jinding Deposit, Yunnan Province, China — A New Environment for Sediment-Hosted Zn-Pb Deposits

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Abstract

The Jinding Zn-Pb-(Sr) deposit occurs in the northern margin of the Lanping-Simao Basin located in the tectonic collision zone between the Indian Plate and the Yangtze Platform. The basin has undergone three phases in its evolution: early rifting, post-rifting, and late compression. The basin's maximum subsidence rates slowed greatly from 270 m/m.y. at the time of late Triassic-mid-Jurassic rifting to about 40 m/m.y. during post-rifting in the Cretaceous. However, maximum subsidence rates reached 500 m/m.y. during the early Tertiary in some subbasins, even though there was simultaneous regional compression. The unique tectonic setting and unusual alluvial fan host rock distinguish the Jinding deposit from other recognized types of sediment-hosted Zn-Pb deposits. Jinding mineralization occurred during the compressional phase of formation of this continental basin. Fan-delta calcite-cemented sandstones and streamflow-dominated alluvial fan sedimentary rocks are the favored facies for sulfide mineral replacement and precipitation, whereas debris-flow sediments (carbonate blocks and carbonate fragment-bearing red mudstone/siltstone) are not. Petroleum inclusions and bitumen in sulfide ore samples suggest a genetic link between the maturity of the basin and mineralization. Fluid inclusion data show that the ore-forming fluids were brines with salinities of 15–24 wt.% NaCl and temperatures of 90–160 °C. $\delta^{34}S$ values of sulfide minerals are variable, but are generally isotopically light (as low as -32.8‰ (CDT)), which suggests that bacterial reduction of sulfate in a shallow, low temperature environment produced reduced sulfur for mineralization. Existing information supports a genetic model that involves the migration of metal-bearing basinal brines up the Pijiang fault where they mixed with shallow pore waters containing reduced sulfur from bacterial reduction of sulfate.

Key words: Lanping-Simao Basin, Jinding Zn-Pb deposit, alluvial fan, basinal brines, bacterial sulfate reduction

INTRODUCTION

The Jinding deposit is the largest sediment-hosted Zn-Pb deposit in China and perhaps the youngest major sediment-hosted Zn-Pb deposit in the world. Jinding was discovered in the early 1960's, and exploration was completed in 1984 by the Third Geological Team of the Yunnan Bureau of Geology and Mineral Resources. The deposit defies classification into currently accepted types of Zn-Pb deposits because of the unique nature of its tectonic setting, associated sedimentary basin, and host rock depositional environment [1, 2, 3, 4]. It is located along the northern margin of the Mesozoic–Cenozoic Lanping-Simao Basin and is hosted by a Paleocene alluvial

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Sedimentary Exhalative Nickel-Molybdenum Ores in South China

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Abstract

Unique bedded Ni-Mo ores hosted by black shales were discovered in localized paleobasins along the Yangzte platform of southern China in 1971. Textural evidence and radiometric dates imply ore formation during sedimentation of black shales that grade into readily combustible beds, termed stone coals, which contain 10 to 15 percent organic carbon. Studies of 427 fluid inclusions indicate extreme variation in hydrothermal brine salinities that were contained by Proterozoic dolostones underlying the ore zone in Hunan and Guizhou. Variations of fluid inclusion salinities, which range from 0.1 to 21.6 wt percent NaCl equiv, are attributed to differences in the compositions of brines in strata underlying the ore bed, complicated by the presence of seawater and dilute fluids that represent condensates of vapors generated by boiling of mineralizing fluids or Cambrian meteoric water. The complex processes of ore deposition led to scattered homogenization temperatures ranging from 100° to 187°C within the Hunan ore zone and from 65° to 183°C within the Guizhou ore zone. While living organisms probably did not directly accumulate metals in situ in sufficient amounts to explain the unusually high grades of the deposits, sulfur isotope ratios indicate that bacteria, now preserved as abundant microfossils, provided sufficient sulfide for the ores by reduction of seawater sulfate. Such microbiota may have depended on vent fluids and transported organic matter for key nutrients and are consistent with a sedex origin for the ores. Vent fluids interacted with organic remains, including rounded fragments of microbial mats that were likely transported to the site of ore deposition by the action of waves and bottom currents prior to replacement by ore minerals.

Introduction

DURING 1971 regional governmental geochemical surveys led to the discovery of a new type of Ni-Mo ore occurring as a thin sulfide bed hosted by black shale in south China (Fan, 1983). In contrast to the relatively low grades of ~0.2 percent Mo in conventional porphyry ores, mined portions of the bedded Chinese deposits contain more than 4 percent molybdenum. The Ni-Mo ores also typically contain at least 2 percent Ni, which was once recovered from deposits in Hunan (C. Nansheng, pers. commun., 1990), and up to 2 percent Zn, 2.5 percent As and 1 to 2 g/metric ton (t) of precious metals, primarily Au, Pt, Pd, and Os (Fan, 1983; Chen et al., 1990). It should be noted that the bedded Ni-Mo deposits have yielded only a minor fraction of China's Mo production, which is largely derived from conventional porphyry deposits (Song et al., 1990).

Historically, the main economic attractions of the Cambrian strata of south China have been thick phosphorites and stone coals that occur in the 10- to 100-m-thick Niutitang Formation black shales (Coveney et al., 1994). The Niutitang Formation routinely contains 5 to 10 percent organic carbon (C_{org}), but in many cases values exceed 10 to 15 percent C_{org}, whereupon the heat content of the shales can reach 800 to 1,000 kcal/kg (Chen et al., 1990). These combustible shales, termed stone coals and described as low quality sapropelic anthracites by Chen et al. (1990), are presumably alginites, given the apparent absence of woody land plants during the Cambrian. Stone coals have been used extensively as fuel for lime kilns and other industrial purposes, as well as for domestic use (Coveney et al., 1994). Throughout the region, Ni-Mo ore occurrences are located where stone coals are thickest; thus, the presence of ore correlates with abundant organic matter suggesting a causal relationship (Chen et al., 1990).

As far as we know, the Chinese mines (Fig. 1) are unique in yielding Mo or Ni as primary products from shale. Yet, deposits similar to the Chinese occurrences, dominated by Ni but containing similar precious metal concentrations, were reported within Devonian black shales of the Yukon Territory (Canada) in 1981. The Canadian deposits indicate that bedded deposits containing Mo, Ni, and precious metals are not confined either to China or to the Cambrian (Hulbert et al., 1992). Published accounts of the Chinese ores and Canadian deposits indicate thicknesses of less than 30 cm (Fan, 1983; Chen et al., 1990). Recent reports of Devonian-hosted deposits, however, containing up to 5 m of 1.4 percent Ni associated with barite, Zn, and precious metals, at the Taiga Nickel property, ~95 km northeast of Dawson City, suggest that thicker and economically valuable deposits may exist in the area (Butterworth and Caulfield, 1998).

General Description of the Ni-Mo Ores and their Geologic Setting

Bedded Ni-Mo ores occur in a 1,600-km-long belt (Fig. 1) within Cambrian metalliferous black shales of the Niutitang and Qiongzhusi formations and their equivalents that unconformably overlie Sinian (latest Proterozoic) dolostone (Fan, 1994; Siegmund and Erdtmann, 1994). Ni-Mo deposits have been reported from Deze in Yunnan, from Hanyuan in Sichuan, from Zhijin and Zunyi (Tianeshan, Xintuguo, and Tuanshanbao) in Guizhou, from Cili and Dayong (Daping,

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