Final Report

P603 – Geological, Tectonic and Metallogenic Relations of South China

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Geological, tectonic and metallogenic relations of South China

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Contents

Geological, Tectonic and Metallogenic Relations of South China — Khin Zaw ........................................... 1.1

Geological GIS Database of South China — Eleanor Bruce and Sue Jungalwalla ........................................... 2.1

Paleogeographic and Tectonic Development of South China — Clive Burrett ................................................ 3.1

Structural History of South China — Ron Berry ................................................................................................. 4.1
Geological, Tectonic and Metallogenic Relations of South China

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EXECUTIVE SUMMARY

This final report presents the GIS compilation of geology and mineral deposits of South China. Compilation of the geology database have been completed for Yunnan, Sichuan, Guizhou, Guangxi, Hunan, Guangdong, Jiangxi, Hubei, Fujian, Anhui, Zhejiang, Jiangsu and Shandong covering the entire South China Terrane. CD-ROMs including geology, geochronology and mineral deposit data for these provinces are delivered to the sponsors with this report. Altogether more than 3300 mineral deposits and occurrences, and 1067 geochronological data points have been compiled spatially from the published literature.

Nearly 400 mineral occurrences are recorded for Yunnan. At least five different styles of lead-zinc-silver mineralisation occur in Yunnan: (1) sedimentary exhalative (sedex) deposits (e.g., Tertiary Jingding/Lanping 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 copper in Sn-W vein and skarn deposits (e.g., Mengzimao). Yunnan also has the potential for Carlin-type and mesothermal gold, porphyry copper-gold, sedimentary copper and mafic-ultramafic-hosted Ni-Cu deposits.

Similarly to Yunnan, Sichuan province has the potential for base and precious metal mineralisation. About 300 mineral occurrences have been recorded for Sichuan. The province has significant stratabound lead-zinc-silver deposits, Carlin-type gold deposits and ultramafic-hosted Cu-Ni deposits. At least, two major styles of lead-zinc-silver mineralisation occur in Sichuan: (1) volcanic-hosted massive sulphide (VHMS) deposits (e.g., Triassic Gacun deposit), and (2) MVT deposits (e.g., Sianian Daqiangzi deposit). Sichuan has excellent potential for the discovery of world class micro-disseminated Carlin-type gold deposits. Many Carlin-type deposits are distributed in NW Sichuan, Gansu and Shaanxi, an area also known as the 'northern Golden Triangle' of China.

Guizhou and Guangxi provinces are adjacent to Yunnan and Sichuan. There are approximately 250 metallic and non-metallic mineral occurrences recorded for Guizhou and about 420 for Guangxi. The two provinces are part of the 'southern Golden Triangle' of China, which forms the region at the junction of Yunnan, Guizhou, and Guangxi provinces. This region has excellent potential for Carlin-type gold deposits.

About 323 metallic mineral deposits have been compiled for Hunan and about 310 for Guangdong. Hunan and Guangdong provinces have many polymetallic lead-zinc deposits associated with Indosinian (Triassic) and Yanshanian (Jurassic to Cretaceous) magmatism (e.g., Shizhuyuan deposit). Significant Devonian to Carboniferous stratabound base and precious metal mineralisation also occur in these provinces and appear to be similar to Sedex type deposits (e.g., Fankou and Dabaoshan deosposits).

In addition, about 220 mineral occurrences for Jiangxi, 219 for Hubei, 152 for Anhui and 104 for Jiangsu provinces are recorded. 132 deposits for Fujian and 166 for Zhejiang and 340 occurrences for Shandong province are compiled. The Jiangxi province has major vein-type tungsten-tin-bismuth-beryllium-sulphide deposits associated with Yanshanian magmatism (e.g., Xihuashan deposit), and the largest porphyry copper deposit in China (e.g., Daxing deposit). Daxing has 1500 Mt ore @ 0.43 % Cu, 0.02 % Mo, 0.16 g/t Au and 1.9 g/t Ag approximately equivalent to 6.45 Mt Cu, 0.25 Mt Mo, 24 t Au and 285 t Ag. Au-(Ag-Mo)-rich porphyry-related Cu-Fe skarn deposits are also found in Jiangxi (Chengmenshan, 1.7 Mt metal @ 0.76 % Cu, 57 t @ av. 0.25 g/t Au and 224 t @ 9.9 g/t Ag, and Wushan, 2.48 Mt metal @ 1.38 % Cu, 67 t @ av. 0.5 g/t Au). This part of the Jiangxi province is also part of the Lower to Middle Yangtze River metallogenic belt of China that has more than 600 t Au. This metallogenic belt extends into the Hubei, Anhui and Jiangsu provinces. The most significant deposits are Tonglushan

AMIRA P603: Geological, tectonic and metallogenic relations of South China — final report, November 2002
(1 Mt metal @ 1.8 % Cu, 69 t @ 1.15 g/t Au), Jilongshan (0.3 Mt metal @ 1.6 % Cu, 37 t @ 4 g/t Au), Fengshandong (0.7 Mt metal @ 1.2 % Cu, 16 t @ 0.38 g/t Au), Shiyouzui (1 Mt metal @ 1.8 % Cu, 19 t @ 0.5 g/t Au), and Jiguanzui (20 t @ 4.87 g/t Au).

Similar deposits are found in Anhui. These are Xinjiaqiao (0.5 Mt metal @ 0.7 % Cu, 24 Mt metal @ 46 % Fe, 105 t Au @ 0.3? g/t Au in sulphide ore and 11.2 t Au @ 4.7 g/t Au in oxide ore), Mancang-Tianyou (32 t @ 6.5 g/t Au), Shizishan (46 t @ 0.3 g/t Au) and Huangshiashan (13.5 t @ 5.8 g/t Au). Jiangsu province also hosts skarn gold deposits (e.g., Fushan, 9 t @ 0.85 g/t Au). In addition, Jiangsu province has Sedex style deposits such as Qixiashan (0.4 Mt metal @ 2.6 % Pb, 0.8 Mt metal @ 0.8 % Zn and 0.4 Mt metal @ 17 % Mn with gold credit (27 t @ 0.9 g/t Au), although the deposits were often overprinted by skarn system associated with Yanshanian magmatism.

Fujian and Zhejiang provinces cover the South China foldbelt along the southeastern margin of the Yangtze craton and are characterised by well-developed Yanshanian intrusive to subvolcanic rocks associated with porphyry to epithermal type copper-gold mineralisation and mesothermal vein deposits. The most important example is the Zijinshan district in Fujian (-100 Mt of ore containing at least 1.6 Mt metal @ 1.09 % Cu and 15 t of Au @ 0.14 g/t Au and 619 t of Ag @ 6.2 g/t Ag). It is the only high-sulphidation epithermal system in China. Epithermal to mesothermal vein-types are found in Zhejiang (e.g., Zhilingtou, 2 Mt ore grading 12 g/t Au, 306 g/t Ag).

Although part of Shandong province is located in the North China Terrane, we included the entire province in our database to compare and contrast the palaeo-geographic, tectonic and metallogenic relations of the South and North China Terranes. The province has unique world class granite-hosted orogenic gold deposits, and is a major producer of gold in China with ore reserves of more than 900 t Au. The most important gold deposits are: Linglong deposit (>100 t @ 3-30 g/t Au), Sanshandao deposit (60 t @ 7 g/t Au), Cangshan (60 t @ 4 g/t Au), Jiaojiang (60 t @ 7 g/t Au), Xincheng (160 t @ 8 g/t Au), Wangershan (45 t @ 7-8 g/t Au), Jingqingding-Rushan (25 t @ 9 g/t Au), Donggerzhuang (20 t @ 11 g/t Au), Hedong and Shangzhuang (20 t @ 7 g/t Au).

The methodology for GIS compilation for the project is reported by Dr. Eleanor Bruce. Detailed stratigraphic correlation and synthesis of fault history of South China across individual provinces are also presented by Dr. Clive Burrett and Dr. Ron Berry in this report.

The project successfully integrated the geology, tectonic and metallogenic relations of South China. The South China region is rich in mineral resources and has the potential for a world class mineral discovery. Many giant base metal deposits [e.g., Baiyin China VHMS and Dongshenming SEDEX deposits], Porphyry copper deposits [e.g., Yulong], copper-nickel deposit [e.g., Jinchuan], several world class orogenic gold deposits in Henan and Xinjiang provinces, and Carlin type deposits in Gansu and Shaanxi are also located in the North China Craton and in the suture zone along the South and North China Cratons. Similar studies should be undertaken for the North China Craton in order to understand the palaeo-geographic, tectonic and metallogenic relation of the formation of these giant ore deposits of China during the collision and amalgamation of the South and North China Cratons.

1. INTRODUCTION AND BACKGROUND

This final report presents the research outcome of the AMIRA P603 project "Geological, Tectonic and Metallogenic Relations of Mineral deposits in South China". The P603 project has two programs: (1) GIS (Geographic Information System) compilation of geological, geochronological and mineral deposit data, and (2) stratigraphic, tectonic and metallogenic studies. This program builds on the SE Asia AMIRA P390A project, which was successfully completed in 1999. The aim of P603 was to establish a similar and compatible GIS, digital geoscience data set and mineral deposit database for South China. The full aims of the P603 project as previously outlined to the sponsors are:

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 distribution based on the GIS database.

3. To develop a geotectonic and metallogenetic model for the evolution and origin of mineralised belts in these regions.
South China is a resource-rich region just north of Myanmar, Lao PDR and Vietnam. The South China region includes the largest metallogenic provinces in China with world-class base and precious metal deposits (Mineral Deposits of China, 1990, 1992, 1995; Zhai and Deng, 1996; White, 2002; Yang et al., 2002). The Sanjiang region, along the western part of South China, covers Yunnan and Sichuan and is notable for its mineralised accreted island arcs, back-arc and rift basins, and contains a diversity of mineral deposit types (Hou Zengqian et al., submitted 2002a, 2003a in press). Mineralisation styles in these provinces and adjacent parts of Myanmar, Laos and Vietnam show many 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, 1999; Hou Zengqian et al., 1999; Hou Zengqian et al., submitted 2002a) have mineralisation styles 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).

South China also hosts copper-(gold) bearing porphyries and mesothermal gold deposits (e.g., the Beiya, Yangla, Jincang deposits in Yunnan, the Denxiang deposit in Jiangxi, the Gaocun deposit in Guangdong). Some of these porphyry copper deposits may also contain molybdenum (e.g., the Machangqin deposit in Yunnan). Base metal skarn deposits in South China are widely distributed along the lower reaches of the Yangtze River (e.g., Taihe Zhou, 1995, 1999; Yusheng Zhai et al., 1996; Yiming Zhao et al., 1999; Yuanming Pan and Ping Dong, 1999). They are also major sources of gold in China, and gold only skarns or skarns with copper are also widely distributed along the lower reaches of Yangtze River (Yanjing Chen et al., in preparation), and account for more than 26% of China's gold resources.

Cu-Fe type VHMS deposits and sandstone-hosted Sedex type deposits (e.g., Jingding) are found in the Sanjiang Region. Carlin-type gold deposits are also widely distributed in the northern Golden Triangle (Gansu and Shaanxi — also known as Chuan-Shaan-Gan) and the southern Golden Triangle (Guizhou, Guangxi and Yunnan — also known as Dian-Gui-Qian) (e.g., Taihe Zhou et al., 2002; Hu Ruizhong et al., 2002; Li and Peters, 1998; Peters, 2002).

Significant Devonian to Carboniferous base and precious metal mineralisation also occurs in the eastern part of the South China Terrane covering Guangdong, Fujian, Jiangxi, Anhui and Jiangsu provinces along the margin of the Yangtze Craton (e.g., Gu Lianxing et al., 1993, 2000). Different metal associations are also recorded (e.g., Pb-Zn type Fankou deposit in Gaungdong province, Cu-Fe type Wushan and recently discovered Yongping deposits in Jiangxi province) (e.g., Gu Lianxing et al., 1993, 2000). South China also hosts significant tungsten-tin sulphide skarn/vein deposits (Chen et al., 1992; Yinghui and Dongsheng, 1993) and these belts extend south into SE Asia. South China is also rich in antimony resources accounting for 55% of the world’s antimony reserves with large world class deposits such as the Xiuxiangshan and Woxi deposits in Hunan and Qinglong and Banpo in Guizhou (Wu Jaida et al., 1990; Wu Jaida, 1993; Xiongwei Hu et al., 1996).

2. GIS COMPILATION

The P603 project area is shown in Figure 1 together with the P390A project area for the GIS compilation of the SE Asian geology and mineral deposits. SE Asia and Mainland China regions are composed of major crustal terranes (Fig. 2). The P390A project covered two main 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). This P603 project focuses on the South China Terrane. Provinces covered by this GIS compilation 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 existed in digital format, and such a database has not yet been established in English.

Data capture and establishment of digital databases for South China were undertaken using ARC/INFO GIS software. The detailed methodology for GIS compilation was comprehensively described in the previous AMIRA reports (Khin Zaw and Rice, 1996a, 1996b, 1997a; Khin Zaw et al., 1997, 1998, 1999a, 1999b; Khin Zaw et al., 2000a, b). Additional information for the data capture is presented by Dr. Eleanor Bruce in this final 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. All digital data are presented to the sponsors in CD-ROM format with this final report. The following colour scheme has been adopted:
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 these retain 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.

Geology Legend: We have also established the ArcView Legend (avl. file) for the Geology Legend incorporating the lithological and stratigraphic characteristics. We documented and defined the polygon ID numbers and descriptions for each geological and stratigraphic-lithologic unit for each province. These polygon ID numbers and descriptions are important as these may be extensively applied for future regional geological correlation across individual provincial boundaries. The GIS compilation of geology and mineral deposit database will be reported for each province as below.

2.1. Yunnan Province
The geology and metallogeny of Yunnan province was presented in the previous AMIRA report (Khin Zaw et al., 1999, 2000, 2001), and is briefly described here.
Yunnan province has a total land area of 394,000 km² 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.

The Bureau of Geology and Mineral Resources (BGMR), Yunnan province has a GIS section that is responsible for 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 T&Tmips software. 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 (Ding Jun, 1999). BGMR has also applied GIS techniques to resource assessment and mineral evaluation in parts of Yunnan province. The GIS section at BRGM has 22 staff but lacks of expertise in deposit database development. They have not prepared a mineral deposit database in English.

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 can be found in the geological memoir Series 1, No. 21 on the Regional Geology of the Yunnan province (1991). Geological investigation in Yunnan started after 1911 and was well-developed during the war of resistance against Japan (1937–1945). The Bureau of Geology and Mineral Resources for Yunnan province was established in 1958 and systematic geological mapping has been undertaken since then. A 1:1,000,000 scale geological map was completed in 1965. The Bureau also produced geological maps at 1:200,000 scale covering Yunnan in 1985. Mapping on 1:50,000 scale was started in 1980. About 137 map sheets were completed by 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 Yunnan province is shown in Figure 4 together with a revised polygon ID for each stratigraphic and lithologic unit.

2.2.2. MINDEP database for Yunnan
A considerable amount of spatial mineral deposit data for Yunnan province is available in the literature (e.g., Ding Jun, 1999). For the AMIRA SE Asia P390A project, mineral deposit data for western Yunnan have been compiled, and these data are included in the current P603 project database. The Chinese Academy of Geological Sciences (CAGS) published three sets of 1:4,000,000 scale Mineral Resources Maps of China in 1987 and 1:5,000,000 scale Mineral Resources Maps of China in 1992 and 1999 with explanatory notes for metals, non-metals and energy resources of China (Guo, 1987; Song, 1992; Chen Yuchuan, 1999). These maps show major metal and non-metal deposits of Yunnan. The Chinese Government also published “The Discovery History of Mineral Deposits of China-Yunnan” in 1996. This publication includes about 160 metal and non-metal occurrences of Yunnan. The Metal Mining Agency of Japan (MMAJ) has compiled more than 500 major mineral deposits in China including South China provinces on their web site (www.mmaj.jp). As suggested by the sponsors in the previous meetings, we established the spatial data of
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 terranes 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.
these deposits from the MMAJ maps. MMAJ listed about 50 major deposits from Yunnan. Dr. Khin Zaw visited BRGM, Yunnan and met with Dr. Ding Jun in 1999 and 2000 for collaborative mineral deposits research projects in Yunnan, and Dr. Ding Jun also provided Yunnan mineral deposit data in Chinese. However, as the seal of BRGM is not included in the agreement letter of intent, we excluded the data provided by Dr. Ding Jun in this database. We also acquired mineral deposit data for South China from ECONOMINE (http://www.econominechina.com/) and made an agreement to use the data for this project.

Nearly 400 mineral occurrences have been recorded for Yunnan including lead-zinc-copper-silver, iron, tin, tungsten, gold, and nickel-copper-platinum-palladium occurrences (Fig. 5). Many base metal deposits are widely distributed in Yunnan and there is 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. 6. At least five different styles of lead-zinc-silver mineralisation occur in Yunnan:

1. With copper in sedimentary exhalative (Sedex) deposits (e.g., Tertiary Jingding/Lanping deposit) and Mississippi Valley Type (MVT) deposits (e.g., Carboniferous Qilinchang 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 Dadongchang and Hongshan deposits),

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).

Sedex and MVT deposits: The Jingding deposit is the largest Sedex type deposit in China (Fig. 6) and contains a geological resource of 220 Mt ore grading 7.0 % Zn+Pb, 5.8 g/t Ag and 0.08 % Cd (Kyle and Ning Li, 2002). The deposit is hosted in the Eocene Yunlong Formation consisting of sandstone, siltstone and limestone. These rocks form the upper section of the Lanping-Simaoy basin developed during the Permian to Tertiary. The deposit occurs in the northern part of the Lanping-Simaoy basin (e.g., Qingrong et al., 1992; Shangqing and Sanchuan, 1993; Junjie et al., 1994; Ning Li and Kyle, 1997; Kyle and Ning Li, 2002). The ores were deposited in a smaller sub-basin (probably a rift basin) rich in gypsum. The mineralisation is stratabound with enrichment of celestite (SrCO3) at the base and followed by barite, then sphalerite and galena. The deposit area is also characterised by thrusting of Upper Triassic limestone and Jurassic sandstone. The presence of MVT deposits has also been recently reported in Yunnan (e.g., Qilinchang deposit). The Qilinchang deposit is hosted in the Baizu Formation (Lower Carboniferous) dolomite, and the ore reserves are about 3.32 Mt grading 17.5 % Zn and 6.6 % Pb (Chaoxian Zhou et al., 2001). The ore minerals are sphalerite, galena, and pyrite with a gangue of quartz and carbonates.

VHMS deposits: Major VHMS deposits in Yunnan occur in the Upper Palaeozoic island-arc related Changning-Menglian felsic volcanic belt. This is a belt of 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 at the mining activity at Laochang dates back to the 14th Century. The geological ore reserves of the deposit are at least 20 Mt ore grading 3.8 % Pb, 3.5 % Zn, 1.9 % Cu and 113 g/t Ag (Yang and Mo, 1993, 2001; per. comm., Yang, 1999; Hou Zengqian et al., 1999). The deposit is hosted in Upper Carboniferous volcaniclastic rocks of basaltic-andesitic composition with alkaline affinities (Yang and Mo, 1993; Yang et al., 1993, 1999) and the volcanic units are in fault contact with limestone. Major faults striking N-NW occur in the vicinity of the deposit. The ore is generally massive, fine-grained and banded but sedimentary features such as graded-bedding, ripple marks and sulphide clasts are reported. The ore minerals are sphalerite, galena, chalcopyrite, pyrite, pyrrhotite, arsenopyrite, mimetite, sulphosalts, bornite, magnetite, hematite and cassiterite. Carbonate minerals are relatively abundant, and realgar and orpiment also occur at the top of the ore lenses.

The Dapingzhang deposit is a recently discovered Cu-Zn type, Upper Carboniferous VHMS deposit in Yunnan (Fig. 6) and is similar to the Laochang deposit. The deposit was discovered in 1996 by a Chinese geological team after following up a regional 1:200,000 scale Cu anomaly, and the geologists later 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 intrusions near the southeast margin of the Simao basin. The mineralisation occurs along a strike length of 3000 m and the width of sulphide zone is 10–70 m thick. The extent of the sulphide mineralisation has not been closed off towards the SE. The mineralisation consists of banded sulphides of chalcopyrite, sphalerite, galena

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AMIRA P603: Geological, tectonic and metamorphic relations of South China — Final report, November 2002
and pyrite grading 4.1 % Cu, 1.1 % Zn, 0.6 % Pb, 3.5 g/t Au and 116.6 g/t Ag (per. comm., Paul Chromie, 2000; Hou Zengqian et al., submitted, 2002). The other VHMS deposits are the Cu-Zn type Tongchanglie deposit, the cupriferous Sandashan deposit and Cu-Fe type Dahongshan deposit which are also hosted in Upper Carboniferous to Permian volcanics and metavolcanics.

The Qilinchang Zn-Pb deposit is an example of an MVT deposit in Yunnan. The deposit is hosted in dolomite and limestone of Carboniferous age. The reserves of the deposit are about 3.3 Mt grading 17.5 % Zn and 6.6 % Pb (Chaoxian Zhou et al., 2001). The mineral assemblages are sphalite, galena, pyrite, and calcite. The presence of thick carbonate sequences of Late Proterozoic (Sinian) to Palaeozoic age and the tectonic setting also suggest that there is a potential for Sinian-aged MVT type base metal deposits in Yunnan. The Sinian MVT deposits are reported to the north, in the Sichuan province (e.g., Daliangzi deposit) (see later Sichuan section). The Daliangzi deposit is hosted in a Sinian carbonate sequence and contains 24 Mt grading 10.4 % Zn, 0.8 % Pb and 43 g/t Ag (e.g., Zheng and Wang, 1991). These deposits are similar in style to the MVT deposits of the Lennard Shelf, Western Australia. BHP discovered a new MVT deposit in the Sinian carbonate units in Sichuan and sold it 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 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., Liaocaoeba). The nature of mineralisation is not well understood, and it is thought to be discordant Sedex type mineralisation or MVT type mineralisation.

Copper deposits: Yunnan province has important copper mineralisation styles (Fig. 7). As described above, copper occurs in association with Zn-Pb-Ag-Au type VHMS, Cu-Zn type VHMS (e.g., Permo-Carboniferous Tongchangtie deposit, Yang et al., 1999), Cu-Fe type VHMS (e.g., Permo-Carboniferous Dahongshan deposit, Xu Qidong, 1999), and Sedex deposits. Yunnan also hosts Cu-Zn type Proterozoic deposits (e.g., Dongchuan deposits, Ruan Huichu et al., 1991; Chen Wenming, 1997) but many of these deposits are still poorly documented. These Dongchuan deposits appear to be copper-dominated Sedex deposits (sediment-hosted strataform copper deposits).

Brown (1997) indicates that this type of copper deposit is an important, economically attractive, world-class mineral deposit type, traditionally represented by supergiant such as the Kupferschiefer 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. These copper-silver:cobalt associations occur in the Devonian "Red Bed" strata along a strike length of 2 km with a thickness of 2-4 m. The ore minerals are chalcopyrite, bornite, chalcocite, galena and tetrahedrite. Mineralogy and lateral continuity of the deposit show similarities that are typical of a sediment-hosted copper deposit.

Copper is also associated with epigenetic vein-type and epithermal/porphyry deposits in Yunnan (e.g., Beiya deposit) or porphyry deposits (e.g., Xueiping deposit). Copper bearing vein and skarn (?) deposits are also present. Most of these porphyry copper systems are also associated with molybdenum, and are Himalayan (Tertiary) in age (e.g., Machangqing Cu-Mo porphyry/skarn deposit, Peng et al., 1998), and extend north into Tibet (Hou Zengqian et al., 2003 in press). Examples in Tibet are the Yulong, Mangshong, Duoxiasongduo, and Malasongduo Cu-Mo (Au) deposits (Hou Zengqian et al., 2003b in press). In Yunnan, 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 suggests that the province will become a gold producing region. The relationships of gold deposits, faults and granitoid intrusions in Yunnan are shown in Figure 8. Four distinct primary gold mineralisation types may be recognised: (1) Carlin-type gold deposits (e.g., Kuzhubao, Bashishan, Diheli and Miluo) (Chromie, 2002; Chromie and Khin Zaw, 2001; Chromie and Khin Zaw, submitted 2002), (2) epithermal? Vein, and breccia gold deposits (e.g., Beiya deposit), (3) porphyry copper-gold deposits (e.g., Angla deposit), and (4) medium to high-grade metamorphic rock-hosted, structurally controlled gold deposits along the Adaoshan belt (e.g., Jinchgang and Daping deposits). Presently available geological information suggests three other possible gold mineralisation styles: (1) skarn (?) copper-gold deposits, (2) Cyprus type copper-gold deposits and (3) gold-platinum-palladium in mafic-ultramafic
intrusives.

The Carlin type deposits are located in SE Yunnan adjacent to the Guizhou and Guangxi provinces, a region known as the southern Golden Triangle. These deposits occur along the western margins of the South China Block; within the Youjiang margin sag-basin covering an area of approximately 100,000 km² at the junction between Guizhou, Guangxi and Yunnan provinces (Li and Peters, 1998; Peters, 2002). The Kuzhubao and Bashishan deposits in Yunnan host epigenetic micro-disseminated gold. The gold is hosted within Devonian carbonaceous mudstone units and along fault breccia zones at the contact between Triassic gabbro for the Kuzhubao deposit, and Devonian mudstone units for Bashishan. Gold mineralisation generally occurs within zones of high deformation, especially where later strike-slip and normal faults crosscut earlier low-angled thrust faults. Major sulphide minerals are euhedral and disseminated pyrite, rhombic and acicular arsenopyrite, as well as stibnite and minor iron-poor sphalerite. Gangue minerals are quartz, sericite, calcite, ankerite and chlorite (Chromie and Khin Zaw, 2001; Chromie and Khin Zaw, submitted, 2002). The nature of these deposits in Guizhou and Guangxi provinces will be described in later sections.

**Nickel deposits.** Yunnan has potential for Proterozoic ultramafic-hosted Vosey’s Bay type Ni-Cu-Co±PGE mineralisation styles. The Vosey’s Bay contains 136 Mt grading 1.59 % Ni and significant Cu-Co credits (Naldrett, 1997; Naldrett and Li, 2000). It is interesting to note that Ni-Cu-Co-PGE deposits also occur at Jinchuan in the Gansu province where 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 distributed in Yunnan and Sichuan (for Sichuan see later section). Pt-Pd-Ni-Cu-Co occurrences are also recorded in Yunnan in association with these mafic and ultramafic rocks (Fig. 9).

There is also potential for the Noril’sk type Pt-Pd-Cu-Ni deposit which are associated with Permian to Triassic basaltic volcanic rocks and have 900 Mt grading 2.7 Ni (e.g., Naldrett, 1997). BHP explored for these styles in Yunnan and Sichuan (per. comm., Paul Chromie, 2000).

The Jinbaoshan Pt-Pd-Ni-Cu deposit, 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, aditng and diamond drilling. Chinese geologists estimated a geological resource of 31 Mt grading 1.49 g/t combined Pt+Pd with 1.4 % Cu, and 0.17 % Ni using 0.5 g/t Pt+Pd cutoff value. The deposit is currently under exploration by Pacific Minerals (http://www.pacific-minerals.com/). A new sedimentary exhalative Ni-Mo mineralisation style in Cambrian black shale is also reported at Deze, in Yunnan (Lott et al., 1999). The deposits appear to be related to a deep fracture zone extending from Yunnan, through Guizhou, Hunan, to Zhejiang provinces.

### 3.2. Sichuan Province

Sichuan province lies between 29°21’-110°12’E and 26°03’-34°19’N and it is bordered by Yunnan to the south, Tibet to the west, Qinghai and Gansu to the northwest, Shaanxi and Hubei to the northeast and Guizhou and Hunan to the southwest. Several major orogenic belts in SE Asia and Yunnan pass through Sichuan province and extend into Tibet, Qinghai and Gansu. Similar to Yunnan, Sichuan province has the potential for recoverable mineral resources of lead, zinc, silver, copper, gold, nickel, cobalt, and the platinum group metals.

#### 3.2.1. GIS coverage of geology for Sichuan

For GIS coverage, we digitised the 1:1,000,000 scale geological map from geological memoir Series 1, No. 23 on the Regional Geology of the Sichuan province (1991). Preparation of this memoir began in 1984 based on 80 regional geological map sheets at a scale of 1:200,000. The Sichuan province has a stratigraphy ranging in age from the Archaean to the Quaternary and contains important mineralised foldbelts at the western margin of the Yangtze Craton. A detailed digitised geological map of Sichuan province is shown in Figure 10 together with polygon ID for each stratigraphic and lithologic unit.

#### 3.2.2. MINDEP database for Sichuan

Similar to Yunnan, considerable spatial mineral deposit data for the Sichuan province are available in the literature. Dr. Khin Zaw visited Chengdu and met with Prof. Luo Yanen and the group from the Sichuan Bureau of Geology and Mineral Resources (SBGRM); and also with Prof. Liu Rong and his group from the SW Institute of Metallurgical Mineral Resources Exploration. Both groups assisted the development of the mineral deposit database for Sichuan province. Mr. Luo Yanen of SBGRM provided an “Atlas of Geological Resources and Environment of Sichuan Province” published by the Chengdu Cartographic
Publishing House in 1998, and Mr. Liu Rong also provided a metallogenic map of Sichuan province showing mineral occurrences including metals, nonmetals and energy resources. However, as in the case of Yunnan, there were no seals of SBGRM and the SW Institute of Metallurgical Mineral Resources Exploration in the letter of intent for collaborative mineral deposit research in Sichuan, therefore these maps are not used in this compilation. Dr. Wang Xiaocun from the SW Institute of Metallurgical Mineral Resources Exploration provided gold deposit data from his published work (e.g., Wang Xiaochun and Zhang Zhe-Ru, 1991).

Mineral Resources Maps of China published in 1987, 1992 and 1999 show the major metallic and non-metallic deposits of Sichuan. Metal Mining Agency of Japan (MMAJ) has compiled 32 major mineral deposits of Sichuan province (www.mmaj.jp). Dr. Khin Zaw also collaborated with researchers from the Institute of Mineral Resources, Beijing for a VHMS research project in Sichuan province (e.g., Gacun deposit). The book “The Discovery History of Mineral Deposits of China-Sichuan” published in 1996 also includes major metal and non-metal mineral occurrences. Nearly 300 mineral occurrences are recorded for Sichuan (Fig. 11).

**Lead-zinc-silver deposits:** The relationships of geology and lead-zinc-silver deposits are shown in Fig. 12. At least two major styles of lead-zinc-silver mineralisation occur in Sichuan:

1. Volcanic-hosted massive sulphide (VHMS) deposits (e.g., Triassic Gacun deposit), and
2. MVT deposit (e.g., Sinian Daliangzi deposit).

The Gacun deposit is an important polymetallic, Ag-rich (VHMS) deposit in Sichuan (Fig. 12) and occurs in the Triassic submarine, calc-alkaline volcanic belt which lies in the Yidun collisional orogenic zone of Southwestern China. The deposit has metal reserves of 4 million tones grading 0.44% Cu, 5.40% Zn, 3.70% Pb, 160g/t Ag and 0.44 g/t Au (Hou Zengqian et al, 2000; Hou Zengqian et al, 2001). It is hosted in felsic volcanics associated with an underlying mafic unit (bimodal suite). The volcanics underwent regional lower greenschist facies metamorphism and related deformation during the Yanshanian-Himalayan Orogeny, resulting in folding and shearing of the ore lenses. The deposit is made up of three mineralised zones: a sheet-like upper massive sulphide zone with exhalite (barite, chert and jasper), a middle stringer-stockwork stratabound zone hosted in rhyolitic volcanics and an underlying lower stringer stratabound zone occurring in dacitic volcanics. The ore zone is made up of a series of tabular lenses dipping 70–80°W, and extends over a strike length of 1200 m and a depth of 700 m. The ore minerals are sphalerite, galena, chalcopyrite, pyrite, arsenopyrite, bournonite, boulangerite, and gold (Hou Zengqian et al., 2000, 2001). The deposit is similar to sheet-style VHMS deposits (Large et al., 2001) and is comparable to the Cambrian Rosebery VHMS deposit in western Tasmania (Khin Zaw et al., 1997a, 1999c).

Several carbonate-hosted Pb-Zn-Ag deposits occur within the Sinian dolomite unit of the Kang Dian foldbelt in western Sichuan. Currently mined resources include Daliangzi (24 Mt @ 10.4 % Zn, 0.75 % Pb, 43.1g/t Ag) and Tianbaoshan (20 Mt @ 10.1 % Zn, 1.4 % Pb, 93.6g/tAg) (Fig. 12). Host stratigraphy to Pb-Zn mineralisation is mainly the Sinian Upper Dengying Formation consisting of algal and vuggy dolomites which unconformably overlie a Proterozoic basement of phylrite and schists (Huili Group). Cambrian black siltstone, shale and sandstone unconformably overlie the host Sinian sequence and are in turn unconformably overlain by Permian limestone and basals. Basement stratigraphy has a dominant EW fault structural trend. Sinian and younger platform stratigraphy have NW, NNW and NS fault strikes. Sulphide mineralisation occurs where NW and NNW fault strikes intersect close to regional EW thrust zones (per. comm., Paul Chromie, 2000).

The unconformity between the Cambrian and the Sinian Dengying is important for localising and trapping mineralising fluids. Mineralisation is predominantly epigenetic and occurs within fault-related breccias, veins, joints, karst features and solution collapse breccias. Sphalerite, galena, pyrite, barite and calcite mineralisation occur, along with occasional minor chalcopyrite, and fluorite. Black carbonaceous mudstones are frequently associated with sulphide mineralization in breccia zones and open space karstts. Oxidised surface occurrences contain hydrozincite and are currently mined at several locations. Most of the known resources were earlier identified in remote areas from regional stream sediment sampling, soil sampling and structural mapping.

During 1993, the Sichuan Kang Dian exploration Joint Venture (SKD) was established comprising BHP Minerals Exploration Inc., two Chinese companies, the South West Metallurgical and Geological Exploration Bureau (SMGEB) and the China Non-Ferrous Metal Industrial Corporation (CNNC) to explore for Daliangzi type Pb-Zn deposits within the Sichuan Kang Dian area. Exploration methods consisted of reconnaissance, regional and detailed mapping, contour and grid soil geochemistry, induced polarisation (IP) surveying and drilling. As these deposits
are similar to MVT deposits in the Lennard Shelf, western Australia (Dorling et al., 1998), BHP adopted the exploration model and criteria used in the Lennard Shelf area and discovered the Dayinchang deposit (5.6 Mt @ combined 3% Zn +Pb) just south of the Daliangzi deposit.

Gold deposits: Sichuan has significant gold potential and lies at the northern Golden triangle of China (Sichuan, Gansu and Shaanxi). The region is currently one of the largest potential producers of gold in China and continues to be the focus of further extensive exploration. More than 30 gold deposits and prospects have been found in Sichuan alone over the past 10 years. These deposits have been compiled together with other gold deposits in Sichuan and their distribution is shown in Figure 13. Four distinct primary gold mineralisation deposit types can be recognised: (1) Carlin-type gold deposits in NW Sichuan adjacent to Gansu and Shaanxi provinces (e.g., Dongbeizai, Qiaoqiaoqiang) (Gu Xuexiang, 1996; Wang Xia-Chun and Zhe-Ru Zhang, 1999), (2) tellurium-rich epithermal ? vein gold deposits (e.g., Dashuigou deposit, Jingwen Mao et al., 1995), (3) porphyry copper-gold deposits and (4) medium to high-grade metamorphic rock-hosted, structurally controlled gold deposits. Gold is also associated with VHMS deposits (e.g., Triassic Gacun deposit).

Before the 1980s, gold production in Sichuan was focussed on placer and intrusive-related vein deposits. Sedimentary rock (turbidite)-hosted gold deposits are currently more important in Sichuan. These gold deposits show many characteristics of Carlin-type gold deposits such as host rock, mineralogy and structural setting. The host rocks are mostly Devonian to Triassic carbonaceous, turbidite sequences within the Songpan-Garze accretionary wedge terrain, along the NW margins of the Yangtze Craton. They consist of largely sandstone-siltstone-mudstone, and it is interpreted that the host rocks were accumulated in the back arc basin situated between an active continental island margin (the Kunlun-Qingling fold belt) and a continental island arc (the Yidun island arc).

The dominant structure is N-S and E-W trending regional faults (Palaeozoic) that are crosscut by NW-SE trending faults (Mesozoic). Mineralisation appears to be associated with late structures and occurs mostly within graphitic shear zones or along the altered contacts with quartz-porphyritic or granodioritic dykes of Mesozoic age related to the indosinian (Triassic) and Yanshanian (Jurassic to Cretaceous) orogeny. Ore mineral assemblages are pyrite, arsenopyrite, realgar, stibnite, scheelite, and traces of chalcopyrite, tetrahedrite, tetraedrite, tellurite, sulfoarsenite, tellurite, galena, native arsenic, native gold, pyrrhotite and marcasite. The gangue minerals are mostly quartz, calcite and dolomite. The gold is commonly extremely fine-grained, usually less than 1 micron and refractory. The deposits also show different metal association from Au-As (Dongbeizai), Au-W (Mansoko), Au-Sb (Qiuluo), and Au-U (Laerma) to Au (Pulongba).

The most important Carlin-type deposits in Sichuan are Dongbeizai and Qiaoqiaoqiang (Jingweng Mao et al., 2002). Dongbeizai is one of the largest gold deposits discovered to date in western China (52 t @ 5.54 g/t Au or 1,689,000 oz Au). It is located in Songpan County, about 25 km northwest from the city of Songpan, at an elevation of 3000 m. It was discovered during early 1980 as a result of a reinvestigation program of old reargard showings by the Regional Geological Survey Team of Sichuan province (Gu Xuexiang, 1996). Qiaoqiaoqiang is also a large deposit (15 t @ 4 g/t Au or 405,000 oz Au) similar to Dongbeizai. BHP extensively explored in the region (e.g., Maerhag) and drilled some of the prospects (e.g., Shuiniuja deposit).

Nickel-copper deposits: Sichuan has potential for Proterozoic ultramafic-hosted Voisey's Bay type Ni-Cu-CuPGE mineralisation style and Permian to Triassic Noril'sk type Pt-Pd-Cu-Ni deposits. Proterozoic mafic-ultramafic bodies are distributed in Sichuan. Extensive exposure of Permian Emishen flood basalt covers 259,000 square kilometers in SW China including Sichuan province. Other Palaeozoic ultramafic/mafic intrusions also occur near the basalts margins. Pt-Pd-Ni-Cu-Co occurrences are also recorded in Sichuan in association with these mafic and ultramafic rocks (Fig. 14).

BHP had explored for these styles in Sichuan, and BHP sampling from 1994-1996 shows ultramafic intrusions with nickel depletion in olivines. This chalchphile depletion may indicate the presence of sulphide elsewhere in the intrusions sampled (pers. comm., Paul Chromie, 2000). The important deposits are Lengshuying (2.5 Mt @ 0.9% Ni, 0.5% Cu and 1 g/t PGE) and Limahe (1.5 Mt @ 1% Ni, 0.5% Cu and about 1 g/t PGE) that are hosted in Proterozoic ultramafic rocks and Yangliuping (Danba) deposit in Permian basalt. The Daba deposit area has been explored by BHP and up to 4.7% Ni and 0.6% Cu and 3 g/t PGE have been reported (pers. comm., Paul Chromie, 2000).

In addition, Cu-rich VHMS deposits also occur in Sichuan (e.g., Liwu deposit and Lalachang deposit) (Hou Zengqian et al., 1999). The Liwu deposit is hosted in Silurian-Devonian metavolcanics and forms as a layer-like massive to disseminated copper-zinc mineralisation (30 Mt grading 2.5% Cu and 0.6% Zn). The Lalachang deposit is a currently operating large, layered Cu-Fe deposit hosted in Middle
3.3. Guizhou Province

Guizhou province is bordered by Yunnan and Sichuan to the west, and Hunan and Guangxi to the east and south. According to Chinese geologists, the stratigraphy of Guizhou province is known as "Treasure House of Stratigraphy and Palaeontology". The province is characterised by marine clastic rocks of Middle to Late Proterozoic sequences, Palaeozoic to Early Mesozoic carbonates, and continental clastic rocks of Late Triassic to recent age. The province has considerable potential for base and precious metal deposits.

3.3.1. GIS coverage of geology for Guizhou

For GIS geology coverage, we digitised a 1:500,000 scale geological map from geological memoir Series 1, No. 7 on the Regional Geology of the Guizhou province (1987). A detailed digitised geological map of Guizhou province is shown in Figure 15 together with polygon ID for each stratigraphic and lithologic unit.

3.3.2. MINDEP database for Guizhou

More than 250 mineral occurrences have been recorded for Guizhou (Fig. 16). Metal Mining Agency of Japan (MMAJ) has compiled 22 major mineral deposits of the Guizhou province (www.mmaj.jp). The book "The Discovery History of Mineral Deposits-Guizhou" published in 1996 also contains spatial information for metal and non-metal mineral occurrences in Guizhou province. The province has potential for deposits of micron sized (<1 mm) disseminated gold and these deposits also occur in Yunnan and Guangxi in a region known as the Southern Golden Triangle (Yunnan, Guizhou and Guangxi provinces). These deposits have several similarities with the sediment-hosted Carlin-type deposits in Nevada (Cunningham et al., 1988; Ashley et al., 1991; Cromie, 2002, Cromie and Khin Zaw, 2001; Li and Peters, 1998; Peters, 2002). The southern China Carlin-type gold deposits in Guizhou and Guangxi are hosted predominantly by Palaeozoic to Mesozoic aged siliciclastic and carbonate lithologies. These deposits have reserves of >30 metric tons of contained gold metal, with average grades ranging from 2 g/t to 8 g/t Au and some high grade intercepts of up to 16.8 g/t Au (Cunningham et al., 1988; Li and Peters, 1998; Peters, 2002).

The Carlin-type deposits in Guizhou include Lannigou, Zimuthang, Getang, Yata, Banqi, Ceyang, and Sanchahe and they are hosted predominantly by Permian carbonate and Triassic siliciclastic lithologies. Among these deposits, Lannigou is the largest deposit (80 t @ 7 g/t Au), followed by Zimuthang (60 t @ 5 g/t Au), Getang (22 t @ 6.2 g/t Au), Yata (-15 t @ -5 g/t Au) and Banqi (-10 t @ -5 g/t Au) (Taihe Zou et al., 2002; Hu Ruizhong et al., 2002) (Fig. 17). Similar to Carlin-type deposits in USA, they are mostly epigenetic hydrothermal micron-disseminated gold deposits with associated As, Hg, Sb + Tl mineralisation. Lead-zinc-copper, nickel-copper, and copper-tungsten-tin deposits are also widely distributed in Guizhou province (Fig. 18).

3.4. Guangxi Province

Guangxi province is bordered by Guangdong and Hunan at the east and northeast, Yunnan and Guizhou at the west and Vietnam to the southwest. A systematic geological survey in Guangxi began in 1965 by the Ministry of Geology and Mineral Resources of China and the Geology and Mineral Resources Bureau of Guangxi province. Guangxi province has the potential for tin, tungsten, lead, zinc, copper, iron, manganese, molybdenum, and gold deposits.

3.4.1. GIS coverage of geology for Guangxi

For GIS geology coverage, we digitised a 1:100,000 scale geological map from geological memoir Series 1, No. 3 on the Regional Geology of the Guangxi province (1985). A detailed digitised geological map of the Guangxi province is shown in Figure 19 together with polygon ID for each stratigraphic and lithologic unit. Middle Proterozoic to Quaternary beds are well distributed in Guangxi province.

3.4.2. MINDEP database for Guangxi

About 420 metallic and non-metallic mineral occurrences have been recorded for Guangxi (Fig. 20). Metal Mining Agency of Japan (MMAJ) has compiled 32 major mineral deposits in Guangxi province (www.mmaj.jp). The book "The Discovery History of Mineral Deposits-Guangxi" published in 1996 also contains spatial information for 256 metal and non-metal mineral occurrences in Guangxi province. Similar to Guizhou, this province has potential for Carlin-type gold deposits. The Carlin-type deposits in Guangxi include Gaolong, Huaping, Jinya, Lianshan, Nanlong, Luoluo, Mingshan, Siling and Xiangbo. Among these deposits, Jinya and Gaolong are large deposits with -30 t @ 5.3 g/t Au and 25 t @ 4 g/t Au (Hu Ruizhong et al., 2002) (Fig. 21). Lead-zinc-copper and tinsulphide deposits are also widely distributed in the province mainly associated with Yanshanian granites (Jurassic to Cretaceous) (Fig. 22). Stratatboud Pb-Zn occurrences such as Shiding (Sideng) Pb-Zn deposit also occur in Guangxi. These deposits are hosted in Devonian limestone, dolomite and sandstone, and Gu Lianxiang et al. (2000) indicate that they are
comparable to Sedex deposits. Similar Sedex-like deposits also occur in the Guangdong province (as discussed in the later section).

Yanshanian granite related tin-tungsten-sulphide skarn deposits also widely occur in the Guangxi province. The most notable example is the Dachang ore field, and numerous geochemical studies have been undertaken on these deposits (e.g., Tanelli and Lattanzi, 1985; Lattanzi et al., 1989; Fu et al., 1991, 1993; Peng et al., 1997). The Dachang ore field has about 100 Mt of ore at 1% Sn, 3 to 5% combined Cu, Pb, Zn and Sb and 100 to 300 g/t Ag making it one of the largest tin-polymetallic deposits in the world (Fig. 22). Major deposits include Changpo, Bali, and Longtaoshan tin-sulphide deposit, Lamo copper-zinc deposit, shale-hosted Dafulou deposit and Kangma vein-greisen deposit. The Dachang deposits such as Changpo-Lamo are similar to the Renison-style carbonate replacement tin deposits in western Tasmania (Kitto, 1998).

3.5. Hunan Province

Hunan province lies between latitude 24°00′–30°00′N and longitude 109°10′–114°15′E and is bordered by Guizhou and Sichuan at the west, Hubei to the north, Jiangxi to the east, and Guangxi and Guangdong to the south in total covering a land area of 210,000 km². Geological mapping was undertaken by the Ministry of Geology and Mineral Resources of China and the Geology and Mineral Resources Bureau of Hunan province. The province has potential for iron, lead, zinc, copper, tin, tungsten, bismuth, antimony, molybdenum, and uranium deposits.

3.5.1. GIS coverage of geology for Hunan

For GIS geology coverage, we digitised the 1:1,000,000 scale geological map from geological memoir Series 1, No. 8 on the Regional Geology of the Hunan (1988). A detailed digitised geological map of Hunan province is shown in Figure 22 together with polygon ID for each stratigraphic and lithologic unit. The stratigraphic sequence ranging from Middle Proterozoic to Quaternary units are well distributed in the province; a particularly complete Palaeozoic sequence is exposed.

3.5.2. MINDEP database for Hunan

About 323 metallic mineral occurrences have been recorded for Hunan (Fig. 24). Metal Mining Agency of Japan (MMAJ) has compiled 34 major mineral deposits of the Hunan province (www.mmaj.jp). The book "The Discovery History of Mineral Deposits-Hunan" published in 1996 also contains spatial information for metal and non-metal mineral occurrences of the Hunan province. The distribution of tungsten-tin and lead-zinc deposits is shown in Figure 25 and the gold deposits in Figure 26. The Hunan province has the potential to discover sizeable skarn-type and vein-type tungsten-polymetallic deposits. Many tungsten-tin-sulphide deposits are distributed in Hunan.

The Shizhuyuan deposit is the largest among the economically important skarn-greisen tungsten-polymetallic deposits in China (Jingweng Mao and Li Hongyan, 1995; Jingweng Mao et al., 1996a, b). These deposits occur along the contact between Upper Devonian dolomitic limestones and the Jurassic Yanshanian granitoids. The Shizhuyuan deposit is a very large low grade polymetallic calcic skarn deposit containing 800,000 tons of tungsten, 500,000 tons of tin, 200,000 tons of bismuth, 100,000 tons of molybdenum with beryllium, fluorine and copper. Recently a series of manganese skarn/veins with lead-zinc-silver mineralisation have been found in the area (Jingweng Mao et al., 1996a, b).

Lead-zinc skarn deposits are also found in Hunan (e.g., Huangshaping, Shuioukou and Kangjiawan) associated with Yanshanian granite magmatism (Nanshi Zeng et al., 2000). These lead-zinc skarn deposits also commonly contain high silver content as well as copper, gold, tungsten, molybdenum and bismuth. Most of the gold occurrences in the Hunan province are minor intrusive-related vein type and alluvial deposits derived from these veins (Fig. 26). A few intrusive-related uranium deposits are also found in Hunan but no spatial data are available.

3.6. Guangdong Province

Guangdong province is the southernmost province of China, bordered by Guangxi to the west, Fujian to the east, Hunan and Jiangxi to the north, and South China Sea to the south covering a land area of more than 200,000 km². The province has undergone complex tectonic, magmatic and volcanic activities associated with the Caledonian (Early Palaeozoic), Variscan (Late Palaeozoic), Indosinian (Triassic), Yanshanian (Jurassic-Cretaceous), and Himalayan (Tertiary) Orogenies. The intrusive rocks are genetically and closely related to iron, lead, zinc, copper, tin, tungsten, and rare-metal mineralisation.

3.6.1. GIS coverage of geology for Guangdong

For GIS geology coverage, we digitised the 1:1,000,000 scale geological map from geological memoir Series 1, No. 9 on the Regional Geology of the Guangdong (1988). Regional geological mapping of the Guangdong province on a scale of 1:200,000 commenced in 1950, and the 1:1 000, 000 scale geological map is based on the 1:200,000 maps. A detailed digitised geological map of Guangdong province is shown in Figure 27 together with polygon ID for each stratigraphic and lithologic unit. It is
interesting to note that the oldest rock unit in the Guangdong province is the Sinian sediments.

### 3.6.2. MINDEP database for Guangdong

About 310 metallic mineral occurrences have been recorded for Guangdong (Fig. 28). Metal Mining Agency of Japan (MMAJ) has compiled 33 major mineral deposits of the Guangdong province (www.mmaj.jp). The book ‘The Discovery History of Mineral Deposits—Guangdong’ published in 1996 also contains spatial information for metal and non-metal mineral occurrences of the Guangdong province. The distribution of lead-zinc deposits is shown in Figure 29 and the gold deposits in Figure 30. Guangdong is a major producer of lead, zinc, copper and pyrite in China and has significant stratabound lead-zinc-silver-antimony deposits (e.g., Fankou), copper-lead-zinc-tungsten deposit (e.g., Dabaoshan) and pyrite deposits (e.g., Hongyan deposit) (Gu Lianxing et al., 1992, 2000, in preparation, 2002). The Fankou deposit (42 Mt @ 10 % Zn, 4.8 % Pb, and 101 g/t Ag) and Dabaoshan deposit (126 Mt @ 0.72 % Cu and 21 Mt @ 4 % Zn and 2.3 % Pb) are the most important deposits (Fig. 29). These deposits are hosted in Devonian Carboniferous limestone, siltstone and sandstone. The tectonic setting of these deposits is poorly documented but it is suggested to be an intracratonic basin (Gu Lianxing et al., 1992, 2000, in preparation, 2002) or intra-arc trough between the island-arc (Zhu Shangqin and Chi Sanchuan, 1993). The ore metals are Pb, Zn, and Cu with recoverable W, Sn, Ag, Au, Sb, Hg, U, Bi, Tl and Mo. Ore mineralogy is sphalerite, galena, pyrite, chalcopyrite with minor scheelite and stibnite.

The deposits show vertical and lateral stratigraphic zonation. The general trend from the base upwards is Fe-sulphide>Cu>(Cu-W)>Pb>Zn-Fe>Mn-carbonates, and laterally from feeders they show Cu>W>Pb>Zn-Ag-Fe>Mn zonation. The deposits are commonly controlled by the host rock lithology and growth faults (e.g., Fankou). Under the strataform ores in some deposits, there are fissure-filings, brecci-caementing and impregnated mineralisation that represent the submarine hydrothermal feeder zone, and sub-seafloor replacement of host limestone in the feeder zone. This is recognised at Fankou (per. comm. Gu Lianxing, 2000). These deposits have been compared with Sedex deposits (Gu Lianxing et al., 1993, 2000, in preparation, 2002). Although further detailed geological and geochemical studies are required to understand the origin of these deposits, the presence of the Sedex-like stratabound deposit in South China, however, suggest potential for the discovery of large Sedex deposits in the region.

Guangdong province also has significant mylonite-hosted, mesothermal gold deposits (e.g., Gaocun and Yunxi deposits, also known as Hetai goldfields), stretching from southeastern Guangxi to western Guangdong (Fig. 30). At least six major deposits have been discovered in the field since 1982 making it the largest goldfield in South China (Wang et al., 1997; Guilin Zhang et al., 2001). The gold mineralisation is confined to a series of ductile shear zones in the Yunkai metamorphic rocks (mica schist, feldspar-mica schist, and mica gneiss) of Sinian age. These rocks have been later affected by the Hercynian-Indosinian Orogeny resulting in a series of ENE oriented ductile shear zones (mylonite belts). The Gaocun deposit is hosted in one of these shear zones. The deposit is the largest in the field and has been mined since 1989. Prior to mining, it was estimated to contain 30,700 kg of gold grading 3 g/t Au with intersection as high as 73 g/t Au in sulfidic ores (Guilin Zhang et al., 2001). The Guangdong province has a few porphyry tungsten deposits (e.g., Lianhuashan) (Mutschler et al., 1999).

### 3.7. Jiangxi Province

Jiangxi province is bordered by Hunan and Hubei to the west, Anhui to the north, Zhejiang and Fujian to the east and Guangdong to the south. Jiangxi province is bounded by latitude 24°29′–30°04′N and longitude 113°48′–118°28′E, covering an area of 166,900 km² with a population of 41 million. The province has excellent potential for tungsten, tin, lead, zinc, and copper-gold deposits.

### 3.7.1. GIS coverage of geology for Jiangxi

For GIS geology coverage, we digitised the 1:500,000 scale geological map from geological memoir Series 1, No. 20 on the Regional Geology of the Jiangxi (1990). Jiangxi Bureau of Geology and Mineral Resources carried out regional geological mapping of the Jiangxi province on a scale of 1:200,000 and compiled the 1:500,000 scale geological map. A detailed digitised geological map of Jiangxi province is shown in Figure 31 together with polygon ID for each stratigraphic and lithologic units.

### 3.7.2. MINDEP database for Jiangxi

About 220 metallic and non-metallic mineral occurrences have been recorded for Jiangxi (Fig. 32). Metal Mining Agency of Japan (MMAJ) has compiled 33 major mineral deposits in Jiangxi province (www.mmaj.jp). The book ‘The Discovery History of Mineral Deposits—Jiangxi’ published in 1996 also contains spatial information for metal and non-metal mineral occurrences in Jiangxi province. The distribution of tungsten-tin and lead-zinc deposits is shown in Figure 33 and the copper and gold deposits in Figure 34. The most important vein-type tungsten
deposit is Xihuashan, Dangping and Piaotang (Yan et al., 1980; Wu and Mei, 1982; Tanelli, 1982; Giuliani, et al., 1988). Similar vein-type deposits are also found in adjacent Myanmar (e.g., Mawchi mine, Khin Zaw and Khin Myo Thet, 1983, Hernyungyi Mine, Khin Zaw, 1978). The Mawchi Mine was one of the largest W (Sn) deposits in the world before World War II.

The province has potential for porphyry copper-gold-(molybdenum-silver) mineralisation. The Dexiong district in the Jiangxi province is the largest porphyry copper ore field in China (1500 Mt ore @ 0.43 % Cu, 0.02 % Mo, 0.16 g/t Au and 1.9 g/t Ag approximately equivalent to 6.45 Mt Cu, 0.25 Mt Mo, 24 t Au and 285 t Ag) (Yusheng Zhai et al., 1997; Mutschler et al., 1999; Wenwu He et al., 1999). The Dexiong deposits are associated with granodiorite porphyries of Yanshanian age (148–170 Ma) that intruded slate and phyllite of the Mesoproterozoic Shuangjiaoshan Group. The granodiorite porphyries lie along the intersection of a NW trending fault and NE trending anticlinal axis. The three orebodies, Tongchang, Fujiau and Zhushahong are pipe-like in profile and circular in plan, with the largest, Tongchang, being 0.7 km in diameter. The contact zone between the porphyry and the host rocks is metamorphosed to hornfels. It is interesting to note that two thirds of the copper reserves in the Tongchang deposit are in the country rock and the contact zone. The ore minerals are pyrite, chalcopyrite, molybdenite, tennantite, bornite, and electrum. The other Au-rich porphyry is the Yinshan deposit (1 Mt metal @ 1.7 % Cu, 59 t @ 2 g/t Au).

The Jiangxi province also has porphyry-related Cu–Fe–Au skarn system associated with multiple phases of Yanshanian intrusions into carbonate-rich sequences that formed the Lower to Middle Yangtze River metallocgenic belt (e.g., Taihe Zhou, 1995, 1999; Yusheng Zhai et al., 1996; Yiming Zhao et al., 1999; Yuanming Pan and Ping Dong, 1999; Yanjiang Chen et al., in preparation, 2002), and this belt accounted for more than 600 Mt Au in China. The most important Au-rich porphyry/skarn deposits in the Jiangxi province are Chengmenshan (1.7 Mt metal @ 0.76 % Cu, 57 t @ av. 0.25 g/t Au and 224 t @ 9.9 g/t Ag), and Wushan (2.48 Mt metal @ 1.38 % Cu, 67 t @ av. 0.5 g/t Au). This metallogenic belt extends into Hubei, Anhui and Jiangsu provinces (see below).

3.8. Hubei Province

Hubei province is located in the middle regions of the Yangtze River at latitude 29°05′–33°20′N and longitude 110°21′–116°07′E and is bordered by Shaanxi, Henan and Anhui to the north, Sichuan to the west, and Guizhou, Hunan and Jiangxi provinces to the south covering an area of 185,000 km². The province constitutes two geologically important tectonic domains: the Qinling fold belt to the north and west and the Yangtze craton to the east and south. Magmatic activity related to Caledonian and Yanshanian-Himalayan orogeny in the Hubei province are genetically and closely related to iron, lead, zinc, copper, tin, tungsten, and rare metal mineralisation in the province.

3.8.1. GIS coverage of geology for Hubei

For GIS geology coverage, we digitalised the 1:500,000 scale geological map from geological memoir Series 1, No. 20 on the Regional Geology of the Hubei (1990). Hubei Bureau of Geology and Mineral Resources carried out regional geological mapping of the Hubei province on a scale of 1:200,000 and compiled the 1:500,000 scale geological map. A detailed digitised geological map of Hubei province is shown in Figure 35 together with polygon ID for each stratigraphic and lithologic units. Hubei province has well-developed Early Proterozoic strata forming part of the Qinling-Dabie fold belt between the North and South China Cratons. The Sinian and Palaeozoic sequence are also widely distributed in Hubei.

3.8.2. MINDEP database for Hubei

About 219 metallic mineral occurrences have been recorded for Hubei (Fig. 36) from published literature. Metal Mining Agency of Japan (MMAJ) has compiled 13 major mineral deposits of the Hubei province (www.mmaj.jp). The book ‘The Discovery History of Mineral Deposits of China-Hubei’ published in 1996 also contains spatial information for metal and non-metal mineral occurrences of the Hubei province. The distribution of lead-zinc deposits is shown in Figure 37 and the copper-gold deposits in Figure 38. The Hubei province hosts major Cu–Au metallogenic belt of China along the lower Yangtze River that extends west into Anhui, and consists of significant Cu–Fe or Pb–Zn skarn deposits with high precious metal credits.

The most significant deposits are Tonglushan (1 Mt metal @ 1.8 % Cu, 69 t @ 1.15 g/t Au), Jilongshan (0.3 Mt metal @ 1.6 % Cu, 37 t @ 4 g/t Au), Fengshandong (0.7 Mt metal @ 1.2 % Cu, 16 t @ 0.38 g/t Au), Shitouzui (1 Mt metal @ 1.8 % Cu, 19 t @ 0.5 g/t Au), and Jiguanzui (20 t @ 4.87 g/t Au). Some skarn deposits are Mo- and tungsten-rich (e.g., Tongshankou, Fengshandong, Longjiangshan). Most of the deposits are located in the Daye district, and associated with multiple Yanshanian diorite-granodiorite intrusions. The country rocks are mainly Triassic carbonates and less commonly Carboniferous and Permian carbonates (e.g., Yuanming Pan and Ping Dong, 1999). Major ore minerals are chalcopyrite, chalcocite, bornite, pyrite, molybdenite, pyrite, magnetite, galena, sphalerite, tetrahedrite and...
pyrrhotite. The Hubei province also hosts gossan type gold deposit (also known as invisible gold in weathered supergene zone up to 5 g/t Au) (e.g., Shewushan) (Hong Hanlie et al., 1999).

3.9. Anhui Province
Anhui province is located at latitude 29°26'-34°38'N and longitude 114°45'-119°45'E and bordered by Henan to the west, Shandong to the north, Jiangsu at the west, and Zhejiang and Jiangxi provinces to the south covering an area of 139,000 km². The Yangtze River passes through the province, and the southern part of the province is mountainous with higher relief than the northern part. The Yanshanian magmatic intrusions into carbonate-rich Mesozoic (Triassic) sequences generated an important metallogenic episode forming the largest and richest skarn type iron, copper, gold and silver deposits in China.

3.8.1. GIS coverage for geology for Anhui
For GIS geology coverage, we digitised the 1:500,000 scale geological map from geological memoir Series 1, No. 5 on the Regional Geology of the Anhui province (1987). This 1:500,000 scale geological map is based on the geological survey on a scale of 1:200,000. A detailed digitised geological map of Anhui province is shown in Figure 39 together with polygon ID for each stratigraphic and lithologic units. Similar to Hubei, the Anhui province has well-exposed Early Proterozoic strata forming part of the Qidong-Dabie fold belt between the North and South China cratons. Sinian and Palaeozoic sequences are also widely distributed.

3.8.2. MINDEP database for Anhui
About 152 metallic mineral occurrences have been recorded for Anhui (Fig. 40). Metal Mining Agency of Japan (MMAJ) has compiled 15 major mineral deposits for Anhui province (www.mmaj.jp). The book “The Discovery History of Mineral Deposits of China-Anhui” published in 1996 also contains spatial information for metal and non-metal mineral occurrences in Anhui. The distribution of lead-zinc and copper-gold deposits is shown in Figure 41 and the gold deposits in Figure 42. As in the case of Hubei, the Anhui province consists of the western extension of the Cu-Au metallogenic belt of China along the lower Yangtze River. Most of the skarn deposits are porphyry related and cluster in the Tongling district, which is a major producer of copper, iron with a potential for economic zinc, lead, gold and silver. The deposits consist of Fe-Cu-Au, Cu-Au-Mo, Cu-Au, and Au-Cu metal associations.

The deposits are larger in size than those of Hubei and contain more iron and gold. The largest deposits are Xinqiao (0.5 Mr t metal @ 0.7 % Cu, 24 Mr t metal @ 46 % Fe, 105 t Au @ 0.3 % g/t Au in sulphide ore and 11.2 t Au @ 4.7 g/t Au in oxide ore), Manshan-Tiamashan (32 t @ 6.5 g/t Au), Shizishan (46 t @ 0.3 g/t Au) and Huangshiaoshan (13.5 t @ 5.8 g/t Au) (Guojian Xu, 2001; Taihe Zhou et al., 2002, Yinjiang Chen et al., in preparation, 2002). These skarn deposits mostly have copper grades of more than 1 % (e.g., Tongguanshan, 1.8 % Cu, Fenghuangshan, 1.24 % Cu). These deposits are commonly deformed or have been generated by multiple ore-forming episodes resulting in remobilisation and enrichment of metals. For instance, the largest Xinqiao Cu-Fe-S-Au-Ag deposit was considered to have formed as a Sedex deposit during the Early Carboniferous and was later overprinted by a skarn system related to Yanshanian diorite (110-168 Ma) (Guojian Xu, 2001; Gu Lianxing et al., in preparation, 2002). This resulted in high gold enrichment (116 t), although most of the gold is locked in chalcocylite or pyrite.

Iron only deposits are also abundant in Anhui province (e.g., Changlongshan Fe deposit). The Changlongshan deposit is hosted in Middle Carboniferous to Lower Permian limestones and contains 29 Mt of met grade 35.9-58.6 % Fe (Guojian Xu, 2000). Although these deposits are considered skarn deposits or Sedex overprinted by Yanshanian metasomatism. They are commonly stratabound or stratiform, at a distance from outcropping intrusive rocks and have abundant hematite and a high REE content. Olympic Dam type deposits or IOCG (Iron Oxide Copper-Gold) deposit styles (e.g., Hitzman et al., 1992; Bartor and Johnson, 1996; Davidson and Large, 1998) in Anhui province and in the other Middle to Lower Yangtze River provinces should be considered as potential exploration targets. Anhui province also has a porphyry Cu deposit (e.g., Shaxi deposit) associated with Late Jurassic to Early Cretaceous quartz diorite porphyry that intruded Silurian argillaceous siltstone and Jurassic sandstone (e.g., Yuanming Pan and Ping Dong, 1999).

3.8. Jiangsu Province and Shanghai City
Jiangsu province and Shanghai City are located at latitude 30°42'-35°08'N and longitude 116°20'-121°54'E. The province and the city are bordered by the East China Sea to the east, Anhui province to the west, Shandong province to the north and Zhejiang province to the south. Jiangsu province is hilly land in the western part and consists of mostly plains and lakes in the eastern part covering a total area of 108,000 square kilometers. The regional geology of Jiangsu province is characterised by Late Archean to Early-Middle Proterozoic flysch, ferruginous chert and siltite-karstophyte association followed by the Late Proterozoic clastic sequences. Sinian and Palaeozoic
carbonate and clastic sequences are also exposed in the province. Mesozoic marine carbonates and Quaternary sediments cover most of the eastern part of the province. Considerable iron, copper, lead, zinc and silver deposits are found in the Palaeozoic and Mesozoic sedimentary rocks. Yanshanian (Jurassic-Cretaceous) magmatic-volcanic activity was also accompanied by iron, copper, lead, zinc, silver and gold deposits.

3.8.1. GIS coverage of geology for Jiangsu
For GIS geology coverage, we digitised the 1:500,000 scale geological map from geological memoir Series 1, No. 1 on the Regional Geology of the Jiangsu province (1984). Geological studies in the Jiangsu province started as early as 1920 and probably constitutes the earliest geological survey program in China. Academic staff from the University and Institutions in China (e.g., Nanjing University) and some geologists from Germany and France were also involved in the geological mapping and research work. Systematic geological mapping was started by the Jiangsu Geological Bureau from 1950 to 1970 and a geological map on a scale of 1:500,000 scale was produced in 1984. A detailed digitised geological map of Jiangsu province is shown in Figure 43 together with polygon ID for each stratigraphic and lithologic unit.

3.8.2. MINDEP database for Jiangsu
About 104 metallic mineral occurrences have been recorded for Jiangsu (Fig. 44). Metal Mining Agency of Japan (MMAJ) has compiled four major mineral deposits for Jiangsu province (www.mmaj.jp). The book 'The Discovery History of Mineral Deposits of China-Jiangsu' published in 1996 also contains spatial information for 79 metal and non-metal mineral occurrences. The remainder of the deposit data were acquired from published literature. The distribution of lead-zinc and gold deposits is shown in Figure 45. As the province is covered with Cenozoic sequences, mineral deposits are found only in the lower part of the Yangtze River part of the province. The province has major iron occurrences and some lead, zinc, copper and gold skarn deposits (e.g., Funiu Shan, 9 t @ 0.85 g/t Au). The Qixiashan Pb-Zn-Mn-Au-Ag deposit is considered as a Sedex deposit which is hosted in Carboniferous dolomite, limestone, shale and sandstone (Gu Lianxing et al., 2000), although it was overprinted by a skarn system associated with Yanshanian magmatism (Fig. 45). The deposit contains 0.4 Mt metal @ 2.6 % Pb, 0.8 Mt metal @ 0.8 % Zn and 0.4 Mt metal @ 17 % Mn with gold credits (27 t @ 0.9 g/t Au) (Gu Lianxing et al., in preparation, 2002; Yanjiang Chen, in preparation, 2002).

3.9. Fujian and Zhejiang Province
Fujian and Zhejiang provinces are located in the southwestern part of China with extensive coastlines to the east, and are bordered by Jiangxi, Anhui and Jiangsu to the west and north. The Taiwan Strait lies between the Fujian and Zhejiang coastlines and Taiwan Island. Fujian and Zhejiang provinces have similar areas. Fujian covers an land area of 121,300 km² (about the size of England) with a population of 20 million, and the Zhejiang has a land area of 108,800 km² with a population of more than 45 million. The topography is dominated by rolling hills in the northern and eastern coastal areas, and several islands stretch along the offshore region in the east.

Both Fujian and Zhejiang province have exposed rock sequences ranging in age from Upper Proterozoic, Sinian, Palaeozoic to Quaternary, and are characterised by multiple magmatic activities associated with Jinningian, Caledonian, Variscan-Indosinian, Yanshanian and Himalayan orogeny. These multiple orogenic and magmatic-volcanic events have close genetic relationships with metallic ore formation. Extending from Guangdong province, Fujian and Zhejiang had the most extensive Indosinian and Yanshanian intrusive-volcanic activities that formed an integral part of the South China fold belt consisting of a series of island arcs. The South China fold belt is a northwest extension of the Circum-Pacific metallogenic belt. Endogenous ore deposits such as tungsten, tin, molybdenum, beryllium, copper, niobium, tantalum, iron, and boron are associated with magmatic intrusions in the northwest part of Zhejiang, and molybdenum, lead, zinc, gold, silver and other non-metals such as alunite and pyrophyllite, fluorite and bentonite are associated with volcanism in the southeastern part of Zhejiang. Similarly rare metals, molybdenum, lead, zinc, copper, REE, tungsten, iron, gold and silver are moderately abundant in Fujian province.

3.9.1. GIS coverage of geology for Fujian and Zhejiang
For GIS geology coverage of Fujian and Zhejiang, we digitised the 1:500,000 scale geological map from geological memoir Series 1, No. 4 on the Regional Geology of the Fujian province (1985), and the 1:500,000 scale geological map from geological memoir Series 1, No. 11 on the Regional Geology of the Zhejiang (1989). Fujian Bureau of Geology and Mineral Resources carried out regional geological mapping of the Fujian on a scale of 1:200,000 as early as 1911, and compiled the 1:500,000 scale geological map. Zhejiang Bureau of Geology and Mineral Resources undertook a regional geological mapping on a scale of 1:200,000 between 1959 and 1980 and
produced the 1:500,000 scale geological map. Detailed
digitised geological maps of Fujian and Zhejiang
provinces are shown in Figures 46 and 47 together with
polygon ID for each stratigraphic and lithologic unit.

3.9.2. MINDEP database for Fujian and Zhejiang
About 132 metallic and non-metallic mineral
occurrences for Fujian and 166 deposits for Zhejiang
have been recorded (Figs 48 and 49). Metal Mining
Agency of Japan (MMAJ) has compiled nine major
mineral deposits of Fujian and 7 for Zhejiang provinces
(www.mmaj.jp). The book 'The Discovery History of
Mineral Deposits of China-Fujian and Zhejiang'
published in 1996 also contains spatial information
for metal and non-metal mineral occurrences in Fujian
(76) and Zhejiang (90). The distribution of lead-zinc
and gold deposits in Fujian and Zhejiang are shown in
Figures 50 and 51.

These two provinces cover the South China foldbelt
along the southeastern margin of the Yangtze craton
and are characterised by well-developed Yanshanian
intrusive to subvolcanic rocks associated with porphyry
to epithermal copper-gold mineralisation. The most
important example is Zijinshan district where the only
high-sulphidation epithermal system in China has been
reported. This is located 17 km north of Shaogang
(Chil-Sop So et al., 1998). The district accounted for
at least 100 Mt of ore containing at least 1.6 Mt metal
@ 1.09 % Cu and 15 t of Au @ 0.14 g/t Au and 619 t
of Ag @ 6.2 g/t Ag (Chil-Sop So et al., 1998; Mutschleit
et al., 1999) (Fig. 50). The Zijinshan deposits are
associated with a Cretaceous volcanic and/or sub-
volcanic dome of dacitic composition. The mineralised
granodiorite porphyry occurs as a steeply dipping pipe
intruding S-type Jurassic granite and Late Proterozoic
phyllite and metasiltstone. The deposits show typical
epithermal high-sulphidation alteration zonation
assemblages from the deep sercite+ quartz+ pyrite
(phylllic) upward to dickite+ quartz+ pyrite and
alunite+quartz+pyrite. High copper is typically
developed within the alunite alteration zone and shows
gradual change of ore assemblages from digenite and
enargite at deeper levels to covellite and gold in
shallower levels. Subeconomic chalcopyrite+
tennantite-bornite mineralisation is associated with the
deep phyllic alteration zone (Chil-Sop So et al.,
1998). Similar high-sulphidation Cu-Au deposits are
found in adjacent SE Asian country (e.g., Monywa
deposit in Myanmar, Khin Zaw et al., 1999a).

Zhejiang province is characterised by Proterozoic
and Palaeozoic sequences of the Yangtze craton and the
South China foldbelt separated by NE trending
faults and ophiolitic melange along the southwestern
Pacific margin. Gold and base metal mineralisation in
the province is related to the plate interaction along
this Pacific margin (Pirajno et al., 1996, 1997, 2002).
The Cu-Au mineralisation is attributed to the
Yanshanian tectono-magmatic activity, which resulted
from the northeast subduction of the Pacific plate. The
mineral deposits of Zhejiang province show a wide
variety of styles and types, and were the subject of
collaborative studies by the Department of Geology
and Mineral Resources of Zhejiang province and the
Geological Survey of Western Australia during 1994–
deposits in Zhejiang province include precious (Au-
Ag) and polymetallic copper-lead-zinc with precious
metal credits as well as a number of industrial minerals
(e.g., kaolin, fluorite).

The most important Cu-Au deposit is the vein-type
Zhilingtou (2 Mt ore grading 12 g/t Au, 306 g/t Ag
approximately equivalent to 18 t Au and 494 t Ag
(Guoqian Xu, 1995; Pirajno et al., 1996, 1997, 2002)
(Fig. 51). The deposit is hosted in orthogneiss and
paragneiss of Early Proterozoic age, overlain by
intermediate to felsic volcanics of late Jurassic to
Cretaceous age. The mineralised veins are gold and
silver-rich or copper-, lead- and zinc-rich, and occur
as stockwork, veins and breccia. The ore minerals are
pyrite, sphalerite, galena, chalcopyrite, pyrrhotite,
electrum and rare hessite and sylvanite. The gangue
minerals include a variety of quartz from smoky to
vuggy texture, sericite, chlorite, rhodocite and
rhodochrosite. Geological, fluid inclusions and K-Ar
age data suggest that although the deposit is hosted in
the Precambrian metamorphic rocks, the
mineralisation is related to Yanshanian magmatism and appears
to be similar to an epithermal style deposit (Guoqian
Xu, 1995). Many epithermal deposits tend to be silver
only or silver dominant and can be classified as
epithermal silver deposits (e.g., Dalinkou deposit).

Zhejiang province also has structurally controlled,
shear-zone hosted, orogenic gold deposits (e.g.,
Haungshan gold deposit, 3.3 t @ 9 g/t Au). The deposits are hosted in basement rock (Proterozoic
diorite) associated with Mesozoic volcanic rocks
(Pirajno et al., 1996, 1997, 2002). The Huangshan orebody strikes 60° and dips 40–70° SE and is localised in
the sheared diorite. The ore minerals are pyrite, galena
and rare arsenopyrite, hessite and calaverite. Gold
occurs as in-fills in the pyrite. The gangue minerals are
sericite, ankerite, chlorite, muscovite, calcite and
tourmaline. The province has potential for volcanic-
hosted epithermal and mesothermal lead, zinc, copper
and precious metal deposits.

3.8. Shandong Province
Although most workers consider that the northern part of the
Shandong province is in the North China
Terrane, we included it in our database for the
Shandong province in order to compare and contrast the palaeogeographic, tectonic and metallogenic relations of the South and North China Terranes. Shandong province is bounded by latitude 34°23–38° 24'N and longitude 114°48–122°42'E covering an area of 156,700 km² with a population of 88 million. Shandong province has very substantial gold mineralisation in the Jiaodong Peninsula. The province has unique world class granite-hosted orogenic gold deposits, and the history of gold mining in the province dates back to the Tang Dynasty (907 AD). Shandong province is currently the most important gold province in China, both in terms of gold production (55 t Au in 2000), and ore reserves (more than 900 t Au). Many world class (>100 t Au) gold belts have been found in the province during the last two decades (Yumin Qiu et al., 2002).

3.8.1. GIS coverage of geology for Shandong
For GIS geology coverage, we digitised the 1:500,000 scale geological map from geological memoir Series 1, No. 26 on the Regional Geology of the Shandong province (1991). Detailed digitised geological maps of Shandong province is shown in Figure 52 together with polygon ID for each stratigraphic and lithologic unit.

3.8.2. MINDEP database for Shandong
About 340 metallic and non-metallic mineral occurrences have been recorded for Shandong (Fig. 53). Metal Mining Agency of Japan (MMAJ) has compiled 33 major mineral deposits in Shandong province (www.mmaj.jp). The book “The Discovery History of Mineral Deposits of China-Fujian and Zhejiang” published in 1996 also contains spatial information for metal and non-metal mineral occurrences of the Shandong province. The distribution of gold deposits is shown in Figure 54.

Considerable geological and ore deposit research in the Shandong province has been undertaken by Chinese and overseas geologists (e.g., Jiuhua Xu et al., 1994; Yusheng Zhai, 1997; Wang et al., 1998; He Zhili et al., 1989; Taihe Zhou and Guixian Lu, 2000; Yumin Qiu et al., 2002 and references therein). Most of the gold deposits in the Shandong province are located in the Jiaodong Peninsula that is located in the North China Terrane. The peninsula is characterised by Archean and Proterozoic rocks intruded by Mesozoic granitoids. The gold mineralisation occurs as vein-type (Linglong type) and disseminated to stockwork style deposits (Jiaojia type). The majority of the deposits are hosted in granitoids and account for more than 90% of the gold resources. Recent detailed geological and SHRIMP geochronological studies indicate that the gold mineralisation is related to the two Yanshanian magmatic events (160–150 Ma and 130–126 Ma) (Wang et al., 1998; Yumin Qiu et al., 2002).

Most of the deposits are structurally controlled along prominent NNE trending brittle-ductile shear zones, and associated with silicification, sericitisation and K-feldspar alteration. The orebodies vary from tens of meters to 2000–3000 m in length, 2 mm to 3–6 m in thickness and tens of metres to 500–600 m in depth. The ore minerals are native gold, electrum, pyrite, chalcopyrite, magnetite, pyrrhotite, galena and sphalerite.

The most important gold deposits are Linglong deposit (>100 t @ 3-30 g/t Au), Sanshandaosu deposit (>60 t @ 7 g/t Au), Jiaojia (>60 t @ 7 g/t Au), Xincheng (>60 t @ 8 g/t Au), Wangershan (45 t @ 7-8 g/t Au), Jingjing Ridge (25 t @ 9 g/t Au), Donggerzhuang (20 t @ 11 g/t Au), Helectric and Shangzhuang -20 t @ 7 g/t Au), and few others with 5 to 10 t Au @ 3-6 g/t Au. This province is the richest gold region in China and one of the largest granitoid-hosted orogenic gold belts in the world.

4. GEOCHRONOLOGY DATA COMPILATION
At the suggestion of the sponsors, we undertook a GIS compilation of geochronological data for South China. We made a literature review of previous geochronological studies in South China. Although there were geochronological studies, and data were presented in papers, journals and reports, no detailed and reliable spatial information for location and co-ordinates (latitude/longitude) of the sample points were available. However, considerable amounts of geochronological information are present on the maps from the geological memoir series produced by the various Bureaux of Geology and Mineral Resources. We compiled these data and presented to the sponsors in CD-ROM. All provinces in South China have age data except Guizhou province and the geochronological data were compiled from the following maps of each province:

(1) Magmatic Rock Map of Yunan Province (Attached Map 2 of Regional Geology of Yunan Province), 1:1,000,000 scale
(2) Magmatic Rock Map of Sichuan, 1:1,000,000 scale
(3) Magmatic Rock Map of the Guangxi Zhuang Autonomous Region of the People's Republic of China, 1:1,000,000 scale
(2) Magmatic Rock Map of Hunan Province, 1:1,000,000 scale
(3) Magmatic rocks Map of Guangdong Province, 1:1,000,000 scale
(4) Magmatic Rock Map of Jiangxi Province (Attached map 2 of Regional Geology of Jiangxi Province), 1:1,000,000 scale
(5) Magmatic Rock Map of Hubei Province, 1:1,000,000 scale
(6) Magmatic Rock Map of Anhui Province, 1:1,000,000 scale
(7) Geological Map of Bedrock of Jiangsu Province & Shanghai Municipality, 1:500,000 scale
(8) Intrusive Map of Fujian Province (Attached map 3 of Regional Geology of Fujian Province) 1:1,000,000 scale
(11) Magmatite Map of Zhejiang Province (Attached Map 2 of Regional Geology of Zhejiang Province) 1:500,000 scale
(9) Magmatite Map of Shandong Province (Attached Map 2 of Regional Geology of Shandong Province) 1:1,000,000

Altogether 1067 geochronological data points have been recorded (73 for Yunnan, 197 for Sichuan, 120 for Guanxi, 117 for Hunan, 194 for Guangdong, 97 for Jiangxi, 41 for Hubei, 52 for Anhui, 3 for Jiangsu, 77 for Fujian, 61 for Zhejiang and 35 for Shandong). Figures 55, 56, 57 and 58 show examples of the distribution of the geochronological data. The methods for geochronological data for South China involve largely K-Ar, Rb-Sr and U-Pb analyses for individual minerals or whole rock.

5. CONCLUSIONS

Geology coverages have been completed for Yunnan, Sichuan, Guizhou, Guangxi, Hunan, Guangdong, Jiangxi, Hubei, Fujian, Anhui, Zhejiang, Jiangsu and Shandong covering the entire South China Terrane provinces. CD-ROMs including geology and mineral deposit data for these provinces are presented to the sponsors with this report. Compilation of extensive and voluminous information on geology for these provinces consumes considerable time to include detailed stratigraphic and lithologic units. Table 1 shows how the project was progressed to complete the studies as proposed in the original document.

Table 1. Completed time schedule for GIS module during the time frame of the project.

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Note: Red line denotes completed program during the timeframe of the project.
The geological maps of each province have been placed onto the Digital Chart of the World, which is used as a base map for the project. In this project, we also made regional correlations of the broader tectonostratigraphic units in South China and structural history of the region. Altogether more than 3300 mineral deposits and occurrences have been spatially compiled with forty attributes from the published literature.

Metallogenic relations of the South China Terrane are summarised below:

Yunnan: At least five different styles of lead-zinc-silver mineralisation occur in Yunnan: (1) sedimentary exhalative (Sedex) deposits (e.g., Tertiary Jingding/Lanping 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 copper in Sn-W vein and skarn deposits (e.g., Mengzimiao). Yunnan also has potential for Carlin-type and mesothermal gold, porphyry copper-gold, sedimentary copper and mafic-ultramafic-hosted Ni-Cu deposits.

Sichuan: The province has significant stratabound lead-zinc-silver deposits, Carlin-type gold deposits and ultramafic-hosted Cu-Ni deposits. At least, two major styles of lead-zinc-silver mineralisation occur in Sichuan: (1) Volcanic-hosted massive sulphide (VHMS) deposits (e.g., Triassic Gacun deposit), and (2) MVT deposit (e.g., Sinian Daliangzi deposit). Sichuan has excellent potential for discovery of world class micro-disseminated Carlin-type gold deposits. Many Carlin-type deposits are distributed in NW Sichuan, GanSu and Shaanxi, an area also known as the northern Golden Triangle of China.

Guizhou and Guangxi: The two provinces are part of the southern Golden Triangle of China, which forms the region at the junction of Yunnan, Guizhou, and Guangxi provinces. This region has excellent potential for Carlin-type gold deposits. They also have stratabound base metal tin deposits and, in particular, Guangxi province has important world class tin deposits such as the Dazhang deposit.

Hunan and Guangdong: These provinces have many polymetallic lead-zinc deposits associated with Indosinian (Triassic) and Yanshanian (Jurassic to Cretaceous) magmatism (e.g., Shiziyuan deposit). Significant Devonian to Carboniferous stratabound base and precious metal mineralisation also occurs in these provinces and appears to be similar to Sedex type deposits (e.g., Fankou and Dabaoshan deposits).

Jiangxi and Hubei: This province has major vein-type tungsten-tin-bismuth-beryllium-sulphide deposits associated with Yanshanian magmatism (e.g., Xihuashan deposit), and the largest porphyry copper deposit in China (e.g., Dosing deposits). Dosing has 1500 Mt ore @ 0.43 % Cu, 0.02 % Mo, 0.16 g/t Au and 1.9 g/t Ag approximately equivalent to 0.45 Mt Cu, 0.25 Mt Mo, 24 t Au and 285 t Ag. Au-(Ag-Mo)-rich porphyry-related Cu-Fe skarn deposits are also found in Jiangxi (Chengmenshan, 1.7 Mt @ 0.76 % Cu, 57 t @ 0.25 g/t Au and 224 t @ 9.9 g/t Ag, and Wushan, 2.48 Mt @ 1.38 % Cu, 67 t @ 0.5 g/t Au). This part of the Jiangxi province is also part of the Lower to Middle Yangtze River metallogenic belt that accounted for more than 600 t Au. This metallogenic belt extends into Hubei, Anhui and Jiangsu provinces. The most significant deposits are Tonglushan (1 Mt @ 1.8 % Cu, 69 t @ 1.15 g/t Au), Jilongshan (0.3 Mt @ 1.6 % Cu, 37 t @ 4 g/t Au), Fengshandong (0.7 Mt @ 1.2 % Cu, 16 t @ 0.38 g/t Au), Shitouzi (1 Mt @ 1.8 % Cu, 19 t @ 0.5 g/t Au), and Jiguanzi (20 t @ 4.87 g/t Au).

Anhui and Jiangsu: Anhui province has major skarn deposits such as Xinqiao (0.5 Mt @ 0.7 % Cu, 24 Mt @ 46 % Fe, 105 t @ 0.3 t @ 4.7 g/t Au in sulphide ore and 11.2 t @ 4.7 g/t Au in oxide ore), Manushan-Tiamashan (32 t @ 6.5 g/t Au), Shizishan (46 t @ 0.3 g/t Au) and Huangshiaoshan (13.5 t @ 5.8 g/t Au). Jiangsu province also hosts skarn gold deposits (e.g., Fuiushan, 9 t @ 0.85 g/t Au). In addition, Jiangsu province has Sedex deposits such as Qixiashan (0.4 Mt @ 2.6 % Pb, 0.8 Mt @ 0.8 % Zn, and 0.04 Mt @ 17 % Mn with gold credits (27 t @ 0.9 g/t Au), although it was overprinted by skarn system associated with Yanshanian magmatism. Iron-only deposits are also abundant in the Middle to Lower Yangtze River provinces such as Anhui, Jiangsu and also Hubei provinces. Although these deposits are considered skarn deposits, they are commonly stratabound or stratiform, at a distance from outcropping intrusive rocks and have abundant hematite and a high REE content. Olympic Dam type deposits or IOCG (Iron Oxide Copper-Gold) deposit styles should be considered as potential exploration targets in these provinces.

Fujian and Zhejiang: These provinces cover the South China fold belt along the southeastern margin of the Yangtze craton and are characterised by well-developed Yanshanian intrusive to subvolcanic rocks.
associated with porphyry to epithermal type copper-gold mineralisation and mesothermal vein deposits. The most important example is the Zijinshan district in Fujian (-100 Mt of ore containing at least 1.6 Mt metal @ 1.09% Cu and 15 t of Au @ 0.14 g/t Au and 619 t of Ag @ 6.2 g/t Ag). It is the only high-sulphidation epithermal system in China. Epithermal to mesothermal vein-type deposits are found in Zhejiang (e.g., Zhilingtou, 2 Mt ore grading 12 g/t Au, 306 g/t Ag).

Shandong: The province has unique world class granite-hosted orogenic gold deposits, and is the major producer of gold in China with ore reserves of more than 900 t Au. The most important gold deposits are: Linglong deposit (>100 t @ 3-30 g/t Au), Sanshekandao deposit (~60 t @ 7 g/t Au), Gangshang (~60 t @ 4 g/t Au), Jiaojia (~60 t @ 7 g/t Au), Xincheng (~60 t @ 8 g/t Au), Wangershan (45 t @ 7-8 g/t Au), Jingningding-Rushan (25 t @ 9 g/t Au), Donggerzhuang (20 t @ 11 g/t Au), Hedong and Shangzhuang (~20 t @ 7 g/t Au).

We have successfully integrated geology, tectonic and metallogenetic relations of China. The South China Craton is rich in mineral resources and has a diversification of mineral deposit styles. Similarly, the North China Craton hosts many giant base metal deposits (e.g., Baiyinchang VHMS district, 5.8 Mt metal resource @ 1.22% Cu, and 0.4% Pb and 2% Zn, 1.02 g/t Au and 16 g/t Ag (Hou Zhengqian et al., 1999; Hou Zhengqian et al., submitted, 2002b), Dongshenminio SEDEX deposit, 5 Mt metal Pb+Zn and 220 Mt ore sulphur, Yusheng Zhai et al., 1997), porphyry copper-molybdenum-gold deposits (Yuleng district, ~1000 Mt ore @ 0.99 Cu %, 0.06% Mo and 0.35 ppm Au, Hou Zhengqian et al., in press), copper-nickel deposit (e.g., Jinchuan), several world class orogenic gold deposits in Henan and Xinjiang, and Carlin type deposits in Gansu and Shaanxi provinces. Most of these deposits are located in the suture zone along the South and North Chian Cratons. It is imperative that similar integrated studies should be undertaken for the North China Craton in order to understand the palaeogeographic, tectonic and metallogenetic relation of the formation of the giant ore deposits of China during the collision and amalgamation of the South and North China Cratons.

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Fig. 4. Geology of Yunnan Province
(AMIRA P603 Project)
Fig. 5. Map showing mineral occurrences in Yunnan (AMIRA P603 Project)
Fig. 6. Map showing geology and selected lead-zinc-silver occurrences in Yunnan (AMIRA P603 Project)

Hongshan (Pb-Zn-Cu-Mo) Skarn type (Triassic)

Qilinchang (Zn-Pb) MVT type (Carboniferous)

Jinding/Lanping (Pb-Zn) (Sedex) (Eocene)

Tonchangjie (Cu-Zn-Fe) (VHMS) (Carboniferous)

Laochang Pb-Zn-Ag (VHMS) (Carboniferous)

Dapinzhang Cu-(Pb-Zn-Ag-Au) (VHMS) (Carboniferous)
Fig. 7: Map showing geology and selected copper occurrences in Yuánhān
(AMIRA P803 Project)

- Yangjia (Cu) Porphyry (Triassic)
- Dongchuan-type (Cu) Sedex? (Proterozoic)
- Beijia (Au-Pb-Zn-Cu) Vein/porphyry (Tertiary)
- Dahongshan (Cu-Fe) VHMS (Proterozoic)

Legend:
- Cu occurrences
- Metasediments and carbonates PALAEOZOIC
- Migmatite, gneiss and granite PROTEROZOIC
- Granitoids MESOZOIC TO CENOZOIC
- Granitoids PALAEOZOIC
- Mafic and ultramafics PROTEROZOIC

100 0 100 Kilometers
Fig. 8. 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 ?)

Legend:
- Carlin type deposits
- Porphyry deposit
- Vein/porphyry deposit
- Mesothermal deposit
- 14aucc.shp
- GranitoidsMESOZOIC TO CENOZOIC
- GranitoidsPALAEOZOIC
- Fault
- Yu_pool_ply.shp

100 0 100 Kilometers
Fig. 9. Map showing nickel-copper-cobalt-platinum-pladium occurrences in Yunnan (P603 Project)
Fig. 11. Map showing mineral occurrences in Sichuan (AMIRA P603 Project)
Fig. 12. Map showing lead-zinc-copper-silver-gold occurrences in Sichuan (AMIRA P603 Project)

Gacun (Zn-Pb-Cu-Ag-Au)
VHMS (Triassic)
4 Mt metal @ 5.5 % Zn, 3.7 % Pb,
0.4 % Cu, 160 g/t Ag, 0.3 g/t Au

Tianbaoshan (Zn-Pb-Ag)
MVT (Sinian)
20 Mt @ 10 % Zn, 1.4 % Pb,
93.6 g/t Ag

Daliangzi (Zn-Pb-Ag)
MVT (Sinian)
24 Mt @ 10 % Zn, 0.8 % Pb,
43 g/t Ag

100 0 100 Kilometers
Fig. 13. Map showing gold occurrences in Sichuan
(AMIRA P603 Project)

- Dongbeizhai (Au)
  Carlin Type
  (1,698,000 oz Au)

- Maerkang (Au)
  Carlin Type
  (?)

- Qiaoqiaoshang (Au)
  Carlin Type
  (405,000 oz Au)

- Shuiniujia (Au)
  Carlin Type
  (8 g/t Au)

Legend:
Selected Au deposits
Au-Ag-(Cu-Pb-Zn) occurrences
Faults
Granitoids-MESOZOIC
Sedimentary rocks-TRIASSIC
Sedimentary rocks-PALAEZOIC
Si_geol.shp

100 0 100 Kilometers
Fig. 14. Map showing copper-nickel and PGE occurrences in Sichuan (AMIRA P603 Project)

Yangliuping (Ni-Cu-Pt-Pd) Ultramafic-hosted (Permian)

Lengshuiqing (Ni-Cu-Pt-Pd) Ultramafic-hosted (Proterozoic)

Lalachang (Cu-Fe) VHMS (Proterozoic) 260 Mt @ 0.9 % Cu

Liuwu (Cu-Zn) VHMS (Silurian) 4 Mt @ 2.5 % Cu, 0.6 % Zn

Limah'e (Ni-Cu-Pt-Pd) Ultramafic-hosted (Proterozoic)

Legend:
- Liuwu and Lalachang - VHMS deposits
- Lengshuiqing, Limah'e, Yangliuping - Ultramafic-hosted Ni-Cu deposits
- Cu-Ni-PGE-(Au+Ag) occurrences
- Faults
- Emeishan Basalt-Permian
- Sedimentary rocks-Palaeozoic
- Sedimentary rocks-Sinian
- Metaclastics-Proterozoic
- Sh Geo1.shp

100 0 100 Kilometers
Fig. 15. Geology of Guizhou Province
(AMIRA P603 Project)
Geology Legend (Guizhou)
Fig. 17. Map showing gold occurrences in Guizhou Province (AMIRA P603 Project)

- **Zimudang** (Carlin-type Au) (~30 t @ ~5 g/t Au)
- **Getang** (Carlin-type Au) (~20 t @ ~5 g/t Au)
- **Lannigou** (Carlin-type Au) (~50 t @ ~5 g/t Au)
- **Yata & Banqi** (Carlin-type Au) (10-30 t @ 5-8 g/t Au)

Scale: 100 Kilometers
Fig. 18. Map showing copper-nickel, copper-tungsten, and lead-zinc occurrences in Guizhou Province (AMIRA P603 Project)

- Ni-Cu-Mo occurrences
- Cu-(W+Sn+Pb+Zn) occurrences
- Pb-Zn-Cu occurrences
- Sediments- CENOZOIC
- Metasediments-MESOZOIC
- Sediments-MESOZOIC
- Emeishan basalt-PERMIAN
- Sediments-SINIAN
- Sediments-PALAEZOIC
- Metasediments- PROTEROZOIC
- Granite and migmatite- PROTEROZOIC

100 Kilometers
Fig. 20. Map showing mineral occurrences in Guangxi Province (AMIRA P603 Project)
Fig. 22. Map showing tungsten-tin and lead-zinc-copper occurrences in Guangxi (AMIRA P603 Project)

Lamo, Changpo
Dafulo (Dafulou)
Bali, Longtashan
(Dachang tin-sulphide field)
100 Mt @ 1 % Sn, 3-5 % Pb,
Zn, Cu, 100-300 g/t Ag

Siding (Shiding)
Pb-Zn
Sedex ?
(Devonian)
Fig. 23. Geology of Hunan Province (AMIRA P603 Project)
Fig. 24. Map showing mineral occurrences in Hunan (AMIRA P603 Project)
Fig. 25. Map showing lead-zinc-copper occurrences in Hunan (AMIRA P603 Project)

- Kangjiawan (Pb-Zn) Vein-type
- Huangshaping & Baoshan (Pb-Zn-Cu-Ag) Vein-type
- Shizhuyuan (W-Sn-Bi-Mo+PbZnCu) Skarn-greisen-vein
Fig. 26. Map showing gold occurrences in Hunan (AMIRA P603 Project)
Fig. 28. Map showing mineral occurrences in Guangdong
(AMIRA P603 Project)
Fankou (Zn-Pb-Ag) Sedex ? (Devonian)
(42 Mt @ 10 % Zn, 4.8 % Pb, 101 g/t Ag)

Dabaoshan (Cu-Zn-Pb) Sedex ? (Devonian)
126 Mt @ 0.7 % Cu, 21 Mt @ 4 % Zn, 2.3 % Pb
Gaocun and Yunxi deposits (Hetai Goldfield)
Mylonite-hosted
30,700 kg @ 3-73 g/t Au
Fig. 31. Map showing Geology of Jiangxi Province (AMIRA P603 Project)
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<table>
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<td>11106.03 000 Li-Jin Fm. - PLIOPTOCENE</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Geology Legend (Jiangxi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11106.02 303 Be-Dong Qi-Go UP. UP. DROOCYAN</td>
</tr>
</tbody>
</table>
Fig. 33. Map showing lead, zinc, tungsten and tin occurrences in Jiangxi
(AMIRA P603 Project)
Fig. 34. Map showing copper-gold occurrences in Jiangxi
(AMIRA P603 Project)

Chengmanshan
Cu Fe Au Ag
Skarn
1.7 Mt metal @ 0.78 % Cu,
57 t @ 0.25 g/t Au,
224 t @ 9.9 g/t Ag

Wushan
Cu Au skarn
2.5 Mt metal @ 1.58 % Cu,
67 t @ 0.25 g/t Au

Yinshan
Au (Cu) Porphyry
59 t @ 2 g/t Au,
1 Mt metal @ 1.7 % Cu,

Tongchang (Dexing)
(Porphyry)
(Cu Mo Au Ag)
(1500 Mt ore @
0.43 % Cu, 0.02 % Mo,
0.16 g/t Au & 1.0 g/t Ag)
(6.45 Mt metal Cu, 0.25
Mt Mo, 24 t Au & 285 t Ag)

100 km
Fig. 36. Map showing mineral occurrences in Hubei
(AMIRA P603 Project)
Fig. 38. Map showing copper-gold occurrences in Hubei (AMIRA P603 Project)

Tonglushan & Shitouzui (Au-rich Cu skarn)
2 Mt metal @ 1.8% Cu,
87 t @ 0.5-1.15 g/t Au

Jilongshan (Au-Cu skarn)
37 t @ 4.87 g/t Au
0.3 Mt metal @ 1.6% Cu
Fig. 40. Map showing mineral occurrence in Anhui (AMIRA 603 Project)
Fig. 41. Map showing lead-zinc occurrence in Anhui (AMIRA 603 Project)
Fig. 42. Map showing copper-iron-gold occurrences and granitoids in Anhui (AMIRA 803 Project)

Xinqiao (Cu Fe Au)
Sedex? overprinted by skarn
0.5 Mt metal @ 0.7% Cu,
111 @ 4.7 g/t Au in oxide
& 105 t @ 0.3 g/t Au in sulphide

Manshan & Shizishan (Au-rich skarn)
78 t @ 0.3-6.5 g/t Au
Fig. 43. Geology of Jiangsu Province (AMIRA P603 Project)
Fig. 44. Map showing mineral occurrences in Jiangsu (AMIRA P503 Project)
Fig. 45. Map showing lead, zinc, copper and gold deposits in Jiangsu (AMIRA P603 Project)

Qixia Shan (Zn-Pb-Ag-Au) (Sedex ?)
20 Mt ore @ 4.8 % Zn, 2.6 % Pb, 1.6 % Cu, 75 g/t Ag, 1 g/t Au
Fig. 46. Geology of Fujian Province
(AMIRA P603 Project)
Fig. 47. Geology of Zhejiang Province
(AMIRA P603 Project)
Fig. 48. Map showing mineral occurrences in Fujian
(AMIRA P603 Project)
Fig. 49. Map showing mineral occurrences in Zhejiang (AMIRA P603 Project)
Fig. 50. Map showing lead, zinc, copper, gold and silver occurrences in Fujian (AMIRA P603 Project)

Zijinshan (Cu Au)
High sulfidation
100 Mt ore (1.8 Mt metal @ 1.09% Cu
15 t @ 0.14 g/t Au
619 t @ 6.2 g/t Ag
Fig. 51: Map showing lead, zinc, copper, gold and silver occurrences in Zhejiang
(AMIRA P803 Project)

- Zhilingtou (Au Ag)
  Epithermal/Mesoithermal
  2 Mt ore @ 12 g/t Au, 306 g/t Ag

- Huangshan (Au)
  Mesoithermal
  3.3 t @ 9 g/t Au
Fig. 53. Map showing mineral occurrences in Shandong 
(AMIRA P603 Project)
Fig. 54. Map showing major gold occurrences, faults and granitoids in Shandong
(AMIRA P603 Project)

- Sanshandao & Cangshang (Au)
  Granite-hosted
  (>120 t @ 4-7 g/t Au)

- Jiaojia & Xincheng (Au)
  Granite-hosted
  (>120 t @ 7-8 g/t Au)

- Linglong (Au)
  Granite-hosted
  (>100 t @ 3-30 g/t Au)
Fig. 55. Map showing compilation of geochronological data points (AMIRA P603 Project)
Fig. 56. Map showing comparison of geochronological data points for South China and SE Asia
(AMIRA Pot03 Project)
Fig. 57. Map showing Archaean and Proterozoic ages for South China
(AMIRA P603 Project)
Fig. 58. Map showing major gold occurrences, faults, granitoids and geochronological data in Shandong (AMIRA P603 Project)

- **Sanshandao & Cangshang (Au)**
  - Granite-hosted
  - >120 t @ 4-7 g/t Au

- **Jiaojia & Xincheng (Au)**
  - Granite-hosted
  - >120 t @ 7-8 g/t Au

- **Linglong (Au)**
  - Granite-hosted
  - >100 t @ 3-30 g/t Au

Legend:
- Major Au deposits
- Mesozoic age
- Proterozoic age
- Archaean age
- Faults
- Granitoids
- Sh_geo_ply.shp
Geological GIS Database of South China

Eleanor Bruce and Sue Jungalwalla
Centre for Spatial Information Science, School of Geography and Environmental Studies, University of Tasmania

The Geographical Information Systems (GIS) database contains a compilation of geological data for the 13 provinces of South China included in P603. Spatial data sourced from published geological provincial mapsheets and research information have been integrated to provide a continuous coverage of the P603 study region. Due to the disparate nature of the source data and the differing levels of spatial scales from which the digital information was captured there was a major focus on documentation and reliability assessment in this component of the project.

Techniques used in the digital capture of the spatial data and methods used in database development have been outlined in previous P603 Progress reports. This report will briefly outline the resulting data sets, data accuracy and documentation issues.

COMPONENTS OF THE DATABASE

The GIS database is provided in three CD-ROM volumes with each volume containing data for a specific GIS software (ArcInfo, ArcView and MapInfo) as requested in the initial project sponsors meeting. Information provided on each CD volume has been organized into directories relating to the data content. The data directories include:

- Geology
- Fault Lines
- Counties (1:1M scale sourced from CIESIN 1990)

BROADSCALE GEOLOGY

The geological unit boundaries were captured for each province on a scale of either 1:1,000,000 or 1:500,000 using a combination of hardcopy mapsheets and interpretative research conducted by the geological experts involved in the project (Table 1). The geological database has been designed to allow the query and analysis of geological features on a regional basis. A customised database structure was designed to ensure full representation of the complexity of geological data available from the source mapsheets and research information. The database is stored in MS Access with a single database used to contain the descriptive information for all provinces (refer to AMIRA P603 Progress Report 3 for a description of this database structure).

The geological database contains both polygon and line features. The polygons represent geological mapping units and the line features represent fault lines, boundaries of geological units, water bodies and political areas. The MS Access database is called ssgeology.mdb and contains 2 tables the first storing information relating to polygon features (PolygonDescription) and the second relating to line features (LineDescription). The data has been captured with topological data structure allowing the placement of fault lines and polygon boundaries to be queried according to adjacent features.

PolygonDescription stores all attribute information for the geological mapping datasets and contains 20 fields. These fields allow the entire geological mapping sheet to be queried based on a range of different attributes including geological age, geological formation, geological group, rock emplacement and rock description. Further information on these attributes is provided in the associated Data Dictionary documentation.

It was necessary to adjust the GIS data layers for each province to a common spatial reference using the China Administrative Regions GIS Data 1:1M (CIESIN, 1990) data set as discussed in the P603 November 2000 report. In addition to providing a common spatial reference this adjustment prevents gaps and overlaps in the mapped data caused by mapping discrepancies at provincial boundaries. However, it should be recognised that this may cause positional distortion of geological unit boundaries and faultlines in the border regions (approximately 15–30 km either side of provincial boundaries). The implications of this distortion are outlined in the metadata documentation.
### Table 1. Summary of geological data layers

<table>
<thead>
<tr>
<th>Province</th>
<th>Data Capture Scale</th>
<th>Number of Polygons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yunnan Sheng</td>
<td>1:1,000,000</td>
<td>8020</td>
</tr>
<tr>
<td>Sichuan Sheng</td>
<td>1:1,000,000</td>
<td>5695</td>
</tr>
<tr>
<td>Guangxi Sheng</td>
<td>1:1,900,000</td>
<td>6775</td>
</tr>
<tr>
<td>Guizhou Sheng</td>
<td>1:500,000</td>
<td>10605</td>
</tr>
<tr>
<td>Guangdong</td>
<td>1:1,000,000</td>
<td>5730</td>
</tr>
<tr>
<td>Jiangxi Sheng</td>
<td>1:500,000</td>
<td>8975</td>
</tr>
<tr>
<td>Hunan Sheng</td>
<td>1:500,000</td>
<td>10650</td>
</tr>
<tr>
<td>Hubei Sheng</td>
<td>1:500,000</td>
<td>10370</td>
</tr>
<tr>
<td>Anhui Sheng</td>
<td>1:500,000</td>
<td>8300</td>
</tr>
<tr>
<td>Fujian Sheng</td>
<td>1:500,000</td>
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</tr>
<tr>
<td>Zhejiang Sheng</td>
<td>1:500,000</td>
<td>7100</td>
</tr>
<tr>
<td>Jiangsu Sheng</td>
<td>1:500,000</td>
<td>3700</td>
</tr>
<tr>
<td>Shandong Sheng</td>
<td>1:500,000</td>
<td>5900</td>
</tr>
</tbody>
</table>

### FAULT LINES

The Fault Line database was extracted as a subset of the Geological database and contains only line features relating to geological structures. Each line feature has been coded to distinguish the geological structures. The descriptive data associated with the spatial data set is contained in the MS Access database, LineDescription. In provincial border regions artificial kinks in the fault lines may occur due to the appending of provincial maps and the geographical adjustment process.

### DATA RELIABILITY ASSESSMENT

The GIS database has been developed at a regional scale using source data that allows for a positional reliability of approximately 1 km. Geological and fault line GIS data layers contained within the database have not been field validated due to the broadscale of data capture. Accuracy of the thematic and attribute data was assessed based on comparison with the hardcopy map sheets and research expertise. GIS programs were written to automate the error checking procedures and any identified errors, such as wrongly described features, were corrected. Despite the rigorous error checking techniques an attribute accuracy of 95% has been assigned to account for undetected errors. Errors in the spatial data consistency (for example, disconnected fault lines or over extended line features) were also identified and removed using a combination of automated and manual techniques.

### DOCUMENTATION

Data Dictionary and metadata documentation has been provided to ensure data is used appropriately based on its described level of reliability. This documentation allows potential users to determine the data set's 'fitness of use' for their intended application.

The Data Dictionary contains a description of the data set and the structure of associated files. Each spatial data set is linked to an attribute table or .dbf file that is used to assign descriptive data to the spatial features. These files can be linked to other descriptive files based on a common link field. The field properties and content for each file is described in the Data Dictionary.

Metadata is a description of the characteristics of data that has been collected for a specific purpose (ANZLIC Guidelines, 1996). Metadata was compiled and included on the GIS database CD-ROMs to provide detailed information on data sources, data collection methods, integration techniques, processing history, map projection specifications, scale and geographic extent of data sets. These metadata documents are based on the ANZLIC Metadata Standard Guidelines, and are included on each CD volume. Contact details are also included in the event a sponsor company requires further information to determine the appropriateness of use or encounters a problem in working with the database.
Paleogeographic and Tectonic Development of South China

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Clive.Burrett@utas.edu.au

INTRODUCTION

Until the last 20 or so years, tectonic thinking in China was dominated by the teachings of J.S. Lee (Li Siguang) who wrote the first comprehensive summary of China's geology (Lee 1939). He taught that the tectonics of China was and is dominated by east-west faults which controlled the distribution and development of geosynclines. This thinking continues in more recent Chinese syntheses (e.g. Ren Jishun et al 1987) and underlies much of Chinese geological writing. Of course, this approach ignores structures at a high angle to east-west, which are plentiful in China. Although geological thinking in China now accepts plate tectonic and terrane concepts many authors seem only to half believe the concepts and geosynclinal and non-mobilistic concepts are still firmly embedded in many, if not most, Chinese geologists' views of the earth. Almost all Chinese geological and tectonic maps published by Chinese geologists stop at China's borders. This encourages an insular view of Chinese geology by most Chinese geologists. My impression is that most Chinese geologists now accept plate tectonics in order to get their papers published but are reluctant to accept really that China is a collage of allochthonous terranes that amalgamated over 3 gy and with disparate provenances in Siberia, Kazakhstan and in different sectors of Gondwana. For example, a leading Chinese geologist Ren Jishun (1996) writes about the formation of the 'Chinese protoplatform' between 1000 and 800 Ma and its disintegration into the Yangtze, Sino-Korean and Tarim blocks at 550–500 Ma, their joining Gondwana at 440–400 Ma "with the main body of China becoming a component of Laurasia" between 230–220 Ma. This is a 'wooden blocks in a bathtub' view of terranes which is unlikely to be accurate.

A broad, non-controversial subdivision of the geology of China is shown in Figure 1. The major Phanerozoic blocks/kratons/microcontinents/platforms are North China (Sinokorean Paraplateform) South China (consisting of the Yangtze paraplateform and South China Fold Belt (= Cathaysia) and Tarim. The first tectonic synthesis of Asia was written by Emile Argand in 1924 who used collisions of Tarim and China to account for the development of orogenesis within the intervening geosynclines.

Almost 30 years ago Burrett (1974) subdivided Asia into blocks (which we would now call terranes) and on the basis of contrasting geologies and highly different Paleozoic biogeographic units suggested that these blocks were separated by large oceans and that suturing of these blocks continued into the Jurassic. The coincidence of belts of ultramafies and island-arc volcanics with early Paleozoic faunal province boundaries was used as evidence for the paleo-separation of the blocks. The timing of biogeographic amalgamations and major unconformities were used to date the timing of terrane suturing.

Subsequent reviews (e.g. Enkin et al. 1992; Kliment 1983; Nie 1991; Watson et al. 1987) have confirmed the outlines of the major Phanerozoic terranes and the chronology of their collisions (Table 1).

The major suture in China follows the Qinling (Shan) Mountains and it was suggested (based on unconformities and biogeography) that the North China Block (NCB) fused with the South China Block (SCB) in the late Triassic along the Qinling (Burrett 1974). This was very controversial in 1974, and was met with total scepticism by Chinese geologists in talks given throughout China in 1979. However, two years later, McElhinny et al. (1981) published the first paleomagnetic evidence for the separation of the NCB and SCB based on Permian data and in 1985, Lin et al. demonstrated that the Cambrian-Tertiary apparent polar wander curves for the NCB and SCB did not converge until the Triassic (Lin et al., 1985).

At the same time the terrane concept was being accepted worldwide and by the early 1980s many
Figure 1. Major terranes in China ST= Shan Thai Terrane. From Li et al. (1996).

Table 1 Terminology of major orogenic cycles in China (from Ren 1996)

<table>
<thead>
<tr>
<th>Megacycle</th>
<th>Cycle</th>
<th>Age (Ma)</th>
<th>Major tectonic events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phanerozoic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Himalayan</td>
<td>40-2</td>
<td>Collision between India and Eurasia, creating Himalayas. Quinghai-Tibet Plateau, Kunlun, Qilian and Tianshan rejuvenated Mt; gradual formation of modern geomorphology of China</td>
</tr>
<tr>
<td></td>
<td>Alpine Yanshanian</td>
<td>80</td>
<td>Collision of Asia with N America and W Pacifica, leading to intense tectono-magmatic activation in E China</td>
</tr>
<tr>
<td></td>
<td>Indosinian</td>
<td>200</td>
<td>Opening of Tethys, responsible for break-up of Pangea into Laurasia and Gondwana, with main body of China becoming a component of Laurasia</td>
</tr>
<tr>
<td></td>
<td>Variscan</td>
<td>260</td>
<td>Closing of paleo-Asian ocean resulting in formation of Pangea</td>
</tr>
<tr>
<td></td>
<td>Caledonian</td>
<td>400</td>
<td>Assembly of paleo-Asian ocean resulted in formation of Pangea</td>
</tr>
<tr>
<td></td>
<td>Xingkaian (Pan-African)</td>
<td>500-550</td>
<td>Disintegration of Chinese protoplateform into paleo-Chinese blocks, including Sino-Korea, Yangtze, Tarim, etc.</td>
</tr>
<tr>
<td>Neo-Proterozoic</td>
<td>Yangtzean (Jinningian)</td>
<td>1000-800</td>
<td>Formation of Chinese Protoplateform</td>
</tr>
<tr>
<td>Neo-Proterozoic</td>
<td>Zhongtiaoan</td>
<td>1900-1700</td>
<td>Formation of Sino-Korean platform</td>
</tr>
<tr>
<td>Neo-Archean</td>
<td>Wutaian and Fupingian</td>
<td>2400-2600</td>
<td>Formation of crystalline basement of Sino-Korean platform</td>
</tr>
<tr>
<td>Paleo-Archean</td>
<td>Qianxian and older</td>
<td>3000</td>
<td>Emergence of ancient continental nuclei, with oldest crust of 3800 Ma discovered in N China</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3800</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Tectonic units of China from Wang and Mo (1995).
Figure 3. Paleomagnetic APW paths for some terranes in China. EC = Early Cambrian, EEC = Early Early Cambrian, MO = middle Ordovician, MLT = middle late Triassic. Data compiled by Burrett 1987 unpublished.
influential Chinese geologists accepted an allochthonous terrane analysis for China (e.g. Wang H.Z. 1981).

The discovery and detailed study of ophiolites (e.g. Xie and Guo 1984) and ultra high pressure metamorphics in the Dabie Shan belt of the eastern main Qinling Shan (Fig. 4) and in the Su-Lu area further to the northeast confirmed the Qinling Shan as a major suture between the NCB and the SCB (Zhang, Guoweii et al. 1995; Zhang, Ru-yuan et al. 1995).

The Dabie Shan gneisses and diamond-bearing eclogites have protolith ages of ca. 780 Ma with an ultrahigh-P overprint at 240–220 Ma, enjoyed extreme subhorizontal shortening at 200–180 Ma. Extension followed at 133–122 Ma (Hacker et al. 1995; Oberhansli et al. 2002). The mineral assemblages imply burial and exhumation of continental crust from depths of 100+ km! (Faure et al. 2000). The Qinling belt is displaced along the Tanle Fault and its exact position either within or north of or south of the Jiaodong Peninsula remains controversial (Faure et al. 2000; Wang et al. 1998; Zhai 2002) as is its position within or south of the Korean Peninsula.

The differences between the NCB and the SCB crust are confirmed by extensive studies on Nd and Pb isotopes and compilations of reliable magmatic and metamorphic dates. The oldest rocks in China are in the NCB. Nd model ages range from 4Ga up. The Precambrian geological development of NCB is very similar in terms of ages, greenstone belts and rift basins to that of northern Australia and very different to that of SCB. Precambrian SCB consists of Neoproterozoic to Neoproterozoic volcanic arcs/back-arc basins younging to the southeast.

The SCB consists of two major Proterozoic terranes — the Yangtze and Cathaysia (Fig. 5).

The Cathaysia block/terranes is similar in extent to the South China Fold Belt on many maps. Two prominent and influential tectonicians Ken Hsu and Celal Sengor suggested that Cathaysia and the Yangtze block collided during the Mesozoic (e.g. Sengor et al. 1988). Simple stratigraphic and biogeographic data showed that this was a silly idea even at the time. All subsequent data show that this was a Neoproterozoic suture with Neoproterozoic ophiolites with dates around 1600–800 Ma. However, recent dates on synorogenic granite-orthogneisses from the Kangdian axis of Sichuan Province suggest to Li et al. (2002) that the collision further east was of Grenvillian age at ca.1007 Ma. It is not clear, though, that events in Sichuan were related to the closure of the Proterozoic ocean that separated Yangtze and Cathaysia.

Parts of Yunnan belong to the Shan-Thai Terrane (or Sibumasu Terrane) that extends from Yunnan to Burma to western Thailand, western Malaysia and Sumatra. The Shan-Thai Terrane collided with the Indo-China and South China Terranes in the late Triassic. The Simao Terrane was set-up to include the area between the Ailaoshan Terrane in the east of Yunnan and the Changning-Menglian suture in the west (Fig. 6). The continuation of the Simao Terrane may be in Xizang to the north and with parts of the Indo-China Terrane to the south east (Fig. 7).

There was little data on the provenance of the
Early Precambrian tectonic framework of China (revised from Ma and Bai 1994). 
(1) Early Proterozoic mobile belt; (2) Archean craton; (3) ocean; (4) boundary between tectonic provinces.

Figure 5. Early Proterozoic tectonic framework of China

Sutures and terranes in Yunnan from Wu et al. (1995).

Figure 6.
Figure 7. Sutures in Xizang and Yunnan from Yang (1998)

Figure 8. Reconstruction of Greater Gondwanaland for the Early Cambrian. Arrows on continental crust are paleomagnetic declinations with paleolatitudes.
Chinese and SE Asian terranes when they were first delineated in the 1970s. Subsequent work on palaeomagnetism and biogeography has confirmed that the Shan-Thai (Burrett and Stait 1985), South China, North China, Tarim and the smaller Tibetan (Xizang) terranes were part of a Greater Gondwana during the early Paleozoic (Burrett et al. 1986, 1990). The provenance of the Indo-China Composite Terrane remains enigmatic.

Using data from fossils and paleomagnetism, Burrett et al. (1986, 1990) placed South China to the present day west of Australia as part of a Greater Gondwana. This positioning (Fig. 8) was accepted as reasonable by most later workers. More recently acquired Proterozoic paleomagnetism supports this placement. However, Zheng-Xiang Li at the Tectonics SRC in Perth has published many papers advocating placement of the SCB between eastern Australia and Laurentia at about 800 Ma with subsequent rifting from eastern Australia at about 750 Ma (see list of references in Li et al. 2002). Quantitative comparisons between the Precambrian terranes of South China and eastern Australia do not, however, support this model (Burrett and Berry, in prep.).

**SUMMARY GEOCHRONOLOGICAL HISTORY**

In the following geochronological summary, the most likely tectonic scenarios are presented and alternative models are only briefly mentioned.

**Precambrian**

The oldest rocks in South China are Archean in age but are rare. The extent of Archean shown in Figure 10 is grossly exaggerated.

In the Mesoproterozoic, South China consisted of the Cathaysia Terrane in the east extending from Guangdong northeastwards to Zhejiang and probably includes the Ryeongnam Terrane of southern South Korea. Cathaysia is separated from the composite Yangtze Terrane by a broad orogenic belt active from >1200 Ma to about 800 Ma trending from Guatangxi to north Zhejiang. Yangtze was bordered by tectonically active margins in the north (along the Qinling), in the south, west and east. Yangtze consists of island arc complexes and microcontinents that fused probably in the Sibao orogeny at about 1000 Ma approximately at the same time as the Grenvillian orogeny. Cathaysia probably collided with the Yangtze collagge at about 850 Ma (Jinningian orogeny) although, based on data from Sichuan, Li et al. (2002) argue for a 1000 Ma collision.

Cathaysia has felsic igneous events at 2713, 2280, 2063, 1837, 1743, 1686, 1438, 1100, 890 and 644 Ma and major deformation events at ca. 1850 Ma and 868 Ma.

Western Yangtze has major felsic igneous activity at 2957, 2450, 1657, 907 and 890–830 and deformation at 1000 and 850 Ma.

The Kunyang ‘Group’ in Yunnan and the Kangding form a north-south belt of definitive pre-Sinian Precambrian rocks (Fig. 12). This was a Mesoproterozoic arc complex deformed at about 1000 Ma with synorogenic granite-gneissies at 1007 Ma (Li et al. 2002). A later Proterozoic rift developed after 1000 Ma with deformation at 850 Ma caused by the collision of Cathaysia and Yangtze. The Kangding Precambrian remained an uplifted axis that acted as a narrow paleogeographic high and a source of sediment from the Sinian to the Tertiary.

Extensive continental rhyolitic-dacitic volcanics were erupted during the Sinian, Post-Jinningian (post-ca. 860 Ma) to pre-basal Cambrian sedimentary piles in South China are included in the Sinian chrono-
stratigraphic unit which is an approximate temporal
equivalent of the Australian Adelaean. The South
China Sinian (Fig. 13) starts with post-orogenic
‘molasse’ followed by thick siliciclastics which include
extensive glacial deposits followed by 1000 m of
widespread platform carbonates. Deep marine
conditions are recognised along the Qinling margin
in Sichuan and in Huanan. The Dabieshan basic
magmatic protoliths were formed at 780 Ma.

**Mesozoic-Cenozoic**

During the Triassic, an extensive carbonate platform
contracted, resulting in widespread terrestrial
conditions in the Jurassic. The Songpan-Ganzi area in
western Sichuan was a huge region of Triassic turbiditic
sedimentation with mainly a South China provenance
in the early Triassic and a north China provenance in
the late Triassic. The collision of North China and
South China along the Qinling and the collision of
Shan-Thai with South China occurred in the Late
Triassic. Triassic granites are widespread in Shan-Thai,
Sichuan and Huanan (Figs. 22, 23).

During the Jurassic and Cretaceous subduction (Figs
24, 25) from the west and the east led to widespread
intrusion of Yenshanian granites in Sichuan and
Guangxi. Subduction along the paleo-Pacific margin
led to extensive extrusion of calc-alkaline volcanics in
the Jurassic to Cretaceous. The Late Triassic collisions
produced the paleo-Bayan Har and paleo-Qinling
mountains which became major sources of sediment
feeding the terrestrial Jurassic Sichuan basin.

Mid-Tertiary folding (the ‘Himalayan’ orogeny) in
western Sichuan was due to the collision of India with
Asia (Fig. 26). The progressive indentation of India
into Asia (Fig. 27) also resulted in the fragmentation
of China and SE Asia and transcurrent movement along
several very long faults which continue to the present
(Fig. 28). Numerous papers have been written on the
far-field effects of the collision of India with China.

The indentation of India into China continues as
shown by GPS measurements, with India moving
north at 44 mm/yr and China sliding (escaping) east at
10 mm/yr and ESE at 23 mm/yr. Much of the movement
took/takes place along the huge strike-slip faults of
China such as the Alyn Tagh and the Red River Fault
and the resultant interesting patterns of extension and
shortening are a major control on the Cenozoic history
of the SCB (Larson et al. 1999; Zhang et al. 1990; Yue
and Liou 1999).

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Figure 10. Maximum extent of Archean in the Yangtze Terrane, Dabie Terrane and in Shandong Province.

Figure 11. Tectonic framework of China for the Mesoproterozoic to Neoproterozoic (pre-Sinian). From Ma and Bai (1998).
Figure 12. Pre-Sinian Proterozoic paleogeography. The SCB forms at 850Ma.

Figure 13. Sinian paleogeography of SCB.
Figure 14. Cambrian paleogeography.

Figure 15. Ordovician paleogeography.
Figure 16. Silurian paleogeography.

Figure 17. Devonian paleogeography.
Figure 18. Carboniferous paleotectonic sketch from Watson et al. (1987).

Figure 19. Carboniferous paleogeography.
Figure 20. Permian paleogeography.
Figure 21. Permian paleotectonic sketch from Watson et al (1987).
Figure 22. Triassic paleogeography.
Figure 23. Paleotectonic sketch for the Triassic from Watson et al. (1987). SCB fuses with NCB in the Late Triassic. SG = Songpan Ganzhi turbiditic accretionary wedge.
Figure 24. Jurassic paleogeography.

Figure 25. Cretaceous paleogeography.
Figure 26. Cenozoic paleogeography.

Figure 27. Indentation of India into Asia showing areas of shortening and extension. Velocities in mm per annum based on GPS measurements (Larson et al. 1999).
Figure 28. Major transcurrent faults, volcanism and Tertiary basins formed as a result of the indentation of India from Yue and Liou (1999).
Structural History of South China

November 2002
Ron Berry
CODES SRC
Pli-Pleistocene

GIS Comments

Western edge of Yangtze Craton. Mesoproterozoic basement (siliciclastic sequence metamorphosed to greenschist facies) is intruded by abundant Mesoproterozoic granites (Jinning O) with associated silicic volcanics (760-665 Ma) possibly related to an active margin (Panxi-Huanan arc) on the western side of the Yangtze Block. The granites and metamorphics are overlain by an Upper Sinian to Permo-Triassic cover sequence. Jurassic to CretaceousExtension and formation of core complexes. From 35 Ma initiating and then strike slip faulting along the northern margin of Altai Shan shear zone. Pli-Pleistocene escarpment terranes with E-W normal strike slip faults and N-S thrust faults, extremely strong in the west.

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