Summary of Proposed Research Program for Doctor of Philosophy

Title

Tectonic Setting and Tectonometamorphic Evolution of Fuping-Wutai-Hengshan Orogenic Belt, China

Abstract

The Fuping-Wutai-Hengshan area lies within the North China Craton and is one of the classic orogenic belts in China. This project will apply modern geological technology to the region to determine the tectonic setting and evolution of the orogenic belt. In particular, the project will determine the nature, relations and ages of protolithic lithologies and the tectonic environments of their formation, the P-T evolutionary paths of the metamorphic rocks, the relationships between metamorphic mineral growth and deformation episodes, and the precise timing of tectonometamorphic stages. Fieldwork will be an important part of this research since it is the main approach to obtain data on the relations of the major lithologic units and sequences. The original tectonic setting of this orogenic belt will be evaluated by detailed geochemical investigation of the nature of basaltic to felsic volcanic rocks widespread throughout the Wutai Greenstone Terrane and Fuping and Hengshan Complexes. The work necessary for successful elucidation of the cause-and-effect relationships between metamorphic P-T-t paths and mountain-building dynamical process includes (1) careful petrographical examination of critical samples in order to determine metamorphic stages and the relationships between metamorphic stages and deformation episodes; (2) electron microprobe mineral analysis; (3) quantitative calculation of the P-T conditions of different metamorphic events or stages using well-calibrated geothermobarometers; (4) dating the ages of metamorphic events or stages using the Sensitive High Resolution Ion MicroProbe (SHRIMP) at Curtin University; (5) establishing P-T-t evolutionary paths of metamorphism and explaining their cause-and-effect relationships with tectonic process. On the basis of these data, a tectonic model will be developed for the Fuping-Wutai-Hengshan orogenic belt.

Objectives

- **Determine the original tectonic environment of the three metamorphic blocks.** Emphasis will be placed on relationships between meta-basalt chemical compositions and tectonic environment. The research requires detailed field survey, systematically sampling, precise geochemical analyses and interpretation of results.
- **Determine the tectonometamorphic evolution of the three metamorphic blocks.** The cause-and-effect relationships between types of tectonometamorphic P-T-t evolutionary paths and mountain-building dynamical processes will be investigated. This will include: (1) establishing deformation episodes through field and microscopic studies; (2) determining metamorphic mineral generations and evolution stages through petrographic textures and mineral reaction relationships; (3) determining the relationships between metamorphism and deformation; (4) quantitatively calculating P-T conditions for different metamorphic stages through analysis and application of electronic microprobe and well-calibrated geothermometers and geobarameters; (5) establishing tectonometamorphic P-T-t evolutionary paths for the three metamorphic blocks and explaining their cause-and-effect relationships with tectonic processes.
- **Date the lithologies and tectonometamorphic events in the three metamorphic blocks.** Conventional Ar/Ar and single zircon U/Pb SHRIMP methods will be used. The emphasis

will be placed on dating metamorphic ages since a regional framework of rock-forming ages has been partly determined and will be determined by the Supervisors during on-going parallel research.

- Establish a comprehensive tectonic evolutionary model for the Fuping-Wutai-Hengshan mountain belt based on the above data.

Background

The Fuping-Wutai-Hengshan orogenic belt consists of three tectonometaphorphic blocks; in the southeast is the medium to high grade metamorphic rocks of the Fuping Complex; in the northwest is the high grade metamorphic rocks of the Hengshan Complex; and between these two blocks is the Wutai Greenstone Terrane (Fig.1). The combination of excellent exposure, diverse rock types, abundant mineral resources, complicated tectonic phenomena and continuous metamorphic transition from low-grade to high-grade within the mountain belt has drawn geologists to the area since the last century. In 1871, F. R. Richthofen, a Germany geologist, carried out a field survey in the Wutaishan and Hengshan area. He considered the Wutai greenschists to be a part of the Archean low-grade rock series and Hengshan high-grade gneisses to be equivalent to the Sangan Gneisses outcropping in the Sangan River valley and in Inner Mongolia (Richthofen, 1882[*]). In 1903, B. Willis et al. undertook a field

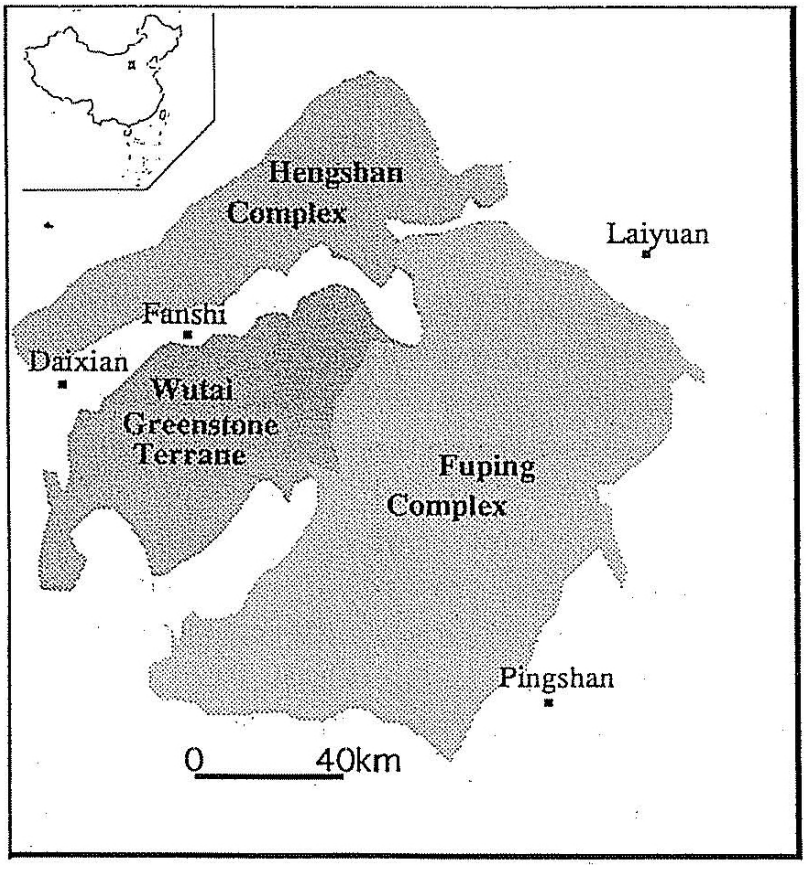

Figure. 1. Schematic geological map of the Wutai Greenstone Terrane and Fuping and Hengshan Complexes.

[*] Richthofen, F.V., 1882. China, part 3, pp 267-398.

trip from Fuping, via Longquanguan to Wutai Mt. They suggested that the gneisses in the Fuping area were comparable to the Archean "Taishan Complex" outcropping in the eastern part of the North China Craton and that, the greenschists in the Wutai area were the Paleoproterozoic in age. They named them "Wutai System". They assigned the more weakly metamorphosed rocks in Wutai area to the Neoproterozoic "Hutuo System" (Willis et al., 1907[*]). Afterwards, Sun (1930) and Yang (1937) did further work on the classification of the Wutai and Hutuo Systems on the basis of Willis et al.'s scheme. These pioneering studies laid an important foundation for later research in this region.

The modern geological survey of this region started with 1:1,000,000 mapping in the Wutai area during the early 1950s (Wang, 1955; Ma et al., 1957; Shen et al., 1959) and 1:200,000 mapping in the Fuping, Wutai and Hengshan regions during the later 1960s to 1970s (Ma, 1963; Geological Survey Bureau of Shanxi Province, 1967, 1971). However, the early studies focused mainly on rock associations, stratigraphic sequences, deformation styles, metamorphic grades and limited K-Ar isotopic dating, and little research was carried out on the tectonic nature and crustal evolution of the mountain belt.
Since the early 1980s, research on the tectonics of this region has increased and several models concerning the tectonic setting and the evolution of this belt have been proposed. Bai (1986) and Bai et al. (1992) for the first time applied Phanerozoic-style plate tectonics to the region and thought the belt belonged to the late Archean continent-arc-continent collision system in which the Fupin and the Hengshan Complexes represent Archean micro-continents, and Wutai Greenstone Terrane represents an intervening island arc. Lie et al. (1990) and Li and Wang (1992) and Wang et al. (1996) further developed the continent-arc-continent collision tectonic model and suggested that the Wutai Group can be divided into several ophiolitic melange zones which were formed from the collision between the Fuping micro-continental block and the Hengshan micro-continental block at the end of the Paleoproterozoic. However, Tian (1991), Yuan and Zhang (1993) and Li and Qian (1995) consider the region represents an ancient continental rift system in which the Fuping and Hengshan Complexes were originally the same continental block which underwent late archean rifting associated with formation of the Wutai sequence. Variations on these models have been proposed by Niu et al. (1994) and Lei et al. (1994). Uncertainty on the tectonic setting of rock units reflect:

- Lack of data on original environments of accumulation of rock units;
- Lack of comparative studies on the metamorphic stratigraphic seqences, deformation episodes and styles, and metamorphic evolution of the three tectonometamorphic blocks; and
- Lack of accurate geochronological data.

In addition, although the Wutai greenstone is considered to be either late Archean or Paleoproterozoic, all tectonic models assume that the Fuping and Hengshan Complexes are older than the Wutai Greenstone Terrane and they were formed during different tectonic cycles. However, provisional geochronological data by Wilde and Cawood show no difference in age of the three blocks. Research into deformation and metamorphism also indicates that both the Hengshan and Fuping Complexes and Wutai Greenstone Belt underwent a similar deformation and metamorphism history, and have similar structural styles and metamorphic P-T-t evolutionary paths, which implies that they were formed during

[*] Willis, B., Blackwelder, E., & Sargent, R.H., 1907. Research in China, Part 1, pp 98-135, 157-159, 363-371.

the same tectonic cycle*. Thus it can be seen that some fundamental questions on the tectonic setting and evolution of this mountain belt have yet to be answered. This PhD research aims to solve these fundamental problems and provide an explanation for the tectonic evolution of the region.

Significance

The Fuping-Wutai-Henghans area is potentially a key area in the world for understanding the nature of Archaean crustal processes. This includes information on the applicability of the plate tectonic model to the Archaean, ways of Archaean crustal growth and accretion, the relationships between high-grade metamorphic areas (eg. Fuping and Hengshan Complexes) and low-grade granite-greenstone terranes (eg. Wutai Greenstone Terrane).

Since the end of the 1960s, plate tectonics has revolutionised our understanding of Earth evolution from the Proterozoic to the present. It has, however, been controversial as to whether or not Phanerozoic-style plate tectonics can be used to account for the Archaean geology. Recently, Phanerozoic-style plate tectonics can be used to account for the Archaean environments, particularly in the form of terrane accretion models, eg. in North America (Hoffman, 1988), Greenland (Friend et al., 1988; Nutman et al., 1993), Western Australia (Myers, 1993; Wilde et al., 1993) and the Sino-Korean Craton (Bai, 1986; Bai et al., 1992; Li et al., 1990; Wang et al., 1996). Alternatively, non-plate tectonic models, eg. mantle plume model, have been proposed by Campbell et al. (1989), Campbell and Griffiths (1990), Larson (1991), Hill et al. (1992), Maruyama (1994), Kumazawa and Maruyama, (1994) and Abbot (1996). The excellent exposure in Fuping-Wutai-Hengshan region makes this an ideal area to test whether or not plate tectonics can be applied to the Archaean.

The relationship of low-grade granite-greenstones to high-grade metamorphic areas is a world-wide problems in Archaean geology. Some researchers think the metamorphic rocks in high-grade areas are the equivalents of granite-greenstones in deep crust (Glikson, 1976; Glikson & Lambert, 1976, Robertson & du Toit, 1981; Li et al., 1982); some think the metamorphic rocks in high-grade areas and granite-greenstones are different both in age and in tectonic setting (Windley, 1973; Shackleton, 1976; Condi, 1981); and some think they are the same in ages but different in tectonic setting (Tarney et al., 1976; Windley, 1984). The excellent exposure in Fuping, Hengshan and Wutai areas provides favourable conditions for establishing unequivocal relationships between the Fuping and Hengshan high-grade gneisses and the Wutai granite-greenstones.

One of the keys to successfully interpreting the tectonic setting and tectonometamorphic evolutions of orogenic belts is precise geochronological dating of major rock units and geological events. It is only in the last decade that the Sensitive High Resolution Ion MicroProve (SHRIMP) analysis on single zircon crystals has been developed (Compston et al., 1984). This new method has been applied to the precise timing of early Precambrian rocks and geologic events, with particular success in Western Australia (Pidgeon et al., 1990; Wilde & Murphy, 1990; Nutman et al., 1993; Nemchin et al., 1994; Connors & Page, 1995; Nelson et al., 1995) and Western Greenland (Friend, 1996; Nutman & Rosing, 1994; Nutman et al., 1996). In the Fuping-Wutai-Hengshan area, although Liu et al. (1985), Li et al. (1990)

* Zhao Guochun, 1995. Metamorphic P-T-t paths of the Fuping Complex, Wutai Greenstone Terrane and Hangshan Complex and their tectonic implications. In: Tectonometamorphic Evolution of Early Precambrian Crust in North China Craton (Research Report submitted to National Natural Science Foundation of China) (eds Lu Liangzhao & Zhao Guochun).

and Sun et al. (1992) have done some geochronological research, the precise geochronological framework to resolve the ages and origins of the main roc units and geologic events in this area has not yet been established. By applying SHRIMP to date the main rock units and to allow separation of different geological events, the research will bring a unique perspective to set up a major tectonic evolutionary sequences for this orogenic belt and gain a better understanding of the nature and origin of the early Precambrian continental crust.

Research Method

The project will integrate field and laboratory studies.

Field work will aim to:

- determine stratigraphic sequences, spatial distribution and relationships of the major rock/structural units within these blocks and provide a firm framework for all subsequent studies of the project;
- collect various structural data to document deformation styles, episodes, superposition relationships and kinematic movement directions;
- examine the contact relations between granitoids and the Fuping and Hengshan complexes and Wutai greenstones;
- collect analytical samples for petrography, geochemistry and geochronology.

Analytical work will include:

- **petrographical analysis** – all the rocks collected for metamorphic P-T-t path study, geochemical analysis and U-Pb isotopic analysis will be carefully examined petrographically;
- **mineral electron microprobe analysis** – in order to set up the metamorphic P-T-t paths of the Fuping-Wutai-Hengshan orogenic belt, minerals suitable for calculating P-T conditions of different metamorphic stages will be analysed by electron microprobe;
- **whole-rock geochemical analysis** – some rock samples will be analysed for major, trace and rare earth elements in order to obtain information on their genesis and the original tectonic environments;
- **isotopic geochronological analysis** – the SHRIMP II mass spectrometer will be used to date the rock-forming and metamorphic ages of the major rock units.

Ethical Issues

This research program does not require testing to be done on humans or animals and does not involve potentially dangerous equipment of any kind.

Facilities and Resources

Facilities for the above analytical work are available at Curtin University and co-operative units around Western Australia. These include the SHRIMP II mass spectrometer at Curtin University, thin section-grinding equipment and research microscopes for petrographical analysis, electron microprobe and SEM instruments (arrangement with UWA) for mineralogical composition analysis, computers for processing analytical data, etc. Ar/Ar analysis will be done at ANU.

Data Storage

The data storage provisions are outlined in the attached Research Data Management Plan and meet the Curtin University Research Data and Primary Materials Policy.

Time Line

This PhD research will be finished within three years. The timetable is as follows:

July-December Year 1
(1) Compiling and reviewing all the available geological data on Fuping, Wutai and Hengshan areas; (2) Examining the thin sections from rock samples already collected from these areas in 1996 and selecting minerals for electron microprobe analysis and some whole-rock samples for geochemical analysis; (3) Learning computer technology and analytical techniques, including SHRIMP operation.

January-April Year 1
(1) Studying conventional and SHRIMP geochronological theories and methods and familiarising with SHRIMP operating technique; (2) initial SHRIMP analysisl (2) Some mineral electronprobe processing(P-T calculationgs); (3) Preparation for field work.

May-July Year 1
Fieldwork in the Fuping, Wutai and Hengshan Mountains, China. The fieldwork tasks include (1) collecting various geological data on stratigraphic and structural relationships and intrusive relationships of geological bodies; (2) systematically collecting of meta-mafic rock samples for geochemical analysis; (3) collecting geochronological samples for determining metamorphic ages; (4) collecting the updated geological references on Fuping, Wutai and Hengshan areas from Journals in China.

August-September Year 2
(1) Petrographic studies on the samples collected in 1997; (2) Further studies on tectonometamorphic P-T-t paths of Fuping-Wutai-Hengshan Mountain belt and their interpretation with respect to tectonic evolutions.

October-December Year 2
Geochemical studies on the samples collected in 1997, including selecting suitable samples, processing results and preparing diagrams showing the relationships between geochemical compositions and tectonic settings.

January-April Year 2
Dating metamorphic events, including (1) selecting suitable geochronological mineral samples (hornbelende, mica, garnet, zircon etc.) for dating; (2) dating samples using SHRIMP; (3) processing analytical results.

May-July Year 2
Further detailed fieldwork in Fuping, Wutai, Hengshan areas in China. The work includes (1) further collection of various geological field data; (2) collecting petrographic, geochemical and geochronological samples; (3) updating references on Fuping-Wutai-Hengshan Mountain belt from Chinese Journals and discussion with local geologists.

August Year 2-July Year 3
(1) Further petrographical, geochemical and geochronological work on the field data and samples collected in Year 2; Revising 1:500,000 early Precambrian geological map of Fuping-Wutai-Hengshan Mountain belt; (3) Interpreting data and establishing a model for the tectonic setting and tectonometamorphic evolution of Fuping-Wutai-Hengshan region; (4) Writing PhD thesis.

References
[A detailed reference list was included.]