Ordovician and Silurian Rocks of Northwest Zhejiang and Northeast Jiangxi Provinces, SE China

by

Zhang Yuandong
Chen Xu
Yu Guohua
Dan Goldman
Liu Xiao

University of Science and Technology of China Press

Ordovician and Silurian Rocks of Northwest Zhejiang and Northeast Jiangxi Provinces, SE China

by

Zhang Yuandong *Chen Xu*
(State Key Laboratory of Palaeobiology and Stratigraphy,
Nanjing Institute of Geology and Palaeontology, Nanjing, China)

Yu Guohua
(Zhejiang Institute of Geological Survey, Hangzhou, China)

Dan Goldman
(Department of Geology, University of Dayton, Dayton, Ohio, USA)

Liu Xiao
(Nanjing Institute of Geology and Palaeontology, Nanjing, China)

University of Science and Technology of China Press
Hefei, China

First published 2007 by University of Science and Technology of China Press
Printed in Hefei, 2007

Ordovician and Silurian Rocks of Northwest Zhejiang and Northeast Jiangxi Provinces, SE China
Zhang Yuandong, Chen Xu, Yu Guohua, Dan Goldman, Liu Xiao
Includes bibliographical references and index

图书在版编目(CIP)数据

浙西北和赣东北奥陶纪和志留纪地层=Ordovician and Silurian Rocks of Northwest Zhejiang and Northeast Jiangxi Provinces, SE China: 英文/张元动等著. —合肥:中国科学技术大学出版社,2007.6
ISBN 978-7-312-02079-7

Ⅰ.浙… Ⅱ.张… Ⅲ.①奥陶纪—地层学—研究—浙江省—英文②志留纪—地层学—研究—浙江省—英文③奥陶纪—地层学—研究—江西省—英文④志留纪—地层学—研究—江西省—英文 Ⅳ.P535.2

中国版本图书馆 CIP 数据核字(2007)第 073636 号

中国科学技术大学出版社出版发行
(安徽省合肥市金寨路 96 号,230026)
中国科学技术大学印刷厂
全国新华书店经销
开本:889×1194/16 印张:12.25 字数:380 千
2007 年 6 月第 1 版 2007 年 6 月第 1 次印刷
印数:1—900 册
定价:152.00 元

Acknowledgments

Chinese Academy of Sciences
Ministry of Science and Technology of China
National Natural Science Foundation of China
Nanjing Institute of Geology and Palaeontology, CAS
State Key Laboratory of Palaeobiology and Stratigraphy, NIGPAS
Bureau of Land and Resources of Zhejiang Province
Zhejiang Institute of Geological Survey
Government of Changshan County, Zhejiang Province
Government of Yushan County, Jiangxi Province
Government of Jiangshan County, Zhejiang Province
Government of Chun'an County, Zhejiang Province
Government of Lin'an County, Zhejiang Province
Government of Deqing County, Zhejiang Province

CONTENTS

Chapter 1 Preface

The border area of Jiangxi and Zhejiang provinces (Jiangshan-Changshan-Yushan, or "JCY area" for short), and the northwestern Zhejiang are classic regions for the study of the Ordovician and Silurian Systems in China. The pioneering geological work in the region dates back to 1871, when the famous German geologist and traveler F. F. Richthofen took an extraordinary field trip from Ningbo (a commercial center at that time) to Tonglu along the Fuchun River, and then to the Tianmu Mountains along the Fenshui River, finally arriving in Wuhu (Anhui) (Richthofen, 1912, p. 667—696)(Fig. 1-1). One of his remarkable contributions to the geology of the region was a geologic profile of Tonglu County to the Tianmu Mountains, in which he identified various rocks of the Sinian and Palaeozoic age, as well as his associated diary on the geology and geography of the western Zhejiang Province.

In 1915, the Japanese geologist S. Noda undertook a more detailed investigation of the stratigraphy and geology of northwest Zhejiang, along the Qiantang and Fuchun Rivers. Among his most noteworthy accomplishments on the geology of the area was the successful subdivision of the Sinian and Palaeozoic rocks into several distinct "Series"of defined ages, such as the"Yinchubu Limestone Series" of Early Palaeozoic.

In 1924, Chu and his colleagues conducted a geological investigation in the western Zhejiang (Chu *et al.*, 1924, 1930). At about the same time, Liu and Chao (1927) conducted a detailed study on the stratigraphy of the region, and successfully established the Early Palaeozoic lithological sequence of the region, which comprises the Taoshuiwu Formation, Yinchufu Series (Formation), Yenwashan Formation, and Fengchu Shale. Subsequently, many different investigations of the coal and mineral resources were conducted in 1930s.

In 1950s, substantial stratigraphic revisions were made by Lu and his colleagues (Lu *et al.*, 1955), who conducted an intensive study of the Palaeozoic strata and collected abundant fossils from the region. They redefined the lithological sequence of Liu and Chao (1927) in a more accurate and detailed set of units, and named the Huangnekang and Changwu Formations. In their system of subdivisions, the Lower Ordovician roughly includes the Yinchufu and Ningkuo Formations, the Middle Ordovician includes the Hulo and Yenwashan Formations, and the Upper Ordovician includes the Huangnekang and Changwu Formations. This sub-division has been widely adopted by subsequent scholars for the region of Zhejiang, Jiangxi and southern Anhui provinces. In the 1950's and early 1960's numerous biostratigraphic and palaeontological investigations were carried out in the region, including studies on graptolites, trilobites, corals and nautiloids (see e.g. Mu, 1956, 1957; Mu & Lee, 1958). In 1959, the National Field Meeting of Stratigraphy was held in West Zhejiang, and it attracted over 200 Chinese geologists, palaeontologists, and engineers, as well as some Russian experts. A proceedings volume was subsequently published to include the noteworthy papers on aspects of the regional geology (National Commission on Stratigraphy, 1963).

In the 1980's, a great deal of attention was paid to the Cambrian-Ordovician boundary sections

in the region, and a large number of palaeontologic and stratigraphic papers were published. Among the most important of these publications was the special volume on the aspects of the Cambrian-Ordovician boundary sections in the Jiangshan-Changshan-Yushan area (JCY area; Nanjing Institute of Geology and Palaeontology ed., 1984). These studies demonstrated that the Duibian section, Jiangshan, was one of the most promising candidates for the boundary stratotype. In 1983 a group of foreign palaeontologists from the United Kingdom, Germany, and Norway (among others) visited the region for the first time.

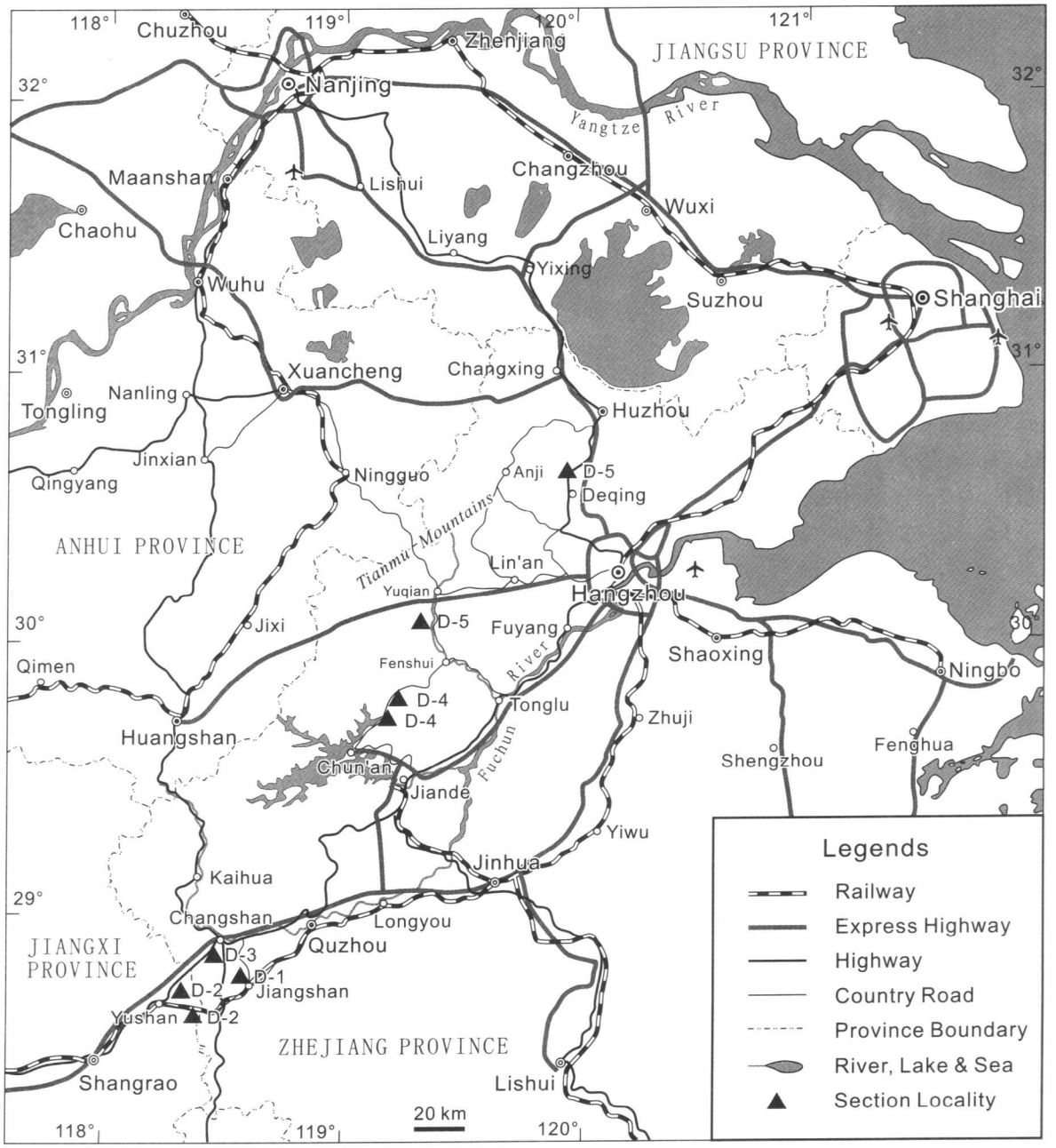

Fig. 1-1 Routes and major sections of the Ordovician and Silurian in Northwest Zhejiang and Northeast Jiangxi, SE China.

The establishment of the Darriwilian GSSP at Huangnitang, Changshan in 1997 was especially important. A special volume was published on the lithological, sedimentological, palaeontological and geochemical aspects of the boundary interval (Chen & Bergström, 1995). In 2003, the Huangnitang GSSP section was taken as the centerpiece of the 'Changshan National Geopark', becoming one of China's protected natural resources. A comprehensive review of the research history of the JCY area and a complete list of the pertinent literature was given by Han (1996).

In 2003, the Ninth International Symposium on the Ordovician System (ISOS) in San Juan, Argentina approved holding the 2007 ISOS conference in Nanjing. The JCY area and NW Zhejiang were proposed as the most significant and suitable regions for the pre-Conference field trip. As part of our preparation for the trip, we spent a great deal of time systematically collecting the Siyangshan and Yinchufu Formations at the Huangnitang section, Changshan, and the fossiliferous Upper Ordovician—Lower Silurian strata in NW Zhejiang. This work has successfully led to the establishment of a complete graptolite succession in the Hirnantian and early Rhuddanian rocks of Chun'an and Lin'an, NW Zhejiang. Additionally, Hirnantian shelly fossils and a fairly rich fauna of earliest Rhuddanian brachiopods were described from the region.

We are indebted to many of our colleagues in NIGPAS for their timely identifications of the shelly fossils discovered during our preparatory work in the region. The trilobites reported in this book, except those previously published or specially noted, were identified by Zhou Zhiyi and Zhou Zhiqiang, the brachiopods by Rong Jiayu and Zhan Renbin, the bivalves by Fang Zongjie, the bryozoans by Xia Fengsheng, the gastropods by Pan Huazhang, and the nautiloids by Zhang Yunbai. We also thank Mr. Xu Honggen of the Zhejiang Institute of Geological Survey (formerly Zhejiang Geological Survey) and Prof. Bian Lizeng of Nanjing University for their valuable support of the pre-conference preparation.

Financial support from the Chinese Academy of Sciences (KZCX2-YW-122, KZCX3-SW-149), the Natural Science Foundation of China (No. 40532009), the Ministry of Science and Technology (2006CB806402), and the State Key Laboratory of Palaeobiology and Stratigraphy (Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences), are acknowledged.

This book is a guide to the pre-conference field trip of the 10th International Conference on the Ordovician System, the 3rd International Conference on the Silurian System and the Annual Symposium of IGCP503 Project (June—July, 2007, Nanjing, China). It may also be used as a reference book for the Field Teaching and Practice of Palaeontology and Stratigraphy in the region, which is usually attended by graduate students from NIGPAS and many other universities of China.

Chapter 2 Geological setting and stratigraphy of Northwest Zhejiang and Northeast Jiangxi Provinces

During the Ordovician and Silurian Periods the South China Palaeoplate was located in the low to mid latitude region of northwest peri-Gondwana (Scotese & McKerrow, 1990; Chen & Rong, 1992; Fortey & Cocks, 2003). It is widely agreed that the palaeoplate had rifted away from, but was still in close proximity to, the Gondwana Land during the Ordovician. However, the orientation and precise palaeolatitude of the plate remain controversial.

The South China Palaeoplate comprises three major regions, which from NW to SE are: the Yangtze Region (usually considered to represent a carbonate platform), the Jiangnan Region (or Jiangnan Belt, slope facies) and the Zhujiang Region (commonly thought to represent a basin facies). Beyond the Zhujiang Region to the Southeast an oldland may have existed, Cathaysian Land (Grabau, 1923—1924), which has also been widely regarded and treated as part of the South China Palaeoplate during the Ordovician and Silurian (Rong & Chen, 1987; Chen *et al.*, 1987; Chen & Rong, 1992; Chen *et al.*, 1995). In the eastern end of the South China Paleoplate, which includes southern Jiangsu, Shanghai, southern Anhui, eastern Jiangxi and western Zhejiang, three palaeoenvironments (i.e. Yangtze Platform, Zhe-Wan* Basin and Cathaysian Land) are thought to have existed (Chen & Bergström, 1995). Our study area, the eastern Jiangxi and western Zhejiang, is generally regarded as belonging to the Zhe-Wan Basin. To the east of this region there is a major fault striking from Shaoxing to Jiangshan of Zhejing (Jiangshan-Shaoxing Fault), separating the Zhe-Wan Basin and the Cathaysian Land (Fig. 2-1).

Ordovician and Silurian rocks are widely exposed in the Northeast Jiangxi and Northwest Zhejiang (Fig. 2-2). They are extensively folded and strike in a NE—SW direction. In Hangzhou (northern Zhejiang) and Shanghai, which are regarded as the eastern part of the Yangtze Region, the Ordovician rocks are dominated by carbonates, including in ascending order the Liuxia, Jingshan, Xianlinpu, Hulo (and synchronous Datianba Formation), Yenwashan, Huangnekang and Changwu Formations. Only a few fossils have been found from this succession. Among these units, the Jingshan Formation and the Xianlinbu Formation are named as regional lithological units in the Hangzhou area. The Jingshan Formation yields nautiloid and conodonts that suggest a similar age to that of the Hunghuayuan Formation; and the Xianlinbu Formation yields conodont and nautiloid faunas resembling those of the Dawan and Kuniutan Formations.

Within the Jiangshan-Changshan-Yushan area (JCY area, in the border of Zhejiang and Jiangxi provinces; Fig. 2-3) and NW Zhejiang the Ordovician and Silurian rocks are differentiated into three types. Between the Cathaysian Land (whose northwest margin has been inferred as coinciding with the Jiangshan-Shaoxing Fault) and the Qiuchuan-Xiaoshan Fault, the Ordovician rocks are

---

* Zhe-Wan, abbreviations of Zhejiang and Anhui provinces, respectively.

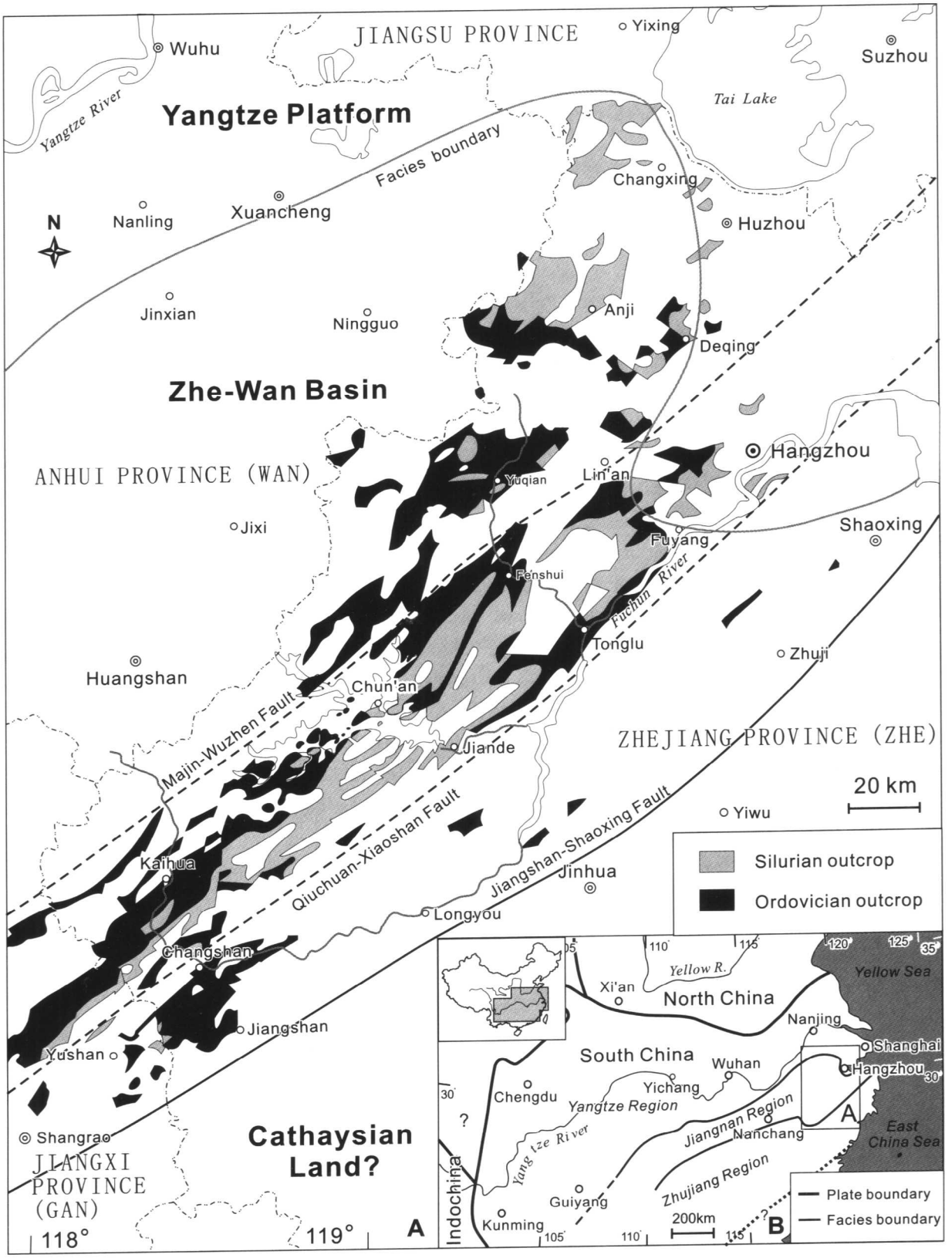

Fig. 2-1 The Ordovician and Silurian outcrops in the JCY area and Northwest Zhejiang(A), and the geological setting of the South China Palaeoplate(B).

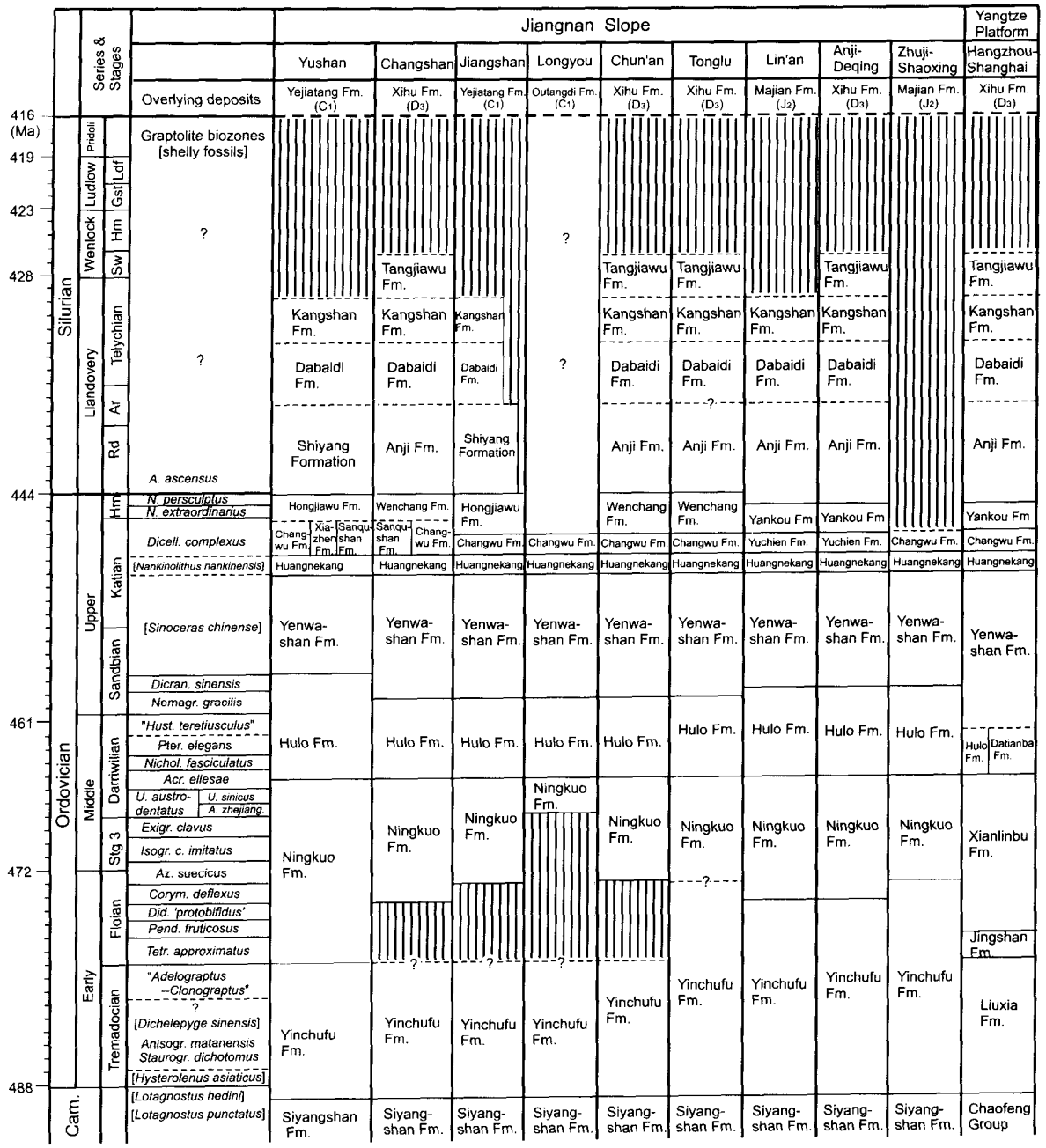

Fig. 2-2 The correlation of the Ordovician-Silurian rocks in the JCY area and the Northwest Zhejiang Province. Data Sources, **Yushan**: Chen & Han, 1964; Chen *et al.*, 1983; Chen & Yang, 1988; Xiao & Chen, 1990; Xiao *et al.*, 1991; Wang *et al.*, 2004; Rong & Zhan, 2006. **Changshan**: Yao & Yang, 1991; Chen & Bergström, 1995; Chen *et al.*, 1995, 1997, 1998, 2003; Zhang, 1993. **Jiangshan**: Chen & Bergström, 1995; Chen *et al.*, 1995; Han, 1983a, b, 1996; Zhang *et al.*, 2004; Zhang *et al.*, 2005; Wang *et al.*, 2004; Rong & Zhan, 2006. **Longyou**: Ge, 1962. **Chun'an**: Zhejiang Geological Survey, 1965; Jiao, 1981; Yu, 1996. **Tonglu**: Zhejiang Geological Survey, 1965. **Lin'an**: Zhejiang Geological Survey, 1967; Ge, 1984; Chen *et al.*, 2007; Yang, 1981, 1983. **Anji-Deqing**: Zhejiang Geological Survey, 1967; Yu, 1996. **Zhuji-Shaoxing**: Ge, 1964; Zhejiang Geological Survey, 1975. **Hangzhou-Shanghai**: Ding & An, 1985; Zou, 1987; Ge, 1990; Bureau of Geology and Mineral Resources of Zhejiang Province, 1989. Stages abbreviation: Ar. Aeronian, Gst. Gorstian, Hm. Homerian, Hrn. Hirnantian, Ldf. Ludfordian, Rd. Rhuddanian, Sw. Sheinwoodian.

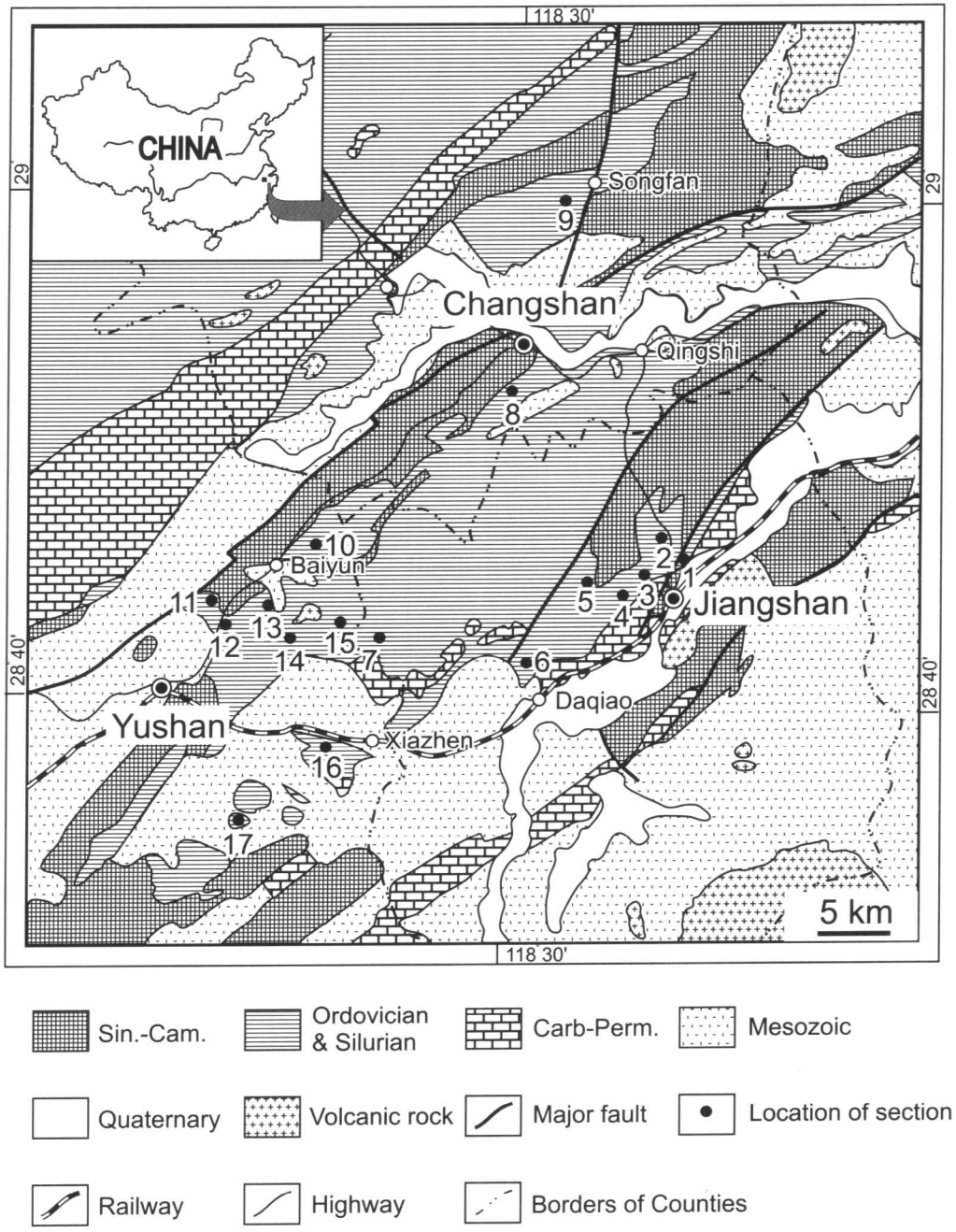

Fig. 2-3 A general geological map of the JCY area, SE China, with the major localities of Ordovician and Silurian sections plotted. Sections: 1. Huangnigang. 2. Fengzu. 3. Hengtang. 4. Quantoupeng and Jinmuwu. 5. Hengdu. 6. Tanshi. 7. Shiyang. 8. Huangnitang. 9. Sanqushan. 10. Chenjiawu. 11. Mojiawu. 12. Huiyingting. 13. Lijiapeng. 14. Jitoushan. 15. Wangjiaba. 16. Tashan. 17. Zhuzhai.

composed of mudstones and carbonates. Between the Jiangshan-Shaoxing Fault and Majin-Wuzhen Fault, the Ordovician deposits are characterized by clastics, predominantly mudstones and sandstones. To the northwest of the Majin-Wuzhen Fault, the Ordovician deposits generally resemble flysch, containing frequent turbidites and well developed Bouma sequence (Fig. 2-1). It seems probable that during the Ordovician and Silurian Periods the JCY area and NW Zhejiang were more extensive-

ly affected by the northwestwardly-advancing Cathaysian Land than was the Yangtze Platform to the northwest. Several northeast-southwest striking faults (the Jiangshan-Shaoxing Fault, Qiuchuan-Xiaoshan Fault, and Majin-Wuzhen Fault) may have been present and active since the Sinian.

In general, the Early and Mid Ordovician rocks (including in ascending order the Siyangshan, Yinchufu, Ningkuo, and Hulo Formations) of the entire region are largely similar, whereas the Upper Ordovician strata display greater differentiation, with the northern part dominated by sandstones, mudstones and conglomerates, the middle part dominated by shales and silty shales, and the southern part by shales and carbonates that contain biostromes and reefs.

Silurian rocks are largely absent in the southern part of the JCY area and NW Zhejiang, with the exception of the Yushan-Jiangshan border area (Shiyang-Yanrui) where earliest Silurian deposits containing abundant brachiopods and other shelly fossils are present. However, to the northwest of the Qiuchuan-Xiaoshan Fault, a thick sequence of Silurian rocks, dominated by poorly fossiliferous sandstones intercalated with silty mudstones and mudstones are exposed. These lithological units, including in ascending order the Anji, Dabaidi, Kangshan and Tangjiawu Formations are poorly controlled chronologically due to the lack of graptolites or other index fossils. Based on a lithological comparison with the litho-units of adjacent regions, the Silurian sequence, at least the Llandovery and lower part of the Wenlock, is nearly complete (Fig. 2-2).

Lithostratigraphy

As stated above, the Ordovician and Silurian litho-units of the JCY area and NW Zhejiang region are correlated with each other and with some key section of the Yangtze Region and Zhujiang Region (Fig. 2-2). These litho-units are discussed below in alphabetic order.

Anji Formation (also known as the *Xiaxiang Formation*)

The Anji Formation was named by the Zhejiang Geological Survey (1967), with its type locality at Paiwu, Huangshu Town, Anji County, West Zhejiang. It is underlain by the Wenchang Formation and overlain by the Dabaidi Formation in a conformable sequence with a thickness of 270 m at the type locality. The Anji Formation is characterized by green-yellow and greenish gray mudstone, shale and siltstone. It can be sub-divided into three parts: a lower part of mainly fossiliferous mudstone, a middle part of greenish gray fine sandstone, siltstone and minor shale, and an upper part of greenish gray shale and siltstone (Yu, 1996). At the Tantou section of Chun'an, the Tangjia section of Lin'an, and the Ximenshan-Tangwuli section of Deqing, the lower part of the formation contains a rich Late Ordovician to earliest Silurian graptolite fauna, including *Normalograptus extraordinarius*, *N. ojsuensis*, *N. rhizinus*, *N. wangjiawanensis*, *N. laciniosus*, *N. avitus*, *N. mirnyensis*, *N. normalis*, *N. normalis brenansi*, *N. acceptus*, *N. angustus*, *N. persculptus*, *N. medius*, *N. anjiensis*, *N. madernii*, *N. jerini*, *N.* aff. *inazaonae*, *Neodiplograptus modestus*, *Neodipl. charis*, *Neodipl. anhuiensis*, *Akidograptus cuneatus*, *Amplexograptus latus*, *Sudburigraptus? angustifolius*, *Sud.? angustifolius longus*, *Sud.* sp. and *Paraclimacograptus innotatus* (see Figs. 7-2, 7-9 for their detailed occurrences and ranges at each section). At the Paiwu section (also known as Huangshu section), graptolites including *Akidograptus ascensus*, *Ak. giganteus*, *Normalograptus avitus*, *N. mirnyensis*, *N. madernii* etc. were recorded (Yang, 1964; Chen *et al.*, 2007). Based on the graptolite succession in the lower part of the Anji Formation, the *N. persculptus* Biozone (only at

the Tangjia section of Lin'an) and the *Akidograptus ascensus* Biozone have been recognized. Accordingly, this part of the Anji Formation is considered to be of latest Ordovician and earliest Silurian age (Fig.2-4).

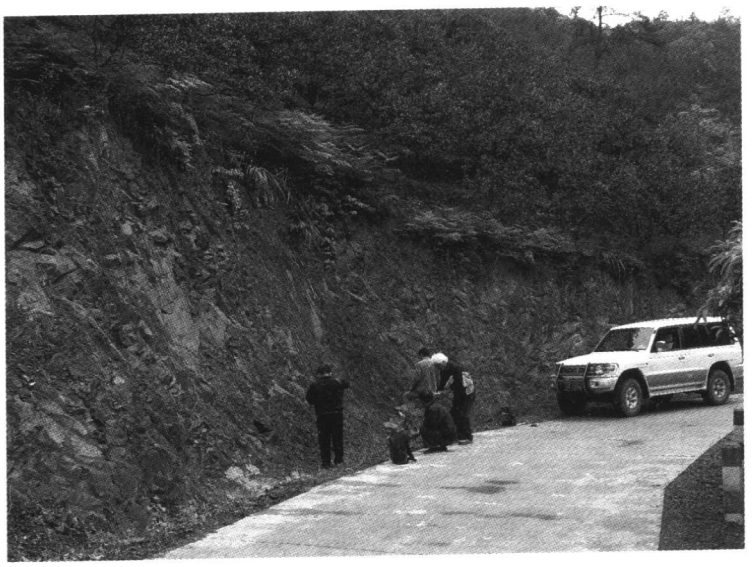

Fig. 2-4 The Anji Formation (early Silurian) at Dakengwu, Chun'an, Zhejiang. The basal part (where the people are working) contains a fairly rich brachiopod fauna of earliest Silurian age.

Brachiopods are also fairly diverse in the lower part of Anji Formation. Just below the graptolites-bearing beds, a brachiopod fauna with *Levenea qianbeiensis*, *Katastrophomena* cf. *scotica*, *Leptaena rugosa*, *Eospirigerina* sp., *Brevilamnulella*, *Glyptorthis*, *Epitomyonia*, *Paracraniops*, *Skenidioides*, and *Coolinia* was recorded (see Rong & Zhan, 2006). Trilobites are rare, only *Dalmanitina* (*Songxites*) *wuningensis* was found. The bivalve *Deceptrix* sp. also occurs in this part of the formation. No fossils have been recorded from the middle and upper parts of the Anji Formation.

The Anji Formation is widely distributed in northwestern Zhejiang, but the thickness varies greatly from 60 m to 443 m among sections (Yu, 1996). In the JCY area, these rocks are correlated with the Shiyang Formation, which is composed of fine sandstone and siltstone intercalated with mudstone.

Changwu Formation

Lu *et al*. (1955) named this formation with its type locality at the Changwu village, a few kilometers to the north of Jiangshan county town, West Zhejiang. It is conformably underlain by the Huangnekang Formation and conformably overlain by the Wenchang Formation, or disconformably overlain by Carboniferous sandstone. The Changwu Formation is composed of lamina-ted green-yellow shale and siltstone, with minor thin-bedded sandstone, and is 280 m thick at its type locality. Generally, the formation can be divided into three members: the lower member consists of laminated greenish gray mudstone and siltstone in minor flysch rhythms (Fig. 2-5A,B), the middle member

of sandstone and siltstone, and the upper member of greenish gray calcareous mudstone with uncommon fine sandstone. In the Changwu Formation, the graptolites *Dicellograptus* cf. *complanatus*, *Orthograptus truncatus* cf. *abbreviatus* and *Climacograptus* sp., *Normalograptus angustus*, *Rectograptus socialis* and *Amplexograptus* sp. have been recorded, indicating a mid to late Katian age (early Ashgillian) (Lu *et al*., 1955; Chen *et al*., 1995; Chen in Zhan & Cocks, 1998).

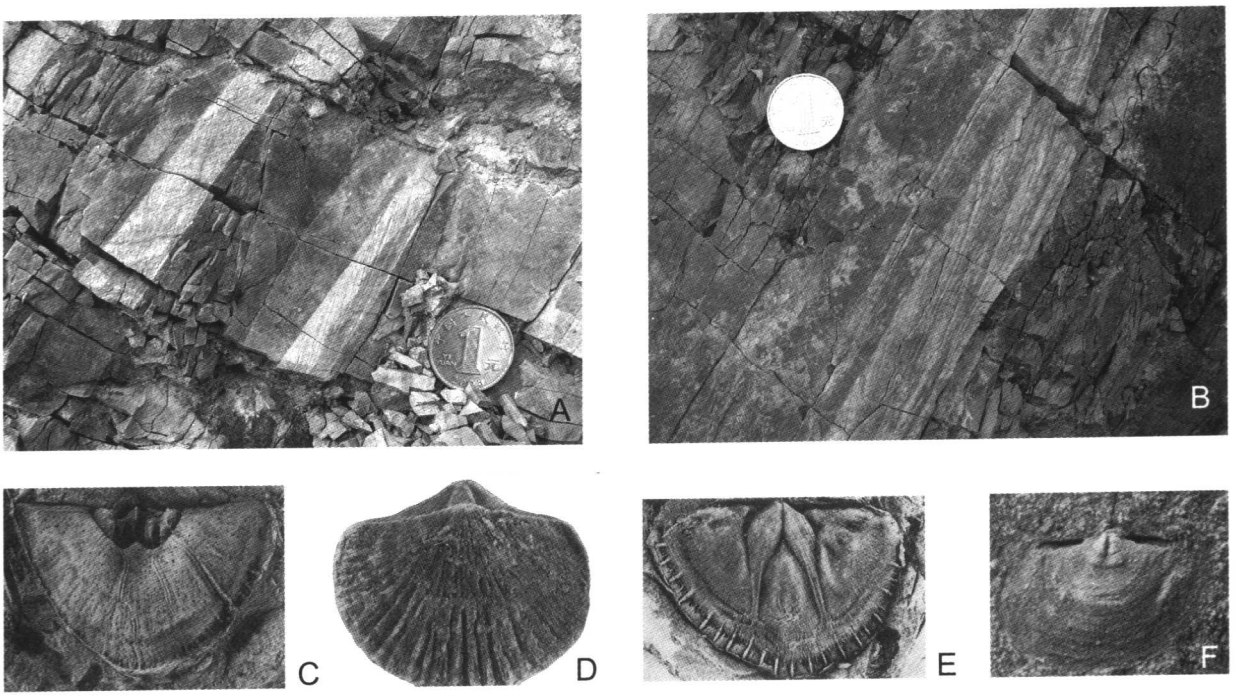

Fig. 2-5 The Changwu Formation (Katian) and some distinctive brachiopods in western Zhejiang. A, B. The flysch-like deposits of Changwu Formation at the Poponong section, Zhitang Town, Longyou County, West Zhejiang. C. *Metambonites meritus* Rong & Zhan, Shiyang—Dianbian, Jiangshan, ×3. D. *Skenidioides* sp., Shiyang—Dianbian, Jiangshan, ×5. E. *Kassinella shiyangensis* Zhan & Cocks, Shiyang—Dianbian, Jiangshan, ×2.5. F. *Foliomena folium* (Barrande), Changwu, Jiangshan, ×10.

It also contains a fairly diverse shelly fauna, including the brachiopods *Eospirifer praecursor*, *Wangyuella ventribiconvexa*, *Foliomena folium* (Fig. 2-5F), *Cyclospira* sp., *Dedzetina* sp., *Skenidioides* sp. (Fig. 2-5D), *Plectorthis*? *tanshiensis*, *Epitomyonia jiangshanensis*, *Triplesia zhejiangensis*, *Bimuria*? sp., *Metambonites meritus* (Fig. 2-5C), *Synambonites biconvexus*, *Anoptambonites* sp., *Rongambonites bella*, *Kassinella shiyangensis* (Fig. 2-5E), *Sowerbyella sinensis*, *S. dianbianensis*, *Holtedahlina sinica*, *Fenomena distincta*, *Christiania* aff. *magna*, *Eostrophina uniplicata*, *Tcherskidium jiangshanensis*, *Eospirigerina yulangensis*, *Antizygospira liquanensis*, and *Ovalospira dichotoma* from the lower and upper members (Zhan & Cocks, 1998); the trilobites *Cyclopyge*, *Microparia* (*Microparia*), *Dionidella* (*Huangnigangia*), *Aethedionide*, *Ampyxinella*, *Collis*, *Pseudampyxina*, *Remopleurides*, *Amphytrion*, *Robergia*, *Parisoceraurus*, *Hadromeros*, *Ovalocephalus*, *Alceste*, *Nileus*, *Pseudopetigurus*, *Birmanites*, *Lisogorites*, *Xuanenia*, *Diacanthaspis*, *Corrugatagnostus*, *Sphaeragnostus*, *Telephina* and *Sarkia* (Zhou *et al*., 2004), and the ostracode *Drepanella* sp. (Chen *et al*., 1995).

The Changwu Formation mainly crops out in West Zhejiang, including Jiangshan, Changshan,