河南汝阳盆地的恐龙化石

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徐莉，1966 年出生于浙江省嘉善县，1988 年毕业于中国地质大学（武汉）地质系，2007 年中国地质大学（武汉）第四系地质学博士研究生毕业。教授级高级工程师，河南省学术技术带头人。1988 年至 2005 年，于河南省地质研究所（现河南省国土资源科学研究院）从事地质矿产、地质环境科研工作；2005 年至今，于河南省地质博物馆从事地质遗迹保护、地层古生物及博物展览科学研究、科学普及及科技管理工作。主持和参与部省级重点项目 20 余项，科研成果获部级科学技术一等奖 1 项，二等奖 1 项，省科学技术进步二等奖 1 项，省厅级科技成果一等奖 8 项。在核心期刊发表论文 23 篇，其中《科学》1 篇，SCI 检索期刊 13 篇，多篇论文获河南省自然科学优秀论文奖。近年来，带领研究团队在河南汝阳、栾川、南阳、义马等地区的古脊椎动物调查、发掘尤其是恐龙的勘查发掘研究方面取得重大成果。

序

河南省汝阳盆地发现大规模的恐龙化石是我意料之中的事，但恐龙的属种特别是巨型恐龙的属种如此之多、个体如此之大，则超出了我的想象；而在发现、发掘、研究与保护和合理利用过程中跌宕起伏的传奇故事，则从一个侧面真实地反映出我们国家和老百姓对古生物地质遗迹资源的认知历程和重视程度。

从我2005年向河南省地质博物馆提供汝阳盆地恐龙化石线索、2006年2月到现场指导化石的勘查与发掘工作，至今已8年有余了。8年间，以徐莉为项目组长、吕君昌为技术负责、贾松海为发掘队队长的这个团队，在张兴辽、蒲含勇两任馆长和中国地质科学院地质研究所的领导及季强研究员的鼎力支持下，克服重重困难，坚持锲而不舍，做了大量深入细致的工作，汝阳地区大批恐龙宝贝凌空出世、震惊世界，使这处世界级的古生物地质遗迹产地昭告天下，成为国家地质公园和第一批国家重点保护古生物化石集中产地，功在当代、惠泽千秋，可喜可贺！

本书采用通俗易懂的专业记述与知识链接手法，全面翔实地记载了迄今对汝阳盆地地层古生物化石调查、勘查与化石发掘修复研究的过程与成果，是一本介绍汝阳恐龙的发现、发掘、研究过程，汝阳盆地白垩系与恐龙生存地质时代，再造恐龙时代生态环境的一部科研与科普知识相结合的好图书，值得热爱恐龙的人士和研究恐龙的学者一读。

谨以此序，纪念为汝阳恐龙发现提供重要线索、默默无闻的已过世的曹鸿欣同志。

董枝明

Dong Zhiming

前　　言

“酒祖之乡❶”汝阳县，在赫赫有名的九朝古都洛阳市，算不上特别有名。养育了豫西一方儿女的汝河，静静地从县城南边流淌而过。住在河东岸的刘店镇刘富沟村民，以惯常的烟草、花生、红薯种植繁衍生息。但2006年春节刚过，寒风料峭中，一群在山沟里东奔西走寻找神秘宝贝的人，惊醒了这个沉寂的小山村，轰然“唤醒”了在这里沉睡1亿多年的庞然大物，掀起了阵阵“恐龙风暴”。

2006年2月，在著名恐龙专家董枝明研究员的指导和帮助下，在地方政府和各级国土资源部门的大力支持下，开始发掘刘店镇上刘富沟村化石点。至今8年间，河南省地质博物馆牵头，联合中国地质科学院地质研究所，中后期吸收兰州大学、河南理工大学、中国科学院南京地质古生物研究所和中石化河南油田石油勘探开发研究院等单位的部分研究人员参与，持续对汝阳盆地开展了大量的地层古生物化石调查、勘查和化石发掘、修复、装架复原及科学研究工作，取得了重大突破：在汝阳县三屯镇—刘店镇约30平方千米的范围内，先后发现密集分布的恐龙化石点105处（时至今日还有化石点陆续被发现）；规模发掘化石点32处，剥离、发掘化石坑土石方3万多立方米，采掘化石“皮劳克❷”278件，重达100吨以上；修复恐龙化石3000余件，复原装架了巨型汝阳龙、汝阳黄河巨龙、史家沟岘山龙、洛阳中原龙4具不同属种的恐龙骨架模型；发现了12种以上的新属种恐龙，已完成研究并公开发表命名了6种新属种恐龙；新发现了丰富的恐龙蛋、龟鳖、无脊椎动物、微体古生物、古植物和遗迹化石等多门类化石，命名为“汝阳巨型蜥脚类恐龙动物群”（吕君昌等，2006）。采用多种鉴定分析研究方法，基本确定其生存地质时代为1.2亿年至1亿年左右的早白垩世中晚期；恢复当时的气候主要为暖湿—干旱交替（以干旱为主）环境，恐龙生存时期汝阳盆地周边古地形起伏不大，植物茂盛，水体发育、辫状河遍布，底栖生物和水体生物繁盛，自然生态系统完整。

国内外对比研究表明，巨型汝阳龙，是白垩纪巨龙类的代表，是世界上最粗壮、化石最完整的巨龙类恐龙；汝阳黄河巨龙，是目前已知亚洲体腔最大、臀部最宽的巨龙类恐龙；洛阳中原龙，是中国目前为止唯一发现、有确

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❶ 见14页科普链接。

❷ 见27页科普链接。

凿证据的大型结节龙类甲龙；汝阳云梦龙，是中原地区首次发现的白垩纪时期的巨型长颈蜥脚类恐龙；史家沟岘山龙，是进步的大型蜥脚类恐龙新属种；刘店洛阳龙，是继栾川发现窃蛋龙后在中原地区首次发现的一个新的进步窃蛋龙类；已发表但未正式命名的禽龙，具有重要的研究意义。已鉴定正在研究的还有大型、中型蜥脚类和大型肉食类、似鸟龙类、窃蛋龙类、驰龙类、小型兽脚类、鸭嘴龙类等。汝阳巨型蜥脚类恐龙动物群家族种类丰富、体格差异大、时代跨度广，具有重要的科学价值。

汝阳巨型蜥脚类恐龙动物群自发现以来，引起了国内外的广泛关注，其科学价值、科普价值和社会经济价值得到了充分认可。2008 年汝阳县被中国地质调查局地层与古生物中心命名为“恐龙之乡”；2011 年，河南汝阳恐龙化地质公园被国土资源部授予国家地质公园；2013 年，河南汝阳化石产地被国土资源部列为第一批国家重点保护古生物化石集中产地（全国 38 处，河南仅此 1 处）。几年来，先后吸引美、德、法、英、加、日、韩、瑞典等国家和中国台湾地区的一批古生物学家，前来河南参与恐龙化石的合作研究或专题研讨，提升了科研水平，其承载的科学价值得到了全球恐龙研究领域的公认。中央电视台围绕汝阳恐龙的发现、发掘与研究，拍摄了《今日说法——石破天惊》、《见证——巨龙惊现》、《巨龙发掘记》等 11 部科教专题片，翔实地记录了汝阳恐龙动物群凌空出世的传奇故事，在央视一、二、四、九、十套多次重复播出；国内外有关报纸与网络中有数万篇关于汝阳恐龙化石的报道。采集的部分化石标本和装架复原模型成为河南省地质博物馆常年展出的灵魂展品，开馆 7 年已吸引了 300 多万名观众慕名参观；装架复原的 2 架恐龙模型在中国台湾常年展出；部分化石标本和装架复原模型接连应邀参加了 2007~2008 年日本的“亚洲大恐龙展”，2010~2011 年美国辛辛那提、夏威夷博物馆专题展，2012~2013 年韩国大恐龙展，2013~2014 年中国香港“巨龙传奇展”等。多个国家、地区，多期次的国际展览，均引起巨大轰动。

为全面反映汝阳盆地地层、古环境、古生物化石调查勘查及与发掘修复研究成果，记录汝阳恐龙腾空出世的历程，普及地学科普知识，我们编写了本书。本书得到河南省 2009 年两权价款“河南省国土资源厅地质矿产科技攻关项目”（项目号：08），以及国家自然科学基金委（项目号：41272022）的资助。各章节分工：前言，张兴辽，徐莉，蒲含勇；1 石破天惊，徐莉，吕君昌；2 巨龙惊现，贾松海，徐莉，张纪明；3 巨无霸家族，吕君昌，常华丽；4 和谐共存，潘泽成、徐莉、王长征；5 红层探秘，徐莉，潘泽成，贾松海，王志宏；6 时代追溯，徐莉，潘泽成，张兴辽；7 孕育无声，胡斌，王长征，王志宏，贾松海；8 盘古论今，张成君，潘泽成，贾松海。全书由徐莉和张兴辽统稿，杨彦秋、常华丽、张菀漪、魏雪芳、Imbabazi Berthe 和 Dembele

Blaise 等英文翻译，杨彦秋英文统稿。

研究成果中，地层及古环境研究人员主要为徐莉、张兴辽、潘泽成、贾松海、胡斌、王长征、张海清、叶剑洪、高殿松等；化石鉴定与研究主要人员有：吕君昌、徐莉、董枝明、季强、小林快次（日本）、姬书安、田中康平（日本）、吴肖春（加拿大）、Eric Buffetaut（法国）、Dale Winkle（美国）、Philip Currie（加拿大）、佟海燕（法国）、东洋一（日本）、潘华璋、文世宣、曹美珍、王德有、朱红卫、刘本培、阎国顺、席运宏、常华丽等；野外发掘与化石修复人员有贾松海、张纪明、刘彦军、韩相松、曾纯军、邱英平、秦世斌、聂小龙、申谊、魏超、张玉清、吴炎华、胡卫勇等。

参加室内工作的人员有：秦爽、豆敬磊、张纪平、马德蕻、吴艳、张婉婉、石晓、仲楠、孙丽、张逸阳、肖乐、刘迪，瞿亚红、王才华等为本书的顺利开展做了大量财务保障工作。

目　录

1 石破天惊——汝阳第一条恐龙的惊世发现

九叶网 Mayinga 小朋友发表博文写道：“记不得是哪一天了，妈妈给我买了一本关于恐龙的书，从此我便爱上了恐龙。我觉得生活在中生代的恐龙很强壮、很可爱、很神奇，它们的个头是那么大，真的太厉害了。现在我已经拥有好几十个恐龙模型，十几本与恐龙有关的科普书，这些可都是我的宝贝。我每天都要妈妈给我讲恐龙的故事，吃饭时也要捧着一本恐龙图鉴。我自己也想成为一只恐龙！……”

自 1822 年英国乡村医生曼特尔发现恐龙（禽龙）牙齿化石以来，人们对恐龙的兴趣日益高涨，恐龙文化在全球方兴未艾，恐龙文化产业蒸蒸日上。科学家们关心恐龙的起源、演化、分布和绝灭，以及所承载的地质、生物、天文、环境信息，以启迪当今社会，警示人们重视地球、保护环境；老百姓对这类体形庞大、种类繁多、形态各异的史前生物如何生存、发展和灭绝充满了好奇与关切，环境保护意识也不断增强；而对于好奇心强、想象力非常丰富的青少年来说，恐龙给了他们很大的想象空间，满足了他们想象的需要，也激发他们热爱大自然、热爱科学。科学家和艺术家借助化石赋予了恐龙新的生命，恐龙化石及恐龙骨架模型是最具科普价值和观赏价值的展品，在自然历史类博物馆展览中举足轻重、不可或缺。

1.1 汝阳第一条恐龙——汝阳黄河巨龙的离奇出世

1.1.1 背景

2005 年 8 月，新建的河南省地质博物馆高大空旷的恐龙展厅，让时任河南省地质博物馆馆长的张兴辽愁上眉头。虽说河南南阳地区的恐龙蛋化石群闻名于世，恐龙蛋和零星的恐龙骨骼化石也在全省多个盆地发现，但河南境内的恐龙骨骼化石一直没有大的发现，展厅高近 20 米，到哪里去征集这么大的恐龙和恐龙骨架模型呢？通过查询和朋友介绍得知，中国科学院古脊椎动物与古人类研究所研究员董枝明先生是著名的恐龙专家，被尊称为“中国龙王”，可以请教他。为此，张兴辽带人专程赴北京拜见了董枝明先生，本意请董先生为河南省地质博物馆拟展出的几具恐龙骨架模型是否科学提出意见，并请介绍几家模型制作单位。但在谈话间，董先生突然说“我知道你们河南有恐龙，栾川、汝阳都有，最好自己发掘，在博物馆内展示河南自己的龙。”一行人员当时都很吃惊，原先只听说过南阳发现有诸葛南阳龙，栾川发现有恐龙牙齿，根据前人资料汝阳盆地产出的是新生代地层，从来没有听说过汝阳有恐龙化石。张兴辽再三询问，董老师仍以毋庸置疑的口气说：“20 世纪 90 年代初，我曾派学生去现场踏勘过，肯定是恐龙化石。没问题，肯定能挖到!”

原来，汝阳县刘店镇、三屯镇在新中国成立前就有挖“龙骨”作中药的传统习惯。

1 An Earth Shattering Discovery

Mayinga was a kid who wrote on blogging website Jiuye: "I can't remember exactly what day it was when my mom bought me a book about dinosaurs, then I just fell in love with dinosaurs. I think dinosaurs living in the Mesozoic were so strong, cute and magic. They were so big and awesome! Now I already have several dinosaur books, dozens of dinosaur toys and models, which are the best things I've ever had. I ask my mother to tell me dinosaur stories every day, and even hold a dinosaur book while I'm eating. I want to be a dinosaur…"

Ever since a dinosaur (Iguanodon) tooth fossil was found in 1822 by a British country doctor, Gideon Mantell, people have been increasingly fascinated by these creatures. Dinosaur culture is in full swing, and dinosaur industry has taken off. Scientists want to understand the origin, evolution, distribution, and extinction of the dinosaurs, as well as the geological, biological, astronomical, and ecological information that they can offer, which admonishes and inspires us to cherish the earth and protect our environment. Ordinary people are full of curiosity about how these big, diverse animals, in so many different shapes and forms, lived, evolved, and perished. As a result, our awareness of environment protection becomes keener and stronger. For kids who are by nature curious and imaginative, dinosaurs offer them a big space for imagination, inspiring them to love nature and science. Scientists and artists bring discovered fossils to life. Dinosaur fossils and skeleton models come with high scientific and artistic values, and are indispensable exhibition attractions in natural history museums all over the world.

1.1 The First Dinosaur in Ruyang: the Strange Birth of *Huanghetitan ruyangensis*

1.1.1 Background

One day in August 2005, in the palatial and empty dinosaur exhibition hall of the newly built Henan Geological Museum (HGM), Director Zhang Xingliao was frowning. Although dinosaur egg fossils in the Nanyang region were ranked as the best of the world, and scattered fossils of dinosaur bones had been found in other basins in Henan, there was still no significant discovery of dinosaur bones in the province. The exhibition hall was nearly 20 meters high, but where to collect a large dinosaur's skeletons to fill the space? By asking around and doing research, he got to know about the renowned dinosaur expert, Mr. Dong Zhiming, a scientist at the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP), Chinese Academy of Science (CAS). Known as "the Chinese King of Dinosaurs", he was recommended as a source for guidance. Therefore, Zhang Xingliao, together with his colleagues, went to Beijing to pay Mr. Dong a visit in person, with the original intention of asking Mr. Dong's opinion and suggestion about several dinosaur models that HGM was going to exhibit. But during the conversation, he suddenly said, "I knew there were dinosaurs in Henan, in places like Luanchuan and Ruyang. You'd better excavate yourself and display your native dinosaurs." All the people from Henan were stunned to hear this. To their knowledge, *Nanyangosaurus zhugeii* was found in Nanyang, some dinosaur teeth were found in Luanchuan. But previous studies had assigned strata in Ruyang Basin to the Cenozoic, and there had never been report of dinosaur fossils over there. Zhang Xingliao asked a barrage of questions, but Prof. Dong was as certain as he could be, "in the 90s of the last century, I sent one of my student to do the field work there. There were dinosaur fossils. No doubt. You can surely find them!"

The story started with the local custom of digging up "dragon bones" and using them as part of the traditional Chinese medicine in Liudian Town and Santun Village in Ruyang County, well before the founding of PRC. As early as in 1989, an old man, Cao Hongxin, who had been collecting "dragon bones" for a long time, bought some strange-looking bones and became suspicious. He sent the bones to the Chinese Academy of Science with a letter that read "Comrades Leader, I don't know what this stuff is, but I think they are good stuff that should belong to the country. I hope you send experts to check it out." The letter was transferred to Mr. Dong Zhiming, who identified it as a possible vertebra of dinosaur. In September 1989, Mr. Dong dispatched his student Lü Junchang to visit Mr. Cao and do field research. With Grandpa Cao as the guide, Lü Junchang searched several hills where villagers used to dig for "dragon bones", but found no fossil site. However, he collected some dinosaur fossils, including humerus, vertebrae, which are now in the collections of IVPP. In 1993 Lü Junchang once again came to Ruyang, with the guidance of Mr. Cao, he found a dinosaur fossil site in Caojiagou, dug out some dinosaur femur bones and vertebra bones (thereafter HGM continued digging at the site and found some dinosaur fossils). At the same time, he also found that local people used spinal vertebrae to anchor cows, and some dinosaur fossils cropped out of the stone walls, which confirmed with certainty that dinosaurs once lived in Ruyang in geological time. Afterwards, Mr. Dong had to lead a joint China-Canada expedition to do dinosaur search in Xinjiang, and Mr. Lü went to the United

States for the doctoral degree. Hence no further work was done in Ruyang. So the news of dinosaur discovery in Ruyang was totally unknown even to the geological institutions in Henan Province. From 1992 to 1995, Henan Bureau of Geology and Mineral Resources organized the survey of 1:50,000 scale Ruyang sheet and Yanglou sheet geological maps, in which the dinosaur-bearing strata in Ruyang Basin were still incorrectly assigned to the Paleocene Mangchuan Formation (E_1m) in the Cenozoic.

After knowing all this, director Zhang Xingliao immediately reported to his superior, Lin Jingshun, then the director of the Department of Land and Resources of Henan Province, and proposed to search and to excavate all-prehistoric vertebrates (dinosaurs, ancient elephants) in the whole province, in order to meet museum's exhibition needs. Director Lin immediately agreed and designated the administrative office to carry it out. Afterwards Henan Geological Museum submitted a project application of "Exploration of Henan's Prehistoric Vertebrates (Dinosaurs, Ancient Elephants) ", and made Ruyang and Luanchuan as exploration areas of top priority.

Around the April of 2005, Li Chui, a villager from Shapin village, Liudian Town, Ruyang County, stumbled upon the Liufugou fossil outcrop when building a new house. The news spread fast. Dragon-bone hunting villagers descended upon the site, dug up all the fossils in shallow beds, and halted digging deeper only because the hill slope collapsed.

On January 6th, 2006, after much work behind the scene, Mr. Dong Zhiming, together with Lü Junchang and Zhang Yuqing, came to Zhengzhou, and proceeded to do field work in Santun of Ruyang, with Zhang Xingliao and Jia Songhai. They met 85-year-old Cao Hongxin first, who led them to scout an excavation site (Fig.1.1). Then it started to snow heavily, so Cao Hongxin brought them to the home of Zhang An, who had been digging "dinosaur bones" for a long time. Then Mr. Zhang took out two large bags of remaining pieces he hadn't sold. Although accurate examination could not be made, they sure looked like dinosaur fossils beyond any doubt. After consultation with Mr. Dong and Dr. Lü, Zhang Xingliao decided to start exploration work throughout the province after the Spring Festival and made Ruyang the number one target of the exploration. They also discussed and decided on the plan of what to do next. To follow it up, the management team of the museum decided to appoint Mr. Dong as the science advisor, and designated Dr. Xu Li as the leader of the project, Lü Junchang as the lead scientist, Jia Songhai as the leader of excavation team. All kinds of preparation of materials and training of personnel were put into motion immediately.

1.1.2 Twists and Turns in the Excavation

After the Spring Festival, February 17, 2006, Dong Zhiming, Lü Junchang, and Zhang

Yuqing came to Zhengzhou from Beijing. And Wang Tao, who was hired from Lufeng Dinosaur Museum of Yunnan Province, flew to Zhengzhou from Yunnan as well. On February 18, 2006, Jia Songhai, Dong Zhiming, Lü Junchang, Zhang Jiming, and Zhang Yuqing as well as other associated personnel as the first team members, arrived at Santun village, Ruyang County. They immediately set out to scout and investigate the areas where “dinosaur bones” had been dug up, guided by Grandpa Cao and Zhang An. The preliminary scouting found that there were still fossils remaining at a fossil spot in Boqizhang village and at another fossil spot in Liufugou (first found by Li Chui). But the ground surface in Liufugou was seriously damaged and “dinosaur bone” poaching had caused a small landslide.

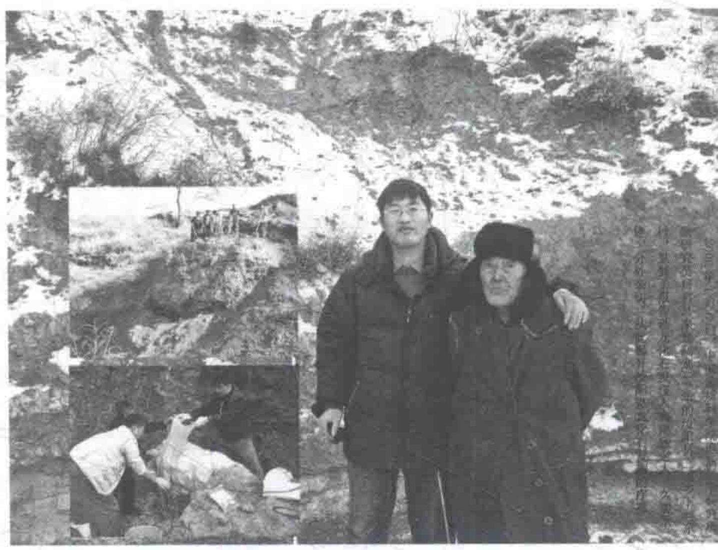


Fig. 1.1 Dr Lü Junchang and Mr. Cao Hongxin in 2006

On the morning of February 20th, Dr. Xu Li and Wu Yanhua arrived at the site with equipment and associated personnel. Further survey and analysis were conducted on the spot. After discussing it over, they concluded that the fossil spot at Shangliufugou was the most favorable for excavation, despite the damages caused by poaching, and that survey and excavation should first be done there to recover what's still left. After the approval from the higher-ups of the HGM and the Department of Land and Resources of Henan Province (DLRHP), search and rescue work, so to speak, started in earnest in the afternoon. Fossils started to appear on the 21st. Meanwhile, the project team fanned out in several groups all over the area to visit the villagers, collect "dragon bones" from them, and search for remaining fossil spots with tips from villagers. Several "dragon bones" found were very valuable, one of which was identified as the femur of a giant sauropod dinosaur. The discovery was published in the Geological Bulletin, Issue 11 of 2006, the first article on the discovery and study of dinosaurs from Ruyang.

On February 23, director Zhang Xingliao, who had just returned from a business trip, accompanied the chief geologist of DLRHP, Wu Guochang, and paleontologist Xi Yunhong, to inspect the site and devise work plans. Because the excavation was a highly skilled work, three technicians from Yunnan's Lufeng Dinosaur Museum were called upon to assist the excavation, as recommended and coordinated by Mr. Dong. While the excavation was going on, a crowd of misinformed villagers gathered around the site and made the ongoing work difficult. Dong Zhiming and Xu Li did their best to persuade and explain to them the situation, showed them the directives and document of approval from the related authorities.

On February 27th, due to heavy snow and slippery roads, the team left four PLKs (fossil plaster blocks in Chinese) in the village government office for temporary storage.

On March 1st, when Jia Songhai was directing villagers to transport two big PLKs, they were stopped by other villagers. Two big PLKs had to be carried to the home of a villager nearby for temporary storage. At noon, Jia Songhai and Zhang Jiming were brought to the local police station for questioning and forbidden to leave. At 5 o'clock, the deputy director of Ruyang LR (Land and Resources) agency came to the rescue and took Jia and Zhang to the county seat.

On 2nd of March, Zhou Jinfang, the deputy supervisor of DLRHP, accompanied by the Party secretary of HGM and the directors of municipal LR agencies, came to Ruyang for a solution of the situation. No consensus was reached after coordinations with the local authorities.

On March 3rd, Ruyang authority seized the fossils temporarily stored in the project team's camp and deposited them in the local police station.

On March 7th, when excavation team returned to the site, they found the unfinished fossil spot had been destroyed, and some separated but unprocessed fossils were stolen.

During this time, the director of Henan Department of Land and Resources, Zhang Qisheng, and deputy director Zhou, were contacting all the parties involved in the dispute and working for a solution. Lin Jinshun, the director of Henan Province's Development and Reform Commission, who was in a meeting in Beijing, got in touch with Luoyang municipal leaders to explain the purpose and importance of the excavation project and hoped to solve the dispute properly and to gain their support for the excavation work.

On March 13th, Zhang Xingliao, Pu Hanyong, Xu Li, Jia Songhai, and Cheng Weiping, the director of Luoyang's LR agency, went to Ruyang to further smooth things over with county leaders, to debrief them with detailed information pertinent to the project. And they gained support from county government after making a promise about the possession of certain fossils after the research was done. It’s agreed upon that the 4 excavated fossils be transported to HGM for repair as soon as possible. Two PLKs that were detained in the villager's home were to be sent back after negotiating with the villagers. At the same time, proactive media coverage of the significance and benefit of fossil excavation in Ruyang was carried out, as well as explaining the difference between archeological relics and fossils. Misunderstanding and suspicions among most villagers was put away.

On March 15th, 4 PLKs detained in the police station were sent back to HGM for repair work.

Two PLKs detained at villager's home contained anatomically very important parts, without which repair and research would be impossible, and research result would not be published. HGM and the county government were very anxious about it. However, for over a year, the villagers were very stubborn about the matter, even after repeated negotiations over the two detained PLK, and mediations by the county and town leaders in person. Later, a so-called "dinosaur fossil protection group" was set up by a number of villagers and a shoddy makeshift "house" was built over the excavation site. On February 2nd of Chinese lunar calendar, the day of "Dragon Raising Head", some villagers held a ceremony of worship and libation for the "dragon".

On March 31, 2007, when the local government and the local police asked for the return of two detained PLKs, their vehicles were detained as well.

On April 7, 2007, Ruyang BPS (Bureau of Public Security) and LR agency, once again attempted to transport away the two PLKs. With two booming sound from one end of the village, some villagers took up farming tools and tried to block the road. Melees ensued and lasted for an hour. On the same day, the main troublemakers were arrested by the police and two PLKs were shipped to Zhengzhou for repair and restoration.

At this point, the event surrounding the dispute of dinosaur fossil excavation in Ruyang largely drew to an end.

The controversy during excavation and villagers' unawareness of fossil preservation came under the provincial government's keen attention. On July 3, 2006, Henan Provincial Government Office issued a directive about strengthening the protection and management of fossils in the whole province. This directive further emphasized the significance of protecting the fossil record, clarified the role of LR agencies, and regulated their managerial functions of fossil excavation, preservation, and export outside the country. It was the first of its kind concerning the regulation, management, and protection of prehistoric fossils and of tremendous significance. In 2010, the State Council of PRC issued "The Regulations of the Protection of Fossils".

Controversies and disputes in the excavation had a nation-wide impact. In April, 2007, CCTV's "Legal Report" produced a documentary "An Earth Shattering Discovery", after searching Internet about this incident and going directly to the locations in Zhengzhou and Ruyang to do the interviews. It offered a relatively objective and analytical narrative of the events, from the perspective of law. The program was broadcast on CCTV on June 4th of 2007, and rebroadcast many times. It was also included in a compilation of "the Best of Legal Report ", and regarded by the professionals in the media as a classic in popularizing and publicizing legal knowledge.

Transcript of "Legal Report" from CCTV International (www.cctv.com), June 4, 2007.

In a village in Ruyang, dinosaur fossils were excavated. When the geologists were about to take them away to do research, villagers had different ideas. They thought that the newly found fossils could improve village's economy and didn't want them taken away from the village.

In the spring of 2004, in a small village in Ruyang, Henan province, something surprising happened. Farmers found some pieces of rock that were different from others in terms of color, shape, appearance, and texture. It's said to have the power to cure sickness. So what on earth are theses rocks? What story lies behind these rocks?

These stones that looked a tail were dug up by a Liufugou villager two years ago. These stones had bone's texture and look, which made them look like animal fossils. But what animal could have a tail this big and thick? The bones were found at the foot of a slope, and villagers said they found rocks like it in the wild all the time.

According to villagers, these rocks were pure dragon bone underneath the rock-like surface. The name "dragon bone" was handed down from the older generations. The tale of dragon spread like wildfire after this tail surfaced. Prior to that time people could only dig up some small pieces with no distinct shapes or forms. Younger people who were not very superstitious thought that dragons were imaginary animal in legends that nobody had ever seen and that the tail was from some other animal.

Villagers guessed all animals they knew, but could not find any answer. What was more amazing was that the stone had a very special power to stop bleeding when ground stone powder was put on a wound. Were these stones really dragon bones? Some persistent villagers were still trying to imagine. Suddenly, someone came up with an animal: dinosaur. The villagers were excited by this speculation, so they quickly told the news to some geology experts through acquaintances. However, experts from Henan Geological Museum shot down villagers' speculations.

Judged by stratigraphic information of Ruyang County area, experts said it was impossible to have dinosaur fossils there, since dinosaurs lived 20 million or 30 million years before the strata were formed there. So there was no real answer to the origin of the stones. The village calmed down, but soon after, some more bizarre discoveries made the whole village excited again. After digging out a tail, villagers dug up two claws and an egg-shaped rock. What were these strange things that kept popping up? Was it possible that Liufugou village really had dinosaur fossils? Experts of Henan Geological Museum also felt very strange about these findings (Note: There is discrepancy with the real event). In February 2006, they decided to go and see for themselves.

After investigation, geologists confirmed that these stones were really fossils and immediately filed a special report to the provincial authorities. Geologists were both pleased and surprised about these fossils at Liufugou Village. A total of six large fossils were found, which were respectively the cervical spine, ribs and coccygeal vertebra part of a dinosaur. Furthermore, to the surprise of the geologists, it was a very rare dinosaur based on preliminary examination. So what species of dinosaur was it? Geologists decided to excavate the fossils as soon as possible and transport them back to the museum for study. The Department of Land and Resources of Henan Province immediately decided to excavate the fossils in an effort to rescue them.

The process of excavation went smoothly. The fossil specimens were carefully packed after the excavation was completed. When the experts were ready to transport the fossils away, something unexpected suddenly happened: the villagers blocked the road. Experts said that the two fossils with greatest research value were detained by villagers. Research could not possibly be complete if the most important parts were absent. Why did the villagers detain such precious dinosaur fossils?

The excavation site was on this hillside. The reporter saw that the villagers set up a small shed there. The villagers said that they also wanted to protect the dinosaur fossils, only that they wanted the fossils to stay in the village. But geologists explained that fossils could only be protected and utilized after they were studied scientifically. Villagers insisted that research could be done with only part of the fossils and the rest could be put into better use as a protection area in the village. Geologists believed that protection area could only be set up if the fossils were found in abundance there.

The villagers were unconvinced by the explanation, and they only felt secure if they could have part of the fossils in the village. The fact of the matter was that Ruyang County was on the official list of impoverished counties in the country, where this village was one of the most impoverished one in the county. Villagers saw hope in the newly found dinosaur fossils, which they thought could bring quick fortune to the village. The geologists and the officials from the county tried to persuade them patiently without success. In frustration, they had to leave with four specimens that were in their possession for scientific research.

The experts determined that the dinosaur lived in the Early Cretaceous period of the Mesozoic, dating from about 100 to 85 million years ago, and was an herbivorous sauropod dinosaur. This species of dinosaurs was the largest terrestrial animals ever lived on the earth, with the maximum weight of 100 tons. According to the experts who had examined the fossils, this particular dinosaur could be up to 27 meters long. It could have had greater value if the "dragon bones" had not been sold.

Currently, technicians are making replica plaster model based on dinosaur fossils, in preparation for exhibition in July this year. However, further research couldn't be done, because the two specimens have not been returned. Meanwhile, officials of Ruyang County have been working on the villagers almost daily, but a handful villagers were most obstinate. Because the village lacked necessary conditions to protect the fossils and scientific research couldn't be delayed any longer, government agencies of the Ruyang County took action on April 6th, 2007, and seized the two specimens from the villagers, which were transported to HGM immediately.

The villagers are still emotionally connected to the fossils, which had brought them surprise and fascination. They still hope that they would one day be returned to them. Geology experts say that dinosaur fossils found in the village are with significant value, which could change and redraw geological map of Henan. It has been basically confirmed that a dinosaur fossil colony existed within Ruyang area, which could benefit considerably from the search and development of the fossil resource.

Moderator (Sa Beining): You were on the scene when the fossils were excavated. What were the circumstances? Could you tell us?

Dong Zhiming: Based on our experience, it is a relatively complete dinosaur, but the villagers smashed the front half of the fossils for money.

Moderator: The villagers believe that the discovery of the fossil could improve the economic situation in the village, so they detained the two pieces of fossil and didn't want others to take them away.

Dong Zhiming: As a fellow countryman, we can understand the feeling, but from researcher’s point of view and according to our laws, personal possession of precious fossils is not allowed. Our "Constitution" stipulates that everything underground belongs to our country. Secondly, "Measures for the Management of Fossils" issued by the Ministry of Land and Resources states that individuals and unauthorized institutions are not permitted to excavate fossils. It is illegal to do it without authorization.

Moderator: We just saw that the local villagers have an idea of directly building a museum in the existing excavation site to preserve those fossils IN SITU.

Dong Zhiming: They do not have such qualifications and conditions. If they can promptly report to the county, and the Henan Province Bureau of Geology and Mineral Resources, when these fossils were found, and if one day we find a large dinosaur burial site, or prehistoric animal site, then the state should declare a conservation area and establish protection museum in this area. I can really understand the idea of the local villagers, but they were too eager. It is impossible that they want to build a museum, because only a small dinosaur tail was found as of now. If in the future we find valuable fossil-rich sites in the area, then there really might be consideration of declaring a conservation area, even building a museum. They have two things going for them right now. The first is favorable stratigraphic formation, and the other is the abundant fossils. Conditions are there.

Moderator: In fact, we had the same idea as the local villagers before we did this program, and we hoped that such precious fossils can bring hope to the local community in the future. But this hope must be built on laws, science, and reasonable planning and development. If we resort to some destructive means, then this hope is likely to be ruined. Therefore, we look forward to the day when the villagers' desire to get rich becomes reality in the future.

1.1.3 Something Beautiful, Something Regretful

On September 12, 2006, the project team returned to Liudian and Santun in Ruyang to resume the survey and excavation. Everything went smoothly with support from the local government and communities. Between September 13 and 30, the team excavated *Zhongyuansaurus luoyangensis* in West Shapinggou, *Ankylosaur* in the northwest of Bandaojin Village, femurs of *Ruyangosaurus giganteus* in Shengshuigou, medium-sized sauropods in the East Shapinggou and *Ankylosaur* in the South Erlang Village. Also, between November 11 and December 27, the team found other dinosaur fossils in the Shengshuigou of Shaping Village, North of Shaping Village, Heyezui and South Erlang Village. Regretfully, however, the first excation location in Shangliufugou Village was under prolonged "protection" by some villagers, and could not be excavated further.

Between April 2006 and June 2007, in cooperation with Yunnan's Lufeng Dinosaur Museum, Sichuan's Zigong Dinosaur Museum, Institute of Geology, Chinese Academy of Geological Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Science, and Beijing Natural History Museum, some skilled technicians were hired to assist HGM in excavating, repairing and restoring fossils. Through hard work at a frantic pace, the first phase of fossil excavation and restoration was completed and three replicas of dinosaur skeletons were mounted at the end of June 2007.

On July 3, 2007, the beautiful Zhengzhou Yellow River Guest House was the host of a birthday party for the "time-travelling" dinosaur, *Huanghetitan ruyangensis*. Over thirty well-known scientists from the United States, Canada, the United Kingdom, France, Japan, South Korea, Taiwan, and mainland China, 40 members of the media, and hundreds of people from all walks of life were there to witness the beautiful birth. The moment the red curtain was lifted, loud cheers and ovations erupted. *Huanghetitan ruyangensis* was 18 meters long, with a height of 6 meters at the shoulder, a width of 3 meters at the shoulder, a height of 5.1 meters at the hip, and a width of 2.8 meters at the hip, and was then "the King Dinosaur of Asia". It still keeps the record of having the longest rib of 2.93 m and the widest sacrum of 1.32 m and still is the dinosaur known to have the deepest body cavity and widest hip in the world. Also coming to this world were two of its companions, *Zhongyuansaurus luoyangensis*, with full-body armors but no tail club, and *Luanchuanraptor*, its neighbor from another geological age and from Luanchuan Basin.

On November 19, 2007, being informed that the CCTV's SciTech Channel was going to film a special on location in Ruyang, the project team and local government persuaded the villagers to remove the makeshift house built over the excavation site of *Huanghetitan ruyangensis*. On the following day, the team cleaned up and excavated the site and discovered one complete and one damaged cervical vertebra, and some fragmented fossils. After repair and restoration, it was found that the size of the newly found fossils was far bigger than cervical vertebrae already mounted on the skeletons, although they looked similar in exterior shapes. Based on this, it was projected that the actual length of *Huanghetitan ruyangensis* is well over 20 meters, not the original 18 meters of the mounted one. Because it's a huge undertaking to modify a mounted skeleton replica, *Huanghetitan ruyangensis* still remains what it was.

Examination of the burial and preservation indicates that *Huanghetitan ruyangensis* is a relatively complete dinosaur, with most parts of the skeletons articulated or slightly dislocated. The cervical, dorsal, and caudal vertebrae are well preserved, and so are the sacrum and dorsal ribs. Because a large number of "dragon bones" were dug up by the villagers, and because some fossils were stolen during the excavation, the beautiful birth of *Huanghetitan ruyangensis* also came with something regretful.

1.2 The New Discovery of Dinosaurs in Henan

Whenever the dinosaurs are mentioned, the first reaction people used to have is "Nanyang and dinosaur eggs". Prior to 2007, ordinary lay persons as well as the paleontology community had little knowledge of dinosaur skeleton fossils in Henan. But the fact is that Henan ranks not only number one in the world when it comes to dinosaur eggs, it also has rich dinosaur bone fossils. Little dinosaur research had been done on Henan's dinosaurs, and only sporadic discoveries were made. Large scale excavation and research are only being conducted in recent years. Despite all this, the scale and quantities of the discoveries in such a short period of time have caught the attention of the world.

The first documented dinosaur fossil discovery in Henan was in 1962, when Pan Zecheng and Guan Baode of the Regional Geological Survey Team, former Henan Bureau of Geology, found 9 boxes of fragmented bones in Dongmeng village of Mianchi County, while surveying the Sanmenxia area. Cheng Zhengwu of Chinese Academy of Geological Sciences identified them as undetermined species of carnivorous dinosaurs *carnosauria* gen.et. sp.indet, probably a species of *Megalosauridae*, and as *Sauropoda* gen.et.sp.indet. The whereabout of the fossils is now unknown. Inquiry to Mr. Cheng about the validity of the dinosaur identification received no certain reply. The project team searched the fossil spot and found nothing.

In 1972, near the Qiupa Village in Luanchuan, during the construction of a small reservoir, several fossils of teeth were found. IVPP's Dong Zhiming identified them as the teeth of a carnivorous dinosaur, *Tyrannosaurus luanchuanensis* (Dong Zhiming, 1979). In

1974, a survey team of the Geological Bureau of Henan Province conducted the "red beds" research project. Li Huanxu, Zhou Shiquan and others found for the first time fossils of dinosaur eggs, metatarsal, and dorsal vertebrae of *Hadrosauridae*, in Majiacun Formation in the west Xichuan Basin, which were few in numbers, but significant in implications. In 1975, IVPP's Zhao Zikui and a survey team of Henan found dinosaur egg of *Youngoolithus xiaguanensis*, and dinosaur footprint fossils (Zhou, 1979). In 1987, a survey team found a variety of dinosaur egg fossils during the regional geological survey of Chimei area, around Miaoshan Reservoir in Miaoshan Formation of Xixia Basin.

In 1993, poaching activities in Xixia Basin revealed a colony of dinosaur eggs rarely seen in the world. Meanwhile, dinosaur eggs were also found in other basins. In the same year, IPVV's Zhao Xijin collected in Xiaguan Basin of Xixia a set of incomplete dinosaur skeletons, which was named as *Nanyangosaurus zhugeii* by Xu Xing. It was reconstructed and mounted in the museum of Baotianman Nature Reserve in Neixiang. In the 1990s, Zhao Xijin, Dong Zhiming, Fang Xiaosi, Wang Deyou and others also discovered some fossils of dinosaur eggs and skeletons in Xixia and Neixiang. But no in-depth study was done on the dinosaur bones.

In June 2006, upon learning the breakthrough in dinosaur excavation in Ruyang area, local government in Luanchuan invited HGM and associated institutions to do research in the area. The project plan was approved by Henan Department of Land and Resources. In March 2007, the project team set up camp in Qiuba, Luanchuan, and found dinosaur egg shells and fragmented bones by roadside with tips from villagers. The excavation soon was in full swing. In an area of less than 50 m^2, mostly theropod dinosaur bones, and some saurischian and ornithiscian bones, were found, from at least six species of dinosaurs. Also found were fossils of some early mammals and lizards. Although these skeletons are mostly small, they were well preserved, could be made into fine specimens and have significant scientific values. Major breakthrough has been made in fossil excavation and research in Luanchuan.

At the same time, according to the project's plan, the team has found in Yima's Jurassic strata five dinosaur footprint fossils, including *Changpeipus xuianna*; 3 dinosaur fossils in Neixiang's Xiaguan Basin, one of which has been named and published; a new species of dinosaurs in Xixia Basin; and new dinosaur eggs localities around Xixia and Neixiang. The project of Henan Prehistoric Vertebrate (Dinosaur and Elephant) Fossil Excavation and Research, has found 243 fossil localities, excavated 61 sites, found 22 new genera or species of dinosaurs, found many mammal and reptile fossils, studied and named 12 new species of dinosaurs, and discovered two dinosaur faunas with global significance. Henan's vertebrate research, especially dinosaur research, took a giant leap forward.

As of this writing, there are 15 counties or cities in Henan where fossils of dinosaur bones, dinosaur egg fossils, or fossils of dinosaur footprints, which distributed in 14 red strata basins, were found, as shown in Table 1.1.

Table 1.1 Dinosaur fossil distribution in the Mesozoic and Cenozoic in Henan Province

Basin	Type of Dinosaur Fossils	Distribution Characteristics	Discovery Time
Lingwumu Basin	Egg	sporadically	1980
Lüshi Basin	Egg	sporadically	
Yima Basin	Dinosaur footprint	sporadically	1962 dinosaur, 2006 and 2009 footprint
Tantou Basin	Egg, dinosaur	densely	large-scale discovery in 2006
Ruyang Basin	Egg, dinosaur	densely	large-scale discovery in 2006
Wulichuan Basin	Egg	densely	1974
Zhaobei Basin	Egg, dinosaur	sporadically	1995
Liguanqiao Basin	Egg	densely	1974
Zhechuan Basin	Egg, dinosaur	densely	1974 egg,1995 two dinosaurs in Hubei
Xixia Basin	Egg, dinosaur footprint	densely	1992 egg,1979 footprint,2001 dinosaur
Xiaguan Basin	Egg, dinosaur footprint	densely	1974 egg,1975 dinosaur
Yangji Basin	Egg	sporadically	1995
Pingchuangguan Basin	Egg	sporadically	1975
Luoshan Basin	Egg	sporadically	1995

(Xu Li, 2007)

As of now, 9 families, 21 genera and 22 species of dinosaurs were found in Henan. This project alone has found 18 genera and 19 species (Lü Junchang, Xu Li, et al., 2013), in two faunas and Nanyang dinosaur egg colony, as shown below (Table 1.2):

Table 1.2 Major dinosaur fossil sites in Henan Province

Area	Origin	Age	Location	Named Dinosaur Species
Nanyang	Xixia Basin	Late Cretaceous	Majiacun Formation	*Xixiasaurus henanensis* *Xixianykus zhangi*
	Xiaguan Basin		Gaogou Formation	*Nanyangosaurus zhugeii* *Baotianmansaurus henanensis*
Luoyang	Ruyang Basin	Early Cretaceous	Haoling Formation, Shangdonggou Formation	*Huanghetitan ruyangensis,* *Ruyangosaurus giganteus,* *Zhongyuansaurus luoyangensis,* *Xianshanosaurus shijiagouensis,* *Luoyanggia liudianensis,* *Yunmenglong,* *Ornithomimidae,* *Ankylosauridae,* *etc,*

Continued

Area	Origin	Age	Location	Named Dinosaur Species
Luoyang	Tantou Basin	Early Cretaceous	Qiupa Formation	*Luanchuanraptor, Qiupalong henanensis Yulong mini, Ankylosauridae, Sauropodomorpha, Giant carnivorous dinosaurs, etc.*
	Sanmenxia Basin	Late Jurassic	Dongmengcun Formation	*Sauropodomorpha*

Detailed taxonomy is as the following:

Sauropodomorpha
    Sauropodomorpha
        Eusauropoda
Titanosauriformes
    Huangetitanidae
        Huanghetitan
            Huanghetitan ruyangensis
    Andesauridae
        Ruyangosaurus
            Ruyangosaurus giganteus
    Incertae familiae
        Xianshanosaurus
            Xianshanosaurus shijiagouensis
        Baotianmansaurus
            Baotianmansaurus henanensis
Somphospondyl
            Yunmenglong Ruyangensis

Carnosauria
    Carcharodontosaurid
        gen. et sp. indet.
    Spinosauridae
        gen. et sp. indet.
    Tyrannosauroidea
        Tyrannosauridae

Tyrannosaurus
Tyrannosaurus luanchuanensis
Theropoda
Oviraptoridae
Luoyanggia
Luoyanggia liudianensis
Yulong
Yulong mini
Ornithomimidae
Qiupalong
Qiupalong henanensis
Troodontidae
Xixiasaurus
Xixiasaurus henanensis
Dromaeosauridae
Luanchuanraptor
Luanchuanraptor henanensis
Alvarezsauridae
gen. et sp. indet.
Mononykus
Xixianykus
Xixianykus zhangi
Gobipterygiformes
Gobipteryx
Gobipteryx sp.
Ornithopoda
Ankylosauria
Nodosauridae
Zhongyuansaurus
Zhongyuansaurus luoyangensis
Ankylosauridae
gen. *et* sp. indet.
Iguanodontia
gen. et sp. indet
Nanyangosaurus
Nanyangosaurus zhugeii

gen. et sp. indet.
specimen from Ruyang

1.3 Dinosaur Family in China and Henan

An examination of global distribution of dinosaur fossils shows that early Jurassic dinosaur fossils are missing in North America; South America lacks the late Jurassic dinosaur fossils; Europe has primarily marine Mesozoic strata, stratigraphic discontinuities, and sporadic fossil distribution; African continent has good stratigraphy, but scattered fossil localities and few late dinosaur fossils. China's terrestrial Mesozoic basins are well developed, with continuous stratigraphy, well-preserved and rich dinosaur fossils. With the exception of Triassic, dinosaur fossils were found in every province except two or three provinces. From the Shandong peninsula in the east, to the snow-capped peaks of Tianshan Mountains in the west, from the Gobi desert in Inner Mongolia in the north, to Yunnan and Guangdong in the sub-tropical south, vast numbers of dinosaur fossils were found, from early Jurassic to late Cretaceous, covering many genera and species, and with distinct features of faunas, which are indispensable for world-wide dinosaur research. Large numbers of dinosaur egg fossils and footprint fossils were also found. (Fig.1.2, Table 1.1).

For the past two decades, Chinese dinosaur research has been in overdrive, as reflected by organizing several large-scale international dinosaur expeditions and research, doing dinosaur exhibition tours, discovering many important fossil localities and strata, studying and naming large numbers of new dinosaur species. Meanwhile, progress has been made in studying dinosaur eggs and trace fossils, mass dinosaur death and extinction, and composition of dinosaur skeletons. In some areas it is in the cutting edge of international dinosaur research. New opportunities have been made available by the discovery of new species and new dinosaur-bearing strata in the Jurassic and Cretaceous. China's dinosaur research has progressed considerably, by cooperating with global science community, applying new research theories and methods, in areas of dinosaur taxonomy, phelogeny, origin and evolution, mass death and extinction, fossil burial research, paleoecology, and paleogeography.

In recent years, new geological museums and geoparks mushroomed, and a new wave of dinosaur excavation swept all over China. New discoveries of dinosaurs are being reported regularly, and dinosaur science popularization as an industry has been thriving. As of now, there are 7 specialized dinosaur museums: Sichuan Zigong Dinosaur Museum, Inner Mongolia Erlian Dinosaur Museum, Zhucheng Dinosaur Museum, Yunnan Lufeng Dinosaur

Museum, Heilongjiang Xiaoxing'anling Dinosaur Museum, Xixia Dinosaur Park, Jiangsu Changzhou China Dinosaur Park (with a museum). Dinosaur theme parks, such as Heilongjiang Jiayin Dinosaur National Geopark, Erlianhote National Geopark, Ruyang Dinosaur National Geopark are being built. China has become a force to be reckoned with in the international dinosaur scene.

Dinosaurs survived and thrived for 160 million years during which the earth had undergone tremendous changes. The original supercontinent Pangaea split gradually and continents drifted into positions that were close to where they are today. Climate changed as well. Early dinosaurs lived in an age with no significant seasonal differences, in warm and humid climate, in which ferns were the main plant on earth. Soon, tall conifer forests and jungles, swaths of cycad plants formed the landscape of the earth. Later, flowering plants appeared on earth and vegetation changed dramatically. However, because this change was very slow, animals were still able to adapt very well.

Table 1.3 China's major dinosaur faunas

Age	Dinosaur Fauna	Site	Location	Major Dinosaur Fauna
Late Cretaceous	Hadrosaur-Titanosauria Fauna	Laiyang, Shandong	Wangshi Formation	*Tsintaosaurus spinorhinus*, *Tanius sinensis*, *Shantungosaurus*
		Nanxiong Basin, Guangdong	Nanxiong Group	*Nanshiungosaurus brevisinus*, *Microhadrosaurus*
		Erenhot Basin, Inner Mongolia	Yilundabasu Formation	*Euhelopus*, Hadrosauridae, Sauropoda
	Luanchuan Fauna	Tantou Basin,Henan	Qiupa Formation	*Luanchuanraptor*, *Qiupalong Henanensis*, *Ornithomimus*, *Yulong mini*, Alvarezsauridae
Early Cretaceous	Psittacosaurid-Ptrosaurian Fauna (Jehol Biota)	Laiyang Basin,Shandong	Qingshan Formation	*Tsintaosaurus spinorhinus*, *Psittacosaurus siensis*
		Junggar Basin, Xinjiang	Tugulu Group	*Tugulusaurus faciles*, *Kelmayisaurus petrolicus*, *Wuerhosaurus homheni*
	Psittacosaurid-Ptrosaurian Fauna (Jehol Biota)	Alasan Basin、Ordos Basin	Wulansuhai Formation	*Probactrosaurus*, *Nurosaurus*, *Sinornithomimus*
		Western Liaoning, Inner Mongolia	Jiufotang Formation	Theropod
			Yixian Formation	Theropod
	Ruyang Gigantic Sauropod Dinosaurian Fauna	Ruyang Basin, Henan	Haoling Formation	*Ruyangosaurus giganteus*, *Huanghetitan ruyangensis*, *Zhongyuansaurus luoyangensis*, *Luoyanggia liudianensis*, *Xianshanosaurus shijiagouensis*

Continued

Age	Dinosaur Fauna	Site	Location	Major Dinosaur Fauna
Early Cretaceous	Hekou Dinosaurian Fauna	Mazongshan Region, Gansu	Hekou Group	*Probactrosaurus mazongshanensis, Huanghetitan liujiaxiaensis, Yongjingensis datangi*
	Mazongshan Dionosaurian Fauna	Fenpoquan and Yujingzi Basin	Xiagou Formation, Zhonggou Formation	*Xiongguanlong baimoensis, Beishanlong grandis, Gebititan shenzhouensis*
Late Jurassic	Neosauropod-Mamenchisaurus Fauna	Szechwan Basin	Upper Shaximiao Formation	*Mamenchisaurus constructus, Mamenchisaurus hochuanensis, Yangchuanosaurus shangyouensis, Yangehuanosaurus magus, Chialingosaurus, Tuojiangosaurus, Chungkingosaurus jiangbeiensis*
		Junggar Basin, Xinjiang	Shishugou Formation	*Tienshanosaurus chitaiensis, Mamenchisaurus*
Middle Jurassic	Yanliao Biota	Northern Hebei, Western Liaoning, Inner Mongolia	Tiaojishan Formation	*Epidexipteryx, Anchiornis*
	Eusauropod-Shunosaurus Fauna	Szechwan Basin (Dashanpu, Zigong,etc.)	Lower Shaximiao Formation	*Shunosaurus. lii, Datousaurus, Omeisaurus tianfuensis, Szechuanosaurus, Gasosaurus, Xiaosaurus dashanpensis, Huayangosaurus taibaii, Tuojiangosaurus multispinus*
		Junggar Basin, Xinjiang	Wujiawan Formation	*Bellusaurus sui, Monolophosaurus jiangi*
Early Jurassic	Prosauropod-Lufengosaurus Fauna	Lufeng Basin, Central Yunnan Basin, Jinning Basin etc,Yunnan	Lufeng Formation	*Lufengosaurus huenei, Yunnanosaurus, Dilophosaurus sinensis, Diachongosaurus lufengensis, Tatisaurus oehleri*
		Dafang Basin, Guizhou		Anchisaurus *(Gyposaurus)*

Fossils of eight families, eleven genera, fifteen species, two comparable species and six uncertain species of dinosaur eggs (Wang Deyou, 2008) were discovered in Xixia Basin, Henan Province. Four species of new dinosaurs were named: *Nanyangosaurus zhugeii*, *Baotianmansaurus henanensis*, *Xixianykus zhangi* and *Xixiasaurus henanensis*. The scope, quantity, diversity, and condition of preservation of dinosaur eggs are simply the best in the world and treasures of the natural history. They are the heart and soul of Funiushan National Geopark and Xixia Dinosaur History Park, a large dinosaur theme park, which serves as a perfect dinosaur research base and new attraction for tourists and science popularization.

In-depth research has indicated that the Gigantic Ruyang Sauropoda Fauna is an important part of China's Early Cretaceous, which was primarily consisted of herbivorous sauropoda and other species that were thought to be living in Late Jurassic before the discovery. They are very valuable for both science research and science popularization, which has been included in the list of "National Fossil Sites and Dinosaur Geoparks". Ruyang Dinosaur History Museum has been built and opened to public.

Luanchuan dinosaur fossils are mainly of small theropods, such as *Dromaeosaurids, Oviraptorosauria, Ornithomimosauria, Tyrannosauroidea*, and of early mammals and lizards. It is another dinosaur fauna in the Late Cretaceous that is very valuable for science research and for geopark attractions. Four species of dinosaur egg fossils, two species of dinosaur fossils and three species of fossils of early mammalian animals were found.

The Yima Biota, with fossils of 36 classes and 90 species vegetation including gingko, which is the earliest known and the best preserved in the world, and animals such as fish, bivalves, insects, estherians, turtles, has been well known in the world of palaeontology. Five newly found dinosaur track fossils prove Henan's status as a dinosaur paradise and increase tremendously its science popularization value.

Henan Province is a bona fide treasure trove of dinosaur fossils and on the cutting edge of fossil protection, science research, and product development in China.

Science links

Birthplace of Chinese Wine

Thousands of years ago, legend has it that Du Kang invented wine in Ruyang and he has been worshipped as the "God of Wine" and "Father of Wine" ever since. Born in Ruyang, Du Kang was the fifth king of the Xia Dynasty. He was synonymous to fine alcoholic drinks in Chinese history and literature, as vividly reflected in a well-known poem titled "A Short Song" by Cao Cao, the great warlord and the prime minister of the East Han dynasty:

Full of feelings, full of melancholy,

Thoughts of worry won't leave me.

What can dispel this care of mine?

There is only Du Kang's wine.

According to Chinese history and anecdotes, Du Kang left a bowl of porridge in a cave by accident. Several days later, he found that it had fermented and was emitting an intoxicating smell. He figured it out the mystery behind the smell through trial and error, and the wine-making was thus invented. People loved this stimulating beverage and regarded it as god-sent. Du Kang earned the title "King of Wine" and his reputation was cemented in history.

In September 1972, Premier Zhou Enlai hosted the banquet in honor of visiting Japanes Prime Minister, Tanaka Kakuei, in which Du Kang Wine was served. In 1988, the Ministry of Foreign Affairs of PRC designated Du Kang Wine as "the Wine of State Banquet".

Dragons, Dragon Bones, Dinosaurs

The dragon is an animal totem worshipped by our ancestors, who believed that dragons symbolized luck, fortune, and shield against disaster. In reality, dragons didn't exist as animals. They were deified and imagined as having bodies of serpents, head of pigs, antlers of deers, ears of bulls, beards of goats, talons of eagles, and scales of fish, and being omnipotent. They were not dinosaurs, which were actually special species of reptiles that once lived on earth.

"Dragon bones"(*longgu*) is a Chinese word for traditional herbal medicine, including the fossils of many Cenozoic mammals that were buried in Quaternary loess. Their main mineral composition is clays such as kaolinite, which is highly absorptive. Their chemical composition is mainly carbonate calcium ($CaCO_3$), calcium phosphate ($Ca_3(PO_4)_2$), iron, potassium, sodium, aluminum and other trace elements. In ancient times they were used as an herbal medicine to sooth nerves, cleanse livers, and absorb pain.

These "dragon bones", which were eaten by villagers in Ruyang for 30 years, are just quartz or carbonate rocks, which are residual substance from animal bones that have been lithified in the sandstones and mudstones. They almost lost all the value as medicine except as an agent of absorption.

Dinosaurs were once the dominant and thriving animals in geological history, the lords of the Mesozoic between 230 million years BP and 66 million years BP, and a special family of the reptiles. An English country doctor Gideon Mantell first discovered dinosaur fossils in 1822, when he found some giant teeth and skeletons embedded in rocks. After careful examination and study, he considered these teeth and bones came from some gigantic reptiles, which he named Iguanodon. Soon after, skeletons of two other types of giant reptiles were also found in England. In 1842, scientist Sir Richard Owen officially named them dinosaurs, meaning "terror lizards", which were translated as "terror dragons" in Chinese. Since then, dinosaur study has been going on with ever-increasing enthusiasm.

The difference between dinosaurs and other reptiles: the biggest difference between dinosaurs and other reptiles is their stances and locomotion. Dinosaurs had an upright stance with sturdy, columnar limbs under the torso, which enabled walking and fast running. This advantage gave them wide range and efficiency of movement and travel, which was superior to other reptiles. They evolved and thrived in a unique fashion, while other reptiles only crawled with four limbs spread along the sides of the torso.

Emergence and evolution of dinosaurs: in the Triassic period, between 251 and 199.6 million years ago, reptiles were dominant terrestrial animals. In Late Triassic, dinosaurs appeared and began to evolve. But they were small-sized and predominantly carnivorous. In the Jurassic, dinosaurs underwent rapid evolution, through which sauropods became gigantic in body sizes, which were the largest terrestrial animals ever lived on earth. And theropods became more agile and fast. They were the absolute rulers of the land. In the Cretaceous, diversity and distribution of dinosaurs peaked, saurischids became smaller due to the need to survive and carnivorous dinosaurs became more intelligent. They came up with more enhanced offensive and defensive capabilities.

In the long 160 million years during which dinosaurs lived and thrived, the Earth also underwent drastic changes. The supercontinent Pangaea rifted and drifted to positions similar to what it is today. Climate and environment also changed along with tectonic drift. In the early dinosaur period, there were no apparent seasonal changes and it was humid and wet. Ferns were the primary land plants. Soon after, tall conifer forests and low cycad shrubs formed the dominant landscapes on earth. Flowering plants followed and brought about significant changes to the vegetations on earth. However, animals adapted well because the changed came very slowly in geological time scale.

Is Dinosaur Research Part of Archaeology?

A lay person generally thinks that paleontologists are doing archaeology works, which is quite laughable. It is very necessary to clarify the difference between the two fields of research and professions:

First of all, the conceptual difference between "cultural relics" and "fossils" must be established. "Cultural relics" refer to valuable historical heritages in the development of culture, such as architecture, monuments, tools, weapons, utensils, and works of art. They are relics left behind by human history, which are reflective in multiple facets of human social functions, societal relations, ideologies, conditions and environments in which humans utilized and changed the nature, and are part of irreplaceable human history and culture.

The essential differences between fossils and relics are:

- Fossils refer to the remains of organisms and traces of activities formed in prehistoric geological times which were embedded in strata, including fossils of plants, invertebrates, vertebrates, and animal traces. They are the testimony of history and the scientific foundation for studying the origin and evolution of species. Fossils are different from relics. They are important remnants of earth's biology and geology, and the precious and irreplaceable natural heritages of our country. They are not historical or cultural relics and not part of archaeology.
- The time frame of archaeology is post-history, while that of fossil research is pre-history. This concept is already deeply entrenched in the collective mind of the public. To confuse the two on purpose will greatly hinder both legislation and jurisdiction.
- The natural property and condition of preservation are different between fossils and cultural relics, so are the means of excavation and ways of research. They should not be covered under the same laws and regulations.
- As fields of scientific research, relic research is a social science and fossil research is a natural science. The former belongs to archaeology, and the latter to paleontology, which is the internationally recognized classification.
- As for placement of field of study and educational model, paleontolgy is a natural science, while archaeology is history research of social sciences. In the directory of bachelor's, master's, and doctoral degrees published by the State Council and the Commission of Education, paleontology has always been included in geology, with the name of paleontology and stratigraphy; archaelogy is included in history, with the name of archaeology and museumology. They are in different systems of scientific research and must not be under uniform management.

Hopefully this will clear up the confusion between the two disciplines of research and help avoid laughable gaffes. However, do archaeology and paleontology in anyway overlap? Just ever so slightly. For example, the State Administration of Cultural Heritage and the Ministry of Land and Resources jointly announced in "the Directive of Clarifying and Strengthening the Protection and Management of Fossils " (2003) that fossils of paleohominids, paleoanthropos, and human-related Quatenary fossils are subject to the jurisdiction of the the Sate Administration of Cultural Heritage, and that rest of the fossils are subject to the jurisdiction of MLR. Therefore, vertebrate fossils since the Quatenary fall into the category of cultural relics. When paleontologists study the whole process of vertebrate evolution, they need to take into consideration of Quatenary vertebrate fossils. Therefore, the two fields do overlap at one point even though they are vastly different in nature.

How to Protect Fossils?

Fossils and cultural relics are both protected by the law. The government has always placed top priority on the protection of fossils and taken effective measures to ensure the enforcement. The

Ministry of Land and Resources is vested with the power for the overall protection, supervision, and management of fossils by State Council's directive in 1998, and has put forth a detailed directive "Strengthening the Protection of Fossils" in 1999. "Regulations on the Protection of Fossils" was signed by Premier Wen Jiabao and approved by the State Council in 2010. "Implementation of the Regulations on the Protection of Fossils" was signed by the minister of MLR, effective since March, 2013. Protected fossils are divided into two categories: high-priority protection and general protection.

Following fossils enjoy first-class high-priority protection:

- holotypes of fossils that have been formally studied and published;
- all fossils within a fossil protection zone;
- fossil specimens within very valuable fossil-bearing strata and formations;
- complete or relatively complete paleovertebrate fossils (including fossils of paleoanthropos);
- fossils with special significance in evolution and taxonomy;
- rare or relatively rare fossils within the country;
- large-scale, densely-exposed fossil sites with stacked fossils of skeletons, silicified woods, vertebrate traces, eggs, and other relics;
- fossil specimens collected and preserved in various museums, relic protection institutions, and in other agencies that have not been confirmed by the Departments of Land and Resources.

2 The Rise of Giant Dinosaurs: Excavating Dinosaur Fossils in Ruyang Basin

"How big is the largest dinosaur?

Larger animals always attract people's interest and attention. In the huge dinosaur family, some species are the largest terrestrial animals ever lived on the earth. How big can dinosaurs be? What species do they belong to? The sauropod dinosaurs are usually regarded as the largest and most spectacular of all dinosaurs in the dinosaur family. They are truly the giants in the dinosaur kingdom.

Every time people pass by a dinosaur skeleton in exhibition hall of a natural history museum, the first sentence they blurt out usually is: "Wow! How big it is!" Since large dinosaurs are the most fascinating and the favorites of the visitors, sauropod dinosaur skeletons are always placed in the most conspicuous locations in most natural history museums as the main attraction.

Mamenchisaurus, Diplodocus, Brachiosaurus, which are all sauropod dinosaurs, were once described as the "highest", "longest", "heaviest" in the world. However, after an even larger dinosaur was discovered in recent years, they have gradually lost their "lustre" that they once enjoyed. "

Excerpt from *Primary School Classroom Network*, *"Popular Science of Dinosaurs"*.

Are there any other unknown species of dinosaurs still buried in Ruyang basin after the discovery of *Huanghetitan ruyangensis*? What are the other important members of this family?

2.1 A Brief History of Finding and Excavating Ruyang's Dinosaurs

A scientist once said, every discovery of dinosaur is earth shattering and worthy of remembering.

While the *Huanghetitan ruyangensis* was being excavated in Liudian Town's Shang Liufugou Village, the project team members were also knocking on the doors of villagers to collect and buy "dragon bones", and to get tips and clues of the fossils, in an all-out effort of investigating and surveying the fossils. A map with a scale of 1:10,000 was surveyed, cross sections of stratigraphy and paleontology with a scale of1:1000 to 1:200 were drawn, and 105 fossil spots were found and investigated (more are being found as of this writing). 32 fossil spots were excavated after evaluation and approval (Fig.2.1).

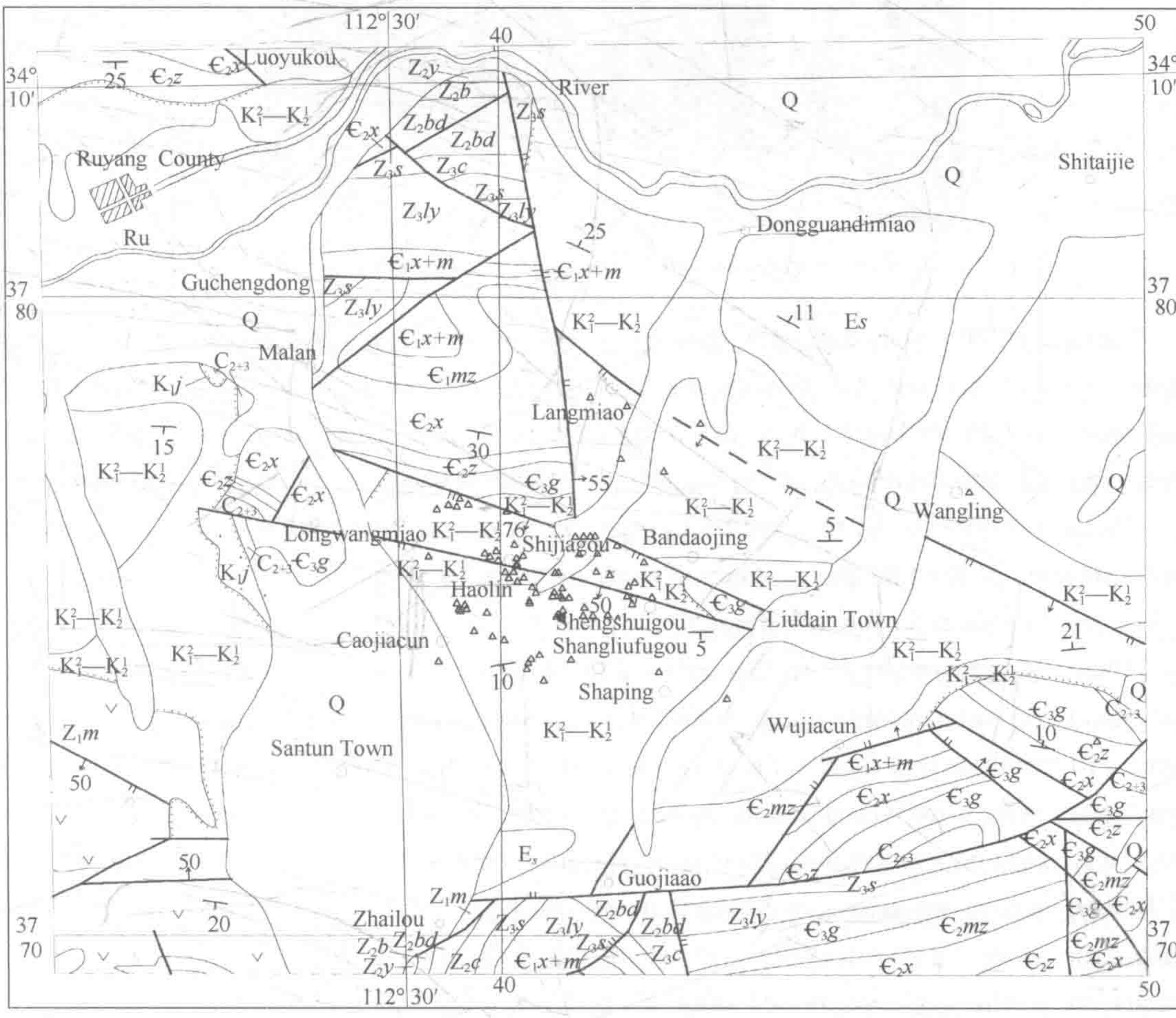


Fig. 2.1 Distribution map of dinosaur fossils in Ruyang

Fossil excavation and collection in the field is an important part of paleontology research (Ding, 2005), especially for the vertebrates. The excavation of Ruyang's dinosaur fossils has made Ruyang known to the world, and it has also produced a highly professional team of excavators for HGM (Fig.2.2). From seeking outside assistance and hiring domestic elites for fossils repair, to building HGM's own excavation and repair team, Ruyang area is without doubt a birthplace, a cradle, and a training ground.

Fig. 2.2 The excavation team at the site of *Huanghetitan ruyangensis* in 2006

Between 2006 and 2009, five phases in excavation of dinosaur fossil from Ruyang region were carried out. For this short period of time, the achievements were remarkable: 278 pieces of plaster blocks with the weight over 100 tons were made, over 3000 fossils were repaired, and fossils of nearly 20 individual dinosaurs were discovered.

Phase I: February 18 to March 12, 2006. Surveys and investigations were carried out on fossil sites in Ruyang Basin. The excavations were focused on the site of *Huanghetitan ruyangensis* in Shangliufugou Village.

Phase II: September 12 to December 27, 2006. The excavation team mobilized local villagers to provide tips and clues about fossils in Santun and Liufu. Material rewards were given as incentives and local villagers were invited to participate in excavation. Dozens of fossil sites were discovered based on the clues provided by villagers. *Zhongyuansaurus luoyangensis* in Shapingxigou, *Ankylosauridae* in Northwest of Bandaojing village, femur of *Ruyangosaurus giganteus* in Shengshuigou village, medium-sized *Sauropodomorpha* in Shapingdonggou, *Ankylosauridae* in south of Erlangmiao Village were discovered successively. The work progressed smoothly and yielded substantial results in general.

Phase III: November 16, 2007 to January 8, 2008. Researchers investigated the sites between Shangliufugou Village in Liudian Town, Huamiaogou in Hongling Village and Haoling. Three dinosaur fossils sites were excavated simultaneously. A large number of dinosaur fossils were collected. The excavation was filmed on location by China Central Television (CCTV) on November 20. The discoveries of seven cervical vertebrae and five articulated dorsal vertebrae of Titanosauriformes from Hongling and Haoling villages drew public attention. CCTV-1 reported it.

Phase Ⅳ: March 11 to December 21, 2008. The excavation team investigated and sorted the clues provided by villagers and discovered more than 90 sites of dinosaur fossils for the past nine months. The team worked non-stop and cleaned up more than 20 sites with residual fossils. Among them, a large number of dinosaur fossils were found from the east of Caojia Village in Santun Town, Haoling in Hongling Village in Liudian Town, Huamiaogou, Shijiagou and Shengshuigou in Shaping Village. A large bulldozer was used for the site containing *Ruyangosaurus giganteus*. 84 pieces of fossils were collected in all, among them 20 PLKs with combined weight of over one ton.

Phase Ⅴ: December 7, 2010 to April 20, 2011. Researchers had been working on the fifth excavation of *Ruyangosaurus giganteus* in Shengshuigou for five months. Earthworks of approximately 30,000 m^3 were removed by machineries. Scattered fossils were also discovered in the southeast of original excavation sites. The fossils of *Ruyangosaurus giganteus* were collected and sorted for the most part.

2.2 Rise of Giant Dinosaurs: *Ruyangosaurus giganteus* in a Changed World

Over thirty years ago, large numbers of bones had been found by villagers when they were digging a ditch at Licaogou, in the north of Shengshuigou Village. These fossils were taken by villagers. In the 1990's, villagers again found fossils when they were reinforcing the ditch. Some villagers still kept fragmented pieces. Due to the highly petrified condition, some of these fossils were even used as cornerstones to build houses. A piece of cylindrical fossil with diameter of 45 cm and edge thickness of 6.5 cm was collected by Jiao Liuhe (it was donated to HGM later and confirmed as the middle part of a femur).

In September 2006, villager Jiao Liuhe found a piece of suspected fossil fragment by the ditch when he was plowing fields in Shengshuigou Village. He told this discovery to Jia Songhai, who was excavating *Zhongyuansaurus luoyangensis* at Shapingxigou at that time. After checking the outcrops, Jia believed there must be more fossils remained. Two persons were asked to dig it. Soon, something in oval shape and with diameter of 30 cm, which villagers thought as a python, appeared. Jia thought it could be a piece of silicified wood and then called Zhang Xingliao, who was then the director of HGM, to ask whether the excavation should be continued or not. Zhang considered that it should be continued to find whatever it was. A huge femur fossil with the length of 1.17m was discovered after one day's excavation. No other fossils appeared in surrounding area. Zhang Xingliao, Xu Li, Pan Zecheng and other experts went to Shengshuigou for an inspection and they suggested that it should be a femur fossil from a dinosaur, which was quite huge and it is of great scientific interest and exhibition value. According to the stratigraphic distribution, the characteristics of lithographic facies, the paleogeography, the strike of femur fossil and the sand body, they inferred that more fossils could be discovered from the northwest, where an important excavation site could be. However, a full-scale excavation of the site was not suitable due to its impact on the agricultural activities, the interests of several farmers and the harvest time.

In November 2006, with the help of the government of Liudian Town, we started the second phase of excavations after negotiating with two villagers about the compensation of young crops and land reclamation. At first, a piece of relatively complete bone (Fig. 2.3, Fig.2.4), which was identified as the scapula, was discovered by searching two meters away from the north west of the thighbone position. No more fossil outcrop had appeared after one month's excavation. The excavation stopped during the Spring Festival.

Fig. 2.3 The first femur fossil found at the site

Between the beginning of 2007 and September 2008, seven skilled workers hired by HGM began to repair fossils excavated from Shengshuigou Village. A piece of incomplete femur fossil, a piece of completes capula and a piece of dorsal vertebrae with the length of 51 cm were repaired by September 2008. It might be the sauropod dinosaurs belonging to Titanosauriformes, which is quite similar to the *Argentinosaurus* which was known as the largest one in the world. But it was still unclear due to the lack of fossils and insufficient comparison.

Many parts of the fossils were still missing based on the repaired parts. Could any fossil still be buried? The then director, Zhang Xingliao, thought about it for a long time. He considered that the burial spot should be in the old river bed extending from NE to SW, according to the analysis on sedimentology. Such huge bones were not easily flushed by water flow and it should be deposited when meeting obstacles or when river bent. It didn't make sense that only small fossils were left. Furthermore, the water flow should have been powerful if the huge bones were moved. Therefore, either bigger or smaller fossils could be somewhere in the upstream and downstream of old river bed. Finally they decided to keep excavating them at all costs from upstream and downstream in order not to regret about it later.

In October 25, 2008, Jia Songhai, as the leader of the team, with other staff, started the third full-scale excacation, which was still advancing towards the northwest (Fig. 2.5). The overlying layers of original fossil burial position reached to 5 meter deep. Large excavation equipment was acquired to remove the covering soil first until dinosaur-bearing bed appeared. Manual excavation was to be done afterwards. The fossil layer was discovered at the depth of 5 meters below the surface. The fossils were distributed with different orientations after clearing up. Just as expected, large amount of fossils were buried there. The work area was expanded to cover 200 m^2 and 6 meters deep by excavators, who were fired up by this miracle. Cervical vertebrae, dorsal vertebrae, caudal vertebrae, femur, sacral vertebra and other parts were discovered at this excavation site. Especially, the sacral vertebra was extremely well-preserved after cleaning. Being 2 meter wide, it is the largest and most complete sacral vertebra of *Titanosauriformes*. Furthermore, the diameter of the dorsal vertebrae is 62 cm, which is 10cm larger than that of *Argentinosaurus*.

Fig. 2.4 Excavation site of the second phase

This excavation phase was completed as no more new fossils were discovered after the excavation advanced 3 meters to the northwest and northeast. Wang Zhihong, an expert on sedimentary environment in Henan Province, was invited to give advice during the excavation. He suggested that the fossil site could be an ancient riverbed running from the northwest to the southeast. Some more fossils may be buried along the downstream in the southeast. However, the excavation plan to the southeast was not acted on, due to budgetary reasons.

In 2010, the HDF (Henan Department of Finance) and HDLR (Henan Department of Land and Resources) approved the Project of Geologic Relics Preservation. After several discussions with experts, the fourth full-scale excavation started.

Between December 2010 and April 2011, led by Zhang Jiming, excavation work was done in a space 70 meters long, 48 meters wide and 7 meters deep. Nearly 30,000 m^3 of earthworks were removed. Some other different individual fossils in the southeast of original excavation sites were discovered. 53 pieces of PLKs were produced. *Ruyangosaurus giganteus* fossil was collected (Fig. 2.6). The site was restored to farm land afterwards.

Fig. 2.5 Removing the cover soil in the third excavation phase

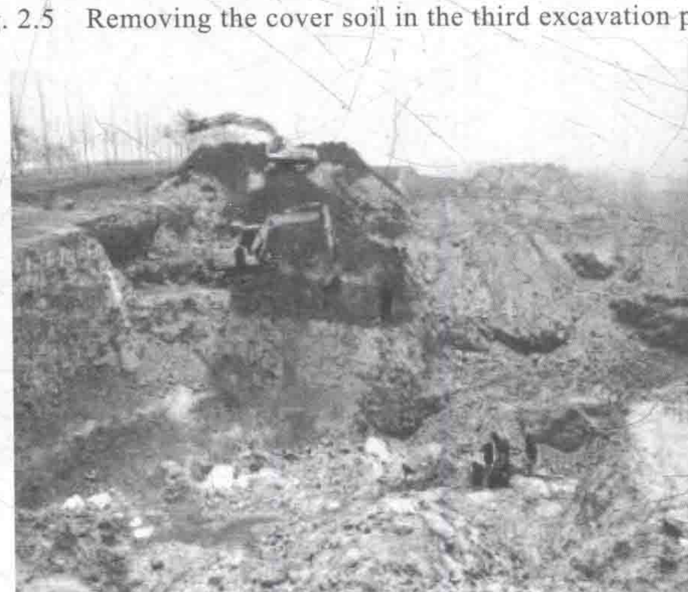


Fig. 2.6 Excavating the *ruyangosaurus giganteus* in the fourth phase

Excavation of *Ruyangosaurus giganteus* went through four phases with 240 days in total. Three sets of large bulldozers were used to remove the earthwork, the volume of which is over 30,000 m^3. 147 pieces of fossil plasters with weight of 82 tons were discovered. Manual work on fossil repair amounts to 2,111 person-day. The scale of the excavation of a single dinosaur, the magnitude of work of extracting, detailing and repairing the dinosaur, are the largest ones the world has ever seen. The tremendous scientific value and public interest about *Ruyangosaurus giganteus* have proved that the full-scale excavation was definitely worthwhile and justified. For this purpose, CCTV produced two episodes of feature films broadcast in several channels. It was also shown as two episodes of a documentary titled "*Walking with Dinosaurs*" (Fig.2.7).

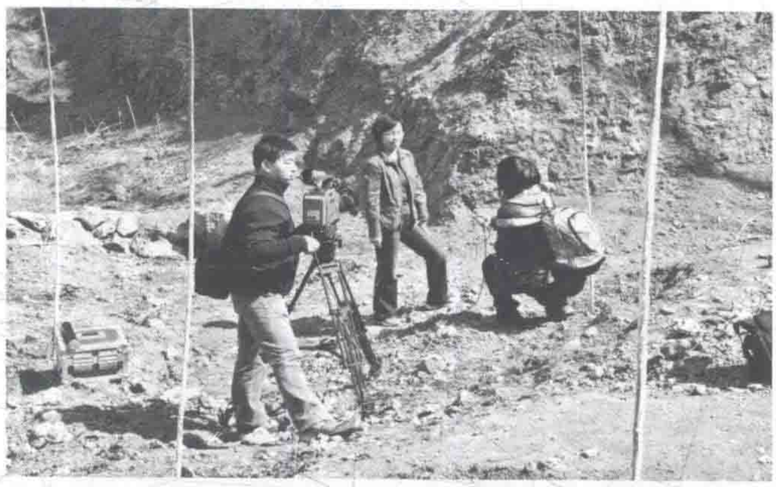


Fig. 2.7 Dr Xu Li was interviewed by CCTV on the set of "the Discovery of *Ruyangosaurus giganteus*"

2.3 IN SITU Conservation: Fossil Excavation Sites at Haoling Village

On the night of December 5, 2007, Du Bingli, the special coordinator from tourist office in Liudian Town, received a telephone call from villagers Shi Zhanting and Shi Xianli that a schoolboy Shi Naodan found a dinosaur fossil and they hoped the experts could check whether it's valuable or not. The leader of the excavation team, Jia Songhai, and the others went to the site immediately. The fossil was found from the field of a villager living under the hillside at Haoling Village. It was already exposed. It was close to the village and was known by many villagers. It was hard to be protected. Therefore, they decided right there to excavate it. Further investigation found that the site of dinosaur fossil was located in the farmland of Haoling villager Ma Shen. The fossil they dug up was the vertebral neural spine. On 13th of December, the fossil bed was exposed. After preliminary repairing, the area of exposed fossil reached to 12 m in length and 7 m in width. It was a gigantic sauropod dinosaur lying sideways. Seven cervical vertebrae were connected with five dorsal vertebrae partially. Some parts of ribs were also discovered. No limbs were found. What action shall be taken? In Situ conservation? Or doing the research after excavation? The project team asked the then director for instructions. After discussion, they were suggested to take the IN SITU conservation approach, since the other parts of skeletons were not well preserved due to the natural causes and farming. But the fossil still had a great sightseeing value. Besides, it was close to the village with wide surrounding space and convenient access. Therefore, environment was in favor of protection and excavation. After the discussion with the government of county and the local department of land and resources, they agreed with the proposal of In Situ conservation. Afterwards, the fossil was processed according to the regulations of In Situ conservation (Fig.2.8).

Fig. 2.8 Zhang Xingliao, the director of HGM, was directing the excavation in the field

In 2008, the government of Ruyang County successfully applied for national geopark of Ruyang dinosaurs. A fossil remains museum was built on the fossil site (Fig.2.9, Fig.2.10).

This discovery attracted the attention of media. On December 11, 2007, CCTV-1 reported this discovery on CCTV News; CCTV "Light of Science" program produced a special episode. Japanese media travelled to Ruyang and reported it in a special as well.

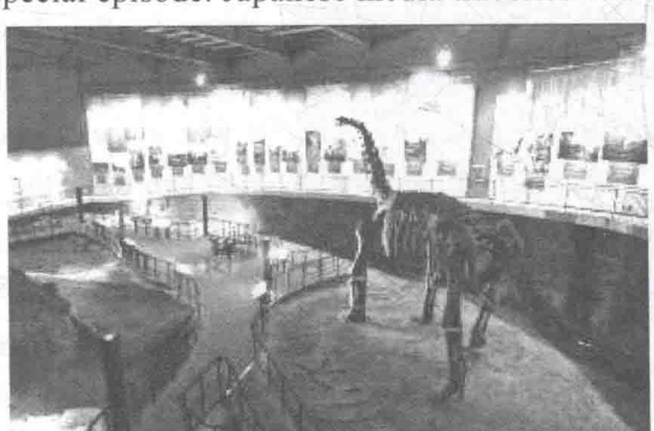


Fig. 2.9 Interior of dinosaur remains hall in Ruyang

Fig. 2.10 Exterior of dinosaur remains hall in Ruyang

2.4 The Head and the Tail: the Excavation of *Luoyanggia liudianensis*

Local villagers became increasingly conscious of searching for fossils since the excavation of Shangliufugou site. In March 2006, a villager found an exposed fossil when he was clipping sharp thorns at the hillside of Shapingxigou in Liudian Town. It was identified as the metacarpus fossil of dinosaur after it was sent to the Bureau of Land and Resources of the County. Since the project team was already driven out of the area, the fossil was guarded by staff arranged by the county administration. But soon it was stolen. In September, the project team went to Liudian Town for the second time. Their mission was to investigate the site. After the coordination with villagers in Shaping, the excavation started on September 16. Fossils were found in conglomeratic sandy mudstone beds. The surfaces had been seriously weathered. After the rock bed was being stripped one layer by one layer from the top based on topography, the fossil outline was cleaned manually and slowly. A great number of small individual dinosaur fossils piled up within an area of 35 m^2. The entire fossils were protected by plaster. After repairing, they found a relatively complete skull, part of dorsal vertebrae, cervical vertebrae, a complete humerus, ischium, pubis, dorsal rib, caudal vertebrae, and especially the well preserved coccygeal vertebra end. (Fig.2.11) The discovery presented strong evidence that it is the only large nodosaurid ankylosaurus in China. After reconstruction, *Zhongyuansaurus luoyangensis* is 5 m in length. It was exhibited together with the *Huanghetitan ruyangensis* on July 3, 2007.

Fig. 2.11 Technicians clearing up the fossil bed

2.5 More Dinosaurs: the Excavation of *Xianshanosaurus shijiagouensis* and *Luoyanggia liudianensis*

On August 13, 2007, Li Jun, the head of Shijiagou Village, and villager Shi Zhengde reported to the excavation team that they found dinosaur fossils in Shijiagou Village, which had already been poached. The team went to investigate and found a fossil impression with a length of 60 cm, which looked like a piece of rib; while some other fossil fragments appeared on the other side. Fossils were preserved in purple silt mudstone with thickness of 20-40 mm. The total thickness is 10 m. A layer of blue gray mudstone with thickness of 40 cm was underneath. An extra thick bed of conglomerates with calcareous argillaceous cementation was on the top.

On September 8, 2008, the excavation team moved into this place. With the active participation of local people, four layers of fossil were discovered by means of manual work and machineries in nearly three months. In the upper part, it was represented by disorderly small and medium-sized fossils which belong to a variety of dinosaurs, such as sauropods, small theropods, ornithopods, etc. There were at least five different types of small theropods. The fossils belonging to medium-sized sauropods were well preserved in the lower strata (Fig.2.12, Fig.2.13). After restoration and studies, two new species, *Xianshanosaurus shijiagouensis* and *Luoyanggia liudianensis* were named. After the reconstruction, *Xianshanosaurus shijiagouensis* is 15.1 m long and over 70% complete.

Fig. 2.12 Searching for fossil layer

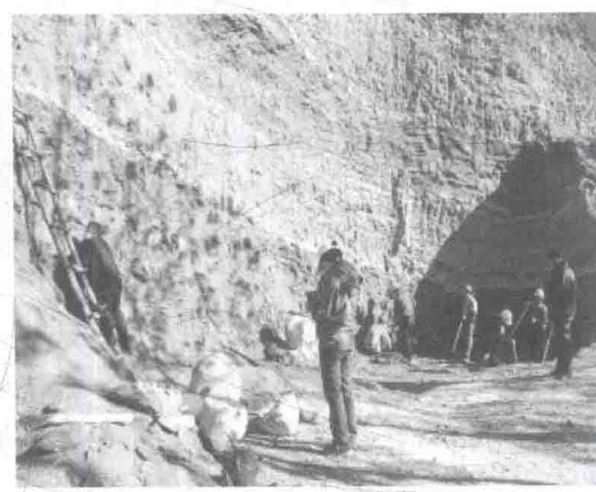


Fig. 2.13 Excavation in progress

However, the fossil layer of this site was not completely excavated due to the following reasons: first, the machineries could not be effectively used due to the thick layer of conglomerates; second, large machinery and equipment could not get through the narrow roads; third, the dynamites could not be used due to the short distance from the village.

Based on analysis of the sediments and the sites of dense fossils, the area of Huamiaogou-Shijiagou-Haoling was the proximal (roots) of an alluvial fan. Large amount of dead dinosaurs bodies were brought to the basin by flood. Afterwards, they were deposited and buried fast, which made the sites dense and relatively integrated. It is the best place for fossils buried in situ. More attention in future should be paid to this area. We should also consider whether the conditions are suitable for In Situ conservation before the excavations. The In Situ conservation is recommended.

2.6 The Long Neck Sticks Out: the Excavation of *Yunmenglong ruyangensis*

The *Yunmenglong ruyangensis* fossils were found on a hill side about 200 m to the south of Huamiaogou Formation at Hongling Village in Liudian Town. It was found by Zhao Anmin, a villager of Huamiaogou who reported to excavation team. On November 25, 2007, Zhao was looking for scorpions by moving stones from gaps of rocks as usual. Suddenly he found a strange white stone. He wondered whether it could be a piece of dinosaur fossil or not. He reported the news to Du Bingli, who was responsible for the matter.

The excavation team confirmed that it was a piece of dinosaur fossil, which was white but broken by Zhao when he was digging. It must be quite big according to the size of exposed part. The lithology of the fossil occurrence: purple silt mudstone, on which 5 m thick layer of deposits overlay. Fossils were covered directly by an ultra-thick and solid layer of conglomerates, which was hard to be removed by manpower. After discussion, the team decided to dig from bottom up. Because of small working area and the short distance to the farmland, the removed rocks were built into a platform in order to minimize damaging farmland and protect the side slope. It was also easy for excavation with such platform to stand on. On December 2, the excavation team was divided into three groups. One group was excavating in this site (sites of Shangliushugou and Haoling villages were excavated simultaneously).

After nearly 20 days of manual work, the fossil layer reached to 5 m deep with direction 35°～215°. The fossil was white. The exposed bones were broken, mostly in pieces 6～10 cm long and 2～3 cm wide. It was disorderly and hard to differentiate the shape. There is a complete fossil of a leg with length of 2.1 m and width of 0.43 m. It was indicative of how fossils were transported and accumulated. Bones are quite large. The fossil site was located in the valley with only one path. The access is very difficult. Four cattle were hired to move the fossil to the side of road. Large and small femurs, teeth, vertebrae, large chevrons, large ribs were discovered after repairing. On January 8, 2008, this phase of small femurs excavations was accomplished.

In 2008, the project of "Ruyang Late Cretaceous Dinosaur Fossils Geological Relics Protection" kicked off and the excavation of dinosaur fossil resumed. Between July 23 and August 21, 2011, the excavation team explored this site again. Overlying strata couldn't be removed by manual work. The thick overlying conglomerates were to be demolished after much deliberations. The excavation team contacted Public Security Bureau of Ruyang

County to get the permission for demolition. However, they were denied due to security concerns during the Olympic Games. Manual work focused on the east slope of the excavation site. After extending to the east for 5 m and 1.2 m to the bottom, the ribs, vertebrae, teeth and so on were found as result (Fig.2.14, Fig.2.15). Dr. Lü Junchang named it as *Yunmenglong ruyangensis* after studying them.

Fig. 2.14 The excavation site of *Yunmenglong ruyangensis*

Fig. 2.15 Stripping away the fossils on site

Science links

1. The Excavation of the Ancient Vertebrate Fossils

Where were the fossils we saw in museums found? Were the skeletons and structures so complete and detailed when they were first discovered? Were they all so exquisite? The answer is no. The fossils we saw in exhibition were buried in strata in the wild. They were found only when they were exposed by weathering and erosions, or when paleontologists searched and excavated them. They are put in display after they are repaired and reconstructed, which is a complex and painstaking process and hard work that also brings much joy to paleontologists.

The fossil excavation and collection is an important part of paleontology research. Scientific discovery and collection is essential for professional research (Ding, 2005)

The article "Field Excavation and Collection of Vertebrate Fossils" is recommended for getting familiar with related techniques. The excavation of fossils must follow "Regulations on Paleontological Fossil Protection". It should be executed by the qualified paleontological institutions or museums, or by the provincial and national level departments of land and resources. No individual is allowed to excavate fossils, especially fossils with high values.

2. Plaster Block (PLK)

"PLK" is a method to package and protect fossils for field collection. It is widely applied in situations when large vertebrate fossils (such as dinosaurs, elephant) were severely weathered and hard to be extracted out from the rock. After stripping out the fossil layers, according to the fossil structure (if they can be determined), the complete fossil layer will be divided meticulously by natural fissures based on the principle that the same part of the fossil should be kept integrally and easy to be transported. The fragment can be attached to the original position. The direction of divided fossils and the numbers for splicing will be marked before making the PLK (Fig.2.16 ~ Fig.2.20).

Materials and Tools:

Plaster, it can be bought from home improvement stores; the model plaster is acquired because of its characteristics of fast condensation and high intensity.

Hemp bags or sturdy textile;

Cotton paper or other type of paper;

Steel wire, wood plank and so on;

Buckets, pots, brushes, markers.

Preparation:

Mix plaster with water: the ratio of plaster and water is 1:1;

Cut the sacks into straps or pieces according to fossil's shapes and sizes.

Wet the cotton paper.

Packing:

a. Pack fossils with wet cotton paper and then gently pat the cotton paper with a wet brush in order to make a close contact between the paper and fossils without gaps. Fill the uneven place with blocks to separate fossils and plaster cases, which make it easy for transportation and removing afterwards.

b. Soak the straps of textile into the plaster water and then attach it to the wet cotton paper. The straps should be pressed and overlapped without gaps. Each layer is flattened and pressed. Multiple layers are required if the fossil is big with loosened surrounding rocks. The strips of wood (bamboo), steel wires or wood planks are necessary to reinforce it.

c. Cut the surrounding rocks on the bottom of fossil after the plaster solidifies completely. Make the plaster to a mushroom shape, big at the top and small at the bottom. This is easy to be separated. Pry the plaster with electric tools or long drilling steel and pick off the extra rocks (earth) from the bottom. By the method of a and b, seamless connection could be achieved. Transport it after it dries up.

Fig. 2.16 Clearing Up

Fig. 2.17 Pry and separate semi-finished PLK

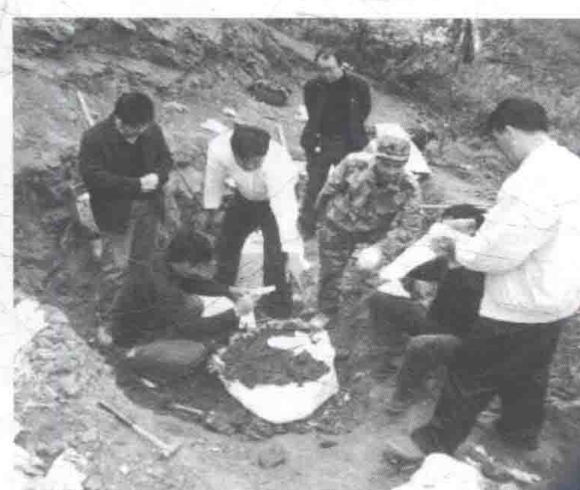


Fig. 2.18 Strip away extra rock at the bottom

3. Fossils Repair

How to restore the fossils out of the plaster which is excavated and packed in the field?

Who is qualified to do the job? Fossils repair is the most important preliminary task in paleontological research, and it is also an indispensable part (Ding, 2005). Special tools are used for repairing fossils. The technicians for fossils repairing are professionally trained. There are only less than one hundred people in China who can do the job. Not only should they possess knowledge of paleontology and petrology and the anatomy of the relevant ancient animals but also they should have patience and focused mentality (Fig.2.21).

Fig. 2.19 Packing the finished plaster block

Fig. 2.20 Moving the plaster block

Fossil restoration uses certain mechanical or chemical methods to separate surrounding rocks from fossils. It is a science, especially the chemistry approach. European and American countries are on the cutting edge in this field. Many techniques we employ are basically taught by them. For example, the pneumatic pen drills are imported from abroad. Mechanical methods are the basic way for dinosaur fossil repairing. Chemical extraction method is required for some small fossils or fossils with nodular form.

Fig. 2.21 Indoor fossil repair: open up the plaster block

Dinosaur fossils repair generally includes the following steps:

a. Register the numbers of fossil plaster marked in the field. The original numbers are always written during the repairing process. Afterwards, numbers should also be marked on fossils. When the restoration is completed, uniform catalog collection numbers and the original field numbers should be documented and registered in order to facilitate the use and preservation.

b. Open the plasters by mechanical methods. Generally, wet the cases of the plaster by hammers and chisels. Remove it carefully until the wrap is exposed. Never hit it hard to avoid damages. Cut the wrap by scissors or hacksaws. It is easy to separate the cases and fossils because there is a layer of cotton paper between (Fig.2.22).

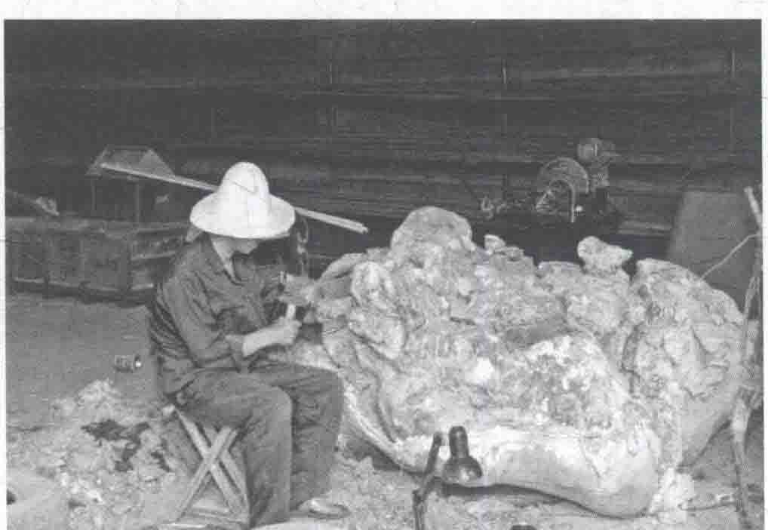


Fig. 2.22 Fossil repair: chisel away the rock

c. "From known parts to unknown parts, from outside to inside, make every effort to complete it" is the principle for cleaning and removing the surrounding rocks of the fossils. There are usually two preservation conditions of invertebrate fossils, stereo and flat. Dinosaur fossils mostly are stereo. Some are continuous and complete; some are scattered. However, the fossils in western Liaoning are kept in flat state. It is important to observe the exposed range of fossils. The restoration should start from known to unknown. Clean it from fossil outcrop to surroundings. For a better understanding of research and assembly, consultations and discussions with paleontologists are indispensable. Retain the original conditions as much as possible. Do not split fossils rashly. Do not do anything without a plan and do not damage the fossils. Mechanical methods, such as hammers, chisels, pneumatic pen drills and some other tools are mainly utilized for repair. First, hammers and chisels are used to clean up the periphery rocks surrounding the fossils. Then, they are replaced by pneumatic pen drills when it is getting close to the surfaces of fossils in order to avoid damages. Inevitably there will be some fall offs which should be glued to the original place immediately.

The bone part from the plate-shaped fossil (Ding, 2005) mostly is pressed into flat form but well preserved. Higher level and more meticulous restoration is required. Dental instrument are utilized for more detailed work. Many master technicians created and summarized a set of techniques during the repairing process in the western Liaoning.

4. Replicas of Dinosaur Skeletons

Replicas of dinosaur skeletons are the exposed bones supported by steel framework with morphological integrity exhibited in museums. Many children could not help asking when they see them in the museum: Are they real or only replicas? Were they this big in reality? How was the body image of the dinosaur reconstructed? In fact, it's all based on fossil studies. After the excavated fossils are repaired, paleontologists will study published research papers and make a comparison on morphometrics to find out the similarities and differences by taxonomy. The species will be identified. The name will be given and then classified to the dinosaur family tree. Take *Huanghetitan ruyangensis* for example, it belongs to the same family with *Huanghetitan liujiaxiaensis* (gigantic sauropod dinosaur) discovered from Gansu province. But they are not identical. It is a new species. Most fossils are not preserved completely. 100% integrities are rare. The missing parts will be reconstructed by paleontologists according to similar cases. If the amount of fossils from the same part is lacking, it will be reconstructed according to the trend of variation in size from known cases. *Ruyangosaurus giganteus*, for instance, has 8 cervical vertebrae, 13 dorsal vertebrae, 5 caudal vertebrae, sacral vertebrae and limbs and digits, from almost every part of the dinosaur body. Therefore, the morphology of each part was clear-cut. However, the number of cervical vertebrae and caudal vertebrae were insufficient. How did they reconstruct the missing cervical vertebrae and caudal vertebrae? According to the research by Dr. Lü

Junchang, dinosaurs from this family should have 17 cervical vertebrae, 13 dorsal vertebrae and 52 caudal vertebrae. The sizes of missing cervical vertebrae and caudal vertebrae can be calculated from the excavated parts. By enlarging or reducing the scale with equal proportion, the specific figures of missing parts will be calculated and made into plaster model. The incomplete fossils can be filled with plaster as well. After all parts are prepared, modules are going to be reproduced. The modules are made from silica with hollow body. The postures of dinosaurs will be designed afterwards. Later on, the dinosaur will be mounted with the support of steel frame (Fig.2.23 ~ Fig.2.27). Undoubtedly, mounted dinosaur skeletons in vivid detail are the main attractions in natural history museums.

For small-sized dinosaurs, real fossils are recommended for assembling the skeletons to make it look more realistic.

Fig. 2.23 Repaired spinal column of *Ruyangosaurus giganteus*

Fig. 2.24 Making replicate modules

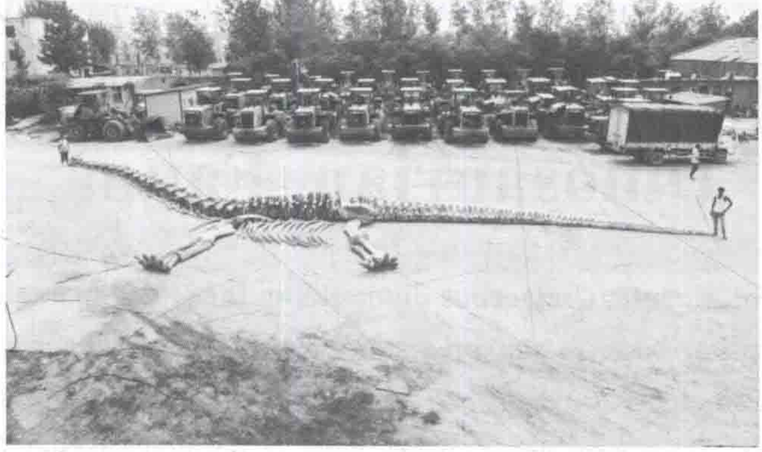


Fig. 2.25 *Ruyangosaurus giganteus* with all parts prepared

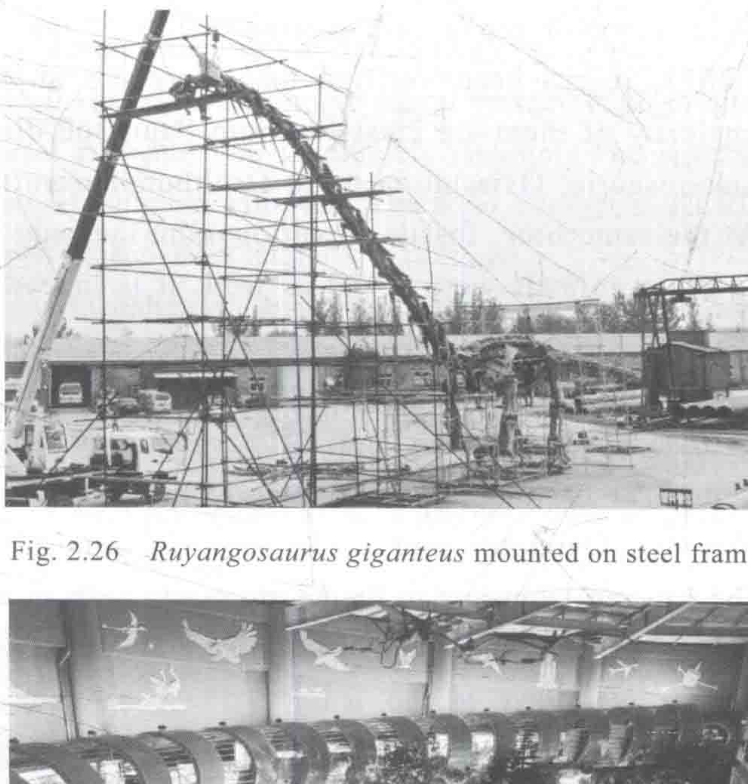


Fig. 2.26 *Ruyangosaurus giganteus* mounted on steel frame

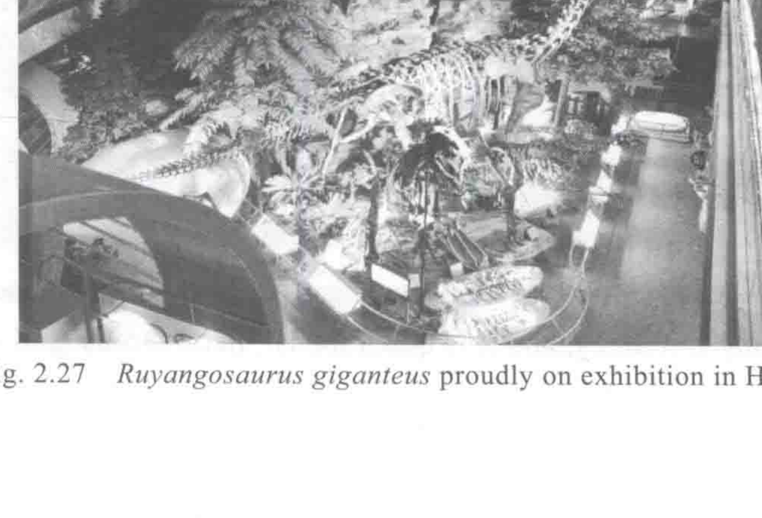


Fig. 2.27 *Ruyangosaurus giganteus* proudly on exhibition in HGM

3 Ruyang Gigantic Sauropod Dinosaurian Fauna

The discovery of gigantic Cretaceous dinosaurs in the Ruyang area of Henan Province invokes our imagination back to the prehistoric world. The Ruyang Gigantic Sauropod Dinosaurian Fauna (Lü et al., 2009b) is one of the most significant dinosaur faunas found in China in recent years. This new dinosaurian fauna is dominated by large-sized sauropod dinosaurs, as well as theropods and medium-sized carcharodontosaurid dinosaurs.

With almost eight years of repair and reconstruction of the discovered fossils between 2006 and 2013, it has been verified that there are at least ten different dinosaurs, and the majority of them are classified into Sauropod dinosaurs, while the rest belonging to Ankylosauria, Oviraptorosauria, Ornithomimosauria, Dromaeosauria and Iguanodontia. At the same time, fossils of various dinosaur egg shells, testudines, bivalves, plants, and other animals were found as well. It is indeed a dinosaur fauna with abundant species.

Six dinosaurs are named, including *Huanghetitan ruyangensis*, *Ruyangosaurus giganteus*, *Xianshanosaurus shijiagouensis* and *Yunmenglong ruyangensis* belonging to Sauropoda, *Zhongyuansaurus luoyangensis* belonging to Ankylosauria, and *Luoyanggia liudianensis* belonging to Oviraptorosauria. These extraordinarily large sauropod dinosaurs found in the Ruyang Dinosaurian Fauna are rarely seen in the same period in the world, characterized by gigantic individual body sizes and diverse species, and among them the *Ruyangosaurus giganteus* is the largest. They provide valuable and rich information on paleoecology, paleoclimatology, and paleogeographic distribution of dinosaurs. Through the phylogenetic analysis of the sauropod dinosaurs of the fauna, their phylogentic positions are confirmed, which is of considerable significance for studying sauropod dinosaur evolution and its diversity in the related time frame and in the related regions.

3.1 *Huanghetitan ruyangensis* Lü et al., 2007

The sauropod dinosaur *Huanghetitan ruyangensis* is the first dinosaur found in the Ruyang area. With long forelimbs, and it is quadrupedal, herbivorous, and characterized with low, short neural spine and huge body cavity. It presents important information about gigantic sauropod's evolution, migration, paleogeography distribution and paleoenvironment. some of the fossils were invited to participate in the Asia Dinosaur Exhibition in Japan as the main attraction which was featured in the background of the conference podium.

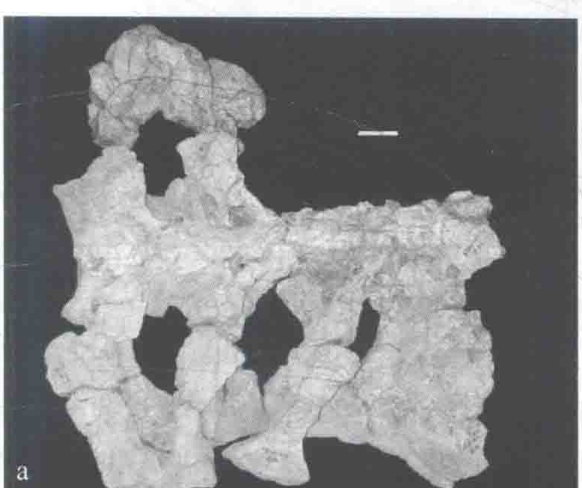
Dinosauria
  Saurischia
    Huanghetitanidae Lü et al., 2007
      Huanghetitan You et al., 2006
        Huanghetitan ruyangensis Lü et al., 2007

Diet: Herbivorous.

Type locality and horizon: Liufugou Village of Liudian, Ruyang County of Henan Province, Lower Cretaceous Haoling Formation (Xu et al., 2007).

Holotype: Partial skeleton including 6 sacral vertebrae, 10 proximal caudal vertebrae; haemal arches, dorsal ribs and one incomplete ischium. The specimen (41HIII-0001) is housed in the Henan Geological Museum. The field number is KLR06-2; two incomplete cervical vertebrae were discovered later.

Diagnosis: New huanghetitanid sauropod differs from *Huanghetitan liujiaxiaensis* in its gigantic size, with the deepest body cavity, one dorsal rib reaching at least 2.93 meters in length, anterior caudal vertebrae with short, mushroom-shaped neural spines, neural arches of the anterior caudal vertebrae short with a small neural canal as compared with the centrum. A large deep, oval postspinal fossa is present on the posterior surface of the neural spine of the anterior caudal vertebrae (Fig.3.1, Fig.3.2)。



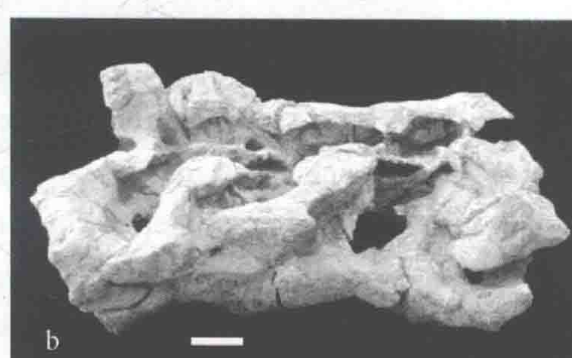


Fig. 3.1 Sacral vertebra of *Huanghetitan ruyangensis* in dorsal view (a) and lateral view (b)

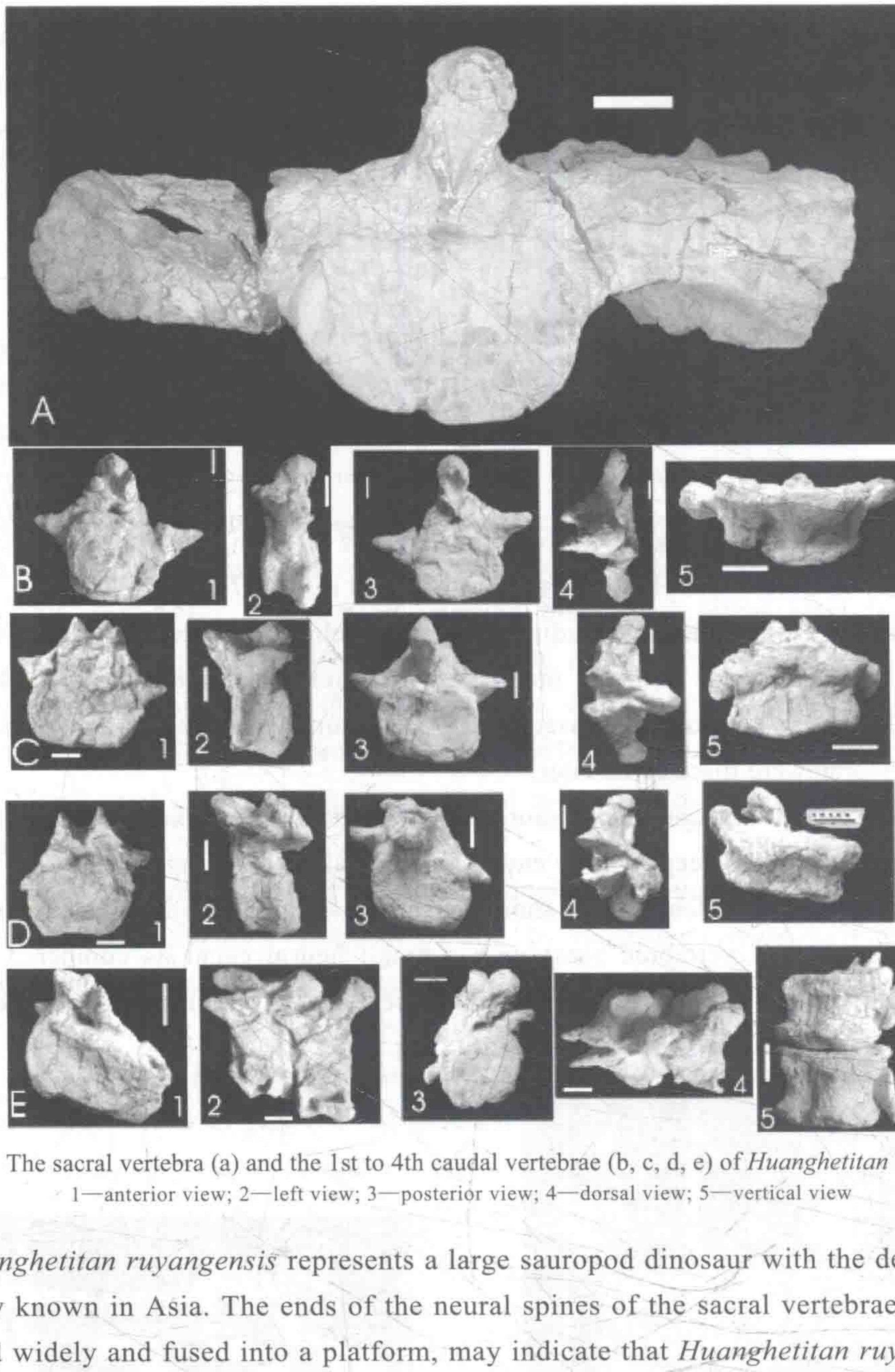


Fig. 3.2 The sacral vertebra (a) and the 1st to 4th caudal vertebrae (b, c, d, e) of *Huanghetitan ruyangensis*
1—anterior view; 2—left view; 3—posterior view; 4—dorsal view; 5—vertical view

Huanghetitan ruyangensis represents a large sauropod dinosaur with the deepest body concavity known in Asia. The ends of the neural spines of the sacral vertebrae, which are expanded widely and fused into a platform, may indicate that *Huanghetitan ruyangensis* is possibly armored. The combined characters of the sacral vertebrae and caudal vertebrae of *Huanghetitan ruyangensis* are unique among the reported large-sized sauropods. Therefore, it deserves a new rank among sauropods: Huanghetitanidae which represents primitive titanosaurs from the Cretaceous, and phylogenetic analysis shows that it falls between Andesauridae and Euhelopidae.

Based on the discovered fossils, *Huanghetitan ruyangensis* is estimated to be 8.2 m high and 18 m long, and it weighs about 60 tons, which is equivalent to ten elephants.

Discussion: Herbivorous sauropod dinosaurs were once the largest terrestrial vertebrate animals. Some of them were estimated to have body length reaching up to 35 meters and the heaviest sauropod dinosaur could weigh up to 100 tons. Sauropod dinosaurs mostly lived in the Jurassic and reached the highest diversity in the Late Jurassic, and only a few lasted into the Cretaceous. Some species developed long body and extremely elongated neck, such as *Diplodocus*, *Barosaurus*, *Omeisaurus*, *Mamenchisaurus* (Young and Chao, 1972; Upchurch and Barrett, 2000), whilst some others developed huge body and short neck, such as *Opisthocoelicaudia* (Borsuk-Bialynicka, 1977). Most of them are found from the Late Jurassic. Compared with the sauropod dinosaurs from the Late Jurassic, the quantity of sauropods from the Cretecaous is few. The titanosaurs are predominant in the Late Cretaceous, while sauropods from the Early Cretaceous are less both in diversity and quantity.

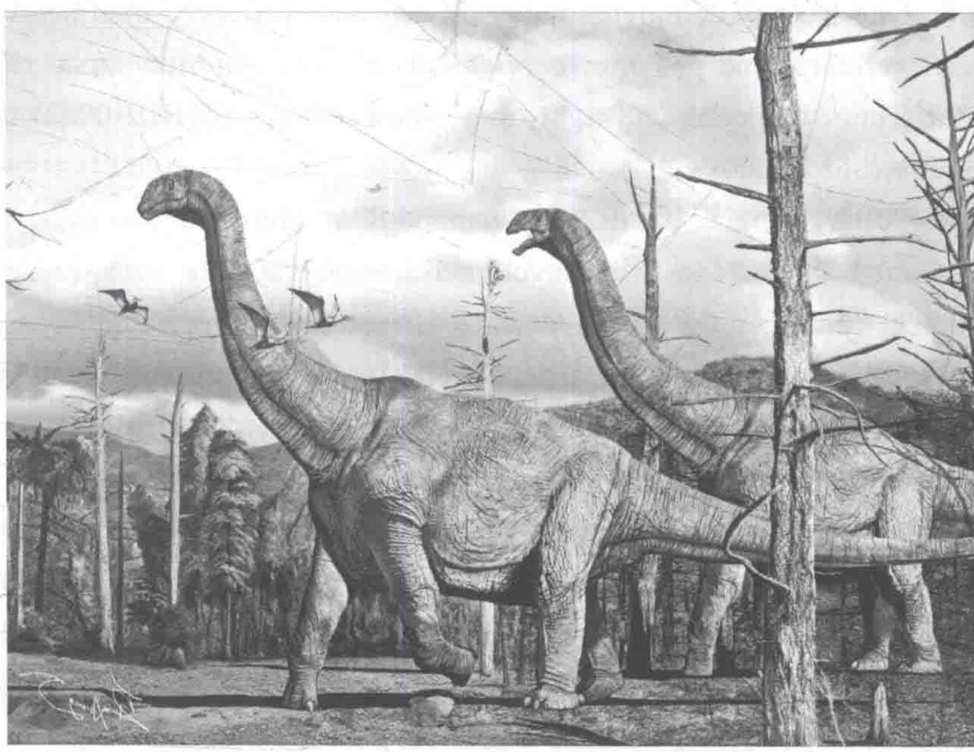


Fig. 3.3 Artist's impression of *Huanghetitan ruyangensis*

(Drawn by Zhao Chuang)

3.2 *Ruyangosaurus giganteus* Lü et al., 2009a

The sauropod dinosaur *Ruyangosaurus gigantenus* was discovered based on an incomplete femur as the clue. The giant creature itself was finally revealed through four seasons of excavation work, which lasted three months, spanning two years.

The dorsal vertebrae of *Ruyangosaurus* is much larger than that of *Huanghetitan ruyangensis*, which indicates that it is much larger than *Huanghetitan ruyangensis*. It obviously represents a new and gigantic dinosaur, which can match *Argentinosaurus* in the size of its centrum. The dorsal vertebrae of *Ruyangosaurus* is much wider than that of *Argentinosaurus*, whilst not as high as the latter. It is the largest dinosaur found in Asia so far.

Somphospondyli Wilson and Sereno, 1998

Ruyangosaurus Lü et al., 2009a

Ruyangosaurus giganteus Lü et al., 2009a

Diet: Herbivorous.

Type locality and horizon: Shengshuigou of Shaping Village, Liudian Town, Ruyang County of Henan Province, Lower Cretaceous Haoling Formation.

Holotype: One nearly complete posterior cervical vertebra, one nearly complete posterior dorsal vertebra, one posterior cervical rib and one anterior dorsal rib, proximal portion of right femur, one complete right tibia. The specimen (41HIII-0002) is housed in the Henan Geological Museum.

Diagnosis: A large sized basal somphospondylian sauropod dinosaur, bearing the following combined characters: well-developed honeycomb-like structures within the cervical and dorsal vertebrae; the ventral surface of the cervical vertebrae strongly concave except for the area near the posterior articular end; extremely elongated middle cervical vertebrae with EI (Elongation Index) greater than 3, anterior cervical vertebrae without pleuroceols, but with poorly developed lateral concavities, structure of neural arches simple with low neural spines; large concavity present on the posterior cervical vertebrae; compared with the centrum, the neural canal of dorsal vertebrae suboval and small; neural spines of dorsal vertebrae low; the pleurocoels of dorsal vertebrae right angular outlines with two right margins parallel to the lateral margin of the anterior articular end and long axis of the centrum respectively; thirteen dorsal vertebrae; six sacral vertebrae (including one dorsosacral vertebra) with neural spines slightly higher than the dorsal margin of the ilium, the last sacral vertebra with convex posterior aricular end; and the dorsal margin of the ilium convex and round.

Ruyangosaurus giganteus is a gigantic sauropod dinosaur, belonging to titanosauriformes. The tibia is robust, with 127 cm in length. The discovered tibia, femur, ribs, dorsal and caudal vertebrae are all extremely strong. The diameter of single dorsal vertebra reaches as much as 61 cm in *Ruyangosaurus*, whilst it is 50 cm in *Argentinosaurus*, the largest dinosaur ever in the world. The *Ruyangosaurus* also replaces *Huanghetitan*, the largest dinosaur ever in Asia housed in Henan Geological Museum, as the most robust and the heaviest dinosaur so far. The discovery of *Ruyangosaurus* demonstrates that the sauropod dinosaurs in the Early Cretaceous reached an incredily higher diversity than previously thought, which is very important for studying the evolution of gigantic dinosaurs.

The femur is estimated to be about 200 cm long. The femoral shaft is compressed anteroposteriorly and has an elliptical in cross section as in other sauropod dinosaurs.

Description: A possible incomplete cervical vertebra is preserved. The width of the centrum is 51 cm, and it is 18 cm long excluding the anterior articular end and 30 cm long with the anterior articular end. The anterior articular end is stongly convex and its posterior articular end is strongly concave. The broken surface of the anterior articular end displays an internal honeycomb-like structure. The neural canal is small compared with the centrum. It is 7 cm wide and 6 cm high. The neural canal is larger in anterior view than in posterior view. The base of the short neural arch is plate-like.

The single posterior dorsal vertebra is nearly complete except for missing a small portion of neural arch (Fig. 3.4). The anterior articular end is convex, while its posterior articular end is strongly concave. There is a single large pleurocoel on the dorsal half of the lateral face of the centrum. Its anteroposterior length is 14 cm, and height is 7 cm. The neural canal is a relatively small suboval. It is 6 cm wide and 8 cm high. The height ratio of the neural canal to the centrum is approximately 15.7%. There is a weakly-developed hyposphene between the neural canal and the postzygapophyses. There are two laminae on the dorsal surface of the right postzygapophysis and one is on the left postzygapophysis, similar to the subsidiary laminae on the lateral surface of the postzygapophysis in *Dongyangosaurus*. A deep concavity is formed by the postzygapophyses and the subsidiary laminae on the dorsal surface of the postzygapophysis above the hyposphene in posterior view. Ten main laminae are present on the neural arch of the dorsal vertebra and are discussed briefly. The spinoprezygapophyseal lamina (sprl) is present, but only weakly developed. It originates on the postodorsal aspect of the prezygapophysis and extends to the anterior surface of the base of the neural spine.

Two spinodiapophyseal laminae (spdl) are present and strongly developed. Each struts from the dorsal portion of the diapophysis to the lateral surface of the base of the neural spine. There are additional laminae on the dorsal surface of the postzygapophysis which are located on the position of the base of the postspinal lamina (posl), as seen in other sauropod dinosaurs. These laminae should be postspinal lamina, and they are weak, disappearing at the base of the neural spine. The medial lamina is postspinal lamina. The lateral lamina is not reported in other sauropod dinosaurs, and thus it is called as a subsidiary postspinal laminae (sposl).

The posterior centrodiapophyseal lamina (pcdl) is the thickest one among the laminae but in contrast the anterior centrodiapophyseal lamina (acdl) is missing. The posterior centrodiapophyseal lamina (pcdl) bifurcates at its base, which forms a shallow concavity on the later surface (Fig. 3.4a). Together with the posterior centroparapophyseal lamina (pcpl) and the paradiapophyseal lamina (ppdl) they form a large, irregularly triangular deep fossa (fpp) (Fig. 3.4a). This fossa, termed as the postparapopophyseal fossa (fpp), holds similar position on the neural arch of dorsal vertabra in *Andesaurus*, but is much larger in *Ruyangosaurus* than in *Andesaurus*.

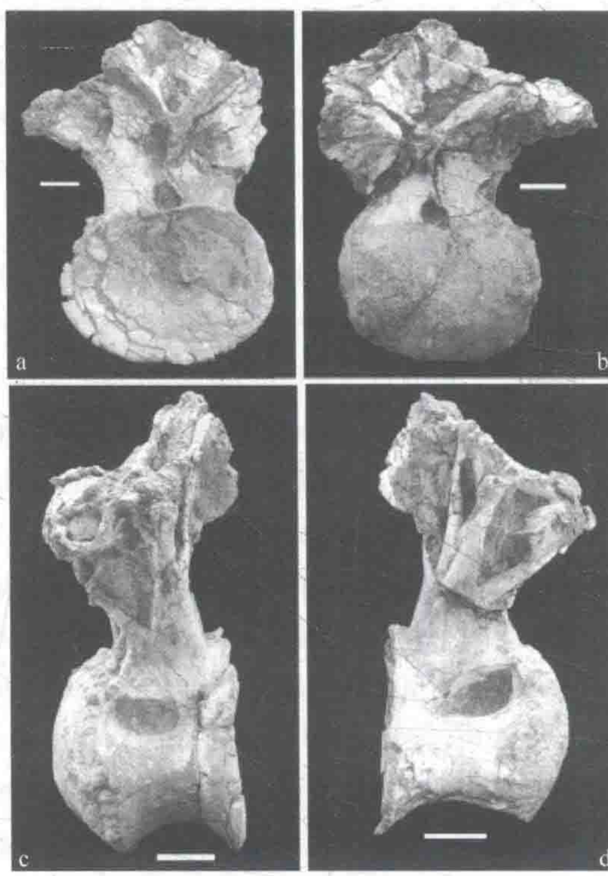


Fig. 3.4 Dorsal view (a), anterior view (b), left lateral view (c), and right lateral view (d) of the dorsal vertebrae of *Ruyangosaurus giganteus*

Scale bar: 10 cm

The parapophysis is not well preserved, but the broken surface of the parapophysis displays a large round fossa within it. The paradiapophyseal lamina (ppdl) which contacts with the parapophysis and the diapophysis is short. The posterior centroparapophyseal lamina (pcpl) is developed, which extends anterodorsal-posteroventrally, forming about a 45° angle with the long axis of the centrum. The centrpostzygapophyseal lamina (cpol) is poorly developed and plate-like. It forms a deep concavity with the posterior surface of the dorsal portion of the posterior centropophyseal lamina (pcdl). The postzygapophyseal lamina (podl) is short. It forms a nearly 45° angle with the long axis of the vertebra. Together with the postzygapophyseal lamina, the spinopostzygapophyseal lamina, and the spinopostzygapophyseal lamina, they form a triangular fossa in dorsal view. The prezygoparapophyseal lamina (prpl) is not well developed and oriented anteroposteriorly rather than transversely. As in *Alamosaurus sanjuanensis*, the centroprezygapophyseal lamina (acpl) is not present.

The ventral surface of the centrum is smooth. The posterior articular end is concave. The broken surface of the anterior articular end shows that numerous small cavities and angular wall produce a honeycombed, camellate pattern of the vertebral internal structure. A similar structure is also present in the dorsal vertebrae of *Saltasaurus*. The neural arch is nearly straight. The distance between the anterior margins of the prezygapophysis and the distal margin of the postzygapophysis is 35 cm, which is almost similar to the length of the centrum.

The tuberosity and the capitum of the posterior cervical rib form 90° angles (Fig. 3.5a). The preserved length of the rib (from the capitum to the distal end along the shaft) is 137 cm. The width of the shaft is 16 cm. There is no concavity or pneumatic opening at the proximal end of the rib. A shallow concavity is present near the proximal end of the rib (Fig. 3.5c). The preserved length of the rib is 183 cm, and the width of the shaft is 18 cm.

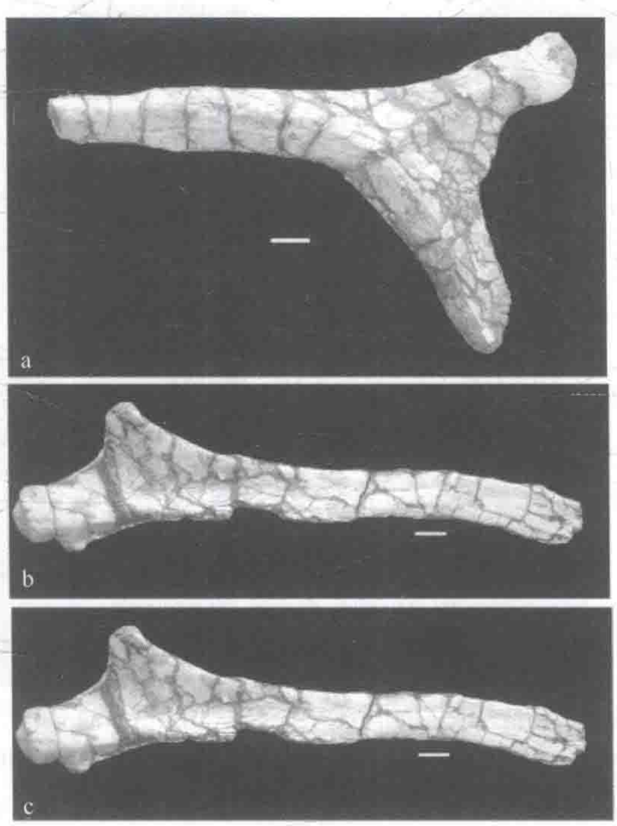


Fig. 3.5 Lateral view of left cervical rib (a). Anterior view and lateral view of anterior dorsal rib (b,c).
Scale bar:10 cm

The preserved proximal portion of the right femur is 120 cm long (Fig. 3.6). It is estimated about 200 cm long. The femoral shaft is compressed anteroposteriorly and has an elliptical in cross section as in other sauropod dinosaurs. The distance between the 4th trochanter and the proximal end of the femur is 90 cm. The fourth trochanter is reduced to a low, rounded ridge. The width of the proximal end is 60 cm. The maximum anteroposterior width is 23 cm. The complete right tibia is 127 cm long. Its proximal end is greatly expanded anteroposteriorly and transversely relative to its main shaft. The proximal articular surface is shallowly concave. The outline of the proximal end is sub-oval (Fig. 3.6d). The maximum anteroposterior diameter of the proximal end (excluding the cnemial crest) is 25 cm. The maximum transverse diameter of the proximal end (including the lateral expansion) is 51 cm. The transverse width of the distal end is 31 cm and the anteroposterior width is 27 cm. The feature that the transverse width of the distal end of tibia is broader than its anter posterior width is the synapomorphy of the unnamed clade, including *Andesaurus*, *Argentinosaurs*, *Alamosaurus*, etc. A distinct notch is present at the distal end.

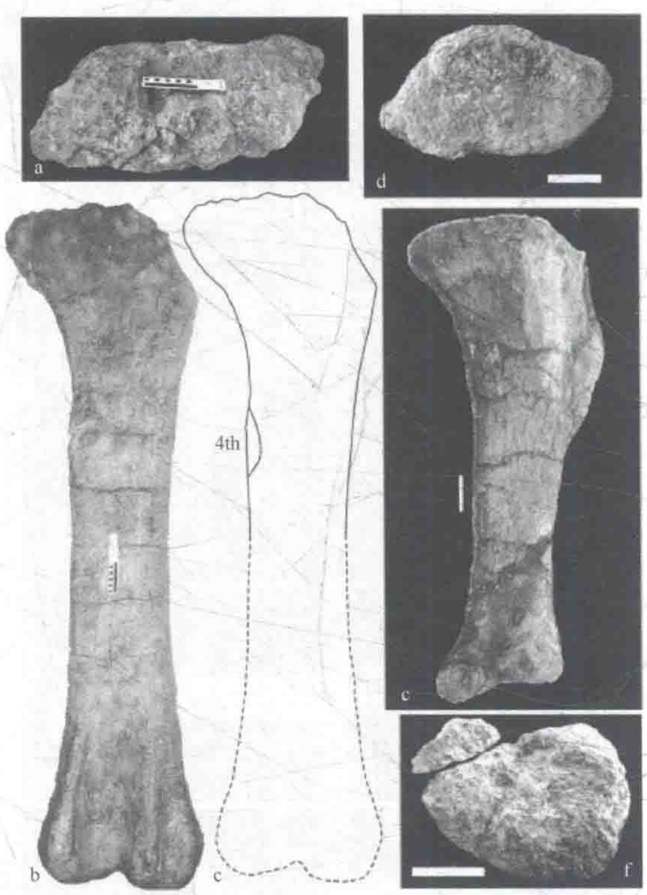


Fig. 3.6 (a) Right proximal femur. (b) Anterior view of right femur image. (c) Sketch of right femur, dotted line representing reconstruction of missing parts. (d) Right proximal tibia. (e) Dorsal and left view of right tibia. (f) Right distal tibia.

Scale bar:10 cm

Discussion: Wilson and Sereno (1998) define Somphospondyli as titanosauriforms more closely related to Saltasaurus than to Brachiosaurus. They bear the following characters: reduced lamination on cervical neural arches; presacral vertebrae composed of spongy bone; anterior and mid-dorsal neural spines posterodorsally inclined; six sacral vertebrae (one dorsosacral vertebra added), and scapular glenoid deflected medially (Wilson and Sereno, 1998). *Ruyangosaurus giganteus* bears all of the above-mentioned characters thus conforming to Somphospondyli.

The dorsal vertebra of *Ruyangosaurus* exhibits a relatively simple structure with low neural arches. The posterior centrodiapophyseal lamina bifurcates at its base, and a similar condition is observed in at least some of the dorsal vertebrae of *Euhelopus*, *Argyrosaurus*, *Argentinosaurus*, and *Alamosaurus sanjuanensis* (Fig. 3.7). The diameter of dorsal centrum in *Ruyangosaurus* is 60 cm, whilst it is only 50 cm in *Argentinosaurus*. However, *Ruyangosaurus* differs from *Argentinosaurus* in that its neural spine is much shorter than that of *Argentinosaurus*.

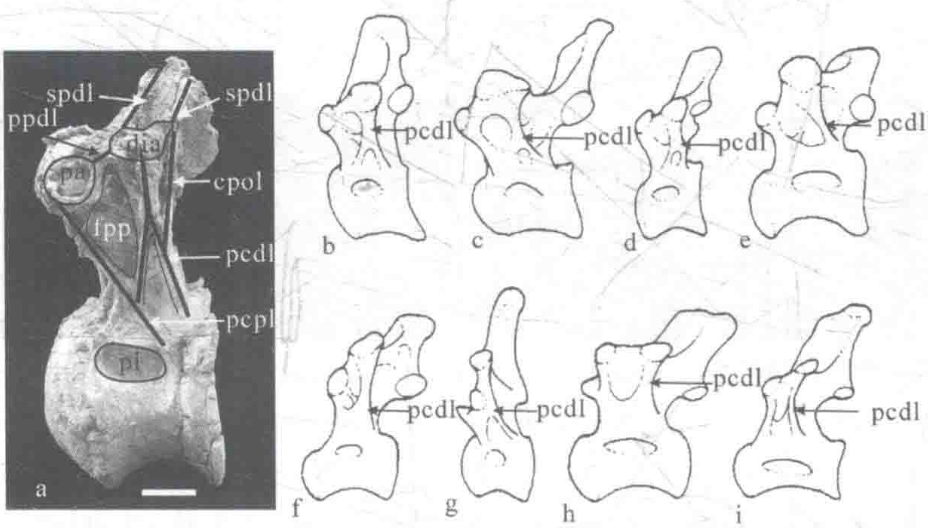


Fig. 3.7 Comparison of dorsal vertebrae of *Ruyangosaurus giganteus* and other sauropods in left view

The posterior dorsal vertebrae of *Ruyangosaurus* differs from that of *Andesaurus* in the neural spine. The former has an almost vertical neural spine, and a prominent prespinal lamina. but the latter has a smaller one, and neural spine well-developed postspinal lamina.

Ruyangosaurus differs from *Epachthosaurus* in that the neural canal and the pleurocoel of the foraner are very large, and a bridge connecting with the prezygapophyses is present. The anterior centroparapophyseal lamina (acpl) is present in *Epachthosaurus* (Fig. 3.7). However, the reverse conditions are present in *Ruyangosaurus* and a large concavity is present under the prezygapophyses and above the neural canal.

It is difficult to compare *Ruyangosaurus* with *Huanghetitan ruyangenis*, because of the lack of the corresponding elements between them. However, the centrum diameter of the dorsal vertebra of *Ruyangosaurus* is much larger than that of *Huanghetitan ruyangensis*, suggesting that even as adult the animals were distinct in terms of body size.

Sauropod dinosaurs were thought to have reached a peak in abundance and diversity during the time interval represented by the Early Jurassic and possibly had extended into the Early Cretaceous, when they were the dominant large terrestrial herbivores. *Ruyangosaurus* is the largest sauropod dinosaur found in Asia so far. The discovery of *Ruyangosaurus* and *Huanghetitan ruyangensis* indicates that a higher diversity of sauropod dinosaurs occurred during the early Late Cretaceous. It may also indicate that titanosauriformes reached a peak in diversity during the interval, from late Early Cretaceous to early Late Cretaceous.

The reconstructed *Ruyangosaurus giganteus* ((Fig.3.8) is 14.5 m high, body length of 38.1 m long, and body weighs approximately 200 tons, which is equivalent to 20 elephants.

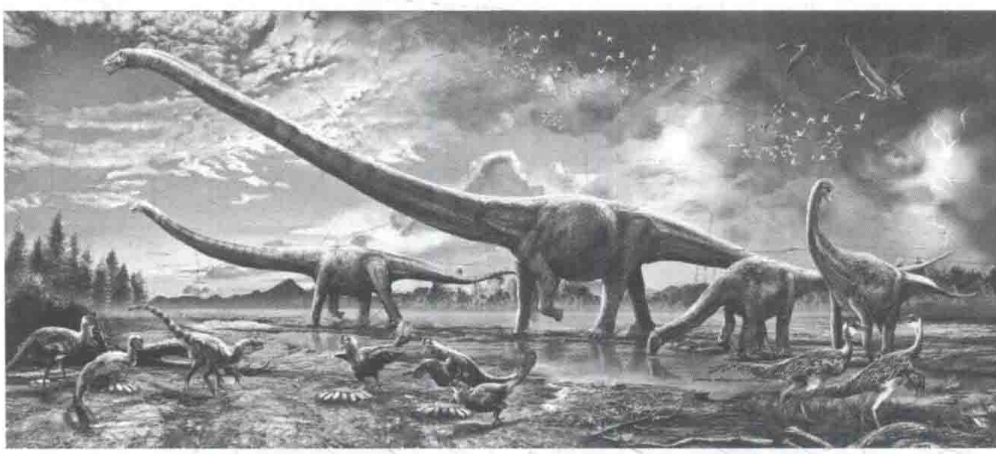


Fig. 3.8 Living scene of *Ruyangosaurus giganteus*

(Drawn by Zhao Chang)

3.3 *Xianshanosaurus shijiagouensis* Lü et al., 2009b

Xianshanosaurus shijiagouensis was discovered in Shijiagou of Hongling Village. It is relatively complete, representing a mid-sized sauropod dinosaur from the early Late Cretaceous, slightly earlier than that of *Huanghetitan ruyangensis*. (Lü et al., 2009b)

Dinosauria
  Saurischia
    Sauropodomorpha
      Xianshanosaurus Lü et al., 2009b
        Xianshanosaurus shijiagouensis Lü et al., 2009b

Diet: Herbivorous.

Type locality and horizon: Shijiagou of Haoling Village, Liudian Town, Ruyang

County of Henan Province, Lower Cretaceous Haoling Formation.

Holotype: Ten naturally articulated anterior caudal vertebrae and one chevron (KLR-07-62-6), one nearly complete right coracoid (KLR-07-62-59), one complete left femur (KLR-07-62-15), and several complete (KLR-07-62-3a, KLR-07-62-59-1) and incomplete dorsal ribs. The specimens are housed in the Henan Geological Museum.

Diagnosis: A medium-sized sauropod bearing the following characters: the elongated tooth with a distinct ridge on the lingual surface of the tooth crown; plate-like neural spines of anterior caudal vertebrae with coarse areas on their middle portions of the anterior and posterior surfaces; distinct fossae present on the anterolateral surface of the base of the prezygapophysis and the anterior surface of the base of the transverse process; coracoid foramen is located closely to the scapula-coracoid suture; and shallow concavity present on the proximal end of the dorsal ribs.

Description: The elongated tooth is about 4 cm long (41HIII-0015), with a distinct ridge on the lingual surface of the tooth crown. The tooth crown is spatulate. The tooth has wrinkled enamel and no denticles are present along the margin of the tooth, similar to tooth of *Brachiosaurus* (Carpenter and Tidwell, 1998; Upchurch *et al*., 2004). The tooth morphology is also similar to that of *Euhelopus zdanskyi*, but differs from other sauropod teeth. The sauropod dinosaur from the Shijiagou may have a close relationship with brachiosaurid dinosaurs. Ten naturally articulated anterior caudal vertebrae are preserved (Fig. 3.9a,b). Articulations between them are mildly procoelous. The anterior articular surface is strongly concave and its posterior articular ends are strongly convex, forming a distinct ball-socket articulation between the centra, and the condition is called procoely by Upchurch (1998). The lengths remain approximately the same over the ten caudal vertebrae. Each centrum is about 12 cm long. The width of the centra becomes smaller distally. The centrum has a bigger width than its heigth (26 cm wide and 18 cm high). The ratio of the centrum length/height is approximate 0.6 (length excluding the posterior articular ball). A large fossa is present on the anterolateral surface of base of the prezygapophysis in the caudal vertebrae and anterior surface of base of transverse process. A portion of the base of the prezygapophysis is fused with the portion of the base of the transverse process, forming a clearly process. The sutures between the centrum and the transverse process, the transverse process and the prezygapophysis, presygapophy the sis and the centrum are clear, and some of them are departed each other. All these indicate that this animal is not an adult. The neural canal is small, with 2 cm in diameter. The central portions of the neural spine on both sides are coarse, indicating a strong muscular connecting between two neural spines. This also means that the tail is strong. The proximal ends of the dorsal ribs are shallowly concave. The ohevron has its proximal facet linked by a transverse “bridge” of bone. The right coracoid is only missing asmall portion. A large coracoid foramen is located closely to the scapula-coracoid suture. The left femur (KLR-07-62-15) is completely preserved (Fig.3.9c—g). It is 126 cm long. The femoral shaft is straight. The fourth trochanter is distinct, and a low rounded ridge. It is situated on the caudomedial margin of the shaft. The horizontal cross-section through the femoral shaft is elliptical. The circumlum is 58 cm under the fourth trochanter. The anterior and posterior surfaces of the proximal portion of the femur are flat. Distally, and the condyles are asymmetrical, the tibial condyle is much broader than fibular condyle.

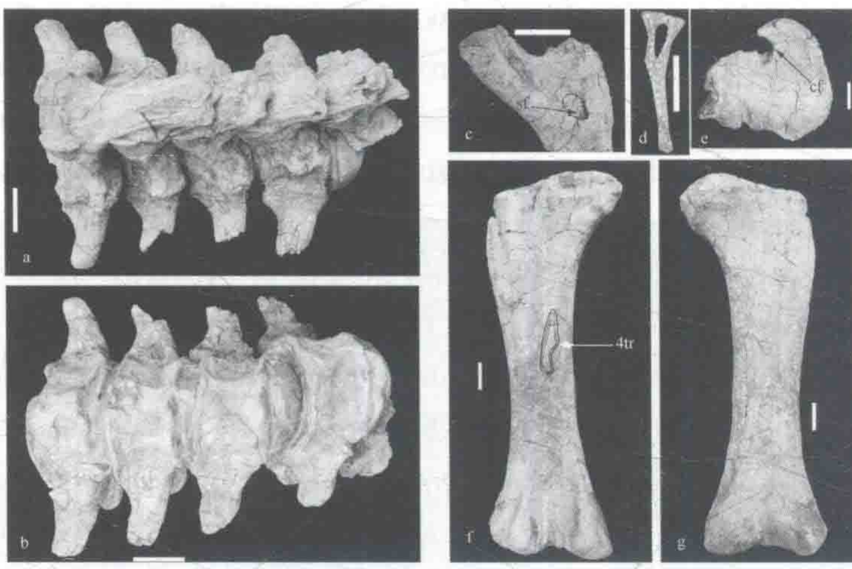


Fig. 3.9 Caudal vertebrae and femur of *Xianshanosaurus shijiagouensis*

Discussion: Two large sized sauropod dinosaurs *Huanghetitan ruyangensis* (Lü *et al.*, 2006, 2007) and *Ruyangosaurus giganteus* (Lü *et al.*, 2009a) from the Ruyang Basin were reported. *Xianshanosaurus* differs from them in both size and characters of the vertebrae. *Xianshanosaurus* is much smaller than them, especially than *Ruyangosaurus giganteus* (Lü *et al.*, 2009a). Although *Xianshanosaurus* shares one character with Titanosauridae, its other characters, such as ribs, femur and so on, are totally different from them. Thus, *Xianshanosaurus* can not be assigned to the Titanosauridae. The spatulate tooth crown, the asymmetrical femoral distal condyles and the chevron proximal facet in *Xianshanosaurus* also confirm that it belongs to Neosauropoda (Wilson and Sereno, 1998; Wilson, 2002).

3.4 *Yunmenglong ruyangensis* Lü et al., 2013

Long-necked dinosaurs in China are famously represented by *Mamenchisaurus hochuanensis*, and *Mamenchisaurus* was discovered later in Xinjiang with a 16 m long neck. All these long-necked dinosaurs are discovered from the Jurassic. Formerly discovered *Qiaowanlong kangxii* from Gansu and *Erketu ellisoni* from Mongolia are from the late Early

Cretaceous. *Yunmenglong ruyangensis*, together with *Qiaowanlong kangxii* and *Erketu ellisoni*, may compose a new Asian clade of the long-necked sauropod dinosaur taxa from the late Early Cretaceous. This clade is primitive than titanosauria but more derived than possibly derived *Euhelopus zdanskyi* in Shandong Province. *Euhelopus zdanskyi* may be more primitive than *Yunmenglong ruyangensis*.

Dinosauria

Yunmenglong Lü *et al.*, 2013

Yunmenglong ruyangensis Lü *et al.*, 2013

Diet: Herbivorous.

Type locality and horizon: Huamiaogou of the Liudian Town, Ruyang County; the Lower Cretaceous Haoling Formation.

Holotype: Seven naturally articulated anterior cervical vertebrae (2nd to 8th) and two isolated posterior cervical vertebrae, one dorsal vertebra, four anterior caudal vertebrae, and one complete right femur (field No. KLR-07-50). These bones originate from one quarry and there is no repeated element, which implies that they belong to a single individual. The specimens are housed in the Henan Geological Museum under registration number 41HIII-0006.

Diagnosis: A long-necked sauropod with the following combination of characters: a distinct pleurocoel and fossa under the base of the diapophysis is present on the axis; the axis of the centroparapophyseal lamina is parallel to the long axis of the centrum; the parapophysis is situated at the middle level of the axial centrum; extreme elongation of the cervical vertebrae; epipophyses of the postaxial cervical vertebrae much elongated and rod-like; two fossae present on the longitudinal depression of the lateral surfaces of the cervicals, the anterior one is shallow and the posterior one is deep and pierces the centrum; neural canal of the dorsal vertebra is triangular in posterior view and located within the large concavity formed by the centropostzygapophyseal laminae and the dorsal margin of the neural canal; distal end of the neural spine of the caudal vertebrae ball-shaped with coarse surfaces, but without postspinal fossa (Fig. 3.10～Fig. 3.12).

The right femur of *Yunmenglong ruyangensis* is 192 cm long, belonging to a giant sauropod dinosaur. It also indicates that there are diverse giant sauropod dinosaurs living in the Cretaceous in Henan Province.

Yunmenglong ruyangensis is the first long-necked sauropod dinosaur found in central China. Phylogenetic analysis (Fig.3.13) shows that *Yunmenglong ruyangensis* belongs to Somphospondyli of the Titanosauriformes. *Erken ellisoni, Qiaowanlong kangxii*, and *Yunmenglong ruyangensis* may form a unique Asian Cretaceous long-necked sauropod subgroup, with *Euhelopus* being a more basal clade of this group.

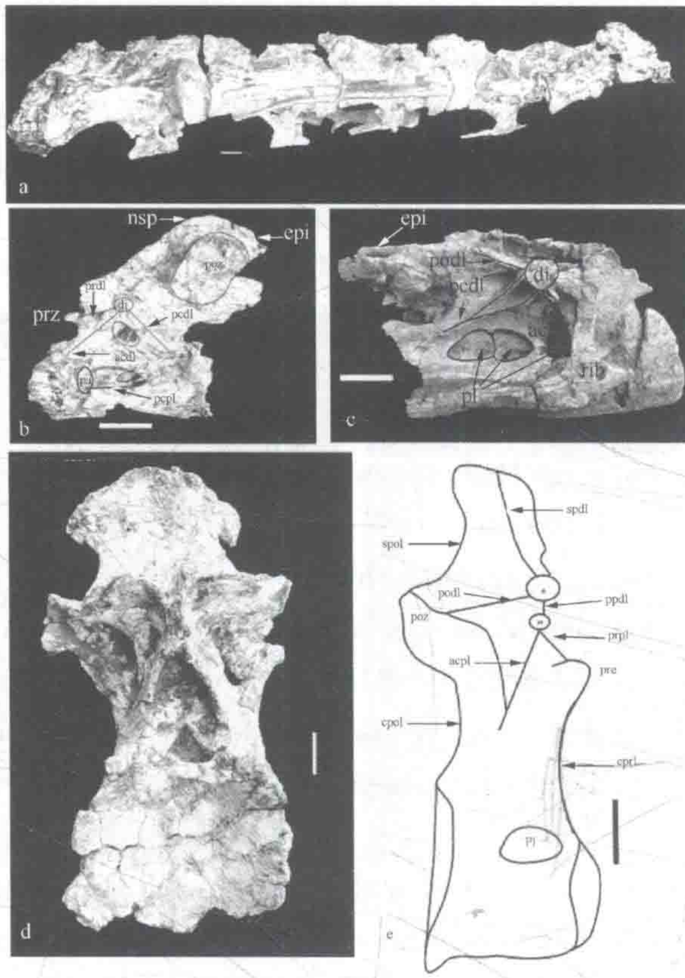


Fig. 3.10 *Yunmenglong ruyangensis*: (a) anterior cervical vertebrae, (b) left lateral view, (c) 5th cervical vertebra, (d) posterior dorsal vertebra, (e) lateral view of the reconstruction of posterior dorsal vertebra.

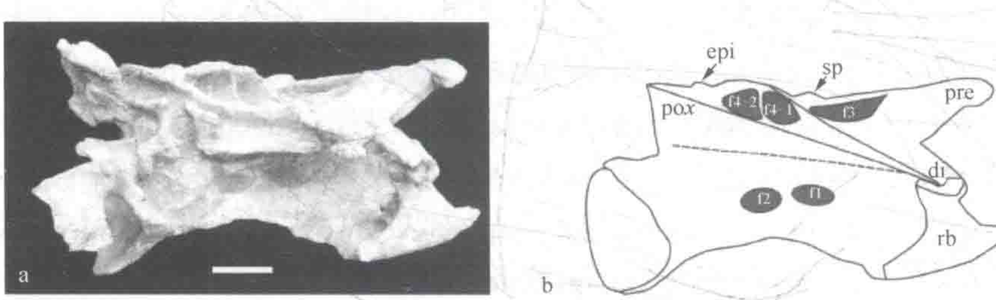


Fig. 3.11 6th cervical vertebra of *Yunmenglong ruyangensis*:

(a)photograph; (b) outline drawing

Somphospondyli is a clade that the interior of the centrum and arch of the vertebrae are composed by numerous spongy pleurocoels. Previous researches suggest that these pleurocoels are probably the main reason for the development of the long neck. Due to these spongy structures, the neck is 60% air. Moreover, the bone is as light as that of the aves, making it much easier to support the elongate neck. The muscle, tendon and ligament attached to the bone can also be optimized, letting the neck move more effectively.

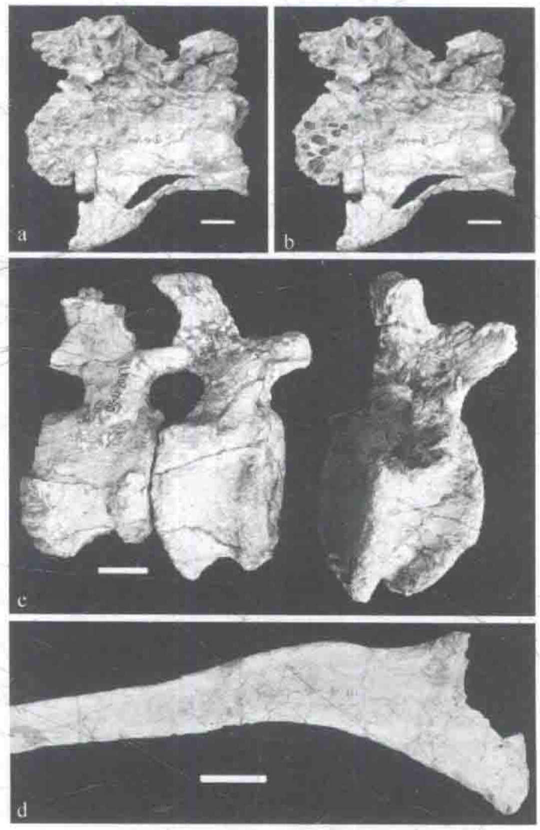


Fig. 3.12 *Yunmenglong ruyangensis*: (a) caudal vertebra in posterior ivew, (b)anterior view, (c) caudal vertebra in lateral view, (d) right rib

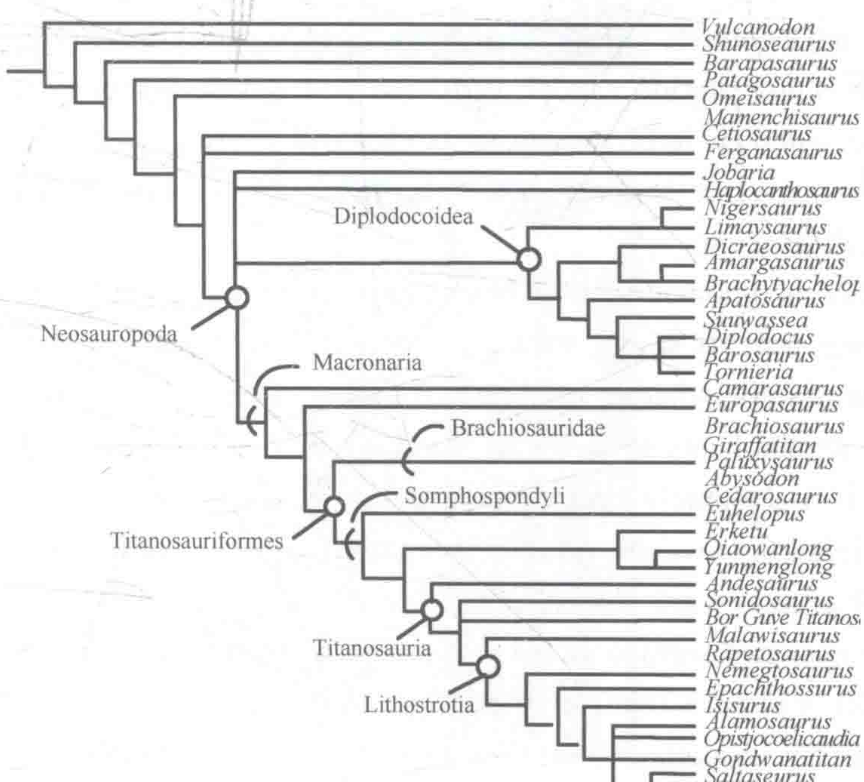


Fig. 3.13 Cladogram of phylogenetic analysis of *Yunmenglong ruyangensis*

3.5 *Zhongyuansaurus luoyangensis* Xu et al., 2007

Zhongyuansaurus luoyangensis was discovered in a slope outside Shaping Village, Liudian Town. Though the fossils were in disorder, the diagnostic characters were clear with the skeleton being relatively complete.

Ankylosaurs are quadrupedal and herbivorous. They are characterized by longitudinal ranged scutes on the dorsal and lateral sides of the body, small tiny teeth and unique skull structure. The bone laminae are various skeletal plates. Some ankylosaurs even developed tiny bone between bone laminae and ranged bone spines, like a protective, full-armored tank. Thus, ankylosaur is vividly named as "tankosaur". Ankylosaurs have been discovered in almosts all continents (Vickaryous et al., 2004).

Ornithischia

Ankyosauridae

Zhongyuansaurus Xu et al., 2007

Zhongyuansaurus luoyangensis Xu et al., 2007

Diet: Herbivorous.

Type locality and horizon: Shaping Village, Liudian Town, Ruyang County of Henan Province; Haoling Formation, Lower Cretaceous.

Holotype: Nearly complete skull and a partial mandible, three neural arches of dorsal vertebra, one nearly complete dorsal vertebra, two dorsal centra, seven mid-anterior caudal vertebrae, three mid-posterior caudal vertebrae and seven fused caudal vertebrae on posterior portion, complete left humerus, two ischia and a pubis, some scutes (with 8 types), dorsal ribs and some other broken bones. The specimen (41HIII-0002) is housed in the Henan Geological Museum.

Diagnosis: A gigantic nodosaurid ankylosaur is characterized by the following features: the skull is longer than its width, with the ratio of about 1.4; parietal portion is flat; in ventral view, the posterior margin of skull and the lateral margin of orbit underby portion are straight; premaxilla bears no teeth; the dentition on maxilla is straight; 18 teeth on the maxillae; there is a semicircle concavity on the posterior downward portion of occipital condyle; paroccipital process and squamosal are not fused; the widths of the distal end and proximal end of humerus are almost equal; the *M. latissimus dorsi* and *M. teres* major adhesion on the posterior surface of the proximal end of humerus is concavity rather than scabbed; the shaft of pubis is relatively straight, different from other nodosaurs.

Description: *Zhongyuansaurus luoyangensis* is based on the follwing features: maxillary shelf is limited to maxilla, the semicircle shaped occipital condyle bears an occipital neck; the deltopectoral crest is less half-length of the shaft of humerus; the length of skull is longer than its width, distal end of the caudal vertebra does not bear bony club; the sharp rostral end is characterized as the typical nodosaur character (Kilbourne et al., 2005). Compared with other nodosaurs with skulls is, the parietal portion of the skull of *Zhongyuansaurus luoyangensis* is flat, whilst it's strongly convex in *Pawpawsaurus* and *Silvisaurus*, and it's moderately convex in *Panoplosaurus* (Fig. 3.14). The pubic shaft is slightly curved without tapering to the distal end, similar to that in *Struthiosaurus languedocensis*, whilst it tappers in *Edmontonia rugosidens* and *Edmontonia longiceps*. The pubic shaft is relatively straight, differing from other nodosaurs with distinctively curved pubic shaft. Its structure is between ankylosaurs and some nodosaurs (Fig. 3.15). The restored *Zhongyuansaurus luoyangensis* is about 5 m long (Fig.3.16).

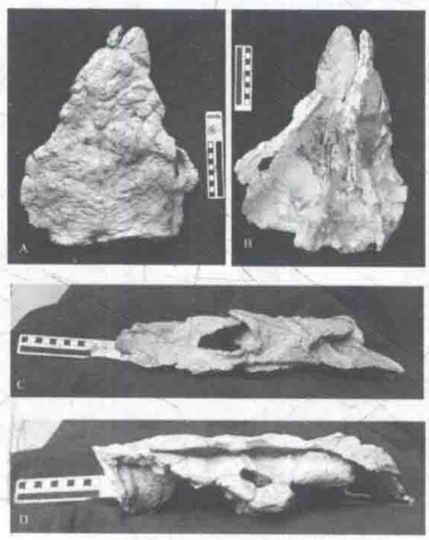


Fig. 3.14 The skull of *Zhongyuansaurus luoyangensis:* (A) in dorsal view; (B) in ventral view; (C) lateral view; (D) occipital view

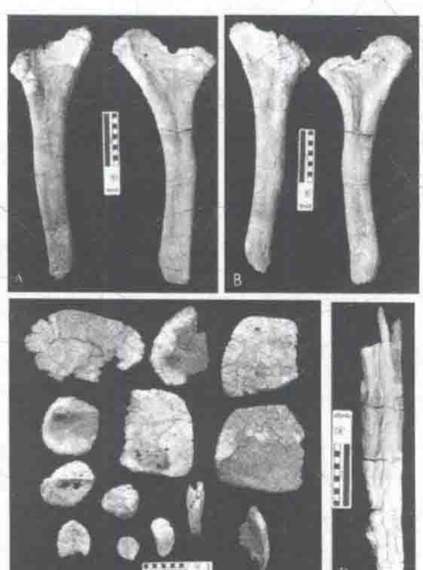


Fig. 3.15 The ischium of *Zhongyuansaurus luoyangensis:* (A) exterior view; (B) interior view; (C) dorsal view of various dermal plates of *Zhongyuansaurus luoyangensis*; (D) lateral view of caudal vertebra

Discussion: Ankylosauria is usually classified two groups. Ankylosaurid group is characterized with bigger skull by than its length, distal end of the caudal vertebra developed with tail club, the other nodosaurid group is characterized with skull length bigger than its width, distal caudal vertebrae fused and the distal end bearing no club (Coombs, 1978).

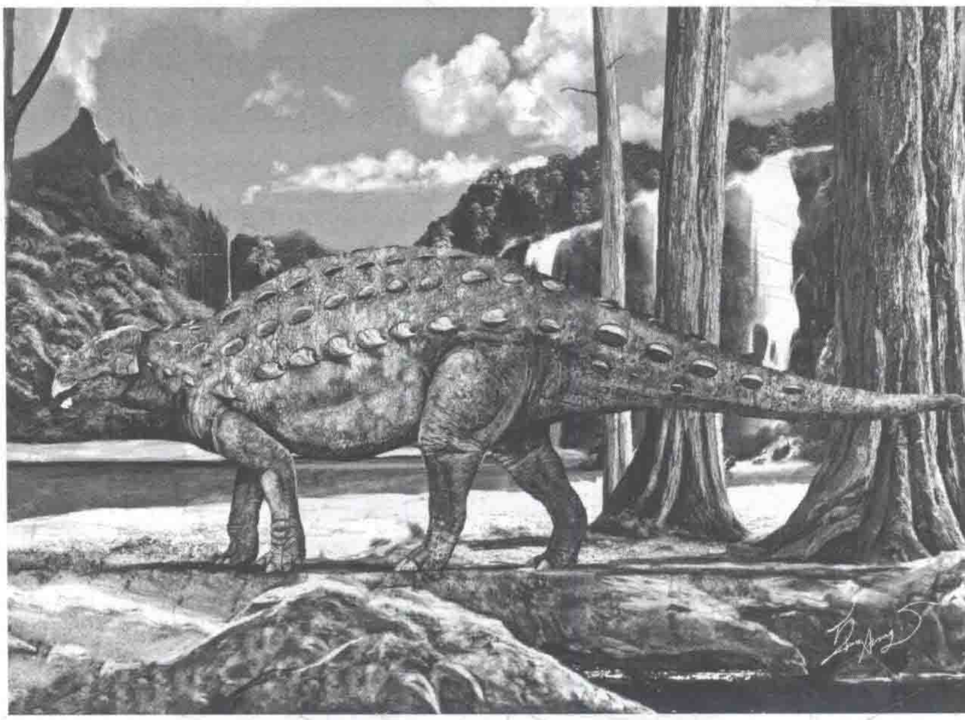


Fig. 3.16 Artist's impression of *Zhongyuansaurus luoyangensis.*
(Drawn by Zhao Chuang)

Compared with other dinosaurs, such as sauropodomorpha, hadrosauroids and small theropods, ankylosaurids are rarely found in China. At present, ankylosaurs mainly include: *Pinacosaurus ninghsiaensis* from Ningxia Hui Autonomous Region, *Tianchisaurus nedegoapeferima* from Xinjiang Uygur Autonomous Region (Dong, 1993), *Pinacosaurus* from Inner Mongolia Autonomous Region (Godefroit et al., 1999), *Tianzhenosaurus yangi* from Shanxi Province (Pang et al., 1998), *Crichtonsaurus bohlinigen*, Cri. benxiensis (Lü et al., 2009) and *Liaoningosaurus paradoxus* from Liaoning Province (Dong, 2002; Xu et al., 2001), and *zhejangosaurus* from Zhejiang Province (Lü et al., 2008). Amongst these ankylosaur fossils, *Liaoningosaurus paradoxus* from Liaoning Province and *zhejangosaurus* from Zhejiang Province are classified as nodosauridae, while others all belong to ankylosauridae or uncertain family taxa.

Zhongyuansaurus luoyangensis is the first nodosaurid discovered with complete skull and well-preserved distal end of caudal vertebrae so far in China. Its skull and caudal vertebrae are with typical nodosaurid characters, whilst its pelvic structure presents no typical nodosaurid characters.

Nodosaurs are mainly distributed in Europe, North America and Australia, and probably in South-America and Antarctica. They reached a high diversity and quantity in the Early Cretaceous and then declined. Only a few nodosaurs lived to the Late Creataceous period. Thus, the discovery of *Zhongyuansaurus luoyangensis* plays an important role in studying ankylosauria evolution, especially in nodosaurid origin, geographic distribution and evolution.

3.6 *Luoyanggia liudianensis* Lü et al., 2009b

The derived oviraptorid, *Luoyanggia liudianensis,* was found in the same locality as *Xianshanosaurus shijiagouensis* (Lü et al., 2009b).

Saurischia
  Theropoda
    Oviraptoridae
      Luoyanggia Lü et al., 2009
        Luoyanggia liudianensis Lü et al., 2009

Diet: Omnivorous.

Type locality and horizon: A quarry at Shijiagou Village, Liudian Town of Luoyang City, Henan Province, Haoling Formation of the Lower Cretaceous

Holotype: A partial mandible (41HIII-00010), a partial pelvic girdle (41HIII-00011 (Field No. KRL 07-62-44a)) and right ilium, ischium and nearly complete pubis (KLR07-62-49-1) and right metatarsals (KLR07-62-28a-16). Specimens are housed at the Henan Geological Museum, Zhengzhou, Henan Province.

Diagnosis: An oviraptorid differs from other oviraptorids in that the rostral part of the mandible is not downturned and the mandibular symphysis is V-shaped, and the shaft of the ischium is slightly concave caudally.

Description and discussion: The dentary bears two branches which extend postodorsally and postoventrally, forming the anterior margins of the large external mandibular fenestra. As in other derived oviraptorid dinosaurs, the dentary is toothless. In dorsal view, the mandibular symphysis is V-shaped, unlike in other oviraptorids, where the mandibular symphysis is U-shaped. Both rami of the mandible are bent postolaterally, differing from other oviraptorids, whose the rami are bent medially (Osmólska *et al.*, 2004). Two partial pelvic girdles are exposed their medial sides (KRL 07-62-44a, LR07-62-49-1). The anterior portion of the ilium is missing in KRL07-62-44a. But it is well preserved in

KRL07-62-49-1. The proximal end of the ilium is curved ventrally. The ventral end of the preacetabular process is nearly at the same level with the ventral margin of the pubic peduncle. The dorsal margin of the ilium is straight, similar to that of *Nomingia*, but differs from other oviraptorids such as *Chirostenotes*, *Heyuannia* and *Shixinggia* (Lü and Zhang, 2005). The width of the acetabulum is 2 cm. The pubic peduncle is much deeper than the ischial peduncle, similar to that of *Caudipteryx*, but different from other oviraptorosaurs, whose pubic peduncle is as deep as the ischial peduncle (Osmólska et al., 2004). The brevis fossa is short, weakly concave on the medial surface of the postacetabular process. The ischium is complete, and its length is 10 cm from the proximal end to the distal end. The shaft of the ischium is slightly curved caudally. As in other oviraptorids, the ischium has a medially positioned, triangular obturator process. The boundary between the anterior margin of the ischiac shaft and the anterodorsal margin of the obturator process is clear, but in other oviraptorids, it gradually becomes into the anterodorsal margin of the obturator process. The left pubis is complete. The length of the pubis is 16 cm, with a apron of 9 cm. The pubic boot is short (Fig.3.17).

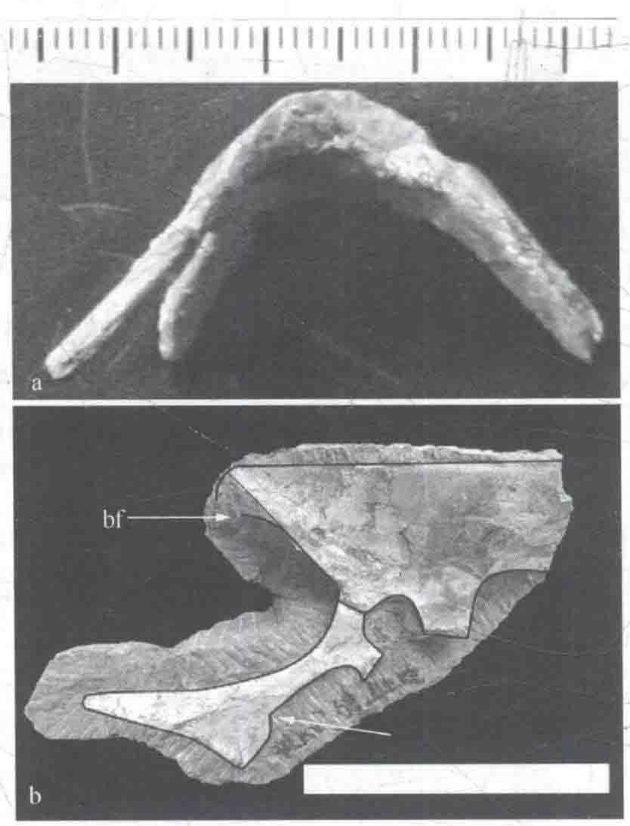


Fig. 3.17 The mandible (upper) and illium (lower) of *Luoyanggia liudianensis*

Luoyanggia liudianensis clearly differs from other oviraptorids in the shape of the rostral end of the lower jaw. The much deeper pubic peduncle than the ischial peduncle, which is similar to that of *Caudiptery*, indicates that *Luoyanggia* may have a certain relationship with *Caudiptery*. However, the detailed taxonomic position depends on the discovery of more specimens.

Luoyanggia liudianensis differs from other oviraptorids in that the rostral part of the mandible is not downturned, and the shaft of the ischium is slightly concave caudally, and the anterior margin of the ischiac shaft is sharply transferred to the anterodorsal margin of the obturator process. *Luoyanggia liudianensis* is the only oviraptor discovered in Ruyang area, following the oviraptorid first discovered in Luanchuan area.

3.7 *Iguanodon*

Iguanodons are mainly from the early Cretaceous. The discovery *Iguanodon* in Ruyang area indicates that the Ruyang Gigantic Dinosaurian Fauna may have been from the late Early Cretaceous. Only the caudal vertebrae are partly preserved, so we cannot verify which specific genus or species it belongs to. But it still can be postulated that not only the herbivorous giant sauropod dinosaurs, but also the large ornithopod dinosaurs and iguanodons lived together in the Ruyang Gigantic Dinosaurian Fauna. The structure and size of the persevered caudal vertebrae are extremely similar to that of *Iguanodon bernissartensis* from the Early Cretaceous found in Belgium. Thus, it can be estimated the nine natrally articulated caudal vertebrae are the seventh to fifteenth. Iguanodontid dinosaurs was prosperous from the early Early Cretaceous until its descendant Hadrosauridae appeared. Hadrosauridae replaced the Iguanodon gradually and became the most prosperous species, resulting in Iguanodon's extinction in the late Cretaceous. Thus, we inferred that the strata in Ruyang Basin, together with the gigantic sauropod dinosaur fauna, were formed in the late Early Cretaceous (Zhang et al., 2013).

Iguanodontidae

Iguanodon Mantell, 1825

Genus and Species.indet.

Diet: Herbivorous.

Type locality and horizon: Shaping Village, Liudian, Town Ruyang County; Haoling Formation of the Lower Cretaceous.

Holotype: Middle and anterior portion of nine sequential caudal vertebrae. The specimen (41HIII-0014) is housed in Henan Geological Museum.

Description: Nine caudal vertebrae are preserved (Table 3.1, Fig. 3.18) (Zhang et al., 2013), and they should be the middle and anterior caudal vertebrae judged from the size and morphology. The structures of these caudal vertebrae are extremely similar to those of the seventh to fifteenth caudal vertebrae in *Iguanodon bernissartensis* from the Early Cretaceous in Belgium and the sizes of the former are slightly bigger than that of the latter.

Table 3.1 Measurements of *Iguanodon* indet.

Moasurement	Length(mm)	Anterior articular surface		Posterior articular surface	
		Height(mm)	Width(mm)	Height(mm)	Width(mm)
caudal vertebra 1	108	185	165	180	210
caudal vertebra 2	107	194	161	205	173
caudal vertebra 3	120	198	131	195	140
caudal vertebra 4	130	156	114	120	165
caudal vertebra 5	142	174	118	137	180
caudal vertebra 6	127	183	126	136	187
caudal vertebra 7	132	164	123	121	170
caudal vertebra 8	133	143	132	130	153
caudal vertebra 9	115	137	125	134	145
chevron 1	517	—	—	—	—
chevron 2	504	—	—	—	—
chevron 3	504	—	—	—	—
chevron 4	435	—	—	—	—
chevron 5	390	—	—	—	—
chevron 6	338	—	—	—	—

From the well-preserved caudal vertebrae series in *Iguanodon bernissartensis*, it can be estimated that the nine caudal vertebrae probably be the seventh to fifteenth caudal vertebrae. The caudal vertebrae are almost well-preserved except for the neural arches. The neural arch of the tenth caudal vertebra is well-preserved. The seventh, eighth and ninth caudal vertebrae are relatively shorter, and the anterior and posterior articular surfaces are concave with the posterior articular surfaces much strongly. From the tenth caudal vertebra, the anterior articular surfaces are slightly concave and the left latter's become almost flat, whilst all the posterior articular surfaces are still concave. The ventral surface of the caudal vertebrae bears a shallow ventral groove. The lateral surface of the anterior vertebrae is adducted and flat. The lateral surfaces of the fourteenth and fifteenth caudal vertebrae bear weak longitudinal ridge. The height of all the vertebrae is larger than their width. The lateral surface of the fourteenth caudal vertebra in *Iguanodon bernissartensis* develops longitudinal ridge (also called horizontal ridge). Thus, it indicates that the lateral surface develops longitudinal ridge from the fourteenth caudal vertebra in *Iguanodon* discovered in Ruyang area.

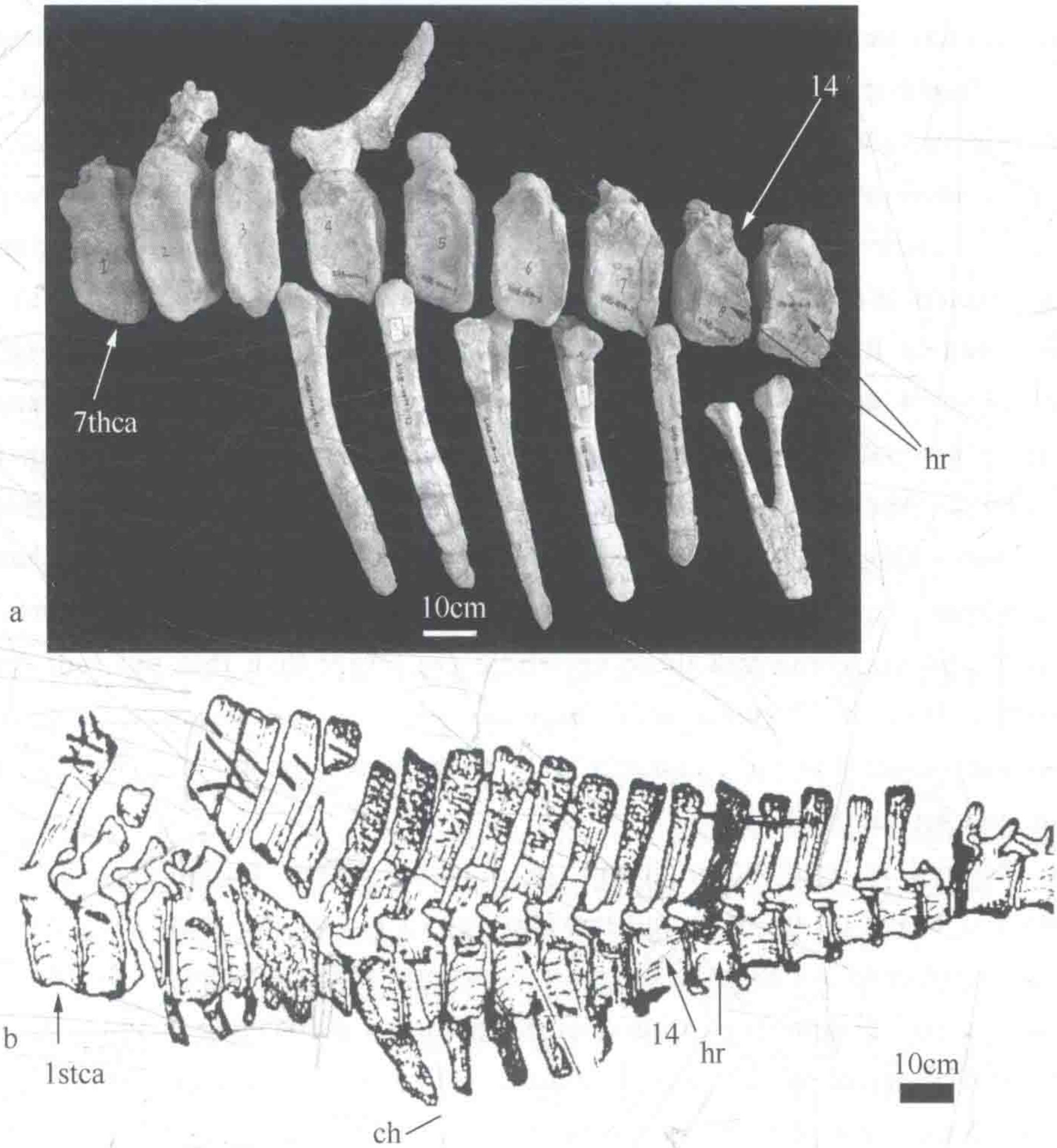


Fig. 3.18 Comparison of caudal vertebrae of (a) *Iguanodon indet.* and (b) *Iguanodon bernissartensis*

Compared with the vertebra centrum, the chevron is much longer. The proximal end of the chevron has no bridge. The anterior shaft of the chevron is curved backward, whilst the posterior shaft is almost straight and the distal end tapers clearly. One chevron shows pathology that it is strongly flat ernd platelike at both the anterior and the posterior parts It may be caused by some unknown disease.

Comparison and Discussion: The anterior and posterior articular surfaces of the nine preserved caudal vertebrae are characterized by higher than wideh. Chevrons are elongated, slightly curved and laterally flat, similar to that in Iguanodon and Hadrosaur. However, in hadrosaurs, the dorsal margin and ventral margin of the anterior and posterior articular surfaces of the anterior caudal vertebrae are straight with a developed ventral ridge, forming a hexagon in cross-section. The specimen found in Ruyang has no longitudinal ridge in lateral surface, and it bears weak longitudinal ridge from the fourteenth caudal vertebra. Thus, it belongs to Iguanodon rather than Hadrosauridae. Iguanodons found from the Lower Cretaceous in China include: *Probactrosaurus mazongshanensis*, *Nanyangosaurus zhugeii*, *Shuangmiaosaurus* and *Jizhousaurus*. *Shuangmiaosaurus* was firstly classified into Hadrosauridae, but later study proves it belonging to stem Iguanodontia. Both *Shuangmiaosaurus* and *Jizhousaurus* are established based the skull characters. Thus, they have no comparison with the new specimen found in Ruyang area. *Nanyangosaurus zhugeii* is a middle-sized iguanodon, with body about 4 m long. The articular surfaces of the vertebrae of *Nanyangosaurus zhugeii* are platycoelous, while they are amphicoelous in the new specimen found in Ruyang. Thus, the new iguanodon specimen found in Ruyang differs from *Nanyangosaurus zhugeii*. It is also different from *Probactrosaurus mazongshanensis* in caudal vertebrae structures. *Probactrosaurus mazongshanensis* has only three to five hexagonal caudal vertebrae and these vertebrae are larger than that those of *Iguanodon bernissartensis* from the Cretaceous in Belgium. *Iguanodon bernissartensis* is about 10 m long, which indicates that the estimated body of the new iguanodon in Ruyang is longer than 10 m, and probably 11 m.

The incomplete iguanodon found in Ruyang Basin is similar to *Iguanodon bernissartensis* based on the size and morphology of the caudal vertebrae. Its discovery adds a new member to the Ruyang Gigantic Sauropod Dinosaur Fauna. Besides the giant herbivorous sauropod dinosaurs, mid-sized herbivorous dinosaur iguanodon also existed in the same ecological niche, which indicates that their food maybe different. The discovery of Iguanodon plays an important role in the geological distribution, evolution, and paleoenviroment of iguanodontia. Moreover, it also demonstrates that the strata in Ruyang Basin in which the Ruyang Gigantic Sauropod Dinosaur Fauna is hosted should be dated to late Early Cretaceous, consistent with conclusions drawn by studying other animals.

Science links

1. How to name a newly found dinosaur?

Like modern creatures, prehistoric creatures are generally named using Latin or Latinized spelling according to international naming rules of animals and plants. Main reference books include *International Code of Zoological Nomenclature (the 4th edition)*, *Latin of Paleontology Nomenclature* and so on. Above the genus level, single name is used; for species, a binominal nomenclature is used, while subspecies use three-part taxonomic designation. Each nomenclature should be in accord with the

Law of Priority. In addition, the spelling of genus and species must use italicized letter. The first letter of genus should use capital form while the first letter of species should use lower case. To avoid duplications, one must log in the official website of International Commission on Zoological Nomenclature (http://uio.mbl.edu/NomenclatorZoologicus/) and check for duplicates. The name can be officially published only after it is verified that there's no duplicate.

Names of genus and species can use words that provide detailed characteristics of dinosaurs, such as *Ruyangosaurus giganteus*, where giganteus is exactly derived from the gigantic body type of these dinosaurs. And also, we can name them by the geographic name where they were found, for example *Huanghetitan ruyangensis* is named after Ruyang where this kind of dinosaurs was found. We can even denominate them using the names of people who have made outstanding contributions to paleontology, like *Caudipteryx dongi* is named after Professor Dong Zhiming, a famous dinosaur expert.

2. How come sauropod dinosaurs grew so huge? Dinosaurs that were never too old to grow.

Why could sauropod dinosaurs grow so huge? Such as the newly found gigantic *Ruyangosaurus giganteus*, whose length is over 30 meters. We are just like small ants if we human beings stand in front of it. Studies showed that sauropod dinosaurs kept growing throughout their life. When they were young, they possessed the fastest growth rate among all types of dinosaurs. When they entered adulthood they slowed down somewhat, but they would not stop growing until late in life. Therefore, the fast growth rate and long growth time enabled sauropod dinosaurs to take the position of the No.1 giant among dinosaur families and no predator can threaten the safety of adult sauropod dinosaurs.

Generally speaking, sauropod dinosaurs could live for 40 to 60 years, maybe longer. Large theropod dinosaurs, like the famous *Tyrannosaurus*, could live for about 25 years, while small theropod dinosaurs, like *Microraptor*, could only live for 3 to 4 years. However, *Psittacosaurs*, belonging to *Ceratopsia*, were also small-sized and could live longer than 10 years.

3. Armored tanks of dinosaurs – *Ankylosaurus*

After *Stegosaurs* became extinct from the ecosystem, *Ankylosaurus*, armed to the teeth, debuted on the stage of terrestrial life. *Ankylosaurus*, which means stiff lizard, is a species of herbivorous medium-sized dinosaurs lived in the Late Cretaceous. The most distinctive feature of *Ankylosaurus* is its armor. The armor includes solid knobs and plates embedded in the skin. We can find similar scutes on crocodiles, armadillos and some types of lizards. Hardened keratin covered the armor. These osteoderms are arranged according to their size, from wide and flat plates to small and round knobs. Plates are lined up in rows on *Ankylosaurus*' neck, back and behind. Small knobs fill in the gaps between big plates while smaller plates spread over arms, legs and tails.

The famous tail club of *Ankylosaurus* is formed by several pieces of big osteoderms, and they fuse with the bottom section of caudal vertebra. The tail club is an active protective weapon which could give the attackers a heavy blow. In addition, the tail club can be whipped structurally and big tail club can cause serious damage to body. However, it still cannot explain whether it was used for fighting between the same species or for resisting the predators, or both. Besides, *Zhongyuansaurus luoyangensis* is the only ankylosaurid without tail club.

4. The never-ending bad rap of Oviraptorosaurs

Oviraptorosaurs mainly lived in the Late Cretaceous. It's about two meters long and approximately the same size as the ostrich. Its sharp claws and long tail suggest their strong athletic ability and swift movement. And its sturdy tail, which looks like the tail of kangaroo, can keep the balance of its body and make it run fast.

Oviraptorosaurs lived together in groups. Adult oviraptorosaurs laid their eggs in conical nests built with mud. Center of the nest has a depth of 1 meter and the diameter of the nest is 2 meters. Nests separated with each other at a distance of 7 to 9 meters. The size of oviraptorosaurs is small, so they sometimes covered the nest with plant leaves and used the heat in the decaying process of plants to incubate eggs naturally.

"*More than 80 million years ago, a terrible disaster was about to strike, just as a 2 meter long dinosaur was closing in on a dinosaur egg in stealth...*" This was the scene discovered by American paleontologist Roy Chapman Andrews in Mongolian Gobi desert, in 1923. When it was discovered, the dinosaur skeletons were on the top of a batch of Protoceratops' eggs, so scientists speculated that it was stealing the eggs of other dinosaurs. As a result, scientists gave it a bad name, *Oviraptorosaur*. Actually, *Oviraptorosaur* was not stealing eggs, but bravely protecting its own eggs and died.

Later people speculated how *Oviraptorosaur* stole dinosaur eggs, according to its body features, such as beaks looking like birds and bearing no tooth. They thought *Oviraptorosaur* kept the egg in its mouth first and then broke it using external force. Hence, *Oviraptorosaur* has been unjustly blamed all along.

In 1990, during a joint expedition to Inner Mongolia by Chinese and foreign scientists, they found a complete oviraptorosaur skeleton that was lying over a batch of eggs and it seemed that it was hatching. It looked like that it was buried by a precipitous sand storm during the incubation. What's more, scientists speculated that they were possibly omnivorous based on the hard keratin shell of its beaks and the hard beaks could easily open the shells of molluscs. As a result, most scientists consider oviraptorosaurs were not egg poachers. On the contrary, they could incubate. As a result, many new reconstructed pictures of oviraptorosaurs show feathers on them, which strongly reflect the view that oviraptorosaurs could incubate. However, under the rules of *Law of Priority* in *International Code of Zoological Nomenclature,* we cannot change its name.

5. Dinosaurs, the Lords of the Mesozoic land, how to classify them and how many species did they have?

Up to 2010, the named species of dinosaurs had reached over 1000.

Dinosaurs lived between 235 million years to 66 million years ago. They were reptiles that could walk uptight on hind legs and dominated the global ecosystem for over 160 million years. Most dinosaurs had become extinct, but their descendants, birds, survive and thrive to this day.

The most distinctive difference between dinosaurs and other reptiles is their standing posture and locomotion. Dinosaurs could keep a totally upright stance and their four limbs are straight down the body. This structure is more advantageous for walking or running than other reptiles (such as crocodiles, whose limbs are stretching outwards). According to their pelvic structures, dinosaurs are divided into two clades: Saurischia and Ornithischia.

The main differences between them are the pelvic girdle structures:

Saurischia has a three-pronged pelvis from the side view. Its pubis is under the ilium and extends forward while the ischium extends backward which is similar to lizards.

Ornithischia's ilium is extend foreward and backward. In the front part of pubis, there's a big apophysis and it extends downward the ilium while the back pubis is parallel to ischium, largely extending to the under and anterior part of the ilium. Therefore, Ornithischian pelvis is four-pronged from the side view.

Saurischia includes Sauropoda and Theropoda.

Sauropoda still can be divided into Prosauropoda and Sauropodomorpha.

Prosauropoda mainly lived between the late Triassic to the early Jurassic. It was an omnivorous or herbivorous dinosaur with medium-sized body, such as the first large-sized dinosaur *Plateosaurus* and *Anchisaurus,* which lived in the early Jurassic.

Sauropodomorpha mainly lived in the Jurassic and the Cretaceous. They were mostly herbivorous and had small head, long neck, long tail and spoon-like teeth. The most famous representatives of Sauropodomorpha are *Mamenchisaurus*, *Seismosaurus* and *Amphicoelias fragillimus*. *Mamenchisaurus*, which lived in the Late Jurassic, were found in Sichuan and Gansu Province. Its neck is consisted of 19 cervical vertebrae and is as half long as its body. In addition, *Seismosaurus* and *Amphicoelias* were the largest animals known in that period.

Theropoda lived between the late Triassic to the Cretaceous. They were carnivorous and walking by two feet with sharp digits. They had huge heads and large brains and were the most intelligent of all dinosaurs. Their sharp teeth were like daggers or knives. *Tyrannosaurus* is the most famous, while others like *Allosaurus* and *Giganotosaurus* are also well known.

Ornithischia are divided into five genera: Ornithopoda, Stegosauria, Ankylosauria, Ceratopsia, and Pachycephalosauria.

Ornithopoda have the most fossils discovered in the Ornithischia and even in Dinosauria. They walked on two feet or four limbs. They have individual predentary bone on the mandible. Their teeth only grew in the cheek. The teeth crown in upper jaw turn inward while the teeth crown in lower jaw turn outward. They lived from the Late Triassic to the Cretaceous and were all herbivorous. This genus of dinosaurs includes *Hadrosaurus*, *Iguanodon* and so on.

Stegosauria is quadrupedal with straight bone lamella in the back and two or more pairs of sclerotin goads in the tail. They mainly lived from the Jurassic to the Early Cretaceous and were the first genus of dinosaurs to go extinct. The representative species was *Stegosaurus* that lived on plains, and *Kentrosaurus* found in Tanzania.

Herbivorous Ankylosauria, with short and sturdy body covered with boney plates, primarily lived in the Early Cretaceous, including *Hylaeosaurus* lived in Europe continent, *Polacanthus* lived in England, *Euoplocephalus* lived in America, and *Edmontosaurus* lived in Mongolia.

Ceratopsian is also quadruped and herbivorous. The back of the skull was enlarged into scute over the neck. They mostly lived in the Late Cretaceous. *Psittacosaurus* found in North China was the ancestral to Ceratopsians, which include *Triceratops* that are as popular as *Tyrannosaurs*. The gentle and herbivorous *Protoceratops* are also well known.

Pachycephalosauria has thick and swollen skull and its temporal holes is closed. Its pubis in pelvis are crowded out by ischium and do not constitute the pelvic girdle. They mainly lived in Cretaceous.

All dinosaurs of both Saurischia and Ornithischia, have in their pelvic girdle a hole among ilium, ischium and pubis, which other reptiles do not have. This very hole illustrates that the two orders of dinosaurs have the closest genetic connection when compared with other orders of reptiles.

6. Are dinosaurs extinct?

Not all dinosaurs died out. They still live around us and some even appear regularly on our dinner tables.

Most dinosaurs became extinct in the world. Some small theropods evolved into birds and are still thriving now. Aves, which include chickens, ducks, geese and eggs we eat daily, all descend from the dinosaurs.

Around 240 million years ago, dinosaurs first emerged in the Triassic. About 66 million ago, in the Cretaceous of the Late Mesozoic, most of them died out in the Cretaceous-Paleogene Mass Extinction Event. The last one perished 63 million years ago in the Paleocene (Tertiary) of

Cenozoic. The Cretaceous-Tertiary Extinction Event was a large-scale extinction in earth's history. It happened at approximately 65.5 million years ago, around the boundary between the Cretaceous of Mesozoic and the Tertiary of Cenozoic. It destroyed most reptiles and plants, including dinosaurs. The Cretaceous-Tertiary Extinction Event is well-known as it caused the extinction of dinosaurs and ushered in the emergence of mammals. However, the Permian-Tertiary Mass Extinction Event was the largest mass extinction event in earth's history, because nearly 90% of organisms perished at that time.

4 Living in Harmony: Dinosaur's Little Friends

Around 100 million years ago, when gigantic dinosaurs were idly roaming the vast land of Ruyang, other creatures that formed the fauna and flora of Ruyang were also thriving in the rivers and ponds, having a good time in their own niches. They included gastropods, bivalves, ostracods, charophytes, all of them were enjoying nature's generous nurture.

4.1 Invertebrate Fossils

4.1.1 Gastropoda

When Xu Li, Pan Zecheng and Jia Songhai from Henan Geological Museum were investigating the geology and collecting fossils in Ruyang area in 2012, they found early Cretaceous non-marine gastropod fossils in Shangdonggou Formation of Ruyang Basin, which were the first of its kind in Henan Province. These gastropod fossils were mainly collected from dark-gray sandy mudstone (H-1245) of the middle part of the Haoling Formation in Shijiagou of Hongling Village and the light-gray sandy mudstone (H-1024, H-2010, H-2-24, H-1272) of the lower part of Shangdonggou Formation in Chang Village, Liudian Town, Ruyang County. Gastropod fossils from the Chang Village, in particular, are extremely significant and abundant (Fig. 4.1, Fig. 4.2) . Examination by Pan Huazhang from the NIGPCAS (Nanjing Institute of Geology and Paleontology, Chinese Academy of Sciences) shows that there are in total eleven species and seven species indet. belonging to ten genera (Tab. 4.1). Fossils of ostracods, bivalves, plants and charophytes were also found in the same formation, which proved to be very significant in stratigraphic delineation.

Based on comparison of the distribution of these gastropods found in the Shangdonggou Formation and Haoling Formation of Ruyang Basin, they are similar to that in the Xiazhuang Formation of Western Hill of Beijing, in the Fuxin Formation of Fuxin of Liaoning Province and in the Miaogou Gastropoda Fauna of Chaoshui Basin of Inner Mongolia. Gastropods from

Ruyang Basin should be included in the family of *Mesocoshliopa cretacea* — *Zaptychius costatus* — *Reesidella multilaminate xiazhuangensis* Pan et Zhu (Pan and Zhu, 2012; Pan, 2012), and dated to the Aptian to Albian of the Early Cretaceous.

Table 4.1 List of Gastropoda Fossils in Ruyang Basin

Location	No.	Name	Quantity
Changcun Cross Section, Shangdonggou Formation	H-2010	*Zaptychius* ? sp.	1
		Pseudarinia wangyimgensis Zhu (Fig. 4.3)	1
		Gyraulus sp.	1
		Gyraulus dongcunensis Yu. (Fig. 4.5)	1
		Lioplacodes sp.	1
	H-2024	*Zaptychius* cf. *costata* Pan et zhu	3
		Gyraulus dongcunensis Yu.	5
		Gyraulus sp.	3
		Mesocochliopa ? sp.	2
		Reesidella multilaminate (Fig. 4.4) *xiazhuangensis* Pan et Zhu (Fig. 4.2)	5
		Pseudarinia sp.	1
		Lioplacodes sp.	2
		Pseudarinia wangyimgensis Zhu	1
		Zaptychius sp.	1
		Physa sp.	1
	H-1272	*Gyraulus dongcunensis* Yu.	3
		Lioplacodes sp.	1
		Zaptychius cf. *costata* Pan et zhu	2
		Gyraulus sp.	2
		Mesocochliopa ? sp.	3
Haoling Formation, Shijiagou, Honglingcun, Liudian Town	H-1245	*Bithynia* sp.	1
		Bithynia sp.	1
		Zaptychius sp.	1
		Zaptychius sp.	1
		Reesidella multilaminate xiazhuangensis Pan et Zhu	1

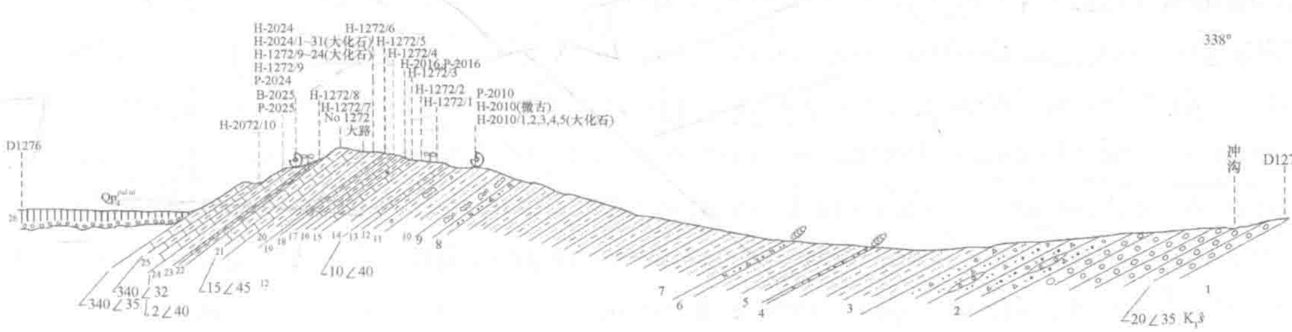


Fig. 4.1 The measured section of Shangdonggou Formation of Lower Cretaceous in Changcun, Liudian Town, Ruyang Country

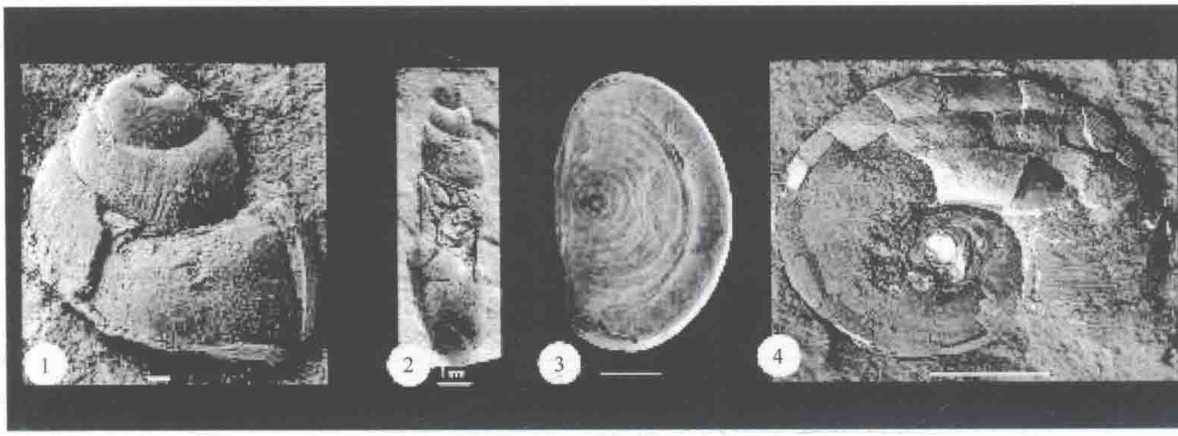


Fig. 4.2 Major assemblage of Gastropods

1—*Scaevicochlea xiazhuangensis* Pan et Zhu; 2—*Pseudarinia wangyimgensis* Zhu; 3—*Reesidella multilaminate xiazhuangensis* Pan et Zhu; 4—*Gyraulus dongcunensis* Yu

4.1.2 Ostracoda

During the survey of geological cross sections in Ruyang Basin, large quantities of ostracods were discovered in the Haoling Formation, the grayish green silt mudstone and the Shangdonggou Formation, the gray calcareous mudstone. It undounbtedly helped to determine the stratigraphy of fossiliferous strata of dinosaurs.

Ostracods were discovered from the multiple geological cross sections of the Haoling Formation, and as many as 14 species were found from one cross section (Table 4.2).

Ziziphocypris is extensively found from the Cretaceous in China. There are no reports of *Ziziphocypris* from the Cenozoic strata so far. *Ziziphocypris costata* is mainly discovered from the lower and upper Cretaceous in both north and south China, such as the upper Cretaceous of the Jiufotang Formation in Yixian and Fuxin Formation in Fuxin of Liaoning Province, Hekou Formation in Lanzhou of Gansu Province, Fengtai Formation in Beijing, Zuoyun Formation in Shanxi Province and Xiguayuan Formation in Hebei Province, etc.; the lower Cretaceous of the Nenjiang Formation in Baicheng of Jilin Province, Sifangtai-Mingshui Formation in Shuangliao of Jilin Province and Paomagang Formation in Hubei Province, etc. *Cypridea unicostata* is mainly exposed in the lower Cretaceous, such as the Tugulu Group of Junggar Basin in Xinjiang, Fengtai Formation in Beijing, Jiufotang Formation and Qiucheng Formation in Hebei, Shahai Formation in Liaoning, Guyang Formation and Bayan Formation in Inner Mongolia, Shangshui Formation and West Tanlou Formation in Henan etc. Also, there are certain quantity of *Cypridea unicostata* specimens from the upper Cretaceous Qingshankou Formation and Nenjiang Formation in Songliao Basin. *C. concina* is widely found from the early Cretaceous strata, such as the Chijinbao Formation in Yumen, Gansu, Fengtai Formation in Beijing, Guyang Formation in Inner Mongolia and Tugulu Group in Xinjiang etc. *Candona shangshuiensis* and *C. aurita* can be seen in the lower Cretaceous Shangshui Formation in Zhoukou, Henan, and the latter also can be seen from the Paomagang Formation in Hubei. *Darwinula leguminella* is commonly exposed from the upper Jurassic to lower Cretaceous in Western Europe, while in China it is exposed from the lower Cretaceous Puchanghe Formation in Yunnan, Dabeigou Formation in Hebei, Shouchang Formation and Guantou Formation in Zhejiang, Xiwa Formation in Mengyin of Shandong and the Upper Jurassic in Jiashan, Anhui. *D. contracta* is extensively developed in the Cretaceous strata of China, such as Puchanghe Formation in Yunnan; the lower Cretaceous Heishidu Formation in Anhui, Fuxin Formation in Liaoning, Lincheng Formation in Hebei, Shangshui Formation in Henan, Penglaizhen Formation and Tianmashan Formation in Sichuan; the upper Ctetaceous Nanxiong Formation in Guangdong, Jiadian Formation in Hubei and Daijiaping Formation in Hunan etc. *Eucypris infantilis* is a genus distributed all over the world, from the late Jurassic to present. *Cypridea* is mainly from the Jurassic to the early Paleogene in Asia, Europe and America, and especially abundant in the Cretaceous. *Cypridea* is also very common in the lower Cretaceous in China, such as Chaganlimennuoer Formation, Guyang Formation and Lisangou Formation in Inner Mongolia, Dabeigou Formation in Hebei, Hekou Formation and Xinminbao Group in Gansu, Zuoyun Formation in Shanxi, Yixian Formation, Jiufotang Formation and Shahai Formation in Liaoning, Fengtai Formation in Beijing and Qiucheng Formation etc. *E. debilis* can be seen from the lower Cretaceous Chaganlimennuoer Formation and Guyang Formation in Inner Mongolia, Xinminbao Group in Gansu, Jiufotang Formation in Liaoning etc. *E. sinuolata* is also discovered in the Jiufotang Formation. *Eucypris* is a genus extensively distributed around the world from the late Jurassic to present. *Cypridea vitimensis* is found from the early Cretaceous strata, such as middle portion of the Hekou Formation in Qinghai, Jiufotang Formation in Liaoning, Zhidan Group in Inner Mongolia, Xiwa Formation in Shandong, Dabeigou Formation in Hebei and Tugulu Group in Xinjiang, etc. The morphology and size of the *Cypridea veridical* is similar to that of the Jiufotang Formation in Yixian, Liaoning. The shellcrust surface of the latter is developed with reticulate pattern, while the former is smooth (Fig. 4.3).

Table 4.2 Ostrocoda distribution in Ruyang Basin

Location	Fossil No.	Name	Quantity (individual)
Cross Section of the Caojia Village	102-H-7	*Ziziphocypris costata* Galeeva, 1956	7
		Ziziphocypris sp.	2
		Cypridea unicostata Galeeva	9
		Cypridea concina Hou	2
		Cypridea sp.	2
		Candona shangshuiensis S. Zhang	1

Continued

Location	Fossil No.	Name	Quantity (individual)
Cross Section of the Caojia Village	102-H-7	*Candona aurita* Hou	1
		Candona sp.	1
		Candoniella sp.	1
	102-H-7	*Darwinula leguminella* Forbes, 1855	1
		Darwinula contracta Mandelstam	1
		Eucypris infantilis Lübimova, 1956	1
		Eucypris debilis Lübimova, 1956	8
		Eucypris sp.	2
	103-H-14	*Ziziphocypris costata* Galeeva, 1956	7
		Cypridea sp.	2
	103-H-16	*Eucypris infantilis* Lübimova, 1956	1
		Eucypris sinuolata Zhang, 1985	38
		Eucypris sp.	2
		Darwinula sp.	5
Cross Ssection of Huamiaogou	105-H-1	*Cypridea vitimensis* Mandelstam, 1963	1
		Cypridea sp.	1
		Eucypris sp.	6
Cross Section of Langdonggou	113-H-2	*Cypridea veridica* Zhang, 1985	27
		Cyclocypris minuta Yang, 1982	41
		Candona deflecta Jiang et Guan, 1978	2
		Candona sp.	5
		Candoniella candida Hao, 1974	19
		Eucypris infantilis Lübimova, 1956	11
		Eucypris sp.	2
Cross Section of West Tuqiaogou	115-H-1	*Cypridea* sp.	1
		Eucypris sp.	1
Cross Section of South Caojiagou	9100-孢-1, 9100-孢-2, 9100-孢-3	*Cypridea subquadrata* Gao er Yang, 1977	1
		Clinocypris sp.	1
Cross Section of the lower south Liufugou	9203-H-1	*Cypridea unicostata* Galeeva	2
Cross Section of north Yujiagou, Caojia Village	131-H- 3	*Ziziphocypris costata* Galeeva, 1955	1
		Ziziphocypris sp.	1
		Eucypris infantilis Lübimova, 1956	1
		Ostrocodes fragments	5
Cross Section of Erlang Village, Liudian County	150-H-1	*Candona* sp.	36
		Eucypris sp.	1

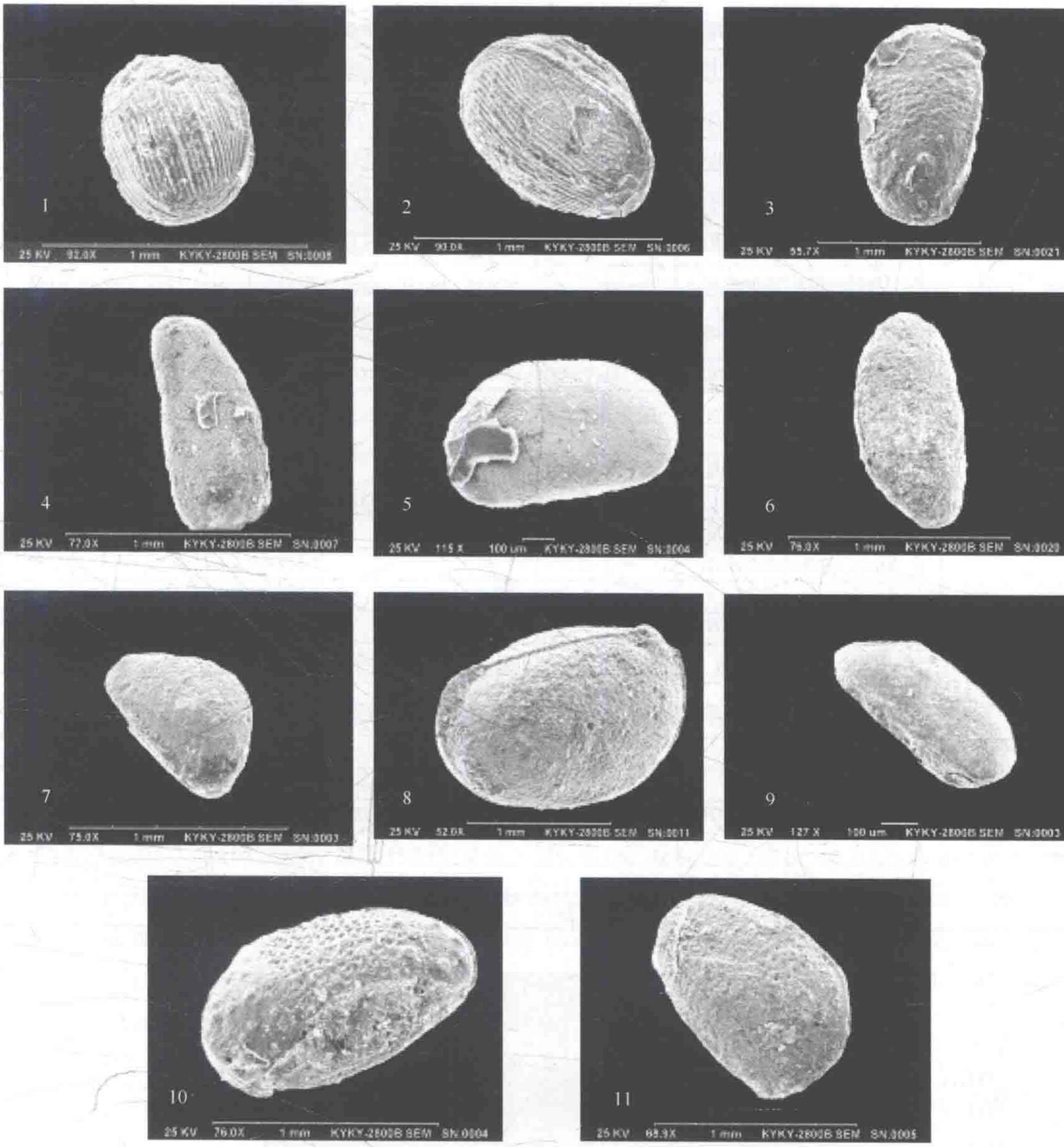


Fig. 4.3 Electro-microscopic scans of major ostracods in Haoling Formation.

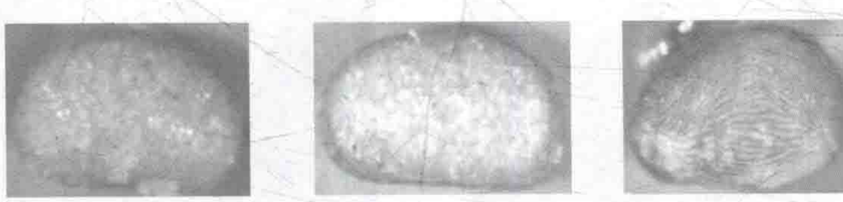
1—*Ziziphocypris costata*; 2—*Ziziphocypris* sp.; 3—*Cypridea* sp.; 4—*Darwinula leguminella*; 5—*Eucypris infantilis*; 6—*Eucypris debilis*; 7—*Candona aurita*; 8—*Cypridea veridica*; 9—*Candona deflecta*; 10—*Cypridea unicostata*; 11—*Cypridea subquadrata*

During the survey of the cross section in Chang Village, Liudian in 2011, a fossil bed was found and collected fossils were examined by the NIGPCAS and the Research Institute of Petrolum Exploration and Development of Henan Oilfield, which identified numerous ostracodes fossils.

As examined by Cao Meizhen from the NIGPCAS and Zhu Hongwei from Henan Oilfield, the results are as follows (Table 4.3, Fig. 4.4).

Table 4.3 List of ostracod fossils in the Shangdonggou Formation in Ruyang Basin

Specimen No.	Identification by Henan Oilfield		Identification by NIGPCAS		Notes
	Fossil Name	Quantity (individual)	Fossil Name	Quantity (individual)	
H-1272/1	*Cyclocyprididae* sp.	2	*Cyclocypris subcalculaformis* Pang	1	
	Candoniella longa	6	*Candoniella porrecta* Ho	2	
	C.mordvilkoi	1			
	C.candida	1	*Candoniella candida* Hao	3	
	Ostracodes fragments	4			
H-1272/2	*Cypridea* sp.	1	*Candoniella* sp.	1	
H-1272/4	*Talicypridea* sp.	1			
H-1272/5	*Candoniella candida*	1			
H-1272/6	*Timiriasevia* sp.	1			
	Talicypridea sp.	1			
	Ostracodes fragments	1			
H-1272/9	*Candoniella* sp.	1	*Candona* sp.		
	Metacypris miniscula	3			
	Metacypris kaitunensis	3			
	Metacypris sp.	1			
H-1272/10	*Eucypris* sp.	1			
			Candona subdeclivis Tian	4	
	Talicypridea sp.	1			
	Cyclocyprididae sp.	6	*Cyclocypris* sp.	3	
H-2024			*Cypridea* sp.		
			Candona subdeclivis Tian		
			Candona cf. *pandidorsa* Zhang		
			Mongolianella sp.		
			Darwinula leguminella Forbes		
			Timiriasevia liaoxiensis Zhang		



a b c

Fig. 4.4 Three typical species of Ostrocods

a—*Timiriasevia* sp.; b—*Talicypridea* sp.; c—*Candoniella longa* sp.

Candona subdeclivis Tian is seen in China's terrestrial Cretaceous strata, such as Qiucheng Formation in Qiuxian, Hebei; Xiazhuang Formation in Beijing; Qingshan Formation in Mengyin, Shandong; Paomagang Formation in Dangyang, Hubei, etc. *Candoniella candida* Hao is found in the Xiazhuang Formation in Beijing; Zuoyun Formation and Zhumabao Formation in Shanxi; Laiyang Formation and Wangshi Formation in Shandong; Nenjiang Formation to Mingshui Formation in Songliao Basin, etc. *Candoniella porrecta* Ho is found in the Paomachang Formation in Dangyang, Hubei and

Nanxiong Formation in Guangdong, etc. *Cyclocypris subcalculaformis* is discovered in the Xiazhuang Formation in Beijiang, Leduminhe Formationn in Qinghai, Sunjiawan Formation in Yixian, Liaoning, etc. *Talicypridea* is only discovered in the upper Cretaceous and not reported in the Cenozoic strata. *C. longa* and *C.mordvilkoi* are reported in the upper Cretaceous Guankou Formation in Sichuan, Paomachang Formation in Dangyang, Hubei and Sanshui Formation in Guangdong. *C. mordvilkoi* also can be seen in the lower Cretaceous Chaganlimennuoer Formation in Inner Mongolia, Fuxin Formation and Jiufotang Formation in Liaoning. *Eucypris* is extensively distributed around the world in the lower Jurassic to present. Fossils of *Timiriasevia* are mainly distributed in the middle Jurassic to late Cretaceous, such as seen in the upper Cretaceous of Dengcan 1 Well in Nanyang, Henan. *Cypridea* is distributed from the Jurassic to early Paleogene in Asia, Europe and America, expecially abundant in the Cretaceous.

4.1.3 Bivalves

Bivalves are found in the strata of silt mudstone of Haoling Formation and Shangdonggou Formation, but are quite different in the two formations.

4.1.3.1 Bivalves fossils from the Haoling Formation

Bivalves were discovered from different layers of two geological cross sections of the Haoling Formation (Fig. 4.5～Fig. 4.7) and they were examined by Liu Benpei from CUG (China University of Geosciences). The results show absence of typical Cretaceous genera like T*rigonioides, Nippononaia, Plicatounio, Pseudohyria,* but the hinge teeth and soft tissue impressions indicate that they belong to *Nakamuranaia* (Suzuki, 1943). The age of Haoling Formation is correlative to that of Yixian Formation—Jiufotang Formation in Liaoning and Qingshan Formation in Shandong.

Fig. 4.5 *Nakamuranaia chingshanensis*, Grabau, 1923

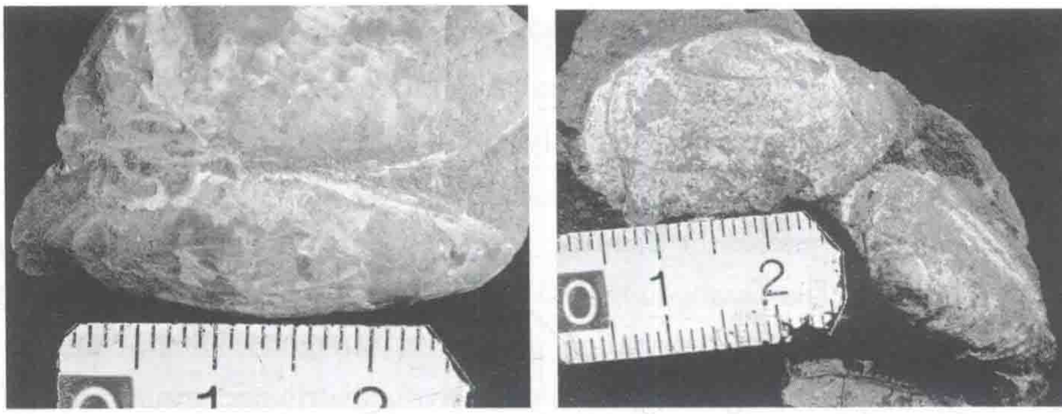


Fig. 4.6 *Nakamuranaia* aff. *chingshanensis*, Grabau, 1923

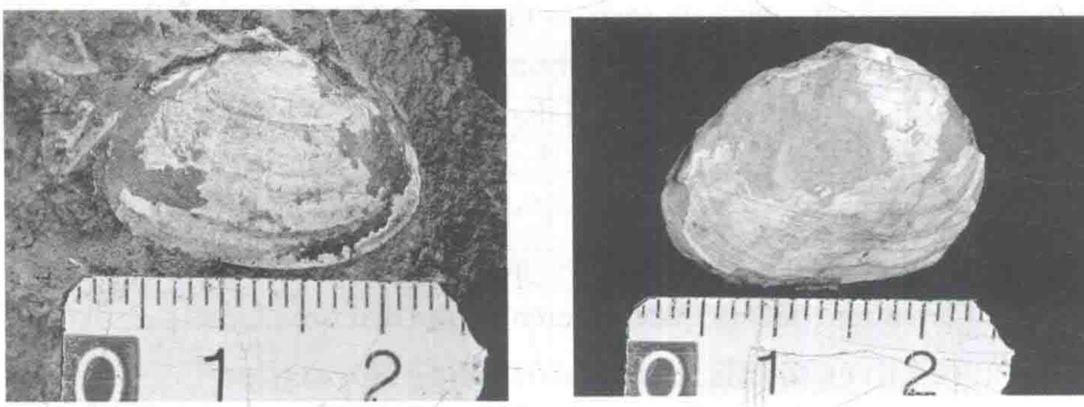


Fig. 4.7 *Nakamuranaia subrotunda*, Gu et Ma

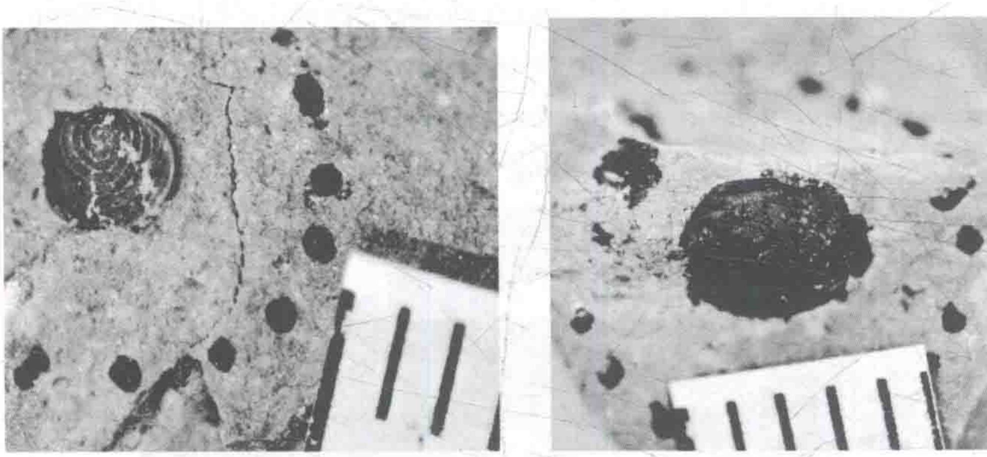


Fig. 4.8 Bivalve fossils found in Shangdonggou Formation

Specimen L1: *Nakamuranaia chingshanensis* Grabau, 1923

Location: Liufugou

Fossil Strata: Haoling Formation

Only one specimen is relatively complete with its partial left shell, 2 antero-pseudocardinal tooth and 1 posto-lamellar tooth preserved. It is oblique trapezoid, with its length to width ratio ranging from 1.4 to 1.6. The anterior portion is round while the posterior portion oblique.

Specimen H1: *Nakamuranaia* aff. *chingshanensis* Grabau, 1923

An anterior adductor impression and a small footprint can be seen on the intima of the left shell. It differs from *Nakamuranaia chingshanensis* in that it has the smaller and elongate shell with length to width ratio more than 2, and slightly oblique posterior portion. There are 4 relatively complete individuals.

Location: Haoling.

Fossil Strata: Haoling Formation.

Specimen H2: *Nakamuranaia subrotunda* Gu et Ma

Nakamuranaia subrotunda differs from the *Nakamuranaia chingshanensis* in that the former has a nearly round shell with length to height ratio ranging between 1.4 to 1.2 and its posterior portion is slightly oblique. There are 5 relatively complete individuals.

Location: Haoling.

4.1.3.2 Bivalves in the Shangdonggou Formation

The project team found a large quantity of bivalves from the Shangdonggou Formation in Chang Village, Liudian Town in the October, 2012. These bivalves were examined by Wen Shixuan, a researcher from the NIGPCAS. The results are as follows: *Limnocyrena cf. rotunda* Martinson, *Neomiodonoides gansuensis* Gu, *Limnocyrena fuxinensis* Gu et Wen, *Ferganoconcha aff. rotunda* Martinson, *Limnocyrena anderssoni* Grabau, *Limnocyren* sp., *Limnocyren jeholensis* Grabau, *Limnocyrena selenginensis* Martinson. These are common genera from the early Cretaceous.

4.2 Sporopollen

According to Niu Guili of Henan Oil Field, varied amounts of spores and pollens were discovered in samples from cross sections of 102-H8 of Caojiacun Santun Town, 105-H4 of Huamiaogou, 111-H5 of Miaoling, 107-H2 of Taishanmiao, 9100-1 and 9100-2 of Caojiaocunnangou, H6005-1 site of Ligedacun, 1245 site of Shijiagou. The quantity of the samples 102-H8, 115-H4, 9100-1 and 9100-2 meet the statistical requirement. The fossil assemblages are all the same, with same dominant species and similar age for these samples. Most of the palynologic fossils were pteridophytes and gymnosperms, with pteridophytes being the dominant elements, except samples 9100-1 and 9100-2, which are dominated by gymnosperms. No angiosperms were seen.

The assemblages include fern spores *Hsuisporites* spp., *H. liaoningensis*, *H. rugatus*, *Cicatricosisporites* spp., *C.* cf. *dahuichangensis*, *C. minor*, *Densoisporites* spp. with *Hsuisporites*, *Cicatricosisporites* and *Densoisporites* being dominant; gymnosperm is composed of *Classopollis* sp., *C. granulates*, *C. parvus*, *C. annulatus*, with *Classopollis* being dominant and a certain amount of *Psophosphaera*. *Piceaepollenites* are the only disaccites seen, ancient pine pollens with unevolved saccus are not seen, and a few monocolpates such as *Cycadopites* and *Chasmatosporites* are found in small amount (Fig. 4.9).

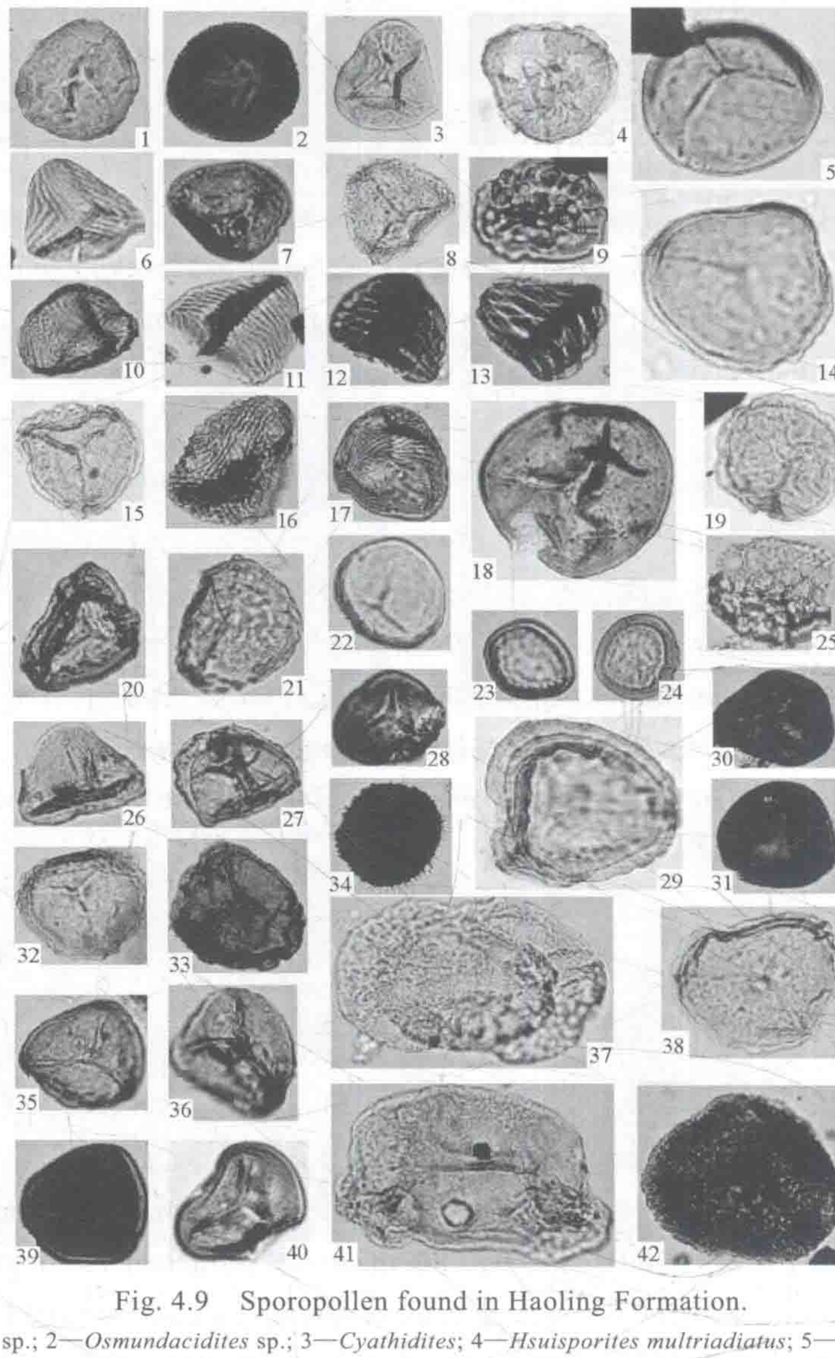


Fig. 4.9 Sporopollen found in Haoling Formation.

1—*Deltoidospora* sp.; 2—*Osmundacidites* sp.; 3—*Cyathidites*; 4—*Hsuisporites multriadiatus*; 5—*Todisporites* sp.; 6—*Cicatricosisporites dorogensis*; 7—*Deltoidospora* sp.; 8—*Undulatisporites* sp.; 9—*Leptolepidites verroucatus*; 10—*Cicatricosisporites* sp.; 11—*Cicatricosisporites* cf. *tersus*; 12—*Cicatricosisporites mediostriatus*; 13—*Cicatricosisporites*; 14—*Punctasisporites* sp.; 15—*Hsuisporites rugatus*; 16—*Cicatricosisporites* sp.; 17—*Cicatricosisporites* cf. *minutaestriatus*; 18—*Punctasisporites* sp.; 19—*Hsuisporites* sp.; 20—*Densoisporites velatus*; 21—*Dictyotriletes* sp.; 22—*Stereisporites* sp.; 23—*Classopolis annulatus*; 24—*Classopolis annulatus*; 25—*Lycopodiumsporites marginatus*; 26—*Cyathidites*; 27—*Hsuisporites multriadiatus*; 28—*Cyathidites australis*; 29—*Densoisporites* sp.; 30—*Cyathidites mesozoicus*; 31—*Deltoidospora balowensis*; 32—*Hsuisporites* sp.; 33—*Hsuisporites rugatus*; 34—*Pilosisporites verus*; 35—*Undulatisporites triangularus*; 36—*Undulatisporites undulaporus*; 37—*Pinuspollenites* sp.; 38—*Hsuisporites rugatus*; 39—*Lygodiumsporites*; 40—*Toroisporites* sp.; 41—*Parvisaccites* sp.; 42—*Microreticuloatisporites* sp.

Table 4.4 Statistical of Sporopollen

Fossil Location	Santunzhen, Shijiagou	Liudianzhen, Huamiaogou	Liudianzhen, Taishanmiao	Santunzhen, Miaoling	Santunzhen, Tuqiaoxigou	Santunzhen, Caojiagou, Nangou			Liudianzhen, Ligedacun	Liudianzhen, Shijiagou
Original No.	102-H-8	105-H-4	107-H-2	111-H-5	115-H-1	9100-孢-1	9100-孢-2	9100-孢-3	H6005-1	H1245
Lab No. / Fossil Name	0620	0630	0631	0635	0639	0641	0642	0643	0650	0706
Punctatisporites sp.	3.60	1			7.77	1.80	2.91	1		3.36
Deltoidospora sp.	3.60	2		1	10.68	1.80	4.85			
D. minor	0.90					1.80				
Cyathidites sp.	0.90	2			1.94		0.97			2.52
C. minor				1						
Todisporites sp.	3.60	1			4.85	0.90	5.83			
Toroisporis sp.	3.60				5.83	3.60				
T. pseudodorogensis				1						
Hsuisporites sp.	13.51	3		1	3.88	0.90	1.94			
H. liaoningensis	1.80									
H. rugatus	3.60									
Cicatricosisporites sp.	8.11	2			10.68	7.21	16.50			1.68
C. cf. *dahuichangensis*	0.90									
C. minor	0.90									
C. variabilis					0.97					
C. minutaestriatus					0.97		3.88			
C. phymatochilus					1.94					
C. imparilis						0.90				
C. ordinatus						1.80				
Sphagdiumsporites sp.	0.90					2.70	1.94			
Undulatisporites sp.	0.90				0.97		1.94			

Continued

Fossil Location	Santunzhen, Shijiagou	Liudianzhen, Huamiaogou	Liudianzhen, Taishanmiao	Santunzhen, Miaoling	Santunzhen, Tuqiaoxigou	Santunzhen, Caojiagou, Nangou			Liudianzhen, Ligedacun	Liudianzhen, Shijiagou
Original No.	102-H-8	105-H-4	107-H-2	111-H-5	115-H-1	9100-孢-1	9100-孢-2	9100-孢-3	H6005-1	H1245
Fossil Name / Lab No.	0620	0630	0631	0635	0639	0641	0642	0643	0650	0706
U. granulatus	0.90									
Cyclogranisporites sp.	0.90				3.88	2.70	1.94			
Schizaeoisporites sp.	1.80					0.90	0.97			
Densoisporites sp.	8.11				2.91					0.84
Granulatisporites sp.	0.90			2	1.94	2.70	0.97			0.84
Rutusotriletes sp.	1.80		1	1						
Osmundacidites sp.	2.70		1	1		1.80	0.97			0.84
Lygodiumsporites sp.	2.70	2		5	2.91	0.90	1.94			7.56
Foveotriletes sp.	0.90				1.94	0.90				
Convolutispora sp.	0.90									
Cibotiumspora sp.		1				0.90				
Uvaesporites tuberosus					0.97					
Alsophillidites sp.					0.97					
Leschikisporites sp.					0.97					
Calamospora sp.					0.97	0.90				
Impardecispora sp.						0.90				
Radialisporis cf. *radiatus*						0.90				
Crybelosporites sp.						1.80				
Lycopodiumsporites sp.							0.97			0.84
Concavisporites sp.							0.97			0.84
Cycadopites sp.	1.80					1.80				2.52
Piceaepollenites sp.	4.50				3.88	6.31	4.85			20.17
Callialasporites sp.	2.70			1		3.60	7.77			0.84

Continued

Fossil Location	Santunzhen, Shijiagou	Liudianzhen, Huamiaogou	Liudianzhen, Taishanmiao	Santunzhen, Miaoling	Santunzhen, Tuqiaoxigou	Santunzhen, Caojiagou, Nangou			Liudianzhen, Ligedacun	Liudianzhen, Shijiagou
Original No.	102-H-8	105-H-4	107-H-2	111-H-5	115-H-1	9100-孢-1	9100-孢-2	9100-孢-3	H6005-1	H1245
Fossil Name \ Lab No.	0620	0630	0631	0635	0639	0641	0642	0643	0650	0706
C. infrapunctatus					0.97					
Classopollis sp.	5.41	1		1	1.94	6.31	8.74			0.84
C. granulatus	1.80									
C. parvus	4.50		1	3		8.11	4.85			
C. annulatus	0.90	1		6	5.83	6.31	2.91			
C.classoides		1			1.94	0.90	1.94			
C. qiyangensis				1	0.97		0.97			
Psophosphaera sp.	6.31				2.91	6.31	6.80		2	
P. bululinaeformis					0.97				1	
Jiaohepollis sp.	1.80	1		1			0.97			
Chasmatosporites sp.	0.90	1		1	0.97	1.80	0.97			0.84
Ephedripites sp.	0.90				1.94	0.90	1.94			
Pinuspollenites sp.		1		1		2.70	2.91			9.24
Abietineaepollenites sp.			1		1.94	2.70	2.91			7.56
Piceites sp.				1	0.97					5.04
Podocarpidites sp.				1	0.97					
Pityosporites sp.				5	4.85	0.90				
Perinopollenites sp.					0.97	1.80	1.94			
Caytonipollenites sp.						0.90		1		
Spheripollenites sp.						1.80				
?*Paleoconiferus* sp.						3.60		1		1.68
Quadraeculina minor						0.90		1	4	

Continued

Fossil Location	Santunzhen, Shijiagou	Liudianzhen, Huamiaogou	Liudianzhen, Taishanmiao	Santunzhen, Miaoling	Santunzhen, Tuqiaoxigou	Santunzhen, Caojiagou, Nangou			Liudianzhen, Ligedacun	Liudianzhen, Shijiagou
Original No.	102-H-8	105-H-4	107-H-2	111-H-5	115-H-1	9100-孢-1	9100-孢-2	9100-孢-3	H6005-1	H1245
Lab No. / Fossil Name	0620	0630	0631	0635	0639	0641	0642	0643	0650	0706
Cerebropollenites sp.						2.70			4	
Parvisaccus sp.						0.90		2		
Stereisprurite sp.										1.68
Uudulatisporites sp.										0.84
Hsuisporites sp.										0.84
Maculatisporites sp.										0.84
Aequitriradites sp.										0.84
Verrucosisporites sp.										0.84
Taxodiaceaepollenites sp.										1.68
Jugella sp.										0.84
Dacryearpites sp.										1.68
Protoconiferus sp.										3.36
Pseudopicea sp.										4.20
Protopicer sp.										0.84
Cedripites sp.										4.20
Fern sporopollens	68.47	14	2	13	67.96	38.74	49.51	5	6	32.77
Gymnosperm pollens	31.53	6	2	17	32.04	61.26	50.49			67.23
Fern fossils										
Sporopollen Fossil Total	111	20	4	30	103	111	103			119
Observation Section No.	2	20	18	15	4	3	4			8

The most significant components in age determination in the assemblages are spores of Lygodiaceae and *Classopollis* of Gymnosperms. Previous studies indicate that Lygodiaceae reached a peak in early Cretaceous, of which *Cicatricosisporites* is the most important indicator. The occurrence and abundance of *Cicatricosisporites* are related to the boundary between the Jurassic and Cretaceous and paleontologists consider it as the index fossil of Cretaceous. Its occurrence provides the key evidence in the division of the Jurassic and Cretaceous sediments. *Cicatricosisporites* has not been reported in China in the published papers about the late Jurassic spores and pollens, as seen in Datonghe Formation in Minhe Basin of Gansu Province, lower part of Tuchengzi Formation in Beipiao City of Liaoning Province (Pu and Wu, 1982). *Cicatricosisporites* were rare in the very beginning of the early Cretaceous untill Valanginian and became abundant during Hauterivian and Aptian. Their presence is relatively high between the upper Cretaceous Shahezi Formation and the lower Cretaceous Qingshankou Formation in Songliao Basin. In northern China, *Hsuisporites* and *Jiaohepollis* are the representative members of the early Cretaceous, and *Cicatricosisporites* and *Classopollis* are common during the early Cretaceous in China. The important early Cretaceous indicators, i.e., *Hsuisporites, Schizaeoisporites, Callialasporites* and *Jiaohepollis*, were discovered in Caojia Village and Miaoling sections.

4.3 Plant Fossils

4.3.1 Plants

Plant fragments were discovered in 2012 in the gray argillaceous limestone of the cross section in Chang Village, Liudian Town (sample No. H2045). Examination by *Researcher* Wu Shunqing from NIGPCAS, (Nanjing Institute of Geology and Paleontology, Chinese Academy of Sciences), indicates that they contain *Brachyphyllum?* sp., cf. *Brachyphyllum obtusicapitatum*, *Ginkgoites* sp., *Podozamites* sp., which were commonly seen in the early Cretaceous.

Although very few plant fossils were found in the strata, it does not illustrate that plants were not abundant during the early Cretaceous, but that the alluvial environment in Ruyang was not advantageous to the preservation of plant fossils. Discovered plant fossils were usually from river-flooded lakes and low-lying swamps.

4.3.2 Charophytes

Two (131-H-3 of Beiyugou, Caojia Village Section and 150-H-1 Erlancun Section Liudian Town) of 53 samples collected by Henan Geology Museum contain charophyte fossils. 12 samples were collected in Caojiacun Section in Santun Town (Fig. 4.10) . Samples and fossils are detailed as follows:

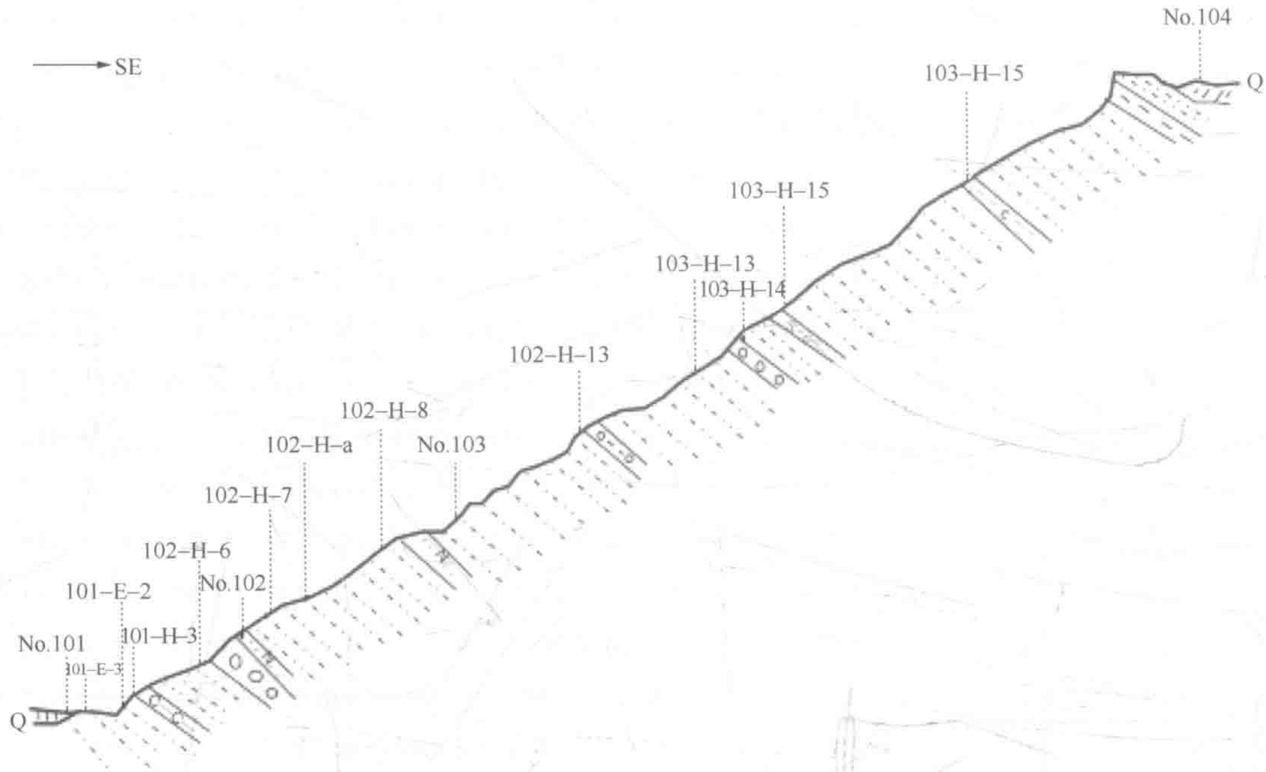


Fig. 4.10 Cross section of Haoling Formation of lower Cretaceous in Caojiacun, Santun Town, Ruyang County

In the charophyte assemblage, *Aclistochara* and *Mesochara* are predominant, while *Obtusochara* and *Sphaerochara* occasionally appear, along with a certain amoutof *Flabellochara* and *Clypeator*. The fossil assemblage also includes: *Clypeator zongjiangensis*, *C. jiuquanensis*, *Flabellochara* sp., *Mesochara stipitata*, *Mesochara symmetrica*, *Mesochara xuanziensis*, *Mesochara volute*, *Mesochara latiovata*, *Aclistochara wangi*, *Aclistochara poculiformis*, *Aclistochara bransoni*, *Aclistochara caii*, *Aclistochara longiconica* and *Sphaerochara verticillata* (Table 4.5, Fig. 4.11) .

Table 4.5 Distribution of Charophyte Fossils in Haoling Formation

Charophyte Fossils	Caojiacun section in Santunzhen			Yujiagou, Caojiacun in Santunzhen	Erlangeun in Liudianzhen
	102-H-7	102-H-8	103-H-14	131-H-3	150-H-1
Clypeator zonjiangensis	4				
Clypeator jiuquanensis			1		
Flabellochara sp.	4	4			
Mesochara stipitata	2		3		
Mesochara symmetrica	1			4	
Mesochara xuanziensis	7				

Continued

Charophyte Fossils	Caojiacun section in Santunzhen			Yujiagou, Caojiacun in Santunzhen	Erlangeun in Liudianzhen
	102-H-7	102-H-8	103-H-14	131-H-3	150-H-1
Mesochara volute	4	5	4		
Mesochara latiovata	3				
Aclistochara wangi	3		17		
Aclistochara poculiformis	1				
Aclistochara bransoni		4			
Aclistochara caii		3	3		
Aclistochara longiconica			1		
Obtusochara sp.		1		1	
Sphaerochara verticillata	2				

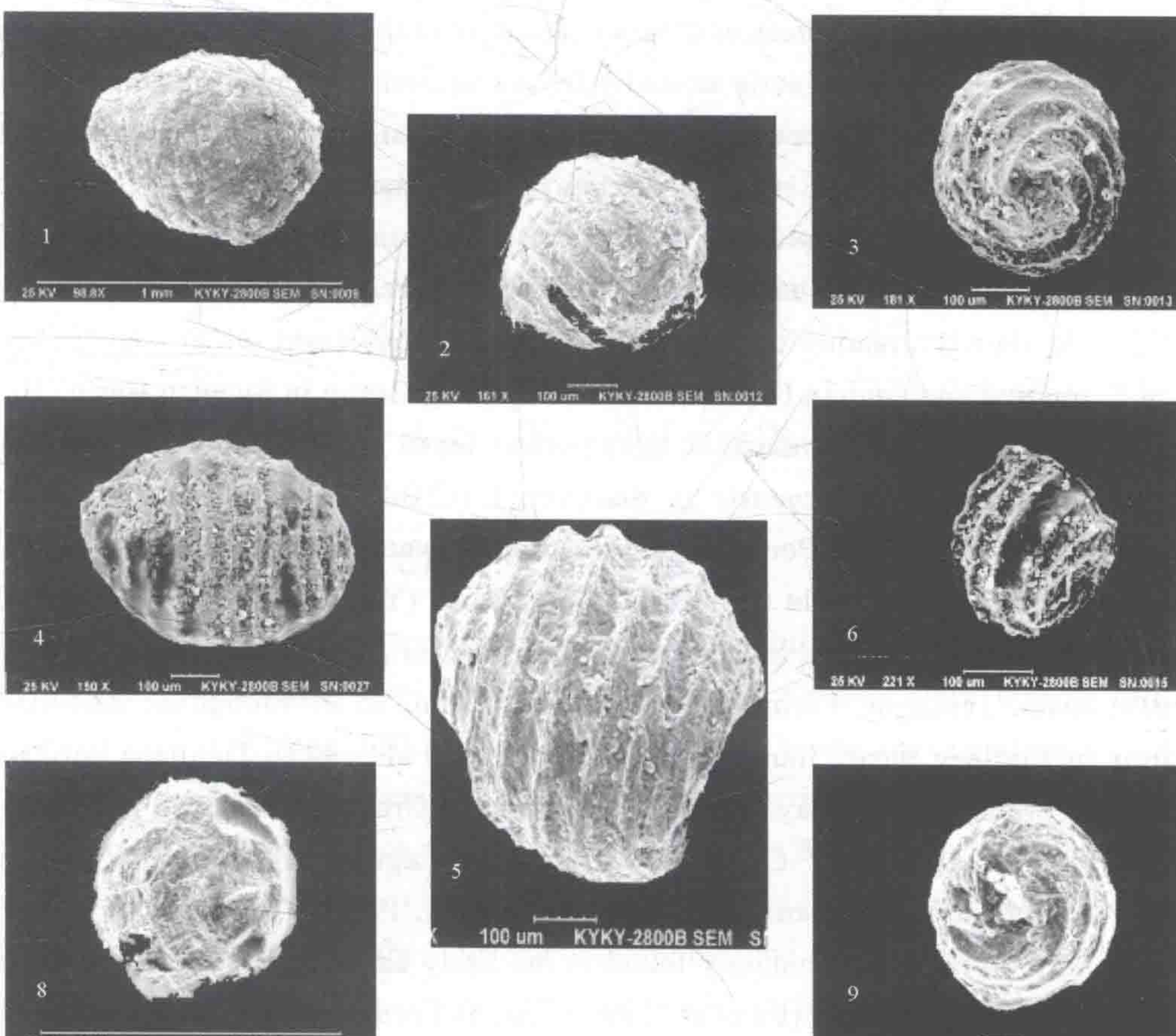


Fig. 4.11 Electro-microscopic scans of major Charophytes in Haoling Formation.

1—*Flabellochara* sp.; 2—*Mesochara voluta*; 3—*Mesochara stipitata*; 4—*Mesochara latiovata*; 5—*Alistochara wangi*; 6—*Alistochara poculiformis*; 7—*Sphaerochara verticillata*; 8—*Clypeator jiuquanensis*; 9—*Alistochara bransoni*

Clavatoraceae is a very special group in charales. Their oogoniums are wrapped by delicate and complex shells composed of vegetative cells. These enclosures can provide reliable basis for the study on the rapid evolution of Clavatoraceae. Evolution of *Flabellochara* → *Clypeator* is a typical evolution series in Clavatoraceae, and it happened between Berriasian and Albian in the early Cretaceous (L. Grambast, 1974). The evolution was carried out mainly through the retraction of bottom cells and appearance and elongation of intermediate cells, which brought about the change from the lateral fan structure on shell of *Flabellochara* to the radial structure on areole of *Clypeator* (Zhu, 2012).

Though *Flabellochara* sp., *Clypeator zongjiangensis* and *Clypeator jiuquanensis* are rare, but with wide distribution and short appearance, they are of great significance in age determination. *Flabellochara* is distributed around the world. Its first appearance was in the initial Berriasian of the Early Cretaceous and thrived in Barremian to mid-Aptian and perished in Aptian. *Clypeator* has a very wide distribution in Asia, Europe and North America, and its geological history was very short, only in the Early Cretaceous. *Clypeator zongjiangensis* is an important early to mid Early Cretaceous specimen in China, and it is widely distributed, and also reported in the Lower Berriasian sediments in northwestern Germany, southeastern France and Switzerland in Berriasian sediments, in Berriasian in Portugal and in Spain, in Hauterivian to Barremian in Ukraine. In China, it appeared in Shushanhe Formation of Kapushaliang Group in Kuche depression of Tarim Basin (Wang et al., 1982), Hutubihe Formation of Tugulu Group in Junggar Basin (Lu et al., 1990) and Bailong Formation and Gudian Formation of Chengqiang Group in Sichuan Basin (Huang et al., 1985). *Clypeator jiuquanensis* is an important fossil in the Barremian extending to the Aptian. *Clypeator jiuquanensis* is discovered in Barremian of northern France, northern Spain, Romania and Portugal, and in strata between Shengjinkou Formation and Lianmuqin Formation of Tugulu Group in Junggar Basin (Yang et al., 2008); Fengjiashan Formation in Shangxian Basin, Shaanxi Province (Li et al., 1981); Guyang Formation of Wuchuan Basin, Lisangou Formation of Guyang Basin, Inner Mongolia; Zhoujiadian Formation in Xinjiang Basin, Jiangxin Province (Wang et al., 1982); Tianjiaba Formation, Zhoujiawan Formation and Huaya Formation of Donghe Group in Huicheng Basin, Gansu Province (Yuan et al., 1991); Chijinbao Formation, Xiagou Formation and Zhonggou Formation in Jiuquan Basin, Gansu Province (Wang et al., 1982).

Mesochara stipitata is commonly found in the Early Cretaceous in China, such as in Tugulu Group in Junggar Basin (Lu et al., 1990); Xiagou Formation and Chijinbao Frmation in Jiuquan Basin, Gansu (Yuan et al., 1991); Yantang Formation in Anhui (Hu et al., 1982); Guyang Formation in Inner Mongolia; Xitanlou Formation in Henan (Jiang et al., 1985); Qiucheng Formation in Hebei; Hekou Formation in Lanzhou, Gansu (Li et al., 1981);

Jiufotang Formation in Fengning, Hebei Province (Lu et al., 1990), Dongjing Formation in Dongyang, Hunan (Zhao et al., 1995). *M. symmetrica* is discovered in Aptian in Americas and the Lower Cretaceous in many sites in China, such as Gecun Formation in Jiangsu Province (Shu et al., 1985), Hekou Formation in Lanzhou of Gansu and Minhe of Qinghai (Li et al., 1981), Tugulu Formation in Junggar Basin (Lu et al., 1990), and Quantou Formation in Songliao Basin (Hu et al., 1982). *M. xuanziensis* and *M. latiovata* are found in Hekou Formation in Minhe, Qinghai Province (Li et al., 1981). *M. volute* and *Aclistochara bransoni* are usually produced in the Upper Jurassic to Lower Cretaceous in China, Mongolia, Russia, Spain and United States. *Aclistochara caii* was first discovered in Xiagou Formation in Jiuquan Basin, Gansu Province (Yuan et al., 1991), and then commonly found in the Lower Cretaceous in northern China, Qiucheng Formation, Hekou Formation, Zuoyun Formation in Shanxi Province, Shangshui Formation and Yongfeng Formation in Henan Province (Wang et al., 1965). *A. wangi* and *A. longiconica* belong to Hekou Formation in Gansu Province (Li et al., 1981) and the former is also found in Shangshui Formation in Henan Province (Wang et al., 1965). *Sphaerochara verticillata* appeared from the Late Jurassic Morrison Formation and Aptian in central-western U.S., in Berriasian in Spain and German; Minhe and Ledu areas in Qinghai Province; Hekou formation in Lanzhou, Gansu Province (Li et al., 1981); Xitanlou Formation in Queshan, Henan Province (Wang et al., 1965); the Lower Cretaceous strata in Xin'an Town, Inner Mongolia (Hao et al., 1983) and Tugulu Group in Junggar Basin in Xinjiang (Lu et al., 1990).

4.4 Trace Fossils

4.4.1 Trace Fossils Classification

Trace fossils are animal traces preserved in rocks and its morphology and structure can be investigated with naked eyes or under microscopes. Because trace makers cannot be determined accurately, it is difficult to give a systematic biological classification based on the current study. For the convenience of research and practical purposes, most scholars use ecological classification of trace fossils. It is also called as Behavioral Classification, which was first proposed by Seilacher (1964, 1967). Then Osgood (1970), Simpson (1975), Ekdale and Bromley (1984) and other scholars supported the complement and description. Presently, it includes eight types, Domichnia, Repichnia, Cubichnia, Fodinichnia, Pascichnia, Fugichnia, Agrichnia and Digestisignia or Feces fossil.

Trace fossils are indicative of the various biological activity records on the surface or the internal of sediments during geological history. The main difference between trace fossils and organism fossils is that the trace fossils represent the habits or behavior of organisms instead of organisms or their castings or prints. Most of trace fossils are in authochthonous burial and rarely transported, so it is helpful to interpret the environment. In addition, trace fossils are often exposed in the strata which lack organism fossils, especially in various sandstone strata, where they offer the only records of life activities.

Being an important indicator of the ancient sedimentary environment, the trace fossils have attracted extensive attention since it was first proposed by Seilacher (1967), and its study has been deepening and improving.

The trace fossils are biogenic sedimentary structures formed by animal activities, not preserved organism fossils, so they can reflect the behavior and details of organism's movement, behavior, and feeding patterns, which even the best preserved organism fossils might not provide. One important characteristic of the preservation of trace fossils is the authochthonous burial. Once formed, it would not be transported and heterochthonously buried. So trace fossils are direct evidence of biological behavior and habits in certain conditions and sensitive indicators of sedimentary environments. In addition, most of trace fossils are made by molluscs, which were abundant but without hard shells or bone during the geological period. The various trace fossils play an irreplaceable role in the analysis of biological features, sediment environments and stratigraphic correlation, especially in the strata lacking organism fossils (such as turbidite rocks and sedimentary rocks). In the study area, trace fossils from the Cretaceous strata are abundant and provide significant biogenic structure information on the analysis of sedimentary environment.

Abundant trace fossils are discovered in sandstone and sandy mudstone beds of the Cretaceous Xiahedong Formation, Haoling Formation and Shangdonggou Formation in Ruyang Basin. According to the occurrence and individual form, they were divided into: vertical burrow, J-shaped burrow, Y-shaped burrow, U-shaped burrow and straight-curved trace fossils, as shown in Fig. 4.12.

4.4.1.1 Vertical burrows

Vertical burrows occur in silty mudstone. Burrows are perpendicular or slightly tilted to the layers, appearing as solitary or in groups; individual is characteristic of being straight, tubular, slightly curved or funnel shaped at the top, and not branched. Burrows (Fig. 4.12c) extend from the surface into the layer at right angles or high angle with the diameter of 1.5~2cm, with depth ranging mostly within 40cm, usually 2~20cm. These burrows are passively filled. Trace makers are generally considered to be floating organism or filter feeding animals. The organisms live in burrow tubes and feed through filter, which is commonly seen in sedimentary environment with dynamic hydrology.

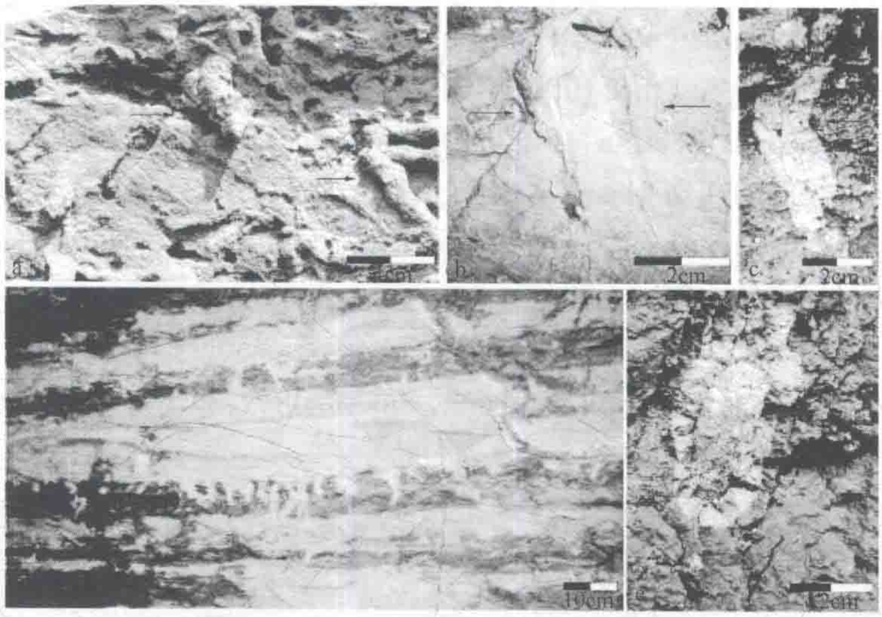


Fig. 4.12 Features and occurences of Cretaceous trace fossils in Ruyang Basin

a—*Palaeophycus tubularis*, preserved on the bedding plane of fine grained sandstone, from layer 10 at Caojiaocun(the middle part of the Xiahedong Formation); b—*Scoyenia* sp., occur in red muddy siltstone with horizontal lamination and are parallel to the bedding plane, from layer 10 at Caojiaocun(the middle part of the Xiahedong Formation); c—Unnamed bioturbation structures, vertical, inclined and mottled burrows developed in the muddy siltstones, from laryer 73 at Langpowa(lower part of the Shangdonggou Formation); d—*Psilonichnus* sp. The ichnofossils are U-, W-, J- or Y-shaped burrows, which are vertical or slightly inclined to the bedding plane from layer 34 at Haoling (the lower part of the Haoling Formation); e—*Palaeophycus tubularis*, nearly perpendicular to bedding, perserved in red silty mudstone from the lower part of the Shangdonggou Formation

4.4.1.2 U-shaped burrow

U or W shaped burrows, as well as J or Y shaped, are tubular burrows, which are nearly perpendicular to layers. (Fig. 4.12d). These burrows are perpendicular or slightly tilted to the layers with diameter of 6~46 mm and length of 15~60 mm, extending downwards and gradually tilting to parallel level of the layers. Some webbed structures are developed among burrow tubes. The trace makers are mainly plankton-feeding or mud-eating organisms and they often exhibit two types of behavior of living and eating in the burrows. U-shaped burrow indicates moderately dynamic sedimentary environments, appearing in the sedimentary environment of moderate hydrologic energy.

4.4.1.3 Straight-curved trace fossil

These trace fossils are generally featured with straight, slight bending or random curved traces, with preserved marks and grooves, along with burrows close to the surface. They are parallel or almost parallel to the layers. Sometimes they penetrated into layers at various angles. Trace makers include not only animals crawling and dragging on the layers, but also burrowing and mud-eating animals. Generally, these fossils are produced in quiet or low-energy depositional environments. Two common types are as follows: the *Palaeophycos tubularis* is a tubular burrow distributed nearly parallel to layers with the length of 8 cm and diameter of 30 mm, and its center tube diameter is 16 mm with distinct wall, appearing in the 10th layer sandstone of Caojiacun Section and silty mudstone of Langpowa Section (Fig.4.12a); *Scoyenia gracilis* is a tubular burrow distributed nearly parallel to layers with crescent shaped backfill structure,and it is 90 mm long and 9 mm wide, parallel to the layer in the 12th layer sandstone of Caojiacun Section (Fig. 4.12b).

According to the previous research on terrestrial ichnocoenosis, these three types of trace fossils are common in flood plains and shallow lucustrine shore sedimentary environment.

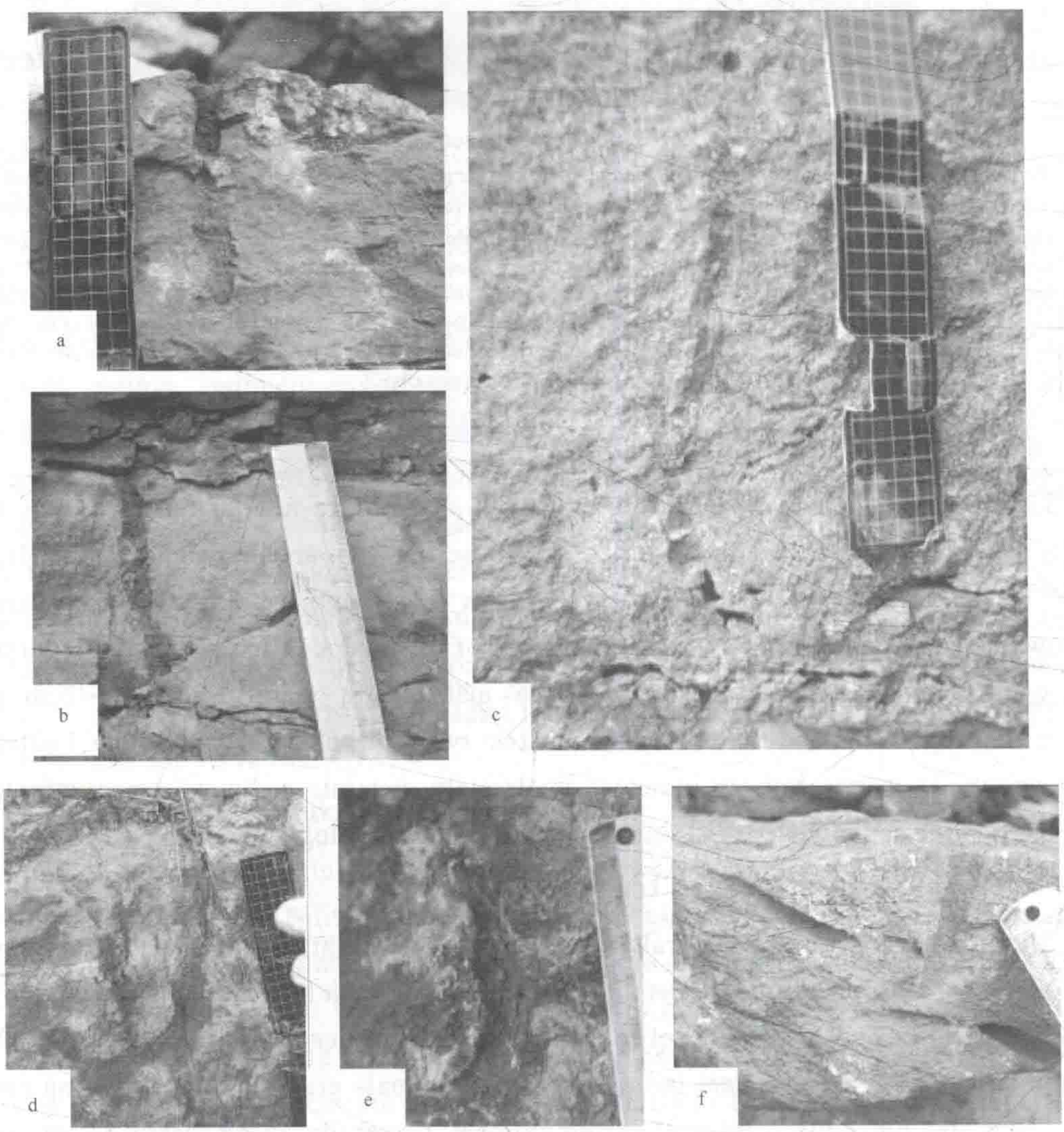


Fig. 4.13 Trace fossils of *Skolithos*

a, b—in the 12th layer of silty sandstone; c—in the 10th layer of fine sandstone; d—in the 10th layer of fine sandstone; e, f—in the 12th layer of fine sandstone

4.4.2 Trace Fossils in the Study Area

4.4.2.1 *Psilonichnus* (Fig. 4.12d)

Description: U-shaped and W-shaped tubular burrows in vertical cross section, J-shaped and Y-shaped tubes included, with the diameter of 6~46 mm and length of 15~60mm.

Strata: the Lower Cretaceous, Haoling Formation

Locality: Haolingcun Section, Ruyang County

The burrow is vertical or slightly inclined to the layers. The trace makers are mainly the animals feeding on planktons or eating mud, and they often exhibit both living and eating behavior in the burrow. The trace colony is preserved in the same strata with the dinosaur fossils. They lived together in temporary flooded alluvial plain as the frontal part of alluvial fan.

4.4.2.2 *Palaeophycos* (Figs. 4.14 and 4.15)

Description: Cylindrical burrows slightly curved and nearly parallel to the layers, not branched, smooth surface without ornaments and thin-walled. The filling color is the same as the surrounding rock. The diameter is 0.5~3 cm and its visible length is 15 cm. It is distributed parallelly to the layers.

Strata: The Lower Cretaceous Xiahedong Formation and Haoling Formation, the Upper Cretaceous Shanghedong Formation.

Locality: Caojiacun Cross Section and Shijiagou Cross Section in Santun Town, Langpowa Section in Liudian Town in Ruyang County.

Palaeophycos is widely distributed in the Cretaceous strata in Ruyang Basin. According to Pemberton and Frey (1982), there are five species: *P. tubularis* Hall, 1847, *P. striatus* Hall, 1852, *P. heberti* (Saporta, 1872), *P. sulcatus* (Miller et Dyer, 1878) and *P. alternatus* Pemberton et Frey, 1982. Based on the analysis of previous reseach, *Palaeophycos* is formed in the river beds and batture bars. Also, some reseachers consider the mark was formed by mud and sand filling in the space the worms burrowed through.

4.4.2.3 *Planolites* (Fig. 4.14a)

Description: Thin tubular burrows straight to slightly bent, elliptical in vertical cross section view, with a diameter of 1~2 mm and visible length of about 85 mm, filled with silty mud deposit that is the same as surroundings, with smooth wall, distributed in parallel to layers, preserved as semi-relief.

Strata: 12th layer of Xiahedong Formation, Lower Cretaceous

Locality: Caojiacun Section in Santun Town, Ruyang County

Planolites is rare in the Cretaceous strata of Ruyang Basin, only found in Caojiacun cross section. According to previous study, *Planolites* sp. is formed in the flood plain and it is also considered to be formed by mud and sand filling in after worms burrowed through the deposits.

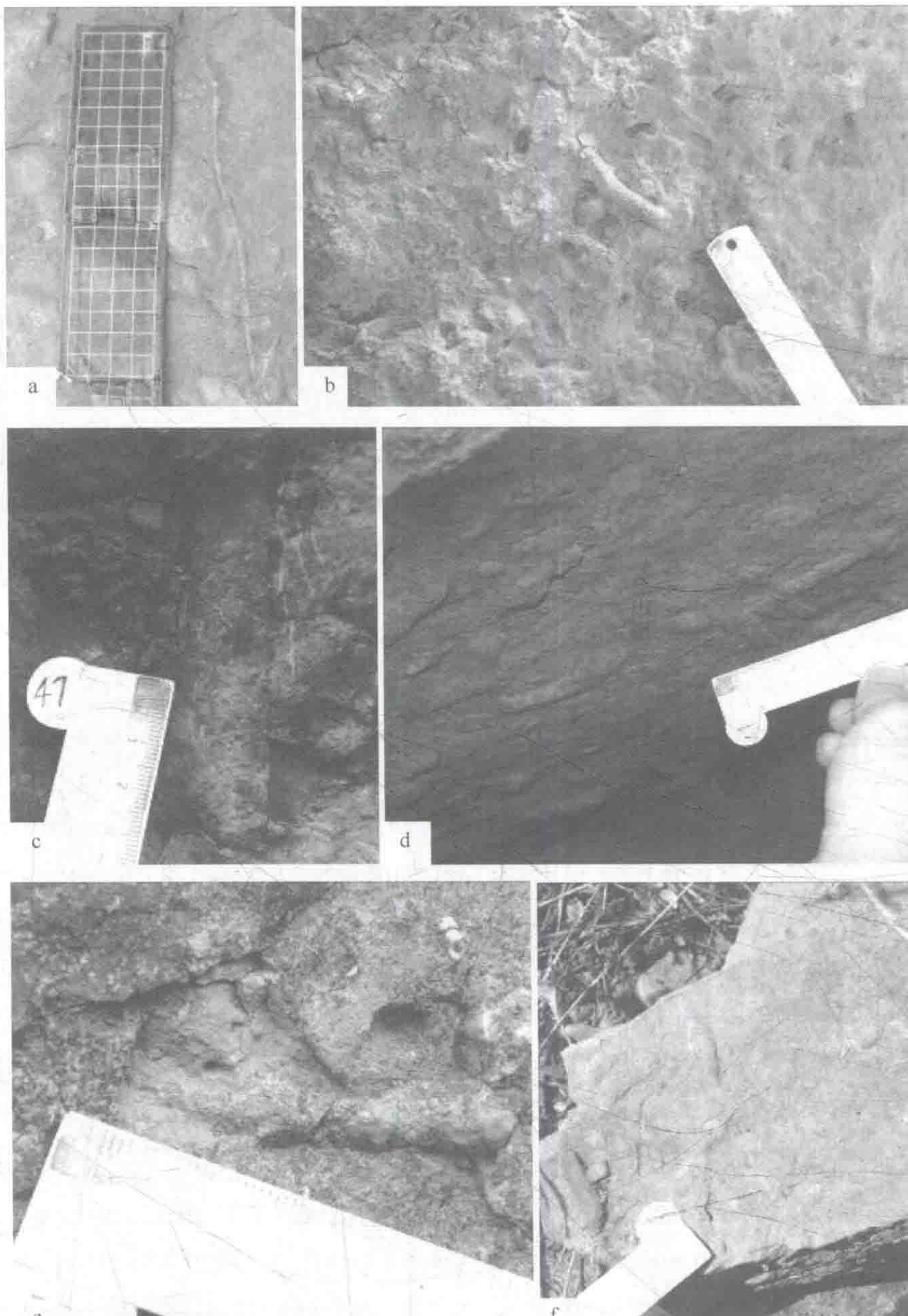


Fig. 4.14 Features and occurences of Cretaceous trace fossils in Ruyang Basin

a—*Planolites montanus*, a smooth, straight to curved, unbranched burrow that is parallel to bedding plane from layer11 in the middle part of the Xiahedong Formation; b—*Palaeophycus tubularis*, from layer 12 in the middle part of the Xiahedong Formation; c—f—from layer 47 in the middle part of the Haoling Formation. These burrows were generated mostly in silty fine grained sandstones

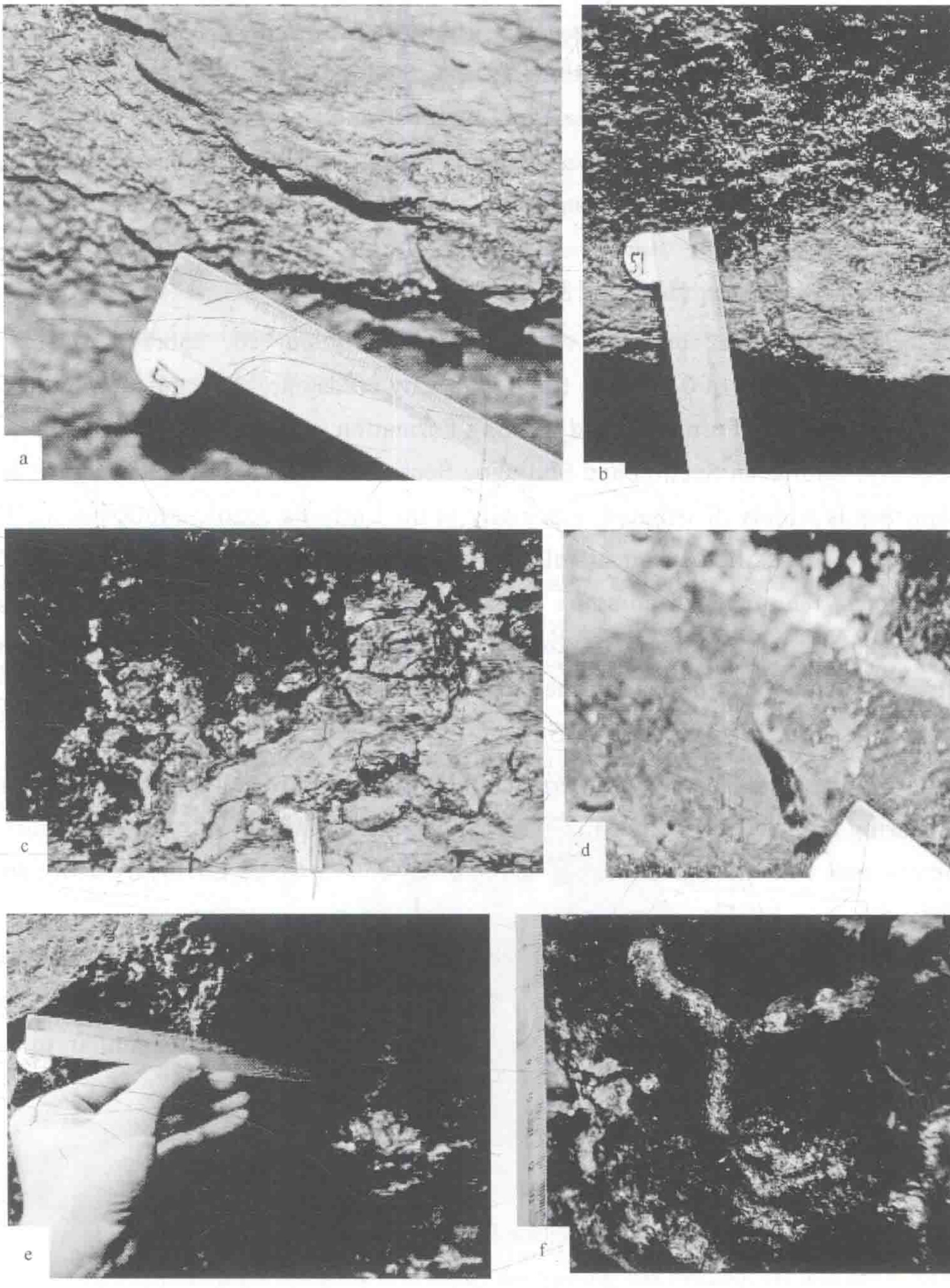


Fig. 4.15 Features and occurences of Cretaceous trace fossils in Ruyang Basin

a—*Palaeophycus tubularis;* b—*Skolithos* ichnosp, preserved in fine grained sandstones of layer 51(the middle part of the Haoling Formation); c—*Rhizoliths*, preserved in red mudstone of layer 52; d—*Planolites* isp., preserved in the bottom of fine grained sandstones from layer 54; e—f—*Palaeophycus tubularis*, occured in the bottom of coarse grained sandstones from layer 53

4.4.2.4 *Scoyenia gracilis* (Fig. 4.12b)

Description: Tubular burrows slightly curved, crescent backfill structures, length of 90 mm and width of 9 mm, distributed in parallel to layers.

Strata: the Lower Cretaceous 12th layer in Xiahedong Formation

Locality: Caojiacun Section in Santun Town, Ruyang County

Scoyenia gracilis is rare in the Cretaceous strata of Ruyang Basin, only found in Caojiaun Section. According to the analysis of this study, *Scoyenia gracilis* is formed in the flood plain environment.

4.4.2.5 *Skolithos* (Fig. 4.13)

Description: Tubular burrows straight, or slightly curved, unbranched, length of 3~13.5 cm and diameter of 0.5~1 cm, filled with silty mudstone, perpendicular to the layers.

Strata: Xiahedong Formation and Haoling Formation in Ruyang Basin.

Locality: Caojiacun Section and Shijiagou Section in Santun Town, Ruyang County.

Skolithos is widely distributed, especially in the Early Paleozoic strata, but the species have not been be classified systematically in a long time. Alpert (1974) reviewed the genus and its species, rearranged 6 common species from 35 once named species, and he also suggested that the trace makers of *Skolithos* were annelids and phoronids. According to analysis of this study, *Skolithos* is formed in alluvial environment.

4.4.2.6 *Rhizoliths* (Fig. 4.15c)

Description: Straight tubular, perpendicular or approximately perpendicular to the layers, bearing branches, diameter of 2~13mm and length ranging from several to dozens of centimeters, and with fillings in gray green and red colors which obviously differ from its surroundings.

Such root traces generally occur around the shallow roots in the original spots. It implies that the ground vegetations were as properous as present. Although we cannot determine what kind plant root it belongs to, we can infer they are similar to current grass-like plants.

Science links

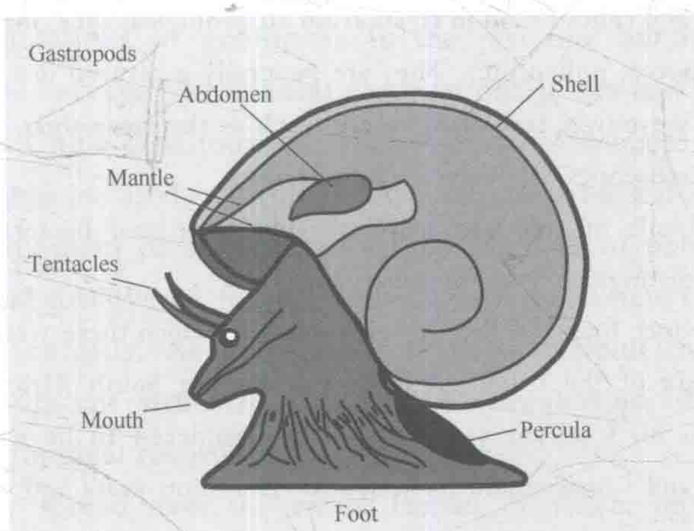
1. Invertebrates

Comparing with the vertebrates, the invertebrates are referred to the organisms without dorsal spines. They are the primitive form of organisms. Species of the invertebrates account for 95% of the total species of all organisms and are distributed around the world. There are more than one million species of invertebrates, which are twenty times of vertebrates and include Echinodermata, Molluscs, Platyhelminthes, Annelids, Coelenterates, Arthropods, Sponges and Nematomorpha. Sir David Attenborough, the famed BBC science host, once said "if all vertebrates disappear from the earth overnight, the world will still be safe, while if all the invertebrates disappear, the whole terrestrial ecosystem would collapse".

In morphology, invertebrates, from the small protozoa to the gigantic squid, are generally with soft bodies and without internal skeletons, but they have exoskeletons to attach muscles and protect their bodies, i.e., Molluscs, Crustaceans and Insects. Apart from having no vertebrae, there are no other similarities within the invertebrates. The invertebrates consist of an incredibly diverse phylum of organisms, in which there are not many common characteristics, just a little kinship with each other. Many types of invertebrates can only be found in the ocean, while some species, such as insects, commonly live on land all over the world.

2. Gastropods

The class of Gastropoda is from the mollusca phylum and one of the most widely distributed and diverse ones in the whole animalia, with species second only to the insects and over 100 thousand in total. They live all over the oceans, lakes, rivers, and on land, with the majority of them being marine. From an evolutionary perspective, acquatic was earlier than terrestrial, marine acquatic was earlier than non-marine aquatic. Periwinkles, whelks, and abalones, which we regard as delicious gourmet food, are all gastropods.



The head of Gastropod is developed very well with a pair or two pairs of tentacles and a pair of eyes. The radula in mouth is extremely developed for feeding and drilling. Its feet are located at the ventral body, so it is named as gastropod. Feet are generally used for crawling and swimming, sometimes for jumping. Some species often secrete a ceratin or calcium operculum in the end of the feet, which has a flat side and a convex or spiral side, with concentric patterns. The operculum can close and cover the shell when it faces threat or needs to sleep and prevent dehydration. Save for a handful of species (such as slugs), most gastropods have shells. The shell is spiral without any symmetry which is caused by body contortion during its growth. The gastropods are usually hermaphroditic and oviparous. Aquatic species breathe with gills and terrestrial ones breathe with the mantles just as pulmonaries. The first appearance of gastropod occurred in the early Cambrian, about 540Ma ago, and thrived from the early to middle Paleozoic (about 480~300Ma).

Most of them are benthic crawlers, and only a few are planktonic, or attached, burrowing and parasitic. Gastropod identification is mainly based on the characteristics of the carcass, shell and aperture morphology and shell decorations. The Diet of gastropods include carnivorous, herbivorous, carrion, plankton, and parasitic.

Gastropods can live in various environments and be very sensitive to environment changes, which means that different gastropoda faunas live in different environments. Therefore, more and more scientists focus on gastropods to study the environment. Research shows that the *Probaicalia-Reesidella* assemblage of the Gastropoda in Jehol Biota represents a freshwater environment, and the assemblage dominated by *Ptychostylus* of *Ellobiidae* may suggest a brackish water environment and the assemblage dominated by *Galba* and *Gyraulus* of *Pulmonata* may indicate a very shallow coastal environment.

3. Microfossils

Some fossils are too small to be seen by the naked eyes. Microfossils were defined as tiny paleontological remains and relics found in strata from all geological ages, for example, foraminifera, radiolaria, flagellates, spores, pollen etc.. They are generally measured in micron or millimeter, in which the rare "giants" are only a few centimeters, such as the *nummulites*. Therefore, microfossils have to be studied by microscopes or electronic microscopes.

Some microbial fossils of μm size, such as tiny algae and bacteria, are specially called nannofossils in order to distinguish from microfossils.

Nannofossils were once found in Precambrian strata in which there were no large fossils. They are the key to the study of the origin of bio-organisms. In South Africa, *Eobacterium isolatum*, discovered in the strata of 3 billion years ago, was considered to be a bacterium. Confirmed microfossils of bacteria and *Cyanobacteria* from about 1.9 billion years ago were found in Ontario, Canada.

Investigation on micropalaeontology is valuable because it can provide accurate stratigraphic information based on the longitudinal and transverse distributions of the microfossils in strata, which is widely applied in petroleum explorations for assessing the geologic age of the strata and reconstructing the paleoenvironment.

5 Exploring the Red Strata: the Cretaceous System in Ruyang Basin

Our knowledge of dinosaurs is acquired through studying the strata in which they were buried. Dinosaur fossils were buried in Mesozoic strata in every continent, from the North to the South Pole. Dinosaur fossils have extensive and broad geographical distribution, and have been discovered in abundance with other fossil resources, which were deposited in Mesozoic strata everywhere.

Mesozoic Erathem in Henan, including Triassic System, Jurassic System and Cretaceous System, consists of well developed and continuous terrestrial strata of deposits. Previous research has accumulated rich knowledge on the stratigraphical sequences and their correlation, including the lithostratigraphy and biostratigraphy of every basin in Henan; detailed chronostratigraphy has been established through the hard work by several generations of geologists in the last one hundred years, especially through the geological surveys and mineral explorations in the last sixty years, since the People's Republic of China was founded. However, the Mesozoic basins in Henan are mostly unconnected and isolated, with different geological background and structure, as reflected in the environment of sedimentation, the richness of paleobiota, the disparity between preserved and discovered fossils, and the difference between the actual and the preserved geological records. As a result, it is very difficult to delineate, compare, correlate, or trace adjacent strata or strata in nearby basins, if relying entirely on terrestrial lithostratigraphical records.

Although widely spread over the entire Henan Province, only spotty outcrops of Cretaceous strata can be found in graben basins and fault depression basins in the west and the southwest of Henan, and in the north slopes of Dabie Mountains, where they are relatively well developed in Yima Basin, Wumu Basin, Ruyang Basin, Tantou Basin, Wulichuan Basin, Zhaobei Basin, Xixia Basin, Xiaguan Basin, Xichuan Basin, Liguanqiao Basin, Rendian Basin, Pingchangguan Basin, Luo Mountain Basin, and Huanggu Basin. The lower Cretaceous consists of a series of volcanic sedimentary rocks and a set of red clastic rocks; the upper Cretaceous consists of a series of red conglomerates, sandy conglomerates, sandstone, siltstone, silt clay and clay, which belong to fluvial-pluvial fan and lacustrine facies of alluvial sedimentation, with volcanic sedimentary facies in some areas.

Ruyang Basin, which is a geological definition and a geographical part of the Waifang Mountains, was formed with Mesozoic-Cenozoic deposits with a thickness of over 4,000 meters and a range from the west of Jiudian of Song Count in the west to the east of Mangchuan of Ruzhou City in the east through Shangdian, Santun and Liudian. Ruyang Basin, a Mesozoic fault basin, which extends from NWW to SEE and then changes to SW-NE, is controlled by two groups of faults that extend northwest and northeast, and by Sanmengxia-Lu Mountain faults in the south and the east, with a width of 8 km from south to north and 34 km from east to west and a total area of 272 square kilometers, in the shape of a arched bow facing southeast. Developed faults in this area form fault-block structure of graben and horst in the shape of a pear. In cross sectional view, the positions of ancient uplifts and basins are clearly shown, reflecting a landscape with intertwined basins and uplifts and an increasing size of the basin from south to north (Fig. 5.1, Fig. 5.2).

Ruyang Basin is characterized by well exposed strata, complex geological structures, developed igneous rocks, and abundant mineral deposits of lead, zinc, and molybdenum. Many institutions and individuals had conducted geological survey and mineral exploration work in the area before the founding of the People's Republic of China.

From the early 20th century to the founding of the People's Republic of China, Ding Wenjiang, Johan Gunnar Andersson, Huang Jiqing, Yang Zhongjian, Pei Wenzhong, Pierre Teilhard de Chardin, George B. Barbour, Bian Meinian, Zhang Renjian, and Han Yingshan had surveyed the geology and mineral deposits in the area, discussed the stratigraphy and geology in the area from different aspects, and devised the stratigraphy of Qingling System, Zuoshui System, Zheng'an System, Fanzhuang System and Wudang Group. Alongside the pioneering work in mapping the geology and the mineral deposits, some of them have remained influential ever since, such as the concept of "the Qinling Geoaxis".

In 1965, the Regional Geological Survey and Mapping Team of Henan Bureau of Geology submitted the 1:200,000 scale geologic map and the map of mineral resources of Linru, in which the strata in Ruyang Basin were subdivided into Upper Cretaceous Jiudian Formation, Paleogene Chenzhaigou Formation, Mangchuan Formation, and Shitaijie Formation in ascending order. The stratigraphical sequence in the 1965 report has been in use to this day and undergone little change in its definition, especially for the Precambrian-Paleozoic strata, where many mineral deposits were found at that time. Between 1991 and 1994, the Second Geological Survey Team of the former Henan Department of Geology and Minerals completed the 1:50,000 scale geologic mapping of Ruyang, Yanglou, and Minggao sheets, in which the stratigraphical viewpoint of 1965 was inherited.

During the work of this project, more than ten layers of strata that contained dinosaur, invertebrate, microbody and plant fossils were discovered in strata originally assigned as

"Mangchuan Formation". In fossil-intensive localities, large scale mapping and detailed cross section survey were conducted, samples of radioactive dating, stable isotopes, geochemical samples, thin rock sections were collected and tests were run. The results suggest that previous designation and correlation of Chenzhaigou Formation and Mangchuan Formation were erroneous and that they should be assigned to Cretaceous, which is consisted of lower Cretaceous Xiahedong Formation, Haoling Formation and Shangdonggou Formation. The overlying Shitaijie Formation, formerly assigned as Paleogene, should be re-studied for its stratigraphical definition (Xu et al., 2012) (Table 5.1).

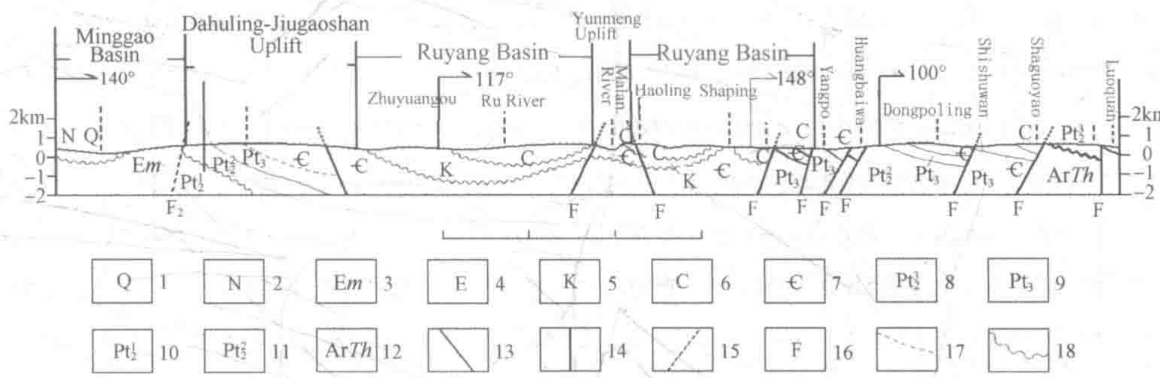


Fig. 5.2 Profile diagram of geological structure of Ruyang Basin

1—Quaternary; 2—Neogene; 3—Mangchuan Formation; 4—Paleogene Luoyang Formation; 5—Cretaceous; 6—Carboniferrous; 7—Cambrian; 8—Sinian Luoquan Formation; 9—Late Proterozoic; 10—Upper Middle Proterozoic; 11—Lower Middle Proterozoic;12—Archean Taihua Group; 13—Fault and its strike; 14—Vertical fault; 15— Projected fault and its strike; 16—Fault number; 17—Parallel Uncomformity; 18—Angular Unconformity

Table 5.1 Correlation and Comparison of Mesozoic Strata in Ruyang Basin

1:200000 Scale Regional Geologic Report of the Linru Sheet, 1964			
Cenozoic	Neogene		Daying Formation
Cenozoic	Neogene		Luoyang Formation
Cenozoic	Paleogene		Shitaijie Formation
Cenozoic	Paleogene		Mangchuan Formation
Cenozoic	Paleogene		Chenzhaigou Formation
Mesozoic	Cretaceous		Part 2
Mesozoic	Cretaceous		Part 1
Paleozoic	Permian	Upper	Shiqianfeng Formation Part 2
Paleozoic	Permian	Upper	Shiqianfeng Formation Part 1
Paleozoic	Permian	Upper	Shangshihezi Formation Part 2
Paleozoic	Permian	Upper	Shangshihezi Formation Part 1
Paleozoic	Permian	Lower	Xiashihezi Formation
Paleozoic	Permian	Lower	Shanxi Formation

1:50000 Scale Regional Geologic Report of the Mingao, Ruyng, and Yanglou Sheets, 1995				
Cenozoic	Neogene			Daying Formation
Cenozoic	Neogene			Luoyang Formation
Cenozoic	Paleogene			Shitaijie Formation
Cenozoic	Paleogene			Mangchuan Formation
Cenozoic	Paleogene			Chenzhaigou Formation
Mesozoic	Cretaceous	Lower Cretaceous	Jiudian Formation	Part 2
Mesozoic	Cretaceous	Lower Cretaceous	Jiudian Formation	Part 1 (L2, L1)
Paleozoic	Permian	Upper Permian	Shihezi Formation	Pingdingshan Sandstone
Paleozoic	Permian	Upper Permian	Shihezi Formation	Part 2
Paleozoic	Permian	Upper Permian	Shihezi Formation	Part 1
Paleozoic	Permian	Lower		Shanxi Formation

This Report Henan Geological Museum, 2013			
Cenozoic	Neogene		Daying Formation
Cenozoic	Neogene		Luoyang Formation
Cenozoic	Paleogene		Shitaijie Formation
Mesozoic	Cretaceous	Upper K	Shitaijie Formation
Mesozoic	Cretaceous	Lower Cretaceous	Shangdonggou Formation
Mesozoic	Cretaceous	Lower Cretaceous	Haoling Formation
Mesozoic	Cretaceous	Lower Cretaceous	Xiahedong Formation
Mesozoic	Cretaceous	Lower Cretaceous	Jiudian Formation
Paleozoic	Permian	Upper Permian	(Pingdingshan Part) Shangshihezi Formation
Paleozoic	Permian	Lower Permian	Xiashihezi Formation
Paleozoic	Permian	Lower Permian	Shanxi Formation

5.1 Jiudian Formation

In 1962, Henan Research Institute of Geology named the gray, light red clastic crystal tuffs, found around Tianhu in Song County, the Tianhu Formation and assigned it to the late Cretaceous. In 1964, Henan Regional Geological Survey Team named the same strata Jiudian Formation, which was subdivided into the upper and lower part and assigned to the early Cretaceous. In 1989, "*Lithostratigraphy of Henan Province*", as a part of the national stratigraphical study and comparison, was published by the Henan Department of Geology and Minerals, in which the name of Jiudian Formation was chosen and the name of Tianhu Formation was discontinued. In 1996, the Second Geological Survey Team of Henan Province completed the 1:50,000 scale Ruyang Sheet and Yanglou Sheet of regional geographic map, in which the Jiudian Formation was inherited, subdivided into upper and lower part, and assigned to the early Cretaceous (Henan Department of Geology and Minerals, 1996).

Jiudian Formation crops out mainly between Jiudian of Song County and Baishu of Ruyang County, and is divided into upper and lower strata based on their lithology. No cross section study was done during this work. The following introduction is based on previous studies.

5.1.1 The Lower Jiudian Formation (K_1j^1)

Onsite geological cross section of lower Cretaceous Jiudian Formation (K_1j^1) in Pihuzigou in Song County is shown in Fig. 5.3.

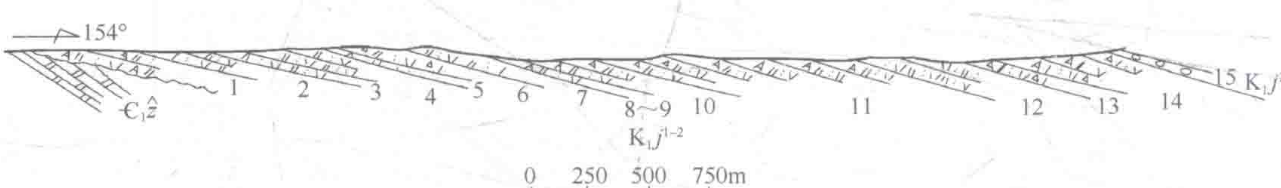


Fig. 5.3 The cross sectionof the upper part of the Lower Cretaceous Jiudian Formation (K_1j^{1-2}) in Pihuzigou, Song County

Overlying strata: upper part of Jiudian Formation (K_1j^2), pale purple conglomerates.

—————Parallel unconformity—————

The top of lower Jiudian Formation	Thickness 1017.8m
14. Gray and red sedimentary crystal tuff with blocky breccia	148.4m
13. Gray brecciated sedimentary crystal tuff	43.7m
12. Gray, red, thick-bedded, sedimentary blocky crystal tuff	100.0m
11. Gray brecciated crystal tuff	300.0m

10. Gray, red thick-bedded sedimentary breccia and crystal tuff 75.1m

9. Gray, medium thick-bedded sedimentary lithie and crystal tuff 8.0m

8. Gray, red thick-layered brecciated sedimentary crystal tuff 7.9m

7. Gray, red medium-thick-bedded gravel, sedimentary crystal tuff 25.8m

6. Gray, red thick-bedded brecciated sedimentary crystal tuff 49.0m

5. Gray, white thick-layered brecciated sedimentary crystal tuff 4.6m

4. Gray, red, medium-thick-bedded crystal tuff with conglomerate lens, scouring surface visible at bottom, developed diagonal cross bedding of crystal tuff 98.6m

3. Gray, white, thick-layered brecciated sedimentary crystal tuff 30.5m

2. Gray, white, thick-bedded brecciated crystal tuff 48.7m

1. Gray, red, thick-bedded gravelly crystal tuff 77.5m

~~~~~~~~~~ Angular unconformity ~~~~~~~~~~

Underlying strata: Cambrian Zhushadong Formation ($Є_1\hat{z}$), striped limestone and dolomite

The top of lower Jiudian Formation's lithologic sequence is: gray, red and white, thick red, blocky breccia (or gravel), thick crystal tuff (Fig. 5.4), with a thickness of 1017.8 m.

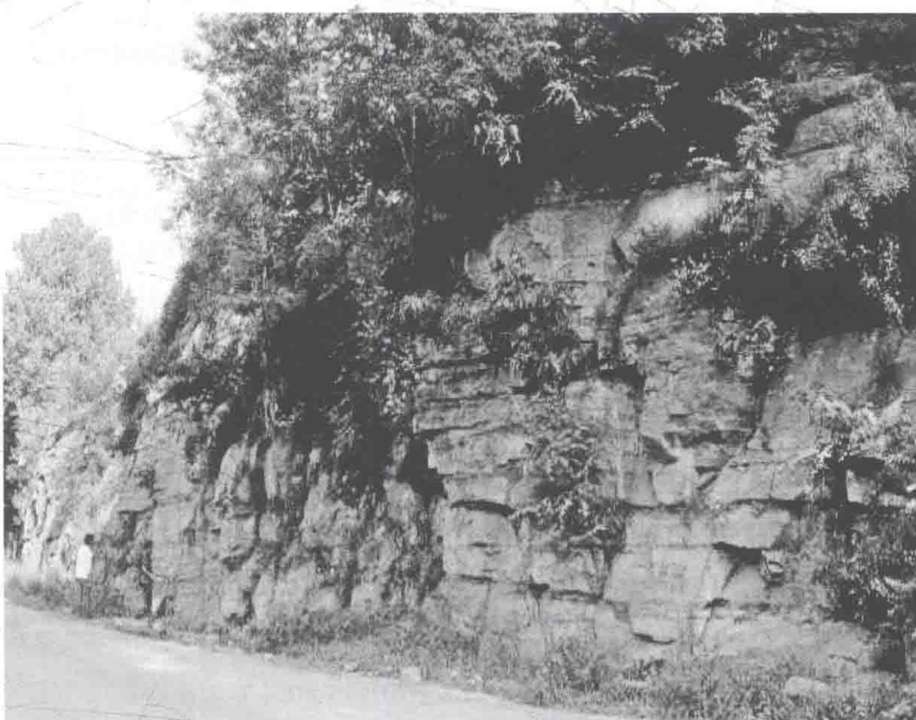


Fig. 5.4 Pale gray crystal tuff with blocky breccia in the middle of lower Jiudian Formation

The bottom of lower Jiudian Formation crops out only in the north of Jiudian in Minggao sheet, with a lithology of conglomerate, including rhyolite, andesite, silicolite, clay and with minor amount of crystal tuff appearing in base cement. The bottom of
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lower Jiuduan Formation is also seen in the bore hole in Siwan with a thickness of 3.88 meters.

5.1.2 The Upper Jiudian Formation (K_1j^2)

The outcrop of the upper Jiudian Formation, located in Guogou-Pei'wa in Song County, is easily accessible through roads, well exposed, lithologically stable, and with well-developed sedimentation structure, well-defined stratigraphic sequence and clear relationship with upper and lower strata. It is summarized as follows:

Onsite geological cross section of the upper Jiudian Formation of Cretaceous in Peiwa in Song County is shown in Fig.5.5.

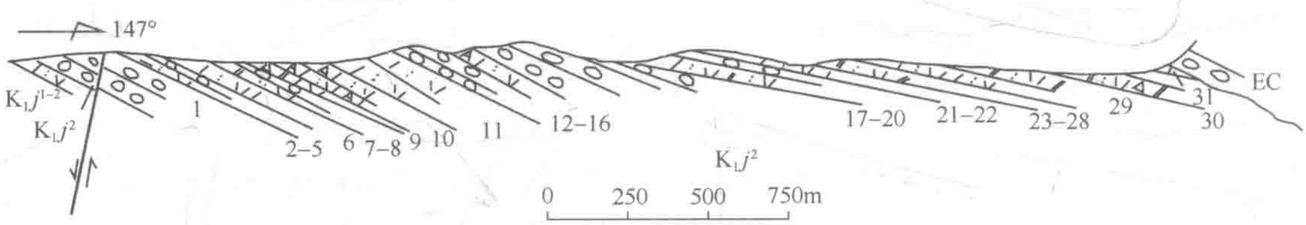

Fig. 5.5 The cross section of the part two of Cretaceous Jiudian Formation (K_1j^2) in Peiwa, Ruyang County

Overlying strata: Xiahedong Formation (K_2x) of the Upper Cretaceous.

———— Complete conformity ————

The upper part of Jiudian Formation (K_1j^2)	837.1m
31. Gray red, thick-layered crystal tuff interbedded with ash white thick-layered crystal tuff	38.2m
30. Gray, green medium-thick-bedded crystal tuff with gray medium-thick-bedded crystal tuff, and cross bedding visible	60.7m
29. Gray, white thin layer crystal tuff interbedded with ash red crystal tuff	60.5m
28. Gray, red, thick-bedded conglomerate with gray green sandstone lenses	9.4m
27. Gray, green thin-layered crystal tuff with red breccia lenses	13.5m
26. Pale red, thick-bedded calcareous crystal tuff	1.0m
25. Gray, green, medium thick-bedded coarse sandstone, with gray green breccia at top	9.7m
24. Gray green medium thick-bedded crystal tuff interbedded with gray green breccia lenses, and with tabular cross bedding	7m
23. Gray, green thin-layered crystal tuff interbedded with ash red thin crystal tuff	9.4m
22. Pale red, thick-bedded crystal tuff	8.7m
21. Gray, green medium thick-bedded crystal tuff interbedded with gray green thin	

crystal tuff 5.1m

20. Gray, red medium thick-bedded conglomerate 4.4m
19. Gray, green, medium thick-bedded crystal tuff with thin-bedded red crystal tuff 26.3m
18. Gray, red medium thick-bedded conglomerate 19.1m
17. Gray, red medium thick-bedded crystal tuff with red crystal tuff 8.4m
16. Gray, red medium thick-bedded conglomerate 33.2m
15. Gray, red thick-layered brecciated crystal tuff 14.3m
14. Gray, red conglomerate, with partial gray red thin-bedded sandstone 11.2m
13. Gray, medium thick-bedded crystal tuff 8.6m
12. Gray, red thick-bedded conglomerate 37.8m
11. Gray medium thick-bedded tuffaceous muddy crystal dolomitic limestone and gray thick-layered tuff 130.4m
10. Gray red thin-medium-bedded crystal tuff and gray thin-bedded brecciated crystal tuff 71.4m
9. Gray red medium thick-bedded crystal tuff with light brownish red breccia lenses 40.5m
8. Gray red thick-bedded conglomerate 9.7m
7. Gray white calcareous crystal tuff and ash red thin crystal tuff interbedded 37.9m
6. Brown, red thin-layered crystal tuff and ash white thick tuffaceous mudstone and dolomite with conglomeratic lenses 55.2m
5. Red, brown thick-bedded conglomerate 16.0m
4. Gray, medium thick-bedded calcareous crystal tuff 6.3m
3. Dark red, brown gray mudstone conglomerate 9.6m
2. Gray, red tuffaceous mudstone and gray calcareous crystal tuff, with conglomerate lenses 9.4m
1. Light purple red, red conglomerate 61.5m

— — — — — Parallel unconformity — — — — —

Underlying strata: the lower part of Jiuduan Formation (K_1j^1): gray white thick-layered crystal tuff

The lithology of the formation is: the lower part is purple red, brown red, thick-bedded massive conglomerate, gray medium-sized, thick-bedded crystal tuff, and tuffaceous muddy dolomitic limestone; the upper part is gray red, gray green, thick-bedded conglomerate, and gray white and gray red crystal tuff interbedded together, with tabular cross bedding and a thickness of 837.1m (Fig. 5.6). Overlying Xiahedong Formation is in parallel unconformity with Jiudian Formation; crystal tuff of Jiudian Formation appears in the conglomerates in the bottom of Xianhedong Formation (Fig. 5.7), which suggests a brief discontinuation between the two formations.

The Lower Jiudian Formation can be seen in east of Baishu, Ruyang Basin.

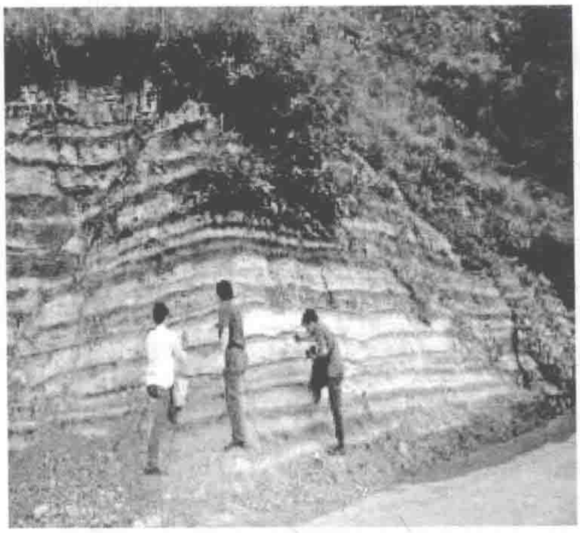

Fig. 5.6 Interbedded brown and gray crystal tuffs with blocky breccia in the upper Jiudian Formation

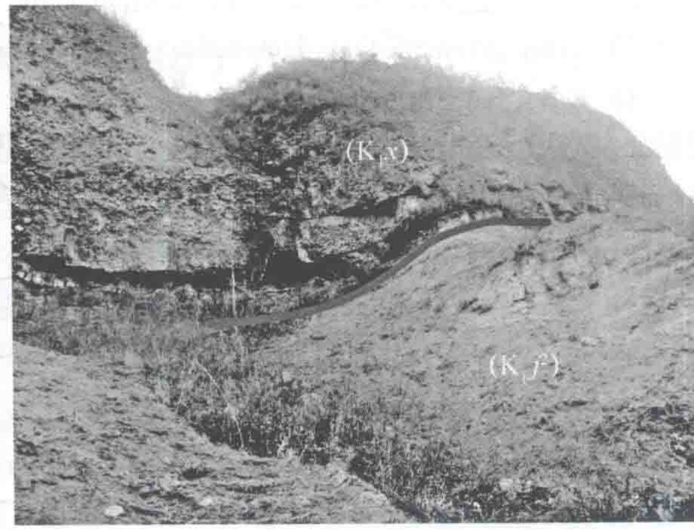

Fig. 5.7 Parallel unconformity between Xiahedong Formation(K_1x) and Jiudian Formation(K_1j^2)

5.2 Xiahedong Formation

Xiahedong Formation is equivalent to the former Chenzhaigou Formation. Henan Regional Geological Survey Team (1964) named it in Chenzhaigou in Yiyang County, while mapping the 1:200,000 scale Luoyang sheet geologic map, with the original definition that "Chenzhaigou Formation is in unconformity with Cretaceous Jiudian Formation and lower Precambrian Xushan Formation, and in gradual transition with overlying Mangchuan Formation, and consists of red conglomerate, glutenite with mudstone and shale". It was dated to early Tertiary (Paleogene). The Second Geological Survey Team of Henan Department of Geology and Minerals (1996) inherited the name in the Ruyang sheet of the 1:50,000 regional geologic map. Based on the new research, the strata were renamed as Xiahedong Formation (Xu Li et al, 2012) and the holostratotype section was surveyed and mapped.

Xiahedong Formation crops out primarily in the west of Malan River, which includes Baishu, Gaojiacun, Jijialing and Datiandi, Guandigou, Jinjiacun, Gujiagou, Beigou, and in the east of Malan River, which includes Zhaojiagou, Zhonwa, Heishipo, with a total exposed area of approximate 30 square km. No dinosaur fossils were found in the strata.

In the work area, Xiahedong Formation crops out in an incontinuous manner. The type cross section survey was done in two segments. The lower strata was surveyed in

Wangtunxigou and Santun, south of the Ruyang County, while the upper strata was surveyed in Zhaojiagou, which is in the east of Malan River and southeast of Ruyang County. There are no complete outcrops and two segments cannot be fully linked. The onsite surveyed sections are decently exposed and lithologically stable. A brief summarization is as follows:

(1) The onsite surveyed geological cross section of Xiahedong Formation (K_1x) of Cretaceous in Wangtunxigou, Ruyang County (Fig. 5.8). The contact relationship with the underlying Jiudian Formation is parallel unconformity. The upper boundary is unseen because of the overlying Quaternary deposits.

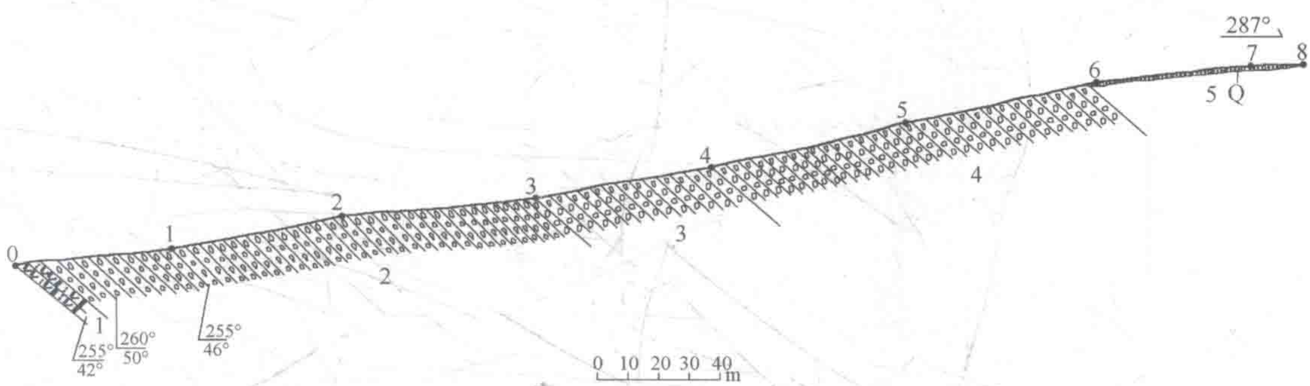

Fig. 5.8 The onsite surveyed cross section of lower Creatceous Xiahedong Formation at Wangtunxigou, Santun Town, Ruyang County

Overlying strata: Quaternary clay, sandy soil (farmland)

~~~~~~~~ Unconformity ~~~~~~~~

Xiahedong Formation (K_1x)	220.51m
3. Purple and gray massive coarse and medium grained polymictic conglomerates, occasionally mixed with unstable sandstone bands, 0.5 ~ 0.8m thick	82.40 m
2. Purple and gray massive coarse and medium grained polymictic conglomerates	39.66 m
1. Purple massive coarse and medium grained polymictic sandstone	98.45 m

— — — — —Parallel unconformity— — — — —

Underlying strata: Jiudiangou Formation (K_1j) of lower Cretaceous. Purple banded crystal tuff.

(2) The onsite surveyed geological cross section of Xiahedong Formation (K_1x)-Haoling Formation (K_1h) of lower Cretaceous in Zhaojiagou, Santun Town-Shijiagou, Liudian Town in Ruyang (Fig. 5.9). The bottom of Xiahedong Formation has not been found because of Quaternary deposits by the Malan River, and the contact relationship with the overlying Haoling Formation is conformity.

Description of the cross section:
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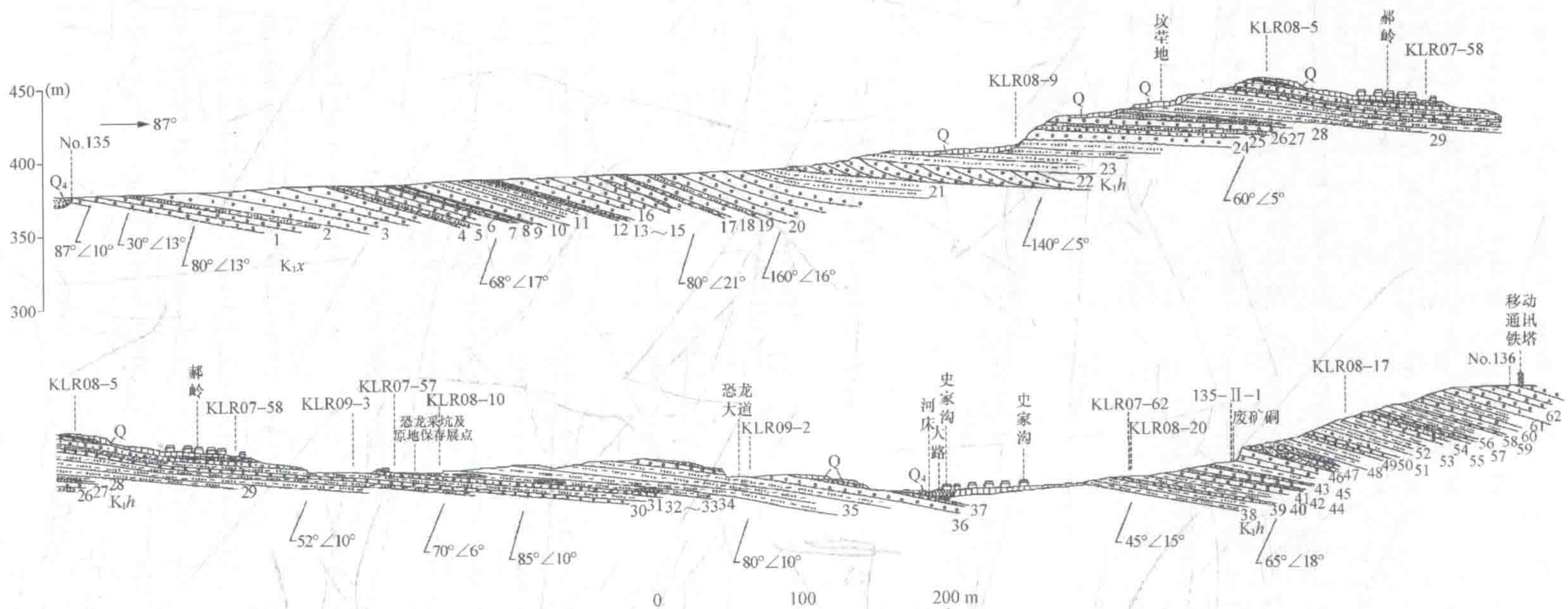


Fig. 5.9 The onsite surveyed cross section of lower Createceous Xiahedong Formation-Haoling Formation from Zhaojiagou, Santun Town, to Shijiagou, Liudian Town, Ruyang County

Overlying strata: Haoling Formation of lower Cretaceous (K_1h), light purple thick-layered medium grained polymictic conglomerates with distinct scouring surface.

———— Conformity————

Xiahedong Formation (K_1x)	Outcrop thickness 142.66m
21. Purple thick-layered argillaceous siltstone	6.36m
20. Light purple and green gray thick-layered medium grained polymictic conglomerates.	22.93m
19. Brown-red, thick-layered massive argillaceous siltstone	1.85m
18. Light purple and green gray thick-layered, medium grained polymictic conglomerates	5.56m
17. Brown-red, thick-layered argillaceous siltstone	1.54m
16. Light purple and green gray thick-layered, medium grained polymictic conglomerates, interbedded with sandstone bands on the top, 0.1 ~ 0.3m thick	28.72m
15. Brown-red, thick-layered pebbly argillaceous siltstone	1.09m
14. White, thick-layered heterogranular feldspatic arenite	0.41m
13. Brown-red, thick-layered pebbly argillaceous siltstone	0.38m
12. Pale white, thick-layered glutenite	0.31m
11. Brown-red, thick-layered argillaceous siltstone	11.54m
10. Light purple, thick-layered medium grained polymictic conglomerates	5.01m
9. Gray and light purple, thick-layered conglomerates	0.60m
8. Gray and light purple, thick-layered medium grained polymictic conglomerates	1.59m
7. Brown-red, thick-layered argillaceous siltstone	0.99m
6. Light purple, thick-layered medium grained polymictic conglomerates	6.41m
5. Light purple, thick-layered medium grained polymictic conglomerates and brown-red, thick-layered pebbly argillaceous siltstone interbedded	2.43m
4. Pale white, thick-layered pebbly heterogranular feldspathic arenite	0.75m
3. Gray-green and light purple, thick-layered medium grained polymictic conglomerates	34.78m
2. Brown-red, thick-layered argillaceous siltstone	1.81m
1. Light purple, thick-layered coarse and medium grained polymictic conglomerates, occasionally interbedded with sandstone band 0.1～0.4m thick	> 7.59m

———— The lower boundary has not been found ————

The lower part of Xiahedong Fomation consists primarily of purple (polymictic) conglomerate; the middle part is mostly purple red conglomerate, brown (gravelly) argillaceous siltstone, gray sandstone, glutenite; the upper part is alternating purple, green, gray and purple argillaceous siltstone, purple sandy shale, with a thickness of 79 ~ 363 meters. In each depositional cycle of conglomerate-argillaceous siltstone, siltstone becomes thinner upward in sedimentation, and the thickness of argillaceous siltstone layer is less than that of conglomerate layer, which is the key criterion to distinguish Xiahedong Formation from the overlying Haoling Formation. Marks of alluvial plane between the two formations are well defined and with frequent occurrence of bands or concentrations of mudstone in the alluvial conglomerates in the lower Haoling Formation (Fig. 5.10).

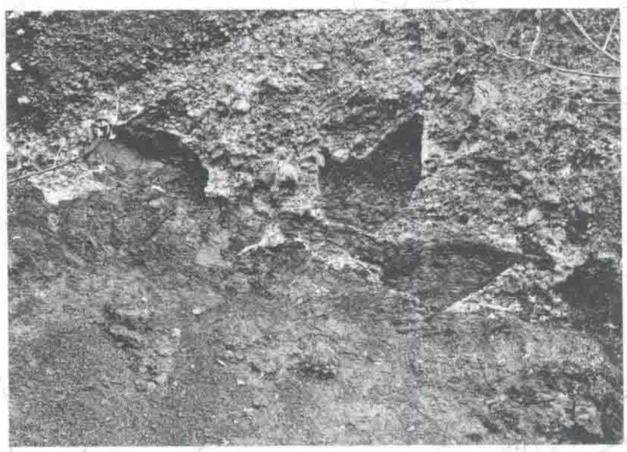


Fig. 5.10 Mudstone blocks from the top of Xiahedong Formation sandwiched into the bottom of Haoling Formation

The reddish purple conglomerate in the bottom contains gravels that vary greatly in rounding, the majority of which are in spherical and elliptic shapes, mixed with angular, sharp-edged gravels. Most are in the sizes of 6cm × 10cm ~ 15cm × 20 cm and from volcanic rocks of Xionger Formation and conglomeratic tuff from Jiudian Formation underneath, which are aligned in directional order and supported by a mixed matrix. Underlying are mixed mudslide gravels with various sizes and poor sorting. (Fig. 5.11, Fig.5.12)

Fig. 5.11 Hugely thick layers of purple conglomerate in the bottom of Xiahedong Formation

Fig. 5.12 Fluvial conglomerate at the bottom of Xiahedong Formation, with varied sizes and poor sorting

5.3 Haoling Formation

Haoling Formation is equivalent to the middle and lower part of the original Mangchuan Formation, which was established by the Regional Geological Survey Team of Henan Province, near Mangchuan of Ruzhou City in 1964, with the original definition that "the lithology is red sandstone, conglomerate, sandy shale, marl limestone and carbonaceous shale, interbedded with pale sandstone and conglomerate." It gradually and conformably transited into underlying Chenzhaigou Formation and overlying Shitaijie Formation and was dated to the Paleogene. It was redefined as "brown-red mudstone, sandy shale, gray-white mudstone, gray sandy conglomerate or interbedded conglomerate, local gray-black carbonaceous shale, fine-grained sandstone and gray-red conglomerate, in conformity with the underlying Chenzhaigou Formation and the overlying Shitaijie Formation", in "*The Lithology of Henan Province*" (1997) by Henan Department of Geology and Minerals.

In 2006, this research discovered several layers of dinosaur and other paleontological fossils in this formation. Based on lithology, paleontological assemblages, sequences of sedimentation, it was broken up and subdivided into two stratigraphic formations, the middle and lower part as the Haoling Formation, the upper part as the Shangdonggou Formation. The onsite type cross section map was surveyed.

Haoling Formation in Ruyang Basin is mainly distributed in the south of Liudian, to east of Malan River, and in the north of Jiliaojie. It also appears in Shangfangou, Qiugou, and Wandiangou, covering an area of about 40 square kilometres.

The onsite surveyed cross section was divided into two segments; the middle and lower part was conducted between Zhaojiagou and Shijiagou; the upper part was in the village of Heyezui in Santun, where the outcrop is excellent, lithology is stable and depositional structure is well developed. Eight auxiliary cross sections were also surveyed in Xiahedong, Caojiacun, Langdonggou, Tuqiaoxigou, Miaoling, Yujiagou, Huamiaogou, Boqizhang, and Zhangling. Eight dinosaur-fossil-bearing layers, two dinosaur-egg-bearing layers, several layers bearing bivalves, gastropods, ostracods, charophyta, pollens and plant fossils were confirmed. Through observing and comparing the whole area, Haoling Formation is in clear conformity with underlying Xiahedong Formation and overlying Shangdonggou Formation, and with prominent scour marks of alluvial activities at the lower boundary. The cross section description is listed below:

(1) The lower part of surveyed cross sections of Haoling Formation is located in Ruyang County, from Santun to Shijiagou, and is in the same cross section as Xiahedong Formation (Fig. 5.9). Outcrop is good, lithology stable, and sedimentary structure

well-developed.

——— Top of the formation not found ———

Haoling Formation (K_1h)	256.56 m
62. Purple, green and gray thick layers of gravel polymictic conglomerate	17.78m
61. Massive brown muddy siltstone	6.34m
60. Purple, lime green thick layers of gravelly polymictic conglomerate	2.27m
59. Reddish brown massive muddy siltstone	5.09m
58. Purple thick-bedded sandstone and conglomerate (lenses)	0.24m
57. Reddish brown massive muddy siltstone	7.59m
56. Purple red, lime green thick-medium gravelly polymictic conglomerate	0.98m
55. Reddish brown massive muddy siltstone	1.96m
54. Gray-green, yellow-green thick-bedded fine-grained feldspathic sandstone	2.45m
53. Green gray thick-bedded gravelly conglomerate	2.45m
52. Massive brown muddy siltstone containing dinosaur fossils (KLR08-17)	11.29m
51. Green, gray, yellow thick-bedded fine-grained feldspathic sandstone, with small wedge-shaped cross-bedding	3.94m
50. Green gray thick gravelly polymictic conglomerate	3.61m
49. Yellow-green thick-bedded fine-grained feldspathic sandstone	0.70m
48. Reddish brown massive muddy siltstone	9.34m
47. Yellow-green thick layers of fine-grained feldspathic sandstone, with large wedge-shaped cross-bedding	11.21m
46. Green gray thick gravelly polymictic conglomerate	8.86m
45. Gray thick, massive silty mudstone, containing locally a large amount of pyrite nodules. Containing abundant bivalves: *Sphaerium coreanicum*, *Sphaerium jeholense, Sphaerium* cf. *pujiqngense, Sphaerium selenginense, Sphaerium* sp.; Abundant gastropods: *Bithynia* sp., *Bithynia* sp., *Zaptychius* sp., *Zaptychius* sp., *Reesidella multilaminate* xiazhuangensis; A small amount of ostracods: *Lycopterocypris* sp., *Cypridea* sp.; A small number of plants: *Podozamites* sp., *Ginkgoites* sp., *Brachyphyllum* ? sp., cf. *Brachyphyllum obtusicapitatum*	6.58m
44. Thick-bedded pebbly gray argillaceous siltstone	1.10m
43. Green gray thick gravel polymictic conglomerate	5.06m
42. Brown thick-bedded silty mudstone	1.80m
41. Gray gravelly polymictic conglomerate	4.06m
40. Massive brown muddy siltstone containing dinosaur fossils (KLR07-62, KLR08-20)	5.18m

39. Gray, pink thick-bedded calcareous cement conglomerate 0.76m

38. Brown thick-massive muddy siltstone 31.23m

37. Brown thick-bedded fine-grained feldspathic sandstone 1.04m

36. Purple red, green, gray thick gravelly polymictic conglomerate 5.32m

35. Brown thick, massive muddy siltstone (gray-green bands), with dinosaur bones scattered at top in different places (KLR09-2) and with thin conglomerate bands 23.38m

34. Brown-red (purple) thick-bedded argillaceous siltstone with thick-bedded fine-grained feldspathic sandstone bands, including dinosaur fossils KLR07-57/58, KLR08-5/10 and bivalves of genus *Nakamuranaia* aff. *chingshanensis* Grabau; *N. sub-rotunda* Gu et Ma 3.82m

33. Green-gray thick-bedded fine grained feldspathic sandstones (including small gravels that phase into conglomerate locally) 1.39m

32. Gray thick-bedded sandy polymictic conglomerate 1.94m

31. Brown muddy siltstone and thick-bedded sandstone, with conglomerate bands, containing dinosaur bones fossil KLR09-3 2.59m

30. Gravelly polymictic thick-layered greenish gray conglomerate 1.94m

29. Reddish brown massive muddy siltstone 18.25m

28. Brown thick-bedded argillaceous siltstone with thin to thick laminated shale and fine sandstone 7.96m

27. Purple red, thick gravelly polymictic conglomerate 3.59m

26. Purple thick laminated shale with with argillaceous siltstone and fine sandstone 2.66m

25. Unequigranular gray thick-bedded feldspathic sandstone 0.53m

24. Thick purple red conglomerate 8.52m

23. Brown blocky muddy siltstone containing dinosaur bone fossils (KLR08-9) 13.68m

22. Purple red thick-bedded polymictic conglomerate, with unidirectional tabular diagonal cross bedding and underlying reddish brown mudstone, scouring surface very distinctive 8.08m

———— Conformity ————

Underlying strata: Xiahedong Formation (K_1x) of lower Cretaceous, purple argillaceous siltstone.

(2) Onsite surveyed cross section of Haoling Formation in Xiahedong Village and Heyezui Village, Santun Town, Ruyang County (Fig. 5.13). It has good exposure and is in conformity with overlying Xiahedong Formation.

Description of the cross section:

Shangdonggou Formation (K_1s): 70. Thick layers of gray conglomerate.

——— Conformity ———

Haoling Formation (K_1h) 418.48m

69. Brown red thick-bedded argillaceous siltstone 16.93m

68. Gray thick-bedded sandstone and conglomerate, 20 to 30 percent gravel, the rest is rock debris, a small amount of feldspar, with clay cementation 2.82m

67. Purple thick-layered fine sandstone 8.87m

66. Purple thick, blocky gravelly polymictic conglomerate, sandstone, composed of quartz andesite porphyry, with downward converging tabular cross-bedding 33.85m

65. Yellow green thick-bedded fine grained feldspathic sandstone 2.61m

64. Gray green, purple thick layers of fine gravelly polymictic conglomerate, sandstone, with a small amount of brown muddy siltstone lenses, containing dinosaur fossils fragments with sizes between beans and walnuts 35.87m

63. Green, gray-green thick-bedded fine-grained feldspathic sandstone 1.52m

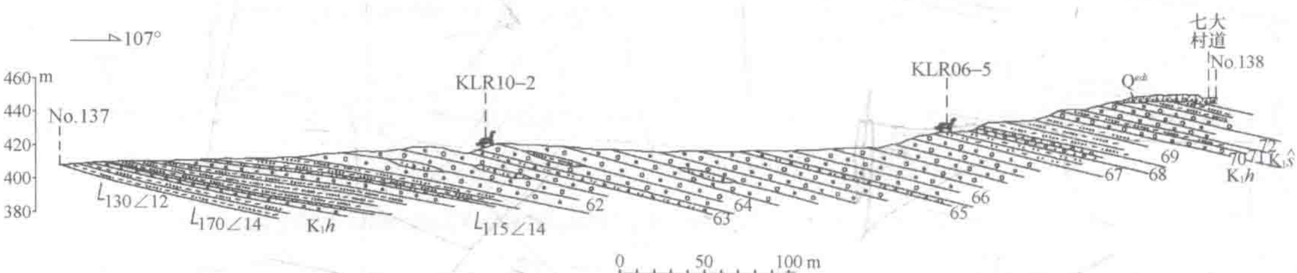


Fig. 5.13 The onsite surveyed cross section of lower Cretaceous Haoling Formation and Shangdonggou Formation at Heyezui, Santun Town, Ruyang County

The lower part of Haoling Formation consists of alternately bedded pale reddish purple conglomerate and purple red brown mud siltstone, mingled with gray sandstone. The middle part is green-gray conglomerate, glutenite, red-brown mudstone conglomerate and siltstone, silt mudstone, mingled with clay, sandstone, gray-green mudstone. The upper part is purple, green gray conglomerate, with sandstone and purple yellow green clay and fine sandstone, interbedded with sandstone, conglomerate (Fig. 5.14).

Haoling Formation is comprised of multiple depositional cycles of conglomerate and grainy, sandy mudstone with normal grading sequence. The thickness of conglomerate in a depositional cycle in the middle and lower part is usually smaller than that of sandy mudstone, while it's the opposite in the upper part of the formation. The color of the conglomerate changes upwards in the regular sequence of purple-red, pale purple red, green gray, purple red, which suggests the depth of water of the sedimentary environment being sequentially from shallow, deep, and shallow, and the correlating depositional condition of oxidation–deoxidation–oxidation (Fig. 5.15).

Fig. 5.14 Interbedded mudstone and sandy conglomerate in the lower part of Haoling Formation

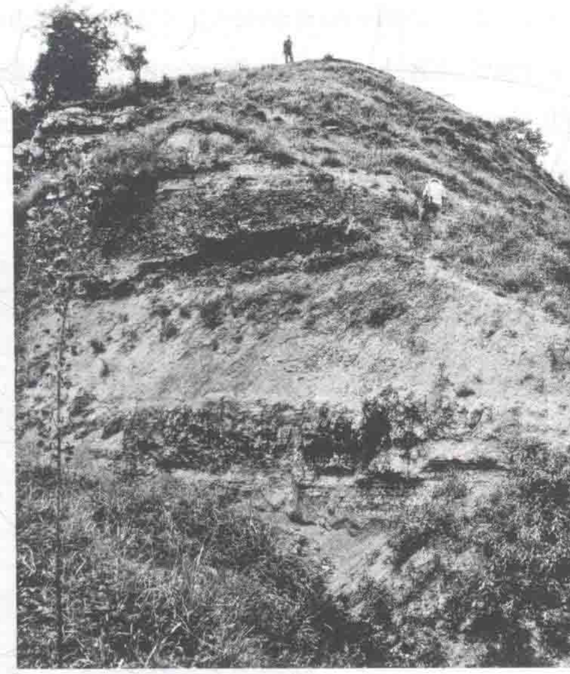


Fig. 5.15 Interbedded brown, red conglomerate, silty mudstone, and light green sandstone at the middle and upper part of Haoling Formation

In the conglomerate formation, occurrence of large unidirectional tabular bedding that converges downwards is common, and small tabular bedding and trough-shaped bedding also exist. Beddings with normal grading are well developed and fluvial scouring marks are very common. Unidirectional tabular bedding and multi-directional wedge-shaped bedding occur frequently in the sandstone (Fig. 5.16, Fig. 5.17). Parts of the conglomerate change radically in both vertical and horizontal direction, including thinning, thickening, forking, overlapping, and rapidly tapering off into sandstone, which is reflective of the typical depositional features of riverine settings.

Fig. 5.16 Large-scale tabular cross bedding in Haoling Formation

Fig. 5.17 Well-developed tabular cross bedding in Haoling Formation

In the upper Haoling Formation, gray, gray-green mudstone with pyrite lenses (silt) occurs frequently and extends stably and locally with distinctive coloring. Calcareous nodules in the reddish, brown argillaceous siltstone and mudstone over the above-mentioned strata are well developed (Fig. 5.18), and change into argillaceous limestone locally, which constitute the defining feature for the middle part of Haoling Formation.

Fig. 5.18 Argillaceous mudstone with calcareous nodules in the middle Haoling Formation

Haoling Formation and Shangdonggou Formation are distinguished by a bed of conglomerate with mixed matrix, which contains gravels from underlying mudstone and sandstone. The lower boundary has prominent plane of alluvial scouring marks, extends stably and is an excellent maker to divide Haoling Formation and Shangdonggou Formation (Fig. 5.19).

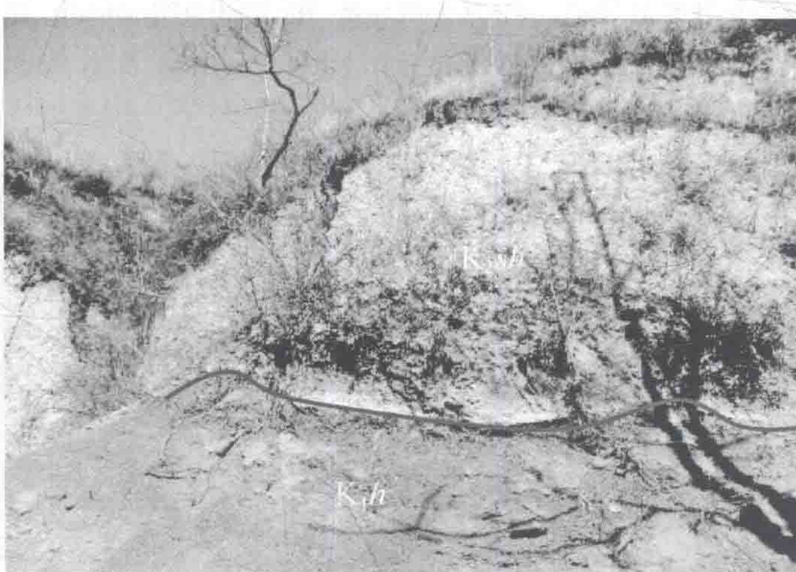


Fig. 5.19 The boundary between Haoling Formation and Shangdonggou Formation

5.4 Shangdonggou Formation

Shangdonggou Formation is equivalent to the upper part of former Mangchuan Formation, and is mainly distributed in the following areas: Erlangmiao, Guanshang, Shang'ao, Tuqiao, Zhuqiao, Liudian. It also crops out spottily west of the Malan River, in Jiaoyepa, Lugouling, Wadiangou, covering a total area of about 40km^2. As of now, two layers of dinosaur fossils, and one layer of invertebrate and micro-organism fossils have been found in the middle-lower part of Shangdougou Formation.

The onsite surveyed cross sections are located in the area between Shangdonggou and Langpo'ao (Fig. 5.20). The outcrops are very good, and the lithology is stable and with developed sedimentary structure.

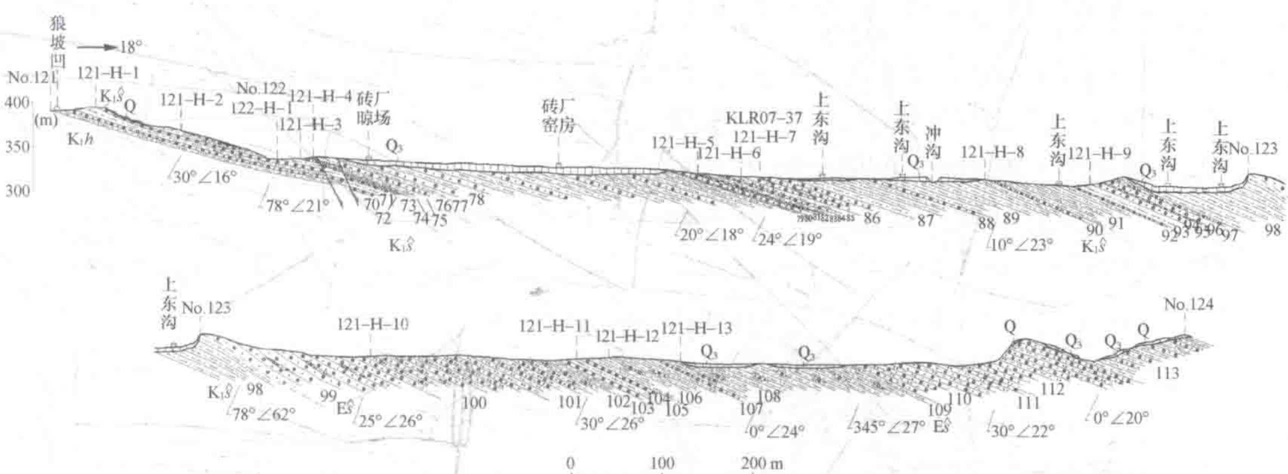


Fig. 5.20 The onsite surveyed cross section of lower Cretaceous Shangdonggou Formation at Langpowa - Xiadonggou, Liudian Town, Ruyang County

Overlying strata: Shitaijie Formation (K_2-E*s*?)

Alternating grayish white, thick and medium bedded sandy conglomerate and brown-red gravel argillaceous siltstone 49.13m

——————Parallel unconformity——————

Shangdonggou Formation ($K_1\hat{s}$) 319.37m

98. Brown-red thick-layered argillaceous siltstone 9.91m
97. Brown-red thick-layered mudstone with pebble (turbidity current deposits) 2.23m
96. Grayish white and light brown-red thick-layered sandy conglomerate 2.60m
95. Brown-red massive argillaceous siltstone 3.71m
94. Grayish white thick-layered sandy conglomerate (in the upper part there are three layers of brown-red argillaceous siltstone with the thickness of 0.1～0.3m) 7.42m
93. Brown-red massive argillaceous siltstone 8.39m

92. Grayish white thick-layered calcareous sandy conglomerate 1.41m

91. Brown-red massive argillaceous siltstone 26.18m

90. Grayish white mid-thick-layered clastic arkose containing fine and coarse gravel 3.02m

89. Brown-red massive argillaceous siltstone 45.66m

88. Grayish white thick-layered sandy conglomerate 4.18m

87. Brown-red massive argillaceous siltstone 30.84m

86. Grayish white thick-layered sandy conglomerate with brown-red sandy debris and argillaceous siltstone lenses (or bands), siltstone with *Ankylosaurus* fossils 16.77m

85. Brown-red thick-layered sandy (fine gravelly) argillaceous siltstone 4.93m

84. Grayish white thick-layered sandy conglomerate 1.30m

83. Brown-red thick-layered sandy gravelly argillaceous siltstone 4.22m

82. Grayish white, clastic arkose with sand and fine gravel 0.31m

81. Brown-red thick-layered sandy (fine gravelly) argillaceous siltstone 2.88m

80. Grayish white thick-layered sandy conglomerate 3.88m

79. Brown-red massive argillaceous siltstone 1.00m

78. Brown-red massive argillaceous siltstone with sandy conglomerate 75.00m

77. Brown-red massive argillaceous siltstone 0.29m

76. Grayish white thick-layered sandy conglomerate with the crystal fragments of feldspar 0.16m

75. Brown-red massive argillaceous siltstone 0.89m

74. Greenish gray and brown-red porphyritic argillaceous medium and fine sandstone 0.08m

73. Brown-red massive argillaceous siltstone 3.39m

72. Grayish white thick-layered sandy conglomerate with the crystal fragments of feldspar 3.34m

71. Brown-red massive argillaceous siltstone 3.78m

70. Gray thick-layered conglomerate (sandy and with scouring surface at the bottom) 1.60m

———— Conformity————

Underlying strata: Haoling Formation(K_1h), brown-red massive argillaceous siltstone 5.57m

The lithological composition of Shangdonggou Formation is mainly of brownish red argillaceous siltstone, grayish white sandy conglomerate, with a thickness of 331 ~ 341m. Layers 71 ~ 82 consist of more than four cycles of gray thick-layered clastic sandstone and massive brown-red argillaceous siltstone; layers 83 ~ 96 consist of six cycles of grayish white, thick-layered sandy conglomerate and brown-red thick-layered pebbly argillaceous siltstone (Fig. 5.21).

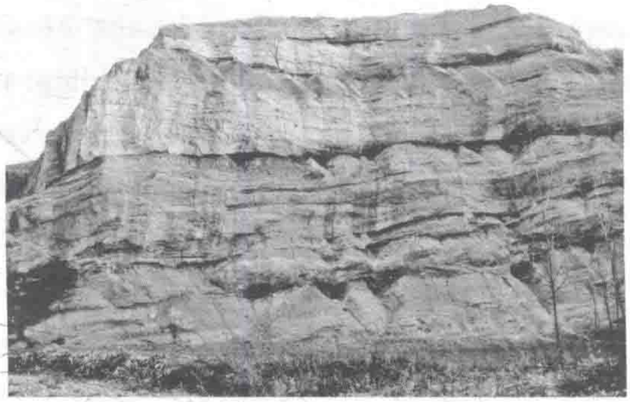


Fig. 5.21 Interbedded light gray and red brown thick-layered sandstone of Shangdonggou Formation

The most prominent feature of Shangdonggou Formation is that the composition of sand and pebbles in sandy conglomerate are mainly white feldsparthic crystal fragments and rock debris (whose source is Jiudian Formation), which took on the color of white snow after weathering (Fig. 5.22). It is the most prominent marker to distinguish Shangdonggou Formation from the upper Haoling Formation. Pronounced erosion plane on the bottom of sandy conglomerate can be observed frequently, where the gravels of silt mudstone are derived from the underlying argillaceous sandstone. Gravel size can reach 1m×0.8 m in spots (Fig. 5.23).

Fig. 5.22 The boundary between Shangdonggou Formation and Haoling Formation, with distinct scour plane between thick, gray conglomerate and brown red mudstone

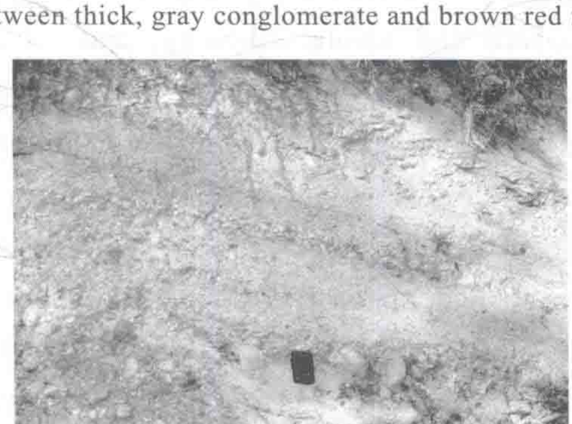


Fig. 5.23 Gray white feldspathic crystal conglomerate in the bottom of Shangdonggou Formation

In this formation, vertical and horizontal variations of sandy conglomerate are considerable, in which unidirectional diagonal tabular bedding and trough-shaped cross bedding of conglomerate, sandstone and conglomeratic sandstone occur, reflecting the depositional feature of alluvial fan and braid-shaped ends of the river.

5.5 Shitaijie Formation

This formation is equivalent to the former Shitaijie Formation as originally defined. In 1964, Henan Regional Geological Survey Team established the formation in the village of Shitaijie, which is in the town of Yanglou, Ruzhou City, and defined it as "lithologically composed of red shale, mudstone and glutenite, conformable with underlying Mangchuan Formation and angularly unconformable with overlying Paleogene." It was dated to Paleogene. The holostratotype cross section is located between the north of the village of Changbei, Liudian Town of Ruyang County and southwest of the village of Shitaijie, which is in the town of Yanglou of Ruzhou City (E: 112°36′, N: 34°07′). During the mapping of 1:50000 scale regional geological map of Yanglou sheet (1996), the Second Geological Survey Team of the Henan Department of Geology and Minerals resurveyed the cross section in the vicinity of the original one, located in Ruyang Basin. This research discovered dinosaur fossils in the underlying strata, which were dated to the early Cretaceous period, and resurveyed the cross section onsite. It is confirmed that Shitaijie Formation is conformable with the underlying Lower Cretaceous Shangdonggou Formation and the original dating of Paleogene was incorrect, and that it might be late Cretaceous. Accurate dating is unavailable due to the lack of fossil evidence. However, it is advisable to reconsider that Shitaijie Formation was dated to Paleogene based on comparison with other basins.

In the work area, Shitaijie Formation mainly crops out in Licun-Langdonggou, south of Shitaijie, with good exposure and stable lithology, and with developed sedimentary structure. The contact relationship with underlying Shangdonggou Formation is conformable and the top is covered by the Quaternary. The outcropped area is about $42km^2$.

(1) The lower part of Shitaijie Formation was surveyed in this work. The surveyed cross section is located between Langpo'ao of Liudian Town and Shangdonggou, which is in the same cross section as Shangdonggou Formation (Fig. 5.20).

Description of the cross section:

The top has not been found

Shitaijie Formation (K_2-E*s*) Thickness of the outcrop 464.98m

113. Brown-red massive argillaceous siltstone interbedded with conglomerate 64.51m

112. Brown-red thick-layered sandy conglomerate interbedded with thick gravelly sandstone and mudstone 61.72m

111. Grayish white and light purple, thick-layered sandy conglomerate 2.31m

110. Alternating beds of grayish white, thick-layered sandy conglomerate with calcareous cement and brown-red gravelly mudstone 51.57m

109. Brown-red, massive argillaceous siltstone 6.66m

108. Brown-red massive argillaceous siltstone with by glutenite lenses 81.06m

107. Purple thick-layered sandy conglomerate 1.83m

106. Brown-red, massive argillaceous siltstone with limited glutenite lenses (or bands) 30.49m

105. Purple, thick-layered medium sandy conglomerate 3.64m

104. Brown-red, massive argillaceous siltstone 6.39m

103. Purple, thick-layered medium sand composite conglomerate 3.67m

102. Brown-red, massive argillaceous siltstone 7.52m

101. Brown-red, massive gravel argillaceous siltstone interbedded with grayish white and brown-red thick-layered sandy conglomerate 36.98m

100. Alternating beds of grayish white, thick-layered sandy conglomerate and brown-red gravel argillaceous siltstone (Fig. 5.30) 49.13m

99. Grayish white and light brown-red, thick-layered sandy conglomerate interbedded with brown-red pebbled sandstone and mudstone bands 7.50m

——— Conformity ———

Underlying strata ($K_1\hat{s}$): Shangdonggou Formation, brown-red thick siltstone 59.91 m

(2) Geologic cross section located in Shitaijie-Licun in Ruyang Country was surveyed by the Second Geological Survey Team of Henan Department of Geology and Minerals (1996).

Overlying strata: Quaternary

~~~~ Unconformity ~~~~

Shitaijie Formation (K_2-E*s*) > 804.4m

25. Light brown, yellow thick-layered conglomerate 97.4m

24. Brown-red, thick-layered argillaceous siltstone 34.6m

23. Brown-red, thick-layered conglomerate 2.8m

22. Brown-red, thick-layered gravelly mudstone interbedded with limited conglomerate lenses 79.1m

21. Brown-red, thick-layered conglomerate 174.2m
~~~~

20.	Brown-red, thick-layered siltstone	1.1m
19.	Brown-red, thick-layered conglomerate	4.4m
18.	Light brown-red siltstone	0.5m
17.	Brown-red thick-layered conglomerate	3.0m
16.	Brown-red thick-layered siltstone	0.3m
15.	Grayish white thick-layered conglomerate	4.4m
14.	Brown-red, thick-layered gravelly mudstone	53.6m
13.	Brown-red, thick-layered conglomerate	86.1m
12.	Brown-red, thick-layered mudstone	0.3m
11.	Brown-red, thick-layered conglomerate	47.8m
10.	Light grayish red, thick-layered conglomerate	65.5m
9.	Brown-red, thick-layered mudstone	16.8m
8.	Grayish white, thick-layered conglomerate	87.2m

——— Conformity ———

Underlying strata: Shangdonggou Formation ($K_1\hat{s}$), brown-red thick-layered siltstone

The lithological composition of this formation mainly includes: brown-red and grayish white conglomerates, sandy conglomerates, brown-red (gravelly) silt mudstone, argillaceous siltstone, mixed with brown-red siltstone, with a thickness of 464 ~ 804 m. The lower part (layers 33 ~ 36) is composed of several cycles of grayish white, light brown-red, sandy conglomerate, brown-red gravelly argillaceous siltstone and brown-red massive argillaceous siltstone (Fig. 5.24).

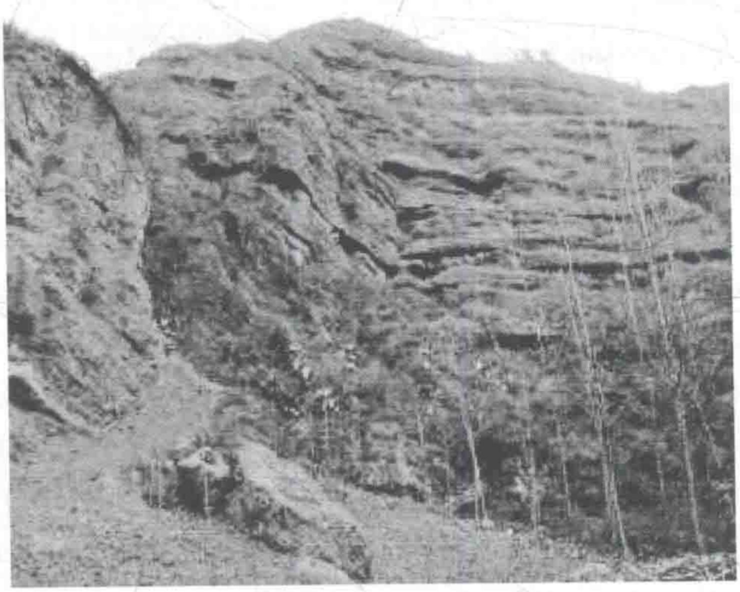


Fig. 5.24 Interbedded gray white thick, medium-thick sandy conglomerte and brown red gravelly muddy fine sandstone in the 34th layer of the cross section

Throughout the area, there are two layers of well developed sedimentary structure in this formation. One is grayish white conglomerate, and the other is sandy conglomerate. The lower part of white sandy conglomerates is stable, which is the significant mark to distinguish Shitaijie Formation from underlying formation (Shangdonggou Formation). But the depth and lithic facies change dramatically: the thick-bedded conglomerate sequence, which is more than 80m thick from east to west, changes into alternating beds of thick-medium layered sandy conglomerate and brown-red gravelly argillaceous siltstone with a depth of 56m. The middle part is grayish white calcareous cemented conglomerates. Because of basal cementation texture, gravels can easily fall off and leave a complete calcareous shell. This feature is very prominent (Fig. 5.25).

Fig. 5.25 Conglomerate with calcareous cementation in the mid-lower Shitaijie Formation

In this formation, the main component of conglomerates and sandy conglomerates is quartz sandstone. And there are also limited dolomite and bands of dolomite containing flint. The gravels, which have the characteristics of high sphericity and good sorting, contain frequent occurrence of grayish and light yellow quartz sandstone lenses or bands usually with normal graded bedding.

Science links

1. How were dinosaurs discovered?

The knowledge about dinosaurs is deciphered from the strata where dinosaur fossils were preserved. Dinosaurs lived for 160 million years on this planet, starting from 200 million years ago, and left their tracks everywhere. However, they were not discovered and understood until the 19th century. How do people nowadays search and find them? As a matter of fact, dinosaurs were mostly discovered by accident and we had no idea what kind of animal they were in the early years. With the advancement of science knowledge, they got understood and made widely known by scientists.

The first piece of dinosaur fossils ever discovered in China was found by a fisherman on the bank of the Heilongjiang River, in Heilongjiang Province, and was later known and excavated by Russian geologists. The first dinosaur fossil discovery in Henan Province was made in 1962, when a geological survey team got tips from local villagers, which were followed up by the experts, who appraised it as a dinosaur. The discovery of dinosaurs in the Ruyang area was the stuff of legend. Since the fifties in the 20th century, villagers had been digging up "dragon bones" when ploughing the farmland and selling most of them as traditional Chinese medicine. Later, a knowledgeable local villager, Cao Hongxin, became suspicious when a giant tooth was found, and contacted the renowned researcher, Mr Dong Zhiming, who confirmed it as dinosaur fossil.

2. How were dinosaur fossils preserved?

Why were some dinosaur fossils spread spottily, some of them mixed up in various sizes, some of them with intact skeletons, some of them in piles? Most dinosaurs were gregarious, just like human beings, and generally seeking to live in places close to abundant food supply, sunlight, and water source, such as sea coasts, lakesides, riversides and by the water ponds. After they died in normal or abnormal circumstances, they were swept away by seasonal water flow (flood, mudslide) and buried rapidly in depressions nearby, such as shallow sea waters, lakes, river beds or ponds. After the chemical exchange between the bones and the carbonate, siliceous and ferruginous materials, which were abundant in the groundwater, organic materials were replaced by inorganic materials, the original forms of the skeleton were kept, and the internal tissues were lithified. If dinosaurs were exposed and decomposed after death, their bones might be separated and scattered in the process of transport by water, which converged from multiple sources to one burial ground. After gravitational sorting, survived and preserved fossils might be piled in disorder, scattered spottily, and in incomplete forms. If the remains were not completely decomposed and flesh was still attached to the bones, and if the distance of transport was short and the burial was swift, the preserved body of fossil could be relatively complete. If sudden disaster struck in one area, such as volcanic eruptions, earthquakes, or large scale landslides, dinosaurs might die in massive numbers and be buried as if in a mass tomb of dinosaurs, such as in the west of Liaoning in late Jurassic to early Cretaceous, where repeated volcanic eruptions buried a large number of dinosaurs and other animals with intact forms in the lake basins. In places like Lufeng in Yunnan, Zigong in Sichuan, dinosaur fossils were discovered in huge piles and large numbers, sometimes exceeding 100 in total. The environment and condition back then could be analyzed based on the settings in which dinosaurs were buried and preserved.

3. Why were all dinosaur fossils found in the sedimentary rocks?

After rocks were formed and exposed above the ground, they went through the process of weathering and erosion, fragmentation, and transport by water, wind, glacier and other external forces, and the process of sedimentation in seabed, lowland (river valley, lake), or in transitional locations between land and the sea. They became hard and solid rocks again after millions of years of compression, transformation, and cementation. Dinosaurs generally congregated by riversides, lakesides, or seashores. Their dead bodies were washed away and buried with mud and sands in river valleys, lake basins, or in the sea, and preserved in the sedimentary rocks which were formed later. Therefore, fossil hunters should target rock strata from that period of time.

6 Tracing the Time: Dating Dinosaur-bearing Strata

In the mid-late Triassic, which was about 230Ma BP, dinosaurs first appeared in the history of the earth. At that time, several continents joined together to form the super-continent Pangaea, which had warm and humid climate and was covered with lush vegetations. Vertebrates emerged quietly and evolved rapidly, and among them were all the major animals that dominate the kingdom of vertebrates on the earth today. Dinosaurs were also undoubtedly strong competitors in the game of evolution. Back then, dinosaurs were concentrated in the South and North American continents, where in 1988 U.S. paleontologists made the most famous discovery in the region, the oldest dinosaur in the world, Eoraptor, in the Ischigualasto Valley in Argentina, located at the foothills of the Andes. Eoraptors were small-sized, carnivorous, theropodian dinosaurs. Paleontologist Paul Sereno found that Eoraptors were neither saurischian nor ornithischian, but seemingly a hybrid of all dinosaurs. He speculated that Eoraptors were the ancestors to dinosaurs that evolved subsequently into two major clades of dinosaurs (Dong Zhiming, 2010). No other dinosaurs from that period of time were found anywhere else in the world, which suggests that dinosaurs probably originated and spread all over the world from South America.

A vast Tethys sea existed when a rift emerged in the Pangaea from late Triassic to early Jurassic. Although ancient continents were splitting up, they were not completely separated, therefore dinosaurs could migrate along the edge of Tethys sea. Dinosaur bone fossils found from that period were very similar to each other across all continents, so scientists suspected that dinosaur fauna was wide spread world-wide and named it the Pan-Tethys Dinosaur Fauna. Strata bearing dinosaur fossils from that time have been found in all continents today. The most representative fossil sites include Karoo Basin in South Africa; Lesotho; the states of Arizona, New Mexico, Texas in the United States; Argentina; Kunta in India; and Lufeng Basin in China's Yunnan Province.

From the late Jurassic to the early Cretaceous, lakes, swamps, shallow sea shelves and deltas dotted the interiors of all known continents in the world, where dinosaurs were truly the rulers of the land and dinosaur fossils were found in large quantities and in all continents. Favorable living environment, abundant food supply, and the absence of predators spurred unfettered growth of the dinosaurs. They exhibited great variations, diversity of species, and trend of gigantic body size, especially the sauropodian dinosaurs, which grew to the terrifying length of over 30 meters in multiple locales. Towards the end of late Cretaceous, carnivorous dinosaurs dominated. But with the extinction of triceratops, dinosaurs gradually exited from the stage of history.

The earliest dinosaurs in China were found in Lufeng Basin. They probably migrated along the sea coast from South America through Tibet, where the Himalayas had yet to emerge, in the early Jurassic (Dong Zhiming, 2010). In Yunan Province, ferocious and meat-eating *Dilophosaurus sinensis*, the largest carnivorous dinosaurs at that time, was found. There also existed *Yunnanosaurus, Lufengosaurus, Anchisaurus (Gyposaurus), Lukousaurus, Jingshanosaurus, Jinshajiangosaurus, Kunmingosaurus wudingensis*, *Diachongosaurus lufengensis* and *Tatisaurus oehleri*, which formed the Prosauropoda-Lufeng Fauna. During the middle Jurassic, dinosaurs expanded their territory and multiplied rapidly in the ancient Chinese continent. From the east edge of Tibet to the Sichuan Basin and Junggar Basin, all kinds of dinosaurs thrived, and among them were *Shunosaurus, Omeisaurus, Gasosaurus constructus*, *Huayangosaurus, Xiaosaurus dashanpensis*, *Szechuanosaurus zigongensis* and *Qiouosaurus bashanensis,* which constituted the Shunosaurus Fauna. Of all fossils, the most abundant are that of sauropods, who had sturdy limbs supporting their large trunk like pillars, walked on four legs, and had elongated neck and tail, which made them the largest land animals ever in earth's history.

Towards the end of Jurassic, the saurischian dinosaurs were dominant, including carnivorous *Megalosaurs, Allosaurus, Yangchuanosaurus*, and herbivorous *Seismosaurus, Diplodocus, Mamenchisaurus, Stegosaurus*. They varied greatly in sizes. Most of them were huge, but the smallest ones were just the size of a chicken. In China, Jurassic dinosaur fossils are distributed in the southwestern and the northwestern areas, including Yunnan, Guizhou, Sichuan, and Xinjiang. At that time, climate in southwestern China was still humid and warm, *Mamenchisaurus, Yangchuanosaurus shangyouensis*, *Tuojiangosaurus multispinus*, *Yangchuanosaurus hepingensis*, *Yandusaurus*, *Chungkingosaurus*, and *Chialingosaurus* continued to thrive there. *Mamenchisaurus* is the largest Jurassic dinosaur ever found in China.

The Cretaceous period saw the end of the reign of dinosaurs, during which the diversity of species and terrestrial distribution of dinosaurs peaked. Cretaceous dinosaurs consisted mostly of ornithischian dinosaurs, such as *Iguanodon, Hypsilophodon, Pachycephalosaurus, Hadrosaurus, Ankylosaurus, and Ceratopsia*. *Stegosaurus* died out in the early Cretaceous. However, *Hadrosaurus, Ankylosaurus, Ceratopsia,* and *Tyrannosaurus* thrived in the late Cretaceous, especially *Ceratopsia*, who evolved into many species in a short period of time. Cretaceous dinosaur fossils are widely distributed in

China. In more than twenty Provinces or Autonomous Regions, such as Xinjiang, Sichuan, Gansu, Ningxia, Shanxi, Inner Mongolia, Heilongjiang, Jilin, Liaoning, Shandong, Henan, Hubei, Hunan, Zhejiang, Guangxi and Guangdong, large numbers of fossils of dinosaur bones and eggs have been found.

As a large family of animals, dinosaurs had dominated the earth for 160 million years. Within the family, however, not all species of dinosaurs lived and became extinct simultaneously. Some species only appeared in the Triassic, some species only in the Jurassic, while others only in the Cretaceous. In the late Cretaceous, about 66 Ma BP, many species of dinosaurs died out suddenly. Among them were herbivorous *Triceratops, Hadrosaurs, Pachycephalosaurus, Edmontosaurus*; and carnivorous *Tyrannosaurus, Pareiasaurus, Carnosaurs*. Although most of dinosaurs were extinct, their offsprings, birds, survived and evolved to this day.

Research on the time in which dinosaurs lived is primarily conducted in two ways. The first is dating fossil-bearing strata and establishing the stratigraphy of sediments where dinosaur fossils are found; the known date of the strata is therefore the time in which dinosaurs lived. The second is comparing and correlating with the known dinosaurs and dinosaur groups, in terms of species, morphology, and evolutional development, in order to determine the probable time frame.

The dinosaur fossils in the Ruyang Basin were found in strata that were originally designated as Tertiary (Paleogene), which is shown to be incorrect by this study. Through the comprehensive comparison of lithostratigraphy, combining with the study of invertebrates and microfossil assemblages, and with the study of dinosaur fauna assemblages, this research determined the date of the strata in which dinosaur fossils were preserved, which also indicates the time when dinosaurs lived in the Ruyang Basin.

6.1 Dinosaur Fossils in Ruyang Basin and Fossiliferous Strata

Dinosaur fossils found in Ruyang Basin are mainly distributed in the area north of Santun Town and Liudian Town, where fossil localities concentrate in the villages of Xiahedong, Shaping, Qixian and Hongling. Fossil localities are spottily spread and no large area with dense fossil distribution has been found as of now.

Most fossils were hosted in brownish red mudstone, silt mudstone and siltstone, and a few in conglomeratic lenses. Fossil fragments were occasionally found in layers of thick conglomerates. Dinosaur fossil sites are many but distributed sporadically. Most excavated fossils were scattered with no apparent pattern, and the skeletons were not intact except some specimens of centrum of Titanosaurs that were found in Haoling, Liufugou and

Shijiagou. Thirty-two fossil sites have been excavated, the vast majority of which were of single layer and single burial. Only in two sites (Shijiagou and Shengshuigou), burials of multiple dinosaurs were found, with mixed sizes and multiple-layered piles. Shijiagou site consists of four fossil-bearing beds. Multiple small theropod fibulas and vertebrae in piles were found in the two upper beds, while medium-large sauropod fossils heaped in the lower beds. In Shengshuigou site, piles of at least three medium-large sauropod femurs, humerus and parts of vertebrae were found. The characteristics of the burials indicate that they were all buried and amassed in low locations when water flow weakened, and that some of the vertebrae were still attached to each other through tendons, since they were transported by water in relatively intact form before they decomposed completely.

In all, 15 layers with dinosaur bone fossils, 2 layers with dinosaur egg fossils, and several layers with invertebrate and sporopollen fossils were found in the lower to middle part of the former "Mangchuan Formation", now renamed as Haoling Formation and Shangdonggou Formation, which is over 600 meters thick. In some sections, multiple layers of fossils were found, such as two layers of dinosaur egg shells, one layer of trace fossils and three layers of dinosaur fossils in the Caojiacun section (Fig. 6.1). Two beds with abundant dinosaur egg shells were discovered in the Caojiacun cross section in Santun Town, which also contained an incomplete dinosaur egg, two layers of invertebrate fossils, and two layers of dinosaur fossils. They are testimony to a thriving dinosaur population in that period of time.

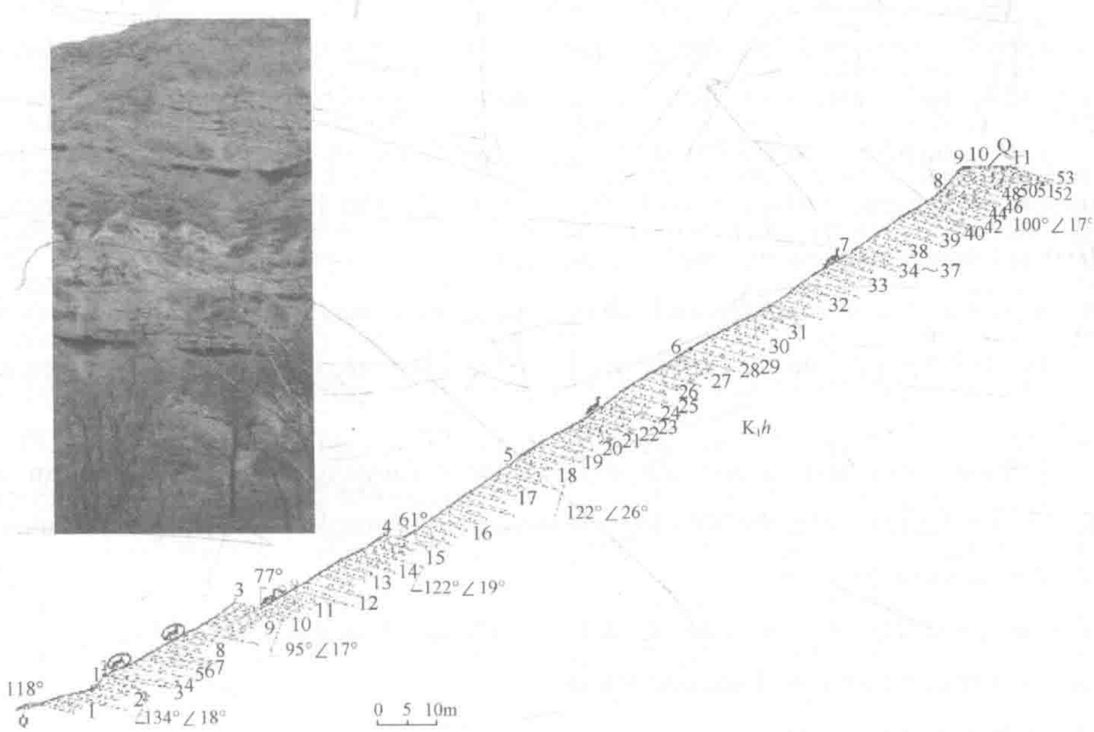


Fig. 6.1 Fossiliferous layers of dinosaur skeletons and other fossils in the onsite surveyed cross section at Caojiacun, Santun Town, Ruyang County

Dinosaur-bearing strata from lower to upper beds:

In Haoling Formation

(1) Giant sauropod, found in Zhaojiagou (fossil site KLR08-9); the lithology is purple argillaceous siltstone.

(2) Giant sauropod, found in Zhaojiagou (fossil sites KLR07-58, KLR08-5, KLR093); the lithology is purple muddy siltstone with gravels.

(3) Gigantic sauropod, *Huanghetitan ruyangensis* (Lü et al., 2007), found in Haoling Formation, buried in situ (where dinosaur relics museum already built) (fossil sites KLR07-57, KLR08-10); the lithology is purple argillaceous siltstone.

(4) Large sauropodian dinosaur, found in the farmland west of Haoling (fossil site KLR09-2); the lithology is thick layered gray argillaceous siltstone with gravels.

(5) Large sauropod, *Xianshanosaurus shijiagouensis* (Lü et al., 2009a) (fossil site KLR07-62); *Oviraptorosaurus, Luoyanggia liudianensis* (Lü et al., 2009a), and *Ornithomimosauria*, found in the Shijiagou; the lithology is purple argillaceous siltstone, with thin layer of conglomerate, or conglomerate lenses; *Yunmenglong ruyangensis* found in Huamiaogou (fossil site KLR07-50); the lithology is purple argillaceous siltstone with conglomerate lenses.

(6) Large-sized sauropod dinosaur was found in the back slopes of Shijiagou (fossil site KLR08-17); the lithology is brown red argillaceous siltstone.

(7) Large-sized sauropod dinosaur was found in the back slopes of Huamiaogou (fossil site KLR07-51); the lithology is brown red argillaceous siltstone.

(8) Large-sized sauropod dinosaur was found in the embanked path through the fields in the northeast of Heyezhui (fossils site KLR06-5); the lithology is brown, red argillaceous siltstone.

(9) Giant sauropod, *Ruyangosaurus giganteus* (Lü et al., 2009b), was found in Shengshuigou of Shaping village (fossil site KLR06-15); the lithology is gray-green, purple argillaceous siltstone (with sandy conglomerate lenses).

(10) Large-sized sauropod, *Huanghetitan ruyangensis*, was found in Liufugou (fossil site KLR06-2); the lithology is purple pebbly argillaceous siltstone, containing gray-green siltstone bands.

(11) Medium-sized nodosaurus, *Zhongyuansaurus luoyangensis,* was found in Shaping Xigou (fossil site KLR06-14); the lithology is gray-green, purple pebbly argillaceous siltstone with sandy conglomerate lenses.

(12) Unnamed *Iguanodon* was found in Shapingdonggon; the lithology is purple argillaceous siltstone (with conglomerate lenses).

In Shangdonggou Formation

(13) Medium-sized sauropod, found in Wanggou, is still under study (fossil site

KLR06-14); the lithology is purple argillaceous siltstone with sandstone lenses.

(14) Incomplete *Ankylosaurus*, found in Erlang village; the lithology is purple argillaceous siltstone .

(15) Incomplete *Ankylosaurus*, found in Wangling of Changcun.

The main characteristic of the assemblages is that huge to large-sized sauropods and small-sized theropod dinosaurs were in the middle-lower beds, and medium-sized sauropods, *Nodosaurus, Hadrosaurus* were in the middle-upper beds. All ankylosaurs were found in the Shangdonggou Formation of the upper strata. Many excavated fossils have not been repaired; the paleontology and biostratigraphy are not yet fully established, but significant difference of dinosaur assemblages from the bottom to the upper strata can be obserbved.

We found two beds with abundant dinosaur egg shells in Caojiachun section in Santunxaing, one incomplete dinosaur egg fossil in the middle-lower beds, and also two beds containing invertebrate fossils and two beds with dinosaur fossils. They clearly show a thriving dinosaur colony in that time.

6.2 Determining the Lower Temporal Boundary of Ruyang Dinosaurs

Dinosaurs were hosted in the Haoling Formation and Shangdonggou Formation, overlying the Jiudian Formation. If the age of Jiudian Formation is determined, we can be certain that the discovered dinosaurs appeared after that time. Since Xiahedong Formation is consisted of thick bedded conglomerates, dependable material for radiometric dating could not be found and other fossiles were difficult to be preserved. Therefore, the Jiudian Formation, which is consisted of sedimentray volcanic tuff, becomes the primary object of our research.

Jiudian Formation in Ruyang Basin has been assigned to Cretaceous ever since it was established by the Regional Survey Team of Henan Bureau of Geology (1964). When the Second Geological Survey Team of Henan Department of Geology and Minerals was mapping the 1:50,000 scale of Minggao, Ruyang, and Yanglou sheets of regional geological map, biotites from the crystalline tuff in the bottom of Jiudian Formation were sampled as K-Ar Argon isotopes, which were dated to 107Ma, and subsequently Jiudian Formation was assigned to the Albian of the late early Cretaceous (Henan Department of Geology and Minerals, 1995).

In cooperation with the Institute of Geology, Chinese Academy of Geological

Sciences, this project collected three groups of zircon SHRIMP U-Pb samples for isotope dating in the tuffs in the lower, middle, and upper part of Jiudian Formation. The locations of the samples (Fig. 6.2), the testing method, procedures, and results are described as the following.

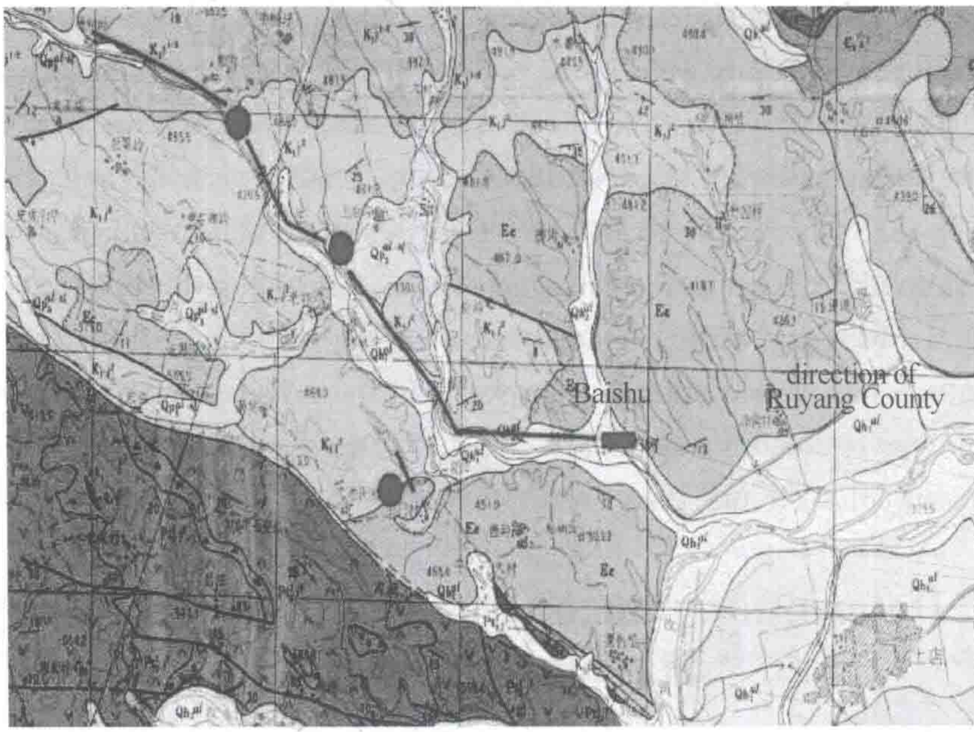


Fig. 6.2 Map of sample locations.

Testing method and procedures: zircons were sorted and selected in conventional manner, refined and puricated under the binocular microscope in the end. Sample zircon and standard zircon TEM were placed in epoxy resins and ground to approximately 1/2 the size to expose the fresh content inside. A final circular target that is 5 ~ 6mm thick and 35mm in diameter was produced, polished, and carbon-coated to be used in cathodoluminescence analysis. Then it was again polished and gold-coated for SHRIMP U-Pb analysis.

18 zircons from Sample C070813-10 were tested for measurement of $^{206}Pb/^{238}U$, excluding 3 zircons contaminated by crust's bedrock, which yielded a weighted mean age of 133.18±0.72Ma from 15 zircons; 22 zircons from Sample C070813-17 were tested for measurement of $^{206}Pb/^{238}U$, excluding 9 sets of outlying data, which yielded a weighted mean age of 129.95±0.91Ma from 13 zircons. It indicates that Jiudian Formation should be assigned to the Hauterivian of the early Crertaceous (Jiang et al., 2010), instead of the Albian which came later. The confirmation of Jiudian Formation's age shows that dinosaurs of Ruyang lived after 130Ma BP and dinosaurs probably also existed in Jiudian Formation, but they have yet to be found.

6.3 Contact Relationship of the Strata

The 1:50,000 scale geological map of Ruyang sheet and Yanglou sheet considered Jiudian Formation and overlying Chenzhaigou Formation were in unconformity (Henan Department of Geology and Minerals, 1996). This view was on the basis of Jiudian formation being assigned to the early Cretaceous and Chenzhaigou being assigned to the Paleogene, which presented a huge gap in between (late Cretaceous missing).

Jiang Xiaojun and others of the Institute of Geology, Chinese Academy of Geological Sciences, considered the two formations are uniform around the boundary, where the upper Jiudian Formation is of shallow lacustrine facies and the conglomerates at the bottom of Xiahedong Formation have no conglomeratic features at the base, but are river bed conglomerates with sandstone lenses, formed by latteral deposits of the frontal braid-shaped delta of an alluvial fan. The frequently occurence of erosion and scouring plane in between is often observed in terrestrial sedimentation and in the overlying strata. The two formations should be considered in conformity, which puts both Xiahedong Formation and the overlying Haoling Formation in early late Cretacous (Jiang Xiaojun et al., 2010).

According to our observations, the conglomerates in lower Xiahedong Formation are with good rounding, mixed in sizes, slightly sorted, with cemented base, and derived mostly from volcanic Xionger Formation as the distant source and sedimentary tuff from Jiudian Formation as the near source (Fig.6.3), which leads to the conclusion that these conglomerates are of alluvial fans in nature. Taking into consideration that in our work, Jiudian Formation is assigned to the Hauterivian of the middle early Cretaceous and Haoling Formation is assigned to the Barremian-Albian of the middle, late early Cretaceous; Xiahedong Formation, sandwiched between Jiudian and Haoling Formations, was formed in the early Barremian. Therefore, there had been no huge time gap between Xiahedong and Jiudian Formations, but there was a sudden change from lacustrine to terrestrial facie in depositional settings, which suggests that differentiated vertical movement might have occurred after the end of Jiudian Formation. Hence we consider the contact relationship of the two as paralell unconformity. Reliable stratigraphic and chronologic data are unavailable as of now, so we could only confirm that Xiahedong Formation was formed in early Barremian of early Cretaceous, based on the stratigraphical sequences (underlying Jiudian Formation being Hauterivian and overlying Haoling Formation being Barremian-Albian).

Fig. 6.3 The bottom of the thick-layered conglomerate at Xiahedong Formation (K_1x) contains gray crystal tuff gravel of Jiudian Formation

Past regional geological surveys considered Haoling Formation and Xiahedong Formation conformable, i.e., the former Chenzhaigou Formation and Mangchuan Formation conformable. However, Jiang Xiaojun and Liu Yongqing considered former "Mangchuan Formation" and former "Chenzhaigou Formation" overlapping unconformable, based on observation of the unconformity of Mangchuan and Cambrian formations around Liudian (Jiang Xiaojun et al., 2010). We tracked the strata in the field and found that the unconformable strata overlying Cambrain formations were the middle upper beds in the margins of Haoling Formation. Unconformable beds vary in different margins of the basin, which indicates geographic overlapping unconformity around the margins of the basin. In the middle, the sedimentation between Haoling Formation and underlying Xiahedong Formation is continuous and with no big change of facies, which points to complete conformity (Fig.6.4).

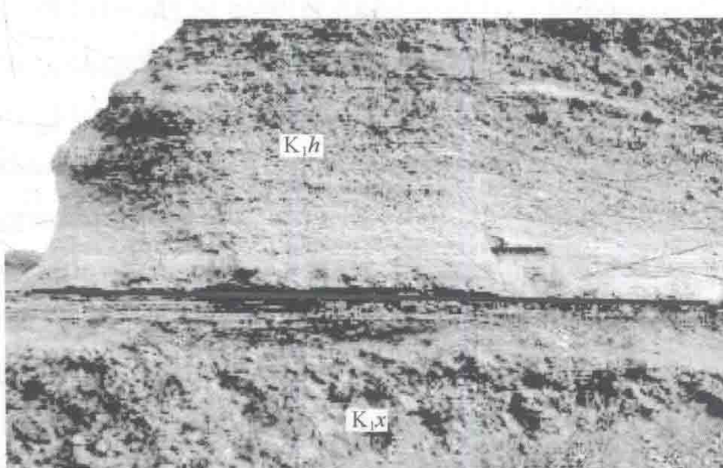


Fig. 6.4 Overlying Haoling Formation (K_1h) in conformity with underlying gravelly sandstone of Xiahedong Formation (K_1x)

Haoling Formation and Xiahedong Formation are distinguished by a planar base of mixed matrix of conglomerate bed, which contains gravels derived from underlying muddy, fine grained sandstones. Prominent scouring marks could be observed on the plane, which extends stably regionally and serves as a good marker to differentiate Haoling Formation and Xiahedong Formation (Fig. 6.5).

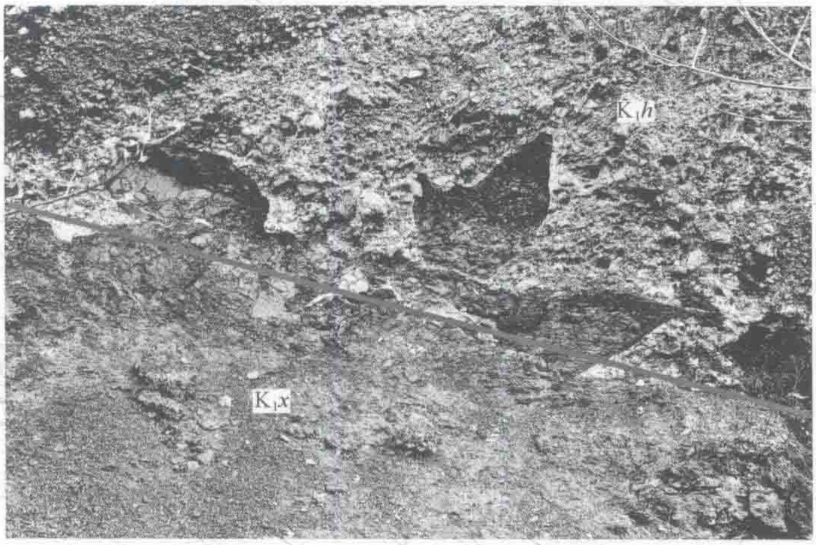


Fig. 6.5 Overlying Haoling Formation (K_1h) in conformity with underlying gravelly sandstone of Xiahedong Formation (K_1x)

The most prominent marker to distinguish Shangdonggou Formation and the underlying Haoling Formation is sandstone and conglomerate that contain feldspar crystals, which turned into the color of snow after weathering (Fig. 6.6, Fig. 6.7), serving as the marker to divide two formations. Occurrence of scouring marks is frequent on the plane of contact and conglomerate bed contains blocks of underlying sandstone, reaching the size of 1m×0.8m in spots. The outcropped thickness of Shangdonggou Formation increases from the west to east. In the middle section of Dangcun, Boqizhang, west Haoling, where the elevation is relatively high, there are only thick bedded conglomerates overlying the hilltops, and the thickness increases gradually to the east, which is related to the eastward graben structure.

Shitaijie Formation was established near the village of Shitaijie in Yanglou, Ruzhou City, when Henan Regional Geological Survey Team (1964) was mapping the 1:200,000 scale Linru sheet of geologic map. It is conformable with the underlying former Mangchuan Formation and widely applied with no change of definition. The stratichronology of the formation was based on a mammal fossil, *Amynodon* sp., found outside the work area, which pointed to Oligocene (Henan Department of Geology and Minerals, 1997).

Fig. 6.6 The conformable contact between grey white conglomerate of Shangdonggou Formation ($K_1\hat{s}$) and underlying purplish red silty mudstone of Haoling Formation (K_1h)

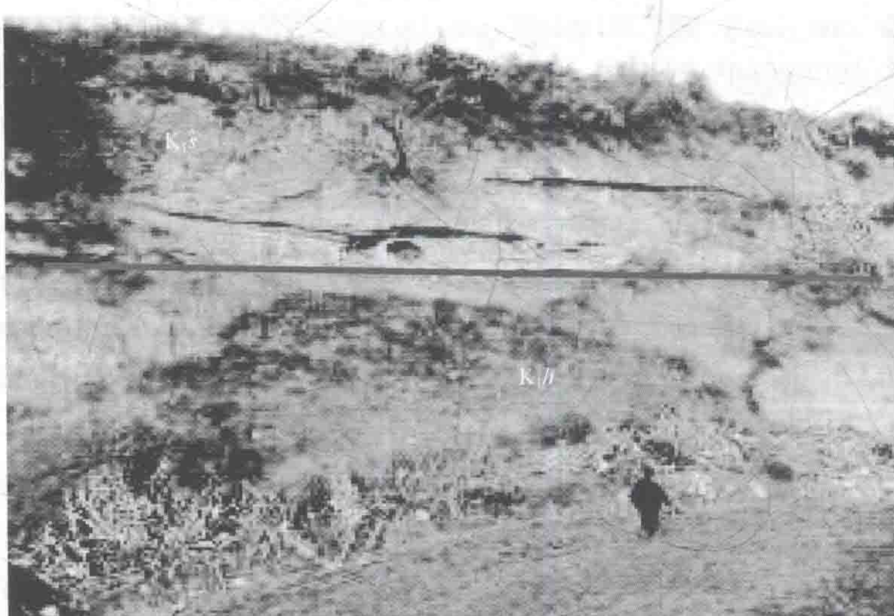


Fig. 6.7 The conformable contact between Shangdonggou Formation ($K_1\hat{s}$) and underlying purplish red silty mudstone of Haoling Formation (K_1h) at the Erliangmiao Village of Liudian town

We collected four sets, dozens of samples in the lower part of argillaceous sandstone in Shitaijie Formation, but no fossils were discovered. Shangdonggou Formation (upper part of former Mangchuan Formation) is already assigned to late Early Cretaceous. The former Shitaijie Formation is depositionally continuous with underlying strata and uniform in sedimentary environment and in conformity (Fig. 6.8). Mammal fossil was found in the upper strata. It is therefore under consideration that the former Shitaijie Formation should also be broken up and assigned to late Cretacous and Paleogene. Due to the absence of indisputable evidence of dating, and to the fact that the type section of Shitaijie Formation was established in the work area, the chronological definition of Shitaijie Formation is not well founded. New in-depth study and comparison should be done to inject new content into our knowledge.

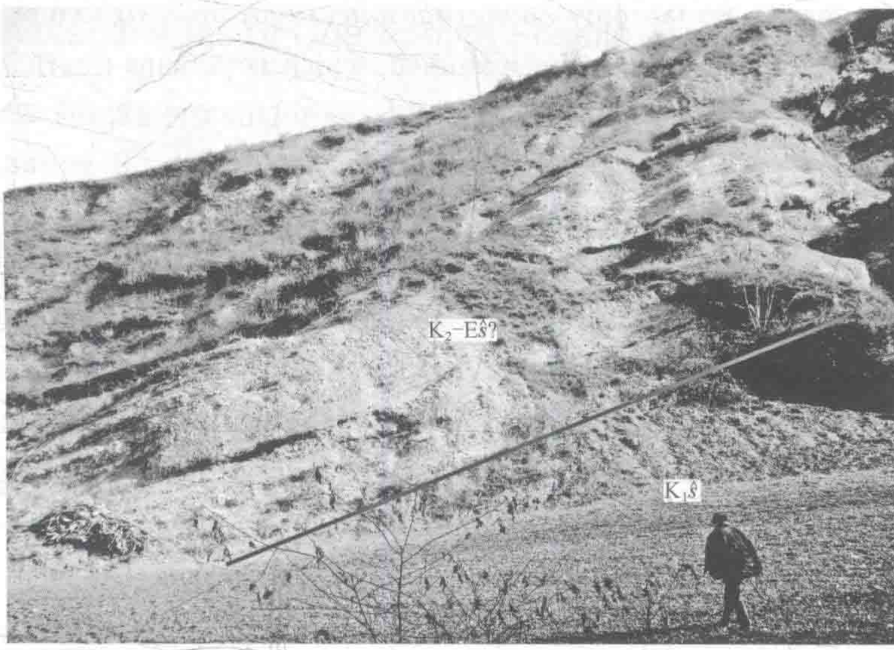


Fig. 6.8 The conformable contact between Shitaijie Formation and Shangdonggou Formation

6.4 The Time Marker of Paleontological Assemblages

6.4.1 Ruyang Gigantic Sauropod Dinosaurian Fauna

After three years of fossil search, excavation, repair and research, it is shown that dinosaurs found in Haoling Formation in Ruyang Basin are from a diverse fauna, primarily consisted of gigantic sauropods, mingled with small theropods, ankylosaurs, hadrosaurs, and large carnivorous dinosaurs. It was named as Ruyang Gigantic Sauropod Dinosaurian Fauna (Lü et al., 2009a). Several teeth of carnivorous dinosaurs were found in Haoling and Shijiagou of Liudian Town in Ruyang County, studies of which showed that they are similar to that of Africa's *Carcharodontosaurus* from between the Aptian in late Early Cretaceous to the Cenomanian in early Late Cretaceous (Holtz et al., 2004; Lü et al., 2009a). Teeth of spinosauridae found in a fossil pit in Shijiagou are similar to that of *Spinosaurs* found in Egypt, which is from Cenomian in the early Late Cretaceous. *Huanghetitan* *ruyangensis* is similar to *Huanghetitan liujiaxiaensis* found in Lanzhou Basin's lower Creaceous Hekou Formation in Gansu Province. *Ruyangosaurus giganteus* is similar to another giant sauropod, *Argentinosaurus*, with similar assemblages of fauna. *Argentinosaurus* is from the Cenomanian to the Turonian in Cretacous. Therefore, on the basis of characteristics of dinosaurian fauna assemblage, Ruyang's dinosaur fauna should be from the Aptian in the late Early Cretaceous to the Turonian in the early Late Cretacous (Xu et al., 2010).

Only ankylosaurs and iguanodons have been found in Shangdonggou Formation, with a few inarticulate fossils. So far, only *Zhongyuansaurus luoyangensis* (Xu et al., 2010), and *Iguanodon* (Zhang et al, 2013) have been studied, which is perhaps a reflective feature of the period between the late early Cretaceous and the eary Late Cretaceous.

6.4.2 Gastropod Fauna

Gastropods were found in both Haoling and Shangdonggou Formations. *Bithynia* sp., *Zaptychius* sp., *Reesidella multilaminate xiazhuangensis* Pan et Zhu, were found in the gray, white, argillaceous sandstones in Haoling in Liudian Town. A large number of invertebrate fossils were found in several beds of gray, white, calcareous mudstones in Changcun of Liudian Town, among which are some very representative gastropods. The study and appraisal by Pan Huazhang of Nanjing Institute of Geology and Paleontology revealed its assemblage as the following: *Zaptychius ?* sp., *Pseudarinia wangyimgensis* Zhu, *Gyraulus* sp., *Gyraulus dongcunensis* Yu, *Lioplacodes* sp., *Zaptychius cf. costata* Pan et Zhu, *Mesocochliopa ?* sp., *Reesidella multilaminate xiazhuangensis* Pan et Zhu, and *Pseudarinia* sp., *Physa* sp.

Based on the distribution and comparison of the above gastropod fauna, gastropods from the Shangdonggou Formation and Haoling Formation in Ruyang Basin are very similar to that of Xiazhuang Formaion in the West Mountains of Beijing, Fuxin Formation in Fuxin of Liaoning, and Miaogou Formation in Chaoshui Basin of Inner Monglia. These gastropod faunas should be assigned to the genera of *Mesocoshliopa cretacea - Zaptychius costatus-Reesidella multilaminate xiazhuangensis* Pan et Zhu (Pan, 2012) and to the Aptian and the Albian in the early Cretaceous.

6.4.3 Bivalves

Bivalve fossils were found in the same beds that contained gastropods in Haoling Formation, in Liufugou of Liudian Town, and in Shangdonggou Formation in Changcun. Among the bivalve fossils in the upper Haoling Formation, *Trigonioides, Charybdis japonica, Plicatounionides, Pseudohyria tuberculata*, which are typical of Cretaceous, were not found. However, a fossil with imprints of hinge teeth and muscle tissues was found and confirmed as *Nakamuranaia* Suzuki, 1943, which is equivalent to Yixian Formation, Jiufotang Formation in Liaoxi, and Qingshan Formation in Shandong.

Bivalves found in Shangdonggou Formation are primarily molluscs, including *Limnocyrena* cf. *rotunda* Martinson, *Neomiodonoides gansuensis* Gu, *Limnocyrena fuxinensis* Gu et Wen, *Ferganoconcha* aff. *rotunda* Martinson, *Limnocyrena anderssoni* Grabau, *Limnocyren* sp., *Limnocyren jeholensis* Grabau, *Limnocyrena* cf. *rotunda* Martinson, *Limnocyrena selenginensis* Martinson, which were common species of the early Cretaceous.

6.4.4 Assemblages of Charophyta Fossils

Charophyta fossils were only found in Haoling Formation and collected from 8 sections of Haoling Formation in Caojiacun, Yujiagou, and Langpo'ao. They include: *Clypeator zongjiangensis* Wang et Lu, *Flabellochara* sp., *Mesochara stipitata* S. Wang, *Mesochara symmetrica* Peck, *L. Grambast*, *Mesochara xuanziensis* Yang, *Mesochara voluta* Peck, *L. Grambast*, *Mesochara latiovata* Zou, *Obtusochara* sp., *Alistochara wangi* Yang, *Alistochara poculiformis* Yang, *Clypeator jiuquanensis* Wang et Lu, *Aclistochara mundula* Peck, *Aclistochara huihuibaodensis* S. Wang, etc. Among them, *Clypeator* was very short lived and limited only to the early Cretaceous in Asia, Europe, and North America. *Clypeator zongjiangensis* was an important fossil in China's early-middle Early Cretaceous. *Clypeator jiuquanensis* was an important element of the Barremian and reportedly found in northern France, northern Spain, Romania, and Portugal; it was found in Shengjinkou Formation-Lianmuqin Formation of the Tugulu Group in Xinjiang's Junggar Basin, Xiagou and Zhonggou Formations in Gansu's Jiuquan Basin, Guyang and Lisangou Formations in Inner Mongolia, Zhoujiadian Formation in Jiangxi's Xinjiang Basin, and Fengjiashan Formation in Shaanxi's Shang County. *Flabellochara* has a global distribution, which started in the early Barremian, thrived in the middle Aptian, and became extinct in the late Aptian. *Mesochara stipitata* from *Characeae* family was found in all 9 samples, which was also commonly found in China's mid-late Early Cretaceous, for instance, Xiagou and Chijinbao Formations in Gansu's Jiuquan Basin, Yantang Formation in Anhui's Xi County, Guyang Formation in Inner Mongolia, Xitanlou Formation in Henan, Qiucheng Formation in Hebei, Hekou Formation in Gansu's Lanzhou, Jiufotang Formation in Hebei's Fengning, Dongjing Formation in Hunan's Hengyang. *Aclistochara mundula* was first found in the Aptian and the Albian stages in the Rockies in the U.S., and is widely distributed in China's mid-upper strata in early Cretaceous. The assemblages of charophyta fossils are basically with the characteristics of the mid-late stage of the early Cretaceous.

6.4.5 Ostracoda

In 2011, a large number of invertebrates and microfossils were found in partially outcropped Shangdonggou Formation, which is mainly of calcareous mudstone, in Changcun-Liudian area. Among the ostracoda found, *Timiriasevia* are most abundant. There are also *Cypridea* sp., *Candona subdeclivis* Tia, *Candona* cf. *pandidorsa* Zhan, *Mongolianella* sp., *Darwinula leguminella* Forbes, and *Timiriasevia liaoxiensis* Zhang.

Timirisevia liaoxiensis Zhang is commonly seen in the lower Cretaceous Fuxin Formation in Liaoxi. *Cypridea* is richest in lower Cretaceous strata. But the fossil samples were too small and fragmented to determine its species. Based on ostracoda found so far, only species from early Cretaceous were observed. No typical species from late Cretaceous was found. Therefore, they are probably from the late early Cretaceous and comparable to Xiazhuang Formation in Beijing and Fuxin Formation in Liaoxi.

6.4.6 Pollens

Samples collected from the cross sections or sites in Caojia Village, Huamiaogou, Miaoling, Taishanmiao, Ligeda Village, in Ruyang Country, were observed to contain some pollen fossils. The primary assemblages are constituted of the following species: *Hsuisporites, Cicatricosisporites, Densoisporites*, which are predominantly fern spores, with *Hsuisporites* spp., *H. liaoningensis*, *H. rugatus*, *Cicatricosisporites* spp., *C.* cf. *dahuichangensis*, *C. minor, Densoisporites* spp. *Classopollis* is the predominant species of gymnosperm spores, together with *Classopollis* spp., *C. granulates, C. parvus, C. annulatus*. There is certain content of *Psophosphaera*. *Piceaepollenites* is only in the double-cuff pollens of conifers. The incomplete differentiation in single cuff of ancient conifers did not appear. The content of *Cycadopites* and *Chasmatosporites* in monocolpate pollen is very low. Therefore, according to the pollen assemblage, the geologic era is more likely to be the late early Cretaceous (Xu Li et al., 2010).

6.4.7 Plant Fossils

A thin coal layer that is 0.02 ~ 0.01m thick and extends to several hundred meters is observed occasionally in Caojiagou, Dingjiagou, Zhangling in the work area. Partly preserved and carbonized plant fossils appear in several beds in Shijiagou and Changcun, which consist of fern spores and pollens of gymnosperms and conifers in general. There were abundant plant fossils in the grey mudstone and siltstone (45 beds) of the Haoling section in Shijiagou. According to the research by Wang Deyou, they are the following genera and species: *Podozamites* sp, *Ginkgoites* sp, *Brachyphyllum ?* sp, cf. *Brachyphyllum* *obtusicapitatum* , which were also the common plant fossils in Cretaceous.

In conclusion, charophyta, ostracods, sporopollen and plant fossils collected in the strata with dinosaur fossils reflect the characters of the mid-late Early Cretaceous. Dinosaur assemblages indicate that the geologic age was between the Aptian in the late of the Early Cretaceous to the Turonian in the early of the Late Cretaceous. Considering that Jiudian Formation as the Hautervian stage (130 Ma) of the mid-early Cretaceous, which is overlain by over 500m of conglomerates of Xiahedong Formation, and that each formation is continuous deposition and in complete conformity, it shows that the dinosaurs discovered so far had lived between the Aptian and the Albian, and that these monstrously gigantic dinosaurs had ruled the the land in the Ruyang Basin for over 20 million years.

7 Growing Silently: Cretaceous Paleoenvironment and its Evolution in Ruyang Basin

What kind of food did the lords of the land eat to make them grow so big 100 million years ago? Where did they like to feed? Where did they play? Was the environment at that time the same as that of Ruyang now? How do scientists reconstruct the environment in the age of dinosaurs?

Brian Ford, a cell biologist at the University of Cambridge, thinks that scientists have already discovered many dinosaur footprint fossils, but almost never found a dinosaur tail trace fossil, although dinosaur usually had a large and long tail. If no tail trace fossils were left on land, it means a dinosaur must lift his gigantic and long tail all time. It does not make much sense, because keeping tail up all the time will consume a lot of energy. So, the real function of dinosaur tail was to adjust direction when moving in the water, with the same function as fish's tail. If we agree dinosaurs were aquatic, most of unsolved mysteries about dinosaurs would be solved. For example, some dinosaurs had two seemingly weak legs but weighed more than 100 tons. If dinosaur lived in the water, the buoyancy of water can relieve lots of weight from dinosaur legs. Ford speculated in his calculation: "dinosaurs should have lived in the lakes with depths of 4.5 to 9 meters most of the time." Furthermore, the temperature in the Cretaceous where dinosaurs lived was much higher than that of today. The lower the water temperature was, the more suitable it was for dinosaurs. Ford said that mud with the dinosaur footprints under water became limestone as time went on. However, many scientists do not agree with this view. Professor Barrett, an archaeologist in Museum of Natural History in London, said that Ford's theory is untenable and that previous research has long ago shown that the leg muscles of dinosaurs were strong enough to support their flexible movement on land and dinosaur's speed of movement was not fast in water.

Although some scientists proposed radical and biased views, there is no direct biological evidence to prove that dinosaurs lived in the water completely. But a dinosaur colony needed to have water, to say the least. Which kind of evidence can help us determine that dinosaurs buried in the strata were living by rivers, or lakes, or the sea? Geological records can serve as clues and guide us to reconstruct the paleoenvironment in which dinosaurs lived. This chapter will provide us with some of sciences behind it.

7.1 The Division of Sediment Environment and their Markers

The criteria to determine sediment environment are summarized into physical, chemical and biological markers that are represented by its depositional characteristics. Physical markers are the sediment textures, grain size distribution, sediment structures, etc, which were formed in or shortly after the process of sediments being transported, and deposited by gravitation, or environmental changes. Chemical markers include syngenetic or quasisyngenetic minerals and rocks, sediment textures formed by chemical reactions, and elemental geochemical, isotopic geochemical characteristics, which were formed in the process of sediment transportation and chemical reaction during the deposition. Biological markers include biological organisms and sediment textures formed by the organisms, which were formed by organism activities and their growth.

Sediment structure is one of the most common macro-level features in the sediments, which consists of sediment components, structures, color disuniformity. Because of its large scale, it can usually be observed and measured in the outcrops in the field and in rock cores. According to the time of its formation, it can be divided into primary sedimentary structures and secondary sedimentary structures. Primary sedimentary structures were formed before its consolidation in the process of depositing or shortly after it. They recorded the information indicative of the depositional environment and energy characteristics in the process. Primary sedimentary structures are important markers to divide sedimentary facies and environment. Secondary sedimentary structures were formed in the process of compaction or diagenesis, which can indicate diagenetic environment. Sediment structures can be divided into three categories according to the causes of formation: ① Physical sedimentary structures refer to those formed by physical factors such as flowing fluid, gravity and other physical factors during debris transportation, deposition, and shortly after deposition; ②Chemical sedimentary structures are those formed on the sediment surface or interior owing to the crystallization, solution and precipitation in the deposition and after deposition. Most of them were formed in the process of sediment compaction and diagenesis, which belong to the secondary sediment structure; ③ Biological sedimentary structures are the various traces or burrows recorded in the sediment surface or interior in the biological activities or growth.

As for the study of sedimentary facies, sedimentology and lithofacies paleogeography had different classification methods in the past. There are mainly two kinds of classification schemes, the first of which is facies and subfacies, the other is facies, subfacies and microfacies (Jiang Xing, 2003; Bin He, 2011). Based on the Mesozoic sedimentary characteristics and various sedimentary environments in Henan province, we selected the classification of facies, subfacies and microfacies to determine sedimentary facies in this area.

7.1.1 Major Identification Markers of Alluvial Fan Facies

An alluvial fan, which develops in the valley mouth, is a cone-shaped debris accumulation, formed mainly by the temporary flood within a limit area. It radiated from the valley mouth towards the basin, with a surface that looks like a cone or fan. Alluvial fans develop in terrains with great altitude variations and in areas with abundant sediment supply.

Alluvial fans can appear singularly, but in most cases many alluvial fans can link together to form belt-shaped or congregated groups along the foot of mountain, which can extend hundreds of kilometers. River channels radiate from the top of the alluvial fan root to the distal fan direction. River channels become gradually shallow towards downstream till the bottom of the channel bed meets the top of the fan, and further downstream, the river sediments form leaf-shaped body in the alluvial fan surface. Rivers on the alluvial fan belong mostly to straight or braided river. River channels often change the path or bifurcate. Webbed river system can form on the top of fan body.

The area of alluvial fan varies greatly and its radius is in the range between less than 100m to more than 150km, with a mean average of less than 10km. The sediment thickness is about several meters to 8 km. In the longitudinal cross-section, alluvial fan is in the shape of concave lens or wedge, and in the transverse cross-section, it is in the shape of a lens. The incline of fan root near the mountain foot is about 5° to 10°, and it becomes more parallel to 2° to 6° further away the foot of the mountain. The thickness of the fan sediment is between several meters and up to about 8000 meters.

The development of an alluvial fan requires rugged terrains and vast supply of sediments. The formation of alluvial fans is therefore controlled by the tectonic setting, the properties of source rocks and climatic conditions. Many studies showed that the large and long active faults and rifts, and arid to semi-arid climate are favorable to the development of alluvial fans. Ongoing fault movement or rifting can result in radical topographic changes and facilitate debris transporting by the river and deposition. Underdeveloped vegetation under the arid and semi-arid condition makes it easier for severe physical weathering, which can produce vast amount of coarse debris. Intermittent floods carry the debris out of the mountainous terrains to form alluvial fans.

Alluvial fan deposit is the coarsest and worst sorted terrestrial sedimentary system near the sediment sources. In general, alluvial fans extend into the river systems with low inclines and fine grains. Some alluvial fans can directly enter into lakes or sea basins to form subwater fan or fan delta sedimentation. Identification markers of alluvial fans include mainly the following features:

(1) Lithological characteristics

Alluvial fan deposition has heterogeneous lithology because of the difference of the source rocks it derives from. Most alluvial fans are primarily consisted of conglomerates with a matrix of sand, silt and clay, while some are of gravelly sandstones and siltstones. Fan root consists of conglomerates and sandstones. Towards the fan end, conglomerates decrease and sandstones and siltstones increase with a decreased thickness. In the transition zone between the fan and the plain, the main deposition is clay. The sediments in the alluvial fans include carbonate and sulfate minerals, such as calcite, gypsum and others, which are deposited synchronously with the debris, or accumulated as a result of surface weathering. The source rocks of alluvial fans determine mineral deposition, which can be used as a clue to speculate the characteristics of sources rocks under certain circumstances.

Alluvial fans are formed under high-energy hydrodynamic conditions with destructive forces. Animals and plants are difficult to be preserved in the alluvial fans. That is the reason why only some scattered vertebrate bones and plant fragments are preserved in the fans, which nearly contain no animal and plant fossils and no organic matters.

(2) Lithologic structures

Sediment of alluvial fan has the characteristics of coarse debris, low maturity, poor rounding, and poor sorting. However, the sorting varies based on different types of deposition. Bull (1960) made a quantitative comparison of debris among all alluvial fan types. The result indicated that the debris sorting of flow deposition is the worst, and grain size changes quickly in the vertical and horizontal direction. Grain size changes gradually to fine from fan root to end, and sorting and roundness gradually improve as well. But, coarse sediments can deposit in the mid or lower parts of fans due to the incised river channel and sediment filling.

(3) Sedimentary structures

Alluvial fans are formed under the condition of intermittent currents, which results in underdeveloped or intermediate bedding. Debris flow deposition forms block bedding or no bedding. Fine argillaceous sediment has thin horizontal bedding. Coarse debris sediment has indistinct and irregular cross bedding with the bedding plane dipping to fan end with an angle of 10°~ 15°. Vertically, bedding structure is a complex interbedded sequence with flow water sediment and argillaceous sediment. In general, debris deposition in alluvial fans can be observed to have scouring-filling structures developed mostly near the fan root. Ripple traces can often be seen in parts of sandy deposition. If gravels show directional alignment, it inclines to the source direction and dips at about 30°~ 40°. Argillaceous sediment surface can develop mud cracks, rain-prints, and current ripples, etc.

(4) Sedimentary coloring

Alluvial fans are the result of debris accumulation brought by intermittent water currents. Sediments often expose in the open air, undergo different degrees of oxidation, and lack dark colored deposits of oxygen-deficient settings. Argillaceous deposits in the alluvial fan are often with the red color, which is an important indicator of arid and semi-arid condition.

(5) Sedimentary assemblage and the characteristics of vertical sedimentary sequence

In the formation and development of the alluvial fans, the grain size and the variation of deposition thickness always show the characteristics of being coarse to fine, thick to thin, from the fan root to the fan end. The debris flow sediment facies and sieve sediment facies mostly occur in the alluvial fan root. River channel and sheet flow sediment facies develop in the whole alluvial fan, but concentrate in the middle of the alluvial fan to alluvial fan end. On the horizontal level, alluvial fan joins with eluvial, diluvial facies towards the source direction, and joins with alluvial plain or aeolian-playa facies towards the deposit zone. Alluvial fans often overlap or intercept with river, lake, or swamp deposition. Sometimes, alluvial fans can be developed simultaneously with seaside (lakeside) plains. Some alluvial fans can directly enter into the quiet water bodies of the lake or sea basins to form underwater fan or fan delta.

Alluvial fan deposition can show progradation, retrogradation or lateral movement due to the difference of sedimentary accumulation rate and basin subsidence rate. This process is distinctly reflected in various alluvial fan sedimentary sequences. When the sedimentary accumulation rate is greater than the basin subsidence rate, alluvial fan deposition will constantly advance in the direction to basin center, and fan root forms on the top of fan mid, and fan mid is above the fan end. This sediment sequence has a reverse cycle of coarsening upwards. On the contrary, when the sedimentary accumulation rate is less than the basin subsidence rate, alluvial fan deposition regresses towards source direction, or moves laterally. As a result, it can form a normal cycle sequence with the size fining upwards.

In different parts of the alluvial fans, their sedimentary sequences are different. The sedimentary sequence is normal sedimentary assemblages in the fan root, which are consisted of blocks of mixed conglomerates and imbricate gravels. The sedimentary sequence in the alluvial fan mid is consisted of blocks of mixed conglomerates, indistinct parallel bedding, gravelly sandstones with cross bedding, and sandstones, from bottom to top. The profile structure of the fan end is usually consisted of scouring-filling structured gravelly sandstones, cross bedding and parallel bedding sandstones, horizontal bedding sandstones and blocky mudstones. Sometimes it develops deformed structures, such as pillow-shaped structure.

7.1.2 The Main Markers of Fluvial Sedimentary Facies

(1) Lithologic characteristics

Fluvial facies has the lithology primarily of clastic rocks and rarely of carbonate rocks. Among clastic rocks, sandstone, siltstone and clay stone are the main components. Conglomerates mostly appear in the mountainous and plain river channel sediments. Clastic rocks are with complex components, which vary with the source rocks in the source area and the catchment, and which generally are unstable and immature. Conglomerates have complex composition. Sandstone is mainly consisted of feldspathic sandstone and coarse sandstone with argillaceous cements being predominant and occasionally with calcareous and ferrous cementation.

Most of the river water is oxygen-poor, and almost neutral to slightly acidic. As a result, clayish minerals like kaolinite are abundant and illites are rare in fluvial facies sediments.

(2) Characteristics of sedimentary structure

Fluvial facies has well-developed beddings with numerous types, but is featured by planar bedding and large-scale trough cross-bedding. The thin beds tilt towards the direction to which the deposition extends, with a dip of about 15°~30°. From bottom up, the sequence of beds becomes thinner in thickness and finer in grain size, in which the normal gradation shows and the thickness of the sequence rarely exceeds 1m and normally is 30cm or thinner. In the river deposition profile, large planar and trough cross-bedding form in the lower part, small planar beddings form in the upper part and wavy beddings form on the top. Asymmetric ripple traces are also commonly found in river sedimentation.

Erosion, incision and scouring structures are formed commonly in the bottom of the river deposition, which often contains muddy gravels and gravels derived the underlying strata. Gravels often have imbricate alignment with the flat surfaces incline to upstream.

(3) Characteristics of fossils

Body fossils generally are not well preserved in fluvial facies. It is very difficult to discover the complete animal and plant fossils, except for fragmented branches, stems, leaves and so on. Typical fossils to indicate river channel subfacies are the petrified wood, which is silicified plant's trunk or stem formed under open system conditions. The carbonized plant debris or complete plant fossils are visible in flood plain marsh sediments, which are mostly preserved under the closed and anoxic conditions. Vertebrate fossils can be seen in fluvial facies strata with younger age.

Trace fossil assemblages such as *Scoyenia* are mainly formed in the flood plain deposits. *Skolithos* trace assemblages are preserved mainly in relatively fine-grained parts of river sands, which are medium or fine sandstone. *Planolites-Taenidium* trace assemblages are mainly preserved in abandoned river channels.

(4) Characteristics of sedimentary sequence

In the cross-section of deposition, normal gradation sequence or cycle of fining upwards is shown from bottom up. The typical cross-section of meandering river deposition should have complete sequence of fluvial deposition, the dual layer structure. Point bar or central bar, and floodplain depositions appear sequentially, formed from lag deposit in the bottom and accumulated to the upper part.

(5) Morphology of deposition

River deposition mostly looks like curved band, ribbon, branch, and so on, in the surface. In cross-section, it is shown as lens that is flat on top and convex to the bottom or as plates embedded in argillaceous sediments. Central bar accretion in the braided river always appears as groups of lens-shaped blocks overlapping with each other and surrounded by argillaceous sediments, which indicates that river has moved back and forth several times.

7.1.3 The Main Markers of Lacustrine Facies

(1) Lithological characteristics

Lake sediments comprise mainly of clay, sandstone and siltstone. Conglomerate is only found in shallow lakes and mostly formed by waves eroding the coast. In general, sandstones in lakes are more complex than marine ones. In comparison with fluvial sandstones, their mineral maturity is higher with a quartz content that is up to 70% and a finer granularity than fluvial sandstones and better sorting.

Clay rocks are widely distributed in clastic lake sediments, and increasing from the lakeshore to the center. The lacustrine clay rocks formed in the deep water under the oxygen deficient environment often contain abundant organic matter and become good sources of petroleum.

Clastic deposition in lakes may also have various types of biogenic and biochemical rocks, such as limestone, marlite, diatomite, oil shale, and others, although with limited thickness and distribution range.

(2) Characteristics of sedimentary structures

There are many types of beddings, but horizontal beddings are dominant. Lakes have a limit area and small wave base depth, and most parts of lakes are under the wave base, so that clay rocks are formed with horizontal beddings, and blocky beddings occasionally. Cross beddings, wavy beddings and others can often be seen near the shore line.

Lake sediments can form well developed ripple marks. The symmetrical ripple marks were regarded as an indicator to distinguish lake facies and river facies in previous studies. But, according to the study of Picard et al., the symmetrical ripples are not exclusive to lake facies and asymmetrical ripples can be formed in the lake deposits, although with the alignment of wave crests being parallel to the shoreline. The steeper ridges of asymmetric ripples tend to dip to the shore line. Mud cracks, rain prints, and blending structures are also found commonly in the lake sediments.

(3) Characteristics of body fossils

Abundant body fossils are an important feature in the lake debris deposition. Common species are ostracods, bivalves, gastropods, and so on.

Algae are also common organisms in the lakes. Charophytes are only in freshwater. Together with Cyanophytes, Diatoms and some Chlorophytes are common lacustrine fossil types. Among them, Cyanophytes are different from their marine species with laminated structures and are often in dendritic forms or with isolated massive nodular structures. In addition, lacustrine facies is characterized with frequent appearance of large amount of terrestrial plant roots, stems, leaves, spores and pollens.

The *Skolithos* trace assemblages are developed in the sandy sediments along the lake littoral zones, and *Scoyenia* trace assemblages are always developed in the muddy or silty lake sediments. *Arenicolites* trace assemblages are in the upper part of shallow lakes and *Planolites* trace assemblages mainly in the lower part. Traces in the deep lakes and semi-deep lakes are mainly of grazing traces, feeding traces and crawling traces, such as *Vagorichnus* and *Gordia*.

(4) Characteristics of sedimentary sequence

There are some regular cyclical variations in the clastic lake sedimentary profiles, such as the mini cycles consisting of conglomerate, sandstone and mudstone in alluvial facies. Combined mini cycles develop in the lake delta front facies, and sometimes, there are mini reversed cycles, which are formed in the shallow lake shore facies. Simple mini cycles consisting of mudstone and silty mudstone are formed in the deep lacustrine facies, and uniform mudstone mainly deposits in the deep lacustrine facies, where mini cycles are absent. These sedimentary cycles are helpful to the study and identification of lake deposits.

(5) Morphology of sandy deposition

The morphology of sandy deposition is an important marker to identify lake environments. Deep and shallow lake depositions generally look like blankets or long sheets. Littoral sandy depositions, including sand bars and levees, are belt-shaped. Sometimes, delta and turbidite sandy depositions are formed in lakes.

7.1.4 Trace Fossil Markers in Terrestrial Deposits

The trace fossils have been used as an important tool to interpret the sedimentary environments, ever since Seilacher (1967) of Germany first proposed ichnofacies, which were well accepted by other scientists, who have further improved and enhanced the study.

Trace fossils are sedimentary structures formed by ancient biological activities when no organisms are directly preserved in the sediments. They present detailed information of habits, behavior, foraging, and feeding of organisms. Sometimes, the best preserved fossils may not be able to provide the environmental information that trace fossils preserved. Furthermore, most of trace fossils are preserved *in situ*, and they can not be transported and re-made after being formed. Therefore, the trace fossils are direct evidence of biological behavior and habits under certain environmental conditions and sensitive indicators of depositional environment. In addition, trace fossils were formed by abundant soft-bodied organisms without hardened shells or bones. They are very important to identify depositional environments in some strata that have no fossils, such as turbidites and sandstones. It has played an irreplaceable role for analyzing biotas, depositional conditions, and even stratigraphic correlation, etc. Furthermore, in-depth study of trace fossils has very important theoretical significance for exploring the origins of life on earth, metazoan evolution, especially the evolution of biological behavior, biodiversity and so on. Similarly, trace fossils have practical value in the biostratigraphy research, event stratigraphy and sequence stratigraphy, and are uniquely valuable in reconstructing palaeoecology and palaeoenvironment.

At present, there have three internationally recognized terrestrial ichnofacies: *Scoyenia* ichnofacies, *Mermia* ichnofacies and *Coprinisphaera* ichnofacies.

7.1.4.1 *Scoyenia* ichnofacies

Scoyenia ichnofacies was originally proposed by Seilacher (1967), which indicate trace fossil assemblages formed in the "non-marine sandstone and shale", such as red strata. Later on, because many trace fossils formed in the non-marine environments were added indiscriminately into *Scoyenia* ichnofacies, it became synonymous to non-marine trace fossils, and lost the original meaning and environmental implications. Frey and Pemberton (1984) redefined the ichnofacies only as *Scoyenia gracilis, Ancorichnus coronus*, or burrow trace assemblages with the similar ecological habits, which have low disparity and crescent-shaped filling structures. The arthropods footprint is an important ichnofacies. At present, *Scoyenia* ichnofacies includes *Scoyenia, Beaconites, Ancorichnus, Taenidium, Palaeophycus, Cruziana, Rusophycus, Diplichnites, Umfolozia, Merostomichnus, Acripes, Siskemia* and various footprints and crawling prints (Fig. 7.1).

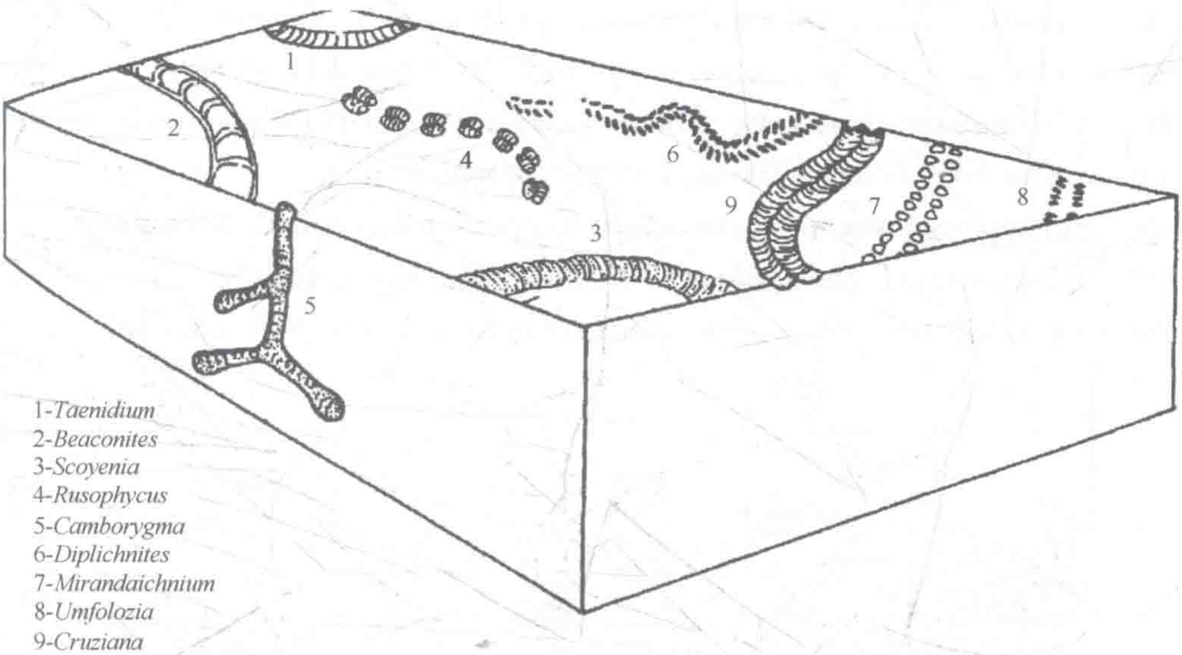


Fig. 7.1 Characteristics of assemblages of *Scoyenia* ichnofacies

Scoyenia ichnofacies can be divided into two assemblages: the first type of trace fossil has a crescent-shaped backfill structure, but no ornamentation (eg. *Taenidium, Beaconites*), which is formed in the soft basement. The second type of trace fossil has striped structure (eg. *Scoyenia, Spongeliomorpha*) and intercepts into the first assemblage, and is formed in the hard basement (Buatois and Mangano, 2002). This kind of repeated occupation or composite ichnofabric structure in the basements indicates the continuous consolidation process of deposition.

Scoyenia ichnofacies develops under the low-energy deposition environment that are cyclically exposed and flooded with the basement cycling between aquatic environment and dry environment. Evidence indicative of the basement's exposure includes symbiotic sedimentary structures such as desiccation cracks, raindrop imprints, and so on. In the river system, this kind of ichnofacies appears in the overbank depositional environment, which covers many sub-environments, such as flood plains, ponds, embankments and crevasse splay (Frey and Pemberton, 1984; Buatois and Mangano, 2002). In the lake environment, *Scoyenia* ichnofacies usually develops in the lake margins, both in the open or closed lakes, and in temporal or permanent lake system (Buatois & Mangano, 1998).

7.1.4.2 *Mermia* ichnofacies

Based on sedimentary characters of the trace fossil assemblage in the Carboniferous lacustrine turbidites in the northwest part of Argentina, and combined with other sedimentary characters of trace fossil assemblage in lacustrine turbidites of different eras in other areas, Buatois and Mangno (1995) proposed *Mermia* ichnofacies, reflecting the features of trace fossils in deposition of completely underwater lake settings .

Mermia ichnofacies is mainly composed of various grazing traces nearly horizontal and non-specific *Fodichnia* by the mud-eating animal in the moving process. There are some crawling traces. Trace fossils has moderate to high diversity. Representative fossils include: *Mermia, Gordia, Helminthopsis, Helminthoidichnites, Vagorichnus, Cochlichnus, Tuberculichnus, Planolites, Treptichnus, Maculichnus, Undichna, Palaeophycus* and others (Fig. 7.2).

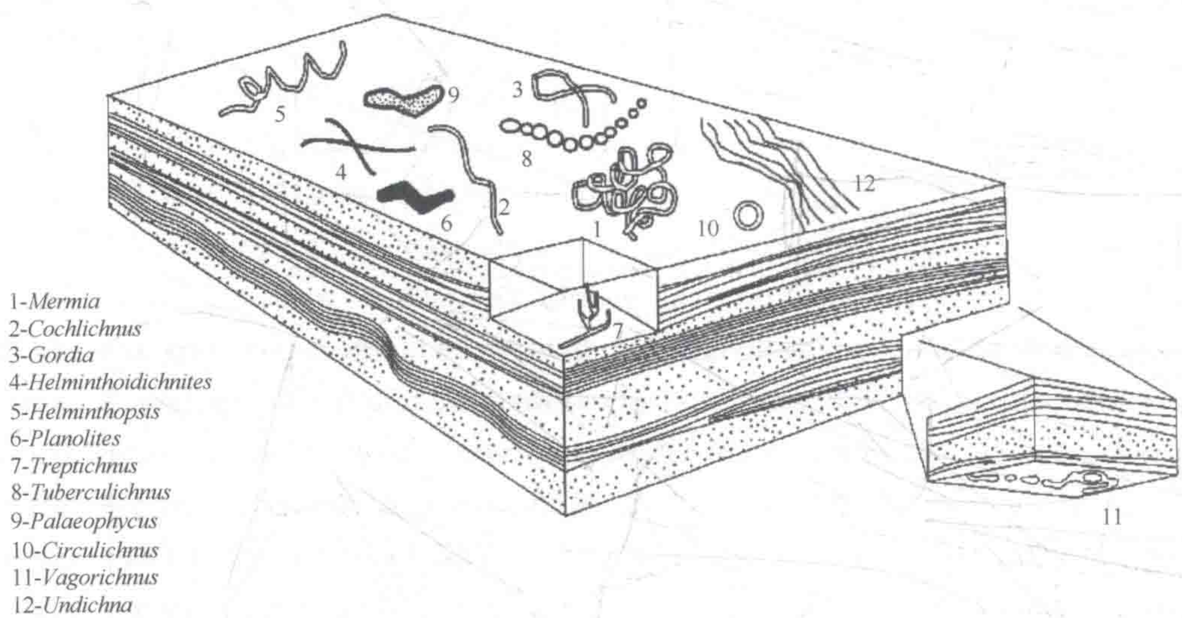


Fig. 7.2 Characteristics of assemblages of *Mermia* ichnofacies

Mermia ichnofacies can be used to distinguish trace assemblage before and after deposit events. If it develops in the fine soft sediments under the oxygen rich and low energy lake environments, it reflects the stable environments, with low accumulation ratio, but always interfered by emergencies such as turbidite current and underflow. Sedimentary structures always are consisted of parallel bedding, gradient bedding and tool prints. It develops in all lake environments from shallow to deep. Because lake system changes greatly, no prototype *Mermia* ichnofacies can be used to indicate shallowness and depth. Buatois and Mangano (2002) extended *Mermia* ichnofacies environments to perpetual flooded plain. Mikulas (2003) supported this view based on researching modern flooded plains. The disparity of *Mermia* ichnofacies in the flooded plain is lower than that in the lakes, as a possible result of the lower stability in flooded plains than that in lakes.

7.1.4.3 *Coprinisphaera* ichnofacies

Genise et al (2000) proposed the *Coprinisphaera* ichnofacies after studying 58 trace fossil assemblages which contained beetles, bees, wasps, scarab beetles, nests of ants, coprolites and footprint of the vertebrates, as well as plant root traces. They are often with moderate or even high diversity and abundant in the paleosols in the herbaceous ecological system. The trace fossils mainly contain: the beetles relics (*Coprinisphaera, Palmiraichnus, Eatonichnus, Celliforma, Monesichnus, Fontanai* and *Teisseirei*), the ichnofacies of bees (*Celliforma, Ellipsoiderchnus, Uruguay, Palmiraichnus* and *Rosellichnus*), the ichnofacies of the wasp (*Chubutolithes, Cocooms*), the ichnofacies of the ants (*Attaichnus, Parowanichnus*), the ichnofacies of termites nests (*Syntermesichnus* or *Tacuruichnus*) (Fig 7.3) .

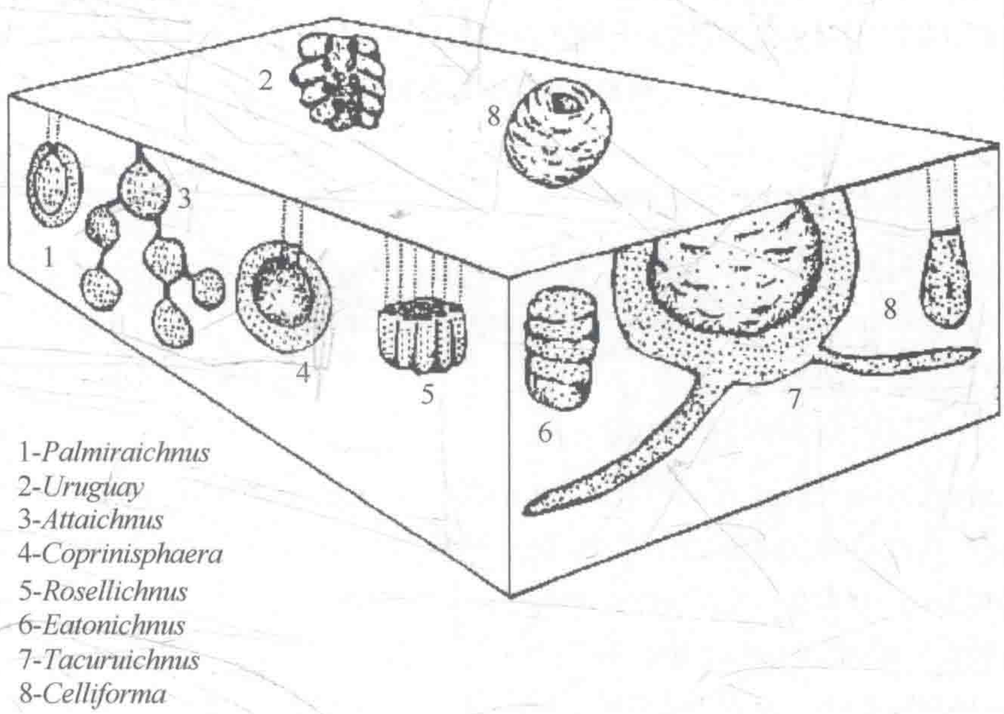


Fig. 7.3 Characteristics of assemblages of *Coprinisphaera* ichnofacies

Coprinisphaera ichnofacies has well preserved records in the strata from Paleozoic to present, although it is still difficult to confirm its existence in the Late Cretaceous. Most of the nests of scarab beetles, ants, bees and wasps are combined with the open ecosystem. Insects of *Hymenoptera* are in favor of looking for the dry soil under the sunshine. Scarabs prefer to seek a place with dung of herbivores. Ants are choosy about the moisture in the air and in the soil in the tropical rainforest. Their nest fossils can indicate the environment factors of the age they lived in. *Hymenoptera* ichnofacies assemblages indicate the relatively dry conditions, however termite nest fossils assemblages reflect much humid environment. Although there are special sedimentary environment in which *Coprinisphaera* ichnofacies develops, the climate plays an important role, even as the primary controlling factor. It is usually related with the development of the paleosol in herbaceous ecological system when climate changing from dry and cold to warm and wet. *Coprinisphaera* ichnofacies formed in paleosol whose base was exposed in the open air, including alluvial plain, flood plain, abandoned channel, natural levee, crevasse splay and environments with plant weathering. It reflects the ability of insects to colonize and live in different life environments.

Above-mentioned are three ichnofacies that are widely accepted as terrestrial ichnofacies assemblages. The first two appeared in river and lake system, and the third one always developed in the paleosol.

7.2 Cretaceous Facies and Sedimentary Characteristics in Ruyang Basin

7.2.1 Sedimentary Facies

Cretaceous sedimentary facies in Ruyang Basin of western Henan include conglomerate, sandstone, mudstone and carbonate facies. A brief introduction is as follows:

7.2.1.1 Conglomerate facies

Conglomerate facies is one of the most widely distributed rock types in the work area. According to the characteristics of rocks, it can be divided into matrix supporting conglomerate facies and particle supporting conglomerate facies.

(1) Matrix supported conglomerate facies

Conglomerate facies is distributed widely in different formations. Its color is purple, light purple, gray green. Different sized gravels are mixed, and the main size is about 3 ~ 20 cm; the largest gravel grain size can reach tens of centimeters. Gravel composition is mainly andesitic porphyrite, quartzite, quartz sandstone, carbonate rock, sandstone, gneiss, tuff and so on, which are closely related to the rock sources. Haoling Formation and Xiahedong Formation conglomerates are consisted of volcanic rocks including Xiongerr Group andesitic porphyrite, dacite, and different types of quartz sandstone in the Ruyang group, and a few vein-shaped quartzite, gneiss, schist. Conglomerates in the Xiahedong Formation and Shitaijie Formation are mainly of quartz sandstone, andesitic porphyrite, and small amount of siliceous striped dolomite and limestone. Argillaceous and silty matrix has a high content in some rocks. Purple red argillaceous conglomerates are formed in this area. Gravel's roundness varies greatly, ranging from sub-angular to round. Gravel is supported by matrix with high content of argillaceous matter. Conglomerate beddings are mostly of blocks and thick beds. Gravel mudstone lenses or argillaceous bands are always formed in these conglomerate beds (Fig. 7.4). Graded beddings were observed occasionally, due to the change of gravel sizes. Eroding plane and scouring marks were seen at the bottom.

(2) Grain-supported conglomerate facies

The gravel color is gray, gray white, and purple gray. The diameters of gravels are mostly of medium to fine gravel and pebble with a diameter of 2 ~ 20cm. Coarse gravels are formed at the bottom. Gravel components are mainly various types of quartz sandstone and various types of andesitic porphyrite and others in the Xionger Group (Fig. 7.5). Gravel rounding is high, sorting is high also, and the matrix is mainly grains. Conglomerate horizontal plane is mostly of half concave lenses with normal gradation sequence, which have commonly large wedge-shaped cross-beddings interbedded with sandstone and conglomeratic sandstone.

Fig. 7.4 Purple red argillaceous conglomerates in braided-river bottom of Shangdonggou Formation

Fig. 7.5 Grain-matrix conglomerate facies with sandstone lens in the bottom of Shangdonggou Formation

These types of conglomerate sedimentary facies can be further subdivided into three microfacies: debris flow deposits, channel deposits, sheet flow deposits.

(3) The debris flow deposits

Debris flow is a high density fluid with mixture of sand, gravel, clay material and water, flowing along slopes and powered by gravity. It is a devastating geological disaster. It has a high clay and water mixture density, and has a high buoyancy to the clastic particles so that sands and gravels can suspend in the flows, which means that sand and gravels are supported by dense matrix of clay and water mixture. Because debris flow's carrying capacity is a function of the matrix strength, the greater the density and the buoyancy are, the greater the diameter of the moved debris is. Therefore, debris flow can support and carry huge boulders. For example, purple blocky conglomerate and gravels are poorly sorted, and have greatly different roundness and indistinct graded bedding, with mixed cementation matrix at the bottom of the Xiaheedong Formation. The base is consisted of not only mud but also sand, which indicates debris flow deposits.

(4) River channel deposits

The river channels on the alluvial fans are distributed mostly in the upper part, from fan root to fan mid. River channel lag deposition consists of poorly sorted gravels and sandy clasts, with indistinct stratification and abundant lenses. The large thin beds converge frequently downwards to form cross-bedding, indicating the property of the traction current and the direction of flow and sediment source. Gravels are arranged in imbricate shape, which has an unobvious groove-shaped sharp contact with the basal scour-and-fill structure. Sedimentary thickness is commonly about tens of centimeters, and with lens-shaped profiles. The stability of alluvial fan channel is very poor, and subject to changes. The lag deposits in the old river channel were covered by sheet flow sediments, and these two types of sediments constitute a finer upwards sedimentary sequence (Fig. 7.6).

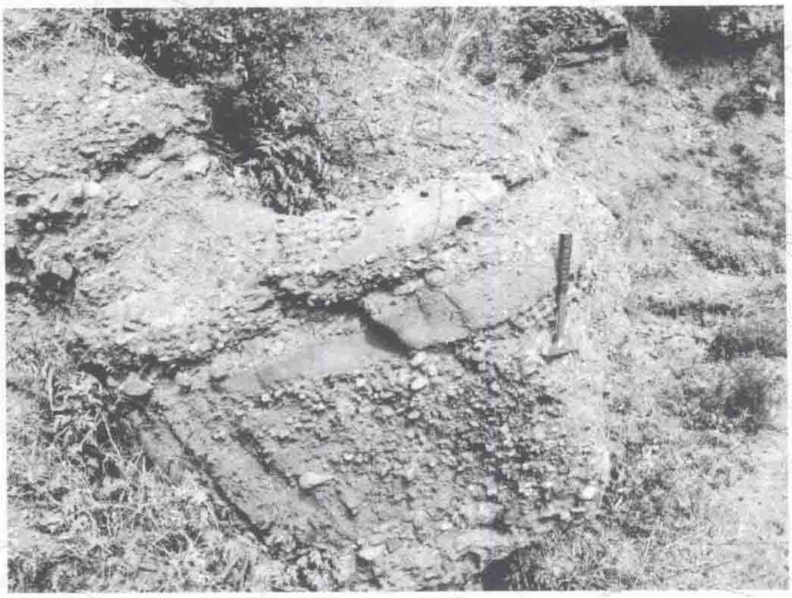


Fig. 7.6 A finer-upwards sequence of braided-river conglomerate, sandy conglomerate and conglomeratic sandstone in Shangdonggou Formation

(5) Sheet flow deposits

Sheet flow is a type of sheet-shaped flood formed on the top part or the whole fan by flood overflowing the channel during the flood periods, which is a shallow, rapid, and temporary current with high energy. Sheet flow is formed commonly in the downstream far from the hill mouth. After the flood peaks, sheet flow changes rapidly into braided channels and sand bars. Sheet flow sediment is mainly consisted of sand with good sorting, and often has small lenticular gravel interbeds and scouring structure. Regression flood can produce finer upwards sedimentary sequence. Argillaceous siltstone and silty mudstone are often seen in the profiles. For example, gravel-containing silty mudstones with thin beds of conglomeratic or gravelly sandstones, silty mudstones are sheet flow deposits in the Ruyang Basin.

These three types of alluvial fan are distributed in unstable condition, and subject to change with every flood, in terms of the volume of the runoff and fan drainage. Debris flow deposits often occupy the largest portion at the upper part of the fan (fan root). River channel and sheet flow sediments are distributed widely in the middle to lower part of the fans (fan mid to fan end).

7.2.1.2 Sandstone facies

Sandstones are only distributed locally in the area, including gravelly sandstone, argillaceous sandstone, calcareous fine-grained sandstone, siltstone, and others.

(1) (Gravelly) Clastic sandstone facies

Rock color is purple-grey, yellow, gray and gray-green. Lens-shaped sand deposits and wedge-shaped cross-bedding are often seen in the strata in the Ruyang Basin, which can be interpreted as formed by the river channel sediments and flood fan sediments associated with river channel lag gravels (Fig. 7.7), or as changing between facies. Trace fossils are often seen.

Fig. 7.7 Gravelly sandstone in lower Haoling Formation

Fig. 7.8 Interbedding of gravelly sandstone and argillaceous fine sandstone

(2) Argillaceous fine sandstone facies

This facies has been found in the Xiahedong Formation and Haoling Formation in the Ruyang Basin, with color being grey to grey green or purple. The bed's thickness is thin to medium. Grain sizes change in a short distance along the strike direction, from coarse gravelly sandstone, argillaceous coarse sandstone, to argillaceous fine sandstone in the Ruyang Basin. Gravel components are mainly consisted of quartz sandstone with good rounding.

Argillaceous fine sandstone facies has also been seen in the Caojiachun and Shijiagou cross-sections of the Xiahedong Formation, and occasionally with trace fossils, which suggests channel levee sediments. This type of sandstone is distributed in sheet-shape occasionally. It was usually formed in the palaeosol with poor drainage in the flood plain by flood overflowing the banks.

7.2.1.3 Mudstone facies

Mudstone is one of the most widespread rocks in the Ruyang Basin, including silty mudstone and clay, with the former being predominant and gravels often seen in local beds. Purple, red, and brown mudstones or silty mudstones and conglomerates or sandstones are commonly interbedded in cross-sections. Grey green mudstones and grey black mudstones are been seen locally, and with varying thickness. Secondary light and grey white calcareous nodule beds and mottled blocks are frequently formed in the massive mudstone, and tubular trace fossils have been observed occasionally. The sediment environment is overbank environment or fan front temporary lake and marsh environment, or flood plain, or flooded lake, or flooded marsh.

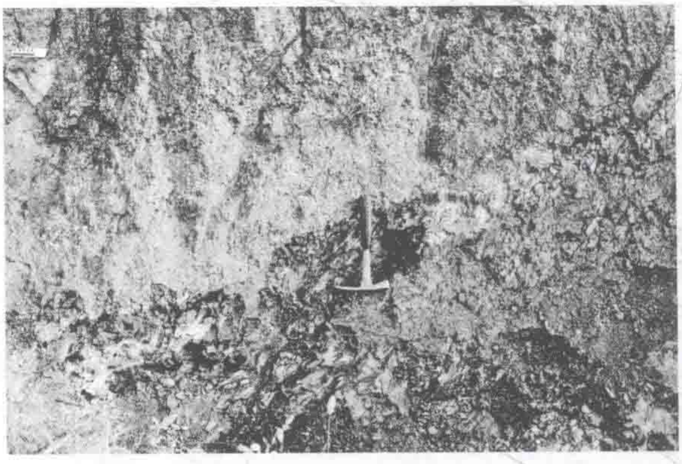


Fig. 7.9 Brownish red mudstone in lower Shangdonggou Formation

Fig. 7.10 Dark grey mudstone, coal band and fan front paludal facies of Haoling Formation

Mudstone facies also includes various types of paleosols, with weak to moderate pedogenesis. Plant root traces can be seen occasionally in the mudstone. Paleosols may suggest that there was a sediment discontinuity for at least several hundred to several thousand years. Grey green mudstone and purple-red mudstone generally appeared interbedded in the palaeosols with medium degree of transformation, which can be interpreted as the decrease of iron ions in saturated water in the gleying process of paleosols, similar to modern soils containing large amounts of organic matter in stage A (Fig. 7.11).

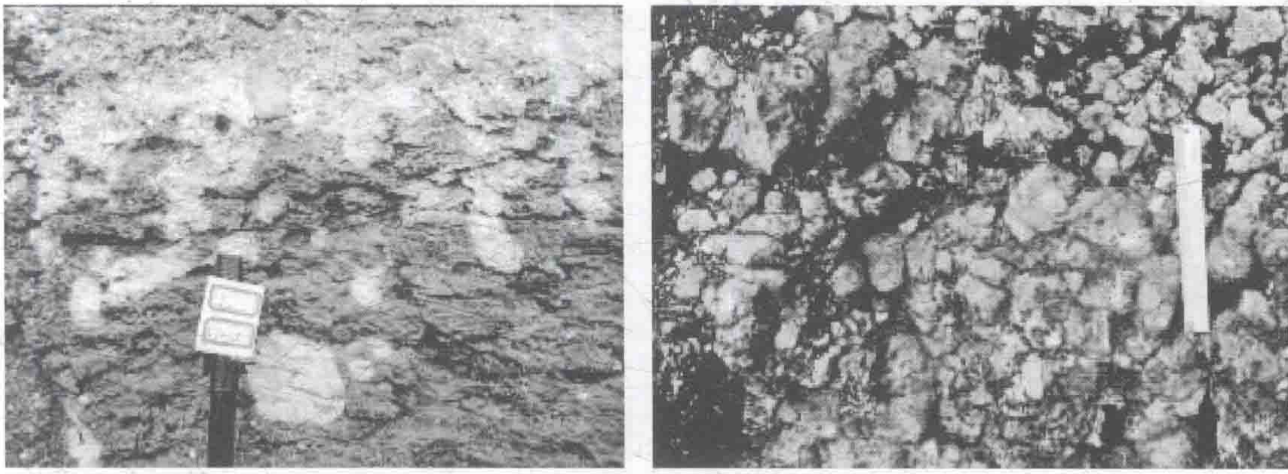


Fig. 7.11 Formative conditions of paleosols in Ruyang Basin

7.2.1.4 Carbonate rock facies

Carbonate rock sediments have been found in parts of Xiahedong Formation , Haoling Formation and Shangdonggou Formation in the Ruyang Basin, which are shown as thin beds of argillaceous siltstone or as len-shape beds with about 0.1 ~ 2.9m thickness per layer. Grey white thin to medium thick argillaceous limestone have been seen in the Shangdonggou Formaiton in Caojiachun section (Fig. 7.12). Thin to medium thick argillaceous limestone and grey medium thick nodular limestone have been seen in the Haoling Formation in the Caijiachun section (Fig. 7.13). It was formed in the shallow flood lake or fan end with local shallow lake deposits.

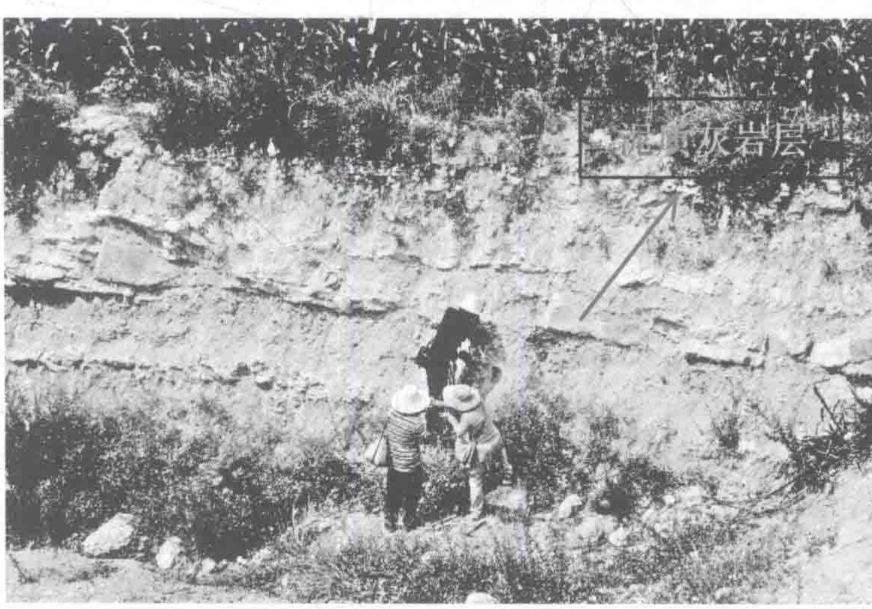


Fig. 7.12 Thin argillaceous limestone interbeded with argillaceous siltstone in Shangdonggou Formation

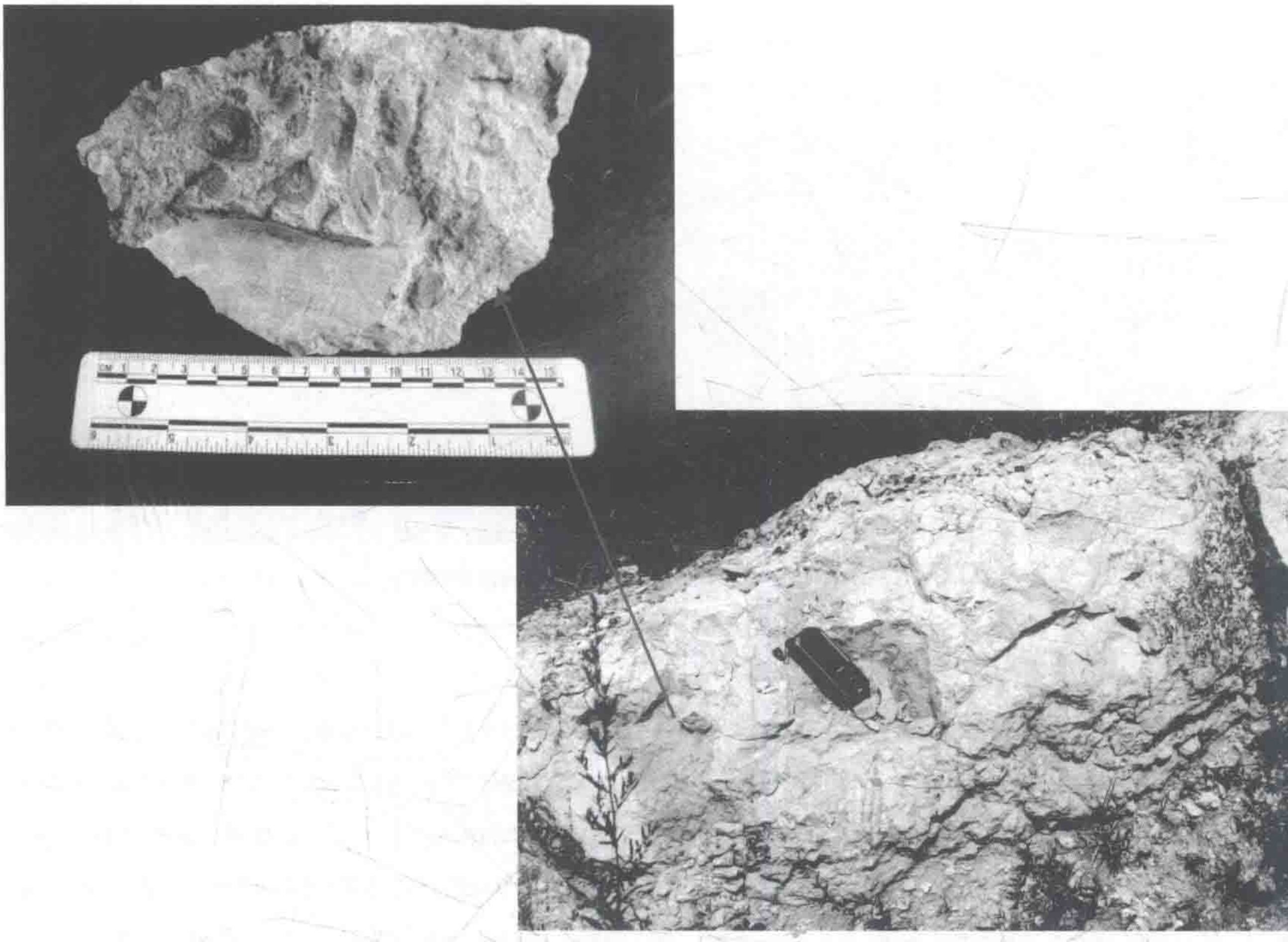


Fig. 7.13 Nodular limestone in middle Haoling Formation

7.2.2 Characteristics of Lithologic Structure and Grain Size

7.2.2.1 Lithological structure

Structural characteristics of clastic rocks are primarily consisted of three aspects. ① the characteristics of clastic particles, such as grain size, shape and structure of the particle surface. ② the characteristics of the filling material, including matrix and cement. ③ the relationship between clastic particles and filling material: supporting and cementing types. Cretaceous rocks in western Henan's Ruyang Basin were terrestrial clastic rocks that include matrix supporting conglomerate facies, particle supporting conglomerate facies and sandstone facies (Fig. 7.14), mudstone facies and carbonate rock facies.

7.2.2.2 Granularity analysis

Granularity is an important characteristic of clastic rocks (mostly sandstones and siltstones), volcanic clastic rocks and carbonate rocks with granular structures. It is an important factor in studying the formation of rocks.

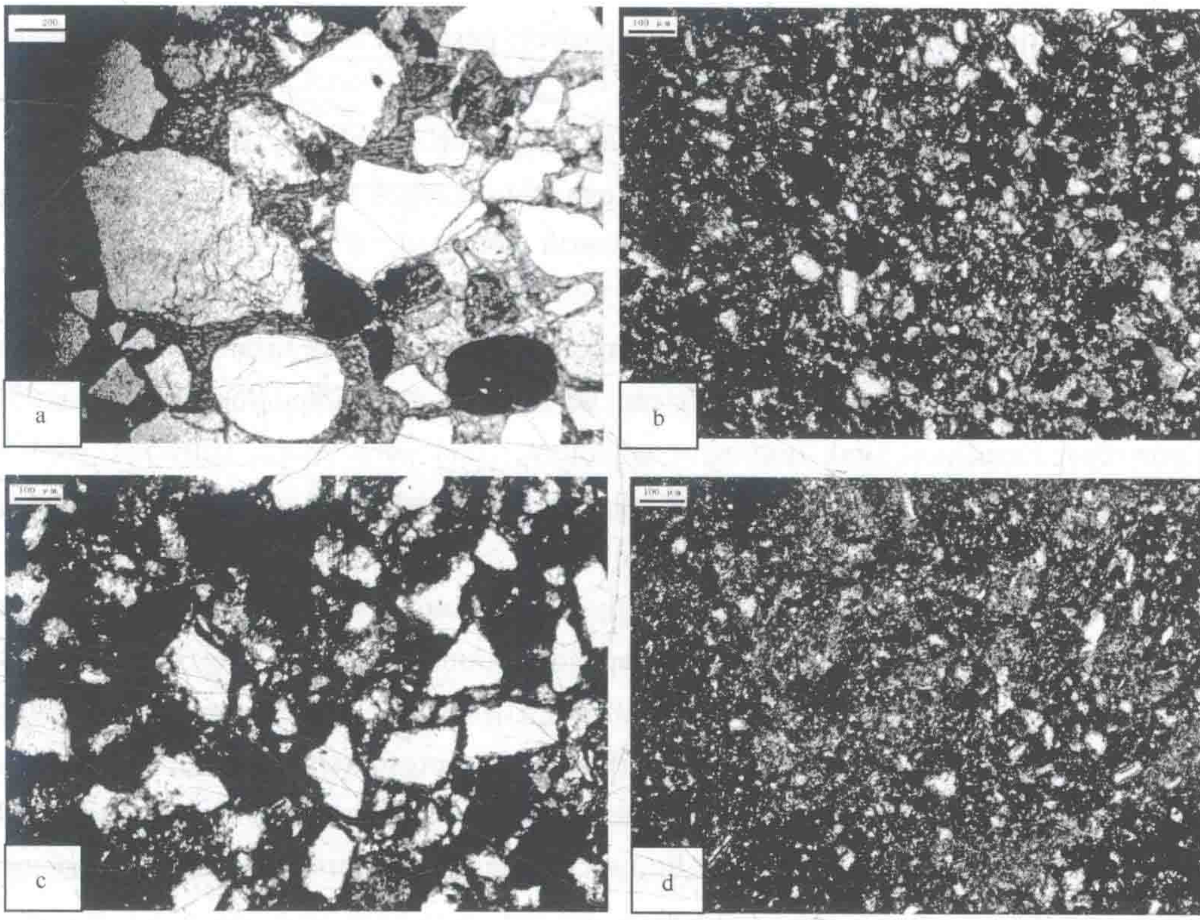


Fig. 7.14 Lithological structure of sandstone in Ruyang Basin

a, b—bottom and top of the 54th layer of sandstone; c—the 12th layer of sandstone; d—the 34th layer of sandstone

There are many granularity analysis methods, for example, direct measurement of grain sizes of unconsolidated sediments and loosened rocks such as gravels, and sieve method, and others. Thin section of grain size analysis or image analysis had been used on the compact rocks. Sliced grain size analysis is used in this book. The results of grain size analysis can be drawn as grain size diagrams, including histograms, cumulative frequency graph, cumulative curve, cumulative probability curve graph and C-M plot, and others, which can be used to determine the characteristics of transportation medium during sandstones formation and sedimentary environments. Based on the grain size figures drawn above and diagensis interpretation, transportation medium and the characteristics of the medium are understood, such as wind, atmosphere, rivers, waves, tidal flow or turbidity current, etc. And it can also indicate the means of particle transportation, such as rolling, dumping, and suspension, before the particle deposition. And then it can be used to determine the depositional environments, such as river, alluvial fan, alluvial plain, dune, beach or shallow sea, etc.

The Cretaceous system in the Ruyang Basin was a set of alluvial fans containing river sediments. Based on the granularity analysis of the sandstones in the Xiahedong and

Haoling Formations, the particle gradations, particle parameters and cumulative probability curves are obtained, and C-M plot is drawn.

The process of granularity analysis of the sandstone samples is: first to determine the grain size gradation and then convert with logarithm method to calculate Φ values. Grain size gradation is divided in Udden-Wentworth standard, which divide grain size as millimeter.

Grain size parameters include the average particle size (M_z) , standard deviation (σ), skewness(S_K) and kurtosis (K_G), which can be used to understand the characteristics of transportation medium and sediment medium, and determine different sediment environments, such as river channel, alluvial fan, alluvial plain, sand dune, beach, and others.

Cumulative probability curve is generally divided into 3 straight lines that represent 3 types of transportation means, which are suspending, jumping and rolling. The intersecting points are called as slim cutoff point (S cutoff point) and thick cutoff point (T cutoff point), which are shown in the horizontal axis. Vertical axis represents the percentage content of every sub-loads, and dipping of each line represent the sorting of each sub-loads. In this way, probability cumulative curve can be used to judge the particle transportation means before depositing.

C-M plot can be used to interpret the comprehensive formation of sediment rocks based on the analysis of sediment structural sequences. Compared with the typical C-M plot, the sandstone depositing background can be determined.

The parameters of grain size, average grain size, standard deviation, skewness (S_K) and kurtosis (K_G) had been determined and calculated for the sandstones in the Ruyang Basin (Table 7.1).

Table 7.1 Statistical table of granularity parameters of sandstone in Xiahedong Formation and Haoling Formation

Sample No.	Mode	Standard Deviation	Kurtosis	Skewness	Minimum	Maximum	Average Value
10-1	3.9299	0.8112	−0.5081	0.4069	0.8799	4.5794	2.5201
10-2	3.0338	0.6875	−0.5442	0.3192	1.4587	4.7220	2.8701
12-1	5.3991	0.9195	−0.1619	0.1516	2.6771	7.6390	4.7091
12-2	5.4152	0.9965	−0.3415	0.3438	1.9695	7.0816	4.0602
34-1	5.0251	0.8742	0.0610	0.0112	1.1088	6.4988	3.8268
34-2	5.2210	0.9256	−0.3488	−0.2883	2.0116	6.7746	4.4673
34-3	5.3153	0.6552	−0.3036	−0.1054	3.5978	7.1133	5.3765
37-1	4.6832	0.9086	−0.0509	0.3756	2.2801	7.7167	4.1613
47-1	5.6055	0.9090	−0.4652	−0.4602	2.2546	6.5439	4.7122
47-2	3.6598	0.8218	−0.4228	0.0082	1.2598	5.3881	3.2760

Continued

Sample No.	Mode	Standard Deviation	Kurtosis	Skewness	Minimum	Maximum	Average Value
49-1	5.2226	0.8810	0.8376	0.1842	1.7791	8.0228	4.0136
49-2	4.0854	0.7753	0.1297	−0.3568	1.6871	5.8259	4.1071
54-1	4.4479	0.8485	−0.4611	−0.2163	0.2275	4.7227	2.9555
54-2	4.8784	0.6120	0.3568	−0.4383	2.5694	6.3531	4.6001
55-1	4.7875	0.7158	−0.1808	−0.2057	2.1973	6.1789	4.2818

From table 7.1, the standard deviation is between 0.5 to 1.4, and sorting is moderate to high. Particle size in the layer is fining upwards. Skewness is negative to positive. Frequency curve is bimodal or unimodal, and usually an asymmetric curve. Suspended load is the main part and grain diameter in the low cutoff point changes greatly for every sediment samples, which indicates a hydrodynamics with great variations.

Cumulative probability curve can be roughly classified into a one-segment of suspending type, two-segment of bumping-suspending suspension type, and three -segment type. The former generally corresponds to the flood turbidity current; The latter two, compared with the former, the curve slope in the tail slightly increases, which corresponds to the early and closing stages of the flood turbidity traction flow. Due to low fluid energy, jumping particles are separated from the loads, but fluid belongs to strong turbulence so that particles are mainly supported by suspending in the turbulence flow. Overall, three segment types are formed basically in the fan mid subfacies, and jumping load is high in comparison with fan end, among three segment types. Fan end subfacies develops one-segment suspending type and two-segment type of jumping: suspending with low jumping particle percentage content. One-segment suspending accumulation curve represents the fine grain size (>2Φ). Based on the research on concomitant sediments, this kind of curve may belong to the braided river channel or flooded plain. When flood overflowed the banks, the main loads in water deposit mostly near the banks. In the jumping-suspending two segment suspending accumulation curves, cutting points change in the range of 2Φ to 4Φ. Size of cutting point suggests a moderate disturbance degree. High disturbance degree is in the coarse grain stage. Therefore high cutoff point size curve shows rapid river environments. Three-segment type is that a sorting traction sub-load with a cutting point of 2Φ to 3Φ, which exists in the end of jumping coarse sub-load. Traction sub-load is generally controlled by the grain size in the source. When river load has a high content of coarse debris and water flowing speed cannot carry it in jumping transportation, particles can move as rolling or slipping transportation. When water flowing speed decreases, they can be deposited together with other debris carried by different transportation ways. This is generally formed in the braided river in the alluvial fan surface.

7.2.2.3 *C-M* plot

In the *C-M* plot, the typical diagram of traction current deposits can be divided into N-O-P-Q-R-S segments. QR segment stands for graded suspension deposit. RS segment stands for well-sorting suspension, which is a kind of complete suspension that grain size and density can not change with water depth. PQ segment mainly stands for suspending transportation but with a small amount of rolling load. OP segment mainly stands for rolling, and rolling load mixes with suspending load. NO segment is consisted of rolling load basically. T area stands for the hydrostatic environment.

In the turbulent flow sedimentary *C-M* plot, the line connecting points of *C* and *M* is considered the $C = M$ baseline. The diagram of turbidity current deposit is characterized by being parallel to the $C = M$ baseline. The diagram of traction current deposit has only a short part line that is parallel to $C = M$ baseline, or not to parallel completely to the $C = M$ baseline.

Grain size parameter *C* and *M* for all the samples are drawn to *C-M* plot (Fig. 7.15), we can find that the grain size parameters are mainly distributed in QR and RS segments. It shows that there is a little rolling load, and the most content is suspended load. Compared with *C-M* plot of turbidity flow deposit, we can find that the sample grain size parameters generally fall within the scope of the turbidity flow deposits, but the scope is narrower than that in the typical turbidite flow deposit. Based on the analysis of *C-M* plot, it can also be found that sandstone layer with cross bedding is distributed in the near PQ segment, and sandstone layer with massive bedding is distributed in the suspension segment on the *C-M* plot. That is, when there is a far distance to matter source, particles with rolling transport decrease, cross-bedding does not develop, and massive beddings are formed. *C-M* plot in this book shows that sandstones are formed in the river environment.

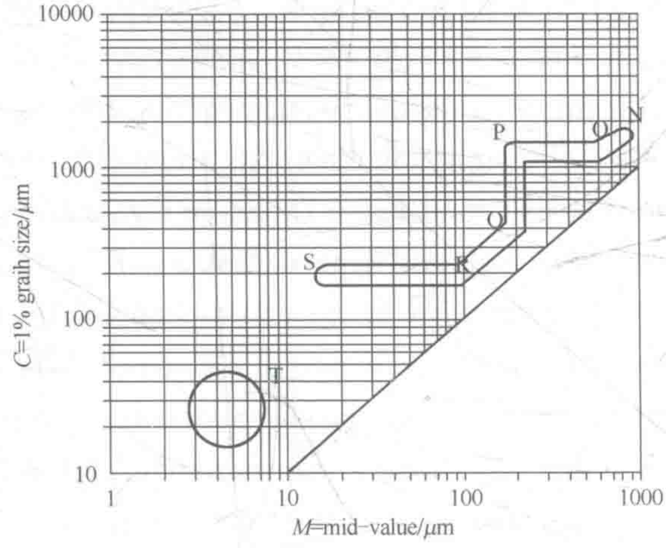


Fig. 7.15 *C-M* plot of grain size of sandstone in Ruyang Basin

7.2.3 Sedimentary Structures and Sedimentary Sequence

7.2.3.1 Sedimentary structures

The sediments in the Ruyang Basin are a set of red-bed sediments with dinosaur fossils in the Mesozoic Erathem. The lithology of the strata are coarse clastic rocks, such as moderate to thick beds of moderate-coarse conglomerates and a small amount of boulder conglomerate, and sandy mudstones, mudstones, siltstones and fine sandstones, and others. Conglomerates have basal cementation which reflects the typical structures of density current or gravity current.

Physically, chemically, and biologically originated sediment structures are commonly found in the strata of Cretaceous Xiahedong, Haoling and Shangdonggou Formations in the Ruyang Basin. Physically originated sediment structures include (Fig. 7.16) planar structures (scour marks), bedding structures (horizontal bedding, cross-bedding, graded bedding, climbing ripple bedding), compound bedding (sandstone and mudstone horizontal interbedding, lenticular bedding and flaser bedding, etc.), exposed structure (rain marks, etc.). Chemically originated sediment structures have hyperplasia and replacement structures (nodular structure, etc.) and crystalline structure, and others. Biologically originated sediment structures have biological trace structures (burrow, footprint, crawling trace, grazing trace, etc.), biological growth structures (plant root, etc.) and other biological bioturbation structures. Calcium nodules, fine strings and nodular calcium mudstone layers are commonly formed in the mudstones, indicating salinization under dry climatic condition.

7.2.3.2 Characteristics of sedimentary sequence

Based on the characteristics of lithology, sedimentary structure and trace fossil assemblages in the Ruyang Basin, the main sediment sequences in the Xiahedong Formation, Haoling Formation and Shangdonggou Formation can be divided into the following 6 types:

Type I: Fan end deposit + fan mid deposit + fan root deposit. The lower part is light purple, red thick layer to huge thick layer of moderate gravel compound conglomerates, and the middle part is light red sandstone with fine gravels. The upper part is brown red silty mudstones. The ratio of thickness is about 1:1:1. This sediment type had been formed in the mid part of Xiahedong and Haoling Formations.

Type II: Fan end deposit + fan root deposit. The lower part is purple, red, massive thick layer of compound conglomerates. The upper part is purple red, massive thick of layer silty mudstones. The ratio of thickness is 1:4 to 2:1. This kind of deposit is formed commonly in the Ruyang Basin.

Type III: Fan mid deposit + fan root deposit. The lower part is grey white, brown red, huge thick clastic sandy conglomerates. The upper part is brown red massive argillaceous siltstones, and their thickness ratio is about 1:1 to 2.5:1.

Type IV: Debris flow deposit, is gravel, sand, mud mixed deposits.

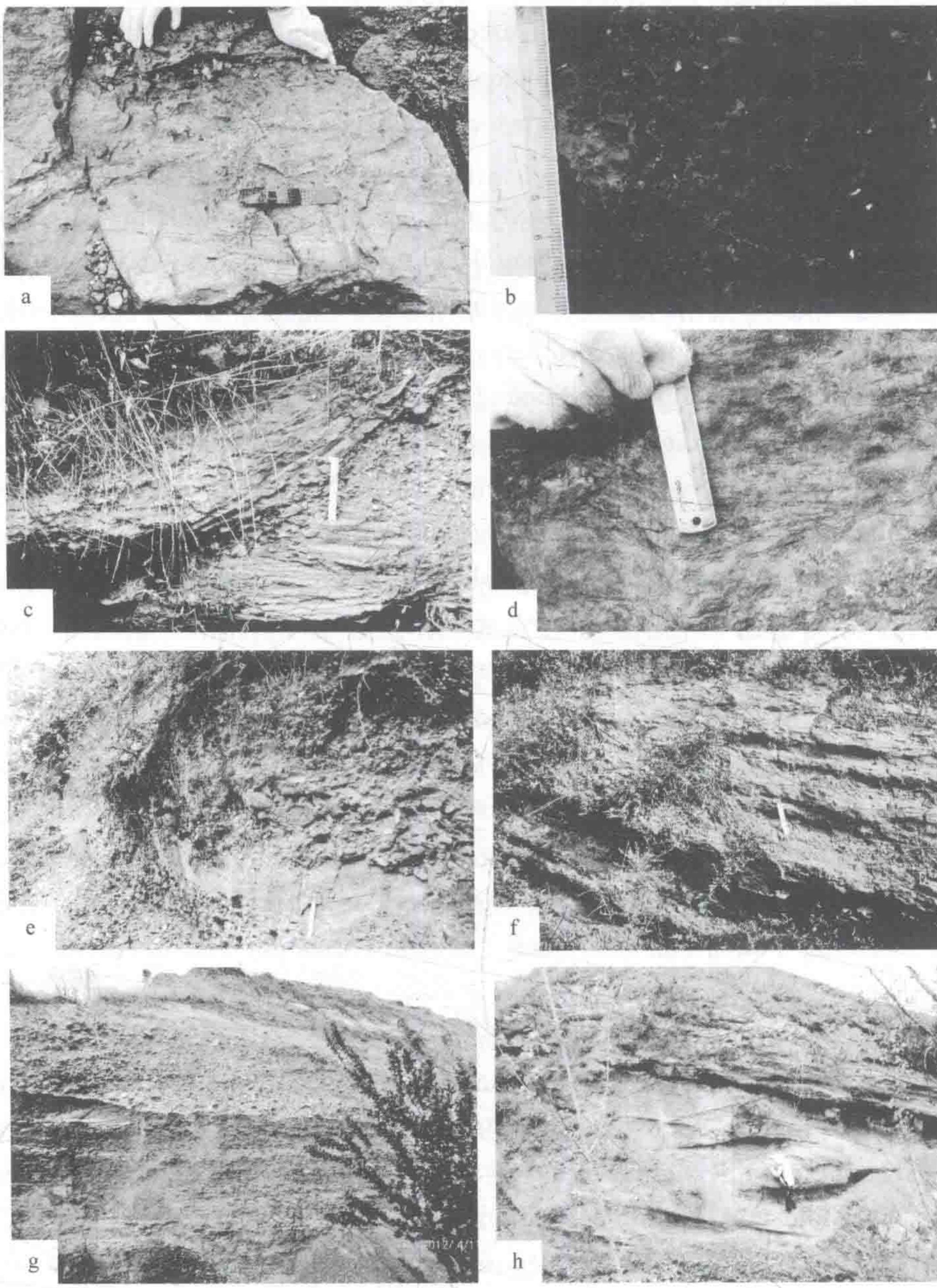


Fig. 7.16 Common sedimentary structures by physical cause in the Cretateous system of Ruyang Basin

a, d—climbing ripple bedding; b—rain marks; c,h—cross-bedding; e—lenticular bedding and vein bedding; f—sandstone and mudstone horizontal interbedding; g—scour marks

Type Ⅴ: Fan root + fan mid deposit. The lower part is grey white huge thick layer of sandy conglomerates. The upper part is brown red siltstones and fine sandstones. Their thickness ratio is about 1:1 to 1:2.

Type Ⅵ: River channel deposit + flood plain deposit. The lower part is consisted of coarse conglomerates, fine conglomerates and coarse sandstones with gravels, and the upper part is silty mudstones. The grain size changes with fining upwards. The thickness ratio of lower part and upper part is about 1:2 to 2:1, which can be interpreted as braided river deposit near the matter source.

7.3 The Cretaceous Sedimentary Environment and Evolution in the Ruyang Basin

7.3.1 The Cretaceous Sedimentary Environment and Evolution

The analysis of lithology, grain size, sediment structure and biological trace fossil assemblage shows that the sediment is a set of alluvial fan and braided river deposits in the Cretaceous Xiahedong, Haoling and Shangdonggou Formations in the Ruyang Basin.

Gravels from tuffs of Jiudian Formation consist of the bottom of Xiahedong Formation with massive beddings and with matrix support. Red composite conglomerates and light red conglomerates containing brown gravelly argillaceous siltstone and grey white debris sandstone are in the lower part of Xiahedong Formation. Roundness of gravels varies widely, with better rounded globular and elliptic shapes being predominant and sub-angular gravels in some beds. Gravel sizes also vary. Gravel composition was mainly volcanic rocks from the Xiong'er Group. Lateral continuity of beds is not good. Each bed primarily consists of different sized lenses with normal grain gradation, which indicates sedimentary characteristics of alluvial fans. The top of the sediment was interbedded with brown, grey green sandy conglomerates and brown silty mudstone and carbonate mudstone. Gravel roundness is good. Horizontal bedding, large planar bedding, groove cross-bedding and scour structure are developed. Straight - curved trace fossils and biological burrows have been seen in the bedding plates. Sediments in the strata have normal grain gradation sequence, which reflects characteristics of braided river sedimentary environment, with mainly river channel and floodplain deposits. This sediment formation constitutes of several normal cycle sequences which were composed of conglomeratic argillaceous siltstone. Sediments are formed in an environment transformed from alluvial fan to braided river.

The lower part of Haoling Formation consists of brown conglomerates, green gray sandy conglomerates, brown argillaceous siltstones, and silty mudstones interbedded with brown yellow and grey white coarse sandstones with horizontal bedding, slightly wavy bedding and large wedge cross-bedding. Scouring structure was formed distinctly on the basal plane of conglomerates. Calcium nodules were formed in the mudstones. Parts of strata changed greatly in the horizontal and vertical directions and bear dinosaur bone fossils and trace fossils. In general, it was a alluvial fan end sediment sequence changing gradually to fining upwards. Sediments were formed mainly in the alluvial fan end and developed in the braided river and flooded plain. The upper part was a thick, brown to grey green bed of conglomerates and yellow, green, fine clastic sandstone interbedded with grey, white, sandy conglomerates. The thickness of conglomerates with huge wedge cross-bedding and massive bedding is much thicker than that of sandstones. The bottom planes of the conglomerates often have scour marks. The grain gradation sequence with fining upwards was the characteristics of alluvial fan mid sediment sequence. The thickness of conglomerate on the top was far thinner than that of argillaceous fine sandstone and silty mudstone, which showed the deposition process of alluvial fan mid changing gradually to fan end. Conglomerates and gravelly sandstones are seen in the middle Haoling Formation; gravelly sandstones in the Haoling Formation had scouring planes contacting with the underlying strata. Wedge cross-bedding or massive bedding were developed in the sandstones, which had a dual-unit structure from coarse to fine and from the lower part to the upper part. It reflects the characteristics of fan front in the braided river sediment sequence. Therefore, Haoling Formation was formed in the alluvial fan—braided river—alluvial fan environments.

The bottom of Shangdonggou Formation was a grey, white, thick layer of compound conglomerates, with basal scour planes. Gravels were with medium diameters primarily, high rounding, poor sorting, matrix supported, and developed wedge-shaped cross-bedding. The bottom of Haoling Formation was brown thick layer of argillaceous siltstones with grey white, sandy conglomerates. The top part was a grey white, thick layer of sandy conglomerates and brown, silty mudstones interbedded with fine gravelly mudstones and argillaceous siltstones. Grain diameters of gravels are medium, with good rounding, low sorting, and grain supported. There was a distinct scouring plane on the bottom part. Sandstone and conglomerate changed greatly in the horizontal direction. Wavy bedding, huge trough and wedge-shaped cross beddings were developed, and biological burrows were also developed in some mudstone bed. This formation consisted of several normal cycles of assemblages, which indicate the alluvial fan end sediment environment.

Base on the characteristics of lithology, sedimentary structure, trace fossils, sandstone grain size and normal cycle sequence and several conglomerate-sandstone-mudstone assemblages, it is shown that the deposit environment went through the process of the alluvial fan root—fan mid—fan end—fan mid—fan end. Braided river channel and sheet flood deposits were formed in the fan mid to fan end or fan edge. Dinosaur fossils were preserved mainly in the sheet flood sediments.

Base on the characteristics of the lithology, sediment structure, trace fossil assemblages and sedimentary cycle in the Ruyang basin, it was shown that the Cretaceous system at this area belongs to typical alluvial fan deposits, in which the shallow flood plain lakes developed at the same time. It provides the scientific proofs to understand the Cretaceous paleoenvironment in the Ruyang Basin in which dinosaurs lived and were preserved.

7.3.2 Trace Assemblages and Sedimentary Environment

As a whole, most of the trace fossils in the Cretaceous Xiahedong Formation, Haoling Formation and Shanghedong Formation in the Ruyang Basin and Qiuba Formation in the Tantou Basin were preserved as complete reliefs, a few as semi complete reliefs. *Planolites* and *Scoyenia* feeding traces were mainly formed in the brown, silty mudstones and siltstones. *Skolithos*, J-shaped, U-shaped dwelling traces and others were mainly formed in the medium thick layer of sandstones. *Palaeophycus* feeding traces and dwelling traces were mainly formed in the fine sandstones and siltstones. *Rhizoliths* were in silty mudstones.

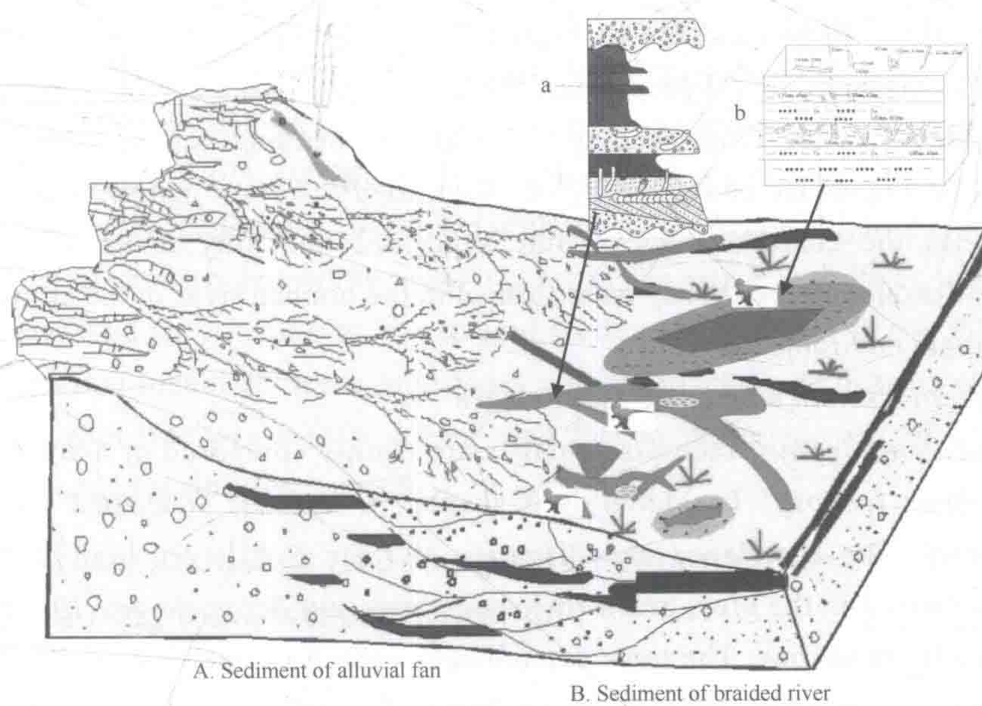


Fig. 7.17 Trace fossil assemblages and their sedimentary envionment in the Cretaceous system of Ruyang Basin

a—*Palaeophycus-Planolites*; b—*Scoyenia-Psinolichnus*

Trace fossils are concentrated in the alluvial fan end subfacies and braided river subfacies in the Xiahedong, Haoling and Shangdonggou Formations in the Ruyang Basin in the Cretaceous system. The sediment settings of each trace fossil were quite different, but the different trace fossil assemblages can indicate the same deposit environment. For example, *Psilonichnus* burrows are mainly distributed in the pond bank environment with temporary waterlogged depression or flooded lake with silty mudstone and sandstone interbeds in the Haoling Formation. *Palaeophycus tubularis* are distributed widely in the river channel with sandstone and conglomerate interbeds in the Ruyang Basin. The trace fossil assemblages of *Palaeophycus tubularis*, *Skolithos ichnosp, Scoyenia gracilis* were formed in the Xiahedong and Haoling Formations in the Ruyang Basin, which indicates the braided river environment in the alluvial fan end. Trace fossil *Rhizoliths* can be used to indicate the palaeosol types.

In conclusion, 6 genera of trace fossils have been found in the Ruyang Basin, including *Palaeophycus, Planolites, Scoyenia gracilis, Skolithos ichnosp., Psilonichnus ichnosp.*, and *Rhizoliths*. According to the occurrence of trace fossils and the bedrock characteristics, they can be divided into *Palaeophycus-Planolites* and *Scoyenia-Psinolichnus* trace fossil assemblages, and their characteristics are as following:

(1) *Palaeophycus- Planolites* trace fossil assemblages

Palaeophycus-Planolites trace fossil assemblages are consisted of *Palaeophycus, Skolithos, Planolites, Scoyenia* and *Rhizoliths*. They are mainly formed in the grey green thick layered fine sandstones, brown argillaceous siltstones and silty mudstones. The abundance and disparity of *Palaeophycus* fossil are high. Some sediment structures like climbing bedding, wedge cross-bedding, trough cross-bedding can be seen in the fine sandstones. The abundance and disparity of *Skolithos, Planolites, Scoyenia* and *Rhizoliths* are low. It has the characteristics of fine sandstone and silty mudstone interbed or argillaceous siltstone interbed. They were formed in the braided river in the alluvial fan end and flooded plain environment.

(2) *Scoyenia-Psinolichnus* trace assemblages

Scoyenia-Psinolichnus trace assemblages are mainly composed of *Scoyenia gracilis* and *Psilonichnus ichnosp*. The latter is Y-shaped, U-shaped, W-shaped and J-shaped tubular burrows. The abundance and disparity of trace fossils are high. *Psilonichnus ichnosp.* was formed in the grey, green fine sandstones, but *Scoyenia gracilis* was formed in the brown silty mudstone. The trace assemblages exhibit characteristics of interbedding between thin grey green fine sandstones and brown, silty mudstone, and grey green fine sandstones as huge lens in the brown silty mudstones in the horizontal direction. These characteristics reflect the waterlogged depression in the fan end or flooded lake environments.

7.3.3 Environmental Significance of Gastropods Assemblages

Shangdonggou Formation and Haoling Formation in the Ruyang Basin mainly consisted of a set of red clastic rocks, including huge thick conglomerates, sandstones and sandy mudstones. The huge thick conglomerate has a low sorting and lowest rounding. Sandy conglomerates changed greatly in the horizontal and vertical directions. Sometimes, sandy conglomerate had distinct cross-bedding, which indicates a very fast deposit that was probably formed in the fast accumulation during seasonal flood events. Thin layer of light grey silty mudstones and argillaceous siltstones indicates shallow flooded plain environment at that time. It showed gastropod's bio-ecological characteristics in the lower part of Shangdonggou Formation. Gastropods were preserved with no order, which indicates the autochthonous burial. They were tiny individuals of *Pulmonata* subclass, which breathed with lung, including *Physa*, *Gyraulus*, *Zaptychius*, *Pseudarinia*, in which *Gyraulus* is the main species. Based on the bio-ecological characteristics, they were living in the quiet shallow water environments. Modern planorbids generally attach on the aquatic plants near lakesides, rivers, and ponds. Therefore, Gastropods group in the lower part of Shangdonggou Formation probably inhabited in the mud and shallow water flooded plain environments where water in the pond was calm.

The difference of gastropods in the center part of Haoling Formation and that in the lower part of Shangdonggou Formation is that *Pulmontata* gastropods decrease in numbers in Haoling Formation, and gastropods in Haoling Formation mainly consisted of tiny *Prosobranchia* subclass *Bithynia*. Many bivalves and plant fragments, which were preserved in the deep grey silty mudstones, co-existed with *Bithynia*. According to the bio-ecological characteristics of modern *bithyniids*, they inhabit in the ponds and lakes with developed aquatic plants. And they belong to the filtered feeders. Gastropods in the middle part of Haoling Formation inhabited in the mudstones with relatively high organic matter content and a water depth that was a little deeper than that in the lower part of Shangdonggou Formation's flooded plain environment.

7.3.4 Characteristics of Ecological Environment in the Ruyang Basin during the Cretaceous period

Research showed that gymnosperms which originated in the late Paleozoic were thriving in the Jurassic period. Angiosperm appeared in mid and late Cretaceous about 100 million years ago and gradually replaced gymnosperm in Cenozoic about 70~3 million years ago. During Mesozoic era, reptiles represented by dinosaurs dominated on the land and became the apex feeder in the food chain at that time. Aquatic organisms and bottom feeders in terrestrial water bodies reached unprecedented prosperity. Therefore, we can probably describe the environment and ecological habits of dinosaurs based on information we have obtained so far: the environment in which dinosaurs lived was not far away from relatively stable water bodies, which were at fan end or near braided river environment without great gradient. Vegetation, benthic organisms and aquatic organisms were well developed and the ecology system was complete. Paleoclimate was alternating between dry and wet, with dry climate being predominant.

Science links

1. Living habits of dinosaurs

Dinosaur family adapted well to the environments and developed rapidly with diversity. They dominated the land ecosystem from the early Jurassic to the late Cretaceous. Dinosaurs had myriad species. Shapes and habits of dinosaurs varied greatly.

The first type was herbivorous dinosaurs, represented by giant sauropods. They lived in the forests near the water sources in groups, in order to get water and food.

The second type was omnivorous dinosaurs. *Ornithomimus*, *Archaeopteryx* and *Oviraptor* were representatives. They rarely lived in groups, most of them were loosely distributed and widespread and the only exception was when they migrated or traveled. They lived in the valleys and forests.

The third type was carnivorous dinosaurs. Most of carnivorous dinosaurs were without definite habitats. They hunted food in surprise attacks, including their own kinds.

2. Difference between terrestrial and marine facies

All rocks formed by deposits are packed with information indicative of the sedimentary environment which is called "sediment facies".

Sediment facies indicates comprehensively a certain sedimentary environment and characteristics of sedimentary rocks formed in this environment. In other words, sediment facies contains not only natural geographical conditions, such as distributions of ocean, land, lakes, glaciers, desert and geo-morphological movements, but also cold, hot, dry and wet climates, and whether the sediment basin was lifted or subsided in the tectonic setting, and sedimentary water medium, and geophysical and geochemical conditions. Because of these different conditions, sediments have different types. In order to distinguish them, the concept of sediment facies has been used to express their temporal and spatial distributions.

The deposit of terrestrial environment is that weathered materials affected by the gravity, water, wind and glaciers, are eroded and transported in physical, chemical and biological processes, and finally deposited in the sediment basin.

Facies represents comprehensive sediment characteristics in the depositional process under a specific environment. Because of the mutability of environment and medium, terrestrial sediments are with complex lithological characteristics and mainly consist of clasts with different grain sizes and multiple types. E. V. Shantser (1984) divided terrestrial deposits into 5 series containing residual soil, water, groundwater, glaciers, atmosphere, in 6 groups, 17 types. It is generally agreed that terrestrial sediments mainly include alluvial facies, drift bed facies, or gravity accumulation, diluvial facies, river deposit, lake deposit, marsh deposit, glacial deposit, aeolian deposit, desert or groundwater deposits (including the cave sediments). Among them, river sediment is the most common, with the following characteristics: ① a dual-unit structure, and common with lenticular sand body; ② semi-rhythmic structure; ③ commonly contain freshwater organisms; ④ common with mud cracks in open air; ⑤ have hydraulic energy and unimodal current structures including scouring planes, large groove cross-bedding, planar cross-bedding, parallel bedding and reverse sand wave bedding. Lake sediments formed under the lake waves and flow are without obvious tidal action. Lake waves are much smaller than that of sea, and it is difficult to carry the sand in the bottom of lakes. So, lake sediments are mainly dispersed, transported deposits of suspending particles.

Marine facies is a generic term for sediment facies formed in marine environment. It can be divided into shore facies, shallow shelf facies, bathyal and abysmal facies according to the sea depth and position. Terrestrial facies is a generic term for sediment facies formed on land under natural geographic environments, including lacutrine facies, fluvial facies, river transient facies, marsh facies and volcanic sediment facies.

Whenever marine facies deposit is mentioned, people always think of the vast seas. Indeed, the size of sea is much bigger that that of lakes. In addition, the salinity of seawater is high, and it is salty. But most of the lakes have low salinity or fresh water, only a small number of lakes have high salinity. Compared to lakes, oceans have tidal action. Therefore differences between lake and ocean lead to the great differences between lake and sea facies.

(1) The differences in sedimentary scale: marine sediments have a large scale. The sea facies generally are distributed in a large scale, such as the Ordovician marine deposits distributed in the northern part of China, whose comparability is larger than that of lacustrine sediment formed in the same area in the later time.

(2) Lake sediments consisting primarily of clastic rocks and carbonate rocks are less than 1%, whereas the proportion of carbonate rocks in marine strata are higher. Shallow sea carbonate sediments developed widely in the northern China and can reach to hundreds of thousands of square kilometers. The scale of lake deposition is small and sediment facies are distributed narrowly. The bigger lake basins are more than ten thousand square kilometers while the smaller ones are less than hundreds of square kilometers.

(3) Marine clastic rocks are relatively uniform in composition with structurally simple and

highly sorted quartz sandstones being predominant, while lacustrine clastic rocks compositions are complex and have vastly different structures, including highly sorted quartz sandstones and poorly sorted feldspathic sandstones or clastic sandstones.

(4) Marine sediments are influenced by changes of global sea level, which means marine sediments have global comparability. Lake deposits are controlled by tectonics, climate and matter source supply, but not controlled by the changes of global sea level. Strata can be compared only within the same lake basin, which does not offer good comparability with other lake basins.

In addition, there are "sea-land transitional facies" between marine and terrestrial facies, such as delta facies, lacustrine facies, barrier island, tidal flat facies and so on.

These sedimentary rocks contain abundant petroleum, natural gas and other minerals, and rich amount of fossils.

8 The Past and the Present: the Early Cretaceous Paleoclimate in the Ruyang Basin

In 2010, paleontologist Martin Sander's research team at University of Bonn in Germany found that bigger animals spend longer time on eating. The body of an animal that devours food is bigger than that of an animal who chews slowly. For example, an elephant almost eats 300 kg of food for 18 hours every day just to satisfy the huge appetite. Imagine how much the *Ruyangosaurus giganteus,* 10 times the size of an elephant, could have eaten every day? Was Ruyang densely forested like today's Sipsongpanna, where these gigantic dinosaurs could find plenty of food? How was the paleoclimate in the Cretaceous in Ruyang Basin able to nurture these giants for millions of years? We can only speculate and study them based on geological records.

8.1 Cretaceous Paleoclimate

Cretaceous was rather special in the history of the earth, in which many important environmental events happened; for example, Ocean Anoxic Event (OAE) (Wager et al., 1976; Schlanger et al., 1976; Jenkyns, 1980; Bralower et al., 1994), Upper Cretaceous Oceanic Red Beds (CORB) (Wang et al., 2005), dense oxygen phenomenon (Hu et al., 2005; Wang et al., 2005), global ocean-level change, black shale with rich organic matter all over the world (Schlanger et al., 1987), carbonate platform subsiding, global large-scale volcano activities (Barrera et al., 1999; Larson, 1991; Ma et al., 2001; Jones et al., 2001), biota radiation and transformation (Leckie et al., 2002), high CO_2 concentration (Berner, 1997), the Cretaceous Normal Superchron (CNS) (Helsley et al., 1969; Cronin et al., 2001; Shi et al., 2002; Zhao, 2005), mass extinction at the end of Cretaceous (Wanlliser, 1996), and others. In particular, the greenhouse effect and mass extinction have direct relevance and implications to the modern human survival and development. It has become a focus in current field of geological studies.

As a geological period that was closest to present, the Cretaceous was the model of extreme greenhouse effect on climate in geological history (Berner, 1994, 2001; Crowley et al., 1995; Herman et al., 1996; Tarduno et al., 1995; Barrera et al., 1999; Berner et al., 2001). The Cretaceous is a textbook case in the study of earth's geo-system and is called "Cretaceous World" (Skeleton et al., 2003) by the geo-science community. Tarduno et al. (1998) suggested that the Cretaceous period was quite warm. Forest vegetation fossils were found in the Alaska and Greenland with latitudes over 85°N (Spicer and Parrish, 1990). Flora and reefs spread to polar region by about 15° degrees (Frakes et al., 1995). Dinosaur fossil was found in the Arctic Circle (Colbert, 1973). Large-sized reptiles intolerant of frigid conditions were found in the Cretaceous sediments in the northern latitude of 78°. evaporites were formed widely in the southern and northern hemispheres, so were terrestrial red beds and carbonate rocks (including organic reefs). Oxygen isotope datasets of foraminifer showed that the global temperature during the Turonian Stage was in the extreme greenhouse condition, and the mean temperature of earth surface was 10℃ higher than it is today (Huber et al., 1995, 2002; Clarke and Jenkyns, 1999; Wilson et al., 2002). The mean global temperature in the Cretaceous Period was 3~10℃ higher than it was before the industry revolution and 4℃ higher than that of present (Thompson et al., 1981; Tarduno et al., 1995; Huber et al., 1995, 2002; Clarke et al., 1999; Barrera et al., 1999; Wilson et al., 2002). The mean temperature along the northeastern of Alaska coast was 10±3℃ during the Cenomanian Stage, based on a study of paleo-plant morphology (Spicer et al., 1990). The mean temperature in the Grebenka of northeastern Russia was 13.0±1.8℃ during the Albian Stage (Spicer et al., 2002).

Early research considered that warm and dry condition was the typical characteristics of the Cretaceous period (Brooks, 1962; Schwarzbach, 1963), but more and more evidence suggested that the late Cretaceous ocean was cold, or even much colder. The oxygen isotope data of benthonic foraminifera in the north Pacific indicated that the temperature of the bottom water was lower than 10℃ (Spicer and Corfield, 1992), and the stable isotope measurement of planktonic foraminifera in the south Atlantic showed that the temperature of surface water was lower than 18℃ (Clarke and Jenkyns, 1999) during the Campanian—Maastrichtian Stages. The temperature in the bottom water near Pacific equator was lower than 18℃ and lower than 20℃ using the calcareous nannofossil thermometer after the Santonian Stage (Douglas and Savin, 1975). The paleo-temperature obtained from stations 463 and 465 in the Pacific subtropical zone indicated a long transition to cold temperature during the late Turonian to Maastrichtian Stage, but temperature in the surface water and bottom water were the highest in the range of 24℃ and 18.8 respectively during Coniacian stage, and the lowest in the range of 20℃and 11.8℃ respectively during Maastrichtian stage (Boersma and Shackleton, 1981). Therefore, this period was called Cretaceous "Ice House" age (Huber and Sloan, 2000). Chen Xi et al. (2011) drew a map of the locations where the direct and circumstantial evidence shows paleoclimate's fast change into cold temperature at 105 million years ago. Direct evidence indicated that glaciers existed, such as glacial striae, moraine in melange accumulations (Hambrey, 1994), ice-raft sediments (Bennett et al., 1996; Bennett and Doyle, 1996), and others. Glauberite calcites were formed in the ice water (Shearman and Smith, 1985). Glauberite calcites of Valanginian and Aptian Stages were found in the Sverdrup Basin and Spitsbergen Island (Kemper, 1983), and also in the late Aptian Stage Cadnaowie Fromation of Valanginian-Aptian Stage in the Eromanga Basin of Australia (De Lurio and Frakes, 1999). They indicated that the water temperature under which glauberite calcites were formed was near the ice point. It was indicative that glaciers had existed at these areas in the early Cretaceous period. The temperature was lowered to about 9℃ at the boundary of Aptian/Albian Stage, and it was the second lowest temperature globally during the Cretaceous period. The circumstantial evidence suggested that organisms appearing in the low latitudes indicate the changes to cold (Frakes et al., 1992). Glacier existence and positive bias of $\delta^{18}O$ in sea water indicate the global sea-level falling quickly (Goldhammer et al., 1987;Sellwood, et al., 1994).

In general, the temperature was cold and wet in the early Cretaceous. It became warmest in the mid of Cretaceous on the earth, which is called the greenhouse climate. It gradually changed to cold in late Cretaceous. Several characteristics stand out:

(1) The Temperature in the Cretaceous period was 3~10℃higher than that of today. The isotope data of planktonic foraminifera in the upper part of high latitude ocean suggested that the paleo-temperature was up to 22~28℃ in the mid Cretaceous Epoch (Huber et al., 1995). The oxygen isotope measurements of deep water benthic foraminifera in the temperate zone of the North Atlantic Ocean showed that the temperature was up to 20℃ in the mid Cretaceous (Norris and Wilson, 1998; Fassell and Bralower, 1999; Huber et al., 1999).

(2) Temperature around the boundary of Cenomanian-Turonian Stage in the middle of Cretaceous period was the highest.

(3) Aptian-Albian and Campanian Stages were warm.

(4) Temperature in the late Cretaceous changed to cold constantly after the peak temperature at the boundary of Cenomanian-Turonian Stage. Temperature changed gradually to warm from the Coniacian and Santonian Stages to the early Campanian Stage, and then to cold all along till the late Campanian. And the speed of change to cold was down through the whole Maastrichtian Stage.

Gerta et al. (2008) had summarized all climatologic records of the Cretaceous Period and found that Cretaceous climate showed not only periodicity, but also that mass extinction events had also happened during the Aptian Stage (125.0±1.0Ma ~ 112.0±1.0Ma), Cenomanian Stage (99.6±0.9Ma ~ 93.5±0.8Ma) and Maastrichtian Stage (70.6±0.6Ma ~ 65.8±0.3Ma) in the early Cretaceous under the low temperature condition, because of climatic transition to cold. It was the largest mass extinction event closest to present since the Phanerozoic Eon on earth. Was the cause the meteorite impact, or volcanic activities, or continental plates converging, or the change of the ocean circulation, or others? It is still an open question to further study. Most organisms, including the dinosaurs, perished in this extinction event, but mammals survived this disaster and evolved to present day. Fischer (1984) summarized the relationship between extinction events and climate and volcanic activities since the Phanerozoic Eon, and found that mass extinctions occurred in the periods of high volcanic activities and temperature decreasing.

CO_2 concentration in Cretaceous period was about 4~10 times of that of present (Bice et al., 2003; Berner, 1994, 1997; Berner et al., 2001; Barrera et al., 1999; Crowley et al., 1995; Herman et al., 1996). High CO_2 concentration was one of the causes of high temperature, and high CO_2 concentration was probably related to the large-scale volcanic activities at that time. Large igneous provinces (LIPs) were formed by the repeated volcanic eruptions due to sea-floor spreading when Pangaea broke up in the early Cretaceous period, and it was also the time when the highest mid-ocean ridges were forming (Larson, 1991; Kaiho and Saito, 1994; Takola, 1998; Jones and Jenkyns, 2001). It is estimated that mid-ocean ridge's production rate was up to $57x10^6$ km^3/Ma during the Cenomanian-Turonian Stages (Jones and Jenkyns, 2001). Oceanic crust area was 1.8 times of that of normal production. It was the time when mantle plume was extremely active (Larson, 1991; Larson and Erba, 1998). Voluminous CO_2 was released from the deep mantle and made CO_2 concentration in the atmosphere increase (Schlanger et al., 1981; Larson, 1991). Research shows that volcanic eruption scale was 10 times higher than that of present and released CO_2 at a mean rate of 1120~1680 ml/m^3 (Poulsen et al., 1999; Otto-Bliesner et al., 2002; Kump et al., 1999).

O_2 concentration in the atmosphere in the Cretaceous period was 150% of that of present (Berner, 1999). It was the warmest period since Mesozoic Era. There was little difference in the interior of continents and no distinct climatic zones from equator to the poles, where there was no ice cover in the Cretaceous period. And sea-level was 60 m higher than that of present (Thompson et al., 1981; Berner, 1997; Norris et al., 2002).

8.2 Climatic Characteristics of Cretaceous Period in China

Large-scale continental drift and significant tectonic activities occurred in the Cretaceous period. The Mid Cretaceous Events accelerated the Atlantic Ocean expansion and

Gondwanaland disintegration. Tethys Ocean started to subduct and shrink. Crustal movement, magmatic activity, and endogenous metal mineralization had been active around Pacific Rim till late in the Cretaceous period. New ocean expansion and mid-oceanic ridge accretion made Cretaceous period the one in which the largest sea transgression happened in the geological history. Many areas on earth had been submerged under the sea, but most of the eastern Asia kept the continental environment. Especially worth mentioning is that the terrestrial Cretaceous system developed in the Northeastern China and southern Tibet. Western part of North America was the second area with developed terrestrial Cretaceous system.

Terrestrial Cretaceous system distributed in North China Platform is an important characteristic in China. China is one of the few countries in which Mesozoic strata, especially Cretaceous terrestrial strata, developed completely and outcropped preferably and were studied at highest level, of which Songliao Basin and northwestern China were representative. The Cretaceous system in the northeastern China was developed in basins controlled by the tectonic faults, such as the Dunhua—Mishan branch fault zone of Tancheng—Lujiang fault zone and Yilan—Yitong fault zone, and Xinan—Taihangshan fault zone.

China's continental tectonic system underwent significant changes from the early Cretaceous (Zhai Mingguo et al., 2003; Shao Jian et al., 2000; Zhang Yueqiao et al., 2006; Wang Yang, 2001; Chen Fajing et al., 1997). Climatic conditions also changed greatly at the same time. Unique desert depositions in China's Cretaceous system were formed under hot and dry condition and distributed mainly in Tarim Basin, Ordos Basin, Sichuan Basin, Simao Bsian, Jianghan Basin, Changtao Basin and north Jiangsu Basin between paleo-latitudes of N20°—N40°. Chinese scientists have been studying extensively on the age of Cretaceous system, depositional environments, and tectonic evolution, and so on, especially the paleoclimate in several Cretaceous basins where mining explorations were conducted. Huang Qinghua et al. (1999) proposed that Songliao Basin was as a whole with wet and hot climatic characteristics of tropic-subtropic zone in the Cretaceous period, and identified 4 dry events based on the pollen dataset. They considered that tectonic movements, volcanic eruptions and carbon cycle were the main factors controlling paleoclimatic changes. Yang et al. (2007) considered that climate in the early Cretaceous epoch was in subtropic warm and wet condition and with seasonal dry stages based on the pollen assemblages of Muling Formation in Jixi Basin in northeastern China. Paleoclimate in the late Mesozoic in the Sichuan Basin displayed periodicity and instability as indicated by the peculiar gypsum sediments, clay minerals and detritus composition index. It can be divided into 3 stages: ①dry and cold climate condition during late Jurassic to early Cretaceous; ②warm and wet climate condition during late Early Cretaceous to mid-late Late Cretaceous; ③after short period of dry and cold climate at K-T boundary, the

Paleogene was with the warm and wet climate condition (Cao Ke et al., 2008).

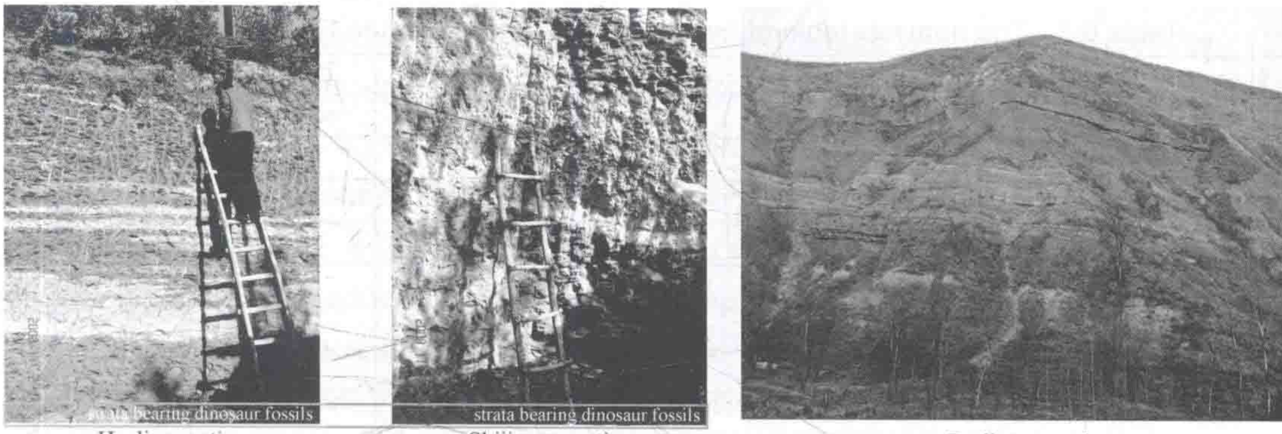
Wang Dongpo (1994) proposed that mass extinction happened at the 1st member of Qingshanlou Formation and the 1st member of Nenjiang Formation, when the lake linked up with open sea and sea water invaded the lake and abruptly changed the salinity, which caused organisms to die at a large scale and formed biogenic accumulation beds. The research on Jehol Biota (Gu Zhiwei, 1962; Ji Qiang, 2002) and birds (Ji et al., 2002) and origin of placental mammals (Zhou Zhonghe et al., 2002; Ji Qiang, 2002) has established a foundation for the study of China's Cretaceous climate and biological evolution.

In summary, paleoclimate during the Cretaceous period was warm-wet or cold-dry in the southern and northern part of China mainland. Jiang Xinsheng et al. (2000) considered that East Asia's overall atmospheric circulation was formed and has been existing since the Cretaceous period. Planetary system of winds and monsoon circulation were probably the main reasons to cause climate change at that time. Simultaneously, large areas of deserts started to spread in China (Chen Shoutian et la., 1996; Jiang Xinsheng et al., 1992), which followed such rules of development: from north to south and from west to east (Jiang Xinsheng et al., 1996; Qi Hua et al., 1993). Additionally, aridification in the northwestern China started to appear (Guo et al., 2002). It is suggested that aridification process started during Cretaceous period and severely impacted the environments at that time. Large scale climate changes had an important influence on the bio-ecological systems. Whether or not they were the direct reasons to cause mass extinction at large-scale is still an open question that needs in-depth study.

8.3 Paleoclimate in the Ruyang Basin

Cretaceous strata in Henan province of China are distributed preferably but outcropped sporadically, mainly in the basins in the western and southwestern Henan, and in north side of Dabieshan mountains. Cretaceous basins are divided into fault depression type and fault graben type based on the cause of formation. Basins spread mainly in NW direction, and then in NE and EW directions. The sediment types were terrestrial facies with clastic rocks and volcanic-sediment rocks.

Samples in this book were collected in the dinosaur fossil beds of Haoling, Shijiagou, and Caojiachun cross sections. All samples were analyzed for organic content (TOC), carbonate content, carbon and oxygen isotopic compositions of carbonate ($\delta^{13}C_{V\text{-}PDB}$, $\delta^{18}O_{V\text{-}PDB}$) and other paleoclimatic and paleoenvironmental parameters, which can be used in the discussion of dinosaur's living environment and burial condition. All three sections are in the Haoling Formation, with the upward sequence of Haoling-Shijiagou-Caojiachun (Fig. 8.1)



Haoling section Shijiagou section Caojiacun section

Fig. 8.1 The actual locations where samples for carbon isotopic analysis were collected

8.3.1 Geochemical Environmental Indicators and Their Significance

8.3.1.1 Geochemical environmental indicators and their significance of Haoling section

43 geochemical samples with 450 cm in length were collected from Haoling section between bed 34 and 35, roughly corresponding to mid and late Aptian stage. The samples were brown argillaceous siltstones interbedded with 0.7m of green, grey thick layer of fine-medium grained sandstone. Dinosaur fossils were in the layer KLR07-57 at approximately 350m altitude in the section 350. The results are listed in the table 8.1. The curves of TOC, carbonate content and carbon and oxygen isotope are in Fig. 8.2.

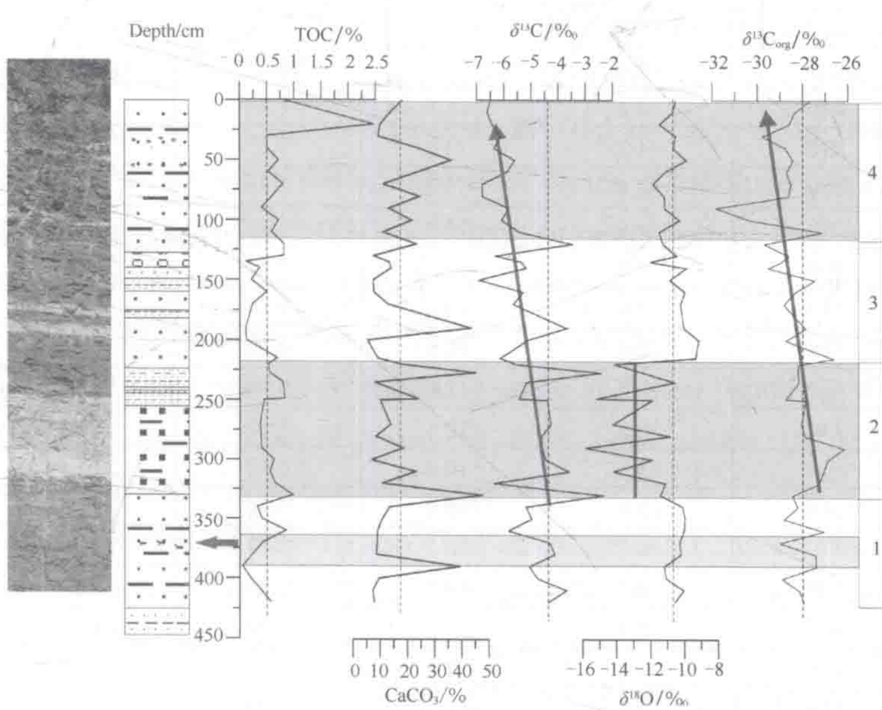


Fig. 8.2 Result of geochemical analysis of the samples from Haoling cross section

Table 8.1 The analysis table of geochemical indicators in the Haoling section

Sample No.	Depth/cm	$\delta^{13}C_{PDB}$/‰	$\delta^{18}O_{PDB}$/‰	TOC/%	$CaCO_3$/%	$\delta^{13}C_{org}$/‰
HL-1	0	-6.5	-10.5	0.82	18.1	-27.7
HL-2	10	-6.6	-10.7	1.14	13.7	-28.3
HL-3	20	-6.4	-11.4	2.46	10.1	-28.6
HL-4	30	-6.1	-10.5	0.51	9.3	-29.8
HL-5	40	-6.4	-10.6	0.51	24.2	-28.7
HL-6	50	-5.6	-9.9	0.71	36.1	-28.4
HL-7	60	-5.9	-11.1	0.53	23.7	-28.7
HL-8	70	-6.8	-11.8	0.80	11.1	-28.5
HL-9	80	-6.8	-11.2		24.5	-28.6
HL-10	90	-5.8	-11.1	0.40	13.2	-31.8
HL-11	100	-6.1	-10.3	0.71	21.6	-30.3
HL-12	110	-5.4	-11.5	0.59	11.1	-27.2
HL-13	120	-3.5	-11.2	0.82	23.4	-29.7
HL-14	130	-6.3	-10.4	0.81	7.6	-28.6
HL-15	135	-5.4	-12.0	0.11	13.4	-29.0
HL-16	140	-5.2	-9.9	0.37	14.1	-29.5
HL-17	150	-6.9	-10.8	0.21	7.5	-27.5
HL-18	160	-5.3	-9.9	0.50	7.8	-28.3
HL-19	170	-5.7	-10.2	0.24	13.0	-28.8
HL-20	190	-3.7	-10.0	0.11	43.4	-27.9
HL-21	200	-5.1	-9.2	0.12	5.4	-28.7
HL-22	215	-6.1	-9.3	0.69	9.2	-26.6
HL-23	220	-5.6	-14.1	0.53	17.9	-28.2
HL-24	227	-2.4	-12.4	0.54	45.2	-28.2
HL-25	235	-5.2	-10.6	0.80	8.1	-28.2
HL-26	249	-5.4	-15.2	0.83	24.0	-28.8
HL-27	250	-4.4	-11.9	0.44	10.0	-27.9
HL-28	270	-4.3	-14.2	0.37	13.9	-28.1
HL-29	280	-4.6	-10.8	0.39	8.5	-27.9
HL-30	290	-4.6	-15.8	0.40	18.3	-26.2
HL-31	300	-4.5	-11.9	0.63	6.8	-26.9
HL-32	310	-3.6	-14.2	0.55	23.1	
HL-33	320	-6.4	-11.1	0.65	10.7	-27.3
HL-34	330	-2.3	-11.4	0.98	47.6	-28.5
HL-35	340	-5.2	-10.1	0.32	13.5	-28.2
HL-36	350	-5.0	-10.0	0.40	10.8	-28.8
HL-37	360	-5.8	-10.0	0.85	9.1	-27.1
HL-38	370	-4.3	-10.3	0.43	8.9	-29.0
HL-39	380	-4.1	-10.2	0.24	8.5	-27.4
HL-40	390	-5.1	-11.2	0.05	39.5	-27.4
HL-41	400	-4.8	-11.1	0.20	9.6	-28.9
HL-42	410	-3.7	-10.1	0.39	7.3	-28.1
HL-43	420	-4.4	-10.6	0.58	7.8	-27.9

Environmental geochemical indicators of the Haoling section (34°06.012′N, 112° 30.773′E, 404.m±) with dinosaur fossils were analyzed. TOC content in the section was mainly in the range of 0.2% to 0.8%. TOC content in the rocks in the upper part was up to 2.5%. But it was obviously influenced by modern vegetation and not indicative of the paleoenvironment (Fig. 8.2). Carbonate content in the rocks was mainly in the range of 5% to 25%. Some layers had high carbonate content up to 40% or so. Stable carbon isotopes of carbonates were in the range of -7‰ to -2‰, and it was lighter from about 330cm in the section to the upper part. Oxygen isotopic compositions of carbonates were in the range of -16‰ to -8‰, with a mean of about -13‰, and it was lighter in the interval of 220 to 330cm in the section. Organic carbon isotopic compositions were in the range of -26‰ to -30‰, and it had a similar change tendency with the carbon isotope of carbonate that was lighter gradually from 330cm in the section to the upper part from -27‰ to -30‰.

Based on the environmental indicators, the paleoclimatic and paleoenvironmental changes were divided into 4 stages for the Haoling section.

Stage 1: in the interval of 420 to 330cm, organic carbon content about 0.1%~0.5%, which was low. Carbonate content was high, up to 10%. Carbon and oxygen isotopic compositions were heavy, up to -6% ~ -4‰ (V-PDB) and -10% ~ -11‰ (V-PDB) separately. Organic carbon isotopes were heavy in the range of -29‰ to -28‰ (V-PDB). Organic carbon isotopes in the sediments were mainly controlled by the precipitation and heavier in the arid environment, based on the research on modern process (Zhang et al., 2003). In summary, paleoclimate during this interval of section was with high temperature, arid, and with rare precipitation. Dinosaur fossils were preserved mainly in this interval, suggesting hot and rare precipitation condition, under which salinity rose in the water bodies and vegetation was very sparse. Food shortage probably led to mass extinction of organisms. Dinosaur fossils were preserved in the braided river facies in the flood plain sediments.

Stage 2: in the interval of 330~220cm, where organic content rose up to 0.4%~0.8%. Carbonate content was relative lower than 15%. Carbon and oxygen isotopes of carbonates were lighter to -7‰~-4‰ (V-PDB) and -12‰~-16‰ (V-PDB) separately. Organic carbon isotopic compositions were heavier in the early stage and then lighter in the range -29‰~ -28‰ (V-PDB). The grain size of sediment rock was coarse. It indicates that the paleoclimate was warm and wet during this stage.

Stage 3: in the interval of 220~120cm. The environmental characteristics were similar to that of stage 1. Organic content was low at about 0.1%~0.2%. Carbonate content was relative high in the range of 10%~40%. Carbon isotope of carbonate was relatively lighter to -7‰~-5‰ V-PDB, and oxygen isotope was distinctively heavier to -11‰~-9‰ (V-PDB). Organic carbon isotope was lighter in the range of -30‰~-28‰ (V-PDB). Lighter carbon isotope of carbonate was probably influenced by the CO_2 with lighter carbon isotope generated from the organic matter decomposition. The paleoclimate was with high temperature and in arid condition, but with more precipitation compared to stage 1.

Stage 4: in the interval of 120cm to surface. Organic content was obviously high to 0.5%. It was abnormally high to about 2.5%, owing to the influence of modern vegetation on the uppermost layer. Carbonate content was relatively low in the range of 10% to 25%. Carbon and oxygen isotopic compositions were lighter in the range of -29‰ to -32‰ (V-PDB). The paleoclimate was in the warm and wet condition and vegetation was lush.

8.3.1.2 Geochemical environmental indicators and significance of Shijiagou section

45 geochemical samples with total length of 420cm were collected from Shijiagou section's 40 to 41 beds. The lithology was mainly green, grey matrix conglomerates and brown muddy siltstones. It was in the age of Sunjiawan stage. Dinosaur fossil layer (KLR07-62) was in the section with a depth of about 350m. The geochemical indicators were shown in the table 8.2. Figure 8.3 demonstrated the curves of TOC, carbonate content, carbon and oxygen isotopic composition changes.

Table 8.2 The analysis table of geochemical indicators of samples from Shijiagou section

Sample No.	Depth/cm	TOC/%	$CaCO_3$/%	$\delta^{13}C_{V\text{-}PDB}$/‰	$\delta^{18}O_{V\text{-}PDB}$/‰	$\delta^{13}C_{org\ V\text{-}PDB}$/‰
SJG-1	0	0.44	2.4	-3.7	-9.3	-28.6
SJG-2	10	—	5.7	-5.8	-13.5	-29.0
SJG-3	15	4.21	6.4	-6.0	-15.1	-29.1
SJG-4	25	1.64	1.0	-4.6	-15.8	-28.7
SJG-5	30	1.13	0.8	-11.2	-16.1	-30.7
SJG-6	40	0.64	1.7	-5.6	-15.0	-29.7
SJG-7	50	0.45	2.1	-4.7	-16.1	-28.6
SJG-8	60	0.75	3.2	-5.7	-14.4	-30.3
SJG-9	70	0.92	7.1	-5.5	-15.0	-29.7
SJG-10	80	1.36	2.2	-5.3	-15.7	-29.4
SJG-11	90	2.05	6.6	-5.1	-16.1	-29.4
SJG-12	100	0.53	4.0	-4.5	-16.2	-30.1
SJG-13	110	0.72	1.7	-4.7	-15.1	-30.5
SJG-14	120	1.27	—	-5.5	-15.4	-30.1
SJG-15	130	1.88	—	-5.5	-16.6	-29.8

Continued

Sample No.	Depth/cm	TOC/%	$CaCO_3$/%	$\delta^{13}C_{V\text{-}PDB}$/‰	$\delta^{18}O_{V\text{-}PDB}$/‰	$\delta^{13}C_{org\ V\text{-}PDB}$/‰
SJG-16	140	1.31	7.3	-3.6	-16.4	-29.1
SJG-17	150	0.95	1.7	-4.0	-16.1	-30.9
SJG-18	160	2.94	11.1	-4.1	-17.3	-30.3
SJG-19	175	1.01	4.3	-4.0	-16.5	-30.2
SJG-20	180	0.58	0.1	-4.7	-10.7	-29.3
SJG-21	190	1.26	2.2	-2.3	-8.1	-28.8
SJG-22	200	0.81	17.3	-2.4	-11.2	-29.3
SJG-23	210	0.66	19.1	-2.0	-11.2	-29.6
SJG-24	220	0.89	16.1	-2.0	-11.1	-29.5
SJG-25	230	-	16.9	-2.2	-10.6	-29.2
SJG-26	240	0.73	17.3	-2.1	-10.5	-28.9
SJG-27	250	0.61	11.2	-2.6	-9.7	-28.9
SJG-28	260	0.31	16.6	-2.5	-11.1	-29.4
SJG-29	270	0.39	31.3	-1.9	-11.7	-27.9
SJG-30	280	0.62	31.4	-1.9	-11.3	-30.2
SJG-31	290	1.83	14.7	-2.9	-11.1	-30.2
SJG-32	300	0.56	15.3	-2.8	-11.3	-30.2
SJG-33	310	0.21	38.6	-3.0	-12.3	-29.8
SJG-34	320	0.91	21.4	-2.9	-12.7	-29.3
SJG-35	325	-	16.2	-4.1	-11.5	-29.0
SJG-36	335	0.98	17.2	-4.0	-10.9	-29.1
SJG-37	340	0.42	20.3	-3.1	-11.4	-28.8
SJG-38	350	0.33	11.7	-3.3	-11.6	-28.9
SJG-39	360	1.03	11.4	-3.3	-11.5	-
SJG-40	370	0.39	19.2	-3.5	-11.4	-28.8
SJG-41	380	0.53	20.3	-3.3	-12.0	-30.2
SJG-42	390	0.34	19.4	-3.0	-12.7	-29.8
SJG-43	400	0.75	21.2	-2.9	-12.3	-29.0
SJG-44	410	0.77	13.5	-2.8	-11.7	-28.0
SJG-45	420	0.63	14.0	-3.3	-11.4	-31.0

The geochemical indicators of the dinosaur fossil bearing layer of the Low Cretaceous in the Shijiagou section (34°05.909′N, 112°31.130′E, 387.4m±) were analyzed. TOC change was divided into 2 obvious stages: 180~420cm and 0~180cm intervals. TOC was below 1% in the interval of 180~420cm, and 1%~2%, some part more than 2%, in the interval of 0~180cm. Organic carbon content in the uppermost layer was high up to 4%, similar to dinosaur fossil bearing layer of the Low Cretaceous in the Haoling section (Fig. 8.3). It was for the similar reason as the Haoling Section that high organic carbon content was influenced by the modern vegetation, and not indicative the paleoclimate condition. Carbonate content change was divided into 2 stages. It was lower than 10% in the upper 180cm part, and higher than 13% in the lower part interval. Carbonate content between 180 cm to 320cm was high in the range of 15%~40%. Carbon isotope of carbonate was in the range of -8‰ to -2‰ (V-PDB), and heavier carbon isotope about -3‰~-2‰ (V-PDB) in the interval 180~320cm and gradually became lighter from 180cm to the upper part. Oxygen isotope of carbonate was in the range of -18‰ to -10‰ (V-PDB) and obviously divided into 2 different stages. It was changed quickly to lighter at the 180cm depth or so and lighter about -16‰ (V-PDB) in the interval 10~180cm depth. It became gradually heavy to -17‰~-15‰ (V-PDB)from 180cm to upper part, and it was -9‰ at the top layer. Oxygen isotope was heavier about -12‰~ -9‰ (V-PDB) in the interval 180~320cm, which was similar to carbon isotope. Organic carbon isotope in the rocks was in the range of -28‰ to -31‰ and had the similar evolutionary trend with that of carbon and oxygen isotope of carbonate. It became gradually lighter about -29.5‰ to -31‰ (V-PDB) from 180cm to the upper part, but changed gradually to heavier from 150cm to the top. The geochemical paleoclimate indicators of TOC, carbonate content, carbon and oxygen isotope in the Lower Cretaceous dinosaur fossil layers in the Shijiagou section were shown in the Fig. 8.8, and had 3 different stages with periodic characteristics.

The palaeoclimate and paleoenvironment were divided into 3 stages for the Lower Cretaceous in the Shijiagou section, based on the geochemical indicators showed in the Fig 8.3.

Stage 1: in the interval of 430~325cm. Organic matter content was low in the range of 0.5%~1%. Carbonate content was relatively high in the range of 12%~25%. Carbon isotope of carbonate was in the range of -3‰ ~ -5‰ (V-PDB), and oxygen isotope was in the range of -11‰~ -9‰ (V-PDB), and lighter compared with stage 2, but heavier compared with stage 3. Organic carbon isotopic compositions were heavier in the range of -29‰ ~ -28‰ (V-PDB). Paleoclimate was relatively warm and arid, but with some precipitation. Dinosaur fossil was preserved in this layer during this stage.

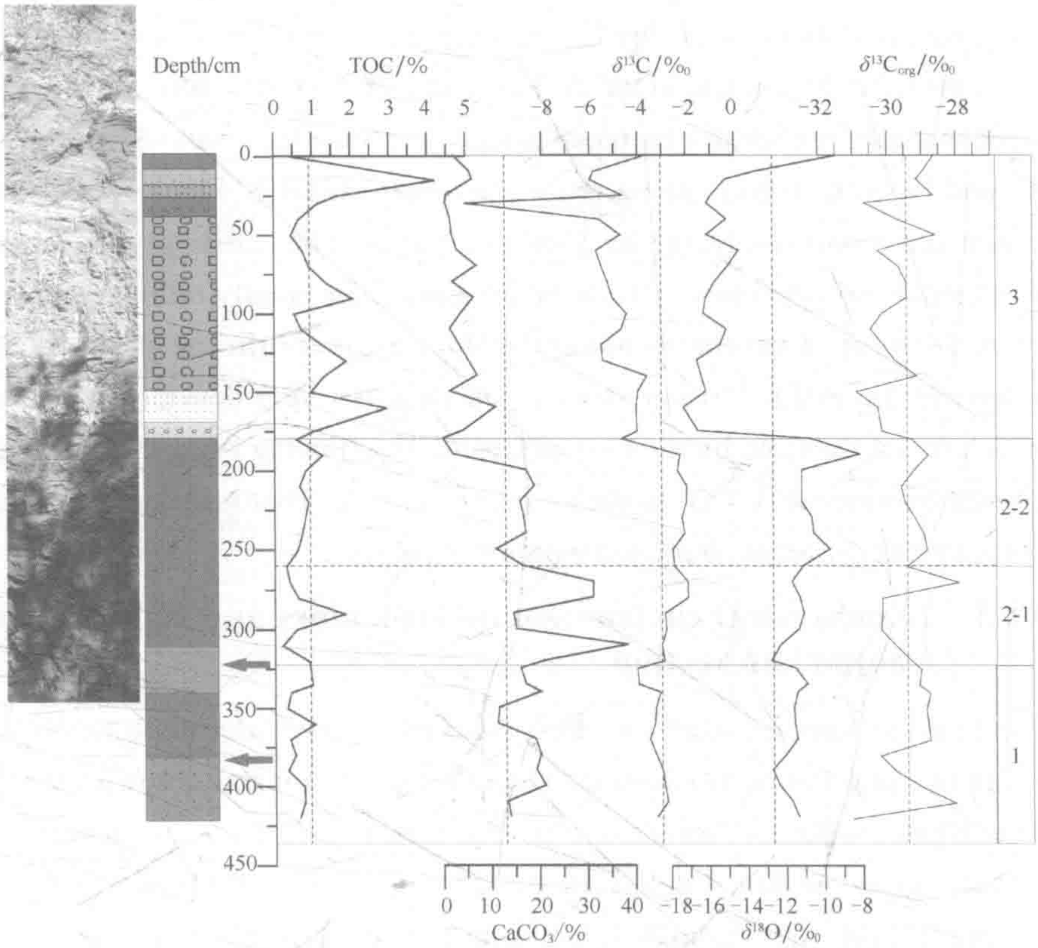


Fig. 8.3 Result of geochemical analysis of the samples from Shijiagou cross section

Stage 2: in the interval 325~120cm. Carbon and oxygen isotopic compositions were heavy and much heavier at the late stage, which was divided into 2-1 and 2-2 sub-stages. Organic matter content was lower than the mean of 0.5%, but highest to about 2% in the mid-interval part, indicating temperature falling and precipitation rising suddenly. Carbonate content was relatively high in the range of 15%~40%. Carbon and oxygen isotope of carbonate was distinctively heavier to -3‰ ~ -2‰ and -12‰~ -8‰ (V-PDB) separately. Organic carbon isotopic compositions were heavy in the range of -29‰ ~ -28‰ (V-PDB). The paleoclimate was with high temperature, arid and with little vegetation at this stage. Atmosphere CO_2 influenced greatly on the carbon and oxygen isotope of carbonates.

Stage 3: in the interval 120 cm to the top. All geochemical indicators changed greatly. Organic matter content rose to the range of 1% to 2%, suggesting development of vegetation. Carbonate content decreased quickly to the range 2% ~ 10%. The carbon and oxygen isotope of carbonate decreased quickly to -8‰ ~ -4‰ (V-PDB) and -18‰~-16‰ (V-PDB) respectively. The organic carbon isotopic compositions were light in the range of -29‰ ~ -30‰ (V-PDB). Sedimentary rocks were coarse sandstones and gravelly rocks. The paleoclimatic characteristics were warm and with high precipitation at this stage, but temperature decreased much more quickly than stage 2. The paleoclimate change was much similar to the global paleoclimate in the Aptian Stage of the Cretaceous period.

The geochemical indicators in the Shijiagou Cretaceous strata displayed distinctive periodicity and the correlation among them were very striking, which was closely related with the sediment environment in the Shijiagou strata. The sediment environments were large river channel and flood plain. Water body in the river greatly influenced the carbonate forming. Development of vegetation along the sides of river influenced greatly the organic carbon isotope in the rocks. Carbon and oxygen isotopes were heavier during stage 1 and stage 2, which was influenced by the CO_2 in the air. The flowing hydrodynamic condition of river reduced the influence of CO_2 in the air on the isotope. That was one of the reasons that isotope in strata was different compared with other stages.

8.3.1.3 Geochemical environmental indicators and significance of Caojiachun section

60 geochemical samples were collected from 23 layers within with length of 8570cm in Caojiachun Haoling Formation section. The lithology was mainly brown muddy siltstone and silty mudstone, with grey sandstone bands. Strata were from the Sunjiawan period. Dinosaur fossil layer KLR08-14 was in the section depth of 350m. The geochemical indicators were in Table 8.3. Figure 8.4 demonstrated the curves of TOC, carbonate content, carbon and oxygen isotopic composition changes.

Table 8.3 Analysis of geochemical indicators from Haoling Formation in Caojiachun section

Sample No.	Depth/cm (bottom—top)	$\delta^{13}C_{V\text{-}PDB}$/‰	$\delta^{18}O_{V\text{-}PDB}$/‰	$CaCO_3$/%	TOC/%
CJC-1	50	-3.7	-10.3	54.0	1.00
CJC-2	85	-1.2	-10.7	62.5	0.14
CJC-3	130	-5.0	-11.0	18.8	0.32
CJC-4	160	-2.5	-10.3	78.3	0.14
CJC-5	200	-3.6	-11.4	29.9	0.13
CJC-6	260	-3.8	-10.8	23.5	0.26
CJC-7	315	-4.4	-10.9	20.2	0.21
CJC-8	382	-3.9	-13.0	27.1	0.27
CJC-9	640	-3.5	-10.6	45.4	0.41
CJC-10	790	-4.0	-11.6	29.3	0.22
CJC-11	860	-2.8	-10.7	12.1	0.06
CJC-12	940	-4.3	-15.4	12.2	0.20
CJC-13	974	-2.8	-11.7	25.4	0.15

Continued

Sample No.	Depth/cm (bottom—top)	$\delta^{13}C_{V\text{-}PDB}$/‰	$\delta^{18}O_{V\text{-}PDB}$/‰	$CaCO_3$/%	TOC/%
CJC-14	1034	-5.3	-9.2	55.2	0.20
CJC-15	1434	-3.3	-10.7	43.1	0.21
CJC-16	1584	-3.0	-12.6	25.6	0.19
CJC-17	1684	-6.3	-10.7	11.6	0.36
CJC-18	1884	-4.3	-11.2	27.3	0.37
CJC-19	2184	-3.9	-11.1	39.4	0.21
CJC-20	2534	-3.8	-11.2	61.4	0.10
CJC-21	2700	-3.2	-11.6	37.7	0.11
CJC-22	2984	-5.0	-10.7	65.2	0.07
CJC-23	3484	-4.8	-10.8	54.4	0.07
CJC-24	3500	-4.5	-12.1	6.0	0.22
CJC-25	3534	-4.8	-11.5	67.6	0.06
CJC-26	3734	-2.7	-12.0	13.9	0.09
CJC-27	3794	-3.6	-10.5	12.1	0.66
CJC-28	4034	-1.5	-11.1	19.9	0.13
CJC-29	4099	-2.5	-11.9	17.4	0.30
CJC-30	4169	-3.5	-14.2	9.4	0.15
CJC-31	4769	-3.9	-11.3	52.0	0.15
CJC-32	4814	-3.5	-12.3	25.2	0.16
CJC-33	4914	-3.9	-17.3	12.3	0.30
CJC-34	5214	-3.6	-11.4	6.3	0.20
CJC-35	5224	-3.1	-11.9	33.0	0.23
CJC-36	5254	-2.7	-11.3	9.4	0.22
CJC-37	5334	-2.8	-13.5	17.9	0.42
CJC-38	5434	-2.6	-11.7	12.6	0.11
CJC-39	5474	-4.1	-17.7	4.4	0.18
CJC-40	5489	-3.9	-10.8	30.3	0.18
CJC-41	5529	-5.4	-11.6	7.5	0.19
CJC-42	5549	-3.6	-11.5	57.1	0.11
CJC-43	5669	-4.6	-11.4	26.7	0.18
CJC-44	5769	-3.3	-10.8	62.1	0.15
CJC-45	5869	—	—	41.4	0.34
CJC-46	6300	-3.5	-11.5	67.5	0.20

Continued

Sample No.	Depth/cm (bottom—top)	$\delta^{13}C_{V\text{-}PDB}$/‰	$\delta^{18}O_{V\text{-}PDB}$/‰	$CaCO_3$/%	TOC/%
CJC-47	6430	-3.9	-11.5	59.6	0.16
CJC-48	6600	-2.5	-12.0	64.0	0.13
CJC-49	6650	-2.2	-11.5	61.3	0.22
CJC-50	6710	-4.3	-12.9	28.4	0.16
CJC-51	6840	-3.2	-11.0	44.8	0.17
CJC-52	7000	-2.6	-11.4	60.5	0.23
CJC-53	7300	-3.4	-11.4	30.0	0.18
CJC-54	7600	-3.0	-10.6	53.5	0.18
CJC-55	7700	-2.8	-13.2	29.1	0.11
CJC-56	7760	-3.7	-11.3	12.2	0.23
CJC-57	8050	-3.8	-11.7	45.9	0.20
CJC-58	8150	-5.5	-9.6	5.1	0.92
CJC-59	8450	-4.3	-13.4	52.3	0.23
CJC-60	8570	-0.8	-11.9	17.8	0.21
D-wallrock	—	-6.3	-11.7	7.3	0.28
D-egg	—	-8.5	-3.2	88.8	0.38

Geochemical indicators in the Cretaceous of Lower Caojiachun were listed in the Fig. 8.4. The ranges of change of the organic matter content, carbonate content, and carbon and oxygen isotopic compositions in the Caojiachun section had high comparability with the Haoling section and Shijiaogou section, which suggests similar environmental changes. The TOC was about 0.1%~0.4% in the Lower Cretaceous with dinosaur fossils, and stage change was obvious. Some layers had high TOC and the TOC is up to 1% in the upper part. The TOC change characteristics was similar to the Haoling and Shijiagou sections and maybe have a similar cause. Carbonate content was in the range of 10%~70%. It was higher than that in the Haoling and Shijiaogou sections. Carbon isotope of carbonate was in the range of -6‰ ~ -2‰ with obvious periodicity. Oxygen isotope of carbonate was in the range of -16‰ ~ -9‰, but with a mean of -11‰ or so from the Fig. 8.4. It changed little except in depth of 3000~4500cm interval with lighter oxygen isotope of carbonate. Carbonate content of the bedrocks was low at 7.3%; organic matter content was about 0.28%; carbon isotope of carbonate was -6.3‰ (V-PDB); oxygen isotope was about -11.7‰ (V-PDB). Carbonate content of dinosaur fossil shells was about 88.8%; organic matter content was about 0.38%; and carbon isotope of carbonate was -8.5‰ (V-PDB); oxygen isotope was about -3.2‰ (V-PDB). There was an obvious difference in carbon and oxygen isotope between dinosaur fossil shells and bedrocks.

The palaeoclimate and palaeoenvironment can be divided into 9 stages for the Lower Cretaceous strata in Caojiachun, based on the geochemical indicators in the Fig. 8.4.

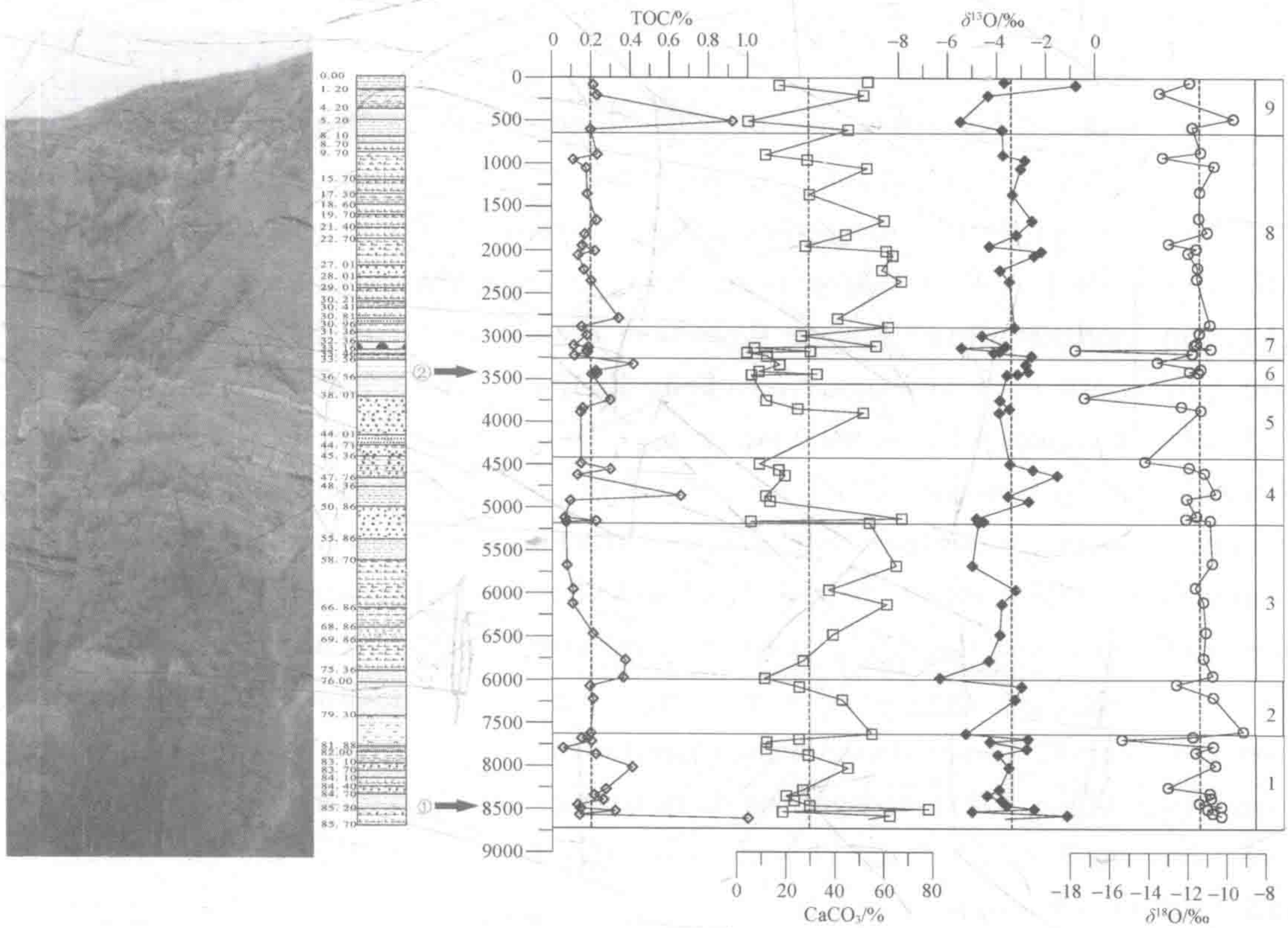


Fig. 8.4 Result of geochemical analysis of the samples from Caojiacun cross section

It was similar to the paleoclimate we have analyzed at Haoling's and Shijiagou's Low Cretaceous in the Ruyang Basin. The odd number stages (stage 1, 3, 5, 7, 9) were warm and wet, and even number stages (stage 2, 4, 6, 8) were with high temperature and dry condition. Warm-wet and arid conditions appeared in alternation in the records of the Caojiachun section. Temperature decreased obviously and humidity increased by a minor degree during the Aptian stage.

8.3.2 Palaeoclimatic Characteristics during the Dinosaur Age in the Ruyang Basin

Organic matter content, carbonate content, carbon and oxygen isotopic compositions, and organic carbon isotopic compositions have been discussed of concerning the Lower Cretaceous strata's cross sections at Haoling, Shijiaogou and Caojiaochun, in the Ruyang Basin of Hennan province. These geochemical paleoenvironmental indicators can reveal the records of the primary environmental palaeoclimate and palaeoenvironmental information to a certain degree and can be used to reconstruct palaeoenvironment. The paleoclimate of the Lower Cretaceous in the Ruyang Basin with dinosaur fossils was under warm-wet or dry conditions. The strata with dinosaur fossils were formed mainly under the high temperature condition.

The Figures 8.5 and 8.6 were the paleoclimatic information recorded in the lower Cretaceous cross sections at Haoling, Shijiaogou, and Caojiachun in the Ruyang Basin, compared with global paleotemperature of the same time. The general characteristics of paleoclimate during the early Cretaceous in the Ruyang Basin were similar to that of the global and northern China. Ruyang Basin was located roughly in the same latitude zone with Sihwa Basin of northwestern Korea in the Early Cretaceous. Planetary system of winds and monsoon climate were the main factors to control paleoclimate in the Cretaceous period. The paleoenvironment and paleoclimate of the two basins showed striking similarity; for example, a 3m interval of terrestrial strata in Sihwa Formation preserved many dinosaur egg fossils in the Sihwa Basin. Braided river and brown-red alluvial plain with calcareous concretion, indicated the dry to semi-dry condition of paleoclimate. Kim et al. (2009) considered that Korea peninsula was in warm and arid and semi-arid condition during the Cretaceous period. These palaeoclimatic characteristics were verified by the paleontological assemblages (Choi, 1985), pedogenesis characteristics (Paik and Chun, 1993; Paik and Lee, 1998; Paik and Kim, 2003), fan-shaped sedimentary association (Rhee and Chough, 1993), radial calcite oolite interbeds in the lacustrine stromatolites (Woo et al., 1991), and flints formed in the lakes (Chough et al., 1996).

Xiang Fang et al. (2009) summarized the paleoclimatic and distributional characteristics of China's mainland in the Early Cretaceous period . Warm and dry climate zone is divided into dry-hot and warm-dry paleoclimate zone, warm-dry paleoclimate zone and warm-wet and warm-dry paleoclimatic zone during the Aptian age from west to east. Warm-wet paleoclimatic zone in the northeastern climate region extended to the southern area. Warm-wet and warm-dry climate region in the Inner Mongolia and Gansu extended further forward to the south. Warm-dry climate zone stretched across northeastern part of Xinjiang to coastal area of eastern China transformed to areas such as the western part of Chongqin, southern part of Hebei and northern part of Guangdong Province. Dry-hot and dry paleoclimate zone shrinked toward east. Warm-wet and warm-dry climate in the Hainan

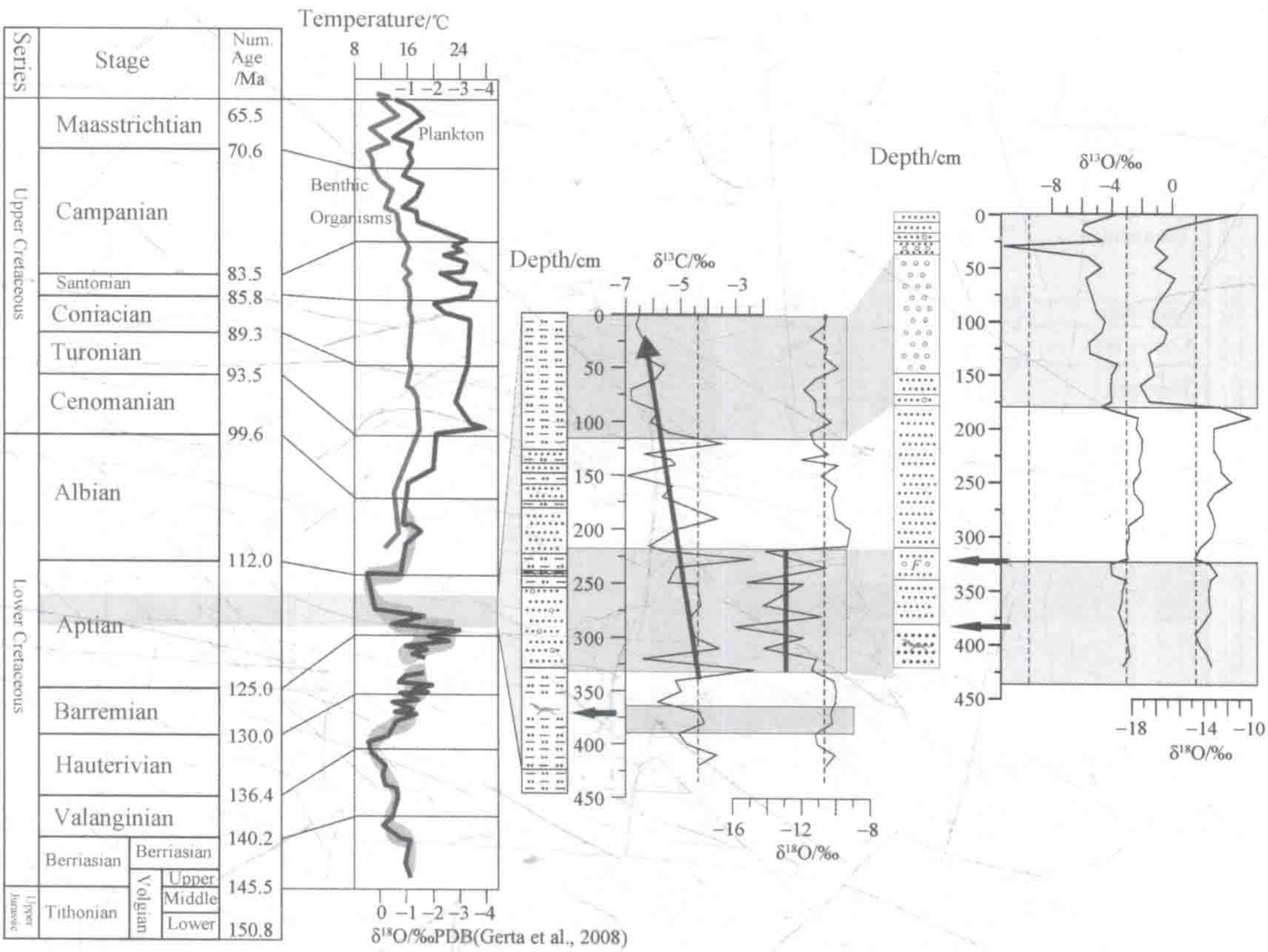


Fig. 8.5 Comparison of paleoclimate and the early Cretaceous strata at Haoling and Shijiagou in Ruyang Basin

Province extended towards northeast to Guangdong Province. Warm-wet climate region in the southern Tibet changed to warm-wet and warm-dry climate during the Albian stage. Warm-wet and warm-dry climate changed to wet-hot climate in the Hainan Province. Palaeoclimatic zone during the Berriasian-Barremian stages demonstrated the characteristic of latitude distribution. The distribution of palaeoclimatic zones showed a great difference during Aptian and Albian stages, with the characteristic of superposition of latitudinal distribution and longitudinal distribution; and at the same time the type of paleoclimatic zones increased. Warm-wet climatic zone was distributed in a minimum area during Hauterivian stage, but warm-wet and warm-dry paleoclimatic region and dry-warm and dry climate had extended to a maximum area. Dry-warm paleoclimate was demonstrated in the southeastern Liaoning, eastern Hebei and northern Shandong, indicating that it was the driest and hottest paleoclimate condition in the early Cretaceous. The maximum distribution of warm-wet and warm-dry climate regions during Albian stage indicated that wet climate extended during this stage, which was related to the global sea-level rising,

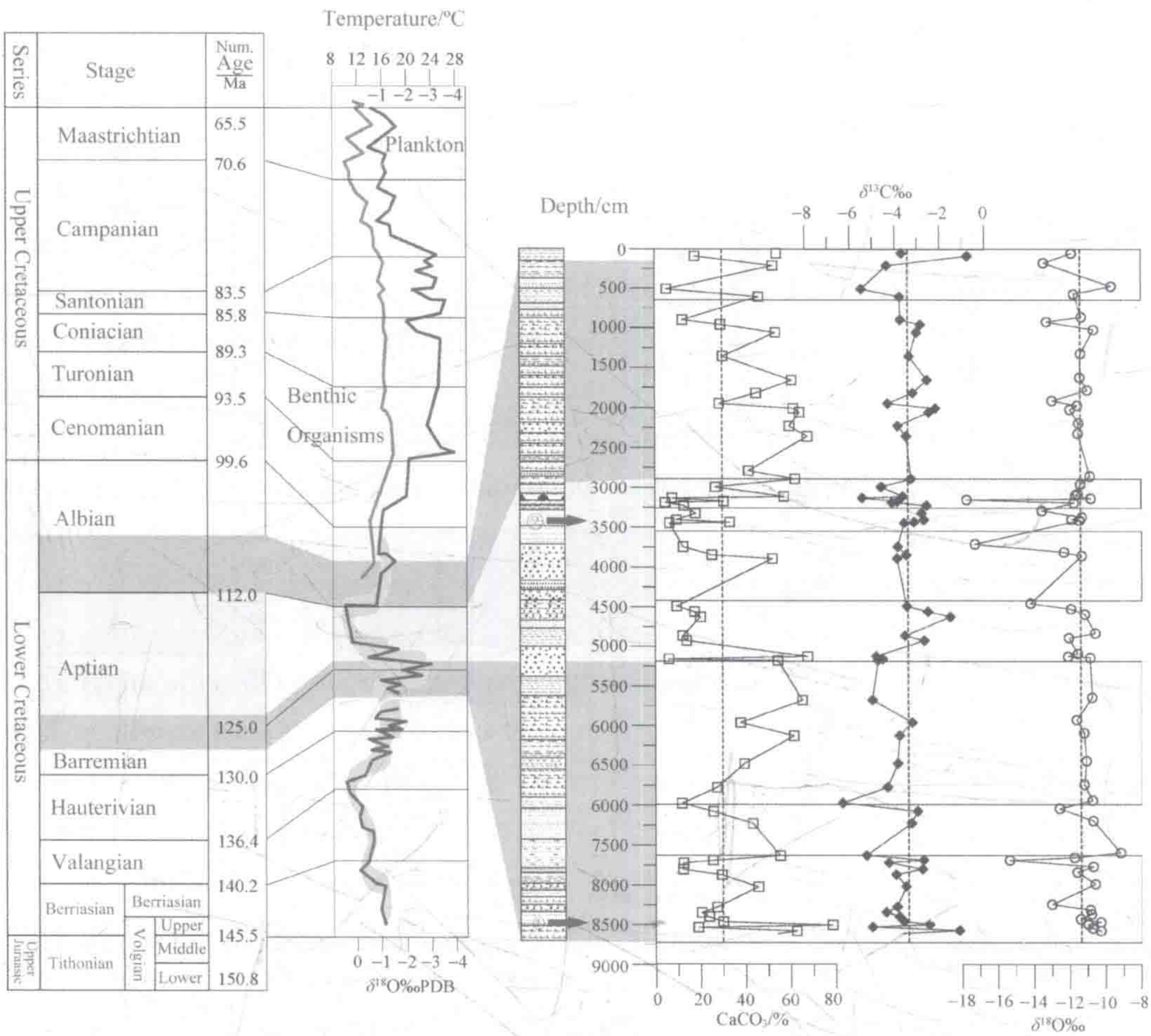


Fig. 8.6 Comparison of paleoclimate and the early Cretaceous strata at Caojiacun in Ruyang Basin

which reached maximum scale during the Cretaceous Period. The paleoclimatic characteristics recorded in the lower Cretaceous strata of Haoling, Shijiagou and Caojiachun in the Ruyang basin were similar to the global paleoclimatic condition during this period. Dense forests, myriad rivers and lakes developed under this paleoclimatic condition, which enabled organisms to thrive and raised the family of gigantic dinosaurs in the Ruyang region.

DINOSAUR FOSSILS FROM THE RUYANG BA

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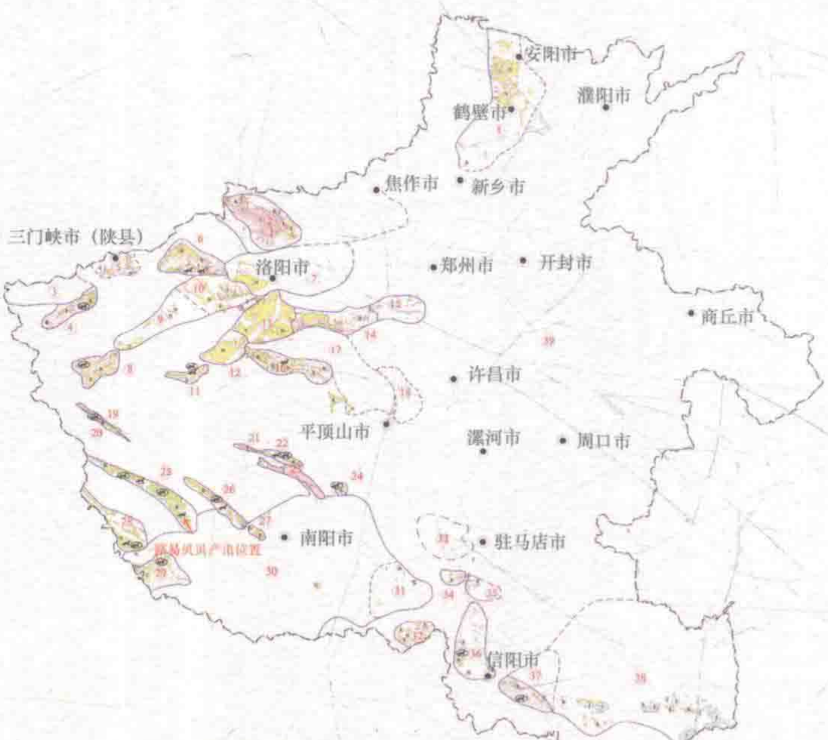
Jia Songhai   Pan Zecheng   Pu Hanyong et al.



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