Palaeontologic and Stratigraphic Research at NIGPAS

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Abstract: The Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPAS) was established to bring together experts in various fossil taxa and geological periods, to conduct both basic and applied research in invertebrate palaeontology and palaeobotany on an integral research platform. Over its 73-year research, NIGPAS has made a lot of milestone discoveries, such as the determination and establishment of the Global Boundary Stratotype Section and Point (GSSP), and the research of fossil lagerstätten Chengjiang Fauna and Wuda Tuff Flora, which both were listed in the 100 IUGS Geological Heritage Sites. The enthusiastic scientists, the abundant fossil lagerstätten, and the ideal geological sections in China all welcome scientists worldwide to tackle global geoscience challenges together. Supported by CAS, NIGPAS has a long tradition in domestic and international collaboration for research, and will continue such cooperation in further explorations.

Keywords: fossils, 73-year research, international cooperation, NIGPAS

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1. Introduction

Our planet has a history spanning 4.6 billion years, with life first appearing between 3.5 and 3.8 billion years ago. How did life originate and evolve from simple to complex forms, migrate from marine to terrestrial environments, and adapt to—meanwhile shape—its surroundings, ultimately creating the vibrant diversity of life we see today? Palaeontology seeks to answer these questions. Studies in this field not only shed light on the origins and evolution of life but also aid in the exploration of geological resources like fossil fuels, including oil, gas, and coal, which were produced through interactions between life and the environment. By helping to identify correlations between strata across various localities and sites, palaeontology supports stratigraphic

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research essential to resource exploration.

Founded on May 7, 1951, NIGPAS was established with a mission to advance research in palaeontology and stratigraphy. This mission arose from the nation's need for fossil energy and mineral resources to support large-scale economic development, which required foundational geological surveys, including the study of palaeontology and stratigraphy.

Over the decades, NIGPAS has served the nation's foundational needs across various stages of China's development. For example, in the early 1950s, NIGPAS helped the searching for coal, iron, aluminum zine and other mineral resources urgently needed by the nation, and compiled a book series, namely the *China Standard Fossils*, including *China Standard Fossil: Plant* (Si and Xu, 1954) and *China Standard Fossil: Invertebrate*, volume 1–3 (Chen *et al*., 1957; Yang Z. *et al*., 1954; Yang J. *et al*., 1955; Gu *et al*., 1957). NIGPAS's Mesozoic stratigraphic study of the Songliao Basin marked another milestone. The research project "Geosciences in the Discovery of Daqing Oilfield" received the National Natural Science Award in 1983. NIGPAS also compiled and published the 12-volume *Academic Reports of National Stratigraphic Congress* (1959), and authored a series of treatises, including *Fossils in China*, *Palaeontology of Xizang*, and *Strata of Xizang*. The *Scientific Investigation Report on the Qomolangma Region (1974–1976)*, resulting from the NIGPAS research project "A comprehensive study on the uplift of the Qinghai-Xizang Plateau and its impact on the natural environment and human activities", was awarded the National Natural Science Award in 1987. NIGPAS also published the *Palaeontology and Stratigraphy of Hong Kong* as a celebration of Hong Kong's return to the motherland (Li *et al*., 1997). Another influential achievement of NIGPAS was the Sinopec Perspective Research Project for Oil and Gas Production "Marine Stratigraphy of China" (2007–2012).

To summarize, the application of palaeontology and stratigraphy in the exploration of fossil energy and mineral resources has well served the country's economic development, which in turn has stimulated the development of palaeontology research as a branch of basic research in China. Nowadays, NIGPAS has established itself as a major force in this regard in the global scientific community. Here in this article, we would like to present a brief summary of the history of NIGPAS, and particularly elaborate on some of its achievements in palaeontologic and stratigraphic research, based on some fossil lagerstätten and excellent geological sections.

2. Disciplinary Nature and Strategic Mission

Palaeontologic research is based on fossils—the preserved remains or traces of past life. Identifying a biological species requires comparison with all known taxa worldwide, meaning palaeontologists must collaborate internationally. Likewise, stratigraphic correlation also depends on global cooperation.

The first generation of Chinese experts in palaeontology and stratigraphy were trained in Western countries. The first- and second-term directors of NIGPAS, LI Siguang (J. S. Lee, 1889–1971) and SI Xingjian (H. C. Sze, 1901–1964), both of whom were CAS Members, studied at the University of Birmingham and Berlin University, respectively. This was typical at that time, as palaeontology had developed in response to the demands of industrial civilization, which first took place in Western countries.

Today, NIGPAS, as the only CAS institute specializing in invertebrate palaeontology and palaeobotany, is tasked with maintaining a research team covering all palaeontologic subfields and geological ages. It also sustains a comprehensive platform for ongoing research. To date, its researchers has published over 9,500 academic papers, ranking among the top three palaeontologic research centers worldwide and leading globally in publications in palaeontology and stratigraphy (Figure 1).

3. Re-opening to the Outside World

The first generation of Chinese experts in palaeontology was largely trained in Western countries, and upon the founding of NIGPAS, their primary focus was on applied basic research to support national economic development. As a result, the subsequent generation primarily conducted their work domestically, with limited opportunities for international collaboration. This changed after the National Science Conference in March 1978, marking the "Springtime of Science" in China. In April 1979, the Palaeontologic Society of China was re-established, and by July 1979, it became an affiliated member of the International Palaeontologic Association (IPA).

From then on, international cooperation flourished, expanding from individual collaborations to larger group initiatives, with NIGPAS hosting more in-

Organization	SCI papers	Total citations	H Index
Nanjing Institute of Geology and paleontology, CAS	1684	17781	44
Museum National d'Histoire Naturelle (MNHN)	1065	10925	36
Paleontological Institute of the Russian Academy of Sciences	1017	5883	28
Sorbonne Universite	970	10111	35
CNRS Institute of Ecology Environment (INEE)	764	8033	34
Natural History Museum London	755	7455	34
National University of La Plata	558	5191	27
Universite PSL (Paris Sciences & Lettres)	551	5083	29
Senckenberg Gesellschaft Fur Naturforschung (SGN)	534	5862	30
Institut de Recherche Pour le Developpement (IRD)	522	5812	31

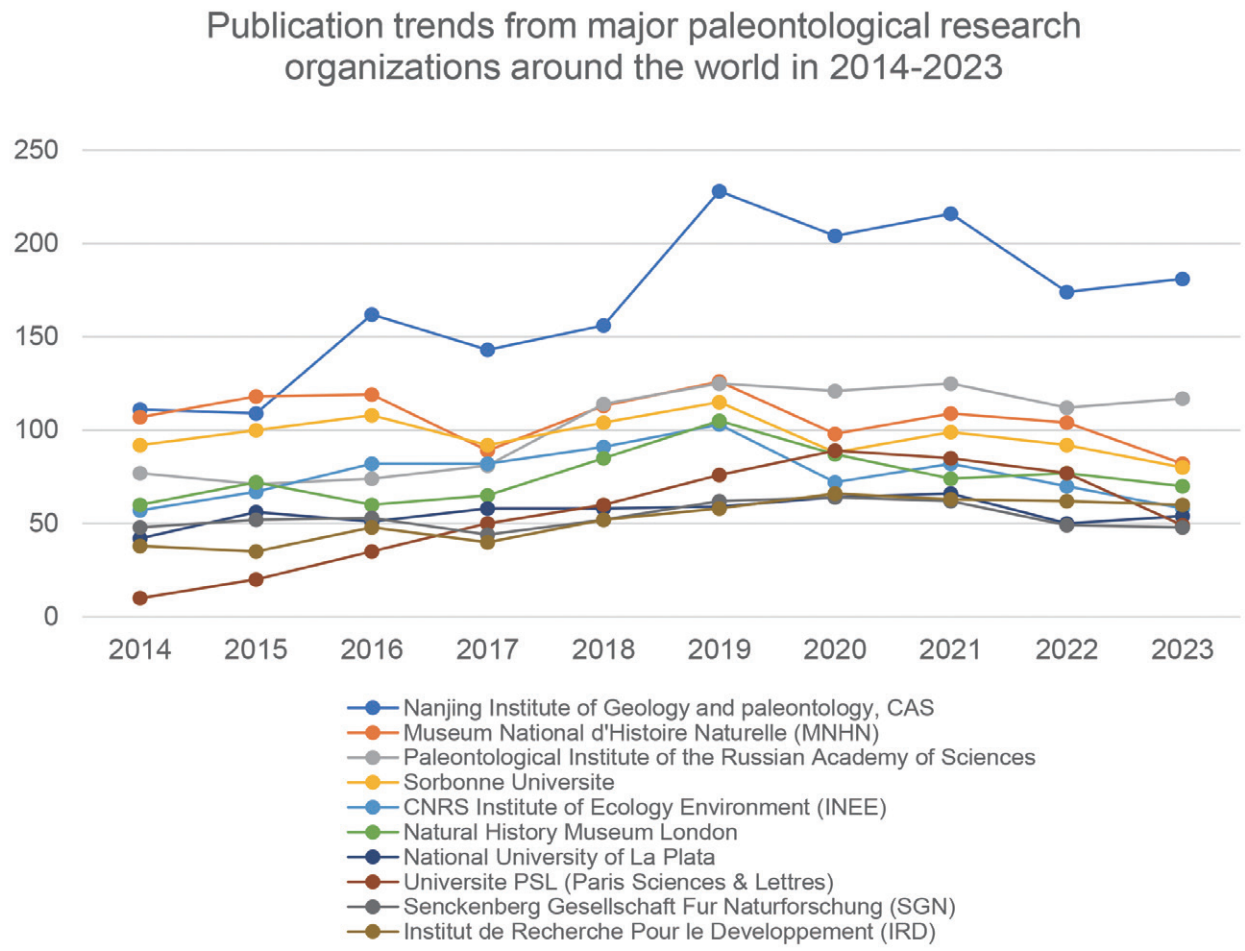

Figure 1. Statistics of NIGPAS's publications in palaeontology in comparison with other major institutions conducting palaeontologic research during the past ten years.

ternational meetings. For example, notable early visits included those paid by the IPA president (April 1979), Prof. Cloud (1980), Prof. Mosbrugger (1983), and delegations from Germany (1980) and India (1983). NIGPAS staff also began visiting the Republic of Korea (1985) and Australia (1986–1987). NIGPAS organized several international conferences, including the International Symposium on the Cambrian-Ordovician and Ordovician-Silurian Boundaries (October 1983), the International Symposium of Cambrian-Ordovician and Field Excursion in Dayangcha (1986), the 11th International Carboniferous Stratigraphic and Geological Congress (1987), and the IGCP 246 Project International Geological Correlation Program Conference (1987). These events marked the beginning of NIGPAS's regular hosting of international palaeontologic gatherings.

The 1980s marked a pivotal period when NIGPAS started to play a major role in the global palaeontologic and stratigraphic communities. From this time onward, NIGPAS researchers increasingly published their results in English, sharing their findings internationally. Gradually, English-language publications became more common, and today, most NIGPAS researchers publish more in English than in Chinese.

Now, all NIGPAS scientists are more or less involved in international collaborations. Over 40 researchers serve on the editorial boards of more than 20 international journals, while more than 30 hold leadership roles in global organizations such as the International Palaeontologic Association (IPA), the International Palaeoentomological Society, the International Organization of Palaeobotany, the International Federation of Palynological Societies, the Asian Palaeontologic Association, and the International Commission on Stratigraphy (ICS). They also sit in international subcommissions on various geological periods within the International Union of Geological Sciences (IUGS), fulfilling roles such as president, vice president, chair, vice chair, and secretary-general. Through these roles, NIGPAS scientists remain actively engaged in academic events, contributing to significant scientific advancements.

4. Research Promoted by International Collaboration

Although NIGPAS encourages scientists to conduct independent research, international collaboration is essential to stay at the forefront of academic advancements. NIGPAS's research spans all geological periods, branches of palaeontology, and encompasses specialized groups focusing on specific issues, such as Early Life Origination and Evolution, Lower Palaeozoic, Upper Palaeozoic, Mesozoic Terrestrial, Cenozoic, Palaeobotany, and Palynology. These groups have naturally formed, driven by long-lasting international partnerships that have led to numerous research achievements, some of which are briefly showcased below.

As IUGU stated, "IUGS-ratified geostandards have authority. They are of the highest importance to the practice of geology and thus receive international recognition…" (IUGS, 2022). Selection by IUGS is highly exclusive and has to subject to severe competition. Here, we elaborate on two types of IUGS-ratified geostandards—Global Boundary Stratotype Section and Points (GSSPs) and IUGS 100 Geological Heritage Sites—in which NIGPAS has been a leading force in scientific investigations, working closely with international collaborators.

4.1 Global Boundary Stratotype Section and Point (GSSP)

The geoscience adage "No dates, no rates" underscores the critical importance of accurate stratigraphic dating. Therefore, an internationally applicable standard for stratigraphic division has to be established. GSSP, also known as "Golden Spikes", is such a standard division of global significance and applicability marked in the International Chronostratigraphic Chart (Figure 2), and is regularly updated by ICS and IUGS.

Of the approximately 110 recognized GSSPs, China is home to 11, with NIGPAS experts leading the research efforts for seven of these and co-leading two others. The nine GSSPs in China involving NIGPAS are the Ordovician Darriwilian GSSP (Huangnitang, Changshan, Zhejiang, 1997), the Cambrian Paibian GSSP (Paibi, Huayuan, Hunan Province, 2003), the Permian Wuchiapingian GSSP (Penglaitan, Laibin, Guangxi, 2004; redefinition ratified 2023), the Permian Changxingian GSSP (Meishan, Changxing, Zhejiang, 2005), the Ordovician Hirnantian GSSP (Wangjiawan, Yichang, Hubei, 2007), the Cambrian Guzhangian GSSP (Luoyixi, Guzhang, Hunan, 2008), the Ordovician Dapingian GSSP (Huanghuachang, Yichang, Hubei, 2008), the Cambrian Jiangshanian GSSP (Duibian, Jiangshan, Zhejiang, 2011), and the Cambrian Wuliuan GSSP (Wuliu, Jianhe, Guizhou, 2018).

These contributions underscore China's and NIGPAS's pivotal roles in establishing global geostandards.

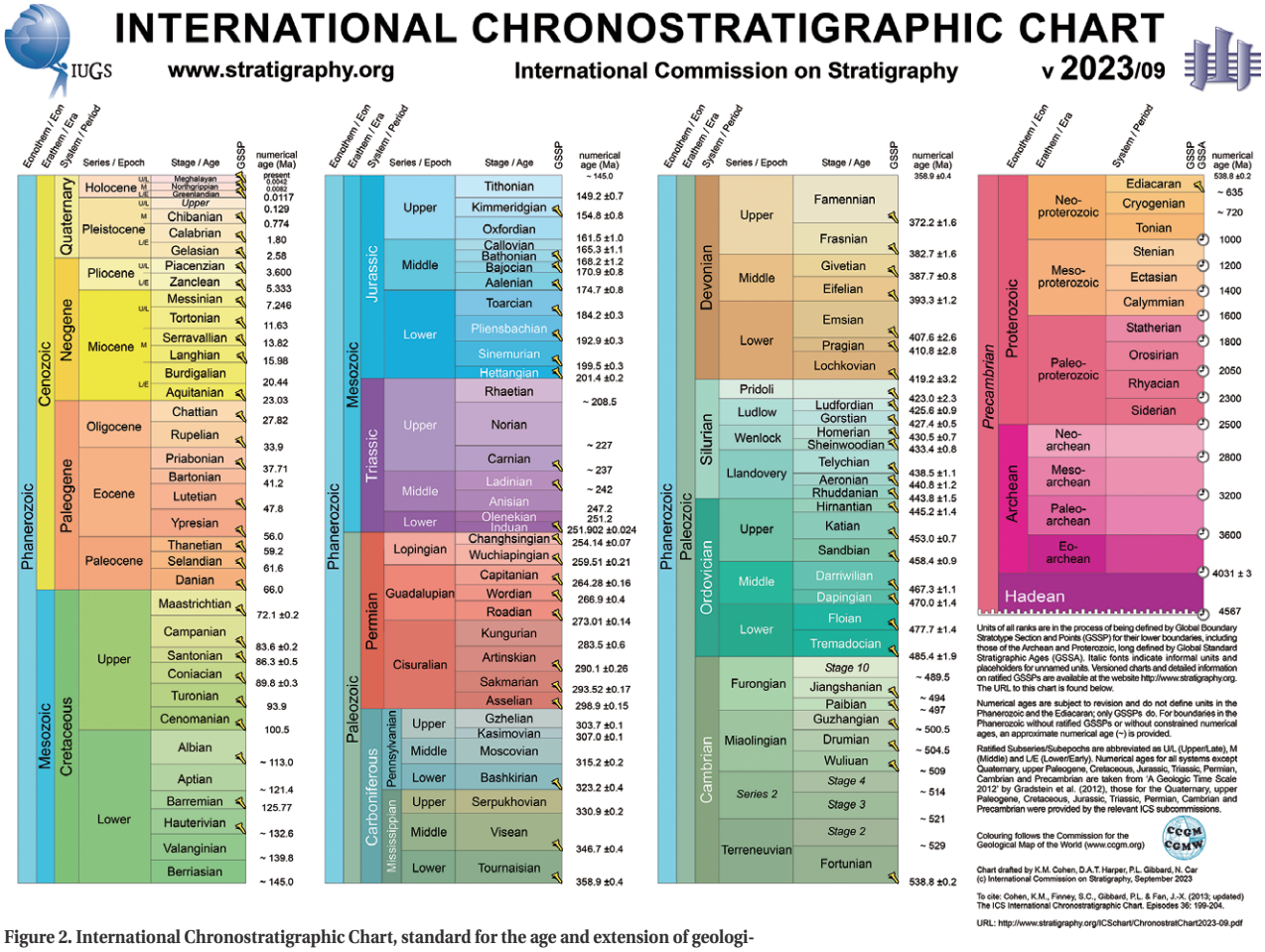

Figure 2. International Chronostratigraphic Chart, standard for the age and extension of geological divisions and boundaries. GSSPs are markedly outstanding.

The establishment of a GSSP requires a nearly perfectly well-accessible natural geological section with excellent exposures, continuous deposition, diverse and abundant fossils, long distance global correlation feasible, and chemostratigraphic analyses possible, free from vertical facies changes. Each of these criteria must be thoroughly investigated. Moreover, a subjective issue should be solved, namely, to be accepted often by consensus or unanimously by the voting members of a subcommission, being composed of internationally diverse experts, and finally approved by ICS and IUGS.

For a country, hosting a GSSP is a point of pride, as establishing one defines a global stratigraphic standard.

4.2 IUGS 100 Geological Heritage Sites

An IUGS Geological Heritage Site is a key location with extraordinary geological features or processes of the highest scientific relevance, and is used as a global reference, contributing substantially to the development of geological sciences (IUGS, 2022).

Since 2022, IUGS has been selecting 100 Geological Heritage Sites every other year. So far, the first and second groups of 100 sites have been selected. In order to recognize the First 100 IUGS Geological Heritage Sites, first, a group of 20 international experts on geoheritage from 13 different countries developed the high standards for recognition; 181 candidates from 56 countries were proposed and were evaluated by 33 international experts. For the second set of 100 sites, 174 proposed sites from 74 countries were reviewed. A total of 714 reviews were done by 89 reviewers, who scored and ranked the sites. The evaluation results were discussed and approved by 20 voting members of the Selection Committee, representing 16 international organizations involved in this global endeavor. This process highlights the ex-

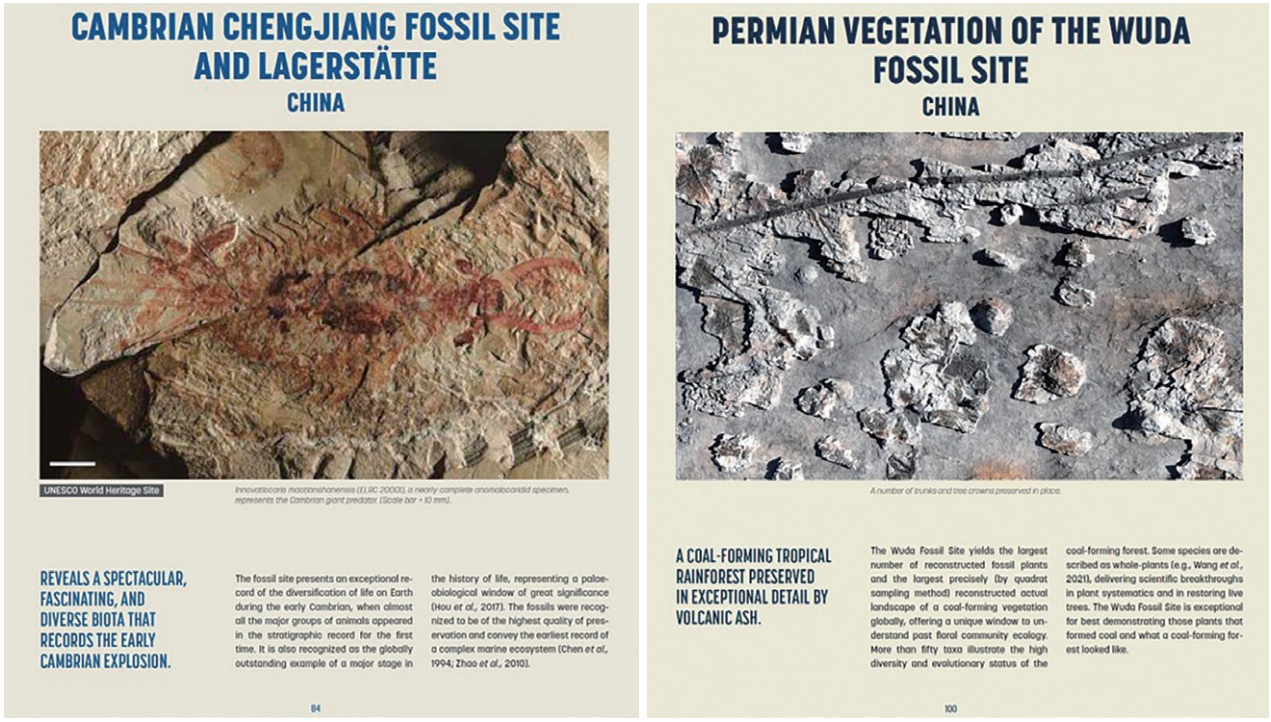

Figure 3. The first pages of the Cambrian Chengjiang Fossil Site and Lagerstätten, and the Permian Vegetation of the Wuda Fossil Site respectively as a brief introduction in the publication of the first and second 100 IUGS Geological Heritage Sites.

tensive international collaboration. The Chengjiang Fauna and Wuda Tuff Flora, selected in 2022 and 2024, respectively, are briefly reported below (Figure 3).

4.2.1 Chengjiang Fauna

The Chengjiang Fauna, discovered in 1984 at Maotianshan, Chengjiang, Yunnan, is one of the most renowned fossil faunas. After nearly forty years of study, it stands out as a globally outstanding example of a major stage in the history of life. This site represents a palaeobiological window of great significance, when nearly all major animal groups first appeared in the stratigraphic record around half a billion years ago. The first fossil discovery site has been well-protected and was designated as a National Geopark in 2001, a UNESCO World Heritage site in 2012, and one of the "First 100 IUGS Geological Heritage sites" in 2022 (IUGS, 2022).

The Chengjiang fossils provide an unparalleled record of the rapid diversification of metazoan life during the early Cambrian, also known as the "Cambrian explosion", and the establishment of a complex marine ecosystem with food webs capped by giant predators (Chen *et al*., 1994). Over 300 species representing more than 20 phyla have been identified, showcasing diverse metazoan body plans akin to those of living groups (Zhao *et al*., 2010; Zhu *et al*., 2019). These fossils address fundamental questions regarding the origin of animal body plans and the genetic mechanism of evolutionary novelties. Especially, the diverse stem-group vertebrates provide important insights into the early evolution of vertebrates, bridging the gap between an amphioxus-like ancestor and craniate vertebrates (Chen *et al*., 1999; Shu *et al*., 1999; Tian *et al*., 2022). The fossils also exhibit exquisite details of hard and soft tissue anatomy, such as appendages, eyes, and digestive and nervous systems (Hou *et al*., 2017). The mode of preservation imparts an extraordinary and rare beauty to these fossils, extending their value beyond scientific significance to aesthetic appeal.

The Chengjiang fossils have attracted attention from international scientists and led to important research on the origin of animals. NIGPAS has collaborated with researchers worldwide, hosting conferences and publishing results in top academic journals. The research was awarded the first-class prize of the National Natural Science Award in 2003

Figure 4. The primitive arthropod *Kylinxia zhangi* with a chimeric body from the early Cambrian Chengjiang fauna. This fossil bridges a crucial evolutionary gap in the origin of Arthropoda, the most diverse animal phylum on the Earth. The scale bar is 1cm.

for its significance. The impact of Chengjiang fauna is substantial on our understanding of animal evolution, and we anticipate further discoveries through international collaborations.

4.2.2 Wuda Tuff Flora (Permian vegetational Pompeii)

Titled "*Permian vegetation of the Wuda Fossil Site, China*", the Wuda Fossils have been selected as one of the Second 100 Geological Heritage Sites (IUGS, 2024). Known as the Permian "vegetational Pompeii" (Wang *et al*., 2012), or Wuda Tuff Flora, this site represents an exceptional fossil forest. The forest was peat-forming and was buried in place by ashfall, now appearing as a tuff bed between two coal seams in the Wuda Coalfield, Inner Mongolia. The tuff is dated to 298.34 ± 0.09 Ma, placing it at the earliest Permian, near the Carboniferous-Permian boundary (Schmitz *et al*., 2021).

Plant remains are preserved not only unusually complete showing gross form, but also often partly permineralized with internal structure. Seven groups consist of the vegetation, namely lycopsids, sphenopsids, filicalean ferns, progymnosperms, seed ferns, early conifers and cycads, including over 50 natural species. Besides, evidences of insect-plant interactions and plant-plant interactions (Zhou *et al*., 2019) are also preserved. In brief, this "Permian Coal Forest offers a glimpse of the late Paleozoic ecology" (Bashforth and DiMichele, 2012) and it was once reported as "Primeval Land Rises from the Ashes: A 'vegetational Pompeii' buried in a coal deposit is shedding light on ecosystem structure and climate during the Permian period." (Hvistendahl, 2012).

The Wuda Tuff Flora has yielded the largest number of reconstructed fossil plants and the largest precisely reconstructed by quadrat sampling method actual landscape of a coal-forming vegetation all over the world, offering a window to detect the community ecology. The over fifty nature taxa show the diversity and evolutionary status of the coal-forming forest. Some species are described as whole-plant taxa, bringing about breakthrough in plant systematics as a solid contribution to life-tree restoration. For instance, the whole plant species *Paratingia wuhaia* (Wang *et al*., 2021) for the first time revealed both the plant gross morphology and inner structure, evidencing the noeggerathialeans belonging to progymnosperms. Such a breakthrough was so significant to be treated as one of

the three great moments in the research of plant evolution (Retallack, 2021). The Wuda fossil site is exceptional in answering questions like "What plants formed coal?" and "What did a coal-forming forest look like?"

Discovered early but recognized as a forest buried by ashfall in 2003, the Wuda Tuff Flora has been extensively studied by an international team of about 30 experts from countries including England, the USA, the Czech Republic, Germany and China. They have published over 60 papers on the taxonomy, ecology and geologic background of this flora. The team includes experts from various disciplinary branches in geology, and palaeobotany, supported by the CAS's "President's International Fellowship Initiative" (PIFI) that supports foreign colleagues' visit/stay (ranging from a few months to two years) in China. This initiative has enabled international collaboration, with colleagues participating in field research at the Wuda fossil site and detailed studies at NIGPAS. Without internationally collective investigation of this flora, the research could never have rapidly reached such an on-depth extent that the scientific value has been well recognizable—since the Second 100 IUGS Geological Heritage Sites, as with the First 100, are recognized for their highest scientific value (IUGS, 2024).

4.3 China's Amber Research

Amber is a gemstone appreciated for its color and natural beauty. Palaeontologic research on amber in China has been intermittent for an extended period, primarily due to the absence of renowned amber biota in China and its surrounding regions. Although the Eocene Fushun amber was discovered over a century ago, it received little attention until recently. An international team led by scientists from NIGPAS has changed this, becoming a global leader in amber research. In 2014, NIGPAS scientists, in collaboration with leading academic institutions and scientists in amber research from Germany, the USA, Poland, India, and France, published the inaugural comprehensive study of the Fushun amber biota (Wang *et al*., 2014). This seminal work not only elevated the status of Fushun amber to that of a world-renowned biota but also significantly enhanced the international standing of China's amber research.

Subsequently, in light of the significant exploitation of mid-Cretaceous Kachin amber from Myanmar, NIGPAS scientists strengthened collaborations with international amber research teams. These collaborations provided NIGPAS scientists with access to advanced technologies like micro-CT and confocal laser scanning microscopy, enabling them making significant progress in their respective fields (e.g., Zhang *et al*., 2018). They also discovered some new bizarre animals from Kachin amber in partnership with scientists specialized in animals or plants all over the world including scientists from Myanmar (Yu *et al*., 2019). The study of Kachin amber has significantly enhanced our understanding of Cretaceous terrestrial ecosystems.

Furthermore, NIGPAS scientists have assembled a substantial international research team to thoroughly investigate the recently discovered Zhangpu amber (Wang *et al*., 2021). This led to an interdisciplinary paper utilizing data from the amber and the surrounding sediments. The Zhangpu amber deposit ranks among the top four worldwide in biodiversity. The findings highlight tropical rainforests as evolutionary museums for biodiversity and suggest that the Mid-Miocene Climatic Optimum probably strongly shaped the East Asian biota via the northern expansion of the megathermal rainforest biome. Therefore, the Zhangpu amber biota provides an ideal snapshot for biodiversity redistribution during global warming and serves as a model for studying amber deposits.

Through these international collaborations, Chinese scientists have emerged as global leaders at the forefront of amber research.

4.4 Unraveling the Mysteries of Early Complex Life on Earth

The sudden appearance of animal fossils in the Cambrian period, known as the "Cambrian Explosion," has puzzled scientists since Darwin's time. Paleontologists have studied Chinese fossils to understand how various animal phyla appeared within just 20 million years in the early Cambrian. Despite extensive research, the origins of these animals and the emergence of complex life forms remain unclear. To answer these questions, scientists at NIGPAS have spent forty years searching for fossil evidence in pre-Cambrian strata. They have discovered and systematically studied many exceptional fossil Lagerstätten, including the Shibantan biota, Weng'an biota, Lantian biota and Yanshan biota, to help us understand the early evolution of complex life on Earth.

Unlike other Ediacaran organisms found around the world, the Ediacaran Shibantan fossils from the Yangtze Gorges area are closer in age to the Cambrian period. They include not only typical Ediacaran life forms but also segmented, bilaterally symmetrical animals, which are more

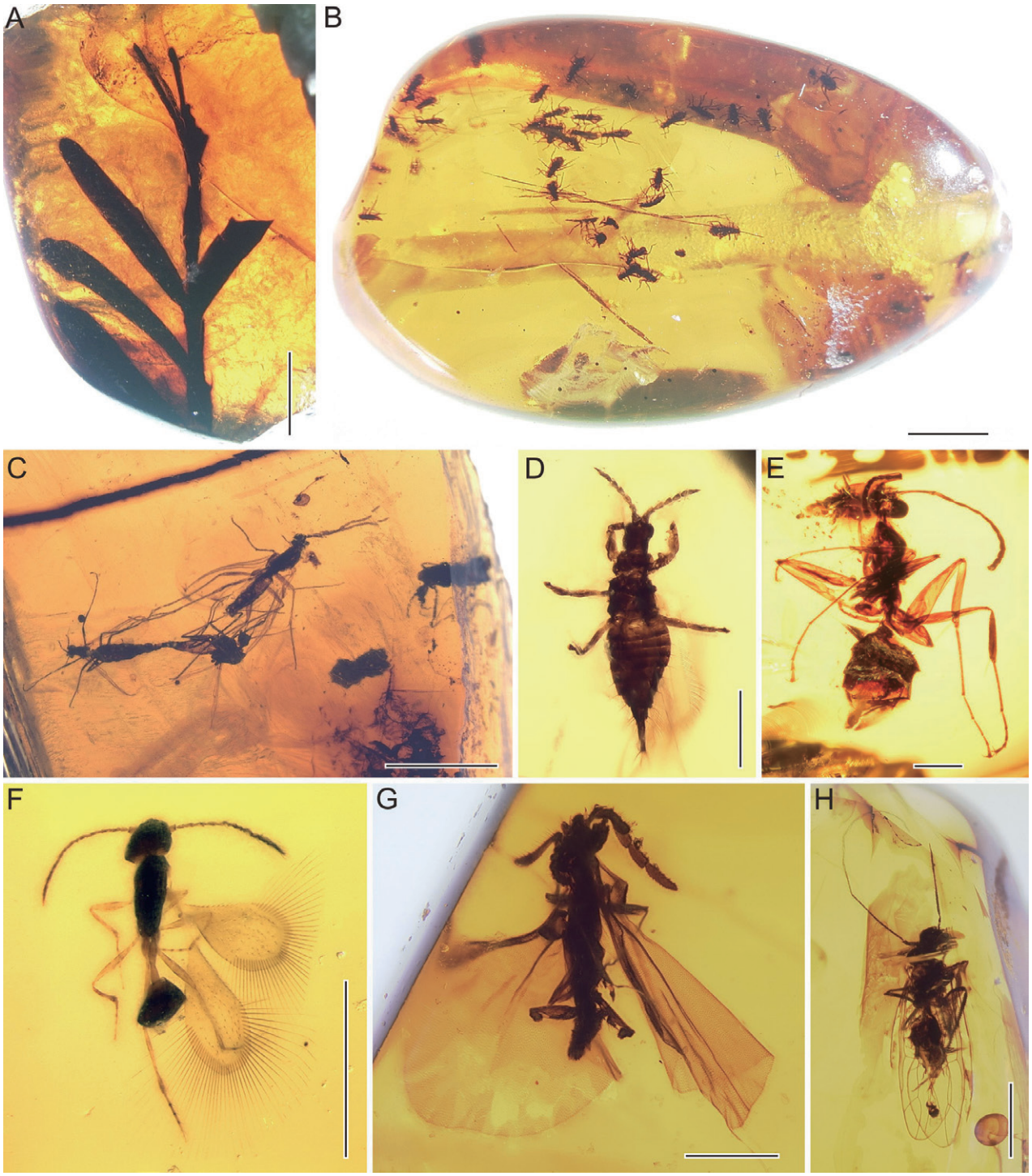

Figure 5. Representative plants and arthropods in Fushun amber. Scale bars represent 2 mm in (A–C and H) and 0.5 mm in (D–G).

complex than their counterparts found elsewhere (Chen *et al.*, 2019). This discovery has deepened our understanding of how these complex creatures evolved.

The Weng'an biota, dating back 570 to 590 million years, is a treasure trove of the world's oldest metazoan fossils. It includes the earliest sponges and embryo-like fossils, which document various developmental stages (Yin *et al.*, 2015). NIGPAS scientists have used these fossils to reconstruct the developmental processes of these ancient organisms, shedding light on the origins of multicellular animals.

But it's not just about animals. Multicellular algae and fungi, crucial components of complex life

forms, also have a rich history. The Weng'an biota has revealed lichens, which are symbiotic combinations of fungi and algae. These lichens are believed to have quickly moved from the ocean to land after the Cryogenian period, making them pioneers in terrestrial ecosystem (Yuan *et al*., 2005).

The Weng'an and Lantian biotas also contain a wealth of multicellular algae fossils. These findings have rewritten the evolutionary history of these algae, including red and green varieties.

In a remarkable discovery, the world's oldest eukaryotic fossil Lagerstätte, the Yanshan biota, was found in North China. Dating back about 1.6 billion years, it contains the oldest micro-algae with detailed cellular structures and numerous large algal specimens (Zhu *et al*., 2016; Miao *et al*., 2024). This finding shows that eukaryotes quickly developed multicellular structures and visible sizes after their origin, with some reaching up to 20 centimeters in length. This pushes back the evolutionary history of eukaryotic multicellular organisms by 600 million years and transforms our understanding of eukaryotic origins.

These discoveries are not just about filling in the gaps in our knowledge of life's history. They're about understanding the processes that led to the diversity of life we see today. As we continue to uncover these ancient secrets, we gain a deeper appreciation for the complexity and resilience of life on Earth.

5. Concluding Remarks

This brief review lists some of NIPGAS's research achievements demonstrating China's contributions to the global palaeontology and stratigraphy. These significant scientific advancements might be basically attributed to the unique fossil lagerstätten and excellent geological profiles over the vast territory of China, but without China's involvement many if not all the scientific questions could not be effectively tackled. Accordingly, one may see from the palaeogeographical map of various geo-historic periods, those palaeo-plates that form the present-day China territory had been located in certain critical position where life-environmental interactions are recorded, evidencing the indispensability of China's data for global analysis.

CAS's openness, cooperativeness and more importantly the certain financial support, such as PIFI, have not only encouraged the establishment of scientific research network, but also made international visits for scientific collaboration feasible. Science knows no borders, but scientists have their own countries. Holding the idea of a community with a shared future for mankind, NIGPAS will always encourage scientists from China and abroad to collaboratively address both theoretical and applied problems for the benefit of the world and humanity.

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