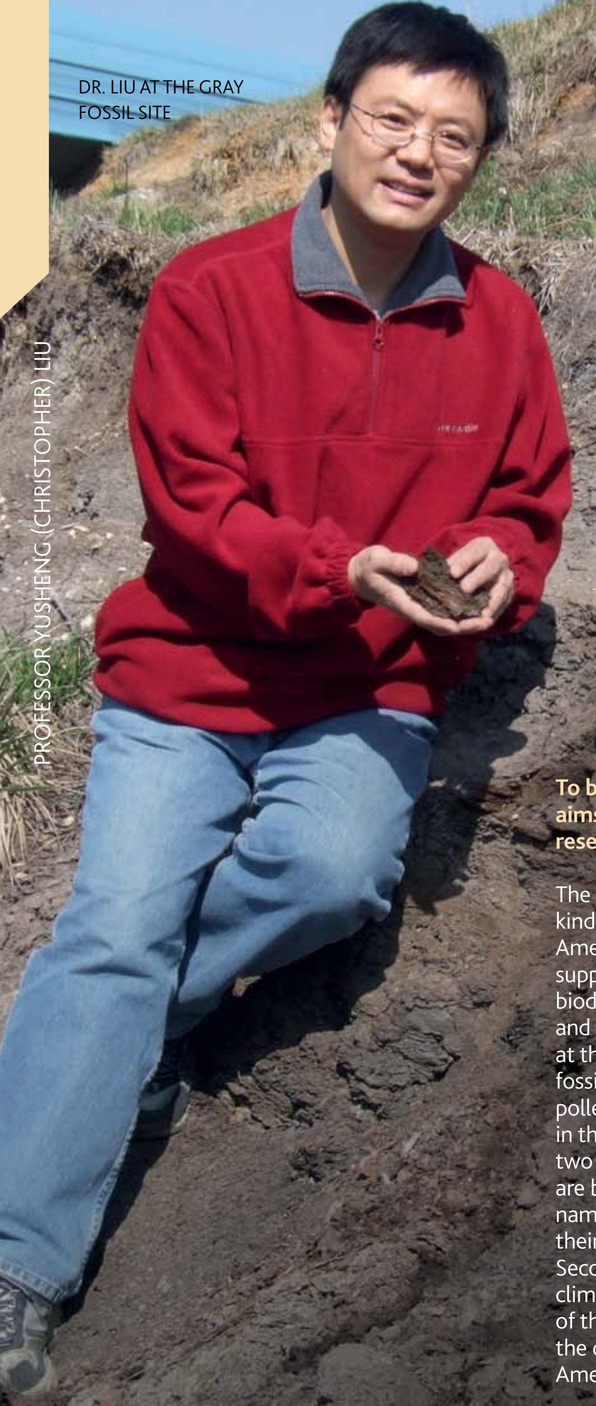
PROFESSOR YUSHENG (CHRISTOPHER) LIU



DR. LIU AT THE GRAY FOSSIL SITE

Unlocking the mysteries of ecology and evolution

Professor Yusheng (Christopher) Liu describes his interest in the paleoecology and paleoclimate of the Gray Fossil Site in Tennessee and explains some of the techniques used by his research team

To begin, could you outline the principal aims and overall objectives of this research?

The principal aims are to understand what kinds of plants lived in southeastern North America about 7 million years ago (it now supports the highest amount of modern biodiversity in the region), and which climatic and environmental conditions were present at that time. We are studying well-preserved fossilised plant materials, such as fruits, seeds, pollen, leaves, and wood, from the Gray site in the northeastern corner of Tennessee, with two objectives in mind. First, the fossil plants are being studied systematically and properly named in order to reveal a full spectrum of their identities and ecological requirements. Secondly, to quantitatively reconstruct the climate conditions (temperature and rainfall) of these fossil plants as a whole to better trace the climate change in southeastern North America.

Why has there been so little investigative research into vegetational and climatic changes in eastern North America?

Paleontological research largely depends on the fossil materials uncovered from sediments in the outcrops. Eastern North America has very limited Neogene outcrops and therefore only a few fossils of this geological period (Neogene, 24 ~ 5 million years ago) have been uncovered. This is the main reason why so little is known about the Neogene vegetations and climate conditions in eastern North America.

Can you provide an overview of the Gray Fossil Site, profiling its evolution and function?

Located in Washington County at the northeastern corner of Tennessee in the USA, the Gray Fossil Site (GFS) represents a rare Neogene site in the eastern half of North America and is still the only fossil site of this age in the southern Appalachians. The site is composed of multiple sinkholes/sub-basins that are believed to be asynchronous events preserving multiple basin-fill histories, with the sediments thought to be as old as early Paleogene.

A high-resolution gravity study on the 4000 m^2 GFS area of the Cambro-Ordovician Knox Group carbonates indicates the presence of 11 depo-centres (or sub-basins) that are aligned along a northwest (joint) and northeast (strike) structural trends. The GFS deposit extends laterally approximately 2.6 ha and consists of about 40 m of dark coloured sediment of lacustrine origin. The sediment can be subdivided into three distinct facies in ascending order – graded, transition and laminated. The overlying fossiliferous laminated facies is about 4 m thick, covered by more than 5 m thick top subaerial alluvium and colluvium layers. The animal and plant megafossils uncovered are all from the organic-rich laminated sediments, which is biostratigraphically dated between 7.0 and 4.5 Ma, ie. the Hemphillian Land Mammal Age (latest Miocene to earliest Pliocene), based on the presence of the rhino Teleoceras and short-faced bear Plionarctos.

Could you explain the leaf physiognomy analysis and coexistence approach deployed in this assay?

Two widely used fossil plants-based methods of either taxonomy-dependent (the coexistence approach) or taxonomy-independent (leaf physiognomy analysis) in quantitative reconstructions of paleoclimates have been employed in the project.

The leaf physiognomy analysis is based on the assumption that there has been selection for leaf physiognomic features (leaf size, shape, and form, serration, and venation) that confer the maximum functional advantage under a variety of environmental conditions; while the coexistence approach follows the principle of the classic Nearest Living Relative method. It is based on the assumption that the climatic requirements of fossil species are similar to those of their NRLs.

The two methods have their own pros and cons. The leaf physiognomy analysis can only apply to leaves of woody dicotyledonous plants, but the coexistence approach is fine with any organs of fossil plants.

To what extent is this research broadening our understanding of the ecological history of eastern North America?

The GFS is the only site of its age in south-eastern North America and as a result it has preserved a unique combination of faunal and floral elements with different climatic conditions and diverse biogeographic distributions.

Warm climate taxa, such as alligators and tapirs are found with cool adapted Eurasian elements, eg. Eurasian badger and red panda. Some plant remains such as Chinese moonseed (*Sinomenium*) and grape (*Vitis*) indicate a strong Asian affinity. Fossil plant assemblage preserves an association dominated by arboreal taxa (oak and hickory) and a herbaceous layer. Carbon isotopic analyses on bulk rock samples, calcite crystals and enamel from several animals confirm the dominance of C_3 plants.

Based on the unique vertebrate assemblage, the large tapir population, the limited presence of horses, and the abundance of arboreal plant fossils, the GFS has been reconstructed to be surrounded by a dense to moderately dense forest under a warmer climate.

OAK LEAF FOSSIL

The Gray area in the Neogene

Professor Yusheng (Christopher) Liu and his colleagues from **East Tennessee State University** have been widely involved in the analysis of the newly-discovered fossil deposit in the southern Appalachian Mountains. The rare find has shed light on the climate and biotic composition of Neogene life in southeast North America

IN MAY 2000 a group of American construction workers who were widening a road near a small town called Gray in northeastern Tennessee unearthed one of the most important fossil finds this century. They discovered dark and sediment-rich clay, packed with the fossil remains of both animals and plants. Unbeknownst to the construction workers, the uncovered fossils were around 7 million years old and represented a rare past community of the Neogene period in North America. The area is now called the Gray Fossil Site (GFS) and is the subject of extensive academic research. The GFS consists of a collection of ancient sinkholes; it extends 2.6 hectares laterally and is around 40 metres deep.

The exceptional preservation of the fossils from the GFS, combined with their rarity and volume, quickly identified the location as one of the most important in North America. It is only the second location containing both animal and plant specimens from the Neogene period known in eastern half of North America. The considerable scientific challenge of now unlocking the secrets of the fossil plants and thus plant life in Gray around 7 million years ago has fallen to Professor Yusheng (Christopher) Liu and his colleagues at East Tennessee State University. By analysing these fossil remains and comparing them to similar modern plants, Liu and his colleagues are reconstructing the climate and biological composition of Neogene southeast North America and particularly the area of the southern Appalachian Mountains in which the GFS sits.

ASIAN ORIGINS

One of the first things Liu noticed about the fossil samples was the presence of a number of species of plants known to be of modern day Asian origin: "Surprisingly, the paleoflora at Gray contains an unusually high percentage of plants showing a strong Asian affinity," he explains. Some of these plant fossils belong to families that are today considered endemic to Asia. Alongside the presence of these temporally 'alien' species, the Gray fossils included alligators and tapirs – now associated with warmer climates. Yet, contradictory to the presence of the warm climate species was the discovery of others such as the Red Panda, a modern day Ailurian found in the Himalayas and subsequently adapted to cooler climates.

While the biotic composition of Gray remains somewhat perplexing, climatic models of the Neogene period have provided us with a possible explanation to this mix. The Neogene is known to be a period of dramatic climate change, the warm greenhouse world of the Paleogene period was coming to an end, eventually to be replaced by

INTELLIGENCE

EXPLORING THE NEOGENE PLANT RECORD OF GLOBAL VEGETATIONAL AND CLIMATIC CHANGES IN EASTERN NORTH AMERICA

OBJECTIVES

The project involves the collection, identification, paleoclimatic reconstruction, paleoecologic analysis, and biogeographical implication of the latest Miocene-earliest Pliocene plant fossils from the Gray Fossil Site in northeast Tennessee. A significant component of the research will involve collecting fossils including well-preserved seeds, fruits, leaves, wood, charcoal, pollen and spores. The systematic, paleoecologic, taphonomic and biogeographic implications of the plants will be assessed.

Quantitative paleoclimatic reconstruction in this region is largely unexplored. Because fossil plants can provide evidence of ancient climates and several techniques for quantitative climatic reconstruction using fossil plants have been improved, study of the Gray paleoflora will contribute toward understanding the nature and patterns of Neogene climate in southeastern North America. These aspects of the research will be addressed by employing leaf physiognomy analysis and coexistence approach.

FUNDING

National Science Foundation – award no. 0746105

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DR YUSHENG (CHRISTOPHER) LIU is a Paleoclimatologist and Paleobotanist, studying the geological record of climate change. After completing his PhD at Academia Sinica in 1992, he carried out a number of postdoctoral fellowships in Austria, Germany, Japan and Canada, before joining the faculty at East Tennessee State University. His research group focuses on the paleoclimate conditions in southeastern North America about 7 million years ago.

REPRESENTATIVE FOSSIL: CHINESE GRAPE SEED

the ice house age of the Quaternary. Life at Gray 7 million years ago provides the team and wider academic community with a fossilised snapshot of the mix of life under serious pressure from rapid climatic changes. This angle of interpretation is perhaps of notable importance due to the process of climate change in the modern world. Neogene Gray may provide answers to questions surrounding survival and species distribution transferable to modern habitats.

FREQUENT FIRES

Secondarily to their work on species composition, Liu and his colleagues have been able to effectively reconstruct the climate of Gray, based on analysis of pollen, leaf, seed, and other plant remains. Of particular importance was the discovery of significant charcoal deposition. The presence of charcoal suggests that Gray was subjected to frequent forest fires. These in turn point to a warm dry climate, as Liu elaborates: "Extensive forest fires swept the region and dramatically changed the biodiversity, causing significant local biotic extinctions". With this evidence in mind Liu and his colleagues have suggested that Neogene Gray had a warm and dry climate, with little seasonal variation. In comparison to the modern day seasons the winters 7 million years ago would have been far less severe allowing for the presence of those species such as alligators and tapirs. Furthermore, the specific area of the GFS may have represented a biological refugium in which species experiencing local extinction may have survived.

One of the most useful fossil groups found at the location were algae. The team found and analysed a diverse range of algal species – at the current count, 19 morpho-species. The presence and diversity of these indicates that Neogene Gray had a number of bodies of water. Furthermore, by comparing these algal remains with their nearest day modern relatives (a technique the researchers used frequently) and analysing their structural properties they have been able to suggest that these water bodies in question would have been stagnant or very slow flowing. The combination of the research allows us to imagine an ancient Gray containing ponds and lakes, with an otherwise warm and dry climate, experiencing little seasonal variation and fairly frequent forest fires.

While the analysis of known species was crucial to the paleo-reconstruction of Neogene Gray, the team also found the fossilised remains of several new species. Of particular interest are the three new species of grapevine (*Vitis*) recognised by their fossil seed remains. Two of the new Vitis species have been identified as having close modern day Asian relatives, again reinforcing the strong Asian presence at the GFS.

DISSEMINATING DISCOVERY

Alongside their academic work the team from East Tennessee State University are involved in a wide range of dissemination programmes. Most notable of which is the construction of a natural history museum next to the GFS. The museum, constructed by the University and Tennessee Department of Transportation, aims to disseminate the techniques employed and knowledge gained at Gray. Further to this Liu has designed two courses based on the work at the GFS, providing students at the University with a cutting-edge research-led education. The team has and continue to participate in relevant international conferences, and are currently in the process of designing a website about the GFS. Integrating both academia and dissemination ensures that the wider public will gain both knowledge and enjoyment from the discovery alongside our increased scientific understanding.

While the GFS has yielded a huge amount of academically important material, the team has faced a unique set of challenges. The diversity of the fossil remains necessitates a similar diversity of expertise in their analysis. Organising this multidisciplinary collaboration has been a challenge for Liu and his colleagues. The synthesis of each area of results into one complete and holistic image of Neogene Gray highlights both the difficulty and importance of collaboration in modern science. While these challenges are significant, the researchers have relished the opportunity to work in such collaboration.

The discovery of the GFS at the turn of the millennium has provided palaeontologists with an invaluable resource. The work at Gray has already yielded surprising and significant discoveries, including the reconstruction of the climate – a result which contradicts the previous climatic models. As analysis continues by Liu's group the information coded in the fossils will gradually be elucidated. Furthermore, as is becoming increasingly important, the public will also be able to engage in the process through the comprehensive dissemination programme designed by East Tennessee State University.

GRAY FOSSIL SITE