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Large scale climate and vegetation gradients in the Neogene of Eastern Eurasia - proxy data and model interpretations

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In the frame of recent, joint research within the Neclime network, a comprehensive data set was compiled comprising flora lists of Cenozoic sites in Eastern Eurasia (Liu et al., 2010; Yao et al., 2010; Popova et al., accepted; Utescher et al., accepted). Here we discuss large scale climate and vegetation patterns in two Neogene time slices, the Middle and the Late Miocene, reconstructed by quantitative interpretations of a total of 75 micro- and macrofloras. The results are compared with data obtained from palaeoclimate modelling studied. To obtain palaeoclimate data from the Miocene floras, the Coexistence Approach (Mosbrugger and Utescher, 1997) is used. Vegetational patterns are reconstructed from diversity of plant functional types (PFTs). For the technique used cf. Utescher et al. (2007) and Francois et al. (accepted).

For both time slices studied, zonal temperature patterns are obtained for Eastern Eurasia. However, when temperature anomalies with respect to present are regarded, it is shown that the latitudinal gradients in each case were considerably shallower than today. Highest anomalies result for the winter temperatures in the high latitudes. Middle to Late Miocene cold month mean temperatures (CMTs) of Eastern Siberia were higher by over 30 °C, while the values reconstructed for SE China are close to

the present-day level (Late Miocene), or even tend to be cooler (Middle Miocene). With CMTs in the continental interior of the mid-latitudes higher by up to 20 °C, and summer temperatures close to modern conditions, seasonality was much less expressed in both time slices. The latitudinal temperature gradient is well reflected by diversities of plant functional types. For example, in the Tortonian, the diversity of the broadleaved evergreen arboreal component, in relation to other tree PFTs, increased between 60 ° and 25 ° Northern latitude from 0 to 55 %. The very warm conditions in the high latitudes supported the presence of woodlands, even in the High Arctic, as is evident from our vegetation reconstruction for the late Miocene. In the South, boundaries of major vegetation units are comparatively close to present. Unlike in Central Europe, where vegetation significantly responded to a distinct Late Miocene Cooling (Utescher et al., 2007), temperature decline in Eastern Asia was comparatively moderate, causing only minor vegetation changes in the mid-latitudes.

The study shows that all areas with a distinct, positive temperature anomaly with respect to present also encountered higher annual precipitation rates (MAP). This also holds for presently dry areas in NW China where for both time slices woodlands are reconstructed. MAP derived from Late Miocene sites in coastal areas of SE China and Japan is highest when compared to other regions, but conditions tend to be slightly drier when compared to present. This might point to a reduced intensity of the SE Asian Monsoon. Regarding the polarity of rainfall, there is evidence for seasonally drier conditions in the continental interior of the mid-latitudes (W China), with precipitation rates of the warmest month below 30 mm. This pattern, already present in the Middle Miocene, becomes more pronounced in the Late Miocene. The drying of the continental interior is also obvious from biodiversity data of plant functional types that are indicative for seasonal drought (e.g., sclerophyllous arboreal components, xeric shrubs and herbs). The intensification of continental drying commonly is referred to Tibetian uplift an intensification of the monsoon systems (e.g., Guo et al., 2004).

The reconstructed, proxy data-based patterns partly are corroborated by model experiments. A simulation for the Tortonian using a fully coupled atmosphere-ocean

circulation model (COSMOS) supports the assumption that Tibetian uplift and intensified monsoon lead to an aridification of the continental interior of Eurasia (Micheels et al., accepted). However, the representation of shallow latitudinal gradients in combination with warm high latitudes, as evident from our proxy data is still unsatisfactory, even when using complex models, and adjusting boundary conditions according to the palaeogeographical settings (e.g., Steppuhn et al., 2007; Micheels et al., accepted).

Recent experiments using COSMOS for the Miocene indicate a strong warming at northern high latitudes and a moderate cooling in the tropics, with anomalies being within the range of the palaeobotany-based reconstruction. The redistribution of heat is caused by changed vertical mixing in the ocean which is related to the frequency of tropical cyclones. The circulation changes in the atmosphere are stronger for the boreal winter than for summer which is in accordance with the proxy data.

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A new Oligocene leaf flora from the Rhodopes (Ustren, Bulgaria) - floristic relations of the Paleogene vegetation of Southeastern Europe

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The Bulgarian palaeobotanical record provides important clues about the Paleogene vegetation of Southeastern Europe that existed in the Tethyan Archipelago and in coastal areas of the evolving Eastern Paratethys. Recently, a leaf flora was discovered in an Oligocene volcano-sedimentary sequence, close to the village Ustren (Rhodopes, South-East Bulgaria). Due to its palaeogeographical settings, the "volcano flora" can provide an insight into the vegetation cover of upland areas of this region. In this study, we focus on regional provenance of Nearest Living Relatives of the taxa recorded and on identification of potential extant reference phytocoenoses.

Up to now, 21 different fossil taxa were identified. To most of them, Nearest Living Realtives (NLRs) can be assigned with sufficient accuracy. It is shown that the major part of these NLRs are presently native to Southeast Asia, and to Northern and Central America, respectively. In rarer cases NLRs exist as relics on the Canary Isles, a taxon described for the first time from Bulgaria, resembles a Ficus species presently occurring in Central Africa, the Arabian Peninsula and India.

Our results testify the close relationship between the European Paleogene flora and the recent, natural vegetation in Southeast Asia and Northern America, prior to the existence of the ASA-GRAY disjunction. Further studies on NLRs of this Paleogene flora can also bring about new insights into phylogenetic history and migration of floral elements.

Global CO_2 rise leads to reduced transpiration in subtropical vegetation

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New data series are presented that show consistent and significant reduction in maximum stomatal conductance (g_{smax}) of ~34% (+/- 12%) in nine common Florida C3 species over the 100 ppm CO_2 increase of the past century. Despite species specific strategies in adaptation of stomatal densities and geometries, all species display highly similar reductions of g_{smax} in response to rising CO_2. Based on the similarity in observed CO_2 responses, we hypothesise that all species reduce g_{smax} in order to optimize carbon gain under the constraint of a physiological cost of water loss. Based on this hypothesis, we develop and validate models that simulate structural stomatal adaptation from photosynthesis and diffusion of CO_2 and water vapor through stomata. We suggest that the ongoing response of g_{smax} to CO_2 is eventually limited by species specific limits to phenotypic plasticity and predict these limits from the adaptation strategies observed. Our model reproduces the observed stomatal adaptation and predicts that adaptation will continue beyond double today's CO_2 concentration of 780 ppm. Angiosperms reach their CO_2 response limits on average at 790 ppm, and conifers on average at 1560 ppm, roughly reflecting the ambient CO_2 under which these lineages evolved. Further, our simulations predict that doubling present CO_2 will decrease the annual transpiration flux of subtropical vegetation in Florida by approximately 60 $W.m^{-2}$. We conclude that stomatal adaptation to rising CO_2 is currently altering the hydrological cycle and climate in

Florida and will continue to do so throughout this century.

CLAMP and Climate: What aspects of an ancient climate does foliar physiognomy really record?

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Despite the long history and widespread application of foliar physiognomy as a palaeoclimate proxy, few people have questioned the relationship between regional climate as measured by meteorological stations and the climate that leaves are exposed to and therefore record. Evapotranspirational cooling is a well-known phenomenon widely studied and applied in urban forestry but largely ignored in plant based palaeoclimate proxies. Moreover most leaf fossil assemblages are the result of local accumulations of minimally transported plant debris in wet environments such as lakes, rivers and swamps. It follows that both leaf margin analysis and it's multivariate derivative, CLAMP (Climate Leaf Analysis Multivariate Program), do not record regional climate but the conditions in, and below, the forest canopy and in close proximity to bodies of water. Both vegetation and aquatic environments affect local temperature and humidity and thus there will always be a disparity between leaf-derived climate signals and those recorded by instruments that are often situated in urban or agriculturally modified landscapes. While to some extent the calibration process can compensate for this, individual modern sample sites used for calibration differ in the extent to which local climate is distinct from that recorded by meteorological stations. In turn this influences the calibration such that there are clear and systematic differences between the observed climate and that predicted by foliar physiognomy. These differences are due to effects such as the thermal capacity of water versus land and evapotranspirational cooling of the canopy/sub-canopy space, which in turn is a function of

seasonal temperature and humidity variations. These differences are most pronounced in monsoon climates.

Here we demonstrate the extent of the disparities between CLAMP-derived climate estimates and those observed and represented in global gridded climate data. Correction factors, applicable to wetland-related fossil sites, are introduced for the Physg3ar calibration dataset to compensate for the differences, and these are applied to 38 Neogene sites from North America.

Nuclear and plastid DNA sets

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The inter-and intracontinental disjunct biogeographic patterns between North America, the Mediterranean and western-central Asian area, and eastern Asia of the genus *Pistacia* were addressed in this paper. Sequences of two nuclear ribosomal DNA loci (ITS and ETS) and seven plastid DNA loci (*trnL-F*, *ndhF*, *psaA-ycf3*, *rps16*, *rpl16*, *atpB-rbcL*, and *psbA-trnH*) were obtained from all the recognized species of *Pistacia*. We analyzed these data using the most parsimony and the Bayesian phylogenetic methods. The Bayesian molecular dating analysis with critically selected fossil calibration points to obtain the age estimates was conducted. We reconstructed ancestral areas of *Pistacia* in the Northern Hemisphere by means of a dispersal-vicariance analysis (DIVA) and a likelihood method (LAGRANGE). Significant discordance was detected between nuclear and the combined plastid DNA data sets. *Pistacia* was shown to be monophyletic in all the analyses. The nuclear DNA phylogeny better delimitates species of *Pistacia* than the combined plastid data set. The American species form a highly supported clade and diverge first from the genus in both nuclear and plastid analyses. One eastern Asian species, *P. chinensis* nests in a clade which includes Mediterranean and central Asian species in all the analyses, whereas another eastern Asian species, *P. weinmannifolia* was detected to be diverged first from the Old-World species in the plastid analyses. Because multiple accessions of *P. chinensis*, *P. lentiscus*, and *P. atlantica* did not form monophyletic groups respectively in the plastid phylogeny, the monophyly of these species was

further examined using Templeton and Shimodaira-Hasegawa tests. Results showed that the monophyly of all these three species were rejected at least by one test. Introgression of chloroplast genome maybe the best interpretation of this infraspecific discordance detected in plastid phylogeny. Bayesian molecular dating analyses showed that the stem age of *Pistacia* is 32.74 mya (95% HPD: 21.62-41.80). The crow and disjunct time between the New World and the Old World species were estimated to be 22.89 mya (95% HPD: 12.60-30.01). The Madrean–Tethyan hypothesis is favored to explain the New and the Old World disjunction in *Pistacia*. The disjunction between eastern Asia and the Mediterranean Eurasian and adjacent areas is hypothesized to be due to a vicariance event via the uplift of the Qinghai-Tibetan plateau, and a dispersal event during the late Tertiary.

Middle Miocene vegetation and climate in the central and southern part of Yunnan, China

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In order to understand the Neogene vegetation succession and climatic changes in Southwest China, we reconstructed the Middle Miocene vegetation and climate at four localities, which are at different latitudes (24°19′25.3″N / 23°35′10.2″N / 22°27′44.5″N / 21°17′05.9″N) along the SW side of the Ailao Mountains in Yunnan Province. The palynological assemblages obtained from the four localities suggest that the Middle Miocene vegetation there was composed of mixed evergreen and deciduous broad-leaved forests with some coniferous forests growing under subtropical conditions. Based on the palynological data, seven paleoclimatic parameters of the four localities are obtained by applying the method of Co-existence Approach and compared with the modern and the Late Miocene and Late Pliocene climatic parameters in Yunnan. The comparison revealed that: 1) Among the four palynological assemblages, the abundance of angiosperms increase while those of gymnosperms and pteridophytes decrease along the gradient of latitudes from north to south. 2) The mean annual temperature (MAT) and mean coldest monthly temperature (MCMT) were obviously lower in Middle Miocene than today (MAT: 13.2 to 14.6 comp. 17.7 to 21° C; MCMT: 2.9 comp. 10.9 to 15.2° C). It suggests that the Ailao Mountains were not high enough to block the summer monsoon and the winter monsoon. 3) In contrast to the Neogene global cooling, the regional values of the

MAT and MCMT in Yunnan increase and accompanied by a decrease of the difference of temperature between the coldest and warmest months (18.4 to 19.1 comp. 9.5 to 12.3 °C) since Middle Miocene. This may be linked to a gradual reduction in the strength of the Asian winter monsoon as the Tibetan Plateau was uplifted.

Key words: Palynology; Paleovegetation; Paleoclimate; Middle Miocene; Yunnan; SW China

Remarks on some possible bias in reconstructing Neogene vegetation and environment in China

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Neogene is an important period for the evolution of vegetations. The distribution pattern of modern vegetation on the earth is largely affected and restricted by the late Cenozoic environment changes to a great extent. Consequently, the relevant Neogene vegetation and its relationship with environment have got more and more attention in the academic circle. Some new approaches, such as various related quantitative and semi-quantitative methods, are increasingly applied in different studies, which greatly improve the resolution of the results. As for the situation in China, the uplift of Qinghai-Tibet Plateau and the formation and afterward development of the East Asian monsoon, are indubitable causing the Neogene vegetation of China a great diversification from place to place. Meanwhile, limited outcrops with discontiguous strata of the widespread terrestrial deposits in China, makes stratigraphic comparison in different regions difficult. In view of the above circumstances, this paper discusses some possible bias in the Neogene vegetation and environmental studies based on some related case studies.

A) Unequilibrium of the data: the existing Chinese Neogene mega-plant and pollen data displace a great imbalance among the different study periods, fossil sites, fossil types and researchers. For example, pollen data from some oilfield were generally compiled in the palynological assemblages that cover thick stratigraphic beds. Their precisions are much lower than these based on separate samples. B) Precise chronological comparison: chronology for the terrestrial strata in China was formerly established mainly based on fossil evidences. Among them, palynology was one of the major approaches, whereas increasing vegetation differentiation in the Neogene of China, implicates the underlying risk in the pollen comparison between

regions. Therefore, other evidences, such as palaeomagnetic study, etc. are necessary as a supplement. C) Advantages and disadvantages in using mega-plant and palynological data: while using comprehensive fossil evidences to restore the palaeovegetation, it is required to make a different treatment of the respective fossil groups based on their characteristics of preservation. Pollen data are generally representative of continual beds for a series of time, but more regional, while mega-plants are often limited to certain definite beds, but more local. In addition, under the different preservation condition, herbaceous plants tend to be more often preserved with pollen rather than the mega-plants. D) Application for quantitative method: a strict standard is necessary in dealing with the original data; so that we will be acquaint in advance to avoid the existing bias caused by the uneven development of the data. It is also definitely important to differentiate pollen data from the mega-plant data. As for a pollen assemblage, percentages for the representative elements are primary important in determining a vegetation type.

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Reconstruction of monsoon climates based on leaf physiognomy of the late Miocene Xianfeng flora, Central Yunnan, China

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The Xianfeng flora from Central Yunnan was chosen to reconstruct the palaeoclimate in the late Miocene. Two well-established quantitative methods were applied in the present study, i.e. Leaf Margin Analysis (LMA) and Climate Leaf Analysis Multivariate Program (CLAMP). Results of the two new Chinese calibrations for both LMA and CLAMP were compared with the former ones. The comparisons appear to confirm the robustness of the two new Chinese calibrations. The MATs from the two new Chinese calibrations (LMA: 17.2±2.38°C; CLAMP-PHYSGCHINA: 15.7±1.33°C) are higher than the present (14.3°C). The MAPs from CLAMP-PHYSGCHINA are 1451.6±225.9 mm, which is obviously higher than that of today (1003.2mm). Based on the comparisons of three late Miocene floras from Yunnan, the results indicate that the climate was warmer and more humid during the late Miocene than that of the present in Yunnan, Southwest China. The differences between temperature in warmest month and coldest month, precipitation in humid and dry seasons indicate the existence of seasonality, but not as

strong as today. Using the relative ratios of MP3WET and MP3DRY to annual precipitation rates as indices, the intensity of the Asian monsoon during the late Miocene was also investigated. The great differences of dry season (winter) precipitation indicate a marked strengthening winter monsoon since the late Miocene, which suggests that the Tibetan Plateau would have not yet been reached to its present elevation in late Miocene.

Key words: Xianfeng flora, Late Miocene, palaeoclimate, monsoon, Yunnan.

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Vegetation of Yunnan

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Yunnan is extremely rich in biodiversity and vegetation type duo to its diverse habitats and topography. More than 16200 plant species of 3008 genera and 433 families were recognized from the region, which make up half of the total species in China. There are at least 167 plant formations in 12 vegetation types in Yunnan, including tropical rain forest and monsoon forest at lowland in southern Yunnan, subtropical evergreen broad-leaved forest on centre Yunnan Plateau, montane humid evergreen broad-leaved forest or cloud forest and mossy forest on upper mountains, deciduous broad-leaved forest, temperate coniferous forest, alpine meadows and alpine scrubs etc. on high mountains in northwestern Yunnan. Except the main vegetation types, there are also particular vegetations with ecological and biogeographical importance, such as limestone vegetation, Mediterranean featured vegetation, including arid scrubs of xerophytes (Maquis) and sclerophyllous forest at warm and dry areas, succulent and thorny scrubs and savanna at hot and dry valleys. Studies on the vegetations of Yunnan and their distribution patterns could give clue to better understand the geological history, origin and evolution of biodiversity and vegetation in Yunnan.

New materials of fossil plants from the Miocene in eastern Zhejiang, China and their paleoclimatic significance

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Zhejiang Province, located in Southeast China, is belonged to the middle-low latitudes of the Northern Hemisphere, where a mid-subtropical monsoon climate prevails. The continental strata in the basinal-hilly areas of eastern Zhejiang Province, comprised several beds of basalt with fluvial-lacustrine interlayers, is called lithologically the Shengxian Formation that is confined to the Miocene based on the geological constraints of the basaltic dates and regional correlations. Recently, abundant plant fossils e.g., fruits, seeds and leave were cellected from the continental strata. The majority of plant megafossils is isolated vegetative or reproductive organs, but leaves attached to branches were also found.

The authors compared the morphological and anatomical characters of the common fossil taxa from the flora with modern plants, assigned the fossil plants to detailed, valid systematic positions: 2 families 4 genera (at least 4 species) of conifers and 8 families 12 genera (at least 16 species) of angiosperm. For a example, fossil *Liquidambar miosinica* Hu et Chaney, shoots, branches, and reproductive organs are preserved in diatomitic mudstone layers with little physical damage. And there are some new materials in the flora. Such as *Ilex protocornuta* X.C. Li et B.N. Sun sp. nov., leaf with short, stout and narrowly sulcate petiole, lamina with base rounded or subtruncate, apex acuminate, leaf shape quadrangular-oblong, venation semicraspedodromous, midvein stout, lateral veins in 3-6 pairs, anastomosing near margin, 2, 4 or 6 strong and predominant marginal lateral spines, some lateral veins projecting beyond the spine apex, margin thickened with sclerenchyma strand; leaf cuticles with cyclocytic or distinctive amphicyclocytic (tricyclic) stomata (giant stomata). Another new species is *Trapa ninghaica* Xiaodong Lv et Bainian Sun sp. nov., a water fossil chestnut, consists of more than 30 specimens, which probably inhabited in lakes and ponds with low-energy and eutrophic environment.

Warm temperate/cool coniferous and broad-leaved deciduous forest as well as a

bamboo forest in the higher hills or at the peaks indicated that the Miocene forest has the vertical variation and a simple multistratified structure, which are similar to the modern subtropical broad-leaved evergreen forest distributed in Southeast China.

This research was conducted under the National Natural Science Foundation of China (No. 40772012), and the Foundation of the State Key Laboratory of Paleobiology and Stratigraphy, Nanjing Institute of Geology and Paleontology, Chinese Academy of Sciences (No. 063101).

Keywords: plant fossils, Miocene, palaeoclimate, Zhejiang

Early Late Miocene floral change in central Japan and its significance in the development of Asian Monsoon

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Late Miocene floras in central and northeastern Japan are mainly distributed in the early Tortonian (11.6 – 9Ma) and Messinian (7.3 – 5.3Ma). Those floras have been studied based on fossil leaves (e.g. Tanai, 1961; Uemura, 1988; Ozaki, 1991). The fossil leaf floras are characterized by the dominance of deciduous broadleaved trees including *Fagus*, *Quercus*, *Alnus*, *Betula*, and *Acer*. Pinaceae (*Picea*, *Abies*, *Tsuga*, and *Pinus* subgen. *Haploxylon*) and Cupressaceae (*Thuja* and *Thujopsis*) increased in the Messinian floras. Those coniferous taxa became majour elements in the Quaternary palaeovegetation in Japan. The floral change of increasing diversity of coniferous taxa is recorded in fruits and seeds assemblages in about 9 Ma in the Tokiguchi Porcelain Clay Formation distributed in northeast of Nagoya, central Japan. The porcelain clay of the formation was deposited in a fluvial system in small basins and overlain conformably by the Toki Sand and Gravel Formation that was deposited in a larger and higher energy sedimentary basin.

Thirteen fruits and seeds assemblages above a tephra layer dated 9.7 Ma by fission track method include 190 taxa including 124 trees, 18 vines, and 48 herbs (Momohara and Saito, 2001). Among them seed cones and shoots of *Sequoia* occur most abundantly. Deciduous broadleaved trees were another major elements in the palaeovegetation in and around the sedimentary basin. Common occurrence of plants with the northern limit of distribution in the warm temperate zone indicates little fluctuation of the warmer oceanic climate during deposition of the porcelain clay. *Stewartia monadelpha* represents the only one cool temperate plant in the lower horizons, but other cool temperate plants and conifers including *Picea* sect. *Picea*, *Pinus* subgen. *Haploxylon*, and *Chamaecyparis pisifera* are present in the upper horizons. Along with the cool temperate plants, herbaceous plants including annuals

increased in the upper horizons.

The increase of cool temperate elements and herbaceous plants was thought to be a reflection of topographic changes in and around the sedimentary basin. During deposition of the lower horizon, plant macrofossils were derived from the wetlands and forests located between the distal end of the fan and uplands along the sedimentary basin. The forest was composed mainly of deciduous broad-leaved trees mixed with conifers and evergreen broad-leaved trees, and the herb layer was less developed. During deposition of the upper horizon, the drainage basin expanded and active tectonism resulted in the uplift of mountains. The cool temperate elements were derived from the montane regions. The tectonism also increased disturbance, which then created new habitats that enabled herbaceous plants (including annuals) to grow on alluvial deposits. The tectonic movements since 9 Ma increased simultaneously in a wide area including East Asia and Himalaya. The uplifted Himalaya developed Asian Monsoon and increased periodic disturbance by flood that caused increase of annual ruderal herbs including *Fatoua villosa*, *Persicaria longiseta*, and *Mosla* spp.

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Miocene pollen record of KC–1 core in the Qaidam Basin, NE Tibetan Plateau and implications for evolution of the East Asian monsoon

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Research on Miocene terrestrial sediments in East Asia can provide a better understanding of the development of the East Asian monsoonal system (EAM), the climatic evolution of eastern Asia, and the influence of the Tibetan Plateau uplift. However, different East Asian summer monsoon (EASM) evolution trends since the Miocene were investigated using on different climatic proxies. The Qaidam Basin at the northeastern edge of the Tibetan Plateau, NW China provides a key location to explore mid-latitude terrestrial climate changes, the evolution of the EAM, and the effects of the Tibetan Plateau uplift based on pollen records. The KC–1 Core was drilled to a depth of 3435 m in the western part of the Qaidam Basin, through the bottom of the SZG Fm, the entire SYSS Fm, and ending just at the upper part of the XYSS Fm, spanning the early to late Miocene (18~5 Ma). Our pollen results show clearly that the conifer pollen taxa dominate in most of the samples; typically *Picea*, *Pinus*, *Podocarpus*, *Tsuga* and *Cedrus* have been identified in pollen slides. The other most common pollen came from shrubs and herbs, such as Chenopodiaceae, *Ephedra*, Asteraceae, *Artemisia*, *Nitraria*, Poaceae, etc. In comparison, the diversity and abundance of broad-leaved pollen taxa like *Quercus*, *Juglandaceae*, *Ulmaceae*, Betulaceae are subordinate. Only a few types of algae and fungal spores have been

found in some samples. Higher thermophilic taxa percentages between 18 and 14 Ma decreased after 14 Ma, which fits well with the Mid Miocene Climatic Optimum between 18~14 Ma and the global climatic cooling after 14 Ma. During the same period, the xerophytic taxa percentages gradually increased and the conifers gradually decreased, suggesting an aridification process in the Qaidam region mainly driven by the gradual strengthening of the EAWM and weakening of the EASM. The global climate cooling process appears to have driven the climatic development of the Qaidam Basin region throughout the Miocene. Although some Miocene faulting near the KC–1 location, as well as other tectonic events, occurred in the Qaidam Basin on its surrounding mountains and even in the northern Tibetan Plateau, they provide little data for calculating the absolute elevation rise caused by the uplift in this region. The lithofacies displayed in the KC–1 borehole show a stable and continuous lacustrine environment without any detectable hiatus. The trends in raw pollen counts and in the pollen taxa of each sample throughout the section (especially the alpine conifers) have remained stable since 18 Ma. No new pollen taxa occurred, possibly indicating that no major uplift of the basin or the surrounding mountains took place during this period. In other words, Miocene tectonic movements at this region appear to have not had significant influence on the lithofacies documented by our samples. So, the changes in the content of vegetation seem to have been driven by the long term climate change and monsoonal weakening and, to a lesser extent, by the uplift of the Tibetan Plateau.

Keywords: Pollen, Qaidam Basin, Tibetan Plateau, Miocene, East Asian monsoon

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Epiphyllous fungi on the Miocene of *Cunninghamia lanceolata*, eastern Zhejiang Province, Southeast China

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Some new materials of fossil plants were found in the Shengxian Formation of the Miocene in Tiantai, Zhejiang Province, Southeast China, this is a continue work and some species have been reported in the previous works. During the microstructure study of the fossil plants, a kind of fossil conifer leaves with fungal fruit bodies need to be paid much attention. From the leaf macro-morphology and cuticular characteristics studied by optical microscope and scanning electronic microscope, the fossil conifers can be identified to *Cunninghamia lanceolata* (Lamb.) Hook. *C. lanceolata* is described from the Miocene Shengxian Formation of eastern Zhejiang Province, Southeast China on the basis of leafy shoots and detached leaves with well preserved cuticle. Also the fossil species has been compared with living *C. lanceolata* on branches, leaves-from, epidermis structures and shows no differences. And an epiphyllous fungus was discovered immersed in the fossil leaves of *C. lanceolata* and believed to be a member of the Microthyriales. The founding of epiphyllous fungi provides the first unequivocal evidence of the occurrence of fossil epiphyllous fungi in the eastern Zhejiang Province. Based on the structure of the thyrothecium, analysis and comparison of the micro-structures of epiphyllous fungi, the fungus can be placed into the family Micropeltaceae, type genus *Callimothallus*, and is described under the name *Callimothallus pertusus* Dilcher. Also the epiphyllous fungi can be used as paleoenvironmental indicators, which indicate a warm and wet habitat of Miocene Zhejiang Province in southeast China.

Key words: epiphyllous fungi, Miocene, *Cunninghamia lanceolata*, Zhejiang Province, *Callimothallus pertusus*

Legume fruits from the Miocene of eastern Zhejiang, China

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Zhejiang Province belonging to the middle-low latitudes of the Northern Hemisphere, is located in northern Southeast Hills, China and adjacent to East China Sea, where a mid-subtropical monsoon climate prevails. A continental stratum, comprising many layers of basalt with Intertrappean fluvial-lacustrine beds, outcrops in the basinal-hilly areas of eastern Zhejiang Province (e.g., Tiantai, Ninghai, Shengzhou, Xinchang), and is called lithologically the Shengxian Formation that is confined to the Miocene based on the geological constraints of the basaltic dates and regional correlations (Li, 2010). Sometimes, it was also named after the Xiananshan Formation but this lithological unit is invalid now (Li, 2010). Many plant fossils, e.g., fruits, seeds and leaves as well as very rarely discovered flowers, are exquisitely preserved in diatomites, diatomitic clays and siltstones of this stratum, which are described as a lacustrine deposit (Li, 2010).

The Miocene flora of eastern Zhejiang Province is one of the national most diverse Tertiary assemblages (Liu and Zheng, 1995). The flora is much more fascinating because its palaeofloristic association is not only composed of paleotropical-tertiary elements (e.g. pantropical) but arcto-tertiary elements (e.g. temperate). Here, we describe several fossil taxa with affinities to the cosmopolitan Leguminosae. Leguminosae or Fabaceae consists of more than 700 genera and 18000 species belonging to three subfamilies (Mimosoideae, Caesalpinioideae and Papilionoideae). The morphotypes presented here are based on fossil fruits, and assigned to the subfamily Papilionoideae. The subfamily Papilionoideae is represented by fossils assignable to the tribes Sophoreae (*Ormosia*), Sophoreae (*Maackia*) and Dalbergieae (*Dalberia*), while the extinct genus *Podocarpium* is also represented by two fossil

fruit types different from the known type species *Podocarpium podocarpum*, a widespread species distributed in the Tertiary of Northern Hemisphere. These fossils confirm the presence of Leguminosae in eastern Zhejiang at least since the Miocene.

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Eocene dicotyledonous woods from South China and their paleoclimatic implication

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Two new Eocene dicotyledonous wood species, *Paraphyllanthoxylon hainnaensis* sp. nov. and *Paraphyllanthoxylon maomingensis* sp. nov. are described from Changchang Basin and Maoming Basin, South China respectively. Changchang Basin (19° 38' N, 110° 27' E) is located near Jiazi Town, Qiongshan County, in the northern portion of Hainan Island. *P. hainnaensis* was collected from the coal-bearing series of Changchang Basin that belongs to the Upper part of the Changchang Formation and is dated as early Eocene–early Late Eocene age. Located in southwestern Guangdong Province, Maoming Basin (21°42' N, 110°53' E) is a small inland intermountain basin that has developed since the Cenozoic. *P. maomingensis* was collected from Youganwo Formation which is subdivided into the lower coal-bearing series and upper caustobioliths (mainly of oil shale) based on their lithologic properties. Jin (2008) dated the age of the Youganwo Formation as Late Eocene.

The genus *Paraphyllanthoxylon* was first established by Bailey (1924) to describe angiosperm fossil woods from the Upper Cretaceous of Arizona, USA. Bailey selected *Paraphyllanthoxylon* as the genus name to indicate its affinity to genera *Bridelia* and *Phyllanthus* of the section Phyllanthoideae of Euphorbiaceae. Bailey's diagnosis of this genus included a distinct combination of anatomical characters: indistinct well-defined growth rings, diffuse-porous wood, solitary or radially grouped vessels, simple perforation plates, abundant tyloses, septate fibers, and heterocellular multiseriate rays. As the two types of fossil woods under study show the complete suite of those diagnostic characters, they are assigned to *Paraphyllanthoxylon*. Nevertheless, they are similar but not identical to any *Paraphyllanthoxylon* species described previously and hence, two new species are established. Not only does this

discovery provide important fossil evidence for research on the phytogeographic history of this genus, but also contributes to our scant knowledge of Palaeogene wood in China.

Great similarity exists between *P. hainanensis* and the woods of some genera in the *Glochidion* group of the Euphorbiaceae, subfamily Phyllanthoideae, such as subtribe *Flueggeinae*, *Antidesma*, *Bischofia*, *Bridelia*, *Hymenocardia*, *Neowawrea*, *Spondiathus*, and *Uapaca*. *P. hainanensis* also resembles Neogene wood *Bischofia.javanice* discovered in Hubei, China and Neogene wood *Bischofia palaeojavanica* collected in India. Extant *Bischofia* species are universally distributed in South and South-East Asia, Australia and Polynesia. They exist mainly in South-West, Central, East and West of China as well as Hainan Island. The species of *Bischofia*, the main species of tropical and sub-tropical evergreen rainforest, grow in humid gully of low latitude mountain and sapling is hydrophytic with good shade tolerance. *P. hainanensis* was collected in the coal-bearing series of the Changchang Formation, in which abundant aquatic plants such as *Nelumbo* and *Salvinia natans* L. are also discovered. Thereby, we deduce that the climate of Changchang Basin is warm and humid during Eocene and the Euphorbiaceae trees grow in the lowland rain forest near lake basin.

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Non-destructive fossil and plant inspection with synchrotron radiation micro-tomography

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X-ray tomography is a non-destructive three-dimensional structure inspection technique, which is suitable to fossil and living plant inspections. Unlike histological techniques, x-ray tomography can section a specimen numerically rather than physically. This not only reduces the efforts on specimen preparation but also save valuable fossils. Compared to x-ray tube based microCT, synchrotron radiation based microCT (SRμCT) has unmatchable advantages in terms of spatial resolution and data acquisition speed. SRμCT has been recently employed in studies of fossil materials. At the Advanced Photon Source (APS) of Argonne National Laboratory, the micro-tomography beamline 2-BM has been optimized and several accessory techniques have been developed for fossil and living plant imaging. In this talk, few examples on fossil and living plant inspections at 2-BM will be presented.

Quantitative paleoclimate estimates from two Late Neogene floras in eastern North America: the Brandywine Deposit and the Citronelle Formation

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The Brandywine Deposit flora and the Citronelle Formation flora are being utilized to generate quantitative climate information for the Late Neogene of eastern North America. The Coexistence Approach, based on the work of Utescher and Mosbrugger, is the method attempted in this study and the results compared to modern values. The Brandywine flora is located on the Mid-Atlantic Coastal Plain approximately 20 km southeast of Washington, D.C., U.S.A. Its geology suggests deposition in a braided stream channel that was only intermittently connected to a main stream during floods. Plant macrofossils and ternary plots of pollen data were previously used by McCartan et al to correlate the deposit to nearby marine formations, suggesting a Late Miocene age, approximately 10–6 Ma. Plant taxa from the original study and newly-identified taxa (i.e., Equisetum, Cleome, and Ranunculus) were incorporated into the current study. The Citronelle Formation, on the northern Gulf of Mexico Coastal Plain, spans westward from the panhandle of Florida, U.S.A. to the eastern portion of Texas, crossing parts of southern Alabama, Mississippi, and Louisiana. Recent geological studies utilized sea level evidence, indications of tropical/subtropical weathering, plant fossils, and correlations with other regional formations to indicate that the Citronelle Formation is approximately 3.4-2.7 Ma (Pliocene/Piacenzian). The Citronelle Formation is characterized as mostly sandy, gravelly in some parts, with scattered clay lenses. The current study of the Citronelle Formation is based on

macrofossils from five different sites. Our co-existence analysis found that the Late Miocene climate along the area occupied by the Brandywine deposit can be characterized as warm temperate with warm month mean temperatures (WMMT) greater than 22^{o}C (actual range was 23.3^{o}-24.2^{o}C) and cold month mean temperatures (CMMT) ranging from 0.1^{o}C-7.8^{o}C. Mean annual temperatures (MAT) were 13.4^{o}C-16.1^{o}C. Mean annual precipitation (MAP) was 897-1206 mm. This is similar to conditions in the area currently, which are also warm temperate (WMMT of 25.5^{o}C, CMMT of 0.3^{o}C, and MAP of 1001 mm). Analysis also shows that the climate along the northern Gulf of Mexico Coastal Plain during the Piacenzian was humid/subtropical as is the modern climate of the area. The WMMT range and CMMT range of the Citronelle Formation were 25.6^{o}C-27.9^{o}C and 4.3^{o}C-8.8^{o}C, respectively, which compares to modern climate parameters of 27.9^{o}C and 9.9^{o}C. The MAT ranged from 14.4^{o}C-20.8^{o}C compared to current MAT of approximately 19.8^{o}C. Interestingly the MAP during Citronelle Formation deposition was a bit less (1122-1250 mm) than exists in the area today (approximately 1486 mm). These results will be compared to planned physiognomic climate analysis using these same fossils as well as other climate proxy data for the Late Neogene.

On the Establishment of the Leaf Physiognomy - Climate Model from Chinese Humid to Mesic Forests and case study

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The relationship between leaf physiognomy and climate is widely used for palaeoclimate reconstructions. As far as Chinese vegetations are concerned, this relationship is still unclear. Fifty samples from humid to mesic forests over China are collected in this study to discuss if previous models are available for the palaeoclimate reconstructions of Chinese Cenozoic floras. Three models are set up as following:

(1) Leaf margin analysis (LMA), a widely used method that applies present-day linear correlation between the proportion of woody dicotyledonous species with untoothed leaves (P) and mean annual temperature (MAT) to estimate palaeotemperatures from fossil leaf floras. The result indicates that, P shows a strong linear correlation with MAT. But the actual relationship is a little different from those recognized from other regions. Among all currently used LMA equations, the one resulting from North and Central American and Japanese data, rather than the widely used East Asian LMA equation, yields the closest values to the actual MATs of the

Chinese samples. A new equation is therefore developed, where MAT = 1.038 + 27.6 × P. The result not only demonstrates the similarity of the relationship between P and MAT in the Northern Hemisphere, but also improves the reliability of LMA for palaeoclimate reconstructions of Chinese palaeofloras.

(2) Single Linear Regression for precipitation. Single linear regression was used to analyze the relationship between leaf physiognomy and precipitation parameters. The result indicates that, leaf margin character shows the highest correlation to growing season precipitation (GSP), which is different from former reports, as most of former reports noted the leaf size correlated to precipitation parameters most. A new equation is set up: GSP = 228.0 + 1707.0 × P, with $r^2 = 0.663$. When applying to Chinese Miocene floras, the results calculated by this new equation are similar to these by Coexistence Approach.

(3) Climate Leaf Analysis Multivariate Program (CLAMP), a multivariate method based on canonical corresponding analysis. New calibrated data from 50 Chinese sample sites are distant from former 144 samples in physiognomic space, which may be caused by the unique characters of leaf physiognomy under monsoon condition in China. Therefore, a new calibrated CLAMP dataset, i.e., PHYSGCHINA, is set up based on these 50 new Chinese samples and 144 former samples from PHYSG3BRC dataset. The result demonstrates that, this new model could improve the accuracy of paleoclimate parameters, especially precipitations for palaeofloras under the monsoon climate condition.

Paleoclimates of Chinese Cenozoic floras were calculated by leaf physiognomy-climate models mentioned above. The Chinese palaeoclimate history in Eocene was similar to that from worldwide record. That was, hot climate presented in early Eocene and continued to early Middle Eocene, and then, climate cooled down from late Middle Eocene to Late Eocene in China. The main palaeoclimate history of Miocene in China was concluded by results from different models: temperature in Middle Miocene was similar to that in nowadays, but the precipitation was much higher.

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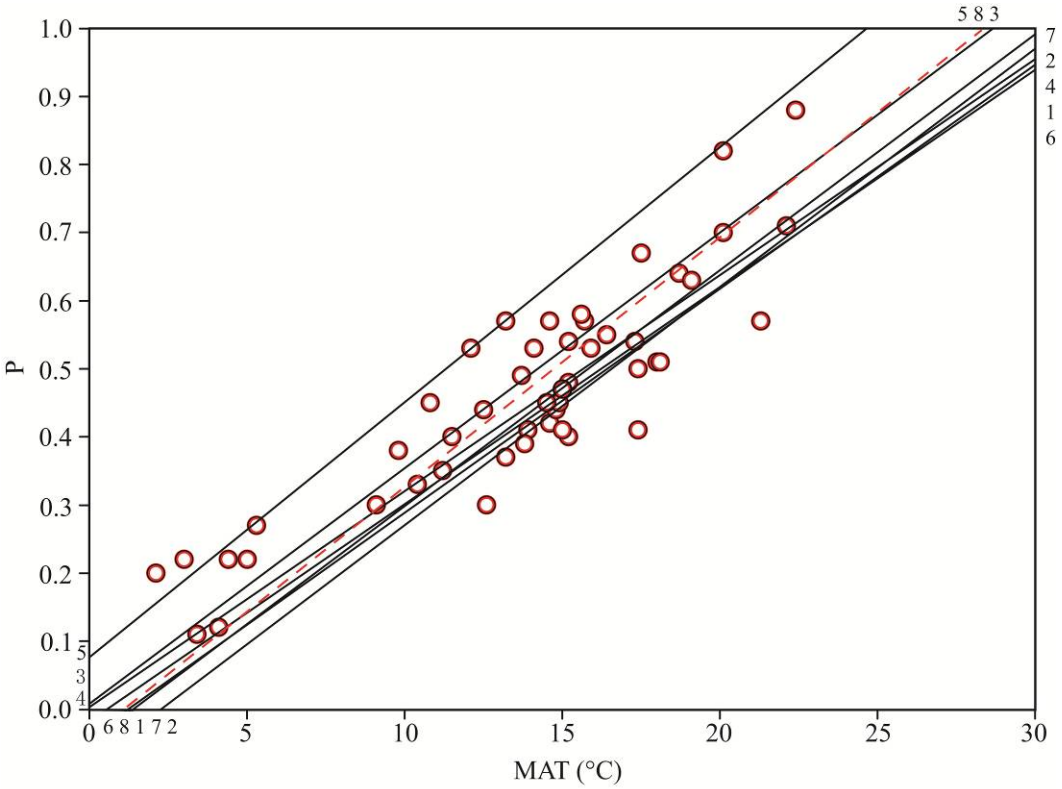

1 East Asia
2 North, Central and South America
3 North, Central America and Japan
4 South America
5 Australia
6 Europe
7 North, Central America
8 China (this study)

Fig. 1 Leaf Margin Analysis based on vegetations in China and other regions.

Palaeovegetations of South China during the Neogene

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With the ever-accumulated data, the Chinese palaeoclimates of the Neogene are better and better understood. Vegetations are strongly dependent on climates. Our study focuses on the Neogene palaeovegetations of South China, to be able to compare their evolution to past climate changes. The Integrated Plant Record (IPR) analysis was used to reconstruct the palaeovegetations. This method looks at the ecophenological type of the nearest living relative of the fossils. These components are: Conifer, Broad-leaved deciduous, Broad-leaved evergreen, Sclerophyllous, Legume-type, Palm, Mesophytic herbaceous, Dry herbaceous, Fern, Azonal woody, Azonal herbaceous, Aquatic. Azonal taxa are excluded from the analysis when reconstructing the vegetation types; therefore, only the zonal components are used in the vegetation classification. Six types of vegetation can be reconstructed: Broad-leaved deciduous forests, Mixed mesophytic forests, Broad-leaved evergreen forests, Subhumid sclerophyllous forests, Xeric open woodlands, Xeric grasslands or steppe. We gathered 72 palaeobotanical sites from the Neogene of South China, and separated them in five time periods: early Early Miocene, late Early – early Middle Miocene, late Middle Miocene, Late Miocene – earliest Pliocene, and Pliocene.

The reconstructed vegetations show a clear latitudinal gradient. The broad-leaved deciduous component is higher in northern regions whereas the broad-leaved evergreen component is higher is southern regions. This is congruent with the latitudinal temperature gradient previously reconstructed. The vegetation of South-East China is reconstructed as a broad-leaved evergreen forest throughout the Neogene. During the Early Miocene, the western regions are drier than the eastern ones. During the Late Miocene, there is no clear West-East aridity gradient. There is another aridification episode of the western regions during the Pliocene. During the Pliocene, there is also an increase of the broad-leaved evergreen component in South China, this indicates a warmer and moister climate. These vegetation changes are associated with the evolution of the monsoon system and the general cooling trends of the Neogene.

Late Pliocene climate based on Leaf Physiognomy from Tengchong, western Yunnan, China

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On the basis of leaf physiognomy of the Late Pliocene Tuantian megaflora from the Mangbang Formation of Tengchong County in Western Yunnan, a quantitative reconstruction of paleoclimate performed with Leaf Margin Analysis (LMA) methodology and the Climate–Leaf Analysis Multivariate Program (CLAMP). The latter produced the following parameters: mean annual temperature (MAT) from 17.2 to 17.7°C; warmest month mean temperature (WMMT) from 25 to 25.5°C; coldest month mean temperature (CMMT) from 9.5 to 10.8°C; length of growing season (GRS) from 9.5 to 9.7 months; growing season precipitation (GSP) from 1834.3 to 1901.2 mm; mean monthly growing season precipitation (MMGSP) from 222.4 to 230.5 mm; precipitation during the three consecutive wettest months (3-WET) from 892.1 to 917.8 mm; precipitation during the three consecutive driest months (3-DRY) from 474.5 to 512.8 mm; relative humidity (RH) from 76.7 to 77.8%; specific humidity (SH) from 10.7 to 10.8 g/kg; and enthalpy (ENTHAL) from 31.8 to 32 kj/kg. However, the MAT obtained from the Chinese LMA regression at 18.7°C, is slightly higher than that from CLAMP. The integrated analysis of those data and three adjacent pollen floras in western Yunnan suggest that the Gaoligong Mountains (a southern portion of the Hengduan Mountains) uplifted to only limited altitudes in the Late Pliocene.

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Rubus and *Sambucus* Endocarps from Pliocene Fudong Flora of Northwestern Yunnan, China

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Numerous well-preserved *Rubus* and *Sambucus* endocarps were described from the Pliocene sediments in Fudong Village of Lanping County, northwestern Yunnan, China. Endocarps of the genus *Rubus* are ellipsoidal or obovoid; often kidney-like in outline; strongly compressed; bilaterally symmetrical; 1.28 to 2.25 mm long and 0.67 to 1.3 mm wide; dorsal face curved; ventral face more or less straight; surface with reticulated ridges, and a straight, smooth seam along the symmetry plan. *Sambucus* endocarps are ellipsoidal or obovoid; symmetrical; laterally compressed; 2-3.5mm long and 1.6-1.8 mm wide; dorsal face convex; ventral face roof-like; surface distinctly transversally furrowed. Discussion on these *Rubus* endocarps are based on morphological comparisons with other genera of Rosoideae, and discussion on these *Sambucus* endocarps are based on morphological comparisons with the other two genera of Adoxaceae and some genera of Caprifoliaceae. It's the first discovery of endocarp fossils of *Rubus* and *Sambucus* in China. And their presence may indicate distribution of the two genera in northwestern Yunnan during Pliocene.

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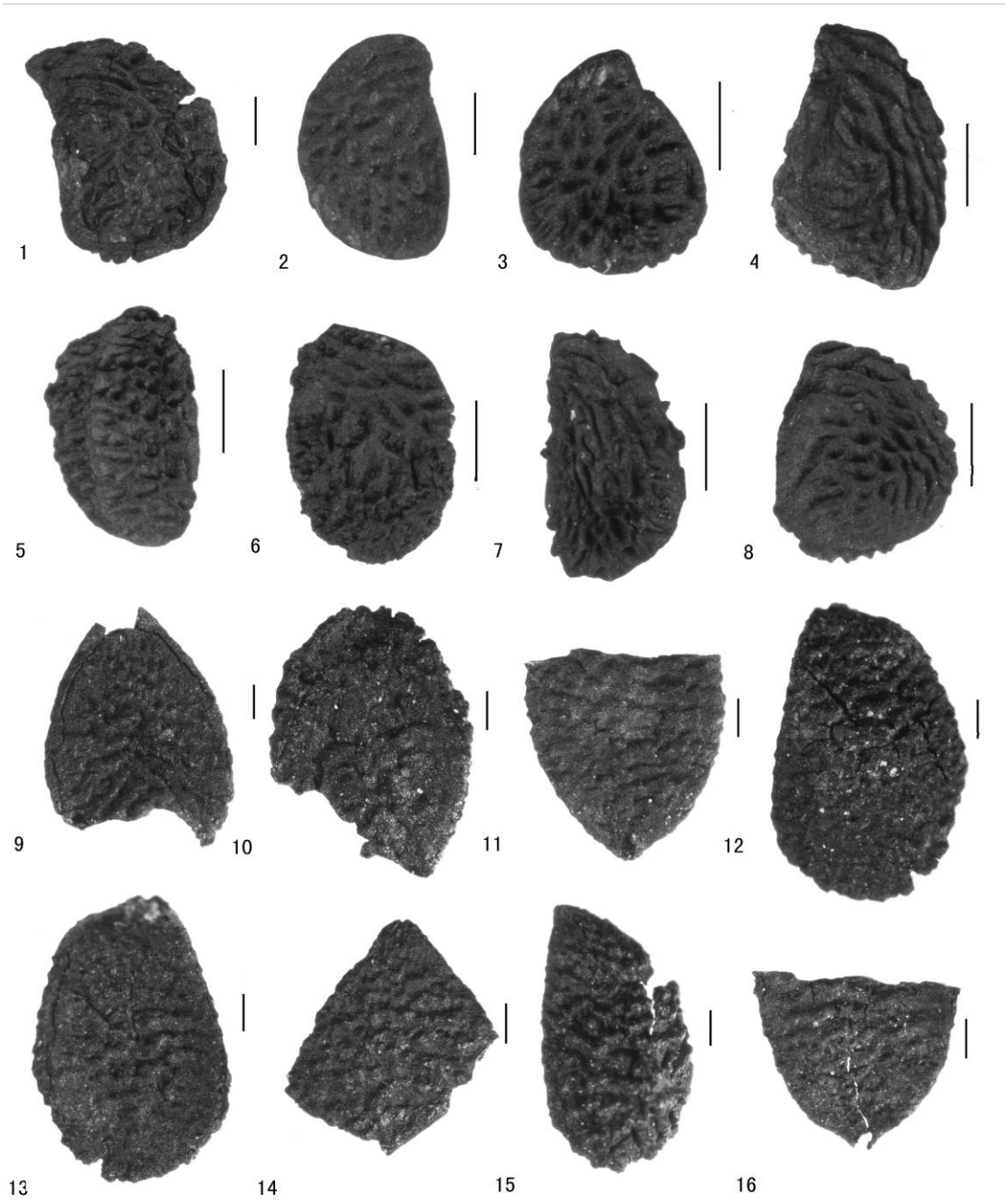

Plate 1. Endocarps of *Rubus* and *Sambucus* observed under dissecting microscope from the Pliocene Fudong Flora (scale bars=0.2 mm).

1-8. Endocarp fossils of *Rubus*.

7-16. Endocarp fossils of *Sambucus*.

Cuticular characters of Rhodoleia fossils from the Pliocene in SW China and their palaeoecologic implications

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The genus Rhodoleia Champion ex Hooker is one of the 31 genera in the family Hamamelidaceae. It today comprises of ca. 9 species (6 species in China) of evergreen trees or shrubs, which are distributed in Indonesia, Malaysia, Myanmar, Vietnam and South China ranging from 7º S to 27º N (Zhang et al. 2003; Zhang and Lu 1995). Mai (2001) have reported four fruit species of Rhodoleia from the European Upper Cretaceous, older and younger Tertiary. However, none of previous report of the fossil Rhodoleia in the Southeast Asia, which is the modern distributing center of this genus.

Thirteen well-preserved fossil leaves of Rhodoleia were discovered in the diatomitic sediments from the Late Pliocene to Early Pleistocene age at Tengchong County, Yunnan Province, Southwest China. The modern leaves of six Rhodoleia species were studied on the architectural and cuticular characters for the comparison with the fossil leaves. The fossil cuticles possess 5-6 polygonal epidermal cells, stellate trichomes, paracytic stomatal apparatus, and papillae in the epidermal cells. All of these characters are in accord with that of the modern leaves of Rhodoleia.Combining the leaf architectural and cuticular characters, the fossil leaves suggest the affinity within the genus Rhodoleia, particularly with R. championii.

The distribution of the modern Rhodoleia suggests that the genus lives under a warm climate with a mean annual temperature (MAT) from 15 °C to 27 °C and a mean annual precipitation (MAP) from 1000 mm to 2500 mm. Hence, the trees of R. tengchongensis in the Late Pliocene - Early Pleistocene might also live under a similar warm and humid climate. The relations between the aridity and the trichomes or papillaes in fossils were investigated through the comparison with the modern

Rhodoleia. Our results show that the xeromorphic features should not be used to indicate environmental aridity in the genus Rhodoleia.

The fossil fruits and seeds of Rhodoleia were first described by Mai and Walther (1985). The fossil records show that the genus of Rhodoleia maybe originated from Europe. Especially, the reliable fossil leaves of Rhodoleia from the Pliocene of West Yunnan in this paper supports a biogeograpic emigration successfully. Following the cooling of global climate after the Mid-Miocene Climatic Optimum (Zachos 2001), the trees of Rhodoleia as a "palaeotropical species" retreated to the tropical and subtropical zones of East and South Asia since the Miocene. Fortunately, the Southwest Yunnan which effected by the Indian and Asian monsoons and the obstruction to the Siberian cold current by the uplifted Tibet Plateau preserves a humid and warm climate almost in the whole Neogene (eg. Zhao et al. 2004; Xu et al. 2004, 2008; Wu et al. 2009). The rapid uplift of Tibet Plateau in the Late Pliocene to Pleistocene disconnected the affiliation between East Asia and Europe ultimately which resulted in the modern distributions of Rhodoleia.

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