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Surface Pollen Investigation for Pollen-Climate Relations along Altitudinal Transects across Subtropical to Lower Montane Zones (1950-3500 m a.s.l.) in Zhongdien, Yunnan Province, SW China

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Abstract Modern surface pollen is investigated for two altitudinal transects in the Zhongdien county, northwestern Yunnan province, SW China. The results from the lower part (1950-3500m a.s.l.) show a correspondence between vegetation and pollen assemblages of arboreal taxa except *Pinus* (*yunnanensis*-type). Although this route is rather associated with artificial pine and *Artemisia* populations, palynoflora shows subtropical evergreen broadleaved forest (SEBF) including *Lithocarpus*/ *Castanopsis* in 1950-2600m a.s.l. The transitional mixed zone in 2600-3050m above sea level is palynologically followed by a montane conifer forest (MonCF) of *Picea*, *Pinus*, *Abies* and *Betula* (3050-3500m a.s.l.) in accordance with vegetation zonation. *Quercus* (*Cyclobalanopsis*-type) alone is abundant not only in the lower SEBF zone but also in the upper MonCF zone probably originated from dwarf sclerophyllous oaks growing in the spruce forest, showing no correspondence to temperature variations along the altitudinal transects. The pollen-climate relations deduced from the surface results are provisionally applied to the published fossil pollen data from Xihu Lake near Er Yuan. Results of the application show a good analogy between the last glacial flora and the transitional zone (2600-3050m a.s.l.) of the present surface data, which provisionally suggests a glacial cooling of 4.2-6.9° C when based on a lapse rate of 0.65° C/ 100m.

Key words: palynology, Yunnan, China, surface pollen, climate change, LGM, tropics.

The role of the tropical Pacific for global climate changes is being focused (Cane, 1998; Clement and Cane, 1999; Lea, 2002). Particularly the interaction between the Tibetan landmass and the Warm Water Pool (WWP) in the western equatorial Pacific, which is a heat engine of the Asian Monsoon climate system, may regulate the Earth's climate via global climate teleconnection driven by the El Niño-Southern Oscillation (ENSO) that leads to regional alternating precipitation pattern in continental scales (An, 2000; Zhou *et al.*, 2001a; Sirocko, 2003; Fukusawa *et al.*, 2003). Repeated lead-lag analyses for phase relations between Greenland and Antarctica also pointed out the Southern Ocean as a likely trigger for millennial-scale climate changes (Blunier *et al.*, 1998; White and Steig, 1998; Blunier and Brook, 2001; Morgan *et al.*, 2002; Weaver *et al.*, 2003; Wunsch, 2003; Huybers, 2004; Taylor *et al.*, 2004), but any convincing physical mechanisms for the southern trigger hypothesis remain uncertain (Schmittner *et al.*, 2003; Stocker, 2003; Schmittner *et al.*, 2004). By contrast, a few recent palaeoclimate proxy records from the low-latitude Pacific regions have reported a warming which was as early as that of Antarctica through the last deglaciation (Seltzer *et al.*, 2002; Visser *et al.*, 2003), suggesting the leading role of the Tibet-WWP system as a trigger for at least orbital-scale deglacial warming. A possible mechanism that rapidly propagates the initial warming in the Tibet-WWP to distant regions is an atmospheric forcing via greenhouse gases (Cane and Clement, 1999; Denton, 2000). Tropic soils or swamps are the main sources of atmospheric N_2O and CH_4 that certainly accelerate the global warming (*e.g.*, Flückiger *et al.*, 1999), and the WWP is apparently a huge source of water vapour as the most important greenhouse gas.

In 1970-80's, an unimportance of tropics for global climate changes was believed on the contrary. This was based on anomalously small (ca. 1-2° C) reconstruction for the cooling at the Last Glacial Maximum (LGM) for tropical sea surface temperatures (SSTs) using old global climate models (GCMs) (CLIMAP, 1976; Gates, 1976; Manabe and Hahn, 1977; Prell, 1980). However, a growing body of evidence begins to suggest a larger LGM cooling centred in ca. 5-6° C for the equatorial Pacific, tropical Africa and Amazonia, based on climate proxies (Stute *et al.*, 1995; Colinvaux *et al.*, 1996; Thompson, 2000; Lea *et al.*, 2000; Seltzer, 2001; Porter, 2001; Visser *et al.*, 2003) and modified climate models (Webb *et al.*, 1997; Hostetler and Clark, 2000; Peltier and Solheim, 2004). Concerning the Tibetan Plateau, no smaller LGM cooling than in the tropical oceans is required from the following logical reasons. Firstly, the smaller thermal inertia of the Tibetan landmass leads to a larger cooling at the LGM than in the WWP. Secondly, the inactivity of the East Asian summer monsoon in glacial periods (An *et al.*, 1991a; Tada *et al.*, 1999; Zhou *et al.*, 2001b), which is fundamentally generated by anomalous heating of the plateau in summer, should be a consequence of anomalous summer cooling in Tibet than in the surrounding oceans. Thirdly, the LGM cooling on the Tibetan plateau should have been no smaller than that of the lowland Amazonia of 5-6° C (Stute *et al.*, 1995; Colinvaux *et al.*, 1996) because an El Niño-like pattern in LGM with decreased east-west SST gradients through the tropical Pacific (Stott *et al.*, 2002; Koutavas *et al.*, 2002) should most probably be shared by neighbouring continents.

One of the evidence against the tropic-trigger hypothesis is a series of palaeoclimatological records from the Yunnan province, SW China (Lin *et al.*, 1986; Sun *et al.*, 1986; Liu *et al.*, 1986; Walker, 1986). The Yunnan plateau (Fig. 1), located in the eastern margin of the Tibetan plateau, is subject to the Tibet-WWP interaction. The pioneering studies by Dr. Walker and his colleagues began with comprehensive descriptions for diversified Yunnan vegetation (Li and Walker, 1986), subsequently followed by fossil pollen analyses for sediment cores from Xihu Lake (26° N; 100° E; 1980m a.s.l.) near Er Yuan (Lin *et al.*, 1986), Dianchi Lake (25° N; 102° 40'E; 1886m a.s.l.) facing Kunming (Sun *et al.*, 1986) and Menghai (22° N; 100° 30'E; 1200m a.s.l.) in Xishuangbanna (Liu *et al.*, 1986). By comparing the fossil pollen variations with the vertical vegetation stratification, Walker (1986) finally addressed the LGM climate of the Yunnan plateau with his estimations 2.5-4° C (at Xihu) and 1-2.5° C (at Dianchi) cooler than today. Although their vegetation descriptions have been very complete, their reconstruction for glacial cooling is apparently too small, compared with recent findings from the (sub)tropical Pacific. A possible reason for this discrepancy is that they adopted an indirect, heterogeneous comparison between pollen and vegetation that can lead to larger error ranges. Otherwise, it may be that they were actually not free from the CLIMAP model result that remained dominant in 1980's depicting 'stable' tropics against global changes. Under the reconstruction with more stable temperature, Walker (1986) introduced 'significantly wetter' LGM conditions for Yunnan to explain the evidence of 1200m snowline depression in Yunnan and the Himalayas shown by Pu (pers. comm.).

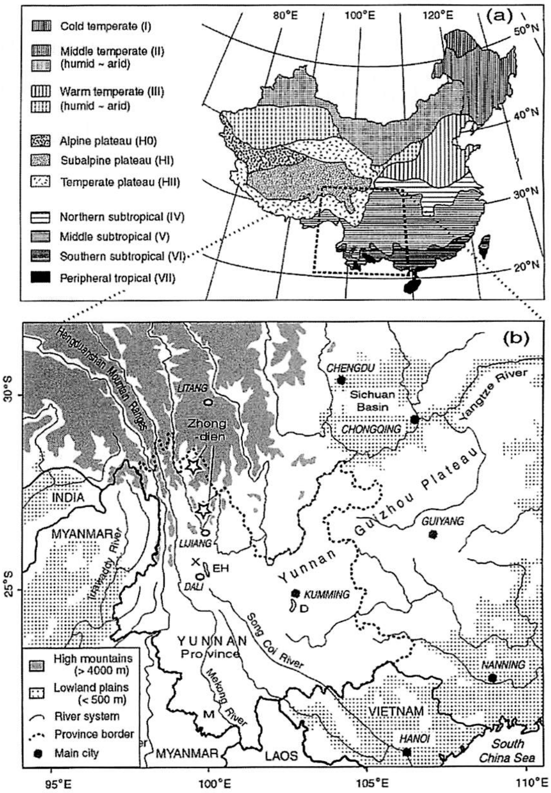

Fig. 1. Locality maps of studied area. (a) Inset with regional climate regimes of China (terms by Domrös and Peng, 1988); (b) Map of the Yunnan province. Codes X, D, M and EH denote core sites Xihu, Dianchi, Menghai and Erhai, respectively. Open stars denote the altitudinal transects studied in the Zhongdien county, Yunnan province, SW China.

In order to address this problem, the authors have performed since 1997 a collection of surface pollen series as well as new lake corings in the northwestern Yunnan province, as part of the Yangtze River Civilization Programme (1997-2001) organised by the International Research Centre for Japanese Studies (IRCJS). The surface pollen investigation, which can provide reliable pollen-climate relations via modern meteorological observations, has been intensively carried out particularly for the last decade worldwide (*e.g.*, Huntley and Prentice, 1988; Bonnefille and Riollet, 1988; Heusser, 1989, 1995; Gajewski, 1995; Xu *et al.*, 1996; Liu *et al.*, 1999; Bush, 2000; Takahara *et al.*, 2000; Tang *et al.*, 2000; Gotanda *et al.*, 2002; Igarashi *et al.*, 2003; Mao *et al.*, 2003; Okuda *et al.*, 2004). Moreover, recent developments of mathematical computing softwares (*e.g.*, Guiot and Goeury, 1996) permit quantitative palaeoclimate reconstruction with visualised statistical confidence regions (Nakagawa *et al.*, 2002, 2003). The Yunnan plateau itself is suitable for pollen-based palaeoclimate reconstruction for the low-latitude Asian continent because of (1) better preservation of natural vegetation than the northern Chinese territory; (2) large altitudinal variations covering subtropical to subarctic climate regimes; (3) large topographic variations leading to innumerable plant refugia that can minimise forest migration lags against climate changes. In this study, we provide the results of surface pollen analysis for two altitudinal transects (1950-3500m a.s.l.) in the Zhongdien county, NW Yunnan province, as part of the 2001-2002 overseas expeditions of the Natural History Museum and Institute, Chiba, as well as an application to a published fossil pollen record from Xihu Lake (Lin *et al.*, 1986). Other surface results and palaeoclimate reconstruction based on our own fossil results will appear in separate articles.

Geographical Configrations for the Yunnan Plateau

1. Topography

High mountains of the northwestern Yunnan province (~5000-6000 m a.s.l.) geomorphologically constitutes the southeastern margin of the Qinghai-Xizang (Tibetan) plateau, cultivating large rivers of southern China and Southeast Asia (Yangtze, Mekong, Song Coi, Salween, *etc*). The Yunnan (-Guizhou) plateau is a peripheral, deeply dissected landmass that rapidly gives way to tropical rainforest of Southeast Asia within a few degrees in latitude. This steep topographic variations lead to a great variety of local temperatures being equivalent to the extent in 25-45° N of East China. An oceanic climate in the south of the province is replaced by a continental climate with seasonal precipitation in the northwest, whereas the thermal contrast between summers and winters is less significant because of the subtropical highland situation. These conditions produce diversified vegetation and soils particularly in the western part.

2. Climate

The climate of the Yunnan province spans the Peripheral tropical zone to the Subalpine plateau zone (terms summarised by Domrös and Peng, 1988) (see Fig. 1a). The Yunnan plateau (ca.1500-3000m a.s.l.) basically belongs to the Middle subtropical zone (V) together with south-central China between the Yangtze river and the Nanling mountain ranges. The threshold climate values of the zone are 2-12° C in January, 15-22° C in July and 800-1300mm/y of precipitation in average (Figs. 2a-d), so this zone is thermally equivalent to the warm-temperate zone of the Japanese archipelago. Nevertheless, the small seasonal temperature contrast between cool summers and mild winters with weak frosts characterises the subtropical plateau climate. Southern hills in and around Xishuangbanna (<ca. 1500m a.s.l.) belongs to the Southern subtropical zone (VI) of South China, with typical subtropical climate of ca.12-16° C in January and 22-28° C in July as well as more than 1200-1400mm mm/y of precipitation. Valley spaces along the Mekong and Song Coi rivers (<400-500m a.s.l.) belongs to the Peripheral tropical zone (VII) with completely frost-free winters (>16° C in January). In the north, mountain slopes in the NW Yunnan province (ca. 3000-4000m a.s.l.) belong to the Temperate plateau zone (HII) of the peripheral Qinghai-Xizang (Tibetan) plateau. The climate values are 2~ -6° C in January, 10-15° C in July and ca. 600-800mm/y of precipitation so this zone is similar to the boreal (subarctic) climate zone of northern Asia. At the Garze station (31° 38′ N; 99° 59′ E; 3393m a.s.l.) for example, the number of frost days amounts to 147.5 per year. Mountain summits above 4000m a.s.l. belong to the Subalpine plateau zone (HI) of the central Tibetan plateau, with temperatures less than -6° C (January), <10° C (July) and <2° C (annual mean). Moisture conditions are generally worse in the northwest and the precipitation is probably 400-600mm / y (*i.e.*, subhumid) (Figs. 2d-e), although exact values are lacking because meteorological stations are restricted below 4500m a.s.l. The permanent snowline appears at ca. 5000m a.s.l. in NW Yunnan mountains similarly to the southern slopes of Himalayas, being at least 1000m lower than in the central Tibetan plateau with less moistures (Domrös and Peng, 1988; Zhang and Lin,

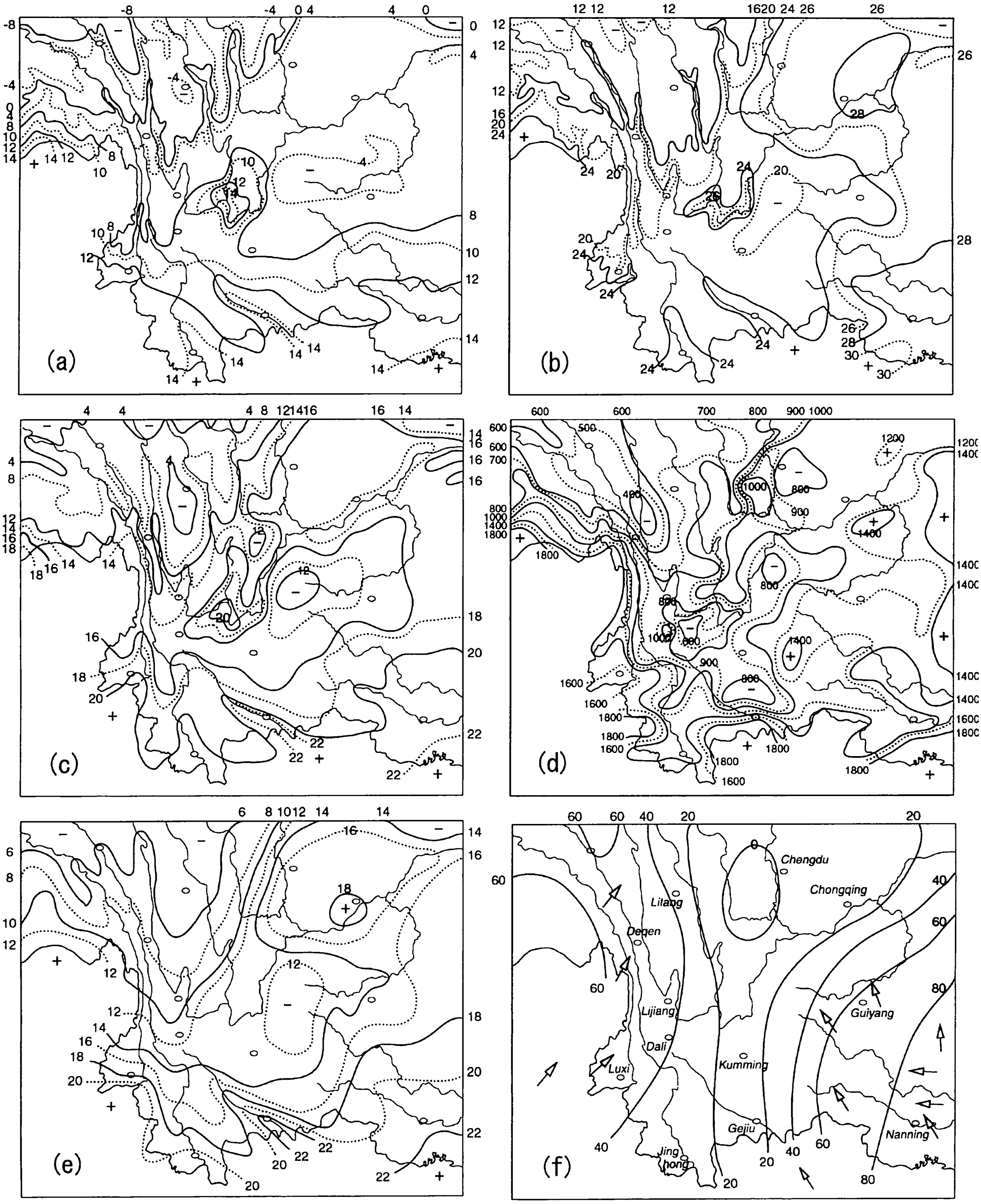

Fig. 2. Geographical properties for the Yunnan Plateau. (a) January mean temperature (℃); (b) July mean temperature (℃); (c) Annual mean temperature (℃); (d) Annual precipitation (mm); (e) Water vapour pressure; (f) Monsoon indices (illustrations after Domrös and Peng, 1988; Zhang and Lin, 1992)

1992).

Seasonality is more significant in precipitation than in temperature in Yunnan province due to the monsoon climate system. The monsoon index, which represents the difference of strength and frequency of seasonal alternating winds between July and January (Domrös and Peng, 1988), shows the minimum values in the Sichuan basin to the central Yunnan plateau, indicating that these areas constitutes a boundary region between the East Asian and the Indian monsoon systems (Fig. 2f). To the east, the Guizhou province and East China are dominated by both developed summer and winter monsoonal winds that provide rainfalls in the form of the polar front. To the west, the western Yunnan province are subject to the Indian summer monsoon from the Bay of Bengal that is responsible for the precipitation up to 2000mm/y. Most of the rainfalls occur between May to September, in contrast to dry seasons between November to March. Cluster analyses for precipitation pattern of Yunnan illustrates the analogy with those of the Sichuan province, the southern margin of the loess plateau to the Shandong peninsula, which are located south of the summer monsoon front being sensitive to the front migrations. On the central Yunnan plateau along a narrow N-S 'corridor', precipitation is lower (ca. 800-900mm/y) with a local rain shadow of <600 mm/y near Dukou (Fig. 2d). The rainfall seasonality is common in the northwestern mountain slopes also, and above 3000 m a.s.l., sparse winter precipitation mostly occurs as snows (Domrös and Peng, 1988; Zhang and Lin, 1992).

3. Temperature lapse rate

In western inner China, altitudinal temperature variations show significant local divergence in both coordinates and elevation, and many of written lapse rates need reconfirmation with references to local meteorological stations. The thermal effect of the elevated Tibetan plateau landmass, which behaves as a massive heat source to the Earth's climate, is also significant in regional scales, providing relatively mild climate to the plateau surface despite the high elevations. For example, the Lhasa station (29°42′ N; 91°8′ E; 3658m a.s.l.) with observed values of -2.3°C (January), 14.9°C (July) and 7.4 (annual mean) provides a temperature lapse rate as low as 0.15-0.3°C/100m, when compared with the neighbouring Nyingchi station (29°34′ N; 94°28′ E; 3000m a.s.l.) with temperatures of 0.2°C (January), 15.6°C (July) and 8.6°C (annual mean) (Domrös and Peng, 1988). Although local differences are large, Domrös and Peng, (1988) have proposed an averaged lapse rate of 0.5 °C/100m for inner China based on the integration of 82 meteorological stations located more than 1000m a.s.l. However, it seems that the thermal effect is not actualised on the isolated NW Yunnan mountains with the lapse rate of 0.65°C/100m for annual mean temperature, at least for the elevations of 2000-4000m a.s.l. (Fig. 3a). Different altitudes show different lapse rates, and lower hills of southern Yunnan (ca. 500-1500m a.s.l.) seem to show lowered lapse rates. Such differences are present between seasons also, with lapse rates of 0.5°C/100m for July while amounting to 0.75°C/100m for January (Fig. 3b) although the stations are restricted in number.

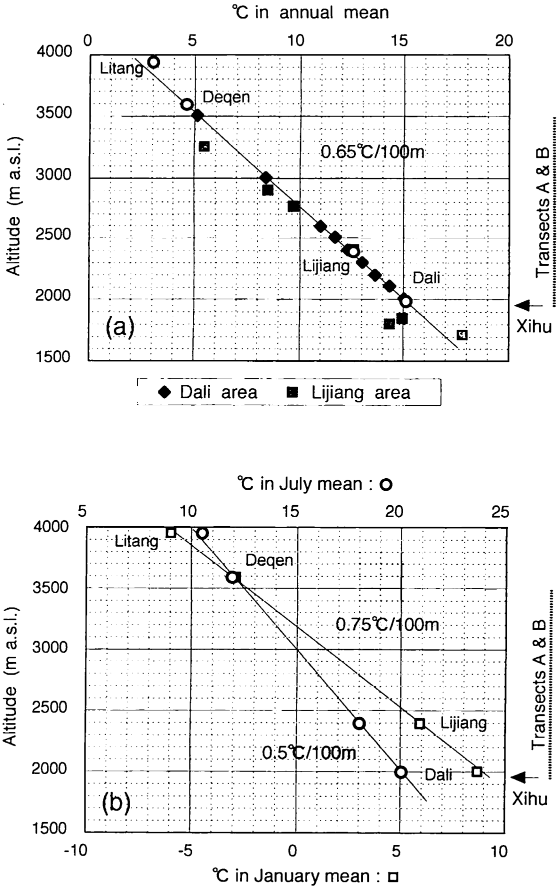

Fig. 3. Temperature lapse rates for western Yunnan plateau and mountains. (a) Annual mean temperature; (b) January and July mean temperatures. (Data from Editorial Board for Dali Municipality, 1998; Editorial Board for Lijiang Municipality, 2001).

4. Vegetation

The natural vegetation of the Yunnan province is very diversified consisting of 240 families (ca.13,000 species) but is dominated by evergreen taxa of gymnosperms and angiosperms, lacking deciduous broadleaved forest zone due to the relatively small seasonal temperature contrast (≤ 12° C). Human influences are smaller compared with other Chinese provinces, with pollen records hardly disturbed except for the last centuries. Currently, natural coniferous vegetation survives in northwestern mountains as well as fragmentary rainforest patches in southwestern lowlands (Fig. 4a). Major vegetation types with the codes of TEF, TS-EF, SEBF, SESF, SCF, MonCF, MonSh, MonMea, *etc* (defined by Li and Walker, 1986) are altitudinally zonated (Fig. 4b).

TEF (Tropical evergreen rainforest) consists of tall evergreen trees 30-40m and rarely 60m high of Dipterocarpaceae, Lecythidaceae, Myristicaceae, Lauraceae, Moraceae, Meliaceae, Euphorbiaceae, Sapindaceae, Sapotaceae, Palmae, *etc.* This forest type occurs the river valleys of Mekong, Song Coi, Salween, *etc* (<500m a.s.l.) with wet and hot climate all year round under the influence of Pacific air mass. The overlying 500-1500m a.s.l. zone is occupied by Montane TEF containing some subtropical species, or Seasonal TEF where precipitation level is lower. When the seasonality is significant with rainy summers and dry winters, TS-EF (Tropical semi-evergreen monsoonal forest) less than 25m high in canopy occur in 500-800m a.s.l. This forest type contains abundant deciduous components (Ulmaceae, *etc*), showing a floristic analogy to the Indian monsoonal forests.

The major part of the Yunnan plateau belongs to SEBF (Subtropical evergreen broadleaved forest) occupying 1500-2700m a.s.l. comprising a few subtypes (SESF, SMBF, *etc*). This forest type is dominated by evergreen trees of Fagaceae (*Lithocarpus, Castanopsis, Quercus, etc*), Theaceae, Lauraceae, Magnoliaceae, Araliaceae, Aquifoliaceae, Elaeocarpaceae, Juglandaceae, Hamamelidaceae, Mysinaceae, *etc.*, containing conifers (*Keteleeria evelyniata, Cupressus, etc*) and some deciduous angiosperms (*Quercus griffithii, Q. aliena, Alnus, Albizia, etc*). On the slopes or valley floors of 1800-3150m a.s.l. with warm, humid conditions, SEBF gives way to subtropical deciduous alder forest of *Alnus nepalensis*, which partially dominates local vegetation. Similarly, some limestone hills of 1500-2000m is locally occupied by subtropical mixed deciduous-evergreen broadleaved forest (SMBF) of *Cyclobalanopsis glaucoides* and *Quercus acutissima* associated with *Carpinus, Celtis, Aphananthe, Ulmus, Zelkova, Viburnum, Rhamnus, etc.* Nevertheless, neither the typical deciduous broadleaved forest nor deciduous-evergreen mixed forest of central China reaches the subtropical highlands.

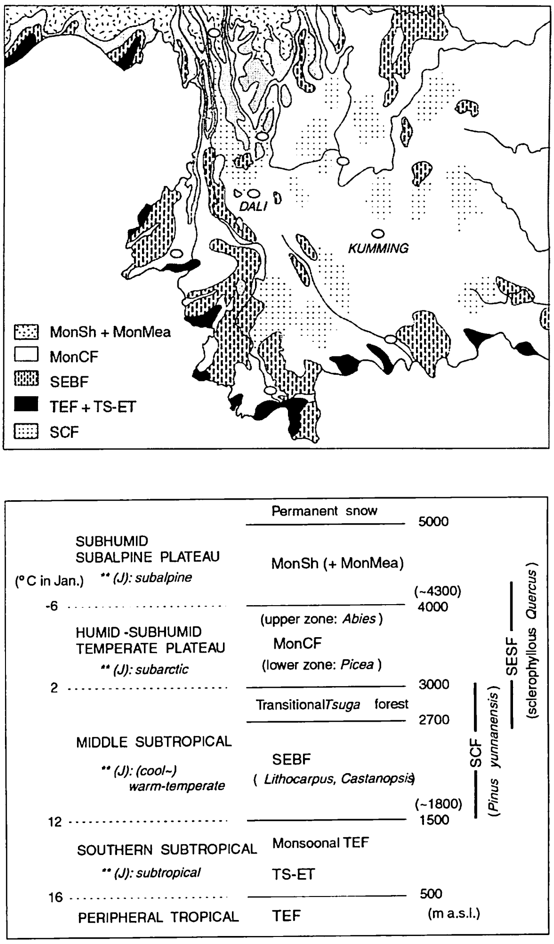

Fig. 4. Vegetation of the Yunnan, SW China. (a) Present vegetation distribution (data and codes from Li and Walker, 1986). (b) Schematic vertical distribution (Li and Walker, 1986) with parallel climate zonation (Domrös and Peng, 1988). Note that these features are very simplified excluding frequent local variations. Double asterisks denote corresponding climatological terms in the Japan archipelago.

In 2700-3000m (or 3100m), transitional mixed forest of *Tsuga dumosa* occurs above the SEBF. The *Tsuga* forest is associated with other montane elements (*Abies, Picea, Pinus, Betula, Quercus, Rhododendron, etc*) and subtropical species (*Castanopsis, Cyclobalanopsis, Alnus, Schima, Machilus, Exbucklandia, etc*). Above this transitional zone, typical MonCF (montane conifer forest) of *Picea likiangensis* occur in 3100-3800m a.s.l. The spruce forest with *Abies* reaches 20-30m high in canopy, associated with *Salix, Betula, Rhododendron, Rosa, Rubus, etc* in understories. *Picea brachytyla* is abundant in the lower montane zone (3100-3500m a.s.l.) near Zhongdien or Deqen where rainfalls exceeds 1400mm/y. *Pinus densata*, relatively thermophilous and drought-tolerant montane conifer, is also a major component in 3000-3400m a.s.l., being more important particularly in the Hengduanshan mountain ranges. In the upper MonCF zone (3500-4000m or sometimes~4300m a.s.l.), the spruces and pines partially gives way to *Abies georgei* associated with *A. forestii, Picea likiangensis, Larix potaninii, etc* under more extreme climate. *Larix* grows in 2700-4000m a.s.l. but in most cases is secondary trees growing after destruction of the spruce or fir forest. *Sabina* (*S. saltuaria, S. pingii, S. recurva, etc*) occurs on sunny slopes in 2400-4500m a.s.l. as a heliophyte. Concerning broadleaved species, pioneer birches constitute secondary *Betula* forest (subtropical deciduous birch forest) after the destruction of MonCF particularly in 3200-3500m a.s.l. in the northwest.

Above the timber line at ca. 4000m a.s.l., MonSh (Montane shrubland) is formed by various conifers and evergreen coriaceous or broadleaved angiosperms (*Rhododendron, Sorbus, Sabina, Salix, Cotoneaster, Berberis, Deutzia, Sinarundinaria, etc*) as low cushion plants that are tolerant to snows in winters and winds all year round. Herbaceous taxa (*Kobresia, Caltha, Sanguisorba, Potentilla, Polygonum, Androsace, Anemone, Stipa, Festuca, etc*) constitutes MonMea (Alpine meadow) forming a mosaic landscape together with the MonSh. In the upper part of the zone, the vegetation becomes sparse replaced by permanent snows above 5000-5100m a.s.l.

In the central Yunnan plateau with dense habitation, the stratification of natural vegetation has been altered, replaced by secondary vegetation types. SCF (Subtropical conifer forest), vegetation type currently widespread in the Yunnan plateau nearly superimposing the SEBF in altitude (*i.e.*, 1500-2800m or~3000m a.s.l.), is more or less secondary except for some undoubtedly natural cases. *Pinus yunnanensis* prefers to dry, infertile soils forming forest with poor stratification with *Cyclobalanopsis delavayi* in 1500-2800m above sea level of the central plateau, associated with *Quercus, Castanopsis, Lithocarpus, Alnus, Rhododendron, Vaccinium, Rubus, Coriaria, Keteleeria, etc.* In 2500-3000m a.s.l. of the northwest, *P. yunnanensis* coexists with sclerophyllous *Quercus* (*Q. longispica, Q. guayavaefolia, Q. pannosa, Q. rehderiana, Q. monimotricha, etc*). The 2500-3000m zone also holds *Pinus armandi* (*Haploxylon*-type) forest on shady slopes with moisture and relatively low temperature. In southern Yunnan (<25°S), *Pinus kesiya* occurs on valley slopes in 1000-1900m a.s.l. *Keteleeria evelyniana* grows in warm sunny places in 1800-2300m a.s.l., frequently mixed with evergreen broadleaved trees such as *Castanopsis delavayi* and *Cyclobalanopsis glaucoides. Cupressus* (*duclouxiana, etc*) grows on calcareous soils in 2000-3000m a.s.l. rarely with *Juniperus formosana.* SESh (Subtropical evergreen shrubland) of *Homonia, Syzygium, Viburnum, Zanthoxylum, etc* occupies open spaces in very lowlands. *Pistacia* and *Engelhardtia* grow amongst limestone rocks in 1000-1500m a.s.l. together with *Rhus, Coriaria, etc.* Higher locations (1900-2400m a.s.l.) are inhabited by *Myrsine* and *Berberis.* SMSh (Subtropical mixed deciduous-evergreen shrubland) is also a common secondary vegetation type on the central Yunnan plateau. This corresponds to deteriorated soil conditions with intense human disturbance in the past. Together with various shrub and herb species, *Pteridium* is dominant that produces trilete-type spores.

SESF (Subtropical evergreen sclerophyllous forest) is seen in the slopes of the Jinsha river with both dry and cold winters that create the small, coriaceous leaf forms. Montane sclerophyllous oak forest (2600-4300m a.s.l.) is dominated by *Quercus aquifolioides* with *Sorbus, Rhododendron, Lonicera, Spiraea, Rosa, Sinarundinaria, etc.* This vegetation type probably adjusts to heavy winter frost and snows (4 ~ -8° C of January mean temperature; <700-900 mm/y of rainfalls). Valley sclerophyllous oak forest in lowland rain shadows (1000-2000m a.s.l.) is dominated by *Quercus cocciferoides* associated with *Q. franchetii, Q. rehderiana, Cyclobalanopsis glaucoides, C. delavayi, Paliurus orientalis, Pistacia weinmannifolia, etc* (Wu, 1980; Li and Walker, 1986).

Materials and Methods

The field research and sampling are carried out for transect A (27° 12′ 51″ – 27° 28′04N″; 100° 2′ 1″ – 99° 53′ 21″E; 1950-3150m a.s.l.) and transect B (28° 23′ 33″ – 28° 20′ 49N″; 99° 45′ 57″ – 99° 46′ 16″E; 3050-3500m a.s.l.) along the Jinsha river in the eastern part of the Diqing Zang Autonomous Prefecture (northwesternmost Yunnan province) (Fig. 5). The transect A roughly corresponds to SEBF to transitional mixed vegetation zones (*i.e.*, Middle subtropical climate zone), whereas the transect B reflects the MonCF vegetation zone (*i.e.*, Temperate-plateau climate zone). Based on the lapse rates in Figure 3, temperature ranges for the two transects are -2.5~9° C (January), 12.5~20° C (July) and 5-15° C (annual mean) altogether. Precipitation is approximately 600-800mm/y based on Fig. 2d. Observed vegetation generally

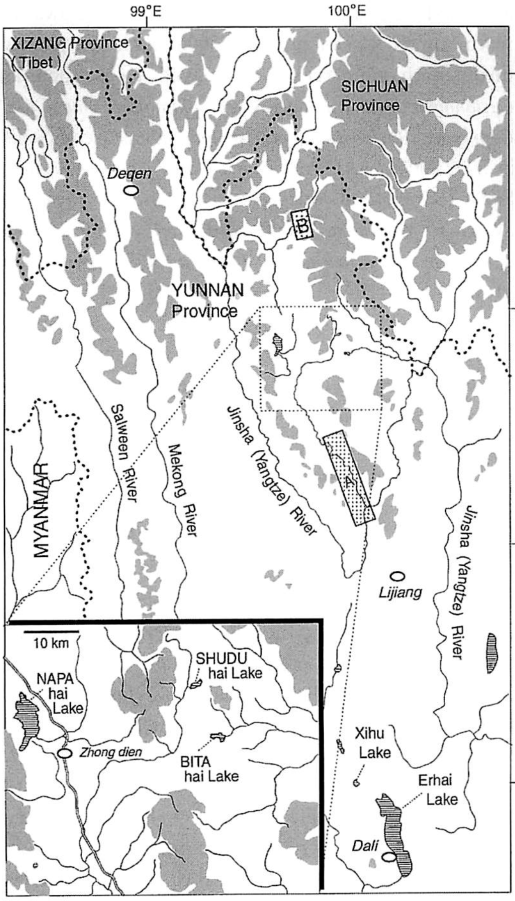

Fig. 5. Map of the study sites, northwestern Yunna province, China. Shaded areas denote mountains > 3000m a.s.l. Dotted rectangles denote altitudinal transects studied.

agrees with the description by Li and Walker (1986), but sclerophyllous oaks were characteristic in the understories of spruce forest. In lower-altitude zones, vegetation preservation was worse with sparse SEBF assemblages, whereas being better in higher altitudes with dense MonCF forest near 3500m a.s.l. The surface materials consisted of moss polsters collected from open spaces outsides the forests, containing underlying soils. The sample sizes were 5-10 grams each (dry weight).

Pretreatment of the pollen analysis was performed in the pollen laboratory of IRCJS using the standard KOH-acetolysis method (Moore *et al.*, 1991). A brief wet sieving was added after the KOH treatment to remove moss tissues and macroscopic charred fragments. More than 200 grains of arboreal pollen (except *Pinus yunnanensis*-type) plus *Artemisia* were counted for each sample, used as the pollen sum for percentage calculation. For pollen identification, collected wild flowers were similarly pretreated with extracted living pollen mounted. The modern pollen slides were numbered mo-168 to -202, preserved in the Natural History Museum and Institute, Chiba. For pollen identification, published pollen atlases by Huang (1972), Academia Sinica (1982) and Wang *et al.* (1997) were consulted as supplements.

Results and Discussion

Results of surface pollen analysis is shown in Figure 6. The spectra are largely occupied by *Pinus yunnanensis*-type (*i.e., Diploxylon*-type), but exclusion of the pines from the pollen sum leads to an altitudinal pollen zonation that is consistent with the parallel vegetation stratification. The SEBF vegetation zone (<2700m a.s.l.) is heavily disturbed with abundant *Artemisia* pollen, but *Lithocarpus/Castanopsis* show sporadical abundance (5-10%) in 1950-2600m a.s.l., showing discernible SEBF palynoflora. The abundance of *Alnus* and *Juglans/Pterocarya* reflects local alder forest and/or secondary forest on the way of succession from bared soils. The transitional mixed vegetation zone (2700-3100m a.s.l.) is palynologically expressed by decreases of broadleaved trees except *Quercus*, replaced by various montane conifers such as *Pinus armandi*-type, *Picea, Abies* and *Tsuga* in ca. 2600-3050m, though the upper limit is not clear. The MonCF vegetation zone (>3000m a.s.l.) is palynologically expressed by the decreases of herbs replaced by *Picea* and *Abies* in >3050m a.s.l. The abundant *Pinus yunnanensis*-type pollen may originated from *P. densata* in this altitude. In additions to the conifers, this pollen zone is associated with *Betula* and Ericaceae (probably *Rhododendron*).

The stable high values (10-20%) of *Quercus* (*Cyclobalanopsis*-type) regardless of altitudes deserve attentions. Above 2600m a.s.l., these oaks are hardly the elements of the SESF (Li and Walker, 1986), and according to our field observations, sclerophyllous oaks of less than 2-3m tall grow abundantly not only in the subalpine shrublands (>4000m a.s.l.) but also in montane spruce forests. This dwarf evergreen oaks, which adjust to winter frosts and snows (Li and Walker, 1986), could logically expand southward during the last glaciation, prevailing the Yunnan plateau. In the Yunnan province, therefore, the abundance of the evergreen-type oak pollen does not necessarily indicate the persistence of warm climate nor SEBF vegetation.

The pollen-climate relations induced from the surface results are subsequently applied to a fossil pollen

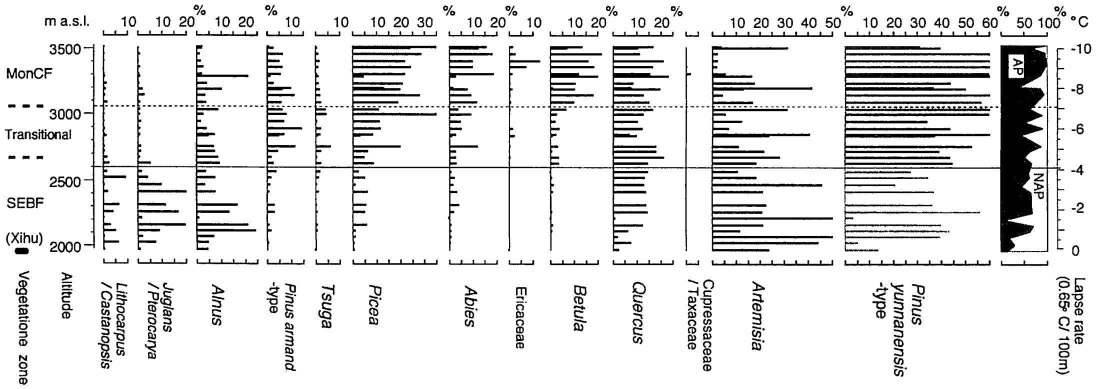

Fig. 6. Results of surface pollen analysis for two altitudinal transects in Zhongdien, Yunnan province, SW China. *Pinus yunnanensis*-type is excluded from the pollen sum. A filled ellipse in the left end denotes the elevation of Xihu Lake. The temperature lapse rate in the right hand is for the annual mean temperature. The AP consists of arboreal pollen except *Pinus yunnanensis*-type. The NAP consists of *Artemisia*, Poaceae, Chenopodiaceae, Asteraceae, Caryophyllaceae, Brassicaceae, Polygonaceae, Umbelliferae, Ranunculaceae, *etc.*

record (Lin *et al.*, 1986) from Xihu Lake (1980m a.s.l.). The 6-13m part of the 13m core (Xi Hu7), covering ca.10,000-17,000 BP yielding abundant pollen of *Picea* and *Quercus* (*Cyclobalanopsis*-type) with little *Betula* (Fig. 7), correlates with the transitional zone (2600-3050m a.s.l.) of the surface results. Under 0.65° C/100m of the lapse rate(see Fig. 3), the above altitudinal difference is equal to a cooling of 4.2-6.9° C in annual mean temperature, exceeding the '1-4° C' suggested by Walker (1986). His estimation is equal to 200-800m of upward vegetation migration based on 0.5° C/100m which he apparently adopted at that time, deducing that he considered the both Xihu and Dianchi (1886m a.s.l.) never went across the upper limit of the SEBF zone even in the LGM. It is possible that they misinterpreted the abundant *Cyclobalanopsis*-type pollen as persistent SEBF vegetation and in turn persistent LGM warmth. The same holds for Dianchi, and its glacial palynoflora with abundant *Cyclobalanopsis* lacking *Castanopsis* (Sun *et al.*, 1986) likewise resembles the transitional zone rather than the SEBF zone of the surface results. When the missing of 20,000-17,000 BP interval (*i.e.*, the LGM) from all the Xihu, Dianchi and Menghai records are taken into consideration, it is also possible that our estimation is no more than a minimum value for likely LGM cooling on the Yunnan plateau.

For reliable temperature reconstruction based on past vegetation migration, it is important to examine a possible drought as another factor against tree growth. The modern precipitation level on the Yunnan plateau is actually no more than 800-900mm/y, not being completely free from aridity if precipitation would have been significantly lowered during the glaciations. However, no drier LGM conditions than today have been resulted for at least the western Yunnan province to southern Himalayan slopes (Fig. 8), which belong to the Indian monsoon regime with persistent moistures from the Bay of Bengal even in glacial periods. The source of the arguments was also Walker (1986), and he even thought that the LGM climate was 'significantly wetter' in these region be-

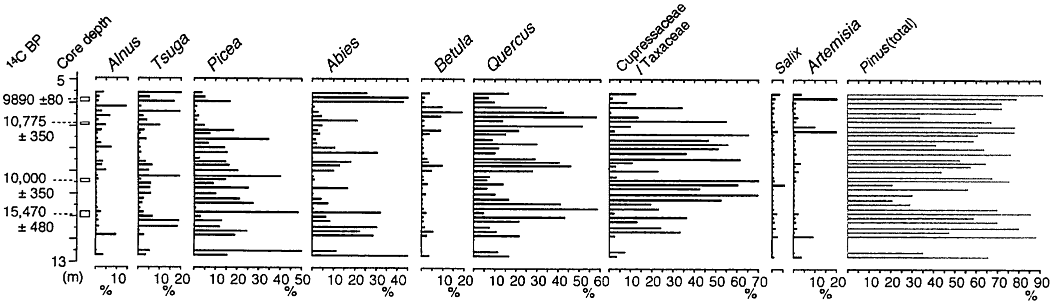

Fig. 7. Fossil pollen diagram from Xihu Lake near Er Yuan (Lin *et al.*, 1986), west-central Yunnan province, SW China. The diagram has been completely redrawn in accordance with Figure 6.

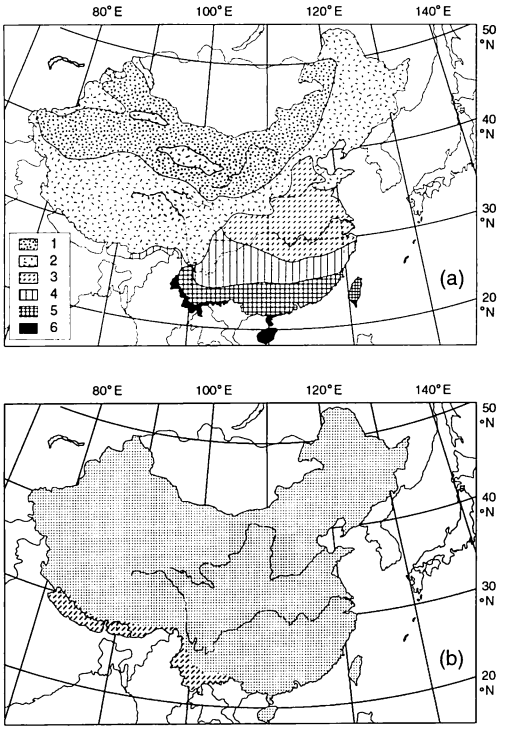

Fig. 8. The LGM environments for China. (a) Palaeovegetation. 1: desert, 2: desert steppe, 3: semi-arid steppe, 4: mixed forest, 5: evergreen forest, 6: (sub)tropical forest. (b) Moisture conditions. Shaded: drier than at present. Hutched: no drier or possibly wetter than at present. (after An *et al.*, 1991b; Winkler and Wang, 1993)

cause of (1) 1200m of snowline depression at LGM in western Yunnan to southern Himalayan mountains (see Derbyshire *et al.*, 1991); and (2) the occurrence of *Dacrydium* and *Dacrycarpus* pollen in ca. 30 ka at Menghai that are exotic podocarps with their closest modern localities in Myammar or the Hainan Island (Liu *et al.*, 1986). The former evidence, which is certainly larger than in the central Tibetan plateau (Kaufmann and Lambeck, 1997) but agrees to those of tropical mountains in Andes, East Africa and New Guinea (Seltzer, 2001; Porter, 2001), can therefore be explained to temperature decreases rather than moisture increases based on our surface results. The 1200m snowline depression is equal to 7.8°C of cooling when based on 0.65°C/100m of lapse rate. The glacial cooling of 4.2-6.9°C is better concordant with the 7.8°C, and can create the snowline migration when associated with a slight moisture increase. This 'no drier' LGM conditions in the southern Tibetan margin do not conflict with the *Dacrydium* and *Dacrycarpus* evidence. Worldwide, a 'humid LGM tropic' hypothesis is being supported by the rainforest (not a grassland) evidence from the Indonesian Sunda Shelf that emerged in 18-20ka (Sun *et al.*, 2000; Bush, 2002; Visser *et al.*, 2004) and from the lowland Amazonia (Colinvaux *et al.*, 2000; Cowling *et al.*, 2001; Baker *et al.*, 2001a, b).

Conclusions

The surface pollen spectra from two altitudinal transects (1950-3500m a.s.l.) in Zhongdien (NW Yunnan), southeastern margin of the Tibetan Plateau, show the vertical zonation of arboreal palynoflora that is correlative with parallel vegetation stratification. A significant consequence of the present results is the abundance of *Quercus* (*Cyclobalanopsis*-type) pollen not only in the SEBF zone (2000-2700m a.s.l.) but also in the upper (transitional to MonCF) zones in 2700-3500m a.s.l.. This means that in Yunnan province evergreen oaks cannot be the indicator of temperature and that their presence does not necessarily indicate warm climate conditions.

A comparison with the fossil pollen record from Xihu Lake (Lin *et al.*, 1986) showed that the glacial palynoflora with abundant *Cyclobalanopsis*-type and *Picea* is correlated with the transitional mixed zone (2600-3050m a.s.l.) of our surface data, provisionally suggesting 4.2-6.9°C of glacial cooling based on 0.65°C/100m of lapse rate. This is significantly larger than the 1-4°C by Walker (1986), being consistent with recent emerging evidence for unstable tropics (*e.g.*, Porter, 2001; Visser *et al.*, 2003). The discrepancy possibly originated from a misinterpretation of evergreen-oak pollen, under the influence of CLIMAP model results in 1970's illustrating stable tropics against global changes. Nevertheless, it is not possible yet to conclude decisive LGM cooling in Yunnan, because (1) the fossil pollen data were presented by different analysts in different ways (subdivision of *Pinus*, identification of hardwoods, *etc* are at least different); (2) no mathematical check for statistical error range evaluation has been performed and (3) all the referred fossil pollen data from Yunnan lack the 20,000-17,000 BP period that exactly comprises the LGM.

In order to address the above problems, the authors currently progress fossil pollen analyses for sediment cores from Erhai Lake (26°N; 100°E; 1940m a.s.l.), together with satellite montane lakes (Bitahai, Napahai and Shuduhai) (see Fig. 5) as our subsequent palynological works in the Yunnan province. The 42m-long Erhai core drilled in 1999 covers the past ca.100,000 years, being physically and geochemically analysed. The present surface results up to 3500m a.s.l. can potentially detect ~10°C of cooling at Erhai. Moreover, the Erhai region presently enjoys local precipitation anomaly exceeding 1000mm per year (Fig. 2d), which guarantees more freedom from possible droughts in glacial environments.

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中国雲南省北西部中旬地域における表層花粉調査

—標高トランセクトによる花粉と気温の相関—

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要　旨　中国雲南省北西部山岳地帯（標高 1950-3500m）の 2 本の標高トランセクトに対して植生・土壌等の現地調査をおこなうと同時に，採取した表層試料（土壌またはセンタイ類群落）を花粉分析し，雲南高原における植生・気候と表層花粉群の相関について検討した．これは千葉県立中央博物館の平成 12-13 年度海外出張成果であり，平成 9-13 年度文部科学省 COE 形成プログラム「長江文明の探求」（課題番号 09CE1001・研究代表者安田喜憲）に研究協力者として参加した成果である．ルート下部ではやや植生の保存は悪かったものの，基本的に花粉は植生垂直分帯とよい相関を示し，標高 1950-2600m には *Lithocarpus*/*Castanopsis* を中心とした亜熱帯常緑樹林（SEBF）要素が，標高 2600-3050m には *Pinus armandi* と *Tsuga* を中心とした漸移帯要素が，標高 3050-3500m には *Picea*，*Abies* を中心とする山地性針葉樹林（MonCF）要素が多産し，花粉と気温の対応関係が確認された．*Cyclobalanopsis* のみは標高と無関係に多産し，おそらく矮性低木として針葉樹林の林床から亜高山帯にまで広く生育する硬葉ガシが反映されており，雲南高原においては温度指標として適当でない．これらの表層花粉結果を大理市北方の Xihu 湖（標高 1980m）から報告されている最終氷期の化石花粉データと比較したところ，標高 2600-3050m の漸移帯部分がもっともよい類似を示した．気温の逓減率を 0.65℃/100m として計算すると，この標高差はあらく 4.2-6.9℃の気温差に換算される．これは 80 年代に見積もられた雲南高原周辺の最終氷期の温度低下量より有意に大きく，低緯度熱帯の気候変動に対する過敏性を示唆する最近の証拠と整合的である．定量的な誤差推定を含めたより直接的な検証を行うために，現在，Xihu に隣接する Erhai 湖からの最終氷期堆積物を分析中である．