THE RECONSTRUCTION OF PALEOVEGETATION AND PALEOCLIMATE IN THE LATE PLIOCENE OF WEST YUNNAN, CHINA

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Abstract. The Eryuan palynoflora from the Late Pliocene of western Yunnan, China is described in this paper, and is compared with two contemporary palynofloras from Yangyi and Longling. The palynological data of the three locations are analyzed to reconstruct the climatic parameters of these areas at that time by using the Coexistence Approach. The Late Pliocene climatic parameters of Eryuan are estimated, i.e., the mean annual temperature ranged from 13.3 to 18.6°C, the mean temperature of the warmest month from 24.6 to 27.5°C, the mean temperature of the coldest month from 1.9 to 12.1°C, the difference in temperatures of coldest and warmest month from 14.2 to 16.6°C, the mean annual precipitation from 619.9 to 1484.3 mm, the mean maximum monthly precipitation from 143.8 to 245.6 mm, and the mean minimum monthly precipitation from 12.7 to 16.4 mm. Both paleovegetation and paleoclimate of the three localities are compared with the modern data at each location. The present study suggests a MAT decrease accompanied by a doubling of the MAP in the Longling area between the Late Pliocene and the present. This seems to be related to the uplift of Gaoligong Mountain in Longling which is now part of the eastern portion (Western Yunnan) of the Tibetan Plateau.

Yunnan is situated on the Southeastern edge of the Qinghai-Xizang (Tibet) Plateau. Geographically, it represents only 4% of China, but it contains 13278 (45.9 %) species of vascular plant (WGYV, 1987). Complex vertical zonation and a variety of vegetation types are characteristic of the modern environment in western Yunnan. In the Cenozoic, the uplift of the Tibetan Plateau strongly influenced the area, forming a very complicated geographic environment (BGMRYP, 1990; Zhang et al., 1997). Former research regards the Neogene as a key stage of terrestrial environmental evolution in Yunnan (Xu et al., 2004).

Eryuan is situated on the western slope of the Diancang Mountain in northwest Yunnan. The Liantie coal-bearing deposit of this area (Figure 1) was assigned to the Sanying Formation of Late Pliocene age, based on a lithostratigraphic

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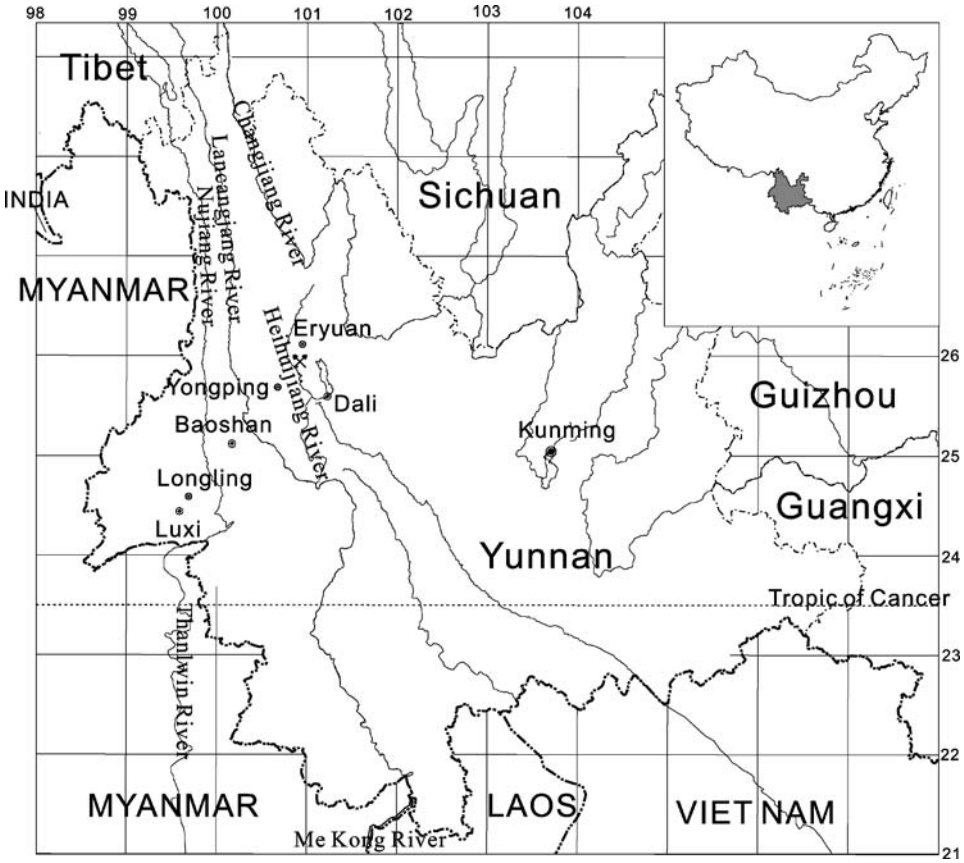


Figure 1. The regional map to show the position of Eryuan, Basoshan (Yangyi), and Longling.

and biostratigraphic comparison with the middle-late Pliocene flora of Mt. Shisha Pangma in the Himalayas (Hsü et al., 1973; Tao and Kong, 1973; BGMRYP, 1990; BGMRYP, 1996; Ge and Li, 1999). Tao and Kong initiated work on the Upper Pliocene Flora of the Sanying Formation (Tao and Kong, 1973).

In western Yunnan two other late Pliocene palynofloras, i.e. Yangyi (Xu, 2002; Xu et al., 2003) and Longling (Xu, 2002; Xu et al., 2003; Xu et al., 2004) have been recorded recently. In the present investigation, seven dimensional climatic parameters of the three locations are estimated using the Coexistence Approach (Mosbrugger and Utescher, 1997; Xu et al., 2000), and paleovegetation, paleoclimate are compared with the modern data.

Materials and Methods

The Liantie coal mine (26°00.20′N, 99°49.06′E, 2280 m a.s.l.) lies in Liantie Village, Eryuan county, Yunnan in China (Figure 1). The profile exposed at Liantie

Coal Mine, is about 90 m thick (Figure 2). The studied section was overlain by Quaternary conglomeratic sediment. The underlying bed is grey limestone (Triassic) (BGMRYP, 1990; BGMRYP, 1996). 56 palynological samples from the profile were collected and analyzed in the present investigation (Figure 2).

The samples were treated by the traditional method of heavy liquid separation (Density = 1.8 g/ml) (Moore et al., 1991; Li and Du, 1999). No pollen grains or spores were found in 11 samples, fewer than 200 grains (3–161) were found in 22 samples, while more than 200 grains (206–613) were found in the other 14 samples. All the samples with fewer than 200 grains are based on counting at least 5 slides under the microscope.

The pollen grains and spores were identified by comparison with the modern palynological literature (IBCAS, 1976; IBCAS and SCIBCAS, 1982; Wang et al., 1995).

The reconstruction of paleoclimate in Eryuan is attempted following the Coexistence Approach (CoA) (Mosbrugger and Utescher, 1997; Xu et al., 2000). The method is based on the coexistence interval of the climatic tolerance of the taxa in a plant assemblage. The climatic tolerances of the seed plants were obtained from the climatic records within their modern distribution area (Wu and Ding, 1999).

As an example, the procedure for obtaining the climatic tolerance of *Quercus* is shown in Figure 3. All points in the distribution of *Quercus* (oak) in China are shown in Figure 3, and seven-dimensional climatic parameters from each point were collected. From the climatic parameter data, the maximum and minimum of each parameter of every single dimension were established. In the four chosen points of *Quercus* distribution in Figure 3, the meteorological stations provided the minimum of Mean Annual Temperature (MAT) being −4.9°C in Mohe, being 24.7°C in Dongfang, the minimum of Mean Annual Precipitation (MAP) being 213.1 mm in Alxa zuoqi, the maximum of MAP being 1869.6 mm in Taipei. Therefore the MAT tolerance of *Quercus* is from −4.9 to 24.7°C, and the MAP tolerance from 213.1 to 1869.6 mm (Figure 7). In the same way, parameters of the other five dimensions viz., the Mean Temperature of the Warmest Month (MWMT); the Mean Temperature of the Coldest Month (MCMT), the Difference of Temperatures of coldest and warmest month (DT), the Mean Maximum monthly Precipitation (MMaP), the Mean Minimum monthly Precipitation (MMiP) are established.

The modern climatic data recorded by the meteorological stations of China are extracted from publications of the Information Department of Beijing Meteorological Center (IDBMC) (1983a, b, 1984a, b, c, d). Sometimes the distribution area of a genus extends beyond China. For example, in the genus *Quercus,* we checked the recent research papers which mentioned the genus with the meteorological record in Belgium (Maes et al., 1999), Spain (Infante et al., 1999), Italy (Nardini et al., 2000), Nepal (Vetaas, 1999), Mexico (De Buen and Ornelas, 2002) and USA (Hutchinson et al., 1999) (Table I); These demonstrate that all the records fall within the range of tolerance of *Quercus*.

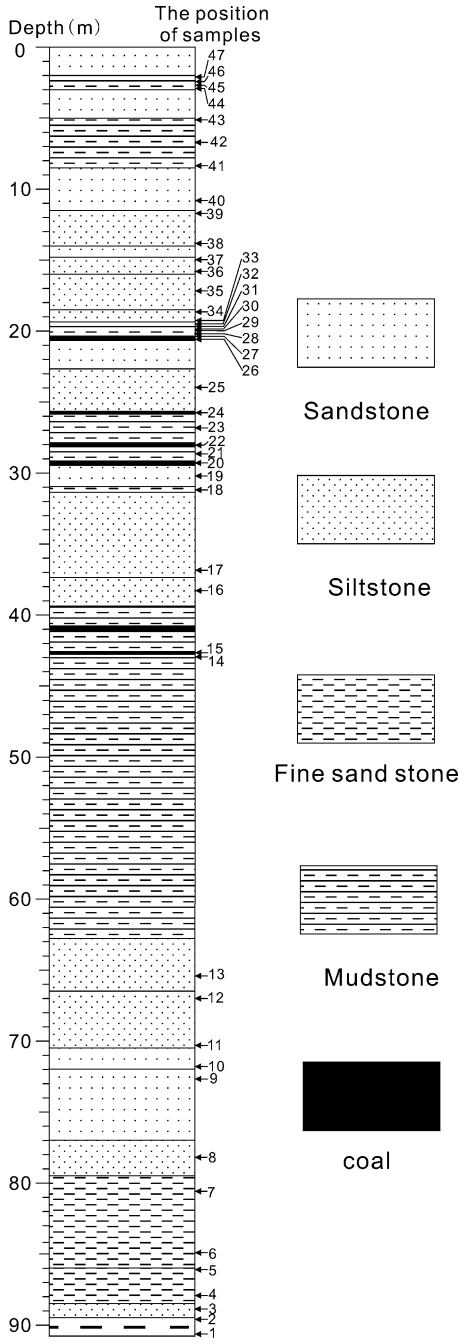


Figure 2. Measured of stratigraphical section of liantie coal mine and the positions of the samples.

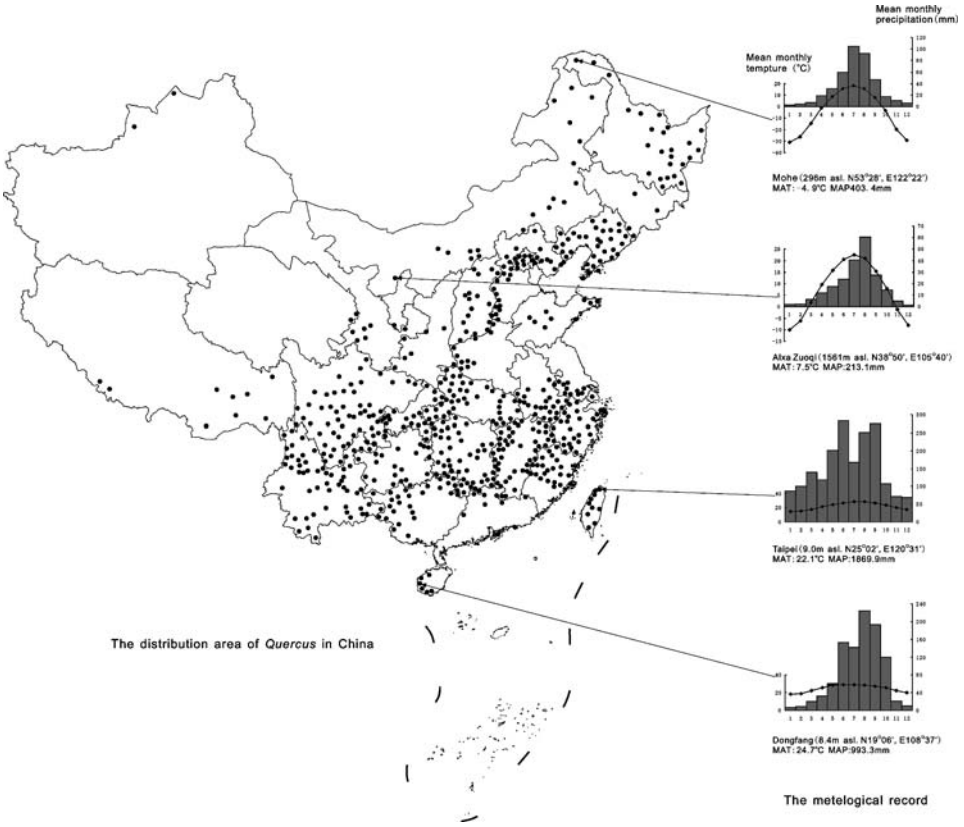


Figure 3. An example (*Quercus*) to show the procedure for obtaining the climatic tolarence.

Result

The Eryuan palynoflora consists of 58 palynomorphs belonging to 49 families. Most are angiosperms (75.9%), but gymnosperms (8.6%) and pteridophytes (15.5%) are also represented (Table II, Figures 4 and 5). Angiosperm pollen represents 44 types assigned to 38 families. The gymnosperms include 4 genera of Pinaceae and 1 type of Taxodiaceae. The pteridophytes include 9 types belonging to 9 families. Based on the appearance of each palynomorph and its main changes in the total pollen diagram (Figure 6), 3 palynological zones could be recognized:

Zone 1 (90.65–66.85 m in depth): Conifer tree taxa range from 27.2 to 87.5% of the pollen sum, thus dominating the pollen assemblage. The montane conifer *Pinus* (pine), ranging from 18 to 86%, is particularly well-represented, while *Abies* (fir), *Picea* (spruce), *Tsuga* (hemlock), and Taxodiaceae were also present. Many broadleaved tree taxa (20 types, mainly *Quercus* (oak) and *Alnus* (alder)), are present, with a total percentage of 5 to 67%. Herbaceous taxa (mainly *Artemisia*,

TABLE I
The MAT and MAP in the distribution area of *Quercus* beyond China form the recent study about the genus

Place	Location	Altitude (m a.s.l.)	MAT (°C)	MAP (mm)
Southeast Belgium[a]	–	320 to 335	7.7	1000
Orense, Spain[b]	42°21′N, 7°51′W	130	14	818
Barcelona, Spain[b]	41°24′N, 2°09′E	90	16	595
Trieste Venezia Giulia, Italy[c]	45°46′N, 13°35′E	20	12.5 to 15.5*	1150
Messina, Sicily, Italy[c]	38°23′N, 15°56′E	500	16.5 to 18.5*	365
Okladunga, Nepal[d]	27°19′N, 86°30′E	1720	16.4	–
Tengboche, Nepal[d]	27°50′N, 86°46′E	3857	3.9	–
Xalapa, Veracruz, Mexico[e]	19°30′N, 96°57′W	1300	18	1500
Vinton, Ohio, USA[f]	39°12′N, 82°23′W	208 to 307	11.3	1024
The tolerance of *Quercus* from Chinese data	–	–	-4.9 to 24.9	213.1 to 1869.6

*Calculated as the arithmetic mean of MCMT and MWMT.
[a]Cited from Maes et al. (1999).
[b]Cited from Infante et al. (1999).
[c]Cited from Nardini et al. (2000).
[d]Cited from Vetaas (1999).
[e]Cited from De Buen and Ornelas (2002).
[f]Cited from Hutchinson et al. (1999).

Chenopodiaceae) representing 13 types are also present, with a total ranging from 3.4% to 25%. A few aquatics (*Typha* (reedmace) and Potamogetonaceae (pondweeds)) are restricted to this zone; the ferns are represented by Polypodiaceae, Gleicheniaceae, Pteridaceae and *Lycopodium* (clubmoss), normally less than 1%.

Zone 2 (66.85–31.95 m in depth): Only two types of conifer (*Pinus* and *Tsuga*, with a total percentage of 19 to 70.7%) are recorded along with a few broadleaved trees (13 types with a total percentage of 11 to 24%), the main genera being *Quercus* and *Alnus*, as well as herbs (6 types) e.g. *Artemisia* and Chenopodiaceae, totaling 3.6 to 32%; no aquatics were found; of the 4 pteridophyte types, *Lycopodium* peaked (46.77%) at 42.5 m in depth.

Zone 3 (31.95–0 m in depth): Conifer tree taxa are represented by three types, i.e. *Abies*, *Pinus*, and *Tsuga*, with a total percentage ranging from 11% to 72.5%; of the 18 broadleaved tree types (10 to 85.7%), *Quercus* and *Alnus* remain dominant, 12 types of herbs, ranging from 5 to 66.7%, are dominated by *Artemisia* and Chenopodiaceae, while 9 types of ferns including Dennstaedtiaceae, Polypodiaceae, Sinopteridaceae, Gleicheniaceae, Pteridaceae, Hymenophyllaceae, Gymnogrammaceae, *Lycopodium* and Selaginellaceae are recorded; *Lycopodium* continues to be important, reaching 67.37% at 24.15 m depth.

TABLE II
The list of palynomorphs

Pteridophyta	
Dennstaedtiaceae	Hymenophyllaceae
Polypodiaceae	Gymnogrammaceae
Sinopteridaceae	*Lycopodium*
Gleicheniaceae	Athyriaceae
Pteridaceae	
Gymnosperms	
Abies	*Tsuga*
Pinus	Taxodiaceae
Picea	
Angiosperms	
Trees and shrubs	Rubiaceae
Alnus	Oleaceae
Betula	Palmae
Carpinus	Theaceae
Corylus	Myrtaceae
Castanea	**Herbs**
Castanopsis	Verbenaceae
Quercus	Cyperaceae
Fagus	*Erodium*
Liquidambar	Polygonaceae
Ericaceae	Chenopodiaceae
Ilex	Convolvulaceae
Ulmus	Gesneriaceae
Juglans	*Humulus*
Lythraceae	Lamiaceae
Euphorbiaceae	Cruciferae
Anacardiaceae	*Thalictrum*
Araliaceae	Gramineae
Fabaceae	Compositae
Rutaceae	*Artemisia*
Tilia	Caryophyllaceae
Meliaceae	**Aquatics**
Celastraceae	*Typha*
Sapindaceae	Potamogetonaceae

The three zones are very similar in having same major tree genera *Pinus*, *Quercus*, *Alnus*, and herbaceous taxa *Artemisia* and Chenopodiaceae. Even though there were some fluctuations in the three zones, the main types remained the same. It shows that a subtropical mixed evergreen coniferous and broad-leaved forest existed in this mountainous area.

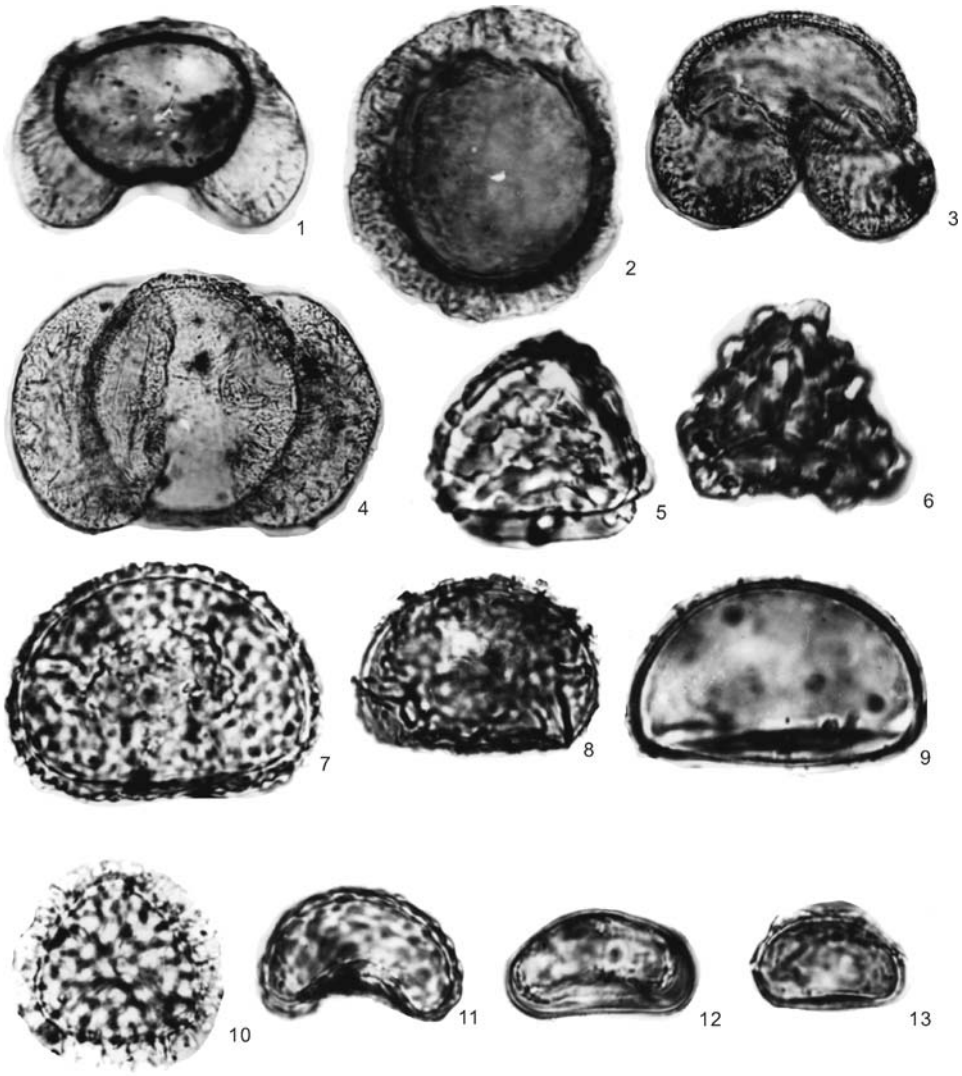


Figure 4. (1). *Cedrus* Trew (2). *Tsuga* Carr. (3, 4). *Pinus* L. (5, 6). *Pteris* Linn. (7, 9, 11). Polypodiaceae (8, 12, 13). Athyriaceae (10). Lycopodiaceae (1–4 × 600, 5–13 × 800).

The paleoclimatic intervals in Eryuan (Upper Pliocene) which were obtained using the Coexistence Approach are shown in Figure 7. The mean annual temperature ranged from 13.3 to 18.6°C, the mean temperature of the warmest month from 24.6 to 27.5°C, the mean temperature of the coldest month from 1.9 to 12.1°C, the difference in temperatures of coldest and warmest month from 14.2 to 16.6°C, the mean annual precipitation from 619.9 to 1484.3 mm, the mean maximum monthly precipitation from 143.8 to 245.6 mm, and the mean minimum monthly precipitation from 12.7 to 16.4 mm (Table III).

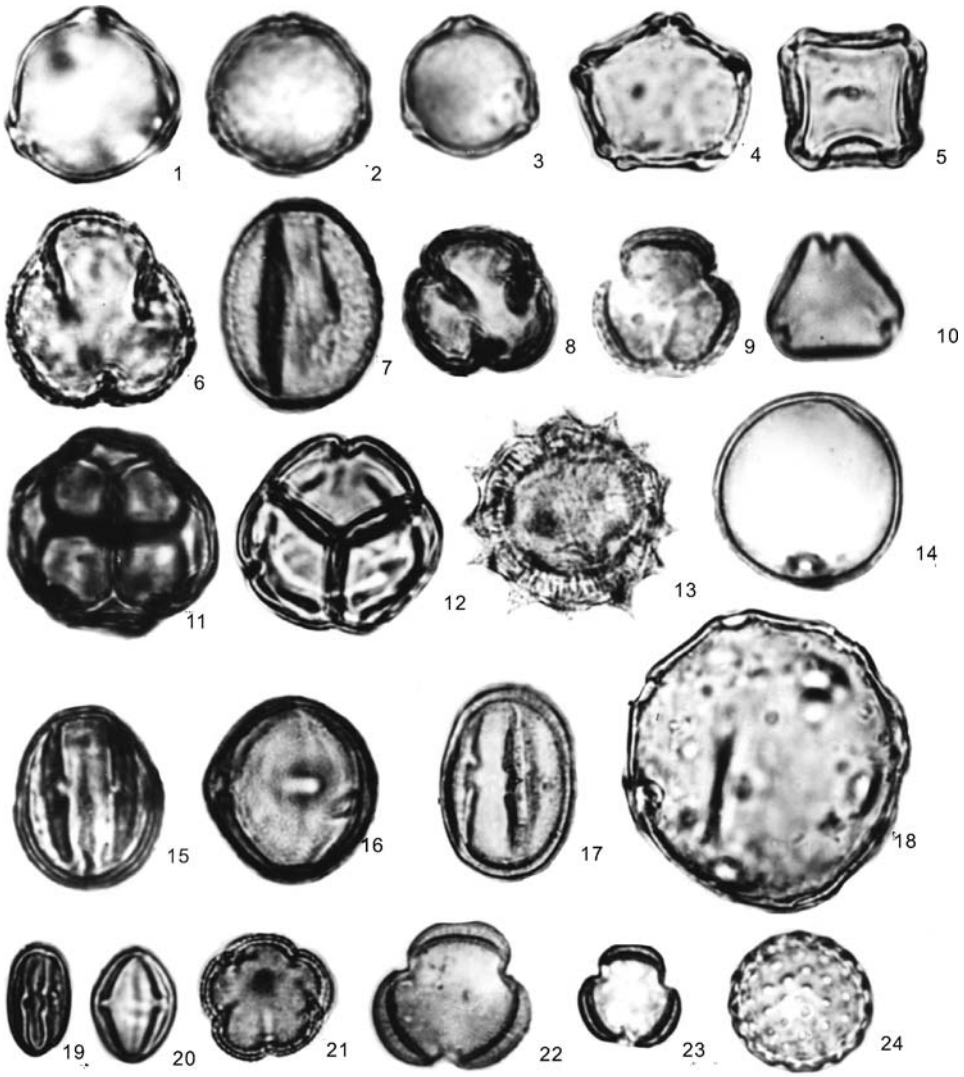


Figure 5. (1). *Betula* L. (2). *Ulmus* L. (3). *Corylus* L. (4, 5). *Alnus* Mill. (6, 7, 8). *Quercus* L. (9). *Artemisia* L. (10). Sapindaceae (11, 12). Ericaceae (13). Compositae (14). Gramineae (15). Leguminosae. (16). Anacardiaceae (17). Polygonaceae (18). *Juglans* L. (19, 20). Castaneoideae (21). Rubiaceae (22, 23). *Artemisia* L. (24). Chenopodiaceae (1–24 × 1000).

Discussion

The Eryuan palynoflora contains much *Pinus* throughout the sequence, the highest level being almost 86%. *Quercus* and *Alnus* were the main angiosperm trees, accompanied by a number of herbs like *Artemisia* and Chenopodiaceae. Some tropical or subtropical types such as *Liquidambar*, Euphorbiaceae, Sapindaceae, Palmae

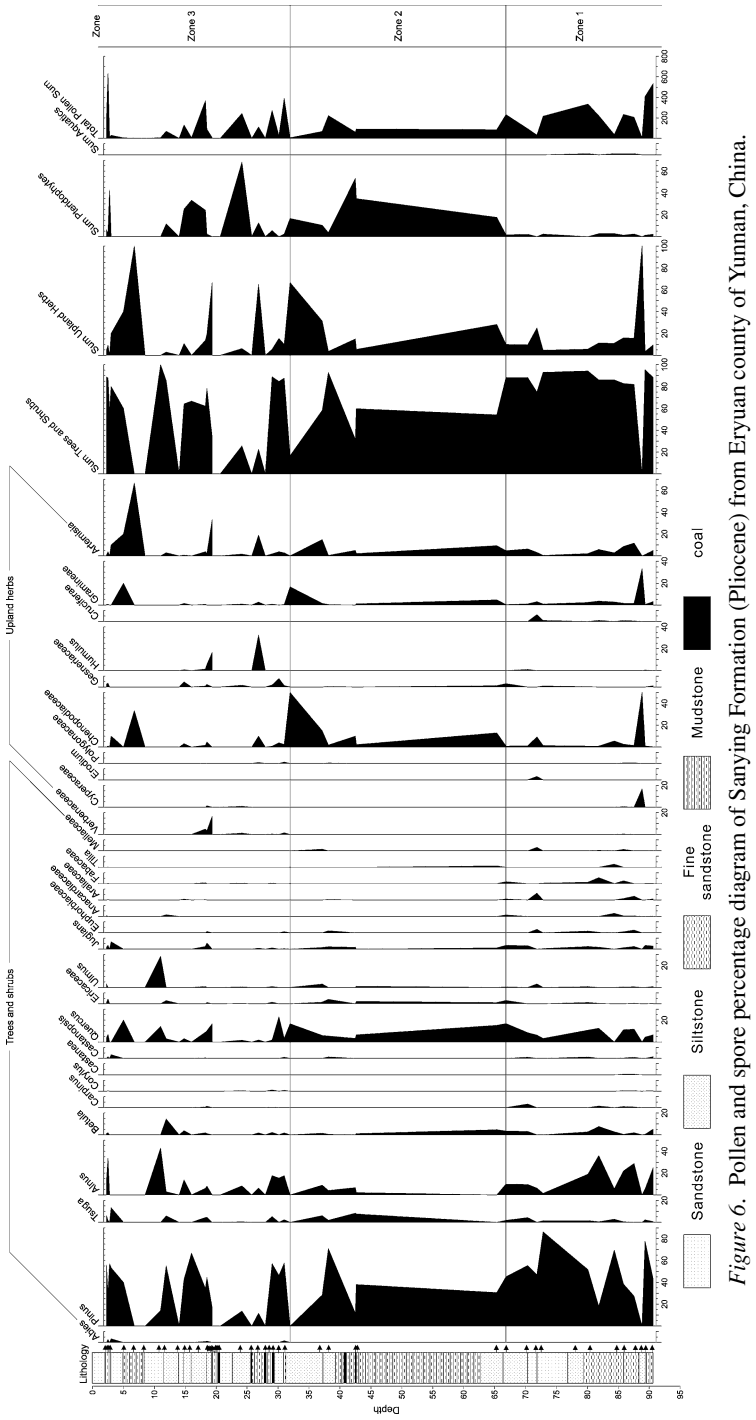


Figure 6. Pollen and spore percentage diagram of Sanying Formation (Pliocene) from Eryuan county of Yunnan, China.

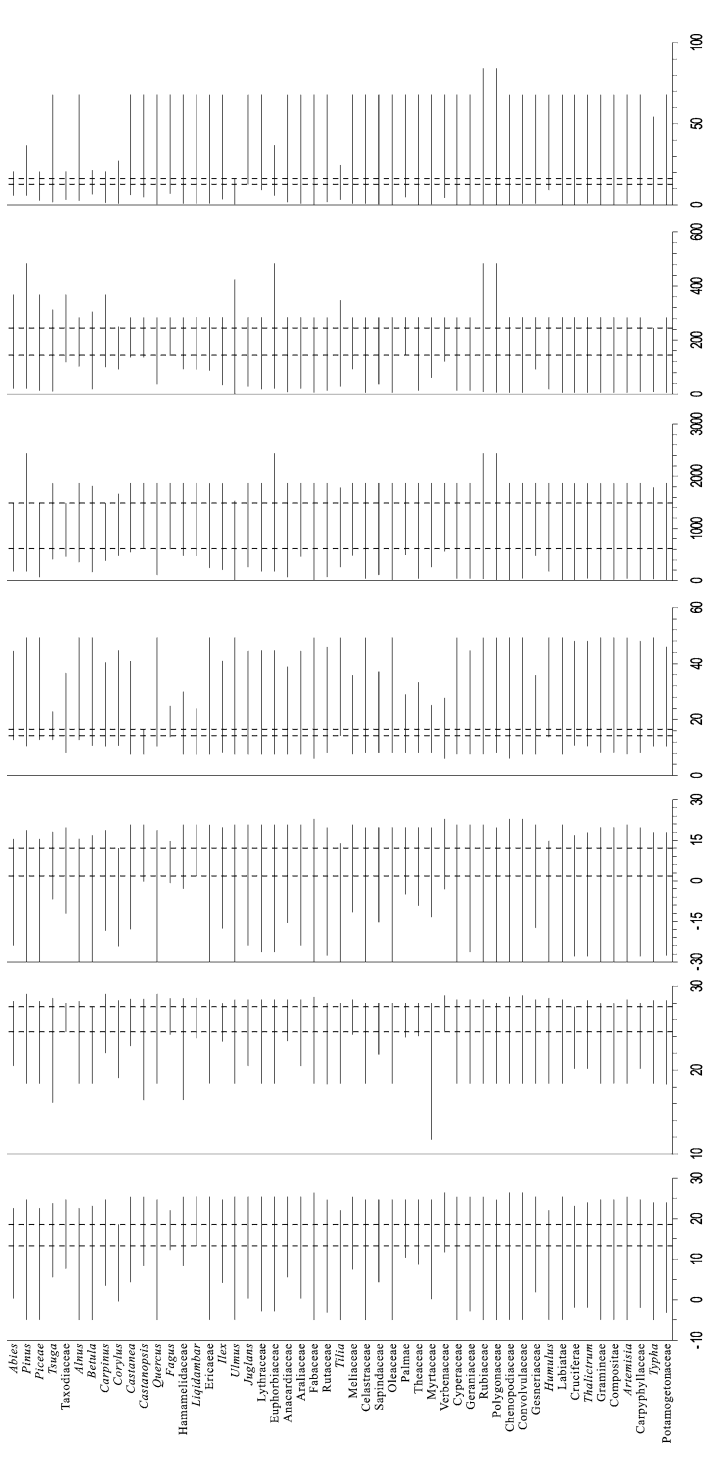


Figure 7. The climatic tolerences of nearest living relatives of the seed plants in Eryuan Palynoflora and the interval of their climatic parameters using Co-existence Approach.

TABLE III
The climate parameters of Pliocene in Eryuan area obtained by the method of Coexistence Approach compared with the modern climate

Climate parameters	Pliocene	Modern
MAT(°C)	13.3–18.6°C	13.9 °C*
MWMT(°C)	24.6–27.5°C	20 °C*
MCMT (°C)	1.9–12.1°C	6.7 °C*
DT(°C)	14.2–16.6°C	13.3 °C*
MAP (mm)	619.9–1484.3 mm	650.2–1456.5 mm**
MMaP (mm)	143.8–245.6 mm	229.0 mm**
MMiP (mm)	12.7–16.4 mm	12.4 mm**

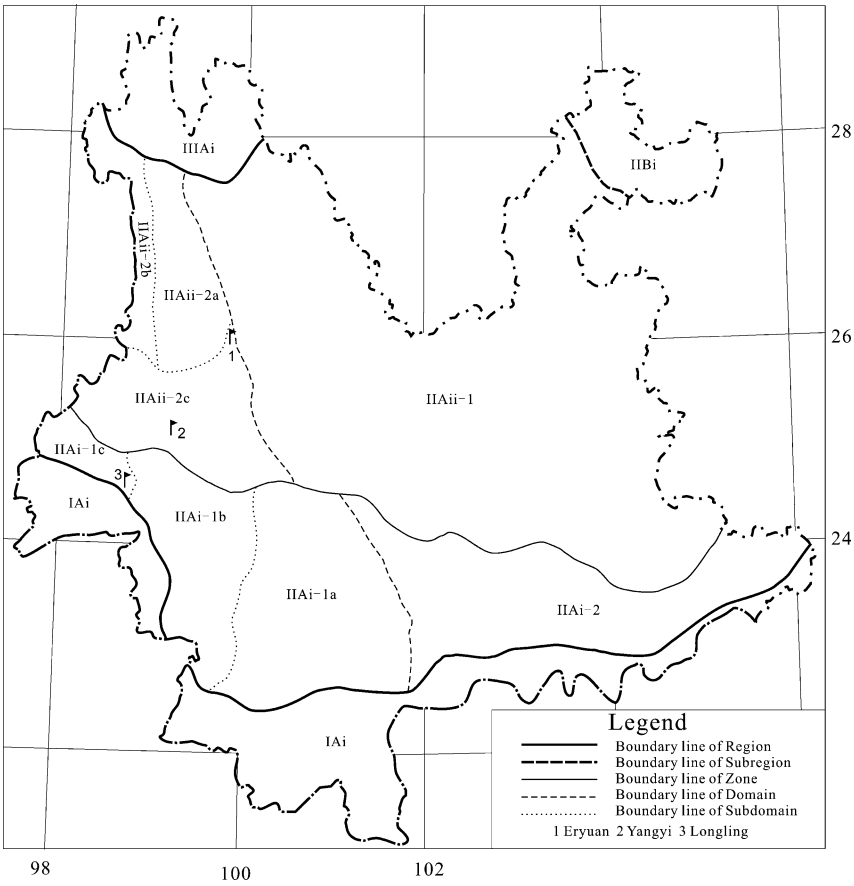
Note. *The record of Eryuan Meteorological Station (WCECA, 1996).
**The record of Dali Meteorological Station (No. 56751) (IDBMC, 1984e; Chen, 2001).

also appeared frequently. It suggests that conifers like *Tsuga*, *Picea*, *Abies* lived at higher altitudes; The predominance of *Pinus* may simply reflect its high pollen production and efficient dispersal. At mid-elevation the forest consisted of *Quercus* (oak), *Alnus* (alder), *Betula* (birch), *Tilia* (lime), *Ulmus* (elm) etc., while the lower part included some thermophilic trees such as *Liquidambar*, Euphorbiaceae, Sapindaceae and Palmae. Herbs such as *Artemisia* and Chenopodiaceae etc. lived on grassy slopes.

The Yangyi, Longling and Eryuan palynofloras are located in western Yunnan (Figure 8), and are Late Pliocene in age (BGMRYP, 1990; 1996). Like the other two palynofloras, the Eryuan palynoflora contains numerous angiosperms (44 of 58 taxa). However the proportion of angiosperm pollen (43.5%) is less than that of the gymnosperms (47.5%) (Table IV).

Based on a comparison of the three localities with the vertical vegetation belts and modern vegetation (Table IV), most elements of the Eryuan palynoflora would appear to have been derived from the semi-moist evergreen coniferous and broad-leaved mixed forest belt at 1600–2500 m, with a small contribution from the coniferous forest above 2900 m. Most elements of the Yangyi palynoflora were derived from the evergreen coniferous and broad-leaved mixed forest of 2700–3000 m, with a minor input from the coniferous forest above 3000 m. Most elements of the Longling palynoflora originated from the modern humid evergreen coniferous and broad-leaved mixed forest at elevations of 1600 to 2500 m, with fewer contributions from evergreen coniferous and broad-leaved mixed forests from 2400 to 2900 m.

The deposits of Sanying Formation (Eryuan), Mangbang Formation (Longling) and Yangyi Formation (Yangyi) in western Yunnan belong to Upper Pliocene (BGMRYP, 1990; BGMRYP, 1996). Using the Coexistence Approach, the paleoclimate of the three localities is quantitively assessed.



Explanation : (Regionalization of Yunnan vegetation):
(I) Region of tropical monsoon forest, rain forest,
(IA) Subregion of monsoon forest, rain forest of western China,
(IAi) Zone of northern tropical seasonal rain forest and semi-evergreen monsoon forest

(II) Region of subtropical evergreen broad-leaved forest,
(IIA) Subregion of semi-humid evergreen broad-leaved forest of western China,
(IIAi) Zone of subtropical monsoon evergreen broad-leaved forest of southern plateau,
(IIAi-1) Domain of monsoon evergreen broad-leaved forest found in midmontane of southwestern Yunnan,
(IIAi-1a) Subdomain of montane *Castanopsis hystrix-C. microcarpa* forest and *Pinus kesiya* var. *langbianensis* forest,
(IIAi-1b) Subdomain of montane *Castanopsis hystrix-C. indica* forest and *Lithocarpus echinotholus* forest,
(IIAi-1c) Subdomain of mid-montane *Castanopsis ferox*, *C. Hystrix-Lithocarpus truncatus* forest,
(IIAi-2) Domain of monsoon evergreen broad-leaved forest of southeastern Yunnan,

(IIAii) Zone of subtropical evergreen broad-leaved forest of northern plateau,
(IIAii-1) Domain of semihumid evergreen broad-leaved forest and *Pinus yunnanensis* forest of central and eastern Yunnan,
(IIAii-2) Domain of semi-humid evergreen broad-leaved forest of Hengduan Mountain western Yunnan,
(IIAii-2a) Subdomain of *Pinus yunnanensis* forest, *Castanopsis orthacantha* forest and Abies forest,
(IIAii-2b) Subdomain of mid-domain *Cyclobalanopsis glauca-Taiwania flousiana* forest and *Neyraudia reynaudiana* grassland,
(IIAii-2c) Subdomain of mid-montane *Castanopsis delavayi-Lithocarpus* forest and *Pinus yunnanensis* forest of estern Yunnan.

(IIB) Region of humid evergreen broad-leaved forest of eastern China,
(IIBi) Zone of mid-subtropical evergreen broad-leaved forest,

(III) Region of alpine vegetation of Qinghai-Tibet Plateau,
(IIIA) Subregion of cold temperate coniferous forest of Southeastern Qinghai-Tibet Plateau,
(IIIAi) Zone of cold temperate coniferous forest and meadow of Southeastern Qinghai -Tibet Plateau, and

Figure 8. The location of Eryuan, Yangyi, Longling, in the vegetation, regionalization map of Yunnan provinces (WGYV, 1987).

TABLE IV
A comparison of modern and Late Pliocene vegetation at the three locations in western Yunnan

Location		Eryuan	Yangyi	Longling
Pliocene palynoflora	The type amount	Paynomorphs:58 Including Angiosperms 44 Gynosperms 5 Pteridophytes 9	Paynomorphs:52 Including Angiosperms 31 Gynosperms 5 Pteridophytes 13 Algae 2	Paynomorphs:82 Including Angiosperms 56 Gynosperms 4 Pteridophytes 20 Algae 2
	Pollen and spores in sum percentage	Angiosperms 43.5% Gynosperms 47.5% Pteridophytes 9.0%	Angiosperms 16.93% Gynosperms 8.15% Pteridophytes 74.14% Algae 0.77%	Angiosperms 76.27% Gynosperms 5.43% Pteridophytes 17.88% Algae 0.40%
Modern vertical vegetation distribution		4000–4700 m, Alpine shrub and alpine meadow, with alpine *Pinus* forest, *Larix* forest and evergreen sclerophyllous Fagaceae forest interlaced distribution		>3000 m, Abies forest
		3100–4200 m, *Picea* and *Abies* forest		2800–3000 m, Montane mossy evergreen broad-leaved forest
		2700–3000 m, *Tsuga dumosa* forest and evergreen coniferous broad-leaved mixed forest		2300–2900 m, *Tsuga dumosa* forest and evergreen coniferous broad-leaved mixed forest
		2400–2900 m, Montane moist evergreen broad-leaved forest		1600–2500 m, Montane moist evergreen broad-leaved forest
		l600–2500 m, semimoist evergreen broad-leaved forest and *Tsuga dumosa* forest		1000–1700 m, Monsoon evergreen broad-leaved forest and *Pinus kesiya var. langbianensis* forest
		<1300 m, Shrub-grassland savanna		<1100 m, Deciduous monsoon forest or shrub-grassland savanna

TABLE V
The paleoclimate and modern equivalent of Eryuan, Yangy and Longling

Location	Position and altitude	Time	MAT (mid-value) (°C)	MAP (mid-value) (mm)
Eryuan	(26°00′N 99°49′E, 2279 m a.s.l.)	Modern	13.9[a]	1078.9[a]
Yangyi	(24°57′N 99°15′E, 1521 m a.s.l.)	Modern	15.5[b]	966.4[b]
Longling	(24°41′N 98°50′E, 1802 m a.s.l.)	Modern	14.9[c]	2122[c]
Eryuan	–	Pliocene	13.3–18.6 (15.95)	619.9–1484.3(1052.1)
Yangyi	–	Pliocene	13.3–20.9(17.1)	797.5–1254.7(1026.1)
Longling	–	Pliocene	18.6–22.1(20.35)	815.8–1254.7(1035.25)

[a]The record of Dali Meteorological Station (No. 56751) (IDBMC, 1984e; Chen, 2001).
[b]The record of Baoshan Meteorological Station (No. 56748) (IDBMC, 1984e; Chen, 2001).
[c]The record of Longling Meteorological Station (WGYV, 1987).

All of the late Pliocene and modern climatic data from the three localities are shown in Table V. The MATs in late Pliocene, with means given in brackets, display a similar trend trend from high temperatures to lower ones (20.35 to 17.1 to 15.95°C) with increasing latitude from Longling through Yangyi to Eryuan. On the other hand, the MAPs remained fairly constant from Longling through Yangyi to Eryuan (with means of 1035.25, 1026.1, and 1052.1 mm respectively) in late Pliocene times.

Based on the modern meteorological records, Yangyi and Eryuan demonstrate that the MATs change with an increase in latitude (15.5 to 13.9°C), while the MAP changed only marginally (966.4 to 1078.9 mm). However, the record from Longling displays a marked difference, with the MAT dropping to 14.9°C, while the MAP doubled to 2122 mm.

The lower MAT and higher MAP at Longling are the main reasons for the differences in the vegetation at Longling. In the modern vegetation of Yunnan, Eryuan and Yangyi are placed in the same vegetation zone (IIAii-2 domain of semi-humid evergreen broad-leaved forest of Hengduan Mountain, western Yunnan), and are even included in the same subdomain (IIAii-2c subdomain of mid-montane *Castanopsis delavayi-Lithocarpus* forest and *Pinus yunnanensis* forest of western Yunnan), while Longling lies in another zone (IIAi-1 domain of monsoon evergreen broad-leaved forest and *Pinus yunnanensis* forest of central and eastern Yunnan) (WGYV, 1987) (Figure 8).

Figure 9 shows the modern hypsographic and climatic change from the Mangshi through Longling, Yangyi (Baoshan), Yongping to Eryuan. It demonstrates that the northwardly moist air-stream may be obstructed by the Gaoligong Mountain causing heavy rainfall and lower temperatures in the Longling area.

Based on the Pliocene climatic data, the MATs are seen to change according to latitude, while the MAP remained roughly the same. It would appear that there was no mountain here at this time. So uplift of Gaoligong Mountain and the eastern portion (Western Yunnan) of the Tibetan Plateau must have occurred during or after the late Pliocene. This corroborates the concept of time-dependent localized shear

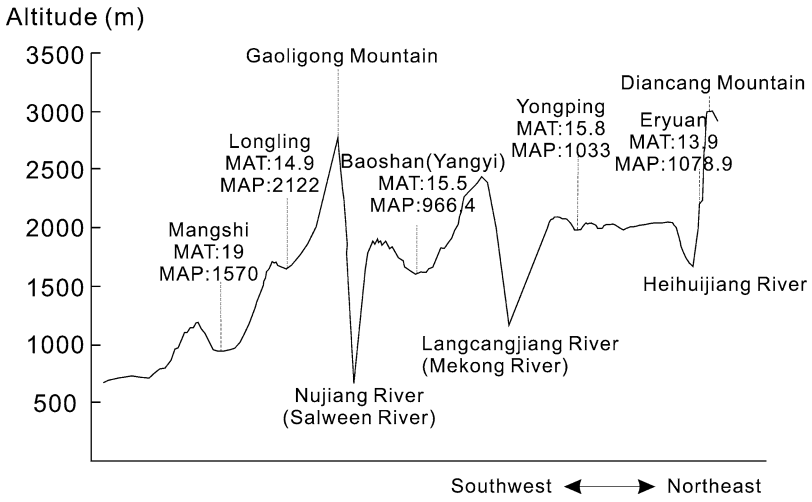


Figure 9. Modern hypsographic and climatic changes form the southwest to northeast in western Yunnan, China. Note: MAT (°C) MAP (mm).

between coherent lithospheric blocks (Tapponnier et al., 2001), which explains the high elevation of the Tibetan Plateau.

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