Neogene zonal vegetation of China and the evolution of the winter monsoon

FRÉDÉRIC M.B. JACQUES, GONGLE SHI & WEIMING WANG

When considering global change in China, it is important to understand how the strength of the monsoon has responded to changes in climate in the past. Here, we use a semi-quantitative reconstruction method, the Integrated Plant Record (IPR) vegetation analysis, to reconstruct the Neogene vegetation of China. The IPR method focuses on the taxonomic, physiognomic and autecological characteristics of fossil plants, whatever the organs concerned, such as palynomorph, diaspore, leaf and wood. Our study includes 107 Neogene fossil assemblages from 74 localities. There is an increase in the broad-leaved deciduous component in the northern areas during the Neogene. This is consistent with global cooling in the Neogene. At the same time, an increase of sclerophyllous and herbaceous components in west, central and north China occurs, which is indicative of aridification. There is no noticeable change in the vegetation of south China at that time. The Pliocene is characterised by an increasing contrast in vegetation between south and north China. The aridification of north China is due to a strengthening of the winter monsoon. Because there is no major change in the vegetation of south China, the weakening of East Asian summer monsoon is improbable. The Pliocene cooling is responsible for colder winters in Siberia, and the winter high pressure over Siberia becomes higher. As a result, the winter monsoon winds are stronger. The evolution of the summer and winter monsoons is not coupled. • Key words: China, palaeovegetation, Neogene, monsoon, Integrated Plant Record, fossil, aridification.

JACQUES, F.M.B., SHI, G. & WANG, W.M. 2013. Neogene zonal vegetation of China and the evolution of the winter monsoon. *Bulletin of Geosciences 88(1)*, 175–193 (6 figures, 3 tables). Czech Geological Survey, Prague. ISSN 1214-1119. Manuscript received April 12, 2012; accepted in revised form October 17, 2012; published online November 30, 2012; issued December 6, 2012.

Frédéric M.B. Jacques, Gongle Shi & Weiming Wang (corresponding author), Department of Palaeobotany and Palynology, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China, wmwang@nigpas.ac.cn • Frédéric M.B. Jacques, Key Laboratory of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Menglun, Mengla 666303, Yunnan, China

Three prominent features characterise the humid/arid climates in China: the Southeast Asian summer monsoon, the South Asian summer monsoon and the winter monsoon (Wang 2006). Most of the water available in China is brought by the summer monsoon. When global climate change becomes a major political concern, we need to question the link between the strength of the monsoon and global climate to understand how arid and humid regions of China will respond to the changes.

Several proxies have been used to study the evolution of the monsoon in the Neogene in China: carbon isotopic data (Kaakinen *et al.* 2006, Passey *et al.* 2009), oxygen isotopic data (Dettman *et al.* 2003, Kaakinen *et al.* 2006, Wang *et al.* 2008), Nd isotopic data (Garzione *et al.* 2005), granulometry (Rea *et al.* 1998, An *et al.* 2001, Vandenberghe *et al.* 2004, Fan *et al.* 2006, Guo *et al.* 2008), marine sediments (Chen *et al.* 2003, Jia *et al.* 2003, Wan *et al.* 2007, Steinke *et al.* 2010), palaeomagnetic data (An *et al.* 2001, Qiang *et al.* 2001, Guo *et al.* 2002), hypsodonty (Liu *et al.* 2009), and the palaeobotanical record (Sun & Wang 2005, Song *et al*. 2008, Jiang & Ding 2009, Sun & Zhang 2008, Xia *et al.* 2009, Jacques *et al.* 2011a, Liu *et al.* 2011, Sun *et al.* 2011, Yao *et al.* 2011, Xie *et al.* 2012). Most of these studies concern one or two sites; only a few gather information at a regional level or all around China (Sun & Wang 2005, Song *et al.* 2008, Jiang & Ding 2009, Liu *et al.* 2011, Yao *et al.* 2011). South China is more sensitive to the Southeast Asian monsoon while north China is more sensitive to the winter monsoon. Therefore, it is necessary to study the whole of China to be able to decipher the differential evolution of both monsoons. A comprehensive quantitative study over China is therefore needed. This study on the palaeobotanical records because the response of vegetation to climate is global.

Several quantitative methods can be used to reconstruct palaeovegetations. The plant community scenarios (Martinetto & Vassio 2010) focus more on the local level and try

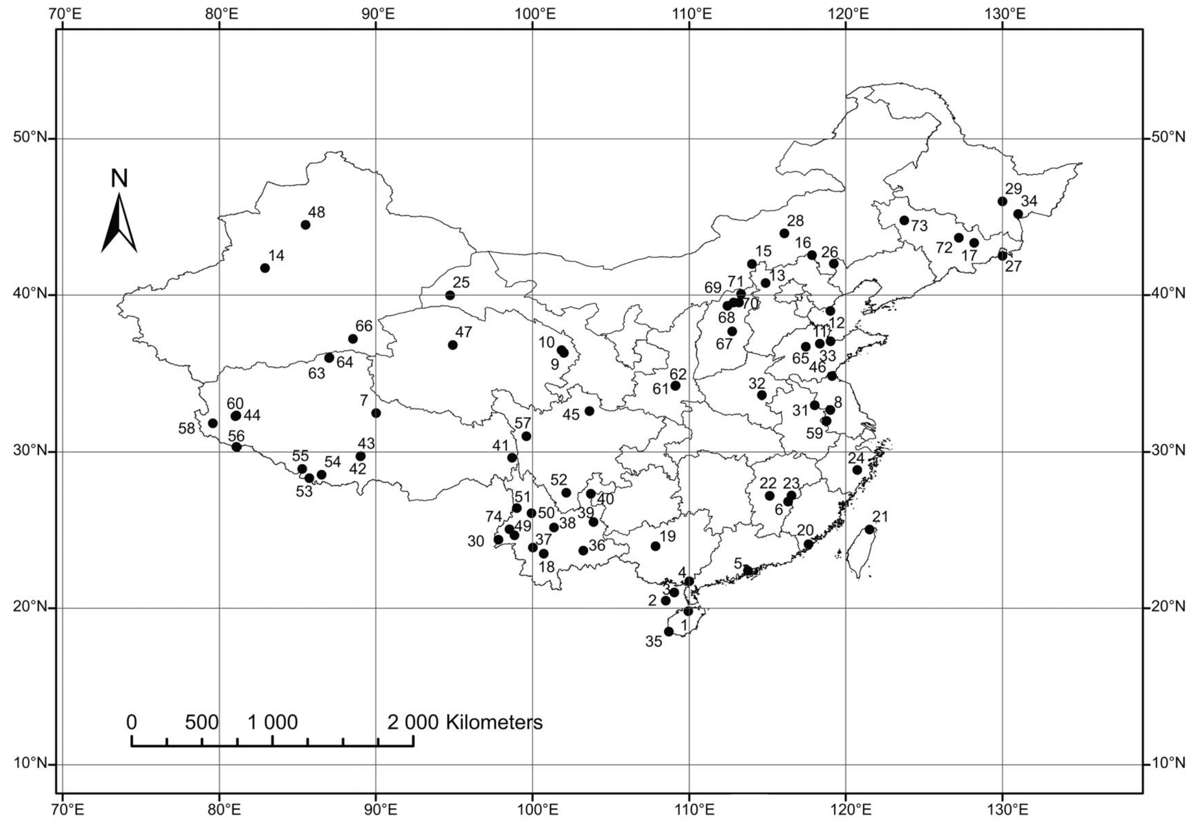

Figure 1. Distribution of fossil sites. The numbers refer to Table 1.

to separate azonal, zonal and extrazonal vegetation. The biomisation (Prentice *et al.* 1996, Yu *et al.* 2003, Chen & Ni 2008, Ni *et al.* 2010) gives good and detailed results at the regional scale for pollen floras. The Integrated Plant Record (IPR) analysis gives good results in reconstructing vegetation based on all organ types, and has been successfully used for the Neogene in European and Asia (Kovar-Eder & Kvacek 2003, 2007; Kovar-Eder *et al.* 2008; Jacques *et al.* 2011b). Because IPR analysis is based on broad definitions of the components, it allows a good interpolation between sites at the regional level (Jacques *et al.* 2011b). The IPR analysis has been validated on modern vegetation in China and Japan (Teodoridis *et al.* 2011b).

We have already reconstructed the Neogene vegetation of south China (Jacques *et al.* 2011b). Extending our work to the whole of China is based on several observations: (1) we cannot understand the evolution of the monsoon without the contrast offered by the different situations in north and south China; (2) the test of the IPR on southern Chinese floras has been successful (Jacques *et al.* 2011b) and can be extended to the whole of China.

This study has two goals: reconstructing Neogene vegetation and discussing the evolution of the monsoon during this period in China.

Material and methods

Fossil sites

Our study focuses on the Neogene because it was the time when the transition of the Chinese climate from a planetary system to a monsoonal system was completed (Sun & Wang 2005). We gathered 74 fossil localities (Table 1, Fig. 1), and separated their geological time into five intervals that represent logical units in terms of palynological zones (Wang 2006, Jacques *et al.* 2011b): early Early Miocene (Aquitanian, early Burdigalian; *i.e.* about 19 to 23 Ma), late Early to early Middle Miocene (late Burdigalian, early Langhian; *i.e.* about 14.5 to 19 Ma), late Middle Miocene (late Langhian, Serravalian; *i.e.* about 11.6 to 14.5 Ma), Late Miocene to earliest Pliocene (Tortonian, Messinian, early Zanclean; *i.e.* about 5 to 11.6 Ma), and Pliocene (late Zanclean, Piacenzian; *i.e.* about 2.6 to 9 Ma). In total, we studied 107 assemblages (Table 1).

Taxonomic, physiognomic, and autecological components

In our application of IPR to analyse fossil plant assemblages, the same groupings as those of previous workers was

Table 1. Fossil sites used for the palaeoclimatic reconstruction.

#	Locality	Name	Province	Formation	Lat	Long	Organ	Reference
Early–Early Miocene								
1	Fushan	Fushan 1	Hainan	Xiayang	19.83	109.93	P	Sun *et al.* (1981)
2	Beibuwan	Beibuwan 1	Guangxi	Xiayang	20.50	108.50	P	Sun *et al.* (1981)
3	Weizhou	Weizhou	Guangxi	Weizhou	21.03	109.05	P	Wu (1980)
4	Leizhou	Leizhou 1	Guangdong	Xiayang	21.75	110.00	P	Sun *et al.* (1981)
5	Zhujiangkou	Zhujiangkou 1	Guangdong	Zhujiang	22.42	113.75	P	Sun *et al.* (1981)
6	Toupo	Toupo 1	Jiangxi	Middle Toupo	26.83	116.32	P	Sun & He (1987)
7	Dingqing	Dingqing 1	Tibet	Lower Dingqing	32.50	90.00	P	Wang *et al.* (1975)
8	Tianchang, Anhui	Tianchang-B	Anhui		32.68	119.00	P	Zheng & Zhang (1986)
9	Xining-Mangle	Xining 1	Qinghai	Xiejia	36.33	102.00	P	Sun *et al.* (1984)
10	Xiejia	Xiejia	Qinghai	Xiejia	36.53	101.85	P	Wang & Deng (2009)
11	Bozhong Basin	Bozhong 1	Shandong	Guantao	36.97	119.00	P	Yao *et al.* (1994)
12	Bohai Gulf	Bohai 1	Hebei	Guantao	39.00	119.00	P	Guan *et al.* (1982)
13	Wuluogong	Wuluogong	Hebei		40.77	114.88	P	Gan (1982)
14	Kuche Basin	Kuche 1	Xinjiang	Jidike	41.73	82.92	P	Sun & Sun (1984)
15	Shangdou-Huade Basin	Shangdou 1	Inner Mongolia		42.00	114.00	P	Wang & Zhang (1990)
16	Weichang	Weichang	Hebei	Hannuoba	42.57	117.84	P	Li *et al.* (2009)
17	Dunhua	Dunhua	Jilin	Qiuligou	43.35	128.18	L	Li & Yang (1984)
48	Junggar Basin	Huoerguosi	Xinjiang		44.50	85.50	P	Sun & Wang (1990)
48	Junggar Basin	Xican 1	Xinjiang	Shanwan-Taxihe	44.50	85.50	P	Sun & Wang (1990)
48	Junggar Basin	Dushanzi	Xinjiang		44.50	85.50	P	Sun & Wang (1990)
Late Early–early Middle Miocene								
2	Beibuwan	Beibuwan 2	Guangxi	Jiaowei	20.50	108.50	P	Sun *et al.* (1981)
4	Leizhou	Leizhou 2	Guangdong	Jiaowei	21.75	110.00	P	Sun *et al.* (1981)
5	Zhujiangkou	Zhujiangkou 2	Guangdong	Lower Hanjiang	22.42	113.75	P	Sun *et al.* (1981)
6	Toupo	Toupo 2	Jiangxi	Upper Toupo	26.83	116.32	P	Sun & He (1987)
11	Bozhong Basin	Bozhong 2	Shandong	Lower Minghuazhen	36.97	119.00	P	Yao *et al.* (1994)
12	Bohai Gulf	Bohai 2	Hebei	Lower part Minghuazhen	39.00	119.00	P	Guan *et al.* (1982)
18	Jinggu	Jinggu 1	Yunnan		23.50	100.70	P	Song & Zhong (1984)
19	Yalong	Yalong	Guangxi		23.98	107.84	P	Wang (1989)
20	Zhangpu	Zhangpu	Fujian	Fotan	24.12	117.61	P	Zheng (1987), Zheng & Wang (1994)
21	Shihdi	Shihdi	Taiwan	Taliao/Tsouho transition	25.05	121.50	L	Chaney & Chuang (1968)
22	Ji'an	Ji'an	Jiangxi		27.20	115.13	P	Sun & He (1987)
23	Nanfeng	Nanfeng	Jiangxi		27.22	116.53	P	Sun & He (1987)
24	Xianju	Xianju	Zhejiang		28.85	120.73	P	Zheng (1982)
25	Dunhuang	Dunhuang 1	Gansu		40.00	94.72	P	Ma (1991)
26	Pingzhuang	Pingzhuang	Inner Mongolia		42.01	119.22	L	Zhang (1986)
27	Hunchun	Hunchun	Jilin	Tumenzi	41.85	130.00	P	Zhao *et al.* (2004)
28	Tongguer	Tongguer	Inner Mongolia		43.95	116.07	P	Wang (1990)
29	Huanan	Huanan	Heilongjiang	Daodaiqiao	47.00	130.00	L, P	Liu *et al.* (1995), Liu (1998)
48	Junggar Basin	Xican 2	Xinjiang	Shanwan-Taxihe	44.50	85.50	P	Sun & Wang (1990)
Late Middle Miocene								
9	Xining-Mangle	Xining 2	Qinghai	Chetougou	36.33	102.00	P	Sun *et al.* (1984)
30	Mangdan	Mangdan	Yunnan	Nanlin	24.40	97.82	F	Zhao *et al.* (2004)
31	Tianchang, Jiangsu	Tianchang-A	Jiangsu	Yancheng	33.00	118.00	P	Zhang *et al.* (1993)
32	Zhoukou	Zhoukou 1	Henan	Guantao	33.63	114.63	P	Zhang *et al.* (1993)

Table 1. continued

#	Locality	Name	Province	Formation	Lat	Long	Organ	Reference
33	Shanwang	Shanwang	Shandong		36.90	118.33	L, P	Sun *et al.* (2002)
34	Jidong	Jidong	Heilongjiang		45.20	131.00	P	Shu *et al.* (2008)
Late Miocene–earliest Pliocene								
1	Fushan	Fushan 3	Hainan	Dengloujiao	19.83	109.93	P	Sun *et al.* (1981)
2	Beibuwan	Beibuwan 3	Guangxi	Dengloujiao	20.50	108.50	P	Sun *et al.* (1981)
4	Leizhou	Leizhou 3	Guangdong	Dengloujiao	21.75	110.00	P	Sun *et al.* (1981)
5	Zhujiangkou	Zhujiangkou 3	Guangdong	Upper Hanjiang	22.42	113.75	P	Sun *et al.* (1981)
7	Lunpola	Lunpola	Tibet		32.50	90.00	P	Wang *et al.* (1975)
7	Dingqing	Dingqing 2	Tibet	Upper Dingqing	32.50	90.00	P	Wang *et al.* (1975)
9	Xining-Mangle	Xining 3	Qinghai	Xianshuihe	36.33	102.00	P	Sun *et al.* (1984)
11	Bozhong Basin	Bozhong 3	Shandong	Upper Minghuazhen	36.97	117.20	P	Yao *et al.* (1994)
12	Bohai Gulf	Bohai 3	Hebei	Upper Minghuazhen	39.00	119.00	P	Guan *et al.* (1982)
14	Kuche Basin	Kuche 2	Xinjiang		41.73	82.92	P	Jin *et al.* (2002)
18	Jinggu	Jinggu 2	Yunnan		23.50	100.70	P	Song & Zhong (1984)
25	Dunhuang	Dunhuang 2	Gansu	Xishuigou	40.00	94.72	P	Ma (1991)
35	Yinggehai	Yinggehai 3	Hainan	Lower Yinggehai	18.52	108.70	P	Sun *et al.* (1981)
36	Xiaolongtan	Xiaolongtan	Yunnan	Xiaolongtan	23.70	103.23	L	Tao *et al.* (2000), Xia *et al.* (2009)
37	Lincang	Lincang	Yunnan	Bangmai	23.90	100.02	L	Guo (2011), Jacques *et al.* (2011a)
38	Lühe	Lühe	Yunnan	Xiaolongtan	25.17	101.37	P	Xu *et al.* (2008)
39	Qujing	Qujing 1	Yunnan		25.52	103.88	P	Wang & Shu (2004)
40	Zhaotong	Zhaotong	Yunnan		27.34	103.72	P	Song (1988)
41	Markam	Markam	Tibet	Lawula	29.63	98.68	L, P	Tao & Du (1987)
42	Namling	Namling	Tibet	Upper Wulong	29.72	89.00	L	Li & Guo (1976)
43	Wulong	Wulong	Tibet	Upper Wulong	29.75	89.02	P	Song & Liu (1982)
44	Zhada	Zhada 1	Tibet		32.33	81.08	P	Li & Liang (1983)
45	Songpan	Maladun	Sichuan		32.63	103.62	L, P	Liu & Li (2002)
46	Huanghai	Huanghai 2	Jiangsu		34.83	119.12	P	Zheng *et al.* (1981)
47	Dafengshan	Dafengshan	Qinghai		36.83	94.90	P	Zhu *et al.* (1985)
48	Junggar Basin	Xican 3	Xinjiang	Shanwan-Taxihe	44.50	85.50	P	Sun & Wang (1990)
Pliocene								
2	Beibuwan	Beibuwan 4	Guangxi	Wanglougang	20.50	108.50	P	Sun *et al.* (1981)
3	Jiaowei	Jiaowei	Guangxi		21.03	109.05	P	Wu (1980)
4	Leizhou	Leizhou 4	Guangdong	Wanglougang	21.75	110.00	P	Sun *et al.* (1981)
5	Zhujiangkou	Zhujiangkou 4	Guangdong	Yuehai	22.42	113.75	P	Sun *et al.* (1981)
11	Bozhong Basin	Bozhong 4	Shandong		36.97	117.20	P	Yao *et al.* (1994)
15	Shangdou-Huade Basin	Shangdou 3	Inner Mongolia		42.00	114.00	P	Wang & Zhang (1990)
32	Zhoukou	Zhoukou 2	Henan	Minghuazhen	33.63	114.63	P	Zhang *et al.* (1993)
39	Qujing	Qujing 2	Yunnan		25.52	103.88	P	Wang & Shu (2004)
44	Zhada	Zhada 2	Tibet		32.33	81.08	P	Li & Liang (1983)
46	Huanghai	Huanghai 1	Jiangsu		34.83	119.12	P	Zheng *et al.* (1981)
49	Longling	Longling	Yunnan	Yangyi	24.68	98.83	P	Xu *et al.* (2004)
50	Eryuan	Eryuan	Yunnan		26.10	99.93	L P	Tao & Kong (1973), Kou *et al.* (2006)
51	Lanping	Lanping	Yunnan		26.41	99.00	L	Tao (1986)
52	Dechang	Sigeda	Sichuan	Sigeda	27.40	102.15	L	Guo (1978)
53	Shisha Pangma	Shisha Pangma	Tibet		28.33	85.75	L, P	Hsü *et al.* (1973)
54	Yaruxiongla	Yaruxiongla	Tibet		28.56	86.52	P	Li (1983)

Table 1. continued

#	Locality	Name	Province	Formation	Lat	Long	Organ	Reference
55	Gyirong	Woma	Tibet		28.93	85.28	P	Zheng (1983)
56	Burang	Disong	Tibet		30.33	81.08	P	Cao (1982)
57	Changtai	Changtai	Sichuan		31.02	99.60	P	Liu & Li (2002)
58	Xiangzi	Xiangzi	Tibet		31.83	79.58	P	Li & Liang (1983)
59	Nanjing	Nanjing	Jiangsu		31.98	118.76	L	Li, H.M. *et al.* (1984)
60	Xixi	Xixi	Tibet		32.30	81.02	P	Li & Liang (1983)
61	Shuijiazui Village	Shuijiazui	Shaanxi	Bahe	34.22	109.10	P	IBIG (1966)
62	Koujia Village	Koujia	Shaanxi	Bahe	34.23	109.13	P	IBIG (1966)
63	Zhenquancuo Lake	Zhenquancuo 1	Tibet		36.00	87.00	P	Huang & Liang (1983)
64	Zhenquancuo Lake	Zhenquancuo 2	Tibet		36.02	87.02	P	Huang & Liang (1983)
65	Zhangqiu	Zhangqiu	Shandong		36.72	117.45	P	Wang *et al.* (2002)
66	Ruoqiang	Ruoqiang	Xinjiang		37.22	88.53	L	Guo & Gu (1993)
67	Jinzhong Basin	Jinzhong	Shanxi		37.68	112.75	P	Li, Y.T. *et al.* (1984)
68	Shuoxian	Shuoxian	Shanxi		39.33	112.43	P	Tang & Liu (1984)
69	Shanyin	Shanyin	Shanxi		39.53	112.82	P	Tang & Liu (1984)
70	Yingxian	Yingxian	Shanxi		39.55	113.18	P	Tang & Liu (1984)
71	Datong City	Datong	Shanxi		40.08	113.30	P	Tang & Liu (1984)
72	Laoyeling	Laoyeling	Jilin		43.68	127.20	P	Li, Y.T. *et al.* (1984)
73	Qian'an	Qian'an	Jilin		44.78	123.73	P	Jia *et al.* (1989)
74	Tengchong	Tengchong	Yunnan		25.00	98.52	L	Tao & Du (1982)

followed (Kovar-Eder & Kvaček 2003, Jechorek & Kovar-Eder, 2004, Kovar-Eder *et al.* 2008, Jacques *et al.* 2011b). Twelve components are listed as follow:

CON: zonal and extrazonal conifers, grouping all conifers; BLD: broad-leaved deciduous woody angiosperms, leaf-size microphyll, notophyll or mesophyll, leaf texture thin; BLE: broad-leaved evergreen woody angiosperms, leaf-size microphyll, notophyll or mesophyll, leaf texture coriaceous; SCL: sclerophyllous woody angiosperms, leaf-size nanophyll to microphyll, texture thick; LEG: legume-type woody angiosperms, leaf-size or leaflet-size leptophyll to nanophyll; PALM: zonal palms; MEH: mesophytic herbs, herbaceous plants growing in forest understory; DRH: dry land herbs, herbaceous plants growing in open woodlands and grasslands; FERN: ferns, both zonal and azonal; AZW: azonal woody plants, azonal conifers and azonal woody angiosperms; AZH: azonal herbs, reeds, sedges, and other halophytes; AQU: aquatic plants, all hydrophytes.

Fossil taxa were assigned to these components primarily based on the characteristics of their nearest living relatives. Previously published databases (Kovar-Eder & Kvaček 2007, Jacques *et al.* 2011b) and the IPR online database (http://www.iprdatabase.eu/; Teodoridis *et al.* 2011a) were used. Where some fossils were not listed in these databases, the physiognomic and autecological information was checked with reference to local floras or discussion with local botanists. For the palynological record, Song *et al.* (2004) and Yao *et al.* (2011) were a valuable source of information for the nearest living relatives. The data we used are available online (http://www.iprdatabase.eu/).

Vegetation types

The vegetation type of each fossil assemblage was determined by the relative proportions of the different IPR components (Kovar-Eder *et al.* 2008). Recently, new ranges were defined to better accommodate ecotones between the different types of forests (Teodoridis *et al.* 2011b). As there are no major differences between the old and the new thresholds and in order to allow easy comparison with the former publication on south China (Jacques *et al.* 2011b), the original six zonal vegetation types were kept (Kovar-Eder *et al.* 2008):

Zonal temperate to warm-temperate broad-leaved deciduous forests, defined as BLD ≥ 80% of woody angiopserms, and zonal herbs (MEH+DRH) ≤ 30% of all zonal taxa.

Zonal warm-temperate to subtropical mixed mesophytic forests, defined as BLD < 80%, BLE < 30%, SCL+LEG < 20% of woody angiosperms; zonal herbs < 30% of all zonal taxa.

Zonal subtropical broad-leaved evergreen forests, defined as BLE ≥ 30% of woody angiosperms and SCL+LEG < BLE.

Table 2. Reconstructed vegetations and proportion of zonal components. Vegetation type: 1 – broad-leaved deciduous forest; 2 – mixed mesophytic forest; 3 – broad-leaved evergreen forest; 4 – subhumid sclerophyllous or microphyllous forest; 5 – xeric woodland; 6 – xeric grasslands or steppe.

Name	Number	Zonal Woody Angiosperm (%)	BLD (%)	BLE (%)	SCL+LEG (%)	Zonal Herb (%)	DRH (%)	Vegetation Type
Beibuwan 1	2	65.4	50.2	32.7	9.6	15.0	10.6	3
Beibuwan 2	2	59.1	53.1	35.3	11.7	18.4	9.7	3
Beibuwan 3	2	65.1	47.2	40.4	12.5	16.3	11.5	3
Beibuwan 4	2	57.5	46.8	39.2	14.0	16.2	6.1	3
Bohai 1	12	56.3	79.6	16.6	3.8	24.5	9.0	1
Bohai 2	12	63.4	79.6	16.6	3.8	18.6	10.2	1
Bohai 3	12	32.4	82.7	8.6	8.6	50.7	23.2	6
Bozhong 1	11	52.2	74.2	20.0	5.8	24.1	11.4	2
Bozhong 2	11	55.1	74.2	20.0	5.8	19.8	12.0	2
Bozhong 3	11	54.2	82.6	13.5	3.9	23.1	14.0	1
Bozhong 4	11	45.8	87.0	8.5	4.5	26.3	15.5	1
Changtai	57	43.9	66.2	13.9	20.0	27.7	23.0	4
Dafengshan	47	39.2	56.7	27.4	16.0	30.8	20.3	6
Datong	71	47.4	71.2	10.7	18.0	24.5	12.8	2
Dingqing 1	7	41.7	72.7	9.6	17.8	23.9	13.7	2
Dingqing 2	7	54.6	82.3	0	17.7	20.9	7.1	1
Disong	56	60.7	54.5	32.8	12.7	24.2	16.1	3
Dunhua	17	55.6	84.0	8.0	8.0	0	0	1
Dunhuang 1	25	42.3	71.5	14.0	14.5	54.0	36.4	6
Dunhuang 2	25	44.5	72.7	8.2	19.1	37.2	29.2	6
Dushanzi	48	47.3	75.5	12.7	11.8	33.1	12.7	5
Eryuan	50	64.1	64.7	29.1	6.2	0	0	2
Fushan 1	1	79.6	53.9	46.1	0	8.1	4.1	3
Fushan 3	1	82.2	40.1	40.1	7.4	7.7	0	3
Huanan	29	66.2	83.1	9.0	7.9	11.3	3.7	1
Huanghai 1	46	52.2	61.8	24.6	13.6	28.9	16.1	2
Huanghai 2	46	57.6	62.6	22.7	14.7	22.8	12.8	2
Hunchun	27	66.6	73.0	17.0	10.0	12.0	4.0	2
Huoerguosi	48	55.9	66.0	24.0	10.0	19.0	12.0	2
Ji'an	22	64.3	52.4	30.6	11.3	17.6	10.8	3
Jiaowei	3	62.8	51.1	33.9	12.6	22.1	6.2	3
Jidong	34	65.2	62.4	23.4	14.1	17.1	7.9	2
Jinggu 1	18	38.9	67.0	26.7	6.4	3.3	1.7	2
Jinggu 2	18	38.9	67.0	26.7	6.4	3.3	1.7	2
Jinzhong	67	31.3	100	0	0	26.9	20.1	1
Koujia	62	44.1	68.1	12.0	19.9	27.6	20.7	4
Kuche	14	65.8	58.7	23.3	12.7	13.1	8.3	2
Lanping	51	88.8	2.52	78.2	19.3	0	0	3
Laoyeling	72	86.7	72.0	17.2	10.8	0	0	2
Leizhou 1	4	63.2	53.8	36.3	9.9	12.5	7.0	3
Leizhou 2	4	68.6	49.4	30.7	10.9	16.1	6.1	3
Leizhou 3	4	65.8	51.3	30.7	12.3	19.4	7.4	3
Leizhou 4	4	64.7	51.8	36.2	12.0	16.2	8.5	3
Lincang	37	96.3	26.0	63.1	10.9	1.9	1.6	3
Longling	49	57.8	41.4	32.4	21.1	31.8	16.7	6

Table 2. continued

Name	Number	Zonal Woody Angiosperm (%)	BLD (%)	BLE (%)	SCL+LEG (%)	Zonal Herb (%)	DRH (%)	Vegetation Type
Lühe	38	63.1	45.6	34.3	14.6	21.2	9.7	3
Lunpola	7	60.6	82.6	7.6	9.8	27.5	15.7	1
Maladun	45	77.0	74.1	5.4	20.4	2.1	0	4
Mangdan	30	91.8	47.1	48.4	4.5	8.2	4.1	3
Markam	41	70.6	91.3	4.4	4.4	15.3	12.3	1
Namling	42	94.0	44.6	39.3	16.1	6.1	4.0	3
Nanfeng	23	64.8	59.6	29.5	6.4	17.7	11.8	2
Nanjing	59	100	50	10	39	0	0	2
Pingzhuang	26	100	88.2	5.9	5.9	0	0	1
Qian'an	73	56.3	77.0	17.6	5.4	20.3	13.1	2
Qujing	39	53.2	76.1	6.5	17.4	12.1	10.4	2
Ruoqiang	66	35.9	77.8	11.1	11.1	56.1	42.4	6
Shangdou 1	15	51.0	68.4	16.6	15.0	13.4	9.6	2
Shangdou 3	15	22.9	54.9	22.6	22.6	37.1	28.1	6
Shanwang	33	99.4	70.8	22.5	6.7	0.6	0.6	2
Shanyin	69	50.7	72.0	6.0	22.0	27.3	13.7	4
Shihdi	21	98.6	27.5	61.9	4.9	1.4	0	3
Shisha Pangma	53	48.3	80.0	10.0	10.0	8.3	3.2	1
Shuijiazui	61	42.5	58.8	7.1	34.1	33.5	17.4	5
Shuoxian	68	50.9	79.2	3.7	17.1	24.0	14.6	2
Sigeda	52	100	21.8	75.2	3.0	0	0	3
Tengchong	74	88.1	51.4	34.3	14.4	0	0	3
Tianchang-A	31	55.0	58.2	22.8	19.0	9.6	2.2	2
Tianchang-B	8	62.3	66.7	20.5	12.8	6.1	1.4	2
Tongguer	28	58.9	57.6	31.3	11.1	33.9	25.0	5
Toupo 1	6	62.2	51.5	31.0	14.5	12.7	5.6	3
Toupo 2	6	61.0	56.3	30.3	13.4	18.2	11.5	3
Weichang	16	54.7	75.0	8.8	16.2	29.8	13.9	6
Weizhou	3	67.6	47.6	33.7	16.4	20.0	7.2	3
Woma	55	45.1	69.0	14.3	16.7	28.4	13.7	2
Wulong	43	75.6	63.4	26.9	9.7	0	0	2
Wuluogong	13	45.9	67.5	21.2	11.3	11.9	7.9	2
Xiangzi	58	45.0	76.7	12.1	11.2	27.7	22.2	2
Xianju	24	65.5	51.3	20.4	28.3	14.0	5.3	4
Xiaolongtan	36	97.6	29.7	53.4	16.9	2.4	1.8	3
Xican 1	48	64.5	62.0	24.0	14.0	34.0	25.0	5
Xican 2	48	55.4	66.6	20.7	12.7	30.7	26.1	5
Xican 3	48	57.3	72.8	16.5	10.7	17.9	10.8	2
Xiejia	10	42.2	72.4	6.4	21.2	36.3	22.0	6
Xining 1	9	55.6	54.4	21.7	23.9	18.4	14.0	4
Xining 2	9	41.5	68.7	12.0	19.3	34.4	25.9	5
Xining 3	9	57.7	56.1	28.2	15.8	27.6	18.4	2
Xixi	60	32.5	80.2	6.2	13.6	31.4	26.7	6
Yalong	19	78.5	39.0	38.3	22.7	20.0	10.6	3
Yaruxiongla	54	45.3	60.1	20.0	20.0	19.6	5.1	4
Yinggehai 3	35	44.7	53.0	33.2	13.8	25.4	14.4	3

Table 2. continued

Name	Number	Zonal Woody Angiosperm (%)	BLD (%)	BLE (%)	SCL+LEG (%)	Zonal Herb (%)	DRH (%)	Vegetation Type
Yingxian	70	47.8	63.1	14.6	22.2	29.9	14.0	5
Zhada 1	44	38.2	59.5	19.1	21.4	25.3	20.1	4
Zhada 2	44	21.1	65.6	10.4	24.1	30.7	24.8	4
Zhangpu	20	70.3	33.2	43.1	18.1	13.8	5.0	3
Zhangqiu	65	48.8	76.4	7.8	15.8	28.0	20.2	2
Zhaotong	40	85.6	29.6	58.9	11.6	0.6	0.6	3
Zhenquancuo 1	63	37.1	65.5	12.9	21.5	41.7	19.0	6
Zhenquancuo 2	64	39.4	74.1	9.2	16.8	37.1	19.1	5
Zhoukou 1	32	55.6	68.1	21.2	10.8	17.5	9.4	2
Zhoukou 2	32	69.5	71.6	15.7	12.6	14.5	9.9	2
Zhujiangkou 1	5	83.4	48.2	36.2	7.6	0	0	3
Zhujiangkou 2	5	81.8	35.3	42.0	9.4	7.2	3.6	3
Zhujiangkou 3	5	72.1	37.6	42.7	9.6	9.6	4.8	3
Zhujiangkou 4	5	65.2	30.7	42.1	10.3	10.0	5.9	3

Zonal subtropical, subhumid sclerophyllous or microphyllous forests, defined as SCL+LEG ≥ 20% of woody angiosperms and zonal herbs < 30% of all zonal taxa.

Zonal xeric woodlands, defined as SCL+LEG ≤ 20% of woody angiosperms, zonal herbs = 30–40% of all zonal taxa, and MEH > DRH.

Zonal xeric grasslands or steppe, defined as zonal herbs > 40% of all zonal taxa.

Vegetation mapping

The software ArcGIS 9.3 was used to map the vegetational record. We applied the 'inverted distance weighted' algorithm to reconstruct vegetation between neighbouring sites. This algorithm allows interpolation between points, giving more weight to the nearest neighbour points and less weight to the furthest distant points. The following settings were chosen: power 2, variable search radius type, number of points 12, cell size 0.1°. The interpolation was limited to a 3° radius around the sites to prevent over-interpolation.

Results

Vegetation reconstructions

The proportions of each component and reconstructed vegetational types are indicated for all sites (Table 2). All six types of vegetation have been reconstructed. There are great variations among proportions of woody angiosperms and proportions of zonal herb (21.1 to 100% and 0 to 56.1%, respectively). The number of floras for each vegetation type according to age is summarised (Table 3).

Regional and stratigraphic ranges of the vegetation types

Broad-leaved deciduous forests

Twelve floras are assigned to broad-leaved deciduous forests: two from the early Early Miocene in north China, three from the late Early to early Middle Miocene in north China, four for the Late Miocene to earliest Pliocene in north China and on the Tibetan Plateau, and three from the Pliocene in north China and on the Tibetan Plateau. They are represented both by pollen and leaf assemblages. The percentage of herbaceous components varies from 0 to 27.5%.

Mixed mesophytic forests

Thirty-three floras are reconstructed as mixed mesophytic forests: seven from the early Early Miocene in eastern, northern and western China and on the Tibetan Plateau, four from the late Early to early Middle Miocene in northern, eastern and southern China, four from the late Middle Miocene in northern and eastern China, six from the Late Miocene to earliest Pliocene in eastern, western and southwestern China, and on the Tibetan Plateau, and twelve from the Pliocene in northern, eastern and south western China and on the Tibetan Plateau. They are also represented both by pollen and leaf assemblages. The percentage of herbaceous components varies from 0 to 28.9%.

Broad-leaved evergreen forests

Thirty-three sites are assigned to broad-leaved evergreen forests: six from the early Early Miocene, eight from the late Early to early Middle Miocene, one from the late Middle

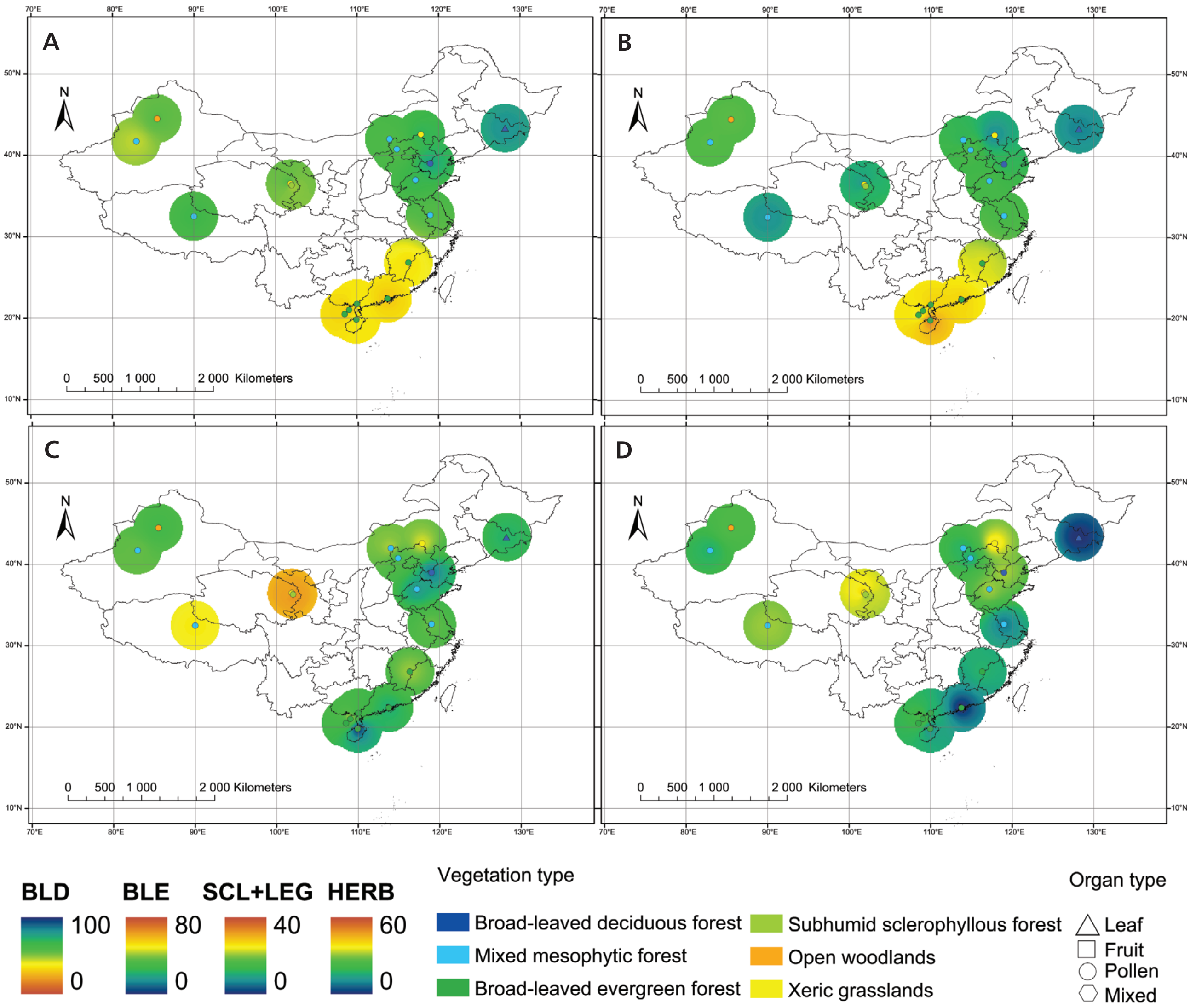

Figure 2. Interpolation of vegetation components during the early Early Miocene. The type of organ found in the assemblage is given by the symbol shape; the colour inside the symbol represents the vegetation types. Colour gradients represent the percentage of a component. • A – the gradient represents the BLD component; B – the gradient represents the BLE component; C – the gradient represents the SCL+LEG components; D – the gradient represents the HERB (MEH+DRH) component.

Miocene, ten from the Late Miocene to earliest Pliocene and eight from the Pliocene. They all occur in south China, except Disong from the Pliocene of the Tibetan Plateau. They are represented by fruit, pollen and leaf assemblages. The percentage of herbaceous components varies from 0 to 25.4%.

Subhumid sclerophyllous forests

Nine sites represented both by leaf and pollen assemblages are reconstructed as subhumid sclerophyllous forests: one from the early Early Miocene of western China, one from the late Early to early Middle Miocene of eastern China, two from the Late Miocene to earliest Pliocene of western China and the Tibetan region, and five from the Pliocene of western China, northern China and the Tibetan region.

Open woodlands

Eight sites, all from pollen assemblages, are assigned to open woodlands: two from the early Early Miocene in western China, two from the late Early to early Middle Miocene in northern and western China, one from the late Middle Miocene in western China, and three from the Pliocene in north China and on the Tibetan Plateau.

Xeric grasslands

Six sites based on leaf or pollen assemblages are reconstructed as xeric grasslands: two from the early Early Miocene in northern and western China, one from the late Early to early Middle Miocene in western China, four

Table 3. Number of reconstructed floras for each vegetation type and each age interval. Vegetation type: 1 – broad-leaved deciduous forest; 2 – mixed mesophytic forest; 3 – broad-leaved evergreen forest; 4 – subhumid sclerophyllous or microphyllous forest; 5 – xeric woodland; 6 – xeric grasslands or steppe.

Vegetation type	1	2	3	4	5	6	Total
Pliocene	3	12	8	5	3	5	36
Late Miocene–earliest Pliocene	4	4	10	2	0	4	24
Late Middle Miocene	0	4	1	0	1	0	6
Late Early–early Middle Miocene	3	6	8	1	2	1	21
Early Early Miocene	2	7	6	1	2	2	20
Total	12	33	33	9	8	12	107

from the Late Miocene to earliest Pliocene in northern and western China, and five from the Pliocene in northern, western and southwestern China and on the Tibetan Plateau.

Vegetation changes through time

Early Early Miocene (Fig. 2)

There is a latitudinal gradient from evergreen forest to deciduous forest. Only Qinghai and Tibet show some slightly arid areas. Western China is humid.

Late Early to early Middle Miocene (Fig. 3)

There is increasing aridity in western China with a strong increase in the herb component in Xinjiang. More open vegetation appears in western China.

Late Middle Miocene (Fig. 4)

Only a few sites are available in south China for this time interval. North China is still humid and warm with a mixed mesophytic forest.

Late Miocene to earliest Pliocene (Fig. 5)

Western China is arid but central China is less arid. Evergreen forests are present in south and southwest China. Aridity is increasing in north China.

Pliocene (Fig. 6)

In the Pliocene, the most important changes occur in north and northeast China. There is an increase of deciduous and herb components. Western China is still arid. Evergreen forests are still dominant in south China. There is a diversity of vegetation types in southwest China (Hengduan Mountains).

Discussion

Neogene cooling

From the Early Miocene to the Pliocene, there is a reduction of the BLE component in north China. This reduction is associated with a cooling in north China. This is part of the global cooling trend of the Neogene (Zachos *et al.* 2001). The mid and high latitudes are warmer during the Miocene than at present times (Wolfe 1994; White *et al.* 1997; Stepphun *et al.* 2006, 2007; Micheels *et al.* 2011; Utescher *et al.* 2011). The latitudinal temperature gradients increased during the Pliocene.

When forests are present, albedo is reduced and temperatures can be higher (Tong *et al.* 2009). Aridification and opening up of the vegetation during the Neogene may have reinforced the cooling of these regions.

Aridification of north and west China

Our results show an increase in the sclerophyllous and herbaceous components during the Neogene in west, central and north China. These results are in agreement with previous studies (Wang 1994, Sun & Wang 2005, Jiang & Ding 2009, Liu *et al.* 2011). This increase of sclerophyllous and herbaceous components has been described as the extension of the inland palynofloristic region to Inner Mongolia and north China (Wang 1994).

However, central China is not as dry during the Late Miocene as during the Pliocene or at present (Fig. 5). Most of the proxies, including isotopes (Dettman *et al.* 2003), grain size (Sun 2004, Fan *et al.* 2006), hypsodonty (Liu *et al.* 2009) and pollen (*e.g.*, Jiang & Ding 2009), point towards a step evolution of aridification. These steps are mostly: around 15–13 Ma (late Middle Miocene), around 10–8 Ma (Late Miocene) and around 3 Ma (Pliocene) (Sun *et al.* 1998, Ding *et al.* 1999, Qiang *et al.* 2001, Sun & Wang 2005, Wan *et al.* 2007, Molnar *et al.* 2010).

Because of the small number of late Middle Miocene sites included in this study, we could not study the 15–13 Ma step. The evolution between the late Middle Miocene and Late Miocene is also difficult to reconstruct; there is slight aridification in northern China, but restricted to some sites (Fig. 5). Therefore, we focus on the 3 Ma aridification that is pronounced in north China (Fig. 6).

From our results, there is a clear contrast between north and south China. While north China undergoes an important aridification, there is no noticeable change in the vegetation of south China. The Pliocene is thus characterized by an increasing contrast in vegetation between south and north China.

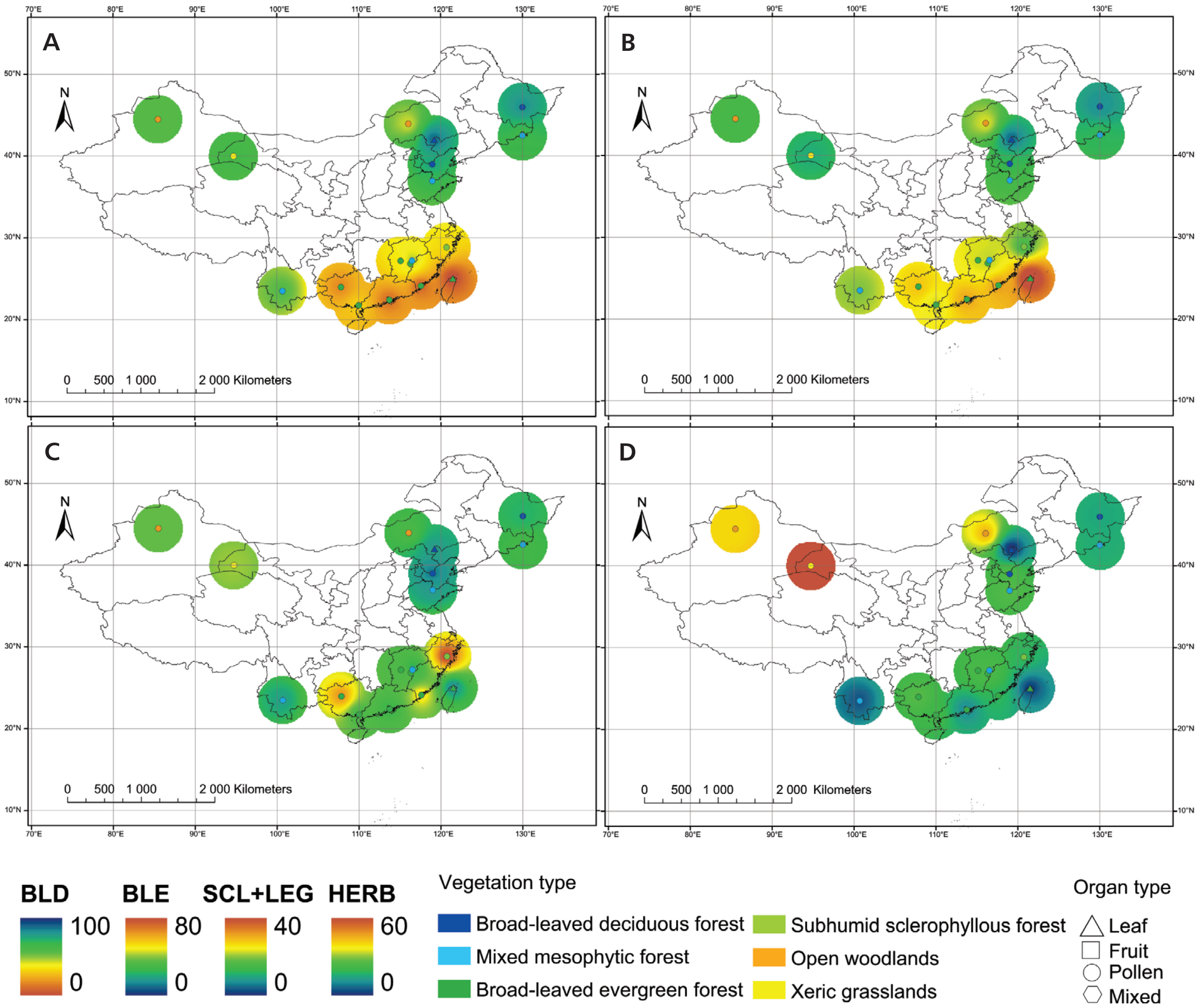

Figure 3. Interpolation of vegetation components during the late Early–early Middle Miocene. The type of organ found in the assemblage is given by the symbol shape; the colour inside the symbol represents the vegetation types. Colour gradients represent the percentage of a component. • A – the gradient represents the BLD component; B – the gradient represents the BLE component; C – the gradient represents the SCL+LEG components; D – the gradient represents the HERB (MEH+DRH) component.

Evolution of the monsoon

In China precipitation is mainly controlled by the monsoon: in summer, the Southeast Asian summer monsoon brings water to the Chinese inland; in winter, the winter monsoon brings aridity in northern China (Liu & Yin 2002). However, besides the monsoon, the westerlies play also an important role in the circulation of air masses in China (Rea *et al.* 1998, Sun 2004). The reorganization of the climate system in China at the Oligocene-Miocene boundary (the broad Paleogene aridity belt that covered most of China was reduced to its western part) has been linked with the development of the Southeast Asian summer monsoon (Sun & Wang 2005). Theoretically, considering all these movements of air masses, aridification of west, central and north China during the Neogene may be linked to either a weakening of the Southeast Asian summer monsoon or a strengthening of the winter monsoon.

West China is still humid during the early Miocene (Fig. 2). This may be due to humidity brought by the Paratethys Sea, which had not totally retreated at that time (Dercourt *et al.* 1993, Rögl 1998, Harzhauser & Piller 2007).

During the aridification of west, central and north China occurring at the Late Miocene-Pliocene transition, there is no major change in the vegetation of south China in our results; therefore, we reject a weakening of the summer monsoon. Palaeoclimatic reconstructions in southwest China during the Late Miocene (Xia *et al.* 2009; Jacques *et al.* 2011a, 2011c) indicate higher precipitation than today, especially in winter and only slightly in summer. Therefore,

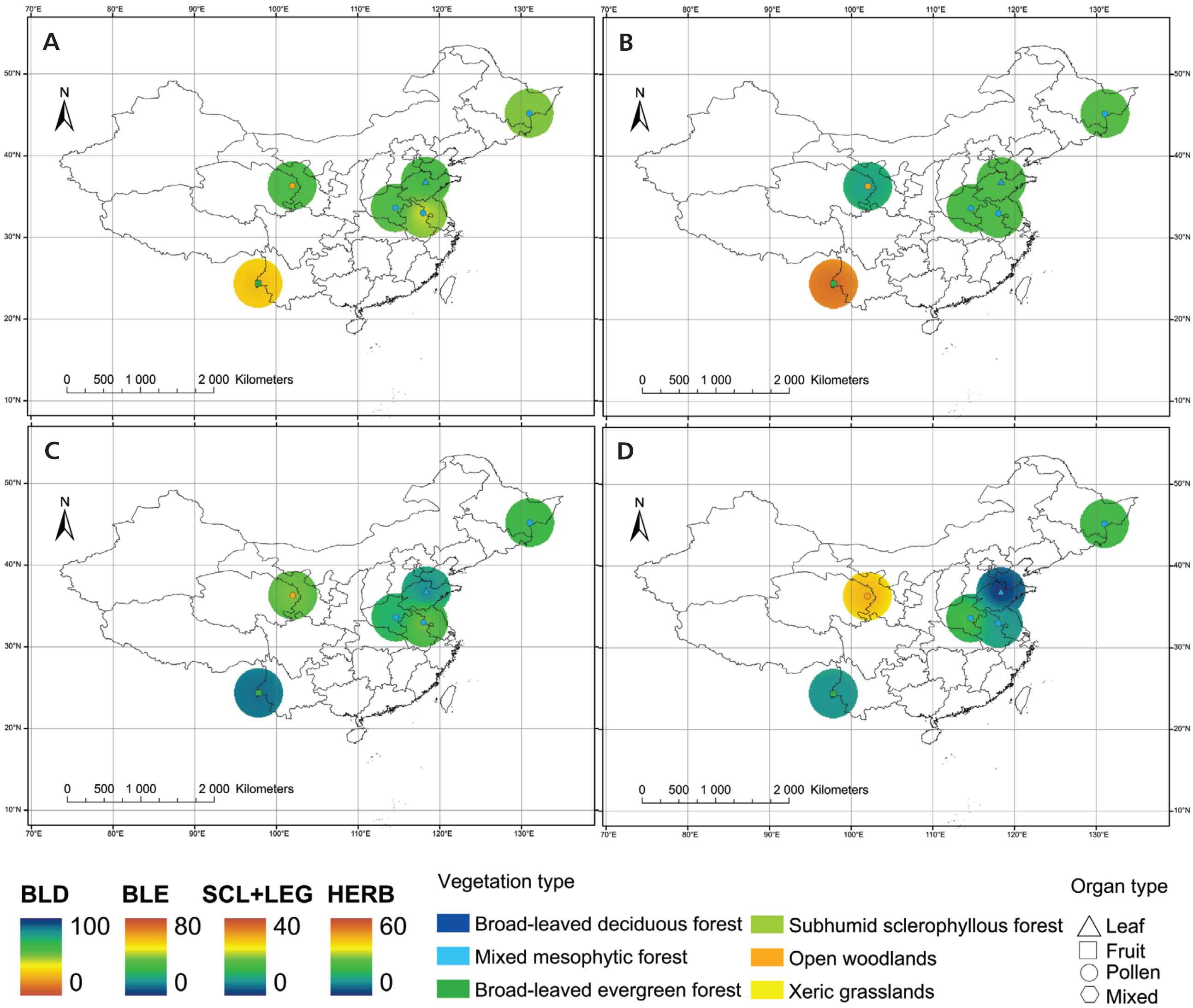

Figure 4. Interpolation of vegetation components during the late Middle Miocene. The type of organ found in the assemblage is given by the symbol shape; the colour inside the symbol represents the vegetation types. Colour gradients represent the percentage of a component. • A – the gradient represents the BLD component; B – the gradient represents the BLE component; C – the gradient represents the SCL+LEG components; D – the gradient represents the HERB (MEH+DRH) component.

the aridification of west, central and north China can only be explained by a strengthening of the winter monsoon. At the same time, the westerlies may have decreased over north China (Sun 2004). Because the Paratethys had already retreated during the Middle to Late Miocene (Harzhauser & Piller 2007), stronger westerlies would not bring large amounts of water anyway. Our results of a weak winter monsoon during the Late Miocene differ from some local simulation results, which indicate stronger-than-present East-Asian winter monsoon winds during the Tortonian (Tang *et al.* 2011).

Several parameters may affect the strength of the winter monsoon. Orbital forcing, glacial-age surface boundary (ice caps and land-sea boundaries during glaciations), mountain-plateau uplift and the retreat of the Paratethys Sea can all influence the winter monsoon (Prell & Kutzbach 1992, Ramstein *et al.* 1997, An *et al.* 2001, Zhang *et al.* 2007, Clift *et al.* 2008, Tong *et al.* 2009). The uplift of the Tibet-Qinghai Plateau has been diachronic (Harris 2006, Wang *et al.* 2008). The uplift of the northern margin may only have occurred in the late Cenozoic (Wang *et al.* 2008). Model simulations show that an uplift of the northern part of the Tibetan Plateau causes an important strengthening of the winter monsoon (Liu & Yin 2002). However, an uplift of the Plateau at 3 Ma has not been confirmed by geologists (Molnar 2005, Molnar *et al.* 2010). The strengthening of the winter monsoon during the Pliocene is not the result of Plateau uplift. The retreat of the Paratethys Sea induces a strengthening of the East Asian summer monsoon and

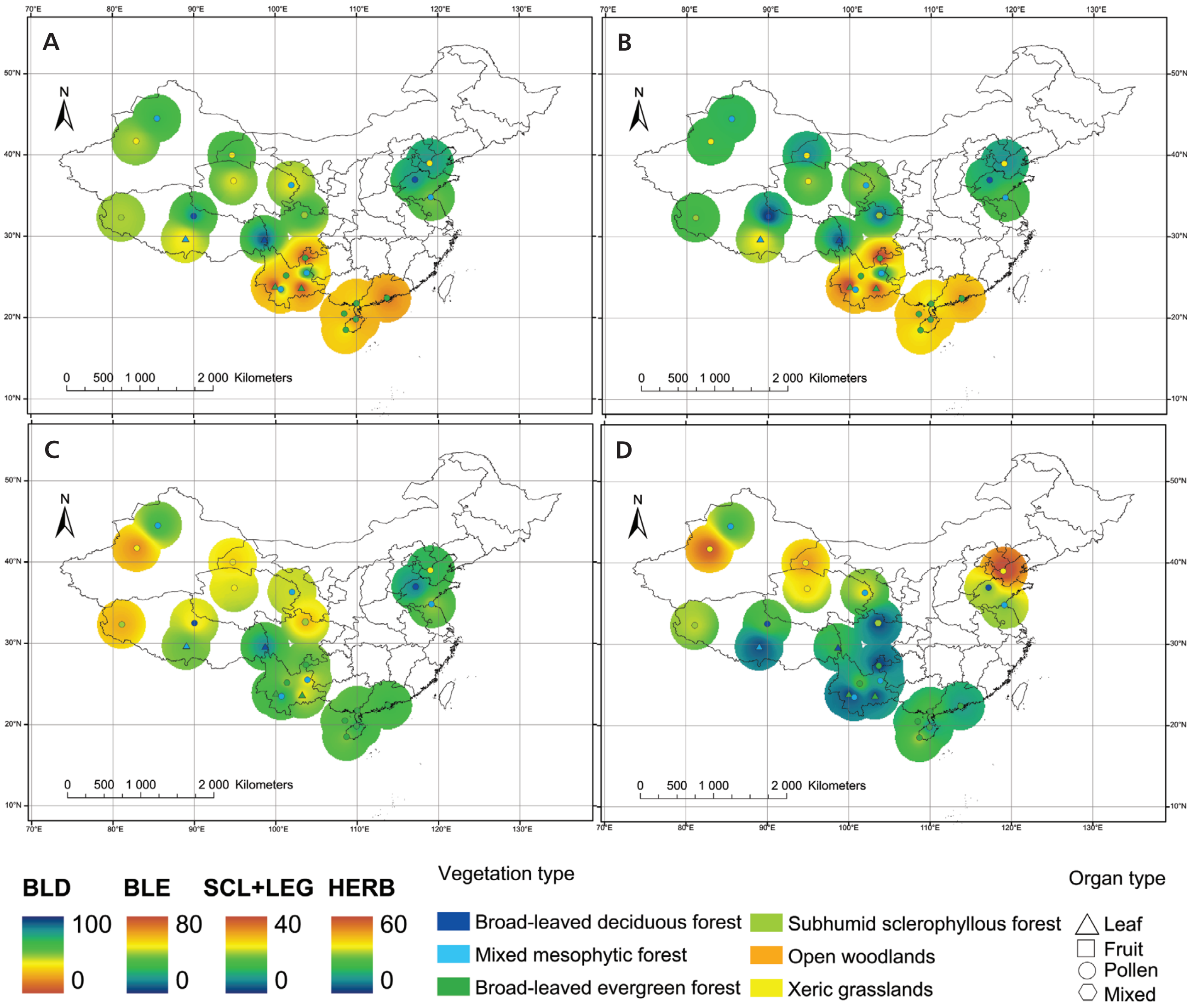

Figure 5. Interpolation of vegetation components during the Late Miocene–earliest Pliocene. The type of organ found in the assemblage is given by the symbol shape; the colour inside the symbol represents the vegetation types. Colour gradients represent the percentage of a component. • A – the gradient represents the BLD component; B – the gradient represents the BLE component; C – the gradient represents the SCL+LEG components; D – the gradient represents the HERB (MEH+DRH) component.

aridification of northwest China (Zhang *et al.* 2007). The Paratethys Sea retreat was almost completed by the end of the Late Miocene (Harzhauser & Piller 2007) and, therefore, cannot be the origin of the winter monsoon strengthening at 3 Ma. In models, a global forcing corresponding to conditions experienced during glaciations show a reduction in precipitation in China (Prell & Kutzbach 1992). The winter monsoon is caused by cold air and high pressure over Siberia in the winter (Ding *et al.* 1995, Chan & Li 2004). The cooling observed on a global scale during the Pliocene (Zachos *et al.* 2001) would have caused cooler temperatures and then higher pressure over Siberia in winter; all this results in a stronger winter monsoon. The cooling in Siberia is demonstrated in the Late Miocene and Pliocene based on carpological data, and is even more pronounced in winter than in summer (Popova *et al.* 2012).

Aridification during the late Miocene to the Pliocene is marked by an increase in C_4 plants (Jia *et al.* 2003, Kaakinen *et al.* 2006, Passey *et al.* 2009). This is worth noting because the development of C_4 vegetation can enhance an increase in aridity (Hay *et al.* 2002). The spread of C_4 vegetation limits evapotranspiration, and therefore increases aridity, which in turn favors C_4 plants over C_3 plants (Hay *et al.* 2002).

Conclusions

The global cooling trend during the Neogene resulted in

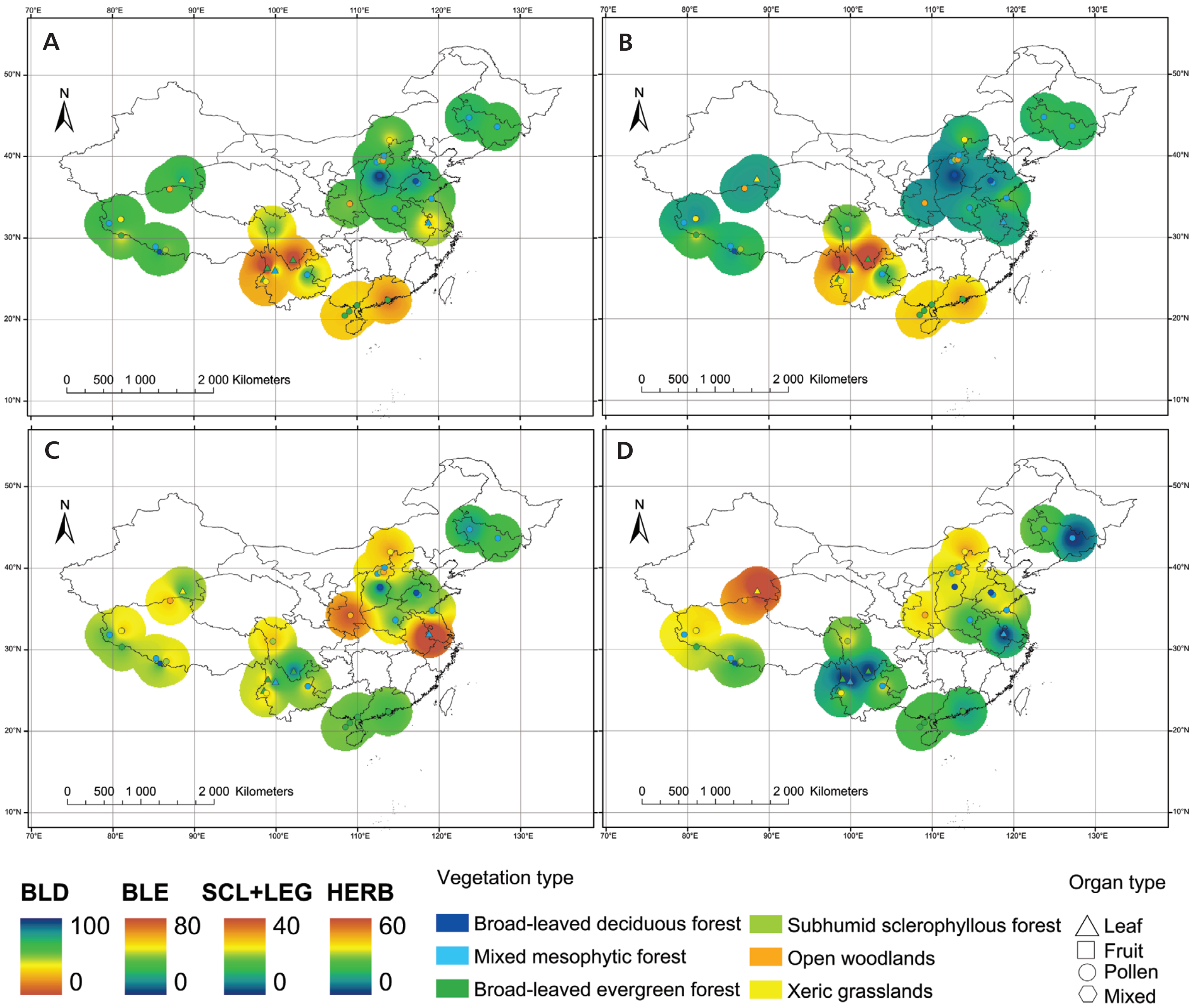

Figure 6. Interpolation of vegetation components during the Pliocene. The type of organ found in the assemblage is given by the symbol shape; the colour inside the symbol represents the vegetation types. Colour gradients represent the percentage of a component. • A – the gradient represents the BLD component; B – the gradient represents the BLE component; C – the gradient represents the SCL+LEG components; D – the gradient represents the HERB (MEH+DRH) component.

an aridification of west, central and north China, as demonstrated by the opening up of the vegetation in these regions. There is no noticeable vegetation change in south China. The Pliocene is then characterised by an increasing contrast in vegetation between south and north China. The Pliocene cooling induced a strengthening of the winter monsoon, which brought aridity to China.

In south China, there is no important change in the vegetation types during the Neogene. The Neogene cooling was less pronounced at low latitudes. The East Asian summer monsoon may have changed less than the winter monsoon.

Our results indicate a decoupling of the evolution of the East Asian summer monsoon and the winter monsoon at least during the Pliocene.

Acknowledgements

We thank T.E.V. Spicer for help with the English, Angela Bruch and an anonymous reviewer for comments on the manuscript. This work was supported by the Pilot Project of Knowledge Innovation, CAS (KZCX2-YW-155) to W.M. Wang, CAS Young Scientists Fellowship (2009YB1-13) and NSFC Research Fellowship for International Young Scientists (41150110108) to F.M.B. Jacques.

References

An, Z.S., Kutzbach, J.E., Prell, W.L. & Porter, S.C. 2001. Evolution of Asian monsoons and phased uplift of the Himalaya-Tibetan plateau since Late Miocene times. *Nature 411*, 62–66. DOI 10.1038/35075035

Cao, L. 1982. Pliocene palynological flora in Disong of Burang, Xizang (Tibet). *Acta Palaeontologica Sinica* 21, 469–483. [in Chinese with English abstract]

Chan, J. & Li, C.Y. 2004. The East Asian winter monsoon, 54–106. *In* Chang, C.P. (ed.) *East Asian monsoon.* World Scientific, Singapore.

Chaney, R.W. & Chuang, C.C. 1968. An Oak-Laurel forest in the Miocene of Taiwan. *Proceedings of the Geological Society of China 11*, 3–18.

Chen, M.H., Wang, R.J., Yang, L.H., Han, J.X. & Lu, J. 2003. Development of east Asian summer monsoon environments in the late Miocene: radiolarian evidence from Site 1143 of ODP Leg 184. *Marine Geology 201*, 169–177. DOI 10.1016/S0025-3227(03)00215-9

Chen, Y. & Ni, J. 2008. Quantitative palaeovegetation reconstruction at large scale based on pollen records. *Journal of Plant Ecology 32*, 1201–1212. [in Chinese with English abstract]

Clift, P.D., Hodges, K.V., Heslop, D., Hannigan, R., Van Long, H. & Calves, G. 2008. Correlation of Himalayan exhumation rates and Asian monsoon intensity. *Nature Geoscience 1*, 875–880. DOI 10.1038/ngeo351

Dercourt, J., Ricou, L.E. & Vrielynck, B. 1993. *Atlas Tethys Paleoenvironmental Maps*. 307 pp. Gauthier-Villars, Paris.

Dettman, D.L., Fang, X.M., Garzione, C.N. & Li, J.J. 2003. Uplift driven climate change at 12 Ma: a long δ^{18}O record from the NE margin of the Tibetan plateau. *Earth and Planetary Science Letters 214*, 267–277. DOI 10.1016/S0012-821X(03)00383-2

Ding, Z.L., Liu, T.S., Rutter, N.W., Yu, Z.W., Guo, Z.T. & Zhu, R.X. 1995. Ice-volume forcing of East Asian winter monsoon variations in the past 800,000 years. *Quaternary Research 44*, 149–159. DOI 10.1006/qres.1995.1059

Ding, Z.L., Xiong, S.F., Sun, J.M., Yang, S.L., Gu, Z.Y. & Liu, T.S. 1999. Pedostratigraphy and paleomagnetism of a similar to 7.0 Ma eolian loess-red clay sequence at Lingtai, Loess Plateau, north-central China and the implications for paleomonsoon evolution. *Palaeogeography, Palaeoclimatology, Palaeoecology 152*, 49–66. DOI 10.1016/S0031-0182(99)00034-6

Fan, M.J., Song, C.H., Dettman, D.L., Fang, X.M. & Xu, X.H. 2006. Intensification of the Asian winter monsoon after 7.4 Ma: Grain-size evidence from the Linxia Basin, northeastern Tibetan Plateau, 13.1 Ma to 4.3 Ma. *Earth and Planetary Science Letters 248*, 186–197. DOI 10.1016/j.epsl.2006.05.025

Gan, Z.B. 1982. Spore-pollen assemblage from the Early Miocene of Wuluogong, Northern Hebei, 59–63. *In* Palynological Society of China (ed.) *Selected papers from the first symposium of the Palynological Society of China*. Science Press, Beijing.

Garzione, C.N., Ikari, M.J. & Basu, A.R. 2005. Source of Oligocene to Pliocene sedimentary rocks in the Linxia basin in northeastern Tibet from Nd isotopes: implications for tectonic forcing of climate. *Geological Society of America Bulletin 117*, 1156–1166. DOI 10.1130/B25743.1

Guan, X.T., Tien, X.M. & Sun, X.H. 1982. On sporo-pollen assemblage and palaeogeography of the Neogene of Bohai, 64–70. *In* Palynological Society of China (ed.) *Selected papers from the first symposium of the Palynological Society of China*. Science Press, Beijing.

Guo, S.X. 1978. Pliocene floras of western Sichuan. *Acta Palaeontologica Sinica 17*, 343–350. [in Chinese with English abstract]

Guo, S.X & Gu, C.G. 1993. Fossil plants from calcareous tufa and palaeoenvironments in Ruoqiang, Xinjiang. *Acta Palaeontologica Sinica 32*, 82–87. [in Chinese with English abstract]

Guo, S.X. 2011. The Late Miocene Bangmai flora from Lincang County in Yunnan, southwestern China. *Acta Palaeontologica Sinica 50*, 353–408. [in Chinese with English abstract]

Guo, Z.T., Ruddiman, W.F., Hao, Q.Z., Wu, H.B., Qiao, Y.S., Zhu, R.X., Peng, S.Z., Wei, J.J., Yuan, B.Y. & Liu, T.S. 2002. Onset of Asian desertification by 22 Myr ago inferred from loess deposits in China. *Nature 416*, 159–163. DOI 10.1038/416159a

Guo, Z.T., Sun, B., Zhang, Z.S., Peng, S.Z., Xiao, G.Q., Ge, J.Y., Hao, Q.Z., Qiao, Y.S., Liang, M.Y., Liu, J.F., Yin, Q.Z. & Wei, J.J. 2008. A major reorganization of Asian climate by the early Miocene. *Climate of the Past 4*, 153–174. DOI 10.5194/cp-4-153-2008

Harris, N. 2006. The elevation history of the Tibetan Plateau and its implications for the Asian monsoon. *Palaeogeography, Palaeoclimatology, Palaeoecology 241*, 4–15. DOI 10.1016/j.palaeo.2006.07.009

Harzhauser, M. & Piller, W.E. 2007. Benchmark data of a changing sea – Palaeogeography, palaeobiogeography and events in the Central Paratethys during the Miocene. *Palaeogeography, Palaeoclimatology, Palaeoecology 253*, 8–31. DOI 10.1016/j.palaeo.2007.03.031

Hay, W.W., Soeding, E., DeConto, R.M. & Wold, C.N. 2002. The Late Cenozoic uplift – climate change paradox. *International Journal of Earth Sciences 91*, 746–774. DOI 10.1007/s00531-002-0263-1

Hsü, J., Tao, J.R. & Sun, X.J. 1973. On the discovery of a *Quercus semicarpifolia* bed in Mount Shisha Pangma and its significance in botany and geology. *Acta Botanica Sinica 15*, 103–114. [in Chinese with English abstract]

Huang, C.X. & Liang, Y.L. 1983. Sporo-pollen analysis on the lacustrine deposit in north part of the northern Xizang Plateau, 153–161. *In* Team of Comprehensive Scientific Expedition to the Qinghai-Xizang Plateau, Academia Sinica (eds) *Quaternary Geology in Xizang*. Science Press, Beijing. [in Chinese]

IBIG (Institute of Botany, CAS and Cenozoic palynology Working Group, Institute of Geology [Ministry of Geology]) 1966. Studies of Cenozoic paleobotany in Lantian region, Shaanxi, 157–196. *In* Institute of Vertebrate Paleontology and Paleoanthropology, CAS (ed.) *Symposium of the field conference of Cenozoic of Lantian, Shaanxi.*

Jacques, F.M.B., Guo, S.X., Su, T., Xing, Y.W., Huang, Y.J., Liu, Y.S., Ferguson, D.K. & Zhou, Z.K. 2011a. Quantitative reconstruction of the Late Miocene monsoon climates of southwest China: a case study of the Lincang flora from Yunnan Province. *Palaeogeography, Palaeoclimatology, Palaeocology 304*, 318–327. DOI 10.1016/j.palaeo.2010.04.014

Jacques, F.M.B., Shi, G.L. & Wang, W.M. 2011b. Reconstruction of Neogene zonal vegetation in South China using the Integrated Plant Record (IPR) analysis. *Palaeogeography,* *Palaeoclimatology, Palaeoecology 307*, 272–284. DOI 10.1016/j.palaeo.2011.05.025

Jacques, F.M.B., Su, T., Spicer, R.A., Xing, Y.W., Huang, Y.J., Wang, W.M. & Zhou, Z.K. 2011c. Leaf physiognomy and climates: are monsoon systems different? *Global and Planetary Change 76*, 56–62. DOI 10.1016/j.gloplacha.2010.11.009

Jechorek, H. & Kovar-Eder, J. 2004. Vegetational characteristics in Europe around the late early to early middle Miocene based on the plant macro record. *Courier Forschungsinstitut Senckenberg 249*, 53–62.

Jia, C.H., Yu, L., Du, N. & Kong, Z. 1989. Changes of vegetation and climate in Qian An County, Jilin Province since late Tertiary. *Scientia Geographica Sinica 9*, 274–282. [in Chinese with English abstract]

Jia, G.D., Peng, P.A., Zhao, Q.H. & Jian, Z.M. 2003. Changes in terrestrial ecosystem since 30 Ma in East Asia: Stable isotope evidence from black carbon in the South China Sea. *Geology 31*, 1093–1096. DOI 10.1130/G19992.1

Jiang, H.C. & Ding, Z.L. 2009. Spatial and temporal characteristics of Neogene palynoflora in China and its implication for the spread of steppe vegetation. *Journal of Arid Environment 73*, 765–772. DOI 10.1016/j.jaridenv.2009.03.011

Jin, X.C., Wang, D.N., Liu, Y.Q. & Zhang, J.P. 2002. Two Cenozoic palynological assemblages of the Kurha section, Kuqa, Xinjiang and their age and environmental significance. *Geological Bulletin of China 21*, 823–833. [in Chinese with English abstract]

Kaakinen, A., Sonninen, E. & Lunkka, J.P. 2006. Stable isotope record in palaeosol carbonates from the Chinese Loess Plateau: Implications for late Neogene paleoclimate and paleovegetation. *Palaeogeography, Palaeoclimatology, Palaeoecology 237*, 359–369. DOI 10.1016/j.palaeo.2005.12.011

Kou, X.Y., Ferguson, D.K., Xu, J.X., Wang, Y.F. & Li, C.S. 2006. The reconstruction of paleovegetation and paleoclimate in the Late Pliocene of West Yunnan, China. *Climatic Change 77*, 431–448. DOI 10.1007/s10584-005-9039-5

Kovar-Eder, J., Jechorek, H., Kvaček, Z. & Parashiv, V. 2008. The integrated plant record: an essential tool for reconstructing Neogene zonal vegetation in Europe. *Palaios 23*, 97–111. DOI 10.2110/palo.2006.p06-039r

Kovar-Eder, J. & Kvaček, Z. 2003. Towards vegetation mapping based on fossil plant record. *Acta Universitatis Carolinae, Geologica 46*, 7–13.

Kovar-Eder, J. & Kvaček, Z. 2007. The integrated plant record (IPR) to reconstruct Neogene vegetation: the IPR-vegetation analysis. *Acta Palaeobotanica 47*, 391–418.

Li, H.M. & Guo, S.X. 1976. The Miocene flora from Namling of Tibet. *Acta Palaeontologica Sinica 15*, 7–20. [in Chinese with English abstract]

Li, H.M., Huang, J.N., Zhang, J.X. & Wang, W.B. 1984. Discovery of fossil plants in the Yuhuatai Formation in Nanjing. *Geological Review 30*, 575–577. [in Chinese with English abstract]

Li, H.M. & Yang, G.Y. 1984. Miocene Qiuligou flora in Dunhua, Jilin Province. *Acta Palaeontologica Sinica 23*, 204–214.

Li, J.F., Ferguson, D.K., Yang, J., Feng, G.P., Ablaev, A.G., Wang, Y.F. & Li, C.S. 2009. Early Miocene vegetation and climate in Weichang District, North China. *Palaeogeography, Palaeoclimatology, Palaeoecology 280*, 47–63. DOI 10.1016/j.palaeo.2009.05.017

Li, W.Y. 1983. Sporo-pollen assemblages from some localities of southern Qinghai-Xizang Plateau in Pliocene and its palaeogeographical significance, 162–166. *In* Team of Comprehensive Scientific Expedition to the Qinghai-Xizang Plateau, Academia Sinica (eds) *Quaternary Geology in Xizang*. Science Press, Beijing. [in Chinese]

Li, W.Y. & Liang, Y.L. 1983. Sporo-pollen analysis on the lacustrine deposits in Zanda Basin during the Pliocene, 132–134. *In* Team of Comprehensive Scientific Expedition to the Qinghai-Xizang Plateau, Academia Sinica (eds) *Quaternary geology in Xizang*. Science Press, Beijing. [in Chinese]

Li, Y.T. *et al.* 1984. *The Tertiary system of China. Stratigraphy of China 13*. 362 pp. Geological Publishing House, Beijing. [in Chinese]

Liu, G.W. 1998. A Miocene palynoflora from Huanan County of Heilongjiang Province, NE China. *Acta Micropalaeontologica Sinica 15*, 48–54. [in Chinese with English abstract]

Liu, G.W., Li, H.M. & Leng, Q. 1995. A preliminary report on Miocene flora from Daotaiqiao formation of Huanan County, Heilongjiang Province, NE China. *Acta Palaeontologica Sinica 34*, 755–757. [in Chinese with English abstract]

Liu, G.W. & Li, W.T. 2002. Upper Cretaceous-Tertiary of western Sichuan Plateau. *Journal of Stratigraphy 26*, 161–169. [in Chinese with English abstract]

Liu, L.P., Eronen, J.T. & Fortelius, M. 2009. Significant midlatitude aridity in the middle Miocene of East Asia. *Palaeogeography, Palaeoclimatology, Palaeoecology 279*, 201–206. DOI 10.1016/j.palaeo.2009.05.014

Liu, X.D. & Yin, Z.Y. 2002. Sensitivity of East Asian monsoon climate to the uplift of the Tibetan Plateau. *Palaeogeography, Palaeoclimatology, Palaeoecology 183*, 223–245. DOI 10.1016/S0031-0182(01)00488-6

Liu, Y.S. (C.), Utescher, T., Zhou, Z.K. & Sun, B.N. 2011. The evolution of Miocene climates in North China: Preliminary results of quantitative reconstructions from plant fossil records. *Palaeogeography, Palaeoclimatology, Palaeoecology 304*, 308–317. DOI 10.1016/j.palaeo.2010.07.004

Ma, Y.Z. 1991. Tertiary sporo-pollen assemblages from South Dunhuang Basin, Gansu Province. *Acta Micropalaeontologica Sinica 8*, 207–225.

Martinetto, E. & Vassio, E. 2010. Reconstructing "Plant Community Scenarios" by means of palaeocarpological data from the CENOFITA database, with an example from the Ca'Viettone site (Pliocene, Northern Italy). *Quaternary International 225*, 25–36. DOI 10.1016/j.quaint.2009.08.020

Micheels, A., Bruch, A.A., Eronen, J., Fortelius, M., Harzhauser, M., Utescher, T. & Mosbrugger, V. 2011. Analysis of heat transport mechanisms from a Late Miocene model experiment which is fully-coupled atmosphere-ocean general circulation model. *Palaeogeography, Palaeoclimatology, Palaeoecology 304*, 337–350. DOI 10.1016/j.palaeo.2010.09.021

Molnar, P. 2005. Mio-Pliocene growth of the Tibetan Plateau and evolution of East Asian climate. *Palaeontographica Electronica 8*, 2A, http://palaeo-electronica.org/

Molnar, P., Boos, W.R. & Battisti, D.S. 2010. Orographic controls on climate and paleoclimate of Asia: thermal and mechanical roles for the Tibetan Plateau. *Annual Review of Earth and Planetary Sciences 38*, 77–102. DOI 10.1146/annurev-earth-040809-152456

Ni, J., Yu, G., Harrison, S.P. & Prentice, I.C. 2010. Palaeovegetation in China during the late Quaternary: biome reconstructions based on a global scheme of plant functional types. *Palaeogeography, Palaeoclimatology, Palaeoecology 289*, 44–61. DOI 10.1016/j.palaeo.2010.02.008

Passey, B.H., Ayliffe, L.K., Kaakinen, A., Zhang, Z.Q., Eronen, J.T., Zhu, Y.M., Zhou, L.P., Cerling, T.E. & Fortelius, M. 2009. Strengthened East Asian summer monsoons during a period of high-latitude warmth? Isotopic evidence from Mio-Pliocence fossil mammals and soil carbonates from northern China. *Earth and Planetary Science Letters 277*, 443–452. DOI 10.1016/j.epsl.2008.11.008

Popova, S., Utescher, T., Gromyko, D., Bruch, A.A. & Mosbrugger, V. 2012. Palaeoclimate evolution in Siberia and the Russian Far East from the Oligocene to Pliocene – evidence from fruit and seed floras. *Turkish Journal of Earth Sciences 21*, 315–334.

Prell, W.L. & Kutzbach, J.E. 1992. Sensitivity of the Indian monsoon to forcing parameters and implication for its evolution. *Nature 360*, 647–652. DOI 10.1038/360647a0

Prentice, I.C., Guiot, J., Huntley, B., Jolly, D. & Cheddadi, R. 1996. Reconstructing biomes from palaeoecological data: a general method and its application to European pollen data at 0 and 6 ka. *Climate Dynamics 12*, 185–194. DOI 10.1007/BF00211617

Qiang, X.K., Li, Z.K., Powell, C.M. & Zheng, H.B. 2001. Magnetostratigraphic record of the Late Miocene onset of the East Asian monsoon, and Pliocene uplift of northern Tibet. *Earth and Planetary Science Letters 187*, 83–93. DOI 10.1016/S0012-821X(01)00281-3

Ramstein, G., Fluteau, F., Besse, J. & Joussaume, S. 1997. Effect of orogeny, plate motion and land sea distribution on Eurasian climate change over the past 30 million years. *Nature 386*, 788–795. DOI 10.1038/386788a0

Rea, D.K., Snoeckx, H. & Joseph, L.H. 1998. Late Cenozoic eolian deposition in the North Pacific: Asian drying, Tibetan uplift, and cooling of the northern hemisphere. *Paleoceanography 13*, 215–224. DOI 10.1029/98PA00123

Rögl, F. 1998. Palaeogeographic considerations for Mediterranean and Paratethys seaways (Oligocene to Miocene). *Annalen des Naturhistorischen Museums in Wien 99*, 279–310.

Shu, J.W., Wang, W.M., Leopold, E.B., Wang, J.S. & Yin, D.S. 2008. Pollen stratigraphy of coal-bearing deposits in the Neogene Jidong Basin, Heilongjiang Province, NE China: new insights on palaeoenvironment and age. *Review of Palaeobotany and Palynology 148*, 163–183. DOI 10.1016/j.revpalbo.2007.09.003

Song, Z.C. 1988. Late Cenozoic palyno-flora from Zhaotong, Yunnan. *Memoirs of Nanjing Institute of Geology and Palaeontology, Academia Sinica 24*, 1–52.

Song, Z.C. & Liu, J.L. 1982. The Tertiary sporo-pollen assemblages from Namling of Xizang, 153–164. *In* Team of Comprehensive Scientific Expedition to the Qinghai-Xizang Plateau, Academia Sinica (eds) *Palaeontology of Xizang, vol. 5*. Science Press, Beijing. [in Chinese with English abstract]

Song, Z.C., Wang, W.M. & Huang, F. 2004. Fossil pollen records of extant angiosperms in China. *The Botanical Review 70*, 425–458. DOI 10.1663/0006-8101(2004)070[0425:FPROEA]2.0.CO;2

Song, Z.C., Wang, W.M. & Mao, F.Y. 2008. Palynological implications for relationship between aridification and monsoon climate in the Tertiary of NW China. *Acta Palaeontologica Sinica 47(3)*, 265–272. [in Chinese with English abstract]

Song, Z.C. & Zhong, B.Z. 1984. Tertiary sporo-pollen assemblages from Jinggu, Yunnan. *Bulletin of Nanjing Institute of Geology and Palaeontology, Academia Sinica 8*, 1–15.

Steinke, S., Groeneveld, J., Johnstone, H. & Rendle-Buhring, R. 2010. East Asian summer monsoon weakening after 7.5 Ma: Evidence from combined planktonic foraminifera Ma/Ca and $\delta^{18}O$ (ODP site 1146; northern South China Sea). *Palaeogeography, Palaeoclimatology, Palaeoecology 289*, 33–43. DOI 10.1016/j.palaeo.2010.02.007

Steppuhn, A., Micheels, A., Geiger, G. & Mosbrugger, V. 2006. Reconstructing the Late Miocene climate and oceanic heat flux using the AGCM ECHAM4 coupled to a mixed-layer ocean model with adjusted flux correction. *Palaeogeography, Palaeoclimatology, Palaeoecology 238*, 399–423. DOI 10.1016/j.palaeo.2006.03.037

Steppuhn, A., Micheels, A., Bruch, A.A., Uhl, D., Utescher, T. & Mosbrugger, V. 2007. The sensitivity of ECHAM4/ML to a double CO_2 scenario for the Late Miocene and the comparison to terrestrial proxy data. *Global and Planetary Change 57*, 189–212. DOI 10.1016/j.gloplacha.2006.09.003

Sun, B.N, Wu, J.Y, Liu, Y.S. (C.), Ding, S.T., Li, X.C., Xie, S.P., Yan, D.F. & Lin, Z.C. 2011. Reconstructing Neogene vegetation and climates to infer tectonic uplift in western Yunnan, China. *Palaeogeography, Palaeoclimatology, Palaeoecology 304*, 328–336. DOI 10.1016/j.palaeo.2010.09.023

Sun, D.H. 2004. Monsoon and westerly circulation changes recorded in the late Cenozoic Aeolian sequences of Northern China. *Global and Planetary Change 41*, 63–80. DOI 10.1016/j.gloplacha.2003.11.001

Sun, D.H., Shaw, J., An, Z.S., Cheng, M.Y. & Yue, L.P. 1998. Magnetostratigraphy and paleoclimatic interpretation of a continuous 7.2 Ma Late Cenozoic eolian sediments from the Chinese Loess Plateau. *Geophysical Research Letters 25*, 85–88.

Sun, J.M. & Zhang, Z.Q. 2008. Palynological evidence for the Mid-Miocene Climatic Optimum recorded in Cenozoic sediments of the Tian Shan Range, northwestern China. *Global and Planetary Change 64*, 53–68.

Sun, M.R. & Sun, S.Y. 1984. Chinese Tertiary Palynology, 322–334. *In* Li, Y.T. (ed.) *Chinese Stratigraphy (13) – Chinese Tertiary*. Geology Press, Beijing.

Sun, M.R. & Wang, X. 1990. Tertiary palynological assemblages from the Junggar Basin, Xinjiang, 122–151. *In* Reaserch Party of Marine geology, Ministry of Geology and Mineral Ressources, Institute of Geology, Chinese Academy of Geological Sciences (eds) *Permian to Tertiary Strata and Palyonological Assemblages in the North of Xinjiang.* China Environmental Science Press, Beijing.

Sun, Q.G., Collinson, M.E., Li, C.S., Wang, Y.F. & Beerling, D.J. 2002. Quantitative reconstruction of palaeoclimate from the Middle Miocene Shanwang flora, eastern China. *Palaeogeography, Palaeoclimatology, Palaeoecology 180*, 315–329.

Sun, X.J. & He, Y.M. 1987. Neogene sporo-pollen assemblages from Jiangxi Province, China. *Botanical Research 3*, 83–108. [in Chinese with English abstract]

SUN, X.J., LI, M.X., ZHANG, Y.Y., LEI, Z.Q., KONG, Z.C., LI, P., OU, Q. & LIU, Q.N. 1981. Spores and pollen, 1–58. *In* SOUTH SEA BRANCH OF PETROLEUM CORPORATION OF THE PEOPLE'S REPUBLIC OF CHINA (eds) *Tertiary Palaeontology of North Continental Shelf of the South China Sea*. Guangdong Science and Technology Press, Guangzhou. [in Chinese]

SUN, X.J. & WANG, P.X. 2005. How old is the Asian monsoon system?-Palaeobotanical records from China. *Palaeogeography, Palaeoclimatology, Palaeoecology 222*, 181–222.

SUN, X.Y., ZHAO, Y.N. & HE, Z.S. 1984. The Oligocene-Miocene palynological assemblages from the Xining-Minghe Basin, Qinghai Province. *Geological Review 30*, 207–216.

TANG, H., MICHEELS, A., ERONEN, J. & FORTELIUS, M. 2011. Regional climate model experiments to investigate the Asian monsoon in the Late Miocene. *Climate of the Past 7*, 847–868. DOI 10.5194/cp-7-847-2011

TANG, L.Y. & LIU, J.L. 1984. Late Cenozoic palynological investigation in the Sanggan River Valley, North China. *Bulletin of Nanjing Institute of Geology and Palaeontology, Academia Sinica 9*, 81–144. [in Chinese with English abstract]

TAO, J.R. 1986. Neogene flora of Lanping and its significance in middle watershed of Selwen-Mekong-Yangtze Rivers, 58–65. *In* TEAM OF COMPREHENSIVE SCIENTIFIC EXPEDITION TO THE QINGHAI-XIZANG PLATEAU, CHINESE ACADEMY OF SCIENCES (eds) *Studies in Qinghai-Xizang Plateau-Special issue of Hengduan Mountains Scientific Expedition (II)*. Beijing Science and Techonology Press, Beijing. [in Chinese]

TAO, J.R. & DU, N.Q. 1982. Neogene flora of Tengchong basin in western Yunnan, China. *Acta Botanica Sinica 24*, 649–655. [in Chinese with English abstract]

TAO, J.R. & DU, N.Q. 1987. Miocene flora from Markam county and fossil record of Betulaceae. *Acta Botanica Sinica 29*, 649–655. [in Chinese with English abstract]

TAO, J.R. & KONG, Z.C. 1973. The fossil florule and sporo-pollen assemblage of Shang-in coal series of Erhyuan, Yunnan. *Acta Botanica Sinica 15*, 120–126. [in Chinese with English abstract]

TAO, J.R., ZHOU, Z.K. & LIU, Y.S. 2000. *The evolution of the Late Cretaceous-Cenozoic floras in China*. 282 pp. Science Press, Beijing.

TEODORIDIS, V., KOVAR-EDER, J., MAREK, P., KVAČEK, Z. & MAZOUCH, P. 2011a. The integrated plant record analysis: internet platform and online analysis. *Acta Musei nationalis Pragae, Series B – historia naturalis 67*, 159–165.

TEODORIDIS, V., KOVAR-EDER, J. & MAZOUCH, P. 2011b. Integrated Plant Record (IPR) vegetation analysis applied to modern vegetation in South China and Japan. *Palaios 26*, 623–638. DOI 10.2110/palo.2010.p10-149r

TONG, J.A., YOU, Y, MÜLLER, R.D. & SETON, M. 2009. Climate model sensitivity to atmospheric CO_2 concentrations for the middle Miocene. *Global and Planetary Change 67*, 129–140. DOI 10.1016/j.gloplacha.2009.02.001

UTESCHER, T., BRUCH, A.A., MICHEELS, A., MOSBRUGGER, V. & POPOVA, S. 2011. Cenozoic climate gradients in Eurasia – a palaeo-perspective on future climate change? *Palaeogeography, Palaeoclimatology, Palaeoecology 304*, 351–358. DOI 10.1016/j.palaeo.2010.09.031

VANDENBERGHE, J., LU, H.Y., SUN, D.H., VAN HUISSTEDEN, J. (K.) & KONERT, M. 2004. The late Miocene and Pliocene climate in East Asia as recorded by grain size and magnetic susceptibility of the Red Clay deposits (Chinese Loess Plateau). *Palaeogeography, Palaeoclimatology, Palaeoecology 204*, 239–255. DOI 10.1016/S0031-0182(03)00729-6

WAN, S.M., LI, A.C., CLIFT, P.D. & STUUT, J.-B.W. 2007. Development of the East Asian monsoon: mineralogical and sedimentologic records in the northern South China Sea since 20 Ma. *Palaeogeography, Palaeoclimatology, Palaeoecology 254*, 561–582. 582. DOI 10.1016/j.palaeo.2007.07.009

WANG, B. 2006. *The Asian monsoon*. 787 pp. Springer, New York.

WANG, C.S., ZHAO, X.X., LIU, Z.F., LIPPERT, P.C., GRAHAM, S.A., COE, R.S., YI, H.S., ZHU, L.D., LIU, S. & LI, Y.L. 2008. Constraints on the early uplift history of the Tibetan Plateau. *Proceedings of the National Academy of Sciences 105*, 4987–4992. DOI 10.1073/pnas.0703595105

WANG, K.F., YANG, J., LI, Z. & LI, Z. 1975. On the Tertiary sporopollen assemblages from Lunpola Basin of Xizang China, and their palaeontographic significance. *Chinese Journal of Geology 4*, 366–374. [in Chinese with English abstract]

WANG, W.M. 1989. Spore and pollen grains from Miocene lignite deposit of Yalong village, Yao autonomous county, Guangxi, China. *Acta Palaeontologica Sinica 28*, 786–802. [in Chinese with English abstract]

WANG, W.M. 1990. Sporo-pollen assemblages from the Miocene Tongguer formation of Inner Mongolia and its climate. *Acta Botanica Sinica 32*, 901–904. [in Chinese with English abstract]

WANG, W.M. 1994. Paleofloristic and paleoclimatic implications of Neogene palynofloras in China. *Review of Palaeobotany and Palynology 82*, 239–250. DOI 10.1016/0034-6667(94)90078-7

WANG, W.M. 2006. Correlation of pollen sequences in the Neogene palynofloristic regions of China. *Palaeoworld 15*, 77–99. DOI 10.1016/j.palwor.2006.03.002

WANG, W.M. & DENG, T. 2009. Palynoflora from the stratotype section of the Neogene Xiejian stage and its significance. *Acta Palaeontologica Sinica 48*, 1–8. [in Chinese with English abstract]

WANG, W.M. & SHU, J.W. 2004. Late Cenozoic palynofloras from Qujing Basin, Yunnan, China. *Acta Palaeontologica Sinica 43*, 254–261.

WANG, W.M. & ZHANG, D.H. 1990. Tertiary sporo-pollen assemblages from the Shangdou-Huade Basin, Inner Mongolia – with discussion on the formation of steppe vegetation in China. *Acta Micropalaeontologica Sinica 7*, 239–252. [in Chinese with English abstract]

WANG, W.M., LI, J.R., WANG, J.D. & HE, Z.J. 2002. Palynological assemblage from Pliocene Zhangqiu Formation of Shandong, and its stratigraphical significance. *Acta Palaeontologica Sinica 41*, 72–76. [in Chinese with English abstract]

WANG, Y., WANG, X.M., XU, Y.F., ZHANG, C.H., LI, Q., TSENG, Z.J.J., TAKEUCHI, G. & DENG, T. 2008. Stable isotopes in fossil mammals, fish and shells from Kunlun Pass Basin, Tibetan Plateau: Paleo-climatic and paleo-elevation implications. *Earth and Planetary Science Letters 270*, 73–85. DOI 10.1016/j.epsl.2008.03.006

WHITE, J.M., AGER, T.A., ADAM, D.P., LEOPOLD, E.B., LIU, G., JETTE, H. & SCHWEGER, C.E. 1997. An 18 million year record of vegetation and climate change in northwestern Canada and

Alaska: tectonic and global climatic correlates. *Palaeogeography, Palaeoclimatology, Palaeoecology 130*, 293–306. DOI 10.1016/S0031-0182(96)00146-0

Wolfe, J.A. 1994. An analysis of Neogene climates in Beringia. *Palaeogeography, Palaeoclimatology, Palaeoecology 108*, 207–216. DOI 10.1016/0031-0182(94)90234-8

Wu, Z.J. 1980. The Late Tertiary palynological characteristics and their significance in the strata from Weizhou Island, Beibu Gulf. *Nanhai Studia Marina Sinica 1*, 51–57. [in Chinese with English abstract]

Xia, K., Su, T., Liu, Y.S., Xing, Y.W., Jacques, F.M.B. & Zhou, Z.K. 2009. Quantitative climate reconstructions of the late Miocene Xiaolongtan megaflora from Yunnan, southwest China. *Palaeogeography, Palaeoclimatology, Palaeoecology 276*, 80–86. DOI 10.1016/j.palaeo.2009.02.024

Xie, S.P., Sun, S.B., Wu, J.Y, Lin, Z.C., Yan, D.F & Xiao, L. 2012. Palaeoclimatic estimates for the late Pliocene based on leaf physiognomy from western Yunnan, China. *Turkish Journal of Earth Sciences 21*, 251–261.

Xu, J.X., Ferguson, D.K., Li, C.S. & Wang, Y.F. 2008. Late Miocene vegetation and climate of the Lühe region in Yunnan, southwestern China. *Review of Palaeobotany and Palynology 148*, 36–59. DOI 10.1016/j.revpalbo.2007.08.004

Xu, J.X., Ferguson, D.K., Li, C.S., Wang, Y.F. & Du, N.Q. 2004. Climatic and ecological implications of Late Pliocene palynoflora from Longling, Yunnan, China. *Quaternary International 117*, 91–103.
DOI 10.1016/S1040-6182(03)00119-8

Yao, Y.F., Bruch, A.A., Mosbrugger, V. & Li, C.S. 2011. Quantitative reconstruction of Miocene climate patterns and evolution in Southern China based on plant fossils. *Palaeogeography, Palaeoclimatology, Palaeoecology 304*, 291–307.
DOI 10.1016/j.palaeo.2010.04.012

Yao, Y.M., Liang, H., Cai, Z., Guan, X., Zhao, Z., Chen, Z., Sun, Z. & Yang, S. 1994. *Tertiary petroliferous regions of China. The Bohai Gulf Basin, vol. IV*. 240 pp. Petroleum Industry Press, Beijing. [in Chinese]

Yu, G., Liew, P., Xue, B. & Li, Z.Y. 2003. Surface pollen and vegetation reconstruction from central and northern mountains of Taiwan. *Chinese Science Bulletin 48*, 291–295.

Zachos, J., Pagani, M., Sloan, L., Thomas, E. & Billups, K. 2001. Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science 292*, 686–693.
DOI 10.1126/science.1059412

Zhang, S.B., Shen, H., Qu, X. & Gao, Q. 1993. *Tertiary in petroliferous regions of China. The Hubei-Henan-Anhui region, vol. V*. 296 pp. Petroleum Industry Press, Beijing. [in Chinese]

Zhang, Z.C. 1986. Tertiary fossil plants from Pingzhuang of Ju'ud League, Nei Mongol (Inner Mongolia). *Bulletin of the Shenyang Institute of Geology and Mineral Ressources 14*, 117–124. [in Chinese with English abstract]

Zhang, Z.S., Wang, H.J., Guo, Z.T. & Jiang, D.B. 2007. What triggers the transition of palaeoenvironmental patterns in China, the Tibetan Plateau uplift or the Paratethys Sea retreat? *Palaeogeography, Palaeoclimatology, Palaeoecology 245*, 317–331. DOI 10.1016/j.palaeo.2006.08.003

Zhao, L.C., Wang, Y.F., Liu, C.J. & Li, C.S. 2004. Climatic implications of fruit and seed assemblage from Miocene of Yunnan, southwestern China. *Quaternary International 117*, 81–89. DOI 10.1016/S1040-6182(03)00118-6

Zhao, X.L., Zhang, X.Q., Wang, M.Z. & Li, C.S. 2004. The assemblage of Neogene sporopollen of Tumenzi formation of Hunchun, Jilin Province. *Journal of the Shandong University of Science and Technology (Natural Science) 23*, 19–23. [in Chinese with English abstract]

Zheng, Y.H. 1982. Miocene pollen and spores from Xianju-Ninghai, Zhejiang, 71–74. *Selected Papers of the 1st Scientific Conference of the Palynological Society of China*. Science Press, Beijing. [in Chinese]

Zheng, Y.H. 1983. Sporo-pollen assemblage of the Wuoma Formation of the Gyrong Basin, 142–152. *In* Team of Comprehensive Scientific Expedition to the Qinghai-Xizang Plateau, Academia Sinica (eds) *Quaternary Geology in Xizang*. Science Press, Beijing. [in Chinese]

Zheng, Y.H. 1987. Fossil pollen grains of Podocarpaceae from Upper Tertiary in Fujian. *Acta Palaeontologica Sinica 26*, 604–615. [in Chinese with English abstract]

Zheng, Y.H. & Wang, W.X. 1994. Sequence of Miocene Fotan group in SE Fujian and its palyno-assemblages. *Acta Palaeontologica Sinica 33*, 200–216. [in Chinese with English abstract]

Zheng, Y.H. & Zhang, S.W. 1986. An Early Miocene palynological assemblage from Drill Hole T_{103} in Tianchang, Anhui Province. *Acta Micropalaeontologica Sinica 3*, 151–160. [in Chinese with English abstract]

Zheng, Y.H., Zhou, S.F., Liu, X.Q., Wang, L.Y., Xu, S.J. & Wang, X.Z. 1981. Neogene sporo-pollen grains from Northern Jiangsu and South Yellow Sea Basin. *Bulletin of Nanjing Institute of Geology and Palaeontology, Academia Sinica 3*, 29–47. [in Chinese with English abstract]

Zhu, Z.H., Wu, L.Y., Xi, P., Song, Z.C. & Zhang, Y.Y. 1985. *A research on Tertiary palynology from the Qaidam Basin, Qinghai Province*. 297 pp. Petroleum Industry Press, Beijing. [in Chinese with English abstract]