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Geographical patterns of Yunnan seed plants may be influenced by the clockwise rotation of the Simao-Indochina geoblock

Hua Zhu *

Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Kunming, China

Floristic patterns of seed plants in Yunnan, southwestern China, were studied to assess the relationship between the floristic geography and geological history. A database of 38 regional floristic studies covering Yunnan was used and the patterns of seed plant distributions across these regional floras were quantified at the generic level. Genera with tropical Asian distributions are the most dominant geographical elements in the Yunnan flora. They show oblique patterns of abundance across Yunnan. They are most abundant in southern and western Yunnan, and their proportion in regional floras declines abruptly in eastern, central and northern Yunnan. The oblique abundance patterns of geographical elements in Yunnan differ from those of genera in southern and eastern China, which had a high correlation with latitudinal gradients controlled by climate. They cannot be explained by climate alone, but can be explained at least partly by the geological history. The oblique abundance patterns of Yunnan seed plants correspond well to the clockwise rotation and southeastward extrusion of the Simao-Indochina geoblock caused by the collision of India with Asia.

Keywords: distribution patterns, geographical elements, Simao-Indochina geoblock, Yunnan, southwestern China

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Edited by:
Samuel Abiven,
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Correspondence:
Hua Zhu,
Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Xue-Fu Road 88, Kunming, Yunnan 650223, China
zhuh@xtbg.ac.cn

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Introduction

Yunnan province in southwest China (21°09′ and 29°15′ N, 97°32′ and 106°12′ E; **Figure 1**) is situated in a transitional zone between tropical south-east Asia and temperate Himalayas, and it has a mountainous topography with elevation ranges from 76.4 m at the lowest valley bottom in the southeast (Red River) to 6740 m at the highest mountain summit in the northwest (**Figure 2**). Yunnan is extremely diverse in habitats and biodiversity. Southern Yunnan with a tropical monsoon climate has a tropical flora of Malaysian affinity (Zhu, 1997, 2008a; Zhu and Yan, 2009a). Central Yunnan with a subtropical climate is largely characterized by a subtropical flora of East Asian affinity (Yan et al., 2009). Northwestern Yunnan, with a temperate climate and alpine-deep valley topography, has a temperate Himalayan flora (Zhu, 2009, 2015).

Studies of the floristic patterns of Yunnan seed plants reveal that the majority of genera found in southern, southwestern and southeastern Yunnan are tropical, while the majority of genera found in northern Yunnan are temperate (Zhu, 2008b, 2012). Among the tropical genera, tropical Asian genera are most common. The abundances of these tropical Asian genera show oblique patterns across Yunnan, not latitudinal gradients as they are in southern and eastern China (Zhu et al., 2007).

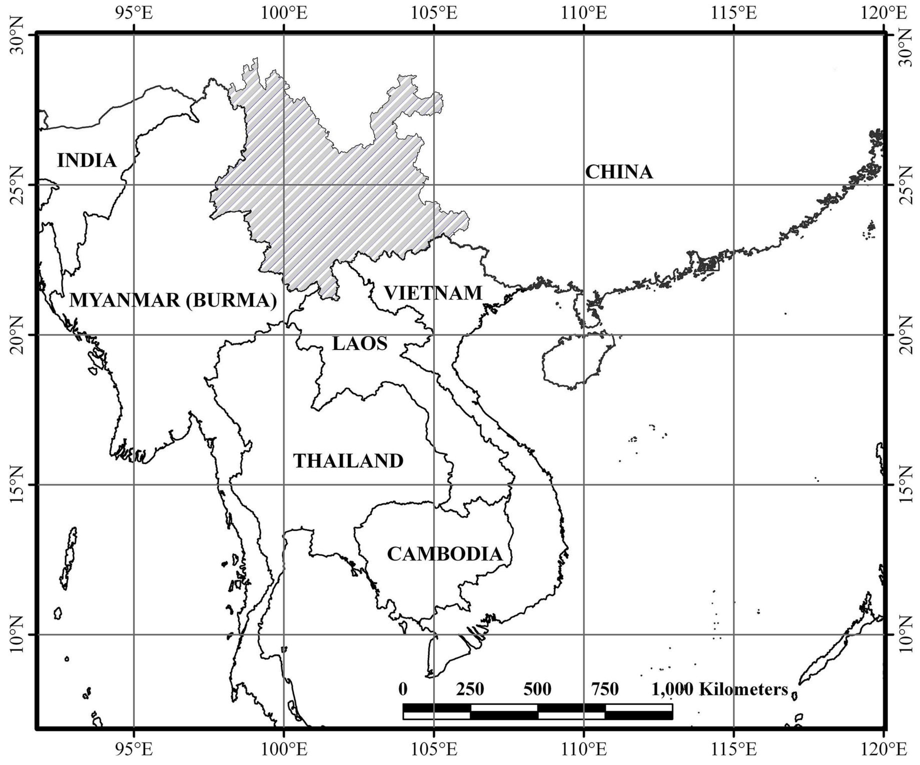

FIGURE 1 | Location of Yunnan (oblique dashed area), southwest China.

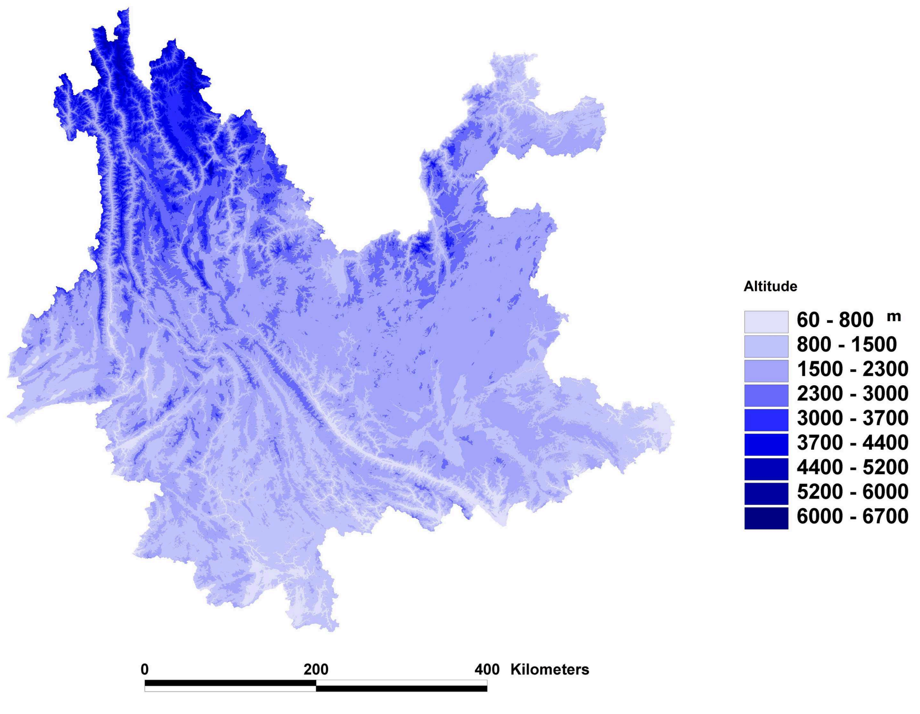

FIGURE 2 | Topography of Yunnan Province.

TABLE 1 | The geographical elements at generic level among the sites (regional flora) from references data.

Research sites	Longitude	Latitude	PT*%	TA*%	TT*%	EA*%	References
Ailao Mts. NR	101.20	24.20	20.36	25.91	21.47	11.23	Zhu and Yan, 2009b
Bulong NR	101.00	22.00	22.33	37.52	9.91	3.69	Zhu et al., 2015
Caiyanghe NR	101.18	22.57	23.40	38.24	11.51	4.48	Zhu et al., 2006a
Cangshan NR	100.00	25.45	18.75	9.45	37.07	13.81	Duan, 1995
Dawei Mountain NR	103.75	22.83	18.75	37.00	13.85	8.46	Wang et al., 2006a
Dazhong Mt. NR	100.85	24.53	24.24	17.08	27.82	12.12	Ding et al., 2006
Dulongjiang NR	98.33	28.25	16.99	18.11	33.66	14.1	Li, 1994
Gaoligong Mt. NR	98.38	27.94	17.57	20.02	27.57	14.43	Li et al., 2000
Gulinqing NR	104.39	23.00	19.00	39.3	9.2	7.1	Kong, 2008
Haba Snow Mt. NR	100.15	27.25	13.98	4.1	43.9	14	Yunnan Forestry Survey Institute, 2009
Huanglianshan NR	102.15	22.95	21.66	37.28	12.31	7.57	Xu, 2003
Jiaozixueshan NR	102.80	26.20	13	6.9	43	12.1	Kunming Institute of Botany Chinese Academy of Sciences and Kunming Forestry Bureau, 2009
Jinguang Temple NR	99.50	25.15	19.19	22.12	25.25	12.77	Liu and Du, 1991
Langping Yunling NR	99.35	26.5	19.45	10.85	42.04	13.2	Yunnan Forestry Survey Institute, 2010
Lujiangba dry-hot valley	98.90	25.00	41.3	13.9	8.8	2.7	Cao, 1993
Nangunhe NR	99.00	23.45	24.40	38.1	10.39	4.62	Yang and Du, 2004
Nanpeng River NR	99.00	23.90	20.45	30	15.22	7.58	Zhang et al., 2010
Northern Gaoligong Mt. NR	98.50	28.00	14.8	17	33.2	17.5	Li et al., 2007
Nuozadu NR	100.43	22.68	25.19	35.39	11.34	4.53	Cao, 2004
Qiaojia dry-hot valley	103.00	27.00	34.00	11.2	24.2	5.3	Cao and Jing, 1989
Ruili Forest Park	97.80	24.00	24.90	35	10.1	2.1	Zhu et al., 2006b
Shilin NR	103.34	24.79	22.22	13.67	30.34	8.97	Cui et al., 2005
Shishan NR	102.86	25.46	21.58	9.34	37.76	12.24	Guo, 1988
Southern Gaoligong Mt. NR	98.76	24.83	25	31.26	18.8	7.8	Meng et al., 2013
Tongbiguan NR	97.65	24.65	20.42	33.8	14.97	9.24	Yin et al., 2007
Wuding region	102.00	25.83	20.38	11.43	32.35	10.27	Li et al., 2009
Wuliangshan NR	100.65	24.38	21.03	24.27	20.82	11.19	Peng, 1997
Xianggelila county	99.92	27.87	13.64	6.83	45.58	14.57	Li and Zeng, 2006
Xiaobaicaoling NR	101.07	26.12	19.62	10.58	39.04	12.5	Wang et al., 2005
Xiaoheishan NR	98.70	24.65	21.06	26.49	19.29	10.46	Wang et al., 2006b
Xishuangbanna NR	101.50	21.50	19.6	51.5	3.9	1.5	Zhu, 1993
Yongde Daxueshan NR	99.80	24.10	18.08	22.15	22.93	11.41	Liu and Peng, 2010
Yuanmou dry-hot valley NR	101.89	25.78	41.88	8.97	19.22	5.13	Li et al., 2008
Yulongxueshan NR	100.32	27.18	17.06	5.29	47.25	12.16	Ou, 1988
Yunajiang NR	102.00	23.67	23.69	24.92	16.88	7.54	Ma et al., 1995
Yunlong NR	102.43	25.50	17.42	11.74	43.57	10.61	Li et al., 2004
Zhaotong Region	104.57	27.78	15.47	12.19	33.27	14.53	Ding et al., 2008
Zixishan Natural Reserve	101.40	24.50	19.74	10.26	40	10	Li et al., 2010

PT, Pantropic elements, defined with the distribution throughout the tropics of the world; TA, the tropical Asian elements, defined in sensu lato, including the typical tropical Asia distribution and tropical Asia to tropical Australia distribution; TT, the typical temperate elements, defined in sensu lato, including the typical north temperate distribution, east Asia and north America disjunct, and Old World temperate distributions; EA, East Asia elements, defined with the distribution from east Himalayas to Japan.

Biogeographical divergence of the flora of Yunnan was initiated by the uplift of the Himalayas and the extrusion of the Indochina block during the Tertiary (Zhu, 2012). The Indian continent collided with Asia at about 50 Ma (Rowley, 1996) causing uplift of the Himalayas, continuous deformation of southwestern China and a large clockwise rotation and southeastward extrusion of Indochina (Harrison et al., 1992; Funahara et al., 1993; Chen et al., 1995; Leloup et al., 1995). The Simao Terrane, which forms the present west and south parts of Yunnan, has been suggested as one of the prominent fragments of the extruded Indochina block (Sato et al., 1999, 2001, 2007). As a whole, the Simao Terrane was displaced southward by 800 km, together with a clockwise rotation of 30°. The rotation processes were believed active until at least the Miocene (Schärer et al., 1990; Chen et al., 1995). These geological events may thus have affected the evolution of the Yunnan flora.

It is interesting to know whether the distribution patterns of seed plants in Yunnan have been affected by geological events. In

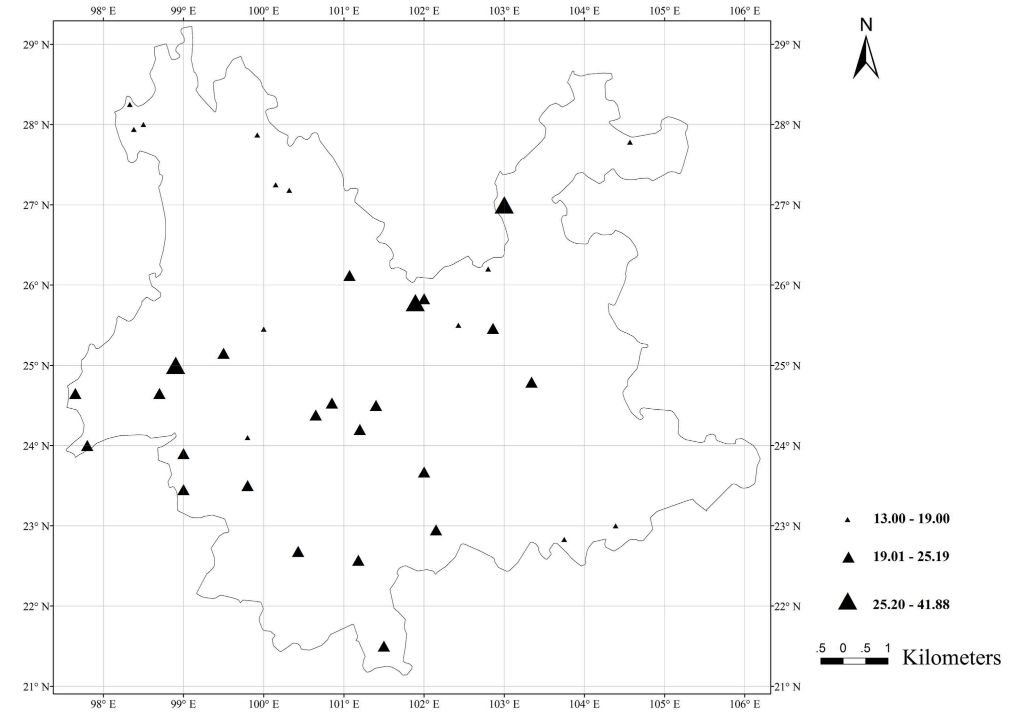

FIGURE 3 | The abundance pattern of the pantropic distributions of geographical elements across Yunnan.

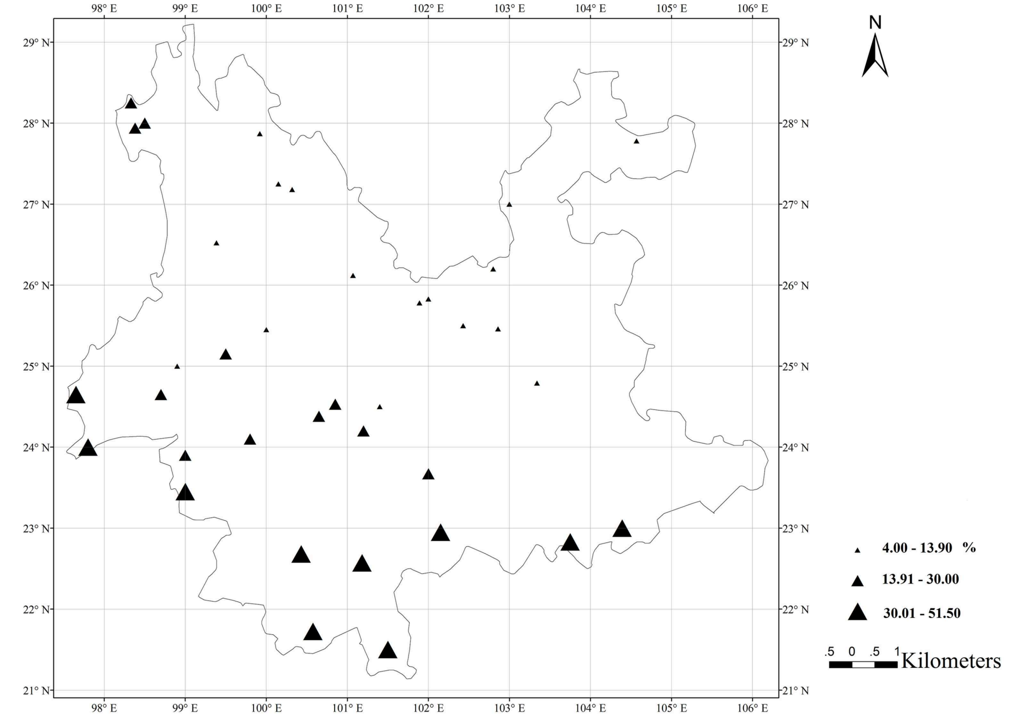

FIGURE 4 | The abundance pattern of the tropical Asian distributions of geographical elements across Yunnan.

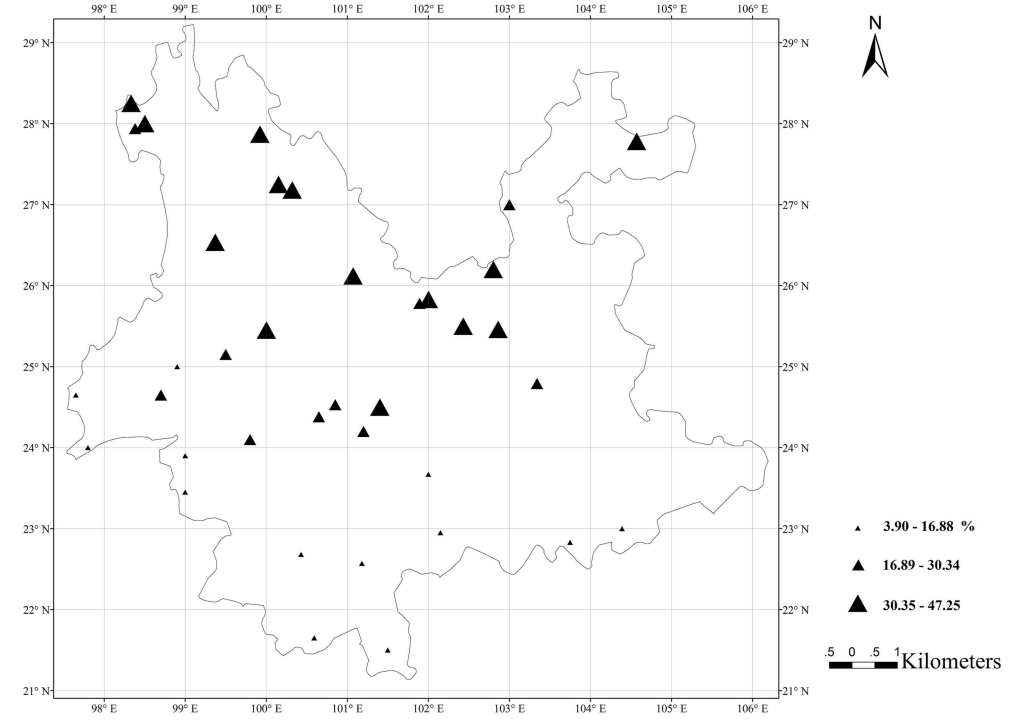

FIGURE 5 | The abundance pattern of the typical temperate distributions of geographical elements across Yunnan.

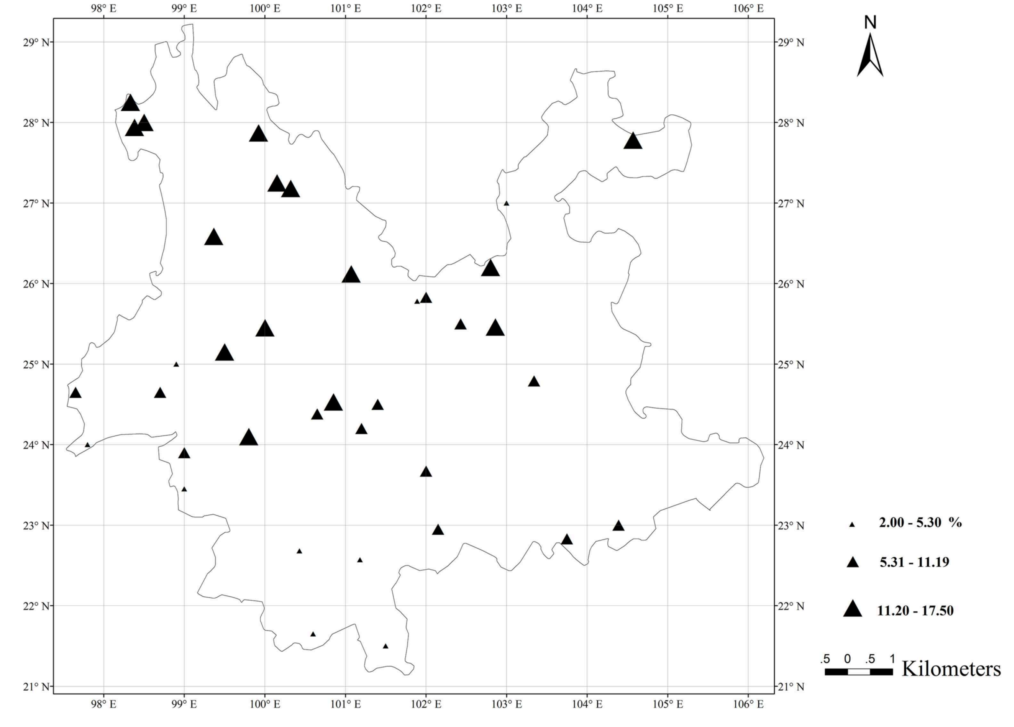

FIGURE 6 | The abundance pattern of the east Asia distributions of geographical elements across Yunnan.

this article, I will address the correspondence by comparing the distribution patterns of Yunnan seed plants and the geological events.

Materials and Methods

A database of 38 regional floristic studies covering Yunnan was used to illustrate the distribution patterns of their floristic elements (**Table 1**). These studies were done mostly in well-protected nature reserves. The seed plant genera were assigned to 15 distribution patterns according to their worldwide geographical distributions, following Wu's classification (Wu, 1991) as follows: Cosmopolitan, Pantropic, Tropical Asia, and Tropical America disjunct, Old World Tropics, Tropical Asia to Tropical Australia, Tropical Asia to Tropical Africa, Tropical Asia, North Temperate, East Asia, and North America disjunct, Old World Temperate, Temperate Asia, Mediterranean region, West to Central Asia, Central Asia, East Asia, and Endemic to China. The Cosmopolitan distributions have little geographical significance and here are not used. Patterns of seed plant distributions across these regional floras were quantified at the generic level based on Wu's documentation. Here the tropical Asian elements are defined in *sensu lato*, including the typical tropical Asia distribution and tropical Asia to tropical Australia distribution. The typical temperate elements are defined in *sensu lato*, including the typical north temperate distribution, east Asia and north America disjunct, and Old World temperate distributions. Such pantropic elements, the tropical Asian elements in *sensu lato*, and the typical temperate elements in *sensu lato*, as well as the East Asia elements are recognized to be the four dominant elements, which contribute the majority not only in the total flora of Yunnan, but also in the regional floras in Yunnan. These four dominant geographical elements were abstracted from the regional floras and are used in our study (**Table 1**).

ArcView software was used for making abundance maps of the four geographical elements from the regional floras. The abundances were grouped into three classes, which were classified by natural breaks, with breakpoints between classes identified using Jenk's optimization, a default classification method in ArcViewGIS 3.1 that reduces variance within classes and maximizes variance between them. Graduated symbols were used.

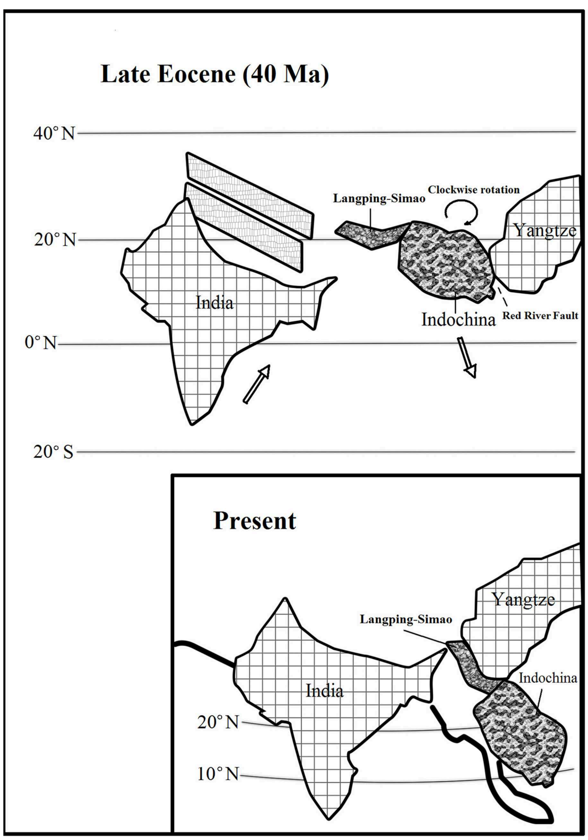

FIGURE 7 | Clockwise rotation and southeastward extrusion of Langping-Simao and Indochina geoblocks during late Eocene (Redrawn from Sato et al., 2001, Figure 7).

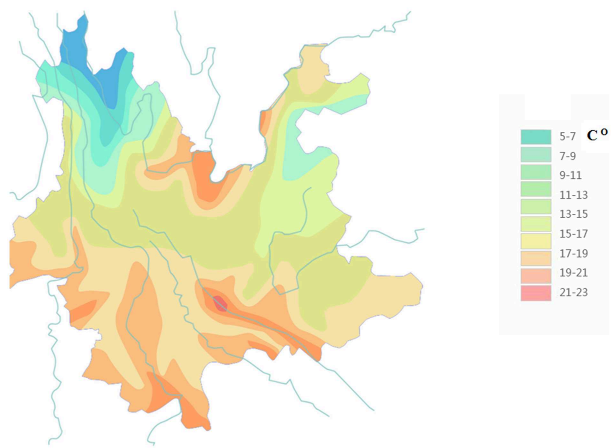

FIGURE 8 | Distribution of annual mean temperature in Yunnan.

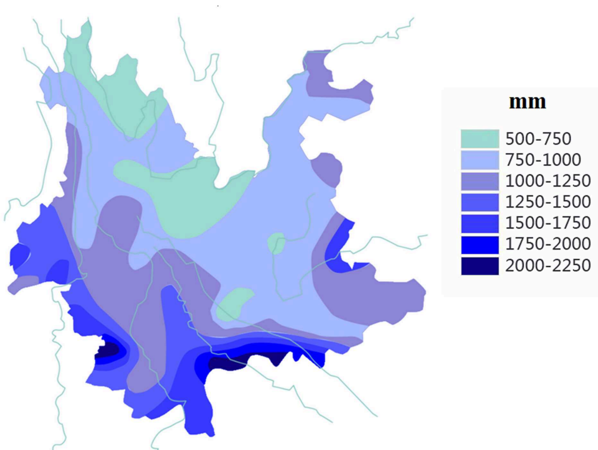

FIGURE 9 | Distribution of annual mean rainfall in Yunnan.

The Simao Terrane, which forms the present west and south parts of Yunnan, was displaced southward by 800 km, together with a clockwise rotation of 30°. The rotation processes were believed active until at least the Miocene. This unique geological history may influence these abundant patterns of dominant geographical elements across Yunnan. Here the abundant patterns of geographical elements across Yunnan were used to discuss the relationship between the floristic geography and geological history of Yunnan.

Results

Genera with pantropc distributions contribute 13–41.88% of the regional floras across Yunnan. The abundance pattern of the pantropic genera shows little correspondence with latitude, but has high proportion at dry-hot valleys (**Figure 3**). The highest proportion, which makes of 41.88% of the total regional flora, is at the Yuanmou dry-hot valley of Jingshan rive in northern Yunnan, and the second highest proportion is at the dry-hot valley of Lujiang rive in western Yunnan. Genera with tropical Asian (*sensu lato*) distributions contribute 4% (in northern Yunnan) to 51.5% (in southern Yunnan) of the regional floras across Yunnan. The abundance pattern shows that they occur mainly in southern and western Yunnan, and their proportions in regional floras declines abruptly in eastern, central and northern Yunnan (**Figure 4**). The typical temperate (*sensu lato*) genera contribute 3.9% (in southern Yunnan) to 47.25% (in northern Yunnan) of the regional floras across Yunnan (**Figure 5**). The east Asia genera contribute 2% in southern Yunnan to 17.5% in northern Yunnan (**Figure 6**).

Obviously, the tropical Asian genera show oblique abundance patterns across Yunnan. For example, in the Dulongjiang region in the far northwest of Yunnan (28.25 N, 98.33 E), the tropical Asian genera contribute 18.11% of the total regional flora, while in the adjacent Lijian region (27.18 N, 100.32 E), the tropical Asian genera only comprise 5.29%.

Discussion

Geographical elements were considered related to latitude and altitude. The abundances of geographical elements across Yunnan show complicated patterns. The abundance pattern of the pantropic genera shows high proportion at dry-hot valleys despite latitude and altitude. The abundance pattern of the typical temperate genera shows some relations to latitude and altitude. The abundance pattern of the east Asia genera shows also some relations to latitude and altitude, but a higher proportion in southeast Yunnan.

In southern and eastern China, the abundances of tropical Asian genera have high correlations with latitudinal gradients (Zhu et al., 2007; Zhu, 2013). However, the abundances of these genera show oblique patterns across Yunnan, not latitudinal gradients. The tropical Asian genera unusually occur in a much higher percentages in western Yunnan than in eastern Yunnan. They decrease in proportion abruptly in northeast of Yunnan.

These abundance patterns of geographical elements across Yunnan show some correspondence with topography, but if we see the geological history of Yunnan (**Figure 7**), these abundance patterns correspond well to the clockwise rotation and southeastward extrusion of the Simao-Indochina geoblock. Compared with the distribution patterns of the annual mean temperature (**Figure 8**) and annual mean rainfall (**Figure 9**) in Yunnan, the abundances of geographical elements across Yunnan also do not show well correspondence with them as the usual.

Therefore, we consider that the relatively high proportion of tropical Asian genera in western and southwestern Yunnan matches the clockwise rotation of the Simao Terrane and the southeastward extrusion of the Simao-Indochina geoblock that facilitated migrations of SE Asian plants. These oblique patterns in Yunnan cannot be explained by climate alone, but can be explained at least partly by the geological history.

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