
Comparison of Miocene fossil floras in lacustrine deposits : Implications for palaeoclimatic interpretations at the middle latitudes of the Pacific rim

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Hong Yang 1996. Comparison of Miocene fossil floras in lacustrine deposits : Implications for palaeoclimatic interpretations at the middle latitudes of the Pacific rim. *Palaeobotanist* **45** : 416-429.

The Early Neogene Shanwang lacustrine deposit in eastern China is similar to the Clarkia deposit of northern Idaho, U.S.A., in age, sedimentary environment, and fossil preservation. Both lake deposits contain well-preserved non-marine fossil biotas, and both are especially rich in plant remains. The two floras shared a high percentage of common genera, and both showed similar taxonomic diversity and habit. The two Miocene floras are comparable to the present-day mixed mesophytic forests of the Yangtze River (Changjiang) Valley of China. Paleoclimatic comparisons are based on plant fossils for the most part, supplemented by information from other fossil groups and from sedimentological data. Evidence from (i) taxonomic associations (both plant and animal), (ii) foliar physiognomy, (iii) taphonomic characteristics, and (iv) sedimentologic data indicate that in the Early Neogene, the two areas experienced similar climatic conditions. The Clarkia area was slightly warmer and more humid compared to a more seasonal climatic regime in the Shanwang area—even though Clarkia was at about 10 degree higher latitude. Our results support the previous hypothesis that paleoclimate in Early to Middle Miocene time was more equable compared to the present day. Our data further suggest that at similar latitudes, floras in western North America represent warmer climatic conditions than their Asian counterparts. The comparative study further suggests that the accuracy of paleoclimatic interpretations can be improved by utilizing large fossil floras of taxonomic diversity from similar environments, and by integrating evidence from other fossil groups and sedimentological records.

Key-words—Plant megafossils, Lacustrine remains, Paleoclimate, Miocene, Pacific rim.

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सारांश

सरोवरी निक्षेपों से प्राप्त मध्यनूतन युगीन वनस्पतिजातों की तुलना: प्रशान्त परिधि के मध्य अक्षांशों की पुराजलवायवी व्याख्याओं का महत्व

होंग यांग

पूर्वी चीन में प्रारम्भिक पश्चनूतन शानवांग सरोवरी निक्षेप, आयु, अवसादन एवं पादपाश्र्मों में अमेरिका में उत्तरी इदाहो के क्लार्किया निक्षेपों के समान हैं। दोनों ही निक्षेपों में असमुद्री अशिमित जीविता विद्यमान है तथा दोनों में भरपूर पादपाश्र्म मिलते हैं। दोनों के वनस्पतिजातों में सामान्य प्रजातियाँ मिलती हैं तथा एक जैसी विभिन्नता प्रदर्शित करते हैं। ये दोनों वनस्पतिजात चीन की यांगसी नदी घाटी के वर्तमान मिश्रित वनों से तुलनीय हैं। पादपाश्र्मों पर आधारित पुरापर्यावरण एक दूसरे से तुलनीय हैं। वर्गिकीय साहचर्य (पौधे एवं जन्तु), आकारिकीय अध्ययन, जैवसादिकीय लक्षण तथा अवसादीय आँकड़ों से प्रदर्शित होता है कि दोनों क्षेत्रों में पश्चनूतन काल में एक जैसी जलवायु थी। वैसे शानवांग की तुलना में क्लार्किया क्षेत्र अधिक गर्म था। इस अध्ययन से प्राप्त आँकड़े पूर्व परिकल्पना की पुष्टी करते हैं तथा इनसे यह भी व्यक्त होता है कि एक ही अक्षांशों पर एशिया की तुलना में उत्तरी अमेरिका के वनस्पतिजातों के समय एक समान जलवायु विद्यमान थी।

NON-MARINE fossil records, especially paleobotanic data, represent a major resource for Cenozoic con-

tinental paleoclimatic interpretations (Wolfe, 1979; Wing & Greenwood, 1993). Paleobotanic comparisons of contemporary fossil floras can offer information on ancient vegetation patterns over large

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geographic areas and provide insight into ancient climatic systems on both local and global scales. Neogene floras and paleoclimatic changes around the Pacific Ocean basin are critical to our understanding of modern floral distribution in the Northern Hemisphere; this has generated recent interest among paleobotanists on both sides of the Pacific Ocean. Liu and Leopold (1994) compared two Miocene pollen floras and their paleoclimatic signals across the Pacific Ocean, which showed that low temperature gradients existed in the northern Pacific rim during Early to Middle Miocene time. However, their comparison was based mainly on palynological data from two different depositional environments.

In this study, we further test the hypothesis of Liu and Leopold by comparing two similar-aged fossil-bearing deposits that accumulated under lacustrine conditions with similar taphonomic factors. We select the two Miocene lacustrine deposits from opposite sides of the Pacific Ocean—Clarkia in northern Idaho (47N, 116W), U.S.A. and Shanwang in Shandong Province, eastern China (36°N, 119°E) (see Smiley & Rember, 1985a; Yang & Yang, 1994, for detailed geographic location maps), for the following reasons: (i) both deposits have similar geologic ages (approximately 17–20 Ma for Clarkia, and approximately 15–17 Ma for Shanwang); (ii) both records contain well-documented and diverse fossil groups; and (iii) the two fossil biotas were deposited in volcanically-related small lake basins with similar taphofacies (Plates 1–3) (Smiley & Rember, 1985a; Yang & Yang, 1994).

COMPARISON OF THE FOSSIL FLORAS

The Shanwang flora

The Miocene Shanwang flora consists of 136 species of macrofossils belonging to 94 genera and 48 families (Hu & Chaney, 1940; Sze, 1951; Academia Sinica, 1978; Li, H. 1982; Yang, 1988). The flora is dominated by angiosperms with high genus diversity: Leguminosae (10 genera), Rosaceae (9 genera), Betulaceae (5 genera), Juglandaceae (4 genera), Rhamnaceae (4 genera), Ulmaceae (4 genera), Hamamelidaceae (3 genera), Lauraceae (3 genera), and Vitaceae (3 genera) (Table 1). At the genus level, *Acer*, *Carpinus*, *Populus*, *Ulmus* and *Tilia* exhibited higher species diversity. However, *Acer*, *Carpinus*,

Carya, *Ceratophyllum*, *Fothergilla*, *Hamamides*, *Juglans*, *Populus*, *Ulmus*, and *Zelkova* are numerically dominant as fossilized specimens (Plate 2). Physiologically, the flora is dominated by woody deciduous plants, such as members of Betulaceae, Fagaceae, Juglandaceae, Salicaceae, Tiliaceae, and Ulmaceae, in association with evergreen members (e.g., Lauraceae, Magnoliaceae, and Sapindaceae). The ratio between evergreen and deciduous plants in the Shanwang flora is about 8.5 per cent. Fossil wood found at Shanwang shows distinct growth rings in cross section (Pl. 1, fig. 2) (Yang, 1988).

The Shanwang pollen flora contains about 25 families and 41 genera, with Betulaceae, Hamamelidaceae, Juglandaceae, Pinaceae, and Ulmaceae predominating (Sung, 1959; Song *et al.*, 1964; Wang, 1981; Liu & Leopold, 1992). The majority of pollen grains represent are woody deciduous angiosperms (e.g., *Alnus*, *Altingia*, *Betula*, *Carya*, *Corylus*, *Fagus*, *Juglans*, *Liquidambar*, *Quercus*, *Ulmus* and *Zelkova*). Among the taxa represented only by microfossils, herbaceous taxa (e.g., *Adiantum*, *Pteridium* and *Ephedra*), aquatic plants (e.g., *Typha* and *Trapa*), and wing-pollinated conifers (e.g., *Abies*, *Larix*, *Picea*, *Pinus*, and *Tsuga*) predominate. A large percentage (45%, 64 genera) of Shanwang's megafossil taxa have not been reported in the pollen record. Nevertheless, even though the macrofossil flora of Shanwang is more diverse than the microflora, the dominant plant taxa from the Shanwang Formation are represented by both macrofossils and their pollen/spore equivalents, and the relative abundance of specimen members is also comparable.

The Clarkia flora

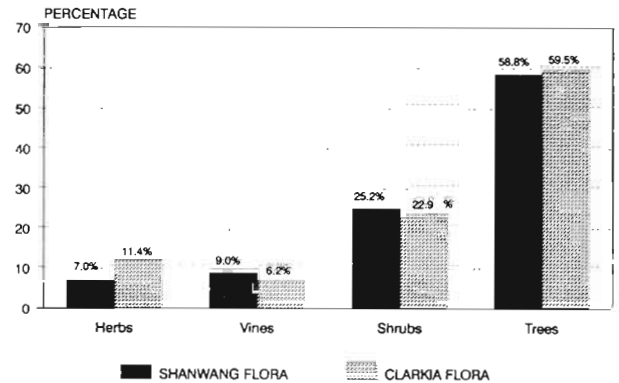
The rich Clarkia Miocene flora in northern Idaho contains abundant macrofossils including about 120 species belonging to about 96 genera and 49 families (Table 1) (Smiley *et al.*, 1975; Smiley & Rember, 1981, 1985b; Rember, 1991). Among them, gymnosperms are well represented (13 genera), and *Taxodium*, *Metasequoia*, *Pinus*, *Amentotaxus* and *Cunninghamia* are common components of the conifer elements. Among angiosperms, Fagaceae (6 genera), Leguminosae (6 genera), Rosaceae (6 genera), Betulaceae (4 genera), Ericaceae (4 genera), Hamamelidaceae (4 genera), Juglandaceae (4

genera), Lauraceae (4 genera), Ulmaceae (3 genera), and Vitaceae (3 genera) exhibit higher diversity at the generic level. However, *Acer*, *Magnolia*, *Lithocarpus*, *Quercus*, *Rosa*, *Salix*, *Smilax* and *Vitis* are of higher species diversity. If specimen numbers are counted, *Acer*, *Betula*, *Castanea*, "*Cocculus*", *Liquidambar*, *Liriodendron*, *Metasequoia*, *Nyssa*, *Pinus*, *Platanus*, *Quercus*, *Pseudofagus*, *Sequoia* and *Taxodium* are well represented. Nevertheless, the flora is dominated by deciduous plants, and the ratio of evergreen to deciduous is about 20 per cent.

Gray (1985) reported an extremely rich microfossil flora from Clarkia P-33 site. A comparison between macrofossil and pollen taxa reinforces the dominant elements that were indicated by macrofossil remains. There are 29 genera represented by leaves and fruits but lack pollen/spore representation. These 29 taxa include genera that have never been recorded as pre-Quaternary pollen in the Pacific Northwest, such as *Caldesia* and *Smilax*. Other taxa, such as members of the Salicaceae, are well known for their low preservational potential. On the other hand, there are 14 genera whose macrofossil remains have not been reported in the Clarkia deposits, include wind-pollinated conifers (e.g., *Cedrus*, *Picea*, *Pseudotsuga* and *Tsuga*) that are dominant as microfossils (Gray, 1985). Some herbaceous and shrubby elements recorded by pollen, such as *Lycopodium* and *Ephedra*, also lack macrofossil representation in the Clarkia flora.

Floral Comparison

I am impressed by the high degree of taxonomic similarity between the two floras from opposite sides of the Pacific basin (Table 1). The two Miocene floras, Shanwang in China and Clarkia in western North America, show the following similarity of characteristics regarding composition, taxonomic diversity, and habits: (i) both fossil floras are dominated by deciduous angiosperms, and they share more than 50 per cent of macrofossil genera (Yang & Smiley, 1991); (ii) the two floras have similar diversity patterns at the genus level, and both are dominated by Fagaceae,



Text-figure 1—Comparison of macrofossil data between Shanwang and Clarkia Miocene floras, showing plant habit indicated by the macrofossil record.

Betulaceae, Salicaceae and other temperate families; (iii) the two fossil floras are dominated by deciduous plants, associated with evergreen taxa; and (iv) the evidence from megafossils in the two floras indicates similar habit patterns (Text-figure 1). On the other hand, the two floras show the following differences: (i) the Clarkia flora has more evergreen plants than the Shanwang flora; (ii) the Clarkia flora has a higher gymnosperm diversity; (iii) Ericaceae, a common family in the Clarkia flora, is absent in the Shanwang flora.

Both Shanwang and Clarkia sediments contain rich and diverse pollen taxa; the main characteristics of the two microfloras are comparable: (i) the two localities share more than 60 per cent of equivalent pollen taxa, and most of the shared genera are also important members in both floras (Yang & Smiley, 1991); (ii) both microfloras are dominated by deciduous families such as Betulaceae, Hamamelidaceae, and Ulmaceae, and are mixed with evergreen taxa such as Pinaceae and Taxodiaceae-Cupressaceae-Taxaceae (T-C-T) complex; (iii) the Clarkia microflora contains more swamp lake border plants which increase upward through the 10 meter section (Gray, 1985; Yang & Smiley, 1991). Although differences exist between macro and micro-fossil records, spores and pollen data resemble the vegetation type as reflected by macrofossils from both sites of the Pacific Ocean.

PLATE 1

- The Shanwang fossil site showing the diatomite sequence in the middle part of the Shanwang Formation.
- Fossil wood from Shanwang showing distinct annual rings in a cross section (X5).
- Enlargement of the diatomite deposits.
- SEM photos showing the same dominant fossil diatom (*Melosira* sp.) from light layers (d) and dark layers (e) of the Shanwang deposit (X 1000).
- The main fossil site in the Shanwang locality.

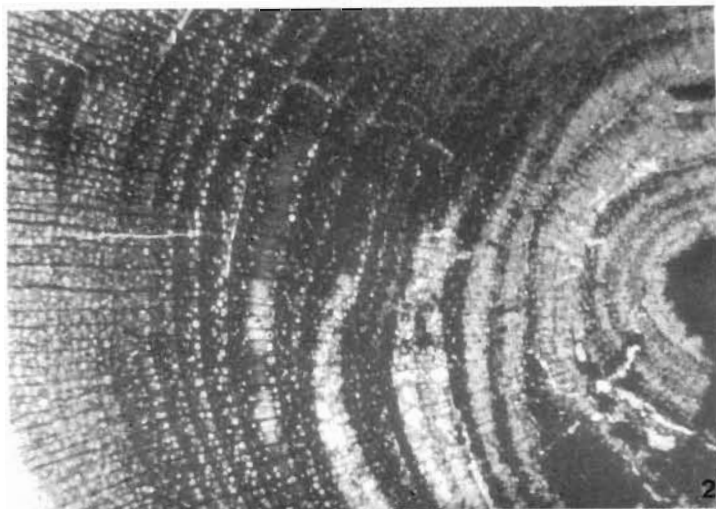


PLATE 1

Table 1—Taxonomic comparison of the two Miocene floras and distribution of their modern equivalents

Family	Genus	Shanwang	Clarkia	Modern Distributions	
				E. As	N. Am
Amentotaxaceae	<i>Amentotaxus</i>	x	x	x	
Taxaceae	cf. <i>Taxus</i>		x	x	x
Pinaceae	<i>Abies</i>		x	x	x
	<i>Picea</i>	x	x	x	x
	<i>Keteleeria</i>	x	x	x	
	<i>Cephalotaxus</i>	x	x	x	
	<i>Pinus</i>		x	x	x
Taxodiaceae	<i>Cunninghamia</i>		x	x	
	<i>Glyptostrobus</i>		x	x	
	<i>Metasequoia</i>		x	x	
	<i>Sequoia</i>	x	x		x
	<i>Taxodium</i>		x		x
Cupressaceae	<i>Calocedrus</i>		x	x	x
	<i>Chamaecyparis</i>		x	x	x
	<i>Thuja</i>		x	x	x
Magnoliaceae	<i>Liriodendron</i>		x	x	x
	<i>Magnolia</i>	x	x	x	x
Anonaceae	cf. <i>Asimina</i>		x		x
Lauraceae	<i>Cinnamomum</i>	x	x		
	<i>Lindera</i>	x	x	x	x
	<i>Litsea</i>	x		x	
	<i>Persea</i>		x		x
	<i>Sassafras</i>		x	x	x
Aristolochiaceae	<i>Aristolochia</i>	x		x	
Nymphaeaceae	<i>Nuphar</i>		x	x	
Menispermaceae	<i>Cocculus</i>		x	x	x
Ceratophyllaceae	<i>Cercidiphyllum</i>	x		x	
Cercidiphyllaceae	<i>Cercidiphyllum</i>		x	x	
Hamamelidaceae	<i>Hamamelis</i>	x	x	x	x
	<i>Exbucklandia</i>		x		x
	<i>Liquidambar</i>	x	x	x	x
	<i>Parrotia</i>		x		x
	<i>Fothergilla</i>	x			x
Platanaceae	<i>Platanus</i>		x		x
Ulmaceae	<i>Aphananthes</i>	x		x	
	<i>Celtis</i>	x	x	x	x
	<i>Ulmus</i>	x	x	x	x
	<i>Zelkova</i>	x	x	x	
Moraceae	<i>Ficus</i>	x		x	
Urticaceae	<i>Pilea</i>	x		x	
Fagaceae	<i>Castanea</i>	x	x	x	x
	<i>Morus</i>		x	x	

	<i>Castanopsis</i>		x	x	x
	<i>Fagus</i>	x	x	x	x
	<i>Quercus</i>	x	x	x	x
	<i>Lithocarpus</i>		x	x	
	<i>Pseudofagus</i>		x	Extinct	
Betulaceae	<i>Alnus</i>	x	x	x	x
	<i>Betula</i>	x	x	x	x
	<i>Carpinus</i>	x		x	x
	<i>Corylus</i>	x	x	x	x
	<i>Ostrya</i>	x	x	x	x
Juglandaceae	<i>Carya</i>	x	x	x	x
	<i>Juglans</i>	x	x	x	x
	<i>Pterocarya</i>	x	x	x	x
	<i>Platycarya</i>	x		x	x
Myricaceae	<i>Myrica</i>	x			x
Comptoniaceae	<i>Comptonia</i>		x		x
Polygonaceae	<i>Polygonum</i>	x		x	x
Flacourtiaceae	<i>Carriera</i>	x		x	x
Stachyraceae	<i>Stachyurus</i>	x		x	x
Theaceae	<i>Gordonia</i>		x	x	x
Salicaceae	<i>Populus</i>	x	x	x	x
	<i>Salix</i>	x	x	x	x
Ericaceae	<i>Arbutus</i>		x	x	
	<i>Pieris</i>		x		x
	<i>Rhododendron</i>		x		x
	<i>Vaccinium</i>		x		x
Styraceae	<i>Halesia</i>		x		x
Symplocaceae	<i>Symplocos</i>		x		x
Ebenaceae	<i>Diospyros</i>	x	x	x	
Tiliaceae	<i>Tilia</i>	x	x	x	x
Sterculiaceae	<i>Commersonia</i>	x		x	
	<i>Firmiana</i>	x		x	
Malvaceae	<i>Malva?</i>		x		x
Euphorbiaceae	<i>Mallotus</i>	x		x	
Saxifragaceae	<i>Hydrangea</i>	x	x	x	x
	<i>Philadelphus</i>		x	x	x
Rosaceae	<i>Amelanchier</i>	x	x		x
	<i>Crataegus</i>	x	x	x	x
	<i>Cotoneaster</i>	x		x	
	<i>Eriobotrya</i>	x		x	
	<i>Malus</i>	x	x	x	x
	<i>Prunus</i>	x	x	x	x
	<i>Physocarpus</i>	x		x	x
	<i>Rosa</i>	x	x	x	x
	<i>Spiraea</i>	x		x	x
	<i>Sprya</i>		x		x

Leguminosae	<i>Albizzia</i>	x		x	
	<i>Amorpha</i>		x		x
	<i>Baubinia</i>		x		x
	<i>Cercis</i>	x	x	x	x
	<i>Derris</i>		x		x
	<i>Gleditsia</i>	x	x	x	x
	<i>Gymnocladus</i>	x	x	x	x
	<i>Leguminosites*</i>	x		-	-
	<i>Indigofera</i>	x		x	x
	<i>Pueraria</i>	x		x	
	<i>Robinia</i>		x		x
	<i>Sophora</i>	x		x	x
	<i>Wisteria</i>	x		x	x
	<i>Podogonium*</i>	x		-	
	<i>Zetia</i>		x	x	
Anacardiaceae	<i>Pistacia</i>	x		x	x
	<i>Rhus</i>	x	x	x	x
	<i>Astronium</i>	x			x
Simarubaceae	<i>Atilacthus</i>	x		x	
Rutaceae	<i>Evodia</i>	x		x	
	<i>Phellodendron</i>	x		x	
	<i>Zanthoxylum</i>	x		x	x
Meliaceae	<i>Cedrela</i>		x	x	
	<i>Chukrasia</i>	x		x	
	<i>Toona</i>	x		x	
Staphyleaceae	<i>Tapiscia</i>	x	x		
Aceraceae	<i>Acer</i>	x	x	x	x
Sapindaceae	<i>Koelreuteria</i>	x		x	
	<i>Sapindus</i>	x	x	x	x
Hippocastamaceae	<i>Aesculus</i>	x	x	x	x
Sabiaceae	<i>Meliosma</i>	x		x	x
Comaceae	<i>Cornus</i>	x	x	x	x
Araliaceae	<i>Kalopanax</i>	x		x	
Nyssaceae	<i>Nyssa</i>		x	x	x
Aquifoliaceae	<i>Ilex</i>		x	x	x
Celastraceae	<i>Celastrus</i>	x		x	x
	<i>Evongmus</i>	x		x	x
	cf. <i>Perrotetia</i>		x		x
Rhamnaceae	<i>Berchemia</i>	x	x	x	x
	<i>Hovenia</i>	x		x	
	<i>Paliurus</i>	x	x	x	
	<i>Zizyphus</i>	x		x	
Vitaceae	<i>Ampelopsis</i>	x	x	x	
	<i>Tetrastigma</i>	x		x	
	<i>Vitis</i>	x	x	x	x
Oleaceae	<i>Fraxinus</i>	x	x	x	x

	<i>Jasminum</i>	x		x	
Carprifoliaceae	<i>Lonicera</i>	x		x	x
	<i>Viburnum</i>	x	x	x	x
Scrophulariaceae	<i>Paulownia</i>	x	x	x	x
Bignoniaceae	<i>Caralpa</i>	x		x	x
Alismataceae	<i>Caldesia</i>		x	x	
Potamogetonaceae	<i>Potamogeton</i>	x		x	x
Smilacaceae	cf. <i>Heterosmilax</i>	x	x	x	x
	<i>Smilax</i>		x	x	x
Graminae	<i>Graminites</i>	x	x	x	x
Cyperaceae	<i>Cyperacites</i>	x		x	x
Typhaceae	<i>Typha</i>		x	x	x

Data from Yang (1988) and Smiley and Rember (1985b)

*Form genera. E.As : Eastern Asia, N.Am : Northern America.

PALAEOCLIMATIC INTERPRETATIONS AND COMPARISON

Comparison with living representatives and assemblages

Table 1 lists genera in both Miocene floras that their living representatives are in the present-day eastern China and/or eastern North America. Both fossil floras contain some relics, such as *Cercidiphyllum*, *Cunninghamia*, *Metasequoia*, *Sequoia*, *Smilax* and *Taxodium*, which are important components in the present-day warm temperate floras. Since such modern relics occur in restricted areas with distinguished climatic parameters, they can be used as paleoclimatic indicators for the fossil flora. For example, *Metasequoia* (the Dawn Redwood), an endemic genus in Lichuan County at the boundary between Sichuan and Hubei Provinces in south-central China, is a common taxon in the Clarkia flora. The *Metasequoia* Valley in Lichuan has 12.7°C mean annual temperature and 21.6°C mean annual range of temperature (Bartholomew *et al.*, 1983; Yang & Smiley, unpublished data). It is evident from the paleobotanic data that both Miocene floras are comparable with the modern mixed mesophytic formation in a warm temperate climatic condition (e.g., the middle and lower Yangtze River Valley, in southern China).

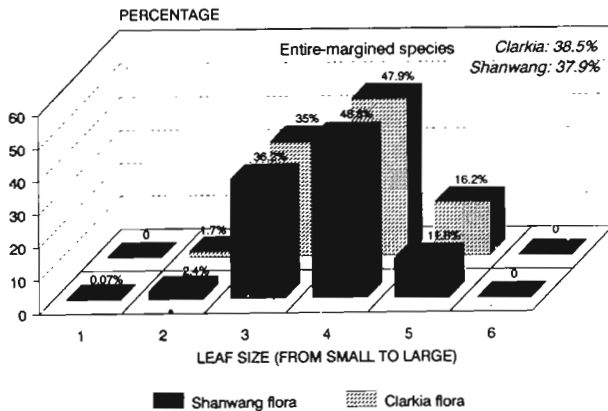
Foliar physiognomic analysis

The foliar physiognomic data of Shanwang and Clarkia floras show very similar patterns (Text-figure 2). Both floras are dominated by mesophyll and microphyll size leaves, and they have the same orders

of leaf size (mesophyll >microphyll >macrophyll >nanophyll >leptophyll >megaphyll). Furthermore, both floras had almost the same percentage of entire margin species (38.46% for Clarkia and 37.98% for Shanwang). The similar percentages of entire margin species in both fossil floras may indicate that the two areas had similar annual temperatures in Miocene time. Well developed growth rings in fossil wood from Shanwang may suggest distinct seasonal changes in Shanwang area during the Miocene time. Paleoclimatic conditions inferred by foliar physiognomic data for the two floras agree with those represented by the living assemblages.

Paleoclimatic indications from other fossil remains and sedimentological data

Both deposits contain extraordinarily-well preserved and highly-diverse non-marine fossil biotas. Fossil diatoms, insects, and vertebrates, when supplemented by sedimentological data, provide additional paleoclimatic information. The diatom floras in the two areas share more than 50 per cent genera, and both indicate warm, open, and fresh-water systems that can be found in present-day warm temperate or subtropical areas (Li, 1982; Bradbury *et al.*, 1985). The same diatom species was found in both dark and light alternates in the fine limitations in the Shanwang deposit (Pl. 1, figs 4, 5). Abundant fossil insects from both localities are dominated by the orders of Hymenoptera and Coleoptera, indicating humid forest type of insect faunas living under warm temperate climatic condition (Lewis, 1985; Zhang, 1986, 1989). Modern relatives of these insect taxa are confined to moist forest floors and lake



Text-figure 2—Comparison of foliar physiognomic data between the two floras, 1=leptophyll, 2=nanophyll, 3=microphyll, 4=mesophyll, 5=macrophyll, 6=megaphyll.

border sites, and some of them are restricted today to the lower middle Yangtze River Valley in China or southern and southeastern United States.

A diverse vertebrate fauna including fish, frogs, toads, tortoises, snakes, alligators, birds, ducks, squirrels, deer, bears, and rhinoceroses was recorded from the Shanwang locality (Yang & Yang, 1994). In contrast, no terrestrial vertebrate fossil has been reported from the Clarkia site after more than 20 years of intensive search. The modern relatives of Shanwang terrestrial vertebrates can be found in warm temperate or subtropical forests (Yan *et al.*, 1983). The fish fauna of Shanwang is dominated by minnows whose modern relatives are living in the Yangtze River Valley today. Likewise, the modern relatives of Clarkia fish (e.g., Pl. 3, fig. 7) can be found in the Great Valley area of California, Southwest United States (Smith & Elder, 1985). An alligator (*Alligator luicus*) found in the Shanwang deposit resembles the two living species of alligators, *Alligator sinensis* living in the lower Yangtze River Valley in China and *Alligator mississippiensis* living in the Mississippi River Valley in South-central United States (Li & Wang, 1987). The two living alligators have restricted distributions, but both areas have similar warm temperate climatic conditions. In addition, a well-preserved fossil squirrel (*Diatomya*) from the Shanwang Formation preserved with its colored

hair, and its modern relatives show twice hair changes during a year in responding to seasonal changes (Li, 1974). This evidence independently confirms distinct seasonality existed in the Shanwang area during the Miocene time as implied by paleobotanic data.

No trace of salt deposits and/or crystal gypsum, which may indicate dry paleoclimatic condition, has been reported in either area. At the topmost of the Shanwang Formation, poorly developed peat deposits may indicate a humid paleoclimatic condition (Yang, 1988). On the other hand, small cycles (finer than 10 cm) of fining-upward laminations found in Clarkia P-33 locality and in the drill cores (Pl. 3, fig. 2) have been interpreted as possible traces of summer storms (Smiley & Rember, 1981, 1985a). Besides, turbidite deposits that may be related to the frequent storms have also been reported from Clarkia area (Smiley & Rember, 1985a; Rember, 1991; Yang *et al.*, 1995). These evidence is consistent with the taphonomic observations that large branches with attached leaves and fruits retaining original coloration and organic biomolecules may be an indication of rapid burial following catastrophic abnormal abscission during rain storms. Plant fossils in the Clarkia site show no specific orientation, and leaves rarely overlap one on other (Pl. 3, fig. 3), suggesting transportation by wind. In addition, the summer storms may also be responsible for causing overturns of lake water resulting in massive killing of fish by degassing poisonous gas from the hypolimnion. The Clarkia fossil fish clearly indicates death by asphyxiation (Pl. 3, fig. 6).

DISCUSSIONS

There are many factors affecting the accuracy of paleoclimatic reconstruction and comparison, but errors are usually introduced by using small-sized floras or by ignoring taphonomic and paleoenvironmental effects. Burnham (1989) has emphasized the size of fossil floras to be used as basis for paleoclimatic reconstruction. Based on a comparative study between modern leaf litter and source forest in a deciduous community, Burnham *et al.* (1992) further recommended that at least 350 to 400 fossil leaves

PLATE 2

Macrofossil representatives from the Shanwang site (all photos are in original size).

- | | |
|----------------------------------|--|
| 1. <i>Populus prostomiti</i> Li. | 4. <i>Magnolia latifolia</i> Tao. |
| 2. <i>Zelkova ungeri</i> Kovats. | 5. <i>Juglans shanwangensis</i> Hu et Cheng. |
| 3. <i>Sequoia</i> sp. (?) | 6. <i>Liquidambar miosinica</i> Hu et Cheng. |

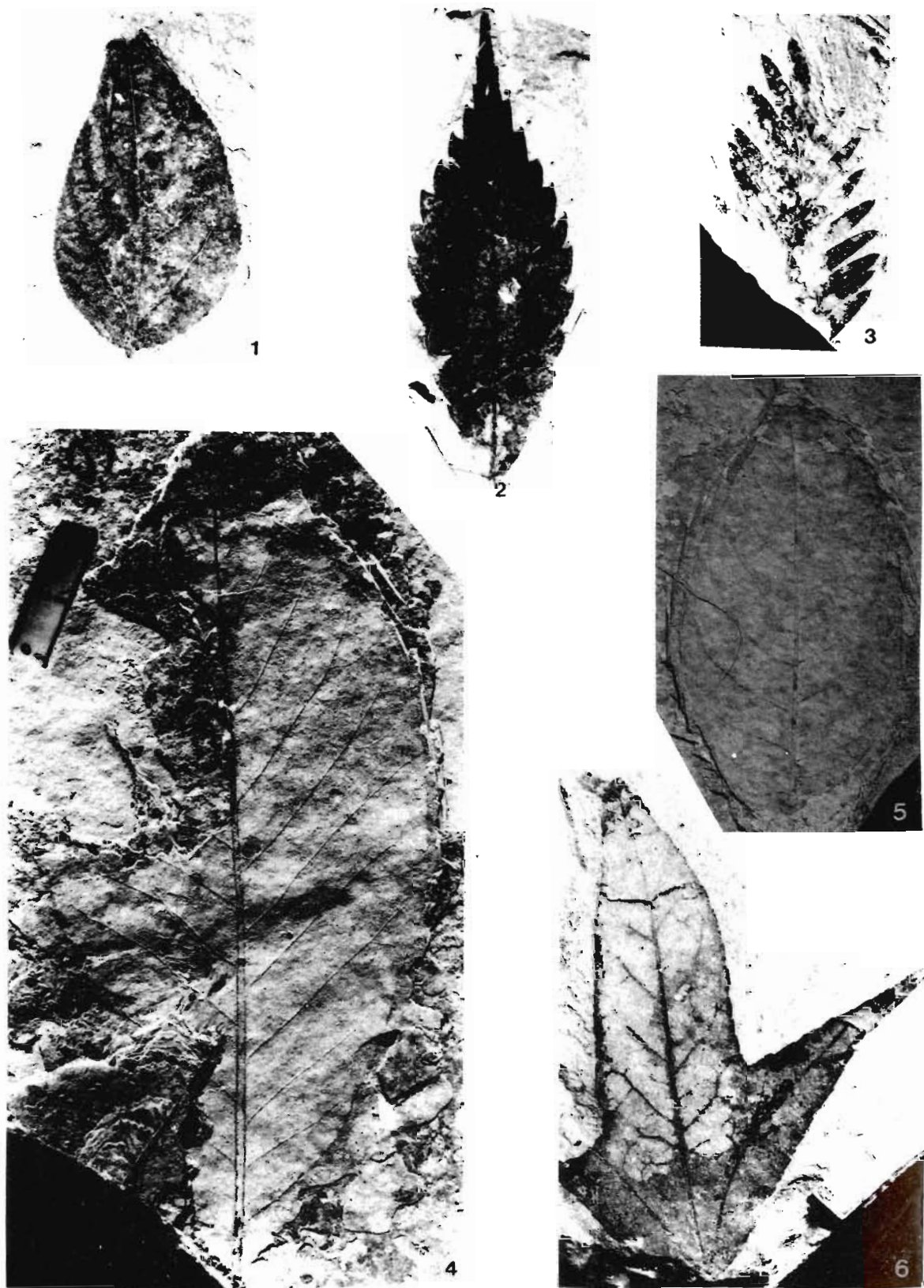


PLATE 2

should be collected in order to recover most of the fossil species that have shed leaves onto the sample site. In this study, our paleoclimatic reconstruction and comparison were based on two well-documented floras resulted from either 20 (Clarkia) or 50 (Shanwang) years of detailed studies and recollecting. Both floras contain close to 100 genera that based on tens of thousands specimens.

Paleobotanists have recognized that results of paleoclimatic reconstruction based on separate macro- or micro-plant fossil data set can vary in a certain extent. According to our experience with Clarkia and Shanwang floras, an attempt to incorporate both macrofossils and pollen and spore data should provide better results, and the two sets of data should be compared and used as complementary resources. For both Clarkia and Shanwang floras, the confidence of identification of plant macrofossils is far excess the microfossils, but microfossil may provide information on regional vegetation. In addition, other fossil records, such as diatoms, insects and vertebrates can also offer additional paleoclimatic evidence and serve the purpose of "checks and balances" for reconstructing ancient climates. The fossil squirrel with hair changing habit from the Shanwang Formation, for instance, provides strong paleoclimatic signals for seasonal changes reinforcing the conclusions drawn by paleobotanic data.

The variation of fossilization potentials in different sedimentary environments is widely realized by paleontologists and taphonomists (Burnham *et al.*, 1992; Greenwood, 1992). Different taphonomic factors and various degrees of taphonomic sieving in different depositional settings can reduce the accuracy of cross-environment paleoclimatic comparison. Methods such as physiognomic analysis which requires direct comparison between fossils and modern forms should be applied with cautions. Burnham (1989) noticed that under the same climatic regime, composition of forest litters—although only the first step in fossilization processes—differs among various subenvironments. Certain leaves are

over-represented in selective subenvironments, while others may be under-represented. Greenwood (1992) estimated that a correction factor, approximate 3:2 between the expected canopy trees and observed litter, exists in modern fluvial environments in Southern Hemisphere rainforests. Unfortunately, such factors, although derived only considering the initial process of fossilization, are unknown in other environments; strong variations in different environments are expected based upon current qualitative observations. Thus, for minimizing taphonomic bias in different sedimentary settings, paleoclimatic comparisons may be more accurate between similar sedimentary environments than between different sedimentary settings.

The paleoclimatic similarity between the two areas across the Pacific Ocean is far more than coincidence. After the Oligocene recovery, global paleoclimate began to warm up, and the warming trend was peaked near Middle Miocene time, setting up the background conditions for the two areas. Liu and Leopold (1994), based on palynological comparison between Shandong (China) and Alaska (USA), recognized a low latitudinal temperature gradient for the middle latitudes of the Northern Hemisphere. Our data derived from paleoclimatic comparison between the two lacustrine deposits at similar latitudes based on both paleobotanical and other paleontological data are in agreement with their basic conclusions. However, our results further suggest that at similar latitudes, the paleoclimate represented by floras in the American side was warmer than the Chinese side. Paleobotanic data from early-Middle Miocene localities in eastern China and western North America have revealed latitudinal controls for vegetation types around the Pacific Basin. Liu and Zheng (1995) recently summarized early-Middle Miocene floras of eastern China and their paleoclimate indications. A north to south latitudinal control for vegetation types was indicated by the contemporary Miocene floras, although the temperature gradient might be lower than the present day.

PLATE 3

1. The exposed Clarkia fossil site (P-33) in northern Idaho, USA showing three major layers of volcanic ash and unoxidized lacustrine deposits.
2. Laminated siltstone from P-33 showing fining upward laminations (scales are in mm).
3. An exposed surface of fossiliferous siltstone at the P-33 site, notice that fossil leaves are preserved without overlapping.
4. *Taxodium* sp from Clarkia P-33 site (X 0.75).
5. *Metasequoia occidentalis* Chaney from Clarkia P-33 site (X 0.3).
6. *Cunninghamia* sp. from Clarkia P-33 site (original size).
7. Fossil fish (*Archoplites clarki* Smith et Miller) from P-33 site, notice the open mouth indicating death by asphyxiation (X 0.5).

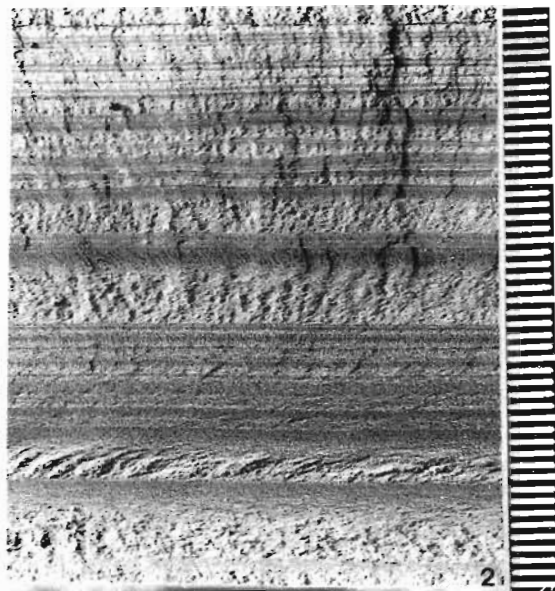
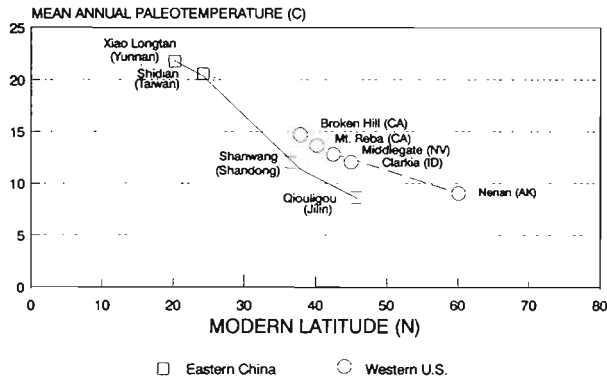


PLATE 3



Text-figure 3—Latitudinal controls of early-middle Miocene floras around the Pacific rim showing the relationship between latitude and estimated mean annual temperature indicated by selected floras from eastern China and western United States. Floral data were derived from Axelrod, 1980, 1985; Chaney and Chuang, 1968; Li and Yang, 1984; Liu and Leopold, 1994; Liu and Zheng, 1995; Smiley and Rember, 1985a; and Yang, 1988.

Similarly, in the American continent, contemporary floras point toward a reduced temperature gradient (Axelrod, 1980, 1985; Smiley & Rember, 1985b). Text-figure 3 presents selected early-Middle Miocene floras from both sides of the Pacific Basin showing the parallel trend and latitudinal control on both sides, and at similar latitudes, floras at the North American continent seem to indicate warm climates. It is evident that climatic zonations similar to the present-day pattern have been well established in Miocene, but the latitudinal temperature gradient was reduced compared the present day. The Pacific Ocean played an important role in controlling paleoclimates, especially the humidity, on both sides of the Pacific Ocean. This phenomena may also be related to a strong topographic control in western North America. Smiley and Rember (1985a) suggested that the high humidity and mild winter at Clarkia may be a result of the combination of local and regional topographic effects due to the lower Cascade and Olympic Mountains to the west and the Hoodoo and Rocky Mountains to the east. Such geographic features were not available in eastern China resulting in much drier and seasonal climate. In addition, we also speculate that intensive volcanic eruptions (e.g., the Columbia River Basalt in the Pacific Northwest) and the direction of prevailing winds in the Northern Pacific may also be responsible for influencing the Miocene climatic pattern that is indicated by the fossil floras on both sides of the Pacific Ocean.

SUMMARY AND CONCLUSIONS

Paleobotanic and paleoclimatic comparisons of the two contemporary fossil floras in Miocene lacustrine deposits provide us evidence for a better understanding of Miocene vegetation and paleoclimatic conditions in both areas. The comparison revealed that : (i) both fossil floras are dominated by deciduous angiosperms and mixed with evergreen elements; they are similar in diversity and habit patterns, although the Clarkia flora contains more conifers and evergreen elements than the Shanwang flora; (ii) both floras are comparable with the modern mixed mesophytic forests living in the Yangtze River Valley in China, representing warm temperate climate; (iii) paleoclimatic conditions in both areas were similar during Miocene time, although a slightly warmer and more humid condition is inferred for the Clarkia area; (iv) mild winter and summer storms might have existed in the Clarkia area; in contrast, distinct seasonality was implied for the Shanwang area; (v) the paleoclimates in both areas were controlled by the Middle Miocene global warming background and the low degree of latitudinal zonation, but at the same latitude, American floras usually indicate warmer climate than those in eastern China; (vi) when employing paleobotanic data to interpret paleoclimates, large fossil floras including both macrofossils and microfossils, other fossil groups (if available), and sedimentological data should be used together; (vii) paleoenvironmental and taphonomic effects must be taken into account while reconstructing paleoclimatic conditions, and paleoclimatic comparisons based on paleobotanical data should be conducted between fossil floras deposited in similar sedimentary environments to avoid taphonomic bias.

ACKNOWLEDGEMENTS

This paper is dedicated to the memory of my late mentor Dr Charles Jack Smiley who passed away on January 1st, 1996. His contributions to the Clarkia research and the fields of geology and paleobotany have influenced me enormously over the past years. I would like to thank the National Natural Science Foundation of China (NSFC 4870079), the University of Idaho Tertiary Research Center Funds, Idaho State

Board of Education (ISBE S92- 057), and the US Forest Service (USFS) for financial support. The manuscript was prepared while the author was an Alfred P. Sloan Postdoctoral Fellow (93-4-6 ME).

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