CONIFER DOMINANTS IN THE MIDDLE TERTIARY OF THE JOHN DAY BASIN, OREGON

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FOREWORD

DURING the early weeks of 1948, it was my good fortune to be in daily contact with Birbal Sahni who was then a visitor at the University of California. We had many discussions of *Metasequoia*, the conifer whose discovery in Asia a few years before was proving of such great interest to botanists and palaeobotanists. My departure for central China in February to visit scattered groves of this survivor from the past brought to a close an enjoyable and profitable opportunity to consider problems of Indian and North American palaeobotany with a leading student of science in Asia. I shall always be happy to recall that on the night of my departure from San Francisco, Dr. and Mrs. Sahni came to the airport to wish me farewell on my journey across the Pacific.

INTRODUCTION

The discovery of *Metasequoia* during the past decade has made necessary an extensive revision of our concepts regarding the Tertiary forests of western North America. Miki's assignment of certain leaves and cones from the Pliocene of Japan to *Metasequoia* (1941, p. 261) at once raised the question whether other fossil specimens previously considered to represent *Sequoia* might not also be referable to this new genus. In 1944 living trees of *Metasequoia* were found surviving in central China, and their recognition and description by Hu and Cheng (1948, p. 153) has provided a basis for interpreting with increasing discernment the many fossil floras in which this genus is represented. Unlike *Sequoia*, whose habit in past time as today appears to have been evergreen, *Metasequoia glyptostroboides* Hu and Cheng is a deciduous tree. In this respect it resembles the swamp cypress, *Taxodium distichum* Richard, of the south-eastern United States.

During the past few years, most of my time has been devoted to a re-study of all the available material of *Sequoia* and *Taxodium* from the Cretaceous and Tertiary of North America. Many of the fossil specimens previously assigned to these genera are now known to represent *Metasequoia*. The characters by which the leaves and cones of this genus, both living and fossil, may be recognized have been considered by Miki, Hu and Cheng, Stebbins (1948, p. 96), and Chaney (1948, p. 509 ; 1951, pp. 174-181, Pl. 6). It will be sufficient at this point to note that a decussate arrangement is characteristic of *Metasequoia*, by which foliage shoots and needles and cones, both pistillate and staminate, may be readily distinguished from those of *Sequoia* and *Taxodium*, in which the arrangement is spiral. Since phyllotaxy and cone-scale position are readily observable on well-preserved fossil material, no difficulty is experienced in separating Tertiary specimens of *Metasequoia* from those of related genera of the Taxodiaceae.

With the hope of reaching a fuller understanding of the nature of the past environments occupied by the trees of these three genera, field studies have been carried on in China under the auspices of the Save-the-Redwoods League, and in the United States with the aid of grants from the Carnegie Institution of Washington, the American Philosophical Society and the University of California. The results of these studies will here be considered in relation to the plant record from the John Day Basin of eastern Oregon, a region which provides an exceptionally complete sequence of Tertiary floral units (Chaney, 1938, p. 633). The Clarno flora, assigned to the Middle and Upper Eocene, is made up largely of evergreen angiosperms of subtropical types ; remains of conifers are rare, and all available specimens appear to be referable to *Glyptostrobus*. In the lower part of the overlying John Day formation, in beds referred to the Upper Oligocene, there are abundant plant fossils of temperate types which appear to have been predominantly deciduous in habit. Among the most numerous of these are the leafy shoots and cones of a tree which has for many years been considered to represent *Sequoia langsdorfii* (Brongniart) Heer. This species was correctly described by Heer from the Miocene of Switzerland (1855, p. 54), but its subsequent recognition at scores of localities at middle and high latitudes outside of western Europe was based in most cases upon incorrect identifications. The record of its presence in the John Day formation is in this category, for all of the leafy shoots and cones assigned to *S. langsdorfii* show the decussate arrangement of *Metasequoia*, and are now assigned to *M. occidentalis* (Newberry) Chaney (CHANEY, 1951, p. 225). In the Mascall formation, whose age is considered to be Middle Miocene, the most abundant conifer is *Taxodium dubium*[1] (Sternberg) Heer. The uppermost sedimentary member of the section, the Pliocene Rattlesnake formation, contains a small flora recently discovered by Wilkinson (CHANEY, 1948, p. 1367); no conifers have as yet been found in this flora, which is characterized by deciduous angiosperms of riparian types. Our present discussion will be confined to floras from the Lower John Day and Mascall formations.

COMPOSITION AND RELATIONS OF THE BRIDGE CREEK FLORA

The John Day formation was laid down during a time of relative quiescence, following outpouring of lava and accumulation of coarse tuffs and mudflows which characterized the preceding Clarno stage (WILLIAMS, 1948, p. 23). Its deposition was completed before the Middle Miocene, during which time there accumulated flows of Columbia River Basalt with a thickness reaching 2,500 ft. in eastern Oregon. However, vulcanism may be considered to have continued during much of the intervening John Day stage; the plant-bearing layers in the Lower John Day formation are largely made up of volcanic ash; their finely bedded character, and the presence in them of glass fragments with fine appendages, are indicative of deposition in quiet water, probably after only local transportation. These layers of leaf shales reach a maximum thickness of two or three feet, and are limited in horizontal extent to a few scores of feet. They appear to have accumulated along stream courses in a region of moderate relief, for they and associated sediments are predominantly fine textured (PL. 4, FIG. 9).

Impressions of leaves and fruits of this Upper Oligocene flora have been found in abundance at four localities in the John Day Basin (PL. 1), and silicified wood is also of wide occurrence. Similar plant fossils have been studied by the writer in the Crooked River Basin to the south (1927, p. 45), and at localities in western Oregon (1938, p. 640). The original locality on Bridge Creek, nine miles north-west of Mitchell, has been most extensively studied (CHANEY, 1925, p. 4) and we shall follow a custom of long standing in referring all of the fossil plants from the Lower John Day formation to the Bridge Creek flora. Table I gives the numerical representation of the most abundant species of the Bridge Creek flora as based upon leaf counts of thirty thousand specimens.[2] From this table is omitted one abundant species of uncertain taxonomic status, represented by 1823 leaves or leaflets making up six per cent of the total; originally described as *Fraxinus integrifolia* Newberry, and later as *Umbellularia oregonensis* (Knowlton & Cockerell) Chaney, this material has not yet been satisfactorily identified, though it may, in part, represent the foliage of a legume, as suggested by Brown.

It is difficult to distinguish between many of the leaf impressions of *Alnus carpinoides* and *Betula heteromorpha*, and the representation of these two species is here combined. The latter appears to be the more abundant, and the two species make up nearly half of the specimens counted. *Metasequoia occidentalis* is another abundant species, and at the Twickenham locality makes up seventy-nine per cent of the florule. In addition to the ten species represented by one per cent or more, and constituting nine-tenths of the specimens counted, additional species are included for comparison

1. A study of the Mascall flora by the writer in association with D. I. Axelrod is now in an advanced stage.

2. For discussion of the method followed in these quantitative studies, see Chaney, 1924, p. 127.

TABLE I — THE NUMERICAL REPRESENTATION OF COMMON SPECIES

	Bridge Creek		Mascall	
	Number of specimens	Total, %	Number of specimens	Total, %
Ginkgo adiantoides (Unger) Heer	0	...	214	2
Metasequoia occidentalis (Newberry) Chaney	8,205	27	228	2
Taxodium dubium (Sternberg) Heer	21	...	3,426	34
Carya bendirei (Lesquereux) Chaney & Axelrod	0	...	1,060	11
Betula and *Alnus*	13,566	46	125	1
Carpinus grandis Unger	740	2	0	...
Ostrya oregoniana Chaney	8	...	26	...
Quercus spp.	2,743	9	2,028	20
Small, unlobed spp.	2,743	9	95	1
Quercus consimilis Newberry	1,855	6	0	...
Quercus clarnensis Trelease	824	3	0	...
Quercus dayana Knowlton	0	...	95	1
Large, lobed spp.	0	...	1,933	19
Quercus pseudo-lyrata Lesquereux	0	...	1,598	16
Quercus merriami Knowlton	0	...	253	3
Ulmus speciosa Newberry	642	2	205	2
Ulmus paucidentata H. V. Smith	0	...	142	1
Cercidiphyllum crenatum (Unger) Brown	485	2	0	...
Platanus dissecta Lesquereux	246	1	354	4
Cedrela merrilli (Chaney) Brown	10	...	0	...
Cedrela trainii Arnold	0	...	199	2
Acer spp.	251	1	667	7
Acer glabroides Brown	251	1	16	..
Acer bolanderi Lesquereux	0	...	230	2
Acer negundoides MacGinitie	5	...	205	2
Acer scottiae MacGinitie	0	...	124	1

with the Mascall flora in the lists of Table I. Other species rare in our collections but significant in this discussion are: *Ailanthus ovata* Lesquereux, *Castanea orientalis* Chaney, *Celtis obliquifolia* Chaney, *Cornus ovalis* Lesquereux, *Fagus pacifica* Chaney, *Hydrangea bendirei* (Ward) Knowlton, *Liquidambar europaeum* Al. Braun, *Nyssa crenata* Chaney, *Pinus knowltoni* Chaney, *Pterocarya oregoniana* Chaney, *Prunus coveus* Chaney, *Rosa hilliae* Lesquereux, *Salix californica* Lesquereux, and *Sassafras bendirei* (Knowlton) Brown. The total number of plant species now recognized in the Bridge Creek flora is thirty-eight, and there is little doubt that others will be recognized in the course of studies now under way.

The Arcto-Tertiary origin of this vegetation has been extensively discussed (Chaney, 1947, p. 145). Five of the Bridge Creek species, *Carpinus grandis*, *Cercidiphyllum crenatum*, *Liquidambar europaeum*, *Metasequoia occidentalis*, *Taxodium dubium*, have been recorded from the Kenai flora of Alaska, of Eocene age (Hollick, 1936). Twenty-four additional Bridge Creek genera are represented in this flora, in many cases by closely related, probably identical species; four additional species have generic representation elsewhere at high northern latitudes. Only *Cedrela merrilli* (Chaney) Brown appears to be certainly of southern origin, though such other species as *Mahonia simplex* (Newberry) Arnold, and possibly *Philadelphus bendirei* (Knowlton) Chaney may also have come up from the south. Fourteen of the Bridge Creek plants are generically represented in the Fushun flora of Manchuria, of Oligocene age (Florin, 1922); the genera are among the most commonly represented in the Arcto-Tertiary flora, such as *Acer*, *Alnus*, *Betula*, *Cercidiphyllum*, *Metasequoia*, *Platanus*, *Quercus* and *Ulmus*. Including records in other Middle Tertiary floras of north-eastern Asia, twenty-six out of the total of thirty-six genera making up the Bridge Creek flora are found at middle latitudes on both sides of the Pacific Basin. Kryshtofovich has pointed out (1929, pp. 307-310) that the older Tertiary forests of Siberia were made up largely of temperate types of hardwood deciduous trees, and has named the wide area which they occupied in north-eastern Asia the Turgai province. His Turgayan flora is a part of what we term the Arcto-Tertiary flora, which made its way progressively southward following the Eocene epoch, presumably in response to climatic and topographic changes.

When we come to consider the relationships of the Bridge Creek flora to vegetation now living, it is apparent that the surviving elements of the Arcto-Tertiary flora have continued their migration southward from

Oregon and Manchuria since the Oligocene epoch. In North America the modern descendants of most of the common members of the Bridge Creek flora now reach their best development in the mixed deciduous forest of the Cumberland Mountains, in the south-eastern United States (BRAUN, 1942, p. 415), over 500 miles south of the latitude of the John Day Basin (PL. 3, FIG. 7). The only important exceptions are *Metasequoia occidentalis*, *Quercus consimilis* and *Cercidiphyllum crenatum*, whose modern equivalents are found living together only in, and on the borders of, the mixed deciduous forest of western Hupeh and eastern Szechuan, in central China (CHENG, 1939, 1949). With the exception of *Platanus*, all of the common Bridge Creek genera are represented by living species in this region, some 700 miles south of the latitude in Manchuria where the Fushun flora is found. These modern forests of central China and the eastern United States, as illustrated on Plate 3, are so similar to the Bridge Creek flora in composition that they provide a sound basis for reconstructing the physical setting in eastern Oregon during the closing days of the Oligocene epoch. In both regions they find their best development in valleys and on slopes; at the lower latitude of the China occurrence, the forest is not known to occur below an elevation of 4,000 ft.; the American forest is also well developed at this altitude, and ranges down to 1,000 ft. Climates of both regions are characterized by a wet growing season, by annual rainfall totalling fifty inches or more, and by average winter minima only a few degrees below freezing.

COMPOSITION AND RELATIONS OF THE MASCALL FLORA

The Mascall formation was laid down following the outpouring of basaltic lavas in the John Day Basin during Middle Miocene time. Here it may represent the time equivalent of the upper part of the Columbia River Basalt, for in adjacent regions deposits containing a similar flora are interbedded in this volcanic series. By the middle of the Miocene, the Cascade Range had been built up by flows and pyroclastics to a height which was altering the climate of eastern Oregon, and to a continuity which was already forming an obstacle to the westward flow of the Tertiary John Day River. The plant-bearing sediments, which occur near the base of the Mascall formation, were laid down in lake basins and swamps which resulted from impaired drainage. They are made up largely of volcanic ash showing little evidence of transportation, and include abundant diatoms. Overlying sands and conglomerates give evidence of non-volcanic deposition; these make up only a small part of the formation, and do not contain plant fossils. Layers of lignitic shale are of common occurrence in association with the plant-bearing beds, which are best developed at several localities along the John Day River east of Dayville. Closely related floras are found in the adjacent Blue Mountains (OLIVER, 1934), and in the Stinking Water Basin to the southeast; the Latah flora of eastern Washington (KNOWLTON, 1926), the Payette of south-western Idaho (KNOWLTON, 1898), the Trout Creek of south-eastern Oregon (MACGINITIE, 1933), and the Forty-nine Camp of north-western Nevada (LA MOTTE, 1936), all have many species in common with the Mascall flora, and appear to be of essentially the same age.

The Mascall column of Table I shows the composition of this Miocene flora, and gives the numerical representation of its fifteen most abundant species, as based upon leaf counts of ten thousand specimens. The total list of species is considerably larger than that of the Bridge Creek, and there is little question that the Mascall forest was of a more varied type. Of the sixty-eight recognized species, *Carya bendirei*, *Quercus pseudo-lyrata* and *Taxodium dubium* make up nearly sixty-one per cent. With twelve other species, each of which constitutes more than one per cent of the total, they make up ninety-five per cent of the flora, and doubtless include most or all of the trees which were dominant in the Mascall forest (PL. 2). Like the Bridge Creek, this flora appears to be largely of northern origin.

COMPARISON OF THE BRIDGE CREEK AND MASCALL FLORAS AND THEIR ENVIRONMENTS

Of the nine genera most abundant at Bridge Creek, *Acer*, *Betula*, *Cercidiphyllum*, *Metasequoia*, *Platanus*, *Quercus* and *Ulmus* are represented in the Mascall flora. But whereas *Betula heteromorpha*, combined with *Alnus carpinoides*, make up nearly half of the leaves and fruits of the Bridge Creek flora, the birches and alders of the Mascall, comprising four species, make up little more than one per cent of the specimen count. The most abundant oak of the Bridge Creek, *Quercus consimilis*, constituting six per cent of the total, is unrepresented in the Mascall, where four species of lobed oaks, a type unknown in North America before the Miocene (Chaney, 1949, p. 194), make up nearly twenty per cent. Leaves of *Acer*, *Platanus* and *Ulmus* are all fairly common in both floras, and some of the rarer genera of the Bridge Creek, such as *Celtis*, *Crataegus*, *Fagus*, *Hydrangea*, *Mahonia*, *Pinus*, *Populus*, *Ptelea* and *Salix*, are also uncommon in the Mascall. On the other hand, *Cercidiphyllum crenatum*, which is rare in the Mascall, comprises two per cent of the Bridge Creek; and *Metasequoia occidentalis*, only ninth in abundance in the Mascall list, makes up over one-fourth of the specimen total of the older flora. The inverted ratios of *Metasequoia occidentalis* and *Taxodium dubium* in the two floras indicate a significant change in the vegetation and environment of the John Day Basin from Oligocene to Miocene time, and will serve as the basis for our further discussion.

As indicated above, *Metasequoia glyptostroboides* is now confined to a limited area in central China; here it occupies well-drained slopes in deep valleys where there is heavy summer rainfall and where winter temperatures are moderate. Too much emphasis cannot be placed upon details of the modern *Metasequoia* environment, since this living tree has been logged off from all but the most inaccessible valleys. If natural vegetation were preserved over a large surrounding area, it is probable that we should find these redwoods of China living under more varied conditions, and ranging northward at lower altitudes than their present situation, between 4,000 and 4,500 ft. In any event we may be confident from its deciduous habit that *M. occidentalis*, the Tertiary ancestor of this tree, also lived in a region of summer rainfall. Whereas the living species may be found under cultivation on the borders of rice paddies, its natural occurrence in the valleys of western Hupeh, and the behaviour of seedlings now under cultivation in California, are strongly suggestive of well-drained slopes rather than of swampy ground. On the other hand, the living *Taxodium distichum* has its best development in lowlands covered by streams during flood, or in swamps where water stands much or all of the year (Pl. 4, Fig. 8); in an extensive survey of the southern Atlantic coastal plain and lower Mississippi river drainage, I have never seen it growing naturally on a well-drained slope. The reduction in number of trees of *Metasequoia occidentalis* from Upper Oligocene to Middle Miocene time, as judged by the greatly lowered representation of its leafy shoots in the fossil record, and the still more marked increase of *Taxodium dubium* during this interval, seem best interpreted as a response to the gradual blocking of drainage and the development of numerous lakes and swamps. Such a change in the terrain would have been a natural result of the major damming of Miocene rivers by the rising Cascade Range to the west, and of minor blocking on a wide scale of streams small and large by lava flows, pyroclastic accumulations, and local warping.

If such changes in topography were taking place, we should expect to find other evidence in the plant population. Comparison of the hardwood members of the two floras fully substantiates the suggestion of progressively impaired drainage. Most of the common associates of *M. occidentalis* in the Bridge Creek flora have modern equivalents which are typically trees of well-drained slopes, both in the United States and in China. With the exception of *Platanus*, which in Eurasia is now confined to the Near East, every common genus of the Bridge Creek flora, and many of those represented by only a few specimens, are now represented by closely similar living species in the valleys of China where *Metasequoia* has survived. The following lists show the modern equivalents of the Bridge Creek species, or in some cases merely the generic representatives, which have been observed in immediate association with *M. glyptostroboides* in the Shui-hsa-pa district of western Hupeh (Pl. 3, Fig. 6); the list of living trees and shrubs is based upon my own observations, supplemented by those of Drs. Cheng Wan-Chun, and of Chu Kwei-ling, who carried on field work in this region during the summer of 1948 (Chu & Cooper, 1950).

Oligocene Bridge Creek Flora of Oregon	Modern Forest at Shui-hsa-pa
Metasequoia occidentalis (Newberry) Chaney	*Metasequoia glyptostroboides* Hu & Cheng
Pinus knowltoni Chaney	*Pinus* spp.
Salix californica Lesquereux	*Salix wilsonii* Seemen
Pterocarya oregoniana Chaney	*Pterocarya paliurus* Batalin
Betula heteromorpha Knowlton	*Betula luminifera* Winkler
Carpinus grandis Unger	*Carpinus fargesii* Franchet
Ostrya oregoniana Chaney	*Ostrya japonica* Sargent
Castanea orientalis Chaney	*Castanea henryi* Rehder & Wilson
Fagus pacifica Chaney	*Fagus longipetiolata* Seemen
Quercus consimilis Newberry	*Quercus glandulifera* Blume
Celtis obliquifolia Chaney	*Celtis labilis* Schneider
Ulmus speciosa Newberry	*Ulmus multinervis* Cheng
Cercidiphyllum crenatum (Unger) Brown	*Cercidiphyllum japonicum sinicum* Rehder & Wilson
Sassafras bendirei (Knowlton) Brown	*Sassafras tzumu* Hemsley
Liquidambar europaeum Brown	*Liquidambar formosana* Hance
Hydrangea bendirei (Ward) Knowlton	*Hydrangea strigosa* Rehder
Rosa hilliae Lesquereux	*Rosa henryi* Boulenger
Prunus coveus Chaney	*Prunus* spp.
Ailanthus ovata Lesquereux	*Ailanthus vilmoriniana* Dode
Acer glabroides MacGinitie	*Acer* spp.
Cornus ovalis Lesquereux	*Cornus controversa* Hemsley
Nyssa crenata Chaney	*Nyssa sinensis* Oliver

There are several species of trees and numerous evergreen shrubs now living in association with *M. glyptostroboides*, which have not been found in the fossil record, and we have no wish to indicate our belief that the modern forest is an exact replica of the Oligocene of Oregon. However, the resemblance of the Bridge Creek flora to the vegetation in the mountains of western Hupeh is so close, especially in the smaller and more open ravines where the variety of trees is not great, that we have no hesitation in stating that the two forests, separated by a span of some thirty million years, are closely related both in origin and in physical requirements.

Comparison of the Mascall flora with the forest now living on the swampy borders of the Wabash river, in south-western Indiana, brings out an equally striking resemblance. The modern swamp cypress forest here is characterized by an abundance of lobed oaks, hickory, sycamore, elm and other trees which are common in the Mascall flora, as shown in the lists which follow.

Miocene Mascall Flora of Oregon	Modern Forest in the Wabash Valley
Taxodium dubium (Sternberg) Heer	*Taxodium distichum* Richard
Smilax magna Chaney	*Smilax rotundifolia* Linnè
Salix hesperia (Knowlton) Condit	*Salix nigra* Linnè
Populus heterophylloides Chaney & Axelrod	*Populus heterophylla* Linnè
Carya bendirei (Lesquereux) Chaney & Axelrod	*Carya ovata* Koch
Betula thor Knowlton	*Betula nigra* Linnè
Ostrya oregoniana Chaney	*Ostrya virginiana* Koch

Quercus columbiana Chaney	*Quercus prinus* Linnè
Quercus dayana Knowlton	*Quercus nigra* Linnè
Quercus merriami Knowlton	*Quercus palustris* Du Roi
Quercus prelobata Condit	*Quercus alba* Linnè
Quercus pseudo-lyrata Lesquereux	*Quercus borealis* Michaux
Celtis dayana Chaney & Axelrod	*Celtis mississippiensis* Bosc
Ulmus paucidentata H. V. Smith	*Ulmus alata* Michaux
Ulmus speciosa Newberry	*Ulmus americana* Linnè
Lindera hesperia Chaney & Axelrod	*Lindera benzoin* (Linnè) Blume
Liquidambar pachyphyllum Knowlton	*Liquidambar styraciflua* Linnè
Platanus dissecta Lesquereux	*Platanus occidentalis* Linnè
Ptelea miocenica Berry	*Ptelea trifoliata* Linnè
Acer bendirei Lesquereux	*Acer saccharinum* Linnè
Acer glabroides Brown	*Acer rubrum* Linnè
Acer negundoides MacGinitie	*Acer negundo* Linnè
Nyssa hesperia Berry	*Nyssa sylvatica* Marsh
Diospyros andersonae Knowlton	*Diospyros virginiana* Linnè
Fraxinus dayana Chaney & Axelrod	*Fraxinus quadrangulata* Michaux

These lists include most of the common species of two forests separated in space by nearly two thousand miles, and in time by some twenty million years. Together with the lists of the Bridge Creek flora and of the vegetation at Shui-hsa-pa, they present striking evidence of forest continuity through geologic time. They also demonstrate that in the John Day Basin the slope forest of the Oligocene, as represented in the fossil record by the Bridge Creek flora, gave way by Middle Miocene time to a lowland forest with new dominants, as represented by the Mascall flora. Here changing conditions of drainage greatly reduced the abundance of *Metasequoia occidentalis* and its upland associates, and a swamp forest characterized by *Taxodium dubium* became widespread.

CONCLUSION

The record of Tertiary rocks in the northern hemisphere indicates that *Metasequoia occidentalis* and *Taxodium dubium* have long been associated in mixed forests in which both coniferous and broad-leaved genera were largely deciduous. The Upper Oligocene forest of the John Day Basin, as indicated by the Bridge Creek flora, included *M. occidentalis* as a dominant. This flora was profoundly altered in Miocene time, when upland topography characterized by well-drained slopes was reduced to poorly drained plains by erosion and widespread volcanic activity. *Metasequoia* and many of its upland associates became fewer in number or disappeared from Oregon, and the Bridge Creek flora was supplanted by the Mascall. This later forest, characterized by *Taxodium dubium* and other trees whose modern equivalents occupy the borders of swamps and shallow lakes, was widely distributed over the Columbia Plateau during Middle Miocene time. Continued uplift of the Cascade Range brought a reduction of rainfall and wider temperature extremes to eastern Oregon. A few representatives of Mascall hardwood genera have survived in the mountains bordering the John Day Basin, but *Taxodium* and most of its lowland associates have been eliminated.

Metasequoia occidentalis lingered on in small numbers as late as Middle Miocene time in North America, and it or an equivalent species is known to have continued down into the Pliocene in Japan. The scarcely distinguishable living species, *M. glyptostroboides*, still lives in remote valleys of central China where there is summer rainfall. The present regime of rainfall in western North America provides a ready basis for explaining the disappearance of *Metasequoia* there, but its elimination from the Cumberland Mountains and elsewhere in the eastern United States, where so many of its hardwood associates have survived in a summer-wet climate, is more difficult to explain. The cause of extinction here may lie in the unfavourable climatic extremes of the Pliocene and Pleistocene; preliminary success of current plantings of *Metasequoia* seedlings in many parts of its Tertiary range suggests that this tree may now flourish in some areas from which it was eliminated during post-Miocene time.

Taxodium dubium lived on in western North America into the Pliocene epoch, and its failure to survive there to the present is doubtless also related to the shift from summer-wet to summer-dry climate. Its living equivalent, *T. distichum*, still occupies topographically suitable environments in the eastern United States, in association with modern equivalents of most of the Mascall species.

This comparison of the Tertiary forests of Oregon with those of today indicates that during the ensuing millions of years since they first came down from the north, there have been units of vegetation like them continuously in existence. Vegetation of the Bridge Creek type is an indicator of Upper Oligocene age in the John Day Basin, but not in the valley at Shui-hsa-pa; a forest of Mascall type is of recent age, not Miocene, in the valley of the Wabash river. To judge with accuracy the age of sedimentary rocks from the plant fossils buried in them, we must not only determine what kinds of trees and shrubs are represented, but we must know where other similar forests have lived before and since. Sound concepts, both of time and space, of palaeogeography as well as stratigraphy, are requisite to a solution of problems involving forests which have migrated widely during ages past. It is encouraging to know that these problems are now being studied on a broad front, in Europe, North America and Asia, wherever the Arcto-Tertiary flora has left in the rocks a record of its wanderings.

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EXPLANATION OF PLATES

Plate 1

1. Slab of volcanic shale from the Lower John Day formation at the Twickenham locality, John Day Basin, Oregon. Common members of the Bridge Creek flora shown are *Metasequoia occidentalis, Betula heteromorpha* and *Cercidiphyllum crenatum* (natural size).

Plate 2

Fossil leaves of the Mascall flora (natural size).

2. Leafy shoots of swamp cypress, *Taxodium dubium* (upper left).
3. Leaf of elm, *Ulmus speciosa* (upper right).
4. Leaf of black oak, *Quercus merriami* (lower left).
5. Leaflet of hickory. *Carya bendirei* (lower right).

Plate 3

6. Grove of *Metasequoia glyptostroboides* in central China. Associated trees are *Betula luminifera, Castanea henryi, Cercidiphyllum japonicum sinicum* and *Quercus glandulifera*. The evergreen conifer is *Cunninghamia lanceolata*.
7. Mixed deciduous forest of the eastern United States. Common trees are *Betula papyrifera, Castanea dentata* and *Quercus borealis*. The evergreen conifer is *Pinus rigida*.

Plate 4

8. Forest of swamp cypress, *Taxodium distichum*, and tupelo, *Nyssa aquatica*, in the Wabash Valley, Illionois. Associated trees, mostly on swamp borders, are *Acer rubrum, Betula nigra, Carya ovata, Liquidambar styraciflua, Platanus occidentalis, Populus heterophylla, Quercus palustris* and *Ulmus americana*.
9. Twickenham locality of the Bridge Creek flora, Oregon. Dipping beds are John Day formation, overlain by Columbia River Basalt. Trees living in the valley are *Populus trichocarpa*, on slopes *Juniperus occidentalis*.

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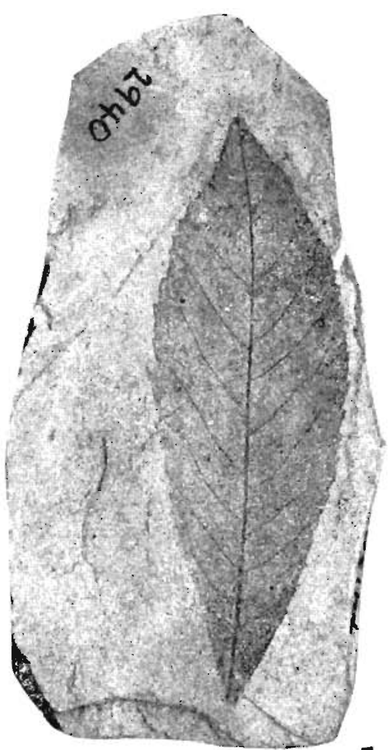

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