The Geobiology and Ecology of Metasequoia.

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Ben LePage
Pacific Gas and Electric Company

Christopher J. Williams
Franklin and Marshall College

Hong Yang
Massey University

Chapter 1

The Evolution and Biogeographic History of *Metasequoia*

BEN A. LePAGE[1], HONG YANG[2] and MIDORI MATSUMOTO[3]

[1]URS Corporation, 335 Commerce Drive, Suite 300, Fort Washington, Pennsylvania, 19034, USA; [2]Department of Science and Technology, Bryant University, 1150 Douglas Pike, Smithfield, Rhode Island, 02917, USA; [3]Department of Earth Sciences, Chiba University, Yayoi-cho 133, Inage-ku, Chiba 263, Japan.

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Abstract: The fossil record of *Metasequoia* Miki is extensive and demonstrates that the genus was widely distributed throughout North America and Eurasia from the early Late Cretaceous to the Plio-Pleistocene. The genus first appears in Cenomanian age deposits from western Canada, Alaska and the Arkagala and Koylma River basins in Russia and indicates that *Metasequoia* had achieved a wide distribution early in its evolutionary history. Exchange of *Metasequoia* between Asia and North America probably occurred across Beringia, which had become functional at the Albian-Cenomanian boundary (ca. 100 million years ago). However, if the inter-continental exchange of the early representatives of this genus occurred prior to the establishment of Beringia, migration would have still been possible across the Spitsbergen Corridor, which was functional during the Early Cretaceous. By the early Tertiary, the distribution patterns do not appear to have changed considerably from that seen during the Late Cretaceous, except that *Metasequoia* became a dominant constituent of the polar Broad-leaved Deciduous Forests. More importantly, the distribution of *Metasequoia* indicates that the genus grew and reproduced under a diverse range of climatic and environmental conditions throughout geologic time, including the cold and unique lighting conditions of the polar latitudes. Of particular interest is the apparent lack of *Metasequoia* fossils in Europe despite the presence of two land bridges linking North America and Europe throughout the early Tertiary and the drying of the Turgai Straits that separated eastern and western Asia up until Oligocene time. *Metasequoia* persisted in western Siberia and the Canadian Arctic until late Pliocene time, and in western Georgia and Japan until the late Pliocene-early Pleistocene. Following the apparent early Pleistocene extinction, *Metasequoia* re-appeared in southeastern China. The pronounced reduction in distribution during the Miocene appears to be coupled with increasing global aridity and cooling and increased competition for resources and habitat from representatives of the Pinaceae. With few exceptions, the bulk of the *Metasequoia* fossils described in the literature indicate that the fossils assigned to *M. occidentalis* are indistinguishable from the living species. The remarkable morphological stasis observed in *Metasequoia* demonstrates that the genus has remained unchanged, at least morphologically, since the early Late Cretaceous.

Key words: China; Cretaceous; evolution; mycorrhiza; land bridges; Napartulik; orogeny; paleogeography; Shui-sha-ba Valley; systematics; taxonomy; Tertiary; Turgai Stait.

1. INTRODUCTION

Metasequoia Miki (Miki, 1941) is one of seven monospecific genera within the Taxodiaceae (now subsumed within the Cupressaceae), with *Metasequoia glyptostroboides* Hu *et* Cheng (Hu & Cheng, 1948) occurring in small and possibly relictual populations in Sichuan, Hubei and Hunan Provinces, China. It occurs as a constituent of the mixed mesophytic forests and grows at elevations ranging from 800 to 1,500 m (Fu & Jin, 1992). *Metasequoia glyptostroboides* grows on acidic alluvial soils in the mountain valleys where there is abundant moisture, mean annual temperature (MAT) is about 13°C, the coldest month mean temperature ranges from –6.1 to 1.7°C (absolute coldest –15.4°C) and the warmest month mean temperature ranges from 23.3 to 32.3°C (absolute warmest 35.4°C) (Bartholomew *et al*., 1983; Fu & Jin, 1992). Rainfall is seasonal with a mean annual precipitation of about 1,300 mm (climate data from Lichuan [1959–1978]); Wang, 1961; Bartholomew *et al*., 1983; Fu & Jin, 1992). For a detailed discussion on the ecology and environment of *M. glyptostroboides* see Williams (this volume).

Although *M. glyptostroboides* currently grows in a part of the world that is moderately warm, it must be pointed out that the temperature conditions under which *M. glyptostroboides* grows today should probably not be considered indicative of the temperatures or environmental conditions under which the ancient representatives of the genus grew, or that *M. glyptostroboides* is incapable of growing under much colder conditions. Snow and freezing temperatures were reported to occur regularly during the winter months by local residents of Modaoxi (Modaoqi), which is located within the Shui-sha-ba (Chinese for *Metasequoia*) Valley where *M. glyptostroboides* is thought to occur naturally (LePage, personal communication with local residents, 2002). *Metasequoia glyptostroboides* trees growing in Montreal, Canada and St. Petersburg, Russia frequently experience winter temperatures as low as –30°C to –40°C (Williams, this volume; LePage, unpublished) and laboratory experiments have shown that the leaves and twigs are frost resistant to temperatures as low as –30°C (Sakai & Larcher, 1987). Wang (1961) indicates that the genus probably had a much more extensive distribution during Recent time and grew under a wider range of environmental conditions than that indicated by the modern, geographically restricted, native populations.

The occurrence of fertile and vegetative remains of *Metasequoia* in the plant fossil record indicates that the genus possessed a much wider distribution that extended well into the polar regions of the Northern Hemisphere throughout the Mesozoic and Cenozoic (Figure 1-1; Appendix A; Florin, 1963; Yang, 1999, Yang & Jin, 2000). Moreover, such a wide distribution in space and in time indicates that representatives of the genus probably grew under a diverse range of climatic and environmental conditions throughout geologic time. The lack of significant morphological diversification observed between living and fossil *Metasequoia* foliage and seed cones leaves little doubt of the accuracy of the fossil identifications. In fact, in almost every report where *Metasequoia* fossils have been described, the authors point out that they are more or less identical to living *M. glyptostroboides*. Nevertheless, the practice of erecting new names for fossil species of *Metasequoia* based on slight differences in the size and shape of the fossil remains, or geologic age has, and continues to pervade the literature.

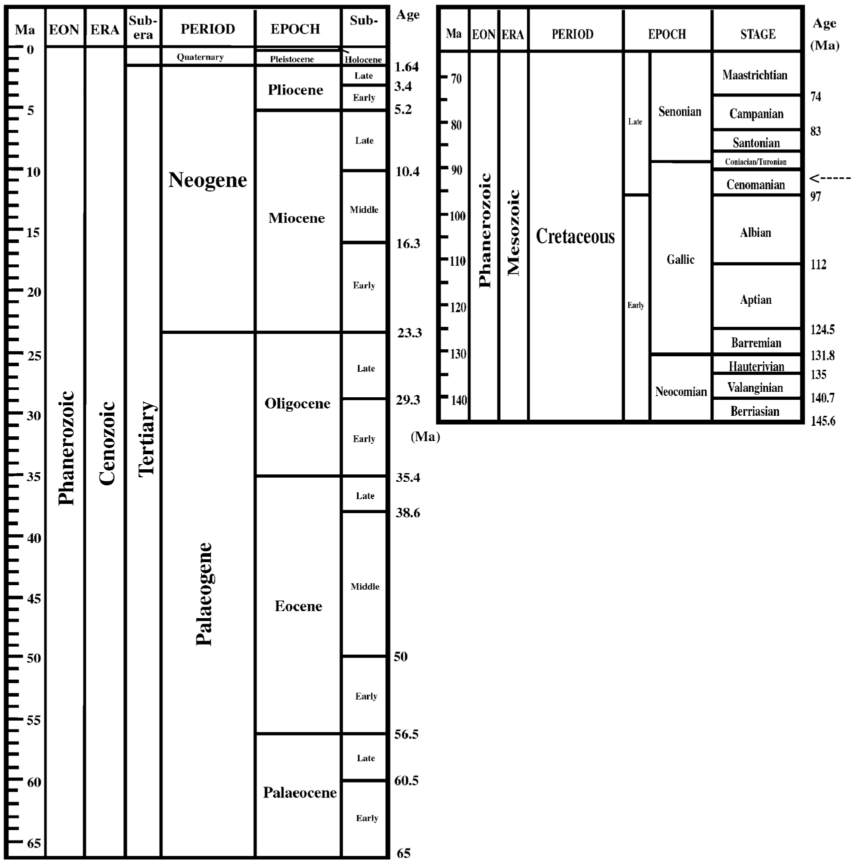

Figure 1-1. Mesozoic and Cenozoic chronostratigraphic chart. Redrawn and modified from Taylor and Taylor (1993). Arrow at the Cenomanian indicates the first occurrence of fossil *Metasequoia* from Russia, Canada and Alaska.

In this paper, the evolution and biogeographic history of the genus are discussed in light of the tectonic and climatic history of the Northern Hemisphere. Examination of the fossils reported in the literature indicate that most of the fossils conform morphologically to the living species *M. glyptostroboides*, providing a spectacular example of morphological, and possibly genetic stasis over a geologically-long period of time.

2. TAXONOMY

The affiliation of *M. glyptostroboides* with the Taxodiaceae was clearly established in the initial description of the fossil material (Miki, 1941) and was substantiated by later studies using living specimens (Hu & Cheng, 1948). Shortly after the living trees were discovered in China, Stebbins (1948) performed the first chromosomal analysis. His work along with studies by Schlarbaum *et al*. (1983, 1984) indicated that *M. glyptostroboides*, ($2n = 22$) is closely related to *Sequoiadendron* J. Buchholz ($2n = 22$) and *Sequoia* Endlicher ($2n = 66$; Figure 1-2). Further molecular studies on the phylogeny of the genus using proteins and nucleotide sequences re-affirmed this grouping and further pointed out that the three taxa formed a "redwood clade (or sequoiod clade)" (Price & Lowenstein, 1989; Brunsfeld *et al*., 1994). This phylogenetic placement was further supported by recent PCR-RFLP data (Tsumura *et al*., 1995) and multi-gene analyses (Kusumi *et al*., 2000) (for details see Yang, this volume). Combining the molecular and morphological data, Gadek *et al*. (2000) adopted earlier suggestions (Pilger, 1926; Eckenwalder, 1976; Brunsfeld *et al*., 1994) that recognized elevation of these three genera to the intra-familial level, the Sequoioideae, within the family Cupressaceae (Figure 1-2).

Metasequoia is one of the most abundant and easily recognized plant fossils found in the Late Cretaceous and Tertiary fossil plant record of the Northern Hemisphere (Chaney, 1951; Florin, 1963; Liu *et al*., 1999; Yang, 1999; Yang & Jin, 2000). Prior to the discovery and description of fossil *Metasequoia* from the late Miocene and Pliocene of Japan (Miki, 1941; Momohara, this volume), most *Metasequoia* remains, commonly seed cones and leaves, were assigned to *Glyptostrobus* Endlicher, *Sequoia*, *Taxites* Brongniart or *Taxodium* Richard (Appendix A). In his seminal paper, Chaney (1951) provided the most up-to-date account of fossil *Metasequoia* in North America. He recognized two fossil species that corresponded to different geologic ages and assigned fossil *Metasequoia* remains from Cretaceous deposits to *M. cuneata* (Newberry) Chaney and those from the Tertiary to *M. occidentalis* (Newberry) Chaney.

Following the establishment of the fossil genus *Metasequoia* more than 20 names for extinct species of the genus were erected over the next 60 years (Liu *et al*., 1999, Appendix A). Recently, Liu *et al*. (1999) found that almost all of these species were based on slight differences in the size and shape of the leaves and seed cones, and that the morphological variation of the fossil remains seen among these 20+ species was part of the natural morphological variability inherent to *M. occidentalis*. Liu *et al.'s* (1999) morphometric analyses led them to conclude that only two species of fossil *Metasequoia*, *M. occidentalis* and *M. milleri* Rothwell *et* Basinger could be recognized from the entirety of the fossil record of the genus. More recently, Stockey *et al*. (2001) recognized a third species, *M. foxii* Stockey, Rothwell *et* Falder from Paleocene (late Tiffanian [Ti_4]) Paskapoo Formation, Alberta, Canada. The establishment of this new species was based on the examination of more than 10,000 specimens.

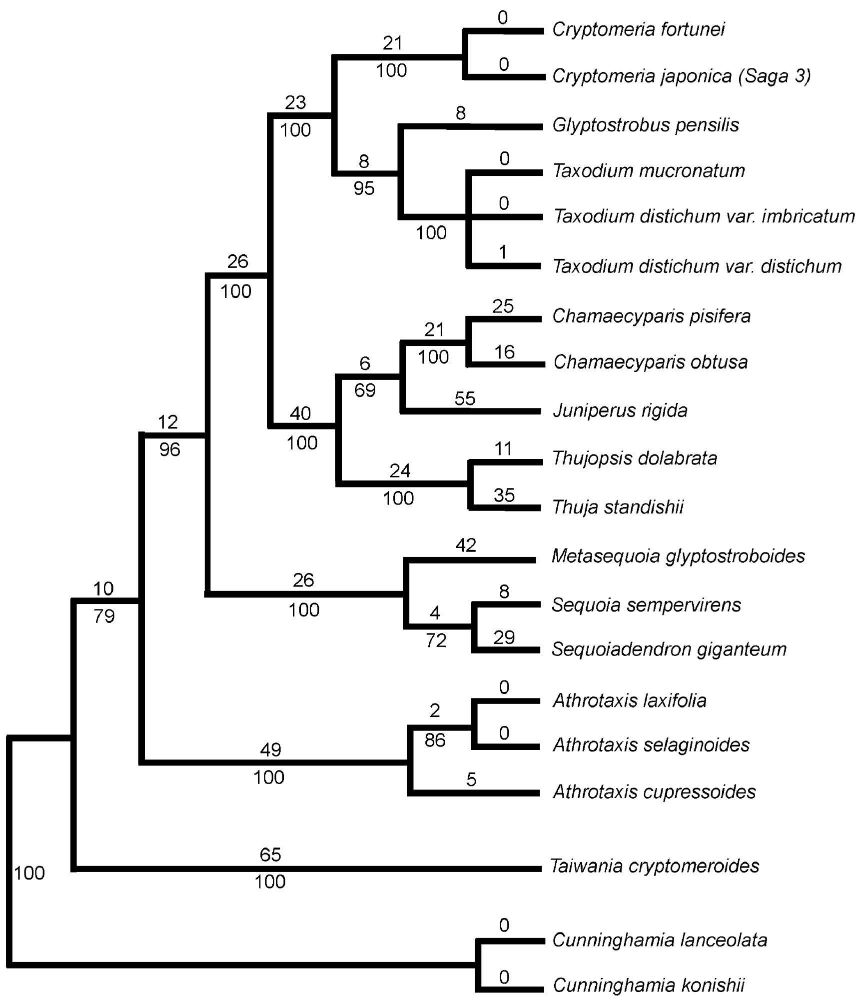

Figure 1-2. Most parsimonious tree for genera of the Taxodiaceae and Cupressaceae *s.s.* by the maximum parsimony method based on sequences of the *matK* gene, *chlL* gene, *trnL-trnF* IGS region and trn intron. The number above each branch is the number of steps separating each node and the numbers below indicate the percent of bootstrap values estimated from 1000 bootstrap replicates. The tree is rooted with *Cunninghamia*. Tree length = 645; Consistency index = 0.860; Retention index = 0.908. Redrawn and modified from Kusumi *et al*. (2000).

3. MORPHOLOGICAL STASIS AND GENETIC VARIATION

The lack of considerable morphological variability and species diversity seen in the fossil record of *Metasequoia* since its appearance in the Late Cretaceous is important. The longevity of biological species is estimated to be less than 10 million (Ma) years and presumed to be the same for all taxa (Raup, 1986). Niklas *et al*. (1983) suggested that the longevity of fossil angiosperms was 3.5 million years. Although there are no data specific to the gymnosperms. Most species gymnosperms are arborescent and the time from germination to sexual maturity is considerably longer then most engiosperms. Therefore species longevity of the gymnosperms is likely between 3.5 and 10 million years. Nevertheless, species longevity within some of the homosporous filicalean ferns and certain conifers, including *Metasequoia*, depart from the proposed extinction pattern by up to an order of magnitude (Rothwell & Stockey, 1991; LePage & Basinger, 1995; Serbet & Rothwell, 2000, Stockey *et al*., 2001). However, the mechanism(s) responsible for such prolonged morphological stasis are still poorly understood.

There is evidence that indicates that the rates of morphological and molecular evolution are correlated and that there is a wide range of rate heterogeneity among taxa that have been examined, but none of these studies included conifers in their analyses (Omland, 1997; Barraclough & Savolainen, 2001). It has also been noted that karyotypic evolution in the gymnosperms is significantly slower than the rates of change seen in amino-acid sequences (Wilson *et al*., 1974a, 1974b; Praeger, 1976; Niklas *et al*., 1985). Omland (1997) suggested that the frequency of species bottlenecks and founder events might either accelerate or slow morphological and molecular evolutionary rates. If the rates of morphological and molecular evolution were correlated, the lack of morphological variability seen in taxa such as *M. glyptostroboides* would predict that the rate of molecular evolution is also low. (Yang, this volume). However, the allozyme variation of 46 single-tree seedlots of *M. glyptostroboides* seeds collected from Hubei and Sichuan Provinces in 1990 and planted at the Ryder's Lane Plantation at Rutgers University in New Brunswick, New Jersey indicate that the genetic diversity of *M. glyptostroboides* is low to average compared to other conifers, with high measures of inbreeding and genetic differentiation (Kuser *et al*., 1997, this volume).

Metasequoia foxii is known only from two localities in Alberta, while *M. milleri* is known only from the middle Eocene Allenby Formation of south central British Columbia, Canada. With the exception of *M. foxii* and *M. milleri*, the morphological stasis observed in *M. occidentalis* is truly remarkable. Despite the fact that *M. occidentalis* was so widely distributed throughout the Northern Hemisphere for nearly 100 Ma and grew as a pioneer species under a wide range of climatic and environmental conditions, detailed examination of the gross morphological features indicates that the morphology of the genus has remained unchanged since it first appeared during Cenomanian time. However, as pointed out by Stockey *et al*. (2001) it is unlikely that the genus was comprised of only three species throughout its evolutionary history and that more species may remain yet to be discovered. The recognition of at least twenty horticultural varieties of *M. glyptostroboides* indicates that the living species is capable of producing distinct morphotypes that could potentially evolve into new species (Kuser, this volume; Leng, this volume; Nugue, this volume).

4. DISTRIBUTION OF *METASEQUOIA GLYPTOSTROBOIDES*

Today the genus is restricted to an area of approximately 800 km^2 along the border of Sichuan, Hunan and Hubei Provinces, China. As recently as 1950 there is evidence to suggest that the distribution of *M. glyptostroboides* in China may not have always been restricted to the presently known locations (Qi *et al.*, 1993; Litoff, this volume). However, these claims await further support from field surveys. The main population occurs in a 25 km long and 1.5 km wide strip along the Modao River in the Shui-sha-ba Valley, Zhonglu Town, Lichuan County, Hubei Province at elevations ranging from 900–1250 m. In the Shui-sha-ba Valley natural stands of *M. glyptostroboides* are comprised of 30–40 individuals and can be found growing on the sides of hills and ravines where moisture is abundant. Those growing on the valley floor and along rivers are thought to have been planted (Figure 1-3; Chu & Cooper, 1950; Meyer, this volume, Williams, this volume).

Figure 1-3. A small grove of *M. glyptostroboides* that appear to have been planted along the bank of the Yujiang River near Shiziba, China.

A second and potentially important tree was recently discovered in Paomu near Luota Town in the Longshan area of Hunan Province. Although the *M. glyptostroboides* tree from this area is architechturally and morphologically indistinct from those of the Shui-sha-ba Valley, micromorphological features of the cuticle indicate that the leaves of the Paomu tree are distinct from those of the Shui-sha-ba Valley populations. More importantly though, Leng *et al.* (2001) and Leng (this volume) compared the anatomy of fossil *Metasequoia* cuticle to the Shui-sha-ba Valley populations and the Paomu tree and found that in every case, the fossil cuticle resembled that of the Paomu tree. Clearly the importance of this discovery and the Paomu tree cannot be emphsized enough if we are to better understand the evolutionary history of the genus. Although there are other reports of *M. glyptostroboides* from other remote areas in Hunan and Sichuan Provinces (see Ling, 1976), a recent field survey has confirmed the Sichuan distributions and two sites in Human Province (H. Yang and Q. Leng, personal observations).

5. PHYTOGEOGRAPHY

The fossil record of *Metasequoia* indicates that the genus was widely distributed throughout the Northern Hemisphere from the Late Cretaceous until the Plio-Pleistocene (Figures 1-4 to 1-12; Appendix B; Florin, 1963; Yang, 1999; Yang & Jin, 2000). However, the fragmentary nature of many of these fossils, along with incomplete descriptions and poor illustrations provided in the literature has made phylogenetic interpretation of fossil *Metasequoia* difficult. *Metasequoia foxii* and *M. milleri* were established on anatomical differences and as Stockey *et al.* (2001) concluded, there is no reason why the genus should only be comprised of three species over its entire evolutionary history. Although species segregation using gross morphological features appears to provide little useful phylogenetic information, we expect that further detailed anatomical studies on currently known and new fossil *Metasequoia* remains may ultimately reveal that the genus possessed a rich and speciose fossil history. As such, the synonomy of fossil *Metasequoia* that we have compiled in Appendix A is based on a detailed literature review and will likely require revision as future taxonomic studies are undertaken. We have made no attempt to revise the current taxonomy of *Metasequoia* as this effort was outside of the scope of this paper.

Nevertheless, the totality of these fossils is important for understanding and interpreting the biogeographic history of the genus. The difficulties associated with providing a reliable and meaningful assessment of the number of species throughout the fossil record of the genus limits the usefulness of interpreting the biogeographic history of the genus at the species level. Therefore, the biogeographic history of the genus is best viewed as being that of a single entity.

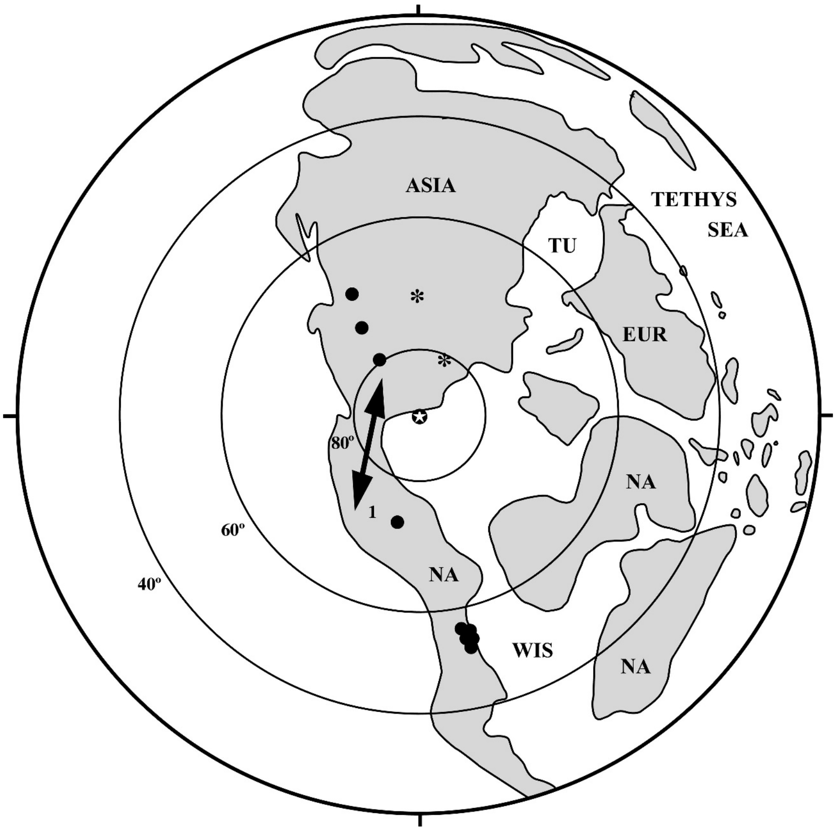

Figure 1-4. Generalized paleogeographic reconstruction of the Northern Hemisphere in polar projection during the early Late Cretaceous (Turonian, ca. 92 Ma), showing the Beringian Corridor (1) and the distribution of fossil *Metasequoia*. *Legend:* NA = North America, WIS = Western Interior Seaway, EUR = Eurasia; TU = Turgai Strait; • = Cenomanian; and * = Turonian. Figures 1-4 to 1-9 are modified after LePage & Basinger (1995a) and the references therein.

Prior to discussing the phytogeographic history of *Metasequoia*, a number of points need to be iterated. Although it is tempting to suggest that the earliest occurrences represent a point of origin, we must remember that the plant fossil record, or any fossil record for that matter, is fragmentary and provides only the briefest of glimpses into a plant's evolutionary history. The use of the plant fossil record to interpret the phytogeographic history of a taxon such as *Metasequoia* represents an interpretation that is based ultimately on a partial data set only. Therefore, the lack of data from a region does not necessarily mean that the genus did not occur there (however, one would not expect a boreal or temperate species to be growing in the sub-tropical/tropical regions). Some possibilities that might explain the lack of *Metasequoia* fossils from a region include:

(1) the chance entry of its remains into the appropriate depositional environment did not occur; (2) the plants entered the appropriate depositional environment, but were not preserved; (3) we have not yet found fossils of that taxon; (4) the fossils may not be recognisable as being those of *Metasequoia*; or (5) the deposits that may have contained *Metasequoia* fossils were destroyed given the glacial history of the Northern Hemisphere. Consequently, as more or new data become available, the original biogeographic interpretations can either become more robust or new patterns can be recognised.

Metasequoia is first recorded in the Cenomanian Arkagala Formation from the Arkagala River and Kolyma Rivers, Russia, the Amkinskaya Formation from the Okhotsk-Chukotka Volcanogenic Belt in the Ul'inskiy Trough near Amka, Russia, unnamed Cenomanian deposits along the Yukon River in Alaska and the Cenomanian Dunvegan Formation from western Canada (Figure 1-4; Appendix A; Hollick, 1930; Baikovskaya, 1956; Samylina, 1962, 1964; Bell, 1963; Lebedev, 1976, 1979, 1982, 1987; Patton & Moll-Stalcup, 2000). The Russian localities were located between about 70°N to 80°N, while those in western Canada and Alaska ranged from around 55°N to over 70°N. Although the most southern locations in Russia and Canada were separated by thousands of miles, biotic interchange between Asia and North America probably occurred via the Beringian Corridor, which was established by Albian time (ca. 100 Ma). However, if the genus possessed a significant Early Cretaceous history that has either not been recorded as part of the fossil record or not yet recognised, the establishment of these apparently disjunct populations would have likely occurred via the Spitsbergen Corridor (LePage & Basinger, 1995).

Regardless of the migrations routes used by *Metasequoia*, the data at hand indicate that (1) *Metasequoia* appears to have had an Early Cretaceous origin, (2) *Metasequoia* was a constituent of the broad-leaved deciduous forests in the polar regions early in its evolutionary history, which may have important implications in the evolution of deciduousness (Vann, this volume) and (3) migration between North America and Asia occurred through the Beringian Corridor, and possibly through the Spitsbergen Corridor if intercontinental migration occurred prior to the establishment of the Beringian Corridor. Further paleobotanical research on Early Cretaceous deposits from Alaska and Chukotka may ultimately provide answers to some of these questions.

The early Late Cretaceous (Cenomanian and Turonian) distribution pattern of *Metasequoia* shown in Figure 1-4 also illustrates two important points. The first is that the genus grew at latitudes ranging from approximately 55°N to over 80°N and experienced a wide range of climatic and environmental conditions. Its polar distribution is particularly interesting because data indicate that *Metasequoia* occurred well above the Arctic Circle and would have grown under the unique polar light regime. That is, the trees would have experienced 3 months of continuous light in summer and 3 months of total darkness during the winter. If we assume that the genus was deciduous, as is the case today, it would have then been well positioned to thrive in these unique polar environments. Second, there is a growing body of evidence to support the idea that the polar regions were cold with freezing temperatures during the dark winter months throughout the Cretaceous and early Tertiary (see LePage, 2003b and references therein). This indicates that the genus was able to tolerate a wide range of temperatures early in its evolutionary history with little effect on its gross morphological features and contradicts the notion that *Metasequoia* cannot tolerate cold or freezing conditions.

By the Late Cretaceous (Coniacian, Santonian, Campanian and Maastrichtian [=Senonian]) the genus was well established along the western coast of North America and the eastern coast of Asia (Figure 1-5). The latitudinal range of distribution extended from about 30°N to about 70°N.

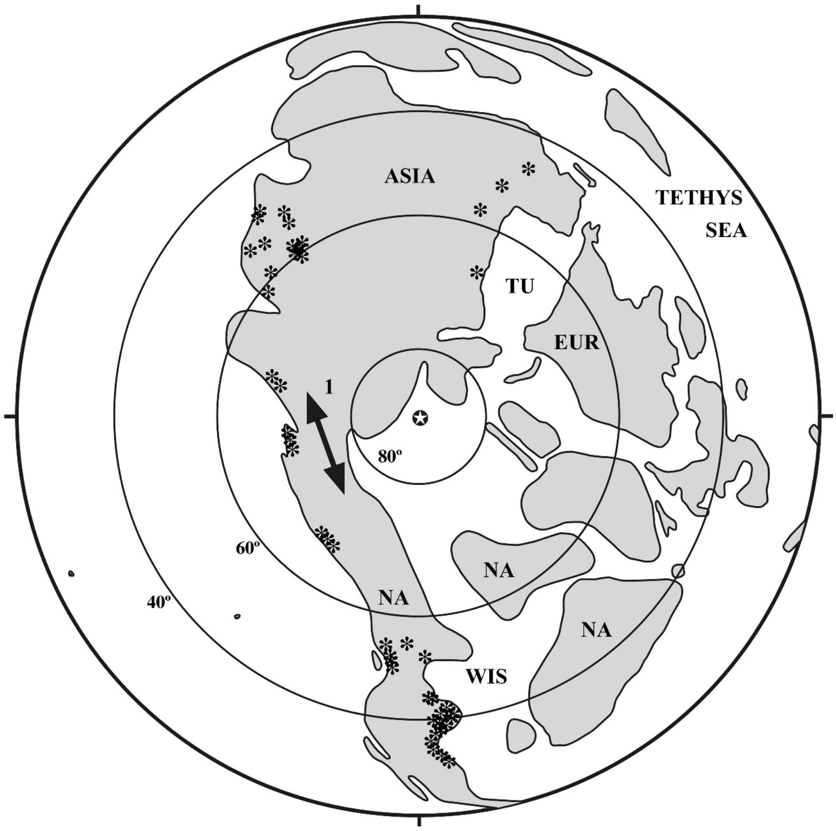

Figure 1-5. Generalized paleogeographic reconstruction of the Northern Hemisphere in polar projection during the Late Cretaceous (Maastrichtian, ca. 71 Ma), showing the Beringian Corridor (1) and the distribution of fossil *Metasequoia. Legend:* NA = North America, WIS = Western Interior Seaway, EUR = Eurasia and TU = Turgai Strait.

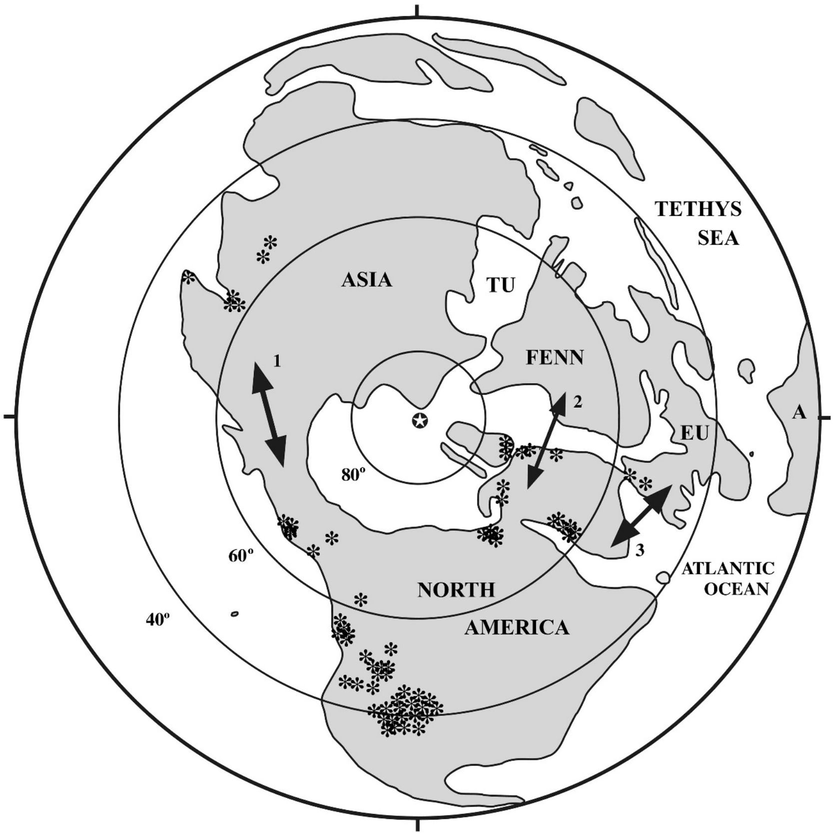

Figure 1-6. Generalized paleogeographic reconstruction of the Northern Hemisphere in polar projection during the Paleocene (ca. 60 Ma), showing the Beringian Corridor (1), DeGeer Route (2), Thulian Route (2) and the distribution of fossil *Metasequoia.* Note the spread of *Metasequoia.* into the westernmost part of Eurasia. *Legend:* TU = Turgai Strait, EU = Europe, A = Africa and FENN = Fennoscandia.

However, at this time the genus showed signs of range expansion into western Asia up to the shores of the Turgai Strait. Maastrichtian age floras from eastern Kazakhstan and the Kuznets Basin indicate that the climate was cooling and becoming more mesic (Baikovskaya, 1956; Makulbekov, 1974; Shilin & Romanova, 1978; Vakhrameev, 1988).

By the early Tertiary, three land bridges were available to flora and fauna for exchange between Asia, North America and Europe (Figures 1-6 and 1-7). The DeGeer Route (McKenna, 1972a, 1983a) linked North America and Fennoscandia throughout the Paleocene and Eocene, while the more southern Thulian Route existed intermittently or as a series of islands between southern Greenland and Europe, also during Paleocene and Eocene time (McKenna,

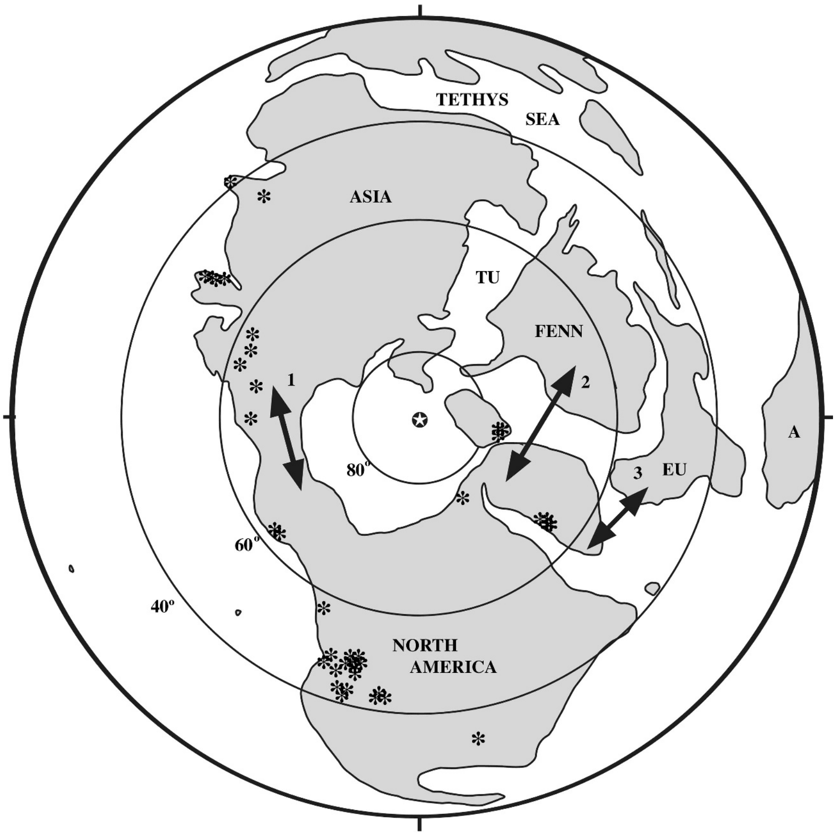

Figure 1-7. Generalized paleogeographic reconstruction of the Northern Hemisphere in polar projection during the middle Eocene (ca. 45 Ma), showing the Beringian Corridor (1), DeGeer Route (2), Thulian Route (3) and the distribution of fossil *Metasequoia.* By the end of the Eocene, the DeGeer and Thulian routes between North America and Europe had been broken. *Legend:* TU = Turgai Strait, EU = Europe, A = Africa and FENN = Fennoscandia.

1972a, 1975; Thiede & Eldholm, 1983). The Beringian Corridor remained a functional conduit between North America and Asia until Pleistocene time (Chaney, 1947; Hopkins, 1967; McKenna, 1972a; Tiffney, 1985).

The early Tertiary (Paleocene and Eocene) distribution pattern of *Metasequoia* indicates continued occupation of western North America and eastern Asia (Figures 1-6 and 1-7). The distribution of the genus in North America appears to have experienced considerable range expansion in the foreland and inter-montane basins of the rising Rocky Mountain Range. In the polar regions, *Metasequoia* became a prominent component of the Greenland, Spitsbergen and Canadian Arctic floras. Despite the use of the North Atlantic routes by other representatives of the broad-leaved deciduous forests of the high northern latitudes, *Metasequoia* did not migrate any further to the east than eastern Greenland, the Faeroe Islands and the Isle of Mull (Seward & Edwards, 1941; Rasmussen & Koch, 1963; Boulter & Kvaček, 1989). The sub-tropical to tropical conditions that were present in Western Europe during the early Tertiary may have precluded the establishment of *Metasequoia* populations in this region at this time (Collinson, 1983). Interestingly, the genus appears to have expanded its range to eastern North America as part of the Atlantic coastal plain floras. Berry (1916) reported the occurrence of *Metasequoia* from the late Eocene Lagrange Formation of Tennessee.

In Eurasia, the populations of *Metasequoia* seen during the Late Cretaceous are no longer recorded along the shores of the Turgai Strait during the Paleocene and Eocene (Figure 1-6). This apparent absence may however be an artifact created by the lack of Paleocene and Eocene age deposits along the southeastern shores of the Turgai Strait.

The western North American and East Asian distributions of *Metasequoia* during the Oligocene differ little from that seen during the Paleocene and Eocene (Figure 1-8). Although *Metasequoia* appears to have disappeared from the polar regions, the lack of Oligocene age deposits from this part of the world might account for the apparent absence of the genus in these regions at this time. It is not known to what extent *Metasequoia* used the North Atlantic land bridges during the Paleocene and Eocene or whether the genus continued to expand further to the east in Europe at this time. Nevertheless, sea-floor spreading in the Norwegian-Greenland Sea at about the Eocene/Oligocene boundary effectively destroyed the North Atlantic land bridges and terminated all terrestrial communication between these two regions (McKenna, 1972b; Dawson *et al*., 1975, 1976; West *et al*., 1977; West & Dawson, 1978; Hoch, 1983). The significance of the North Atlantic land bridges for faunal migration between North America and Europe was recognized by McKenna (1972b) and West & Dawson (1978), who described a 30% similarity between the mammalian faunas of North America and Europe during the late Paleocene, which rose sharply to more than 50% by middle Eocene time and then dropped to about 10% following the Eocene.

Perhaps more important to the distribution pattern of *Metasequoia* were the drying of the Turgai Strait, a major global cooling event at the Eocene/Oligocene boundary and possibly, uplift of the Himalayas. The movement of polar broad-leaved deciduous forest elements, including *Metasequoia* into the West Siberian Plain is coincident with several major events (LePage, 2001, 2003a, 2003c; LePage & Basinger, 1991b, 1995). First was the drying of the Turgai Strait. The Turgai Strait was a shallow epicontinental seaway that extended from the Arctic Ocean to the Tethyan Sea, separating eastern and western Asia and effectively precluding floral and faunal exchange (McKenna, 1972b,

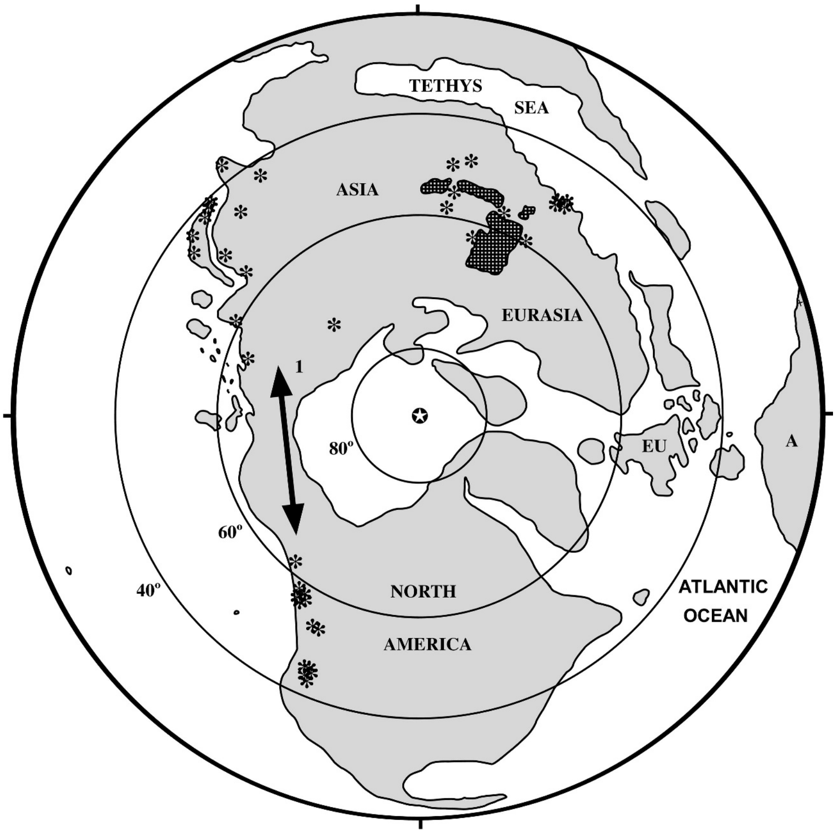

Figure 1-8. Generalized paleogeographic reconstruction of the Northern Hemisphere in polar projection during the Oligocene (ca. 29 Ma), showing the Beringian Corridor (1) and distribution of fossil *Metasequoia*. Note the spread of *Metasequoia*. from Asia into west-central Asia following regression of the Turgai Strait. The stippled region in west-central Asia indicates the location of the remnants of the Turgai Strait. *Legend:* A = Africa and EU = Europe.

1983b; Tiffney, 1985; LePage & Basinger, 1991b, 1995). McKenna (1983b) and Meng & McKenna (1998) convincingly demonstrate major faunal turnovers at the Eocene/Oligocene boundary (Bartonian/Rupelian) in western Europe and the Mongolian Plateau that are coincident with global cooling and drying of the Turgai Strait. Second, was the major global climatic cooling at the Eocene/Oligocene boundary (ca. 34 Ma) that Wolfe (1985) called the Terminal Eocene Event (TEE). Wolfe (1997) reported that 25–40% of the genera that grew in Europe, western North America and Alaska during the Eocene became extinct following the TEE. Third, the effects of the Himalayan orogeny may have created suitable habitat for *Metasequoia* along the southern margin of the

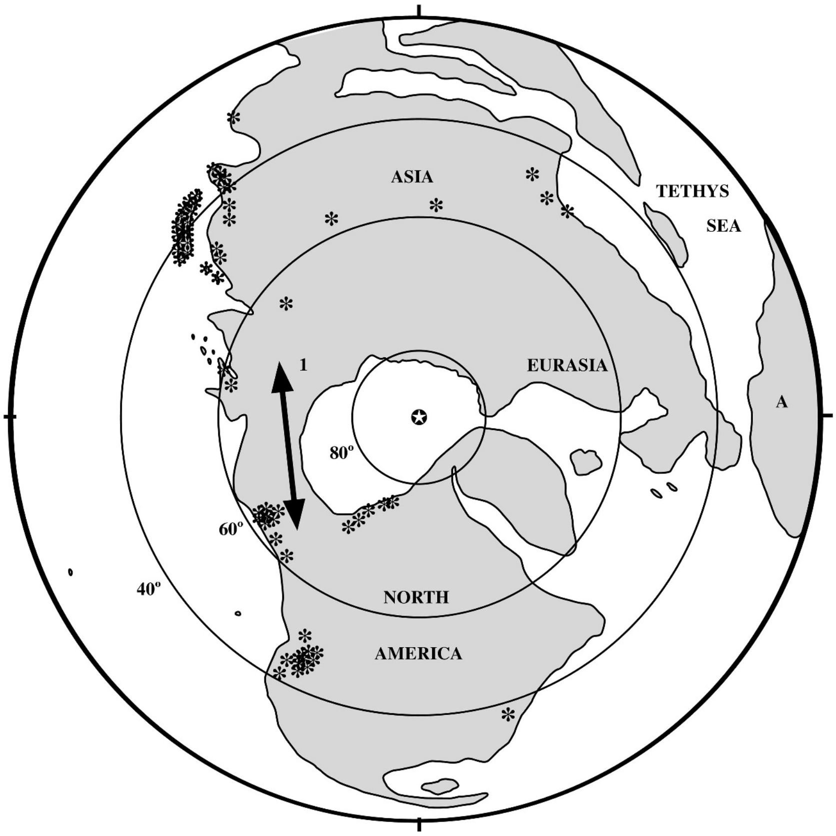

Figure 1-9. Generalized paleogeographic reconstruction of the Northern Hemisphere in polar projection during the Miocene (ca. 14 Ma), showing the Beringian Corridor (1) and the distribution of fossil *Metasequoia*. *Legend:* A = Africa.

Asian plate. Given that *Metasequoia* seems to thrive in regions where orogenic activity is prevalent, the southern coast of Asia may have provided suitable habitat and an extensive migratory corridor between eastern and western Asia.

By the end of the Oligocene the Turgai Strait had dried completely, climate continued to cool, and *Metasequoia* appeared in the West Siberian Plain as part of the thermophilic and mesophytic Turgai floras (Figure 1-8). However, the presence of *Metasequoia* in the West Siberian Plain appears to have been short-lived, for the genus begins to disappear from the region as climate became cooler and drier (Figure 1-9). Paleobotanical and magnetostratigraphic data from the West Siberian Plain indicate that the thermophilic and mesophytic Turgai floras of the late Oligocene and early Miocene (pre-Chron C5D) shifted to a much cooler and drier forest steppe flora by the late early-early late Miocene (Gnibidenko *et al*., 1999).

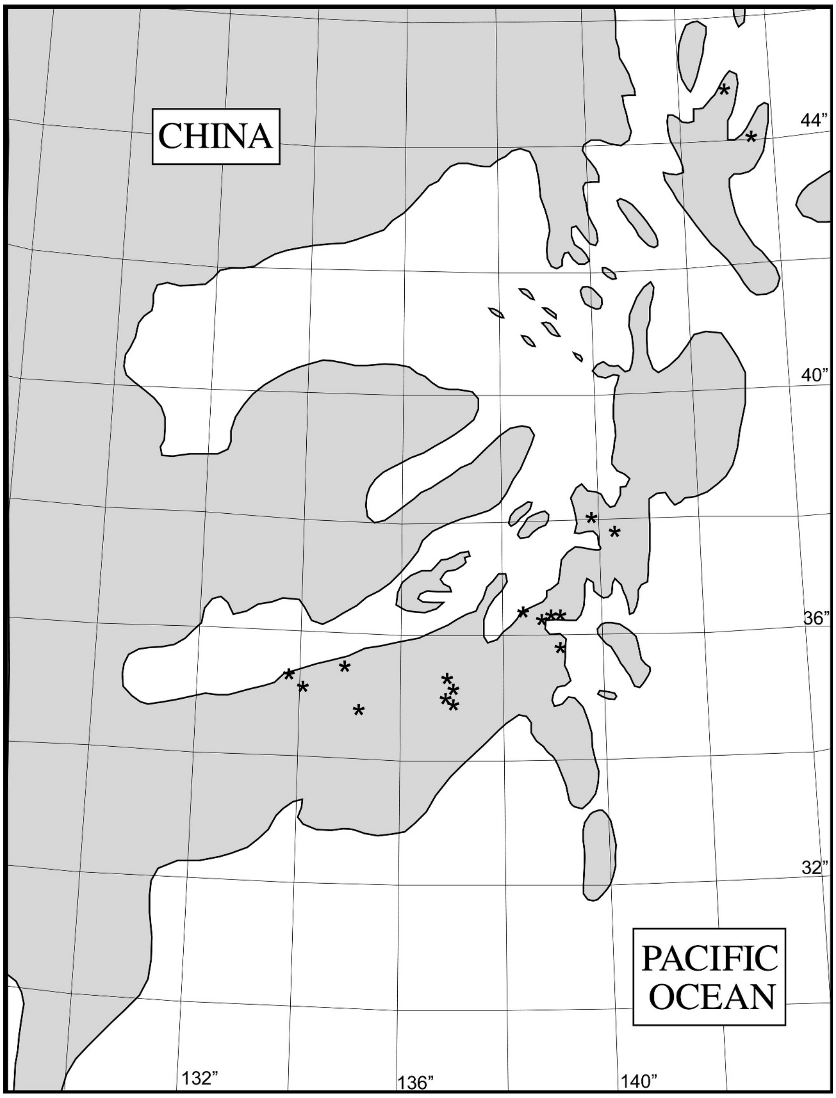

Figure 1-10. Distribution of *Metasequoia* in Japan during the late Miocene. Note the connection between southeastern Japan and the Chinese mainland. Image redrawn and modified from Minato (1965) and Yang (1991).

In North America and Asia, *Metasequoia* persisted in the mid- to high-latitude regions until Miocene time (Figure 1-9). *Metasequoia* is again recorded along the Atlantic coastal plain in the Miocene Calvert Formation of Washington, D.C. (Berry 1909). Despite the increased cooling and drying the genus persisted in the West Siberian Plain, but its distribution had shrunk considerably when compared to that seen during the Oligocene. The inability of *Metasequoia* to migrate into Europe following regression of the Turgai Strait together with other thermophilic and mesophytic elements of the broad-leaved deciduous forests such as *Larix* Miller, *Tsuga* (Endlicher) Carrière, *Picea* A. Dietrich and *Taiwania* Hayata (LePage & Basinger, 1991a; LePage, 2001, 2003a, 2003c, unpublished) remains unexplained.

The late Miocene distribution of *Metasequoia* in Japan indicates that the genus was well represented in Hokkaido and Honshu (Figure 1-10). It is important to note that Japan was connected to the Chinese mainland at this time providing a floral conduit between these two areas. By Pliocene time, habitat partitioning as well as climate and environmental changes caused *Metasequoia* to disappear from Hokkaido (Momohara, 1997, this volume). The populations in Honshu persisted and the genus became established in Shikoku and Kyushu (Figure 1-11). Moreover, the land connection that existed between Japan and the Chinese mainland during the late Miocene was severed during the Pliocene. During the late Pliocene and early Pleistocene *Metasequoia* was well represented in central and southern Japan and the land bridge between Japan and the Chinese mainland was again re-established (Figure 1-12).

With few exceptions the plant fossil record indicates that *Metasequoia* disappeared from the rest of the world during the late Miocene and Pliocene. Late Pliocene occurrences of *Metasequoia* include reports from Arctic Canada (Matthews & Ovenden, 1990; Matthews *et al*., 1990) and western Siberia (Gorbunov, 1957, 1962) and Chochieva (1975) indicates that *Metasequoia* persisted until the late Pliocene-early Pleistocene in western Georgia. *Metasequoia* became extinct in Japan during the latest early Pleistocene, about 1.1 to 0.8 million years ago (Momohara, 1994, this volume; Momohara *et al*., 1990). Given that *Metasequoia* can tolerate temperatures ranging from 40°C to –40°C (Sakai & Larcher, 1987; LePage, unpublished), its demise might have been associated with increasing global aridity, rather than cooler temperatures (Momohara, this volume).

As pointed out by Yang & Jin (2000), the extirpation of *Metasequoia* from China and its re-appearance in present day Sichuan, Hubei and Hunan Provinces is an enigma that elicits at least two major questions. First, did *Metasequoia* survive in southeast China throughout the Pliocene and Pleistocene without being preserved or detected in the plant fossil record? Fossil wood identified as *M. glyptostroboides* was excavated from Wuhan City and dated as being 11,280 ± 190 years B.P. (Qi *et al*., 1993). If this report were accurate, it would then indicate that the genus was much more widespread in China during the recent past and that *Metasequoia* was present in China during Pleistocene time. Alternatively, did *Metasequoia* become extinct in China at the close of the Miocene only to become re-established from the Japanese populations sometime before the latest early Pleistocene? Minato (1965) and Yang

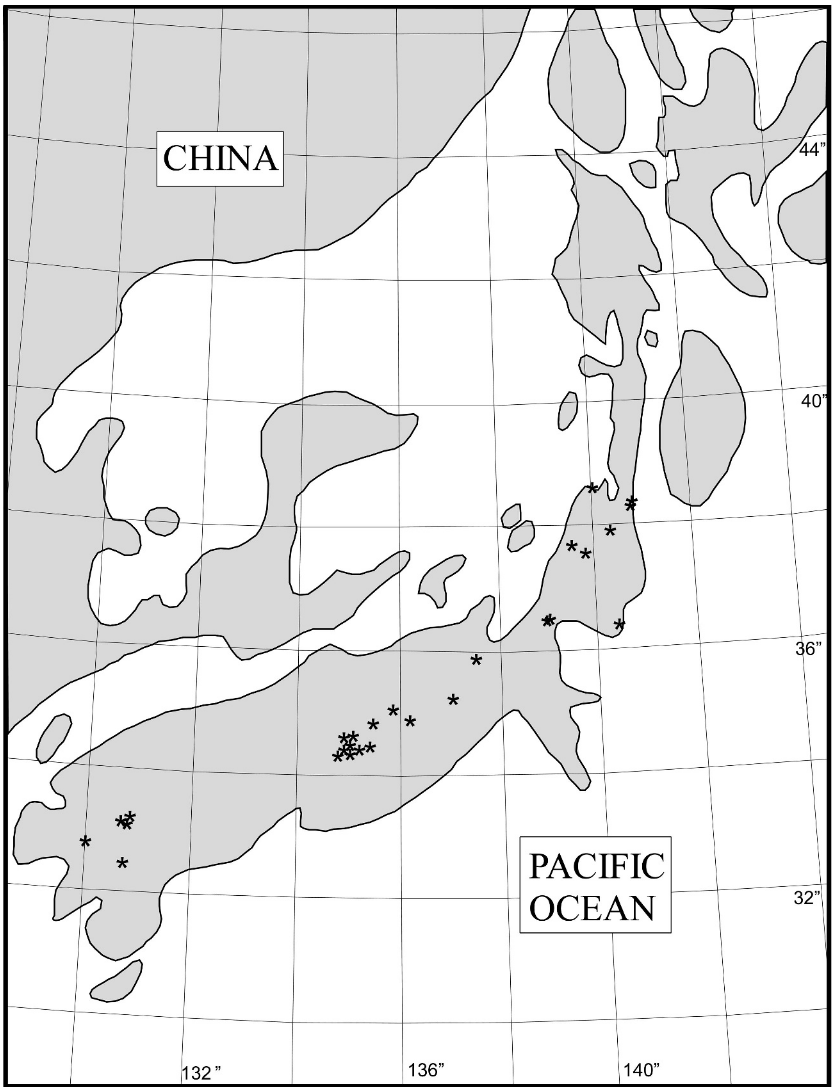

Figure 1-11. Distribution of *Metasequoia* in Japan during the Pliocene. Note that the connection between southeastern Japan and the Chinese mainland that was present during the late Miocene is now broken. Image redrawn and modified from Minato (1965) and Yang (1991).

(1991) indicate that Japan temporarily re-established land connections with China a number of times during Plio-Pleistocene time. Clearly the answer to these questions will require detailed paleobotanical and archaeological studies that are focused on late Tertiary and Quaternary deposits so that the vegetation history of southeast China can be reconstructed in detail.

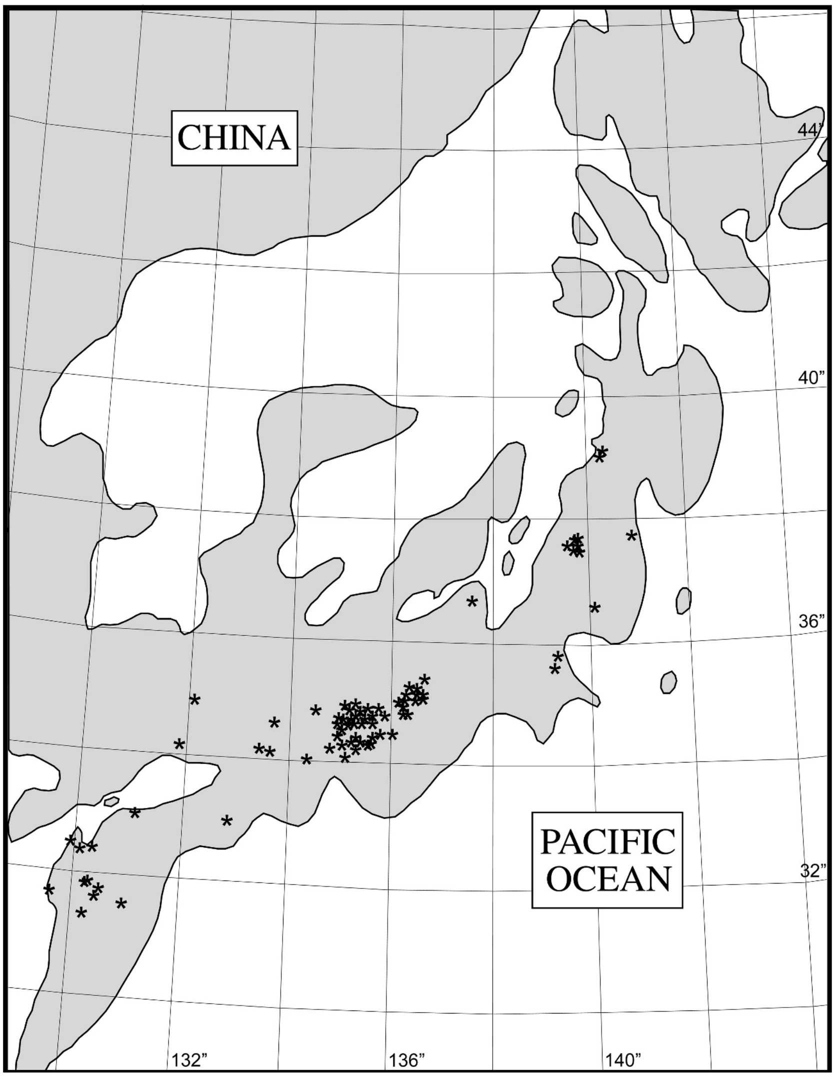

Figure 1-12. The distribution of *Metasequoia* in Japan during the Plio-Pleistocene. Note that the connection between southeastern Japan and the Chinese mainland has been re-established. Image redrawn and modified from Minato (1965) and Yang (1991).

6. PUTATIVE *METASEQUOIA* REMAINS FROM EUROPE

Although there have been a number of reports of fossil *Metasequoia* wood, leaves, seeds and cones from Europe (e.g., Schönfeld, 1955; Zalewska, 1959), the validity of these reports has been questioned (Dorofeev & Sveshnikova, 1963). Throughout the Tertiary the plant fossil record indicates that *Metasequoia* and *Glyptostrobus* co-existed in some lowland swamp forest communities (e.g., Basinger, 1991; Richter & LePage, this volume). However, in the absence of diagnostic leaves and seed cones, the fossil *Metasequoia* wood has been difficult to separate from that of *Glyptostrobus*. Recently, Visscher & Jagels (2003) have shown that it is possible to discriminate between the wood of living representatives of these two genera if a sufficient sample size is available. To determine whether Schönfeld's identification is valid, we recommend that the putative fossil *Metasequoia* wood described by Schönfeld (1955) from the German Miocene browncoals of Düren be re-examined or that additional material be re-collected from the locality where it was first found.

The descriptions and illustrated material of *Metasequoia europaea* Zalewska provided by Zalewska (1959) are interesting and the unilateral conclusion that *Metasequoia* did not occupy Europe should not be dismissed without further study. Given that the genus had reached western Asia/eastern Europe by the Late Cretaceous (Maastrichtian; Figure 1-5), eastern Greenland and western Europe (Isle of Mull and Faeroe Islands; Figure 1-6) during the early Tertiary and persisted in southern Caucasus until the Plio-Pleistocene (Chochieva, 1975), there is no reason why *Metasequoia* should not have been a part of the warm-temperate broad-leaved deciduous forests that began to emerge in this part of the world during the mid- to late Tertiary. The fact that floral elements such as *Tsuga* and *Taiwania*, genera that co-existed with *Metasequoia* in the Canadian Arctic and constituents of the warm-temperate broad-leaved deciduous forests (LePage, 2003a; Richter & LePage, this volume), were reported in Europe during the early Tertiary indicates that the climatic and environmental conditions were suitable for *Metasequoia* to thrive (LePage, 2003a, unpublished). A re-investigation of the *Sequoia* and *Taxodium* fossils, as well as the other taxa that fossil *Metasequoia* has been assigned to in the past (Appendix A) may provide the answer to this enigma.

7. OROGENIES AND ECOLOGICAL COMPETITION

The fossil record of *Metasequoia* indicates that the genus first appeared as a minor constituent of the Late Cretaceous floras of Russia and North America, then became a dominant constituent of the early Tertiary floras of Asia and North America before its final extinction in North America and Asia during the late Tertiary. Although explanations for the demise of the genus have focused on global cooling and increased aridity (Yang & Jin, 2000; Momohara, 1997, this volume), the distribution of *M. glyptostroboides* trees planted in arboreta throughout the world indicate that *M. glyptostroboides* is capable of growing under a wide rage of temperatures, though it is much more sensitive to aridity (Xie *et al*., 1999a, 1999b; Williams, this volume).

Despite the ability of *M. glyptostroboides* to grow under a wide range of climatic and environmental conditions, its extensive range during the early Tertiary shrunk considerably and the number of trees growing in its native habitat today number about 5,000 individuals. Clearly, global cooling and increasing aridity alone do not provide a satisfactory explanation for the near extinction of the genus. However, at the time the genus began to experience range reduction several prominent changes were occurring. If we consider factors such as: physical mechanisms of global climate; changes in the regional landscapes; the emergence of new vegetation formations; and increased competition for space and resources, a possible explanation for *Metasequoia's* decline begins to emerge. To do this we have compared the relative abundance of representatives of the Taxodiaceae to that of the Pinaceae.

Throughout the Late Cretaceous and early Tertiary the representatives of the Taxodiaceae were much more abundant and geographically widespread than those of the Pinaceae (Florin, 1963) despite the initiation of major global tectonic events such as sea-floor spreading in the north Atlantic and uplift of the Himalayas and Rocky Mountains. It is during the Miocene that changes in the relative abundance between these the Taxodiaceae and Pinaceae become apparent. During the Miocene two trends are recognised. First the geographic range and abundance of representatives of the Taxodiaceae such as *Metasequoia* decrease (Jongmans & Dijkstra, 1971–1974; Dijkstra & Schaarschmidt, 1975). Second, the geographic ranges and number of Pinaceae species described from the plant fossil record throughout North America and Asia increase (Jongmans & Dijkstra, 1971–1974; Dijkstra & Schaarschmidt, 1975). These trends appear to be related to large-scale habitat creation and partitioning associated with mountain-building events and subsequent global cooling (Figure 1-13).

In North America, thermal uplift of the Western Cordillera began during the middle Miocene and the elevation of the region rose from about 1,000 m to 4,000–4,500 m (Omar *et al*., 1994). Ecologically, an event of this magnitude was significant, for it created an altitudinally continuous environmental gradient from the low-elevation warm temperate zone to the high-elevation cool temperate and boreal/montane floristic zones. Using the world-wide mean lapse rate of 5.5°C/1,000 m (Wolfe, 1992), the temperature at 4,000 to 4,500 m would have been about 16.5 to 19°C cooler than that seen at 1,000 m, which was probably cold enough to establish a tree line and alpine habitats. On the eastern side of the Western Cordillera, the effects of the rising mountains would have created a rain shadow resulting in an overall decrease in local and regional rainfall and increased aridity.

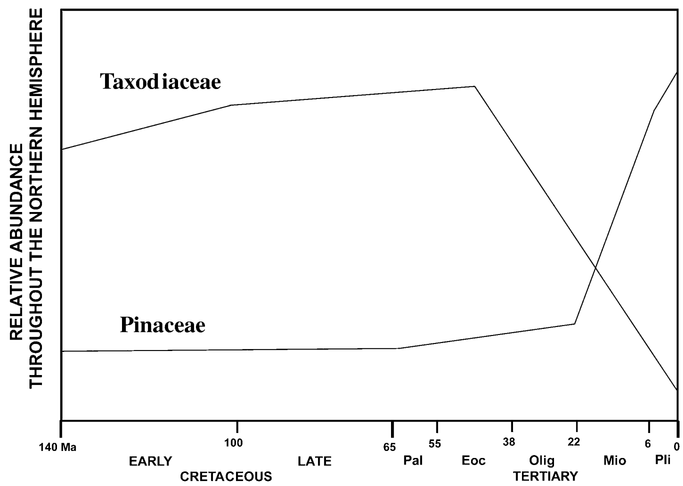

Figure 1-13. Relative abundance of Taxodiaceae as compared to members of the Pinaceae. Note that the relative abundances remain more or less unchanged until Miocene time.

In Asia, uplift of the Himalayas and Tibetan Plateau occurred at about mid-Miocene time, with significant uplift occurring during the late Miocene (Yoshida, 1984; Johnson *et al.*, 1982; Burbank & Johnson, 1983; Mercier *et al.*, 1987; Ruddiman & Kutzbach 1989; Ruddiman *et al.*, 1989). During the late Miocene (5–10 Ma) estimates of 2,500 to 4,000 m of uplift have been proposed, while palynofloral and faunal remains indicate that uplift of the Tibetan Plateau was at least 2,000 m (Hsü, 1978; Liu & Ding, 1984; Mercier *et al.*, 1987). To the north and northeast of the Himalayas, decreased rainfall and increased aridity would have resulted.

These two events together with the global cooling trend were advantageous for plants that were able to tolerate colder temperatures and other environmental stresses not encountered at the lower elevations. However as previously pointed out, *Metasequoia* can tolerate cold to freezing conditions and the creation of new, unstable environments such as those seen in montane environments would have favoured the establishment of extensive *Metasequoia* forests. Clearly other factors precluded the establishment of *Metasequoia* from these emerging habitats. If we consider the nutrient-acquisition strategies and the fungal symbionts utilised by the Pinaceae and Taxodiaceae, a possible explanation begins to emerge.

Read (1984) has proposed that the mycorrhizal strategy employed by plants broadly corresponds to the environment in which they occur (Figure 1-14). The Pinaceae support ectomycorrhizal symbionts, while representatives of the Taxodiaceae support endomycorrizal associations. Thus, in most forests

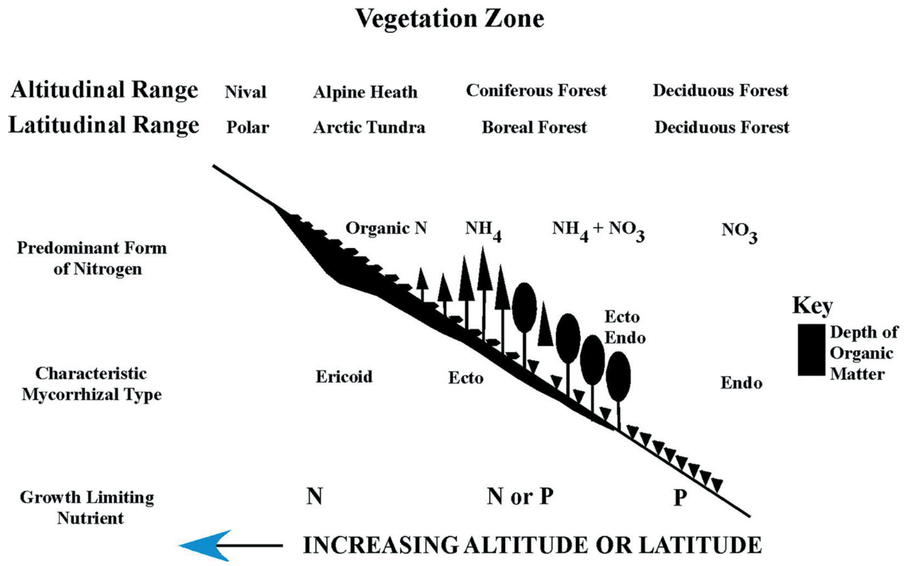

Figure 1-14. Simplified diagram depicting the putative relationship between altitude, latitude, climate, forest type and mycorrhizal type. Redrawn and modified from Read (1984).

growing on mineral- and nutrient-rich soils at low latitudes and altitudes where the temperature is warm and organic turnover is high, plants utilising an endomycorrhizal strategy tend to dominate the landscape. As altitude and latitude increase, the temperature becomes cooler and sometimes drier (depending on aspect) and the rate of biomass accumulation becomes greater than decomposition. In these boreal and cool temperate environments, plants forming ectomycorrhizal associations such as the Pinaceae dominate the landscape. The soils in these environments tend to be organic-rich and depending on the soil conditions, the nitrogen and phosphorous pools are commonly comprised of organic forms that are generally not available to plants (Smith & Read, 1997). Thus, the ectomycorrhizal fungi associated with plants growing in acid organic soils where the nitrogen and phosphorous pools consist of organic forms, produce extracellular enzymes that are capable of degrading the organic components of the forest-floor litter to absorb and mobilise the nitrogen and phosphorus needed by the plants (Smith & Read, 1997).

Therefore, the newly emerging late Miocene and Pliocene high-altitude montane environments of western North America and Asia, together with the global cooling trend that began near the end of the Eocene, increased aridity and nutrient-acquisition strategies would have favored the spread and evolution of ectomycorrhizal plants, such as the Pinaceae.

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10. APPENDIX A

***Metasequoia foxii* Stockey, Rothwell *et* Falder**: Stockey *et al.*, *International Journal of Plant Sciences* 162: 223, figs. 1–7 (2001).

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***Sequoia nordenskioldii* Heer**: Heer, *Flora Fossilis Arctica* 2: 36, pl. 2, fig. 13b; pl. 4, figs. 1a, 1b, 4–38 (1870a).

Sequoia nordenskioldii Heer: Newberry, *United States Geological Survey, Monograph* 35: 20, pl. 26, fig. 4 (1898).

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***Sequoia sempervirens* Endlicher *var. fossilis* Endo**: Endo, *Iwanami Geology and Paleontology Series* 24: 14 (1931).

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***Sequoia cfr. Sequoia tournalii* Brongniart**: Nathorst, *Palaeontologische Abhandlungen* 4: 15 (1888).

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***Sequoia* sp. (cone) Knowlton**, *Harriman Alaska Expedition* 4: 152, pl. 22, fig. 1 (1904).

***Sequoia* sp. (cone) Hollick**, *United States Geological Survey, Professional Paper* 159: 59, pl. 23, figs. 2, 4, 6, 8, 10 (1930).

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***Sequoia* sp. (*Sequoia cfr. chinensis* Endo) Endo**, *Bulletin of the Central Museum of Manchoukuo* 3: 39, pl. 16, fig. 2 (1942).

***Sequoia* sp., Nathorst**: Endo, *A Survey of the Fossils from Japan Illustrated in Classical Monographs* —Part 5, p. 14, 15, pl. 23, figs. 9, 10; pl. 25, fig. 1 (1963).

***Sequoiites langsdorfii* (Brongniart) Seward**: Bell, *Geological Survey of Canada, Bulletin* 13: 47, pl. 27, figs. 4, 6; pl. 29, figs. 1, 3 (1949).

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***Taxites olriki* Heer**: Heer, *Flora Fossilis Arctica* 1: 95, pl. 1, figs. 23–24; pl. 45, figs. 1a, 1b (1868).

Taxites olriki Heer: Heer, *Flora Fossilis Arctica* 2: 23, pl. 1, fig. 8; pl. 2, fig. 5b (1869).

Taxites olriki Heer: Heer, *Philosophical Transactions of the Royal Society* 159: 465, pl. 55, figs. 7a–7b (1870b).

Taxites olriki Heer: Heer, *Kungliga Svenska Vetenskaps-Akademiens Handlingar* 13: 15–16, pl. 1, figs. 9–10 (1874).

Taxites olriki Heer: Heer, *Flora Fossilis Arctica* 4: 64, pl. 16, fig. 8b (1876).

Taxites olriki Heer: Lesquereux, *10th Annual Report of the United States Geological and Geographical Survey*, p. 498 (1878a).

Taxites olriki Heer: Heer, *Flora Fossilis Arctica* 7: 56 (1883a).

Taxites olriki Heer: Dawson, *Proceedings and Transactions of the Royal Society of Canada* 4: 23, fig. 5 (1887).

Taxites olriki Heer: Knowlton, *United States Geological Survey, Bulletin* 152: 225 (1898a).

***Taxites olriki* Heer *var. brevioribus obtusis* Heer**: Heer, *Flora Fossilis Arctica* 7: 56 (1883a).

***Taxites pectens* Heer**: Heer, *Flora Fossilis Arctica* 7: 9, pl. 53, figs. 9, 9b (1883a).

***Taxites validus* Heer**: Heer, *Kungliga Svenska Vetenskaps-Akademiens Handlingar* 13: 13, pl. 1, fig. 11 (1874).

Taxites validus Heer: Heer, *Flora Fossilis Arctica* 7: 56 (1883a).

***Taxites* sp., Nathorst**, *Kungliga Svenska Vetenskaps-Akademiens Handlingar* 20: 35, pl. 1, fig. 8 (1883).

***Taxodium crassum* Hollick**: Hollick, *United States Geological Survey, Professional Paper* 182: 48, pl. 64, fig. 4b only (1936).

***Taxodium cuneatum* Newberry**: Newberry, *Boston Journal of Natural History* 7: 517 (1863).

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***Taxodium distichum miocenum* Heer**: Heer, *Flora Fossilis Arctica* 2: 21, pl. 1, fig. 6; pl. 3, fig. 11c; pl. 4, figs. 5b–5c (1869).

Taxodium distichum miocenum Heer: Heer, *Flora Fossilis Arctica* 2: 32, pl. 3, figs. 30–31; pl. 16, figs. 8b–8c (1870a).

Taxodium distichum miocenum Heer: Heer, *Philosophical Transactions of the Royal Society* 159: 463, pl. 43, figs. 4–5 (1870b).

Taxodium distichum miocenum Heer: Heer, *Kungliga Svenska Vetenskaps-Akademiens Handlingar* 13: 9, 13, 19, pl. 1, figs. 4b, 13c–13d, 15b; pl. 2, figs. 20d, 21; pl. 4, fig. 5 (1874).

Taxodium distichum miocenum Heer: Heer, *Flora Fossilis Arctica* 4: 57, pl. 13, figs. 12–13; pl. 25, figs. 9b, 13 (1876).

Taxodium distichum miocenum Heer: Heer, *Flora Fossilis Arctica* 5: 23, pl. 2, figs. 1b–9 (1878a).

Taxodium distichum miocenum Heer: Heer, *Mémoires de l'Académie Impériale des Sciences de St. Pétersbourg* 25: 33, 48, pl. 8, fig. 25b; pl. 9, fig. 1; pl. 15, figs. 1–2 (1878b).

Taxodium distichum miocenum Heer: Heer, *Mémoires de l'Académie Impériale des Sciences de St. Pétersbourg* 25: 22, pl. 1, fig. 9 (1878c).

Taxodium distichum miocenum Heer: Heer, *Kungliga Svenska Vetenskaps-Akademiens Handlingar* 15: 4 (1878d).

Taxodium distichum miocenum Heer: Lesquereux, *10th Annual Report of the United States Geological and Geographical Survey*, p. 498 (1878a).

Taxodium distichum miocenum Heer: Heer, *Kungliga Svenska Vetenskaps-Akademiens Handlingar* 18: 9 (1880a).

Taxodium distichum miocenum Heer: Heer, *Flora Fossilis Arctica* 6: 12 (1880b).

Taxodium distichum miocenum Heer: Heer, *Flora Fossilis Arctica* 7: 60, pl. 70, fig. 11; pl. 87, fig. 7; pl. 88, fig. 2b; pl. 96, figs. 8–9 (1883a).

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Taxodium distichum miocenum Heer: Dawson, *Royal Society of Canada, Transactions* 8: 79, text-fig. 6 (1891).

Taxodium distichum miocenum Heer: Knowlton, *Geological Society of America, Bulletin* 5: 578 (1893a).

Taxodium distichum miocenum Heer: Knowlton, *United States Geological Survey, Bulletin* 105: 46 (1893b).

Taxodium distichum miocenum Heer: Knowlton, *Proceedings of the United States National Museum* 17: 214 (1894).

Taxodium distichum miocenum Heer: Knowlton, *United States Geological Survey, Annual Report* 17: 878 (1896).

Taxodium distichum miocenum Heer: Newberry, *United States Geological Survey Monograph* 35: 22, pl. 47, fig. 6; pl. 51, fig. 3; pl. 52, figs. 2–4; pl. 55, fig.5 (1898).

Taxodium distichum miocenum Heer: Knowlton, *United States Geological Survey, Bulletin* 152: 226 (1898a).

Taxodium distichum miocenum Heer: Knowlton, *United States Geological Survey, Bulletin* 204: 27 (1902).

Taxodium distichum miocenum Heer: Penhallow, *Proceedings and Transactions of the Royal Society of Canada, 2nd Series* 8: 51, 68 (1902).

Taxodium distichum miocenum Heer: Knowlton, *Harriman Alaska Expedition* 4: 152 (1904).

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Taxodium distichum miocenum Heer: Penhallow, *Report on Tertiary Plants of British Columbia*, p. 91 (1908).

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Taxodium distichum miocenum Heer: Shikama, *Journal of the Geological Society of Japan* 45: 628 (1938).
***?Taxodium distichum* Richard**: Florin, *Kungliga Svenska Vetenskaps Akademiens Handlingar* 61: 16, 30, pl. 1 figs. 1–2; pl. 5, figs. 10–11 (1920).
***Taxodium distichum dubium* Cockerell**: Cockerell, *American Naturalist* 44: 35 (1910).
***Taxodium distichum* Rich. *var. miocaenum* Heer**: Kryshtofovich, *Botanical Journal* 31: 17, text-fig. 1 (1946).
***Taxodium distichum miocenum var. angustifolium* Heer**: Lesquereux, *Proceedings of the United States National Museum* 11: 34 (1889).
***Taxodium dubium* (Sternberg) Heer**: Heer, *Flora Fossilis Arctica* 1: 89, 156, pl. 2, figs. 24–27; pl. 12, fig. 1c; pl. 30, figs. 3–4; pl. 45, figs. 11d, 12d (1868).
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Taxodium dubium (Sternberg) Heer: Lesquereux, *7th Annual Report of United States Geological Survey of the Territories*, p. 388, 409 (1874).
Taxodium dubium (Sternberg) Heer: Lesquereux, *10th Annual Report of the United States Geological and Geographical Survey*, p. 498 (1878a).
Taxodium dubium (Sternberg) Heer: Berry, *United States Geological Survey, Professional Paper* 91: 171–173, pl. 15, figs. 4–6 (1916).
Taxodium dubium (Sternberg) Heer: Berry, *Geological Survey of Canada, Bulletin* 42: 97 (1926a).
Taxodium dubium (Sternberg) Heer: Berry, *Transactions of the Royal Society of Canada, 3rd Series* 20: 191 (1926b).
Taxodium dubium (Sternberg) Heer: Knowlton, *United States Geological Survey, Professional Paper* 140: 27–28, pl. 9, figs. 2, 7–9; pl. 10, fig. 2 (1926).
Taxodium dubium (Sternberg) Heer: Berry, *National Museum of Canada, Memoir* 63: 18 (1930).
Taxodium dubium (Sternberg) Heer: Williams & Dyer, *Geological Survey of Canada, Memoir* 163: 64 (1930).

Taxodium dubium (Sternberg) Heer: Berry, *Geological Survey of Canada, Memoir* 182: 19 (1935).

Taxodium dubium (Sternberg) Heer: Hollick, *United States Geological Survey, Professional Paper* 182: 48, pl. 16, fig. 5; pl. 51, fig. 5a (1936).

Taxodium dubium (Sternberg) Heer: MacGinitie, *Carnegie Institute of Washington, Publication* 465: 132, pl. 3, fig. 4 (1937).

Taxodium dubium (Sternberg) Heer: Gabrielse, *Geological Survey of Canada, Memoir* 319: 95 (1963).

Taxodium dubium (Sternberg) Heer: Makulbekov, *Academia Nauk Kazakhstan SSR, Zoology Institute* 6: 110, pl. 1, figs. 2–3 (1974).

***Taxodium gracile* Heer**: Heer, *Mémoires de l'Académie Impériale des Sciences de St. Pétersbourg* 25: 33, pl. 8, figs. 30b, 31–37 (1878b).

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Taxodium occidentale Newberry: Newberry, *Annals of the Lyceum of Natural History* 9: 45 (1868).

Taxodium occidentale Newberry: Dawson, *Canada Geological Survey, Report of Progress for 1875–76*, p. 260 (1877).

Taxodium occidentale Newberry: Lesquereux, *10th Annual Report of the United States Geological and Geographical Survey*, p. 498 (1878a).

Taxodium occidentale Newberry: Lesquereux, *Illustrations of Cretaceous and Tertiary Plants*, pl. 11, figs. 1–3 (1878b).

Taxodium occidentale Newberry: Newberry, *United States Geological Survey Monograph* 35: 23, pl. 26, figs. 1–3; pl. 55, fig. 5 (1898).

Taxodium occidentale Newberry: Knowlton, *United States Geological Survey, Bulletin* 152: 226 (1898a).

Taxodium occidentale Newberry: Penhallow, *Geological Survey of Canada, Annual Report for 1904*, New Series 16: 390–391A (1906).

Taxodium occidentale Newberry: Penhallow, *Report on Tertiary Plants of British Columbia*, p. 91 (1908).

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Taxodium occidentale Newberry: Hollick, *United States Geological Survey, Professional Paper* 182: 50, pl. 16, fig. 3; pl. 109, figs. 9–10 (1936).

Taxodium occidentale Newberry:Wickenden, *Geological Survey of Canada, Memoir* 239: 51 (1963).

***Taxodium tinajorum* Heer**: Heer, *Flora Fossilis Arctica* 2: 22, pl. 1, figs. 1–5 (1869).

Taxodium tinajorum Heer: Heer, *Flora Fossilis Arctica* 4: 57, pl. 25, fig. 14 (1876).

Taxodium tinajorum Heer: Heer, *Mémoires de l'Académie Impériale des Sciences de St. Pétersbourg* 25: 33, pl. 8, figs. 30a, 38 (1878b).

Taxodium tinajorum Heer: Lesquereux, *10th Annual Report of the United States Geological and Geographical Survey*, p. 498 (1878a).

Taxodium tinajorum Heer: Lesquereux, *Proceedings of the United States National Museum* 11: 34 (1889).

Taxodium tinajorum Heer: Knowlton, *Geological Society of America, Bulletin* 5: 578 (1893a).

Taxodium tinajorum Heer: Knowlton, *Proceedings of the United States National Museum* 17: 214 (1894).

Taxodium tinajorum Heer: Knowlton, *United States Geological Survey, Annual Report* 17: 878 (1896).

Taxodium tinajorum Heer: Knowlton, *United States Geological Survey, Bulletin* 152: 226 (1898a).

Taxodium tinajorum Heer: Knowlton, *Harriman Alaska Expedition* 4: 152 (1904).

Taxodium tinajorum Heer: Hollick, *United States Geological Survey, Professional Paper* 182: 50–51, pl. 10, fig. 4; pl. 13, figs. 2–3, 5–6; pl. 18, fig. 5b (1936).

***Taxodium* sp., Dawson**, *Proceedings and Transactions of the Royal Society of Canada* 11: 56, pl. 6, fig. 10 (1893).

***Taxodium* sp., Dawson**: Knowlton, *United States Geological Survey, Bulletin* 152: 226 (1898a).

***Taxodium*? sp., Endo**, *Journal of Geography, Tokyo* 38: 636 (1926).

***Taxodium* sp., Ichimura**, *Korean Coal-Field Research Report* 1: 10 (1927).

***Taxodium* sp. *indet*., Schloemer-Jäger**, *Palaeontographica, Abteilung B, Pälaophytologie* 104: 61–62, pl. 9, fig. 3; text-figs. 12 (1958).

***Taxodium* (?), Gardner**, *A Monograph of British Eocene Floras*, pl. 27, fig. 3 (1886).

***Taxodium* sp. (*T. cfr. tinajorum* Heer) Endo**, *Journal of the Geological Society of Japan* 45: 89 (1938a).

***Taxus* sp. Mason**, *Carnegie Institute of Washington, Publication* 346: 146, pl. 1, fig. 4 (1927).

***Taxus* sp. Chaney**, *Carnegie Institute of Washington, Publication* 346: 102 (1927).

Torreya densifolia Dawson, *Proceedings and Transactions of the Royal Society of Canada* 1: 25, pl. 5, figs 20, 20a (1882).

***Tumion densifolium* (Dawson) Knowlton**: Knowlton, *United States Geological Survey, Bulletin* 152: 234 (1898a).

***Tumion*? *suspectum* Hollick (*nomen nudum*)**: Hollick, *United States Geological Survey, Professional Paper* 159: 55, pl. 19, figs. 4–6a; pl. 29, fig. 1b (1930).

11. APPENDIX B

Included here are references to sources of published data on the fossil record of *Metasequoia* that extend from Late Cretaceous to Pleistocene time. Although the authors have sought to provide a list as complete as possible, we are aware that there are gaps. Because of the problems associated with reliably identifying fossil *Metasequoia* wood and pollen, references dealing with these types of remains were omitted. No attempts were made to determine the accuracy of the taxonomic and nomenclatural information of all of the fossil species. However, the authors would like to point out that the number of *Metasequoia* specimens residing in collections that have not yet been identified or described is likely to be considerable. Inclusion of these specimens would be of considerable benefit, but this exercise is far outside of the scope of this paper. With few exceptions (i.e., those that the authors have visited personally) or unless indicated in the literature, most of the latitudes and longitudes should be considered approximate and represent the current position of the deposits, rather than their paleo-positions. Unknown geologic formations are listed as "undefined".

11.1. Russia and Former Countries of the USSR

1. Arkagala Coal Basin, upper Kolyma River (ca. 68°N, 153–154°E), Arkagala Formation, Cenomanian (Samylina, 1962; Lebedev, 1976).
2. Arkagala River (63°08'N, 147°01'E), Arkagala and Dolgin Formations, Cenomanian (Samylina, 1988).
3. Okhotsk-Chukotka Volcanigenic Belt, Ul'inskiy Trough near Amka (59°02'N, 140°42'E), Amkinian flora (Uyenminian, Ust'Amkinian and Gyrbykanian assemblages), Amkinskaya Formation, Cenomanian (Baikovskaya, 1956; Lebedev, 1979, 1982, 1987).
4. Vilyuya, Linde, Tyung, Chibida and Tangnaryi Rivers, near Vilyuysk (63°40'N, 121°00'E), Lower Agraphenian floristic complex, Late Cenomanian/Turonian and Lower Chirimyian-Upper Chirimyian, Early to Late Senonian (Sveshnikova, 1967).
5. New Siberia Island (74°50'N, 139°40'E), undefined, Turonian (Baikovskaya, 1956).
6. Zhubankari Mountain near Lake Zaisan (48°05'N, 84°10'E), undefined, Senonian (Shilin & Romanova, 1978).
7. Ulen-Kalkan (ca. 43°51'N, 77°14'E), Iliysk Depression, Ili River Basin, undefined, Maastrichtian (Makulbekov, 1974).
8. Amaan Lagoon, Ilnaivaam and Emima Rivers (62°35'N 179°26'E), Kamchatka Peninsula, Koryak Formation, Late Maastrichtian (Budantsev,

1983; Golovneva & Herman, 1992, 1998; Golovneva 1994a, 1994b; Herman, 1993; Herman & Spicer, 1995, 1997).

9. Eloguy (Yeloguy) River (62°55'N 87°18'E), Krasnoyarsk Province, lower part of the Pokurskoi Formation, Late Cretaceous (Lebedev, 1962).
10. Near Bogopoli (44°16'N, 135°25'E), Sikhote Alin, Taxobinskoi and Bogopoliskoi Formations, Maastrichtian-early Paleocene (Ablaev, 1974).
11. Anadyr, Lamutskaya, Gornaya, Umku-veem and Euchuvytkin Rivers (64°45'N, 175°45'E), Ovrashnii, Bokovoi, Talii, Svetlii and Medveshii Streams, Rarytkin Range, Rarytkin and Koryak Formations, Maastrichtian-Paleocene (Baikovskaya, 1956; Kryshtofovich, 1958b; Golovneva, 1994a, 1994b).
12. Ichvigu-veem River (ca. 64°58'N, 173°59'E), Pekulney Range, Rarytkin Formation, Maastrichtian-Paleocene (Kryshtofovich, 1958a; Golovneva, 1994a, 1994b).
13. Takhobe River (ca. 45°31'N, 137°12'E), Primorye, undefined, Maastrichtian-Paleocene (Baikovskaya, 1956).
14. Lower Amur (ca. 50°56'N, 138°10'E), Primorye, undefined, Maastrichtian-Paleocene (Baikovskaya, 1956).
15. Bureinskaya Tsagayan (49°49'N, 129°50'E), Arkhara (49°28'N, 130°02'E), Raichikha (49°47'N, 129°27'E) and Darmakan River (ca. 49°47'N, 129°21'E), Zee-Bureinskaya Plain, Tsagayan Formation, Maastrichtian-Paleocene (Dorofeev 1951; Sveshnikova 1952, 1963, 1975b; Baikovskaya, 1956; Zamer *et al*. 1963).
16. Snatol River (57°34'N, 157°11'E), western Kamchatka, Napanskya Formation, late Paleocene (Baikovskaya, 1956; Maslova, 2000).
17. Kovachina River (ca. 57°40'N, 158°00'E), Kamchatka Peninsula, undefined, Maastrichtian-Paleocene (Baikovskaya, 1956).
18. Barkinskie clay (53°45'N, 87°12'E), Kuznets Basin, undefined, Maastrichtian-Paleocene (Baikovskaya, 1956).
19. Boguchan River, Amur Valley (49°49'N, 129°50'E), Tsagayan flora, undefined, Paleocene (Kryshtofovich, 1962; Nalivkin, 1973; Krasilov, 1976).
20. Puer Ridge near Malomikhailovka Village (ca. 52°34'N, 140°22'E) on the Amur River, Malomikhailovka Formation, Paleocene (Akhmetiev, 1993; Akhmetiev & Golovneva, 1997).
21. Penjin Bay (63°31'N, 168°00'E), undefined, Eocene (Kryshtofovich, 1958b).
22. Podbazovyi Creek, a tributary of the Taljain River (64°20'N, 175°05'E), Pravotaljainskaya Formation, late Eocene (Akhmetiev & Samsonenko, 1997).

23. Belogolobaya and Duktylikich Rivers south of Ust-Khairyuzovo (57°11'N, 156°45'E), western Kamchatka, Irgirninskaya Formation, late Eocene (Budantsev, 1997).
24. Napana River between Tigil and Sedanka (57°44'N, 158°50'E), western Kamchatka, Russia, Kovachinskaya Formation, late Eocene (Baikovskaya, 1956; Budantsev, 1983, 1997).
25. Irgirnivayam River near Podkagernoye (60°20'N, 161°58'E), western Kamchatka, Russia, Irgirninskaya Formation, late Eocene (Budanstev, 1997).
26. Mainachskii and Tochilinskaya sections near Tigil (58°00'N, 158°10'E), western Kamchatka, Snatol Formation, early Oligocene (Gladenkov *et al.*, 1991).
27. Byeloyarka Village (ca. 57°42'N, 66°08'E), Tavda River, Sverdlovsk region, Nomomikhailovskaya Formation, early Oligocene (Gorbunov, 1962; Dorofeev, 1963a; Sveshnikova, 1963; V.P. Nikitin, personal communication, 2002).
28. Yugan River (ca. 60°40'N, 72°12'E), undefined, ? early Oligocene (Sveshnikova, 1963).
29. Antropovo and Nizhnyaya Pristan Villages (ca. 58°04'N, 65°12'E), Tavda River, Tyumen region, Nomomikhailovskaya Formation, early Oligocene (Dorofeev, 1961, 1963a; Gorbunov, 1962; Zamer *et al.*, 1963; Sveshnikova, 1963; V.P. Nikitin, personal communication, 2002).
30. Tshche-Bas (46°17'N, 59°34'E), Kutanbulak (47°06'N, 61°06'E) and Kenkous (47°09'N, 57°50'E), western Priaralye, Kutanbulakskaya Formation, late Oligocene (Budantsev, 1959; Zhilin, 1974).
31. Kara Chokat near Togyz (47°32'N, 60°32'E), Tashkent Province, Chiliktinskaya Formation, late Oligocene (Uznadze, 1957; Zhilin, 1974).
32. Kumsuat (45°55'N, 58°32'E), western Priaralye, Kutanbulakskaya Formation, late Oligocene (Zhilin, 1974)
33. Lake Khanka (45°00'N, 132°30'E), undefined, Oligocene (Kryshtofovich, 1956).
34. Kuchugui-Kyugelyur River near Khayyr (70°49'N, 133°30'E), Omoloi River Basin, undefined, Oligocene (Dorofeev, 1972).
35. Mt. Ashutas, Lake Zaysan (48°10'N, 84°40'E), undefined, late Oligocene (Kryshtofovich, 1956).
36. Shestakov Log on the left bank of the Bolshaya Kirgizka River 11 km south of Tomsk (56°30'N, 85°05'E), Kasparanskaya Formation, late Oligocene (Gorbunov & Shilkina, 1972).
37. Alexandrovsky and Novy Log (59°10'N, 57°32"E), Visim District, Polevskoi River, Sverdlovsk region, undefined, late Oligocene (Sveshnikova, 1963; Dorofeev, 1970).

38. Section in the southern part of Kvachina Bay near Tigil (58°00'N, 158°10'E), western Kamchatka, Kovachin Formation, late Oligocene (Gladenkov *et al*., 1991).
39. Section in valley on the Lataevoi River near Ust-Khairyuzovo (57°11'N, 156°45'E), Kamchatka, Kovachin Formation, late Oligocene (Gladenkov *et al*., 1991).
40. Altyn-Shokysu Tableland, near Aral'sk, Kzyl-Orda District (47°50'N, 60°80'E), Chiliktinskaya Formation, late Oligocene and Aralskaya Formation, early Miocene (Aquitanian) (Zhilin, 1989; Andreyev, 1991).
41. Bukhtarmi River between Rubtsovsk and Aleysk (51°34'N, 81°11'E and 52°32'N, 82°17'E), southern Altai, undefined, late Oligocene-early Miocene (Schmalhausen, 1887; Kornilova, 1966; Rayushkina, 1968, 1979).
42. Kireyev Village (ca. 56°39'N, 84°11'E), Ob River, Tomsk region, undefined, late Oligocene-early Miocene (Dorofeev, 1960, 1963a).
43. Korf Bay (60°18'N, 165°52'E), eastern Kamchatka, Lower Medvezhkinskaya Formation, early Miocene (Chelebaeva, 1971, 1978).
44. Kiniyak (45°29'N, 58°30'E), Mynsualmas (46°06'N, 56°02'E) and Kintykche (45°42'N, 58°31'E), western Priaralye, early Miocene (Zhilin, 1974).
45. Gusinaya River near Penzhino (63°31'N, 168°00'E), Kamchatka, Gusinskoi Formation, Miocene (Ablaev, 1985).
46. Basal layer of the argillaceous tuff, Khasanskaya Hollow near Kraskino (42°42'N, 130°48'E), Primorye, Khasanskaya Formation, early Miocene (Ablaev *et al*., 1993; Ablaev, 1978; Pimenov, 1990).
47. Right bank of the Dulygaly-Zhilanchik River 4 km north of the Bolattam burial ground (ca. 48°52'N, 65°30'E), Ulutau Region, Karaganda Oblast, undefined, early Miocene (Aquitanian) (Dorofeev, 1963b; Zhilin, 1989).
48. Divide of the Pravaya Granatnaya and Shcherbatovka Rivers near Amgu (45°48'N, 137°36'E), Amgu River Basin, Granatovaya Formation, early to middle Miocene (Klimova, 1981).
49. Southern part of Pavlov section, Primorye, Pavlov Formation, early Miocene (Pimenov, 1990).
50. Prikhankaiskii coal horizon and Chernyshevskaya hollow, Primorye, early and middle Miocene (Pimenov, 1990).
51. Western shore of Lake Khanka (ca. 45°00'N, 132°10'E), Primorye, *Fagus chankaica* layer, undefined, middle Miocene (Pimenov, 1990).
52. Khanka Lake, Primorye (45°00'N, 132°10'E), Khankaiski layer, Botchinskaya Formation, late Miocene (Kryshtofovich, 1946; Baikovskaya, 1974; Ablaev *et al*., 1994).
53. Mammoth Mountain (63°02'N, 133°17'E), Aldan River, undefined, middle to late Miocene (Dorofeev, 1969).

54. Botchi River near Grossevichi (47°59'N, 139°26'E), Sikhote-Alin, Botchi Formation, late Miocene (Akhmetiev, 1973).
55. Rettikhovka Village (44°10'N, 132°44'E), Primorye, undefined, Miocene (Klimova, 1975; Ablaev, 1978).
56. Zaobsky Yar (56°15'N, 83°57'E), Ob River, undefined, early Pliocene (Gorbunov, 1957, 1962; Zamer *et al*., 1963).
57. Guria (41°55'N, 42°02'E), Georgia, undefined, Pliocene (Chochieva, 1975).

11.2. Greenland

1. Atanikerdluk (70°04'N, 52°20'W) and Naujât (70°04'N, 52°09'W), Nûgssuaq Peninsula, Upper Atanikerdluk Formation, Quikavsak (Heer's "Upper Atanikerdluk A" flora) and Naujât (Heer's "Upper Atanikerdluk B" flora) members, early Paleocene (Heer, 1868, 1870b, 1874, 1883a, 1883b; Koch, 1959, 1963, 1964; Schwarz & Weide, 1962).
2. Agssakak (70°33'N, 51°52'W; syn: Asakak), Nûgssuaq Peninsula, undetermined Tertiary [probably Upper Atanikerdluk Formation, Quikavsak member (Heer's "Upper Atanikerdluk A" flora), early Paleocene] (Heer, 1874, 1883a, 1883b; Koch, 1963).
3. Qagdlunguaq (70°06'N, 52°25'W; syn: Kardlunguak) NW of Nunguaq, Nûgssuaq Peninsula, Upper Atanikerdluk Formation, Naujât (Heer's "Upper Atanikerdluk B" flora) member, early Paleocene (Heer, 1883a, 1883b; Koch, 1955; Koch & Pedersen, 1960).
4. Pautût (70°15'N, 52°44'W), Nûgssuaq Peninsula, Upper Atanikerdluk Formation, Quikavsak member (Heer's "Upper Atanikerdluk A" flora), early Paleocene (Heer, 1883a; Koch 1959, 1963, 1964).
5. Tupaussat (70°19'N, 53°06'W), Nûgssuaq Peninsula, Upper Atanikerdluk Formation, Quikavsak member (Heer's "Upper Atanikerdluk A" flora), early Paleocene (Koch 1959, 1963, 1964).
6. Agatkløft (70°35'N, 53°07'W), Nûgssuaq Peninsula, Agatdal Formation, Sonja member, early Paleocene (Koch, 1959, 1963, 1964).
7. Qaersutjaegerdal (70°36'N, 53°05'W), Nûgssuaq Peninsula, Agatdal Formation, early Paleocene (Koch, 1959, 1963, 1964).
8. Kangersôk (70°32.5'N, 53°07'W), Nûgssuaq Peninsula, Agatdal Formation, early Paleocene (Koch, 1963, 1964).
9. Sinifik and Puilasok (69°18'N, 53°05'W), Isunguak (69°45'N, 51°55'W), Igdlokungak (69°52'N, 52°21'W) and Ritenbenks Kohlengrube (70°00'N, 53°00'W), Disco Island, Upper Atanikerdluk Formation, Quikavsak member (Heer's "Upper Atanikerdluk A" flora), early Paleocene (Heer, 1868, 1874, 1883a, 1883b; Koch, 1963).

10. Ingnerit (72°02'N, 55°10'W), Ingnerits Peninsula, undetermined Tertiary, probably Paleocene (Heer, 1883b).
11. Kangiusak (71°44'N, 53°40'W), Svartenbuk Peninsula, undetermined Tertiary, probably Paleocene (Heer, 1883a, 1883b).
12. Prinsesse Thyra Ø (82°00'N, 20°30'W) and Prinsesse Dagmar Ø (81°45'N, 19°00'W), Thyra Ø Formation, late Paleocene-early Eocene (Boyd, 1990).
13. Coal Corner (Christian IV Glacier) near Kangerdlugssuak (78°50'N, 30°50'W), undefined, late Paleocene-early Eocene (Seward & Edwards, 1941; Boulter & Kvaček, 1989).
14. Ivssorrigsok (70°40'N, 54°10'W; syn: Ifsorisok, Qissugssarigsup Qôrua and Kulelv), Nûgssuaq Peninsula, Ifsorisok Formation, late Eocene (Heer, 1874, 1883a, 1883b; Koch, 1959, 1964).
15. Qernertuarssuit (70°48'N, 54°05'W), Nûgssuaq Peninsula, Intrabasaltic, late Eocene (Koch, 1963, 1964).
16. Hareø Island (70°25'N, 54°55'W;syn: Qeqertarssuatsiaq), Intrabasaltic, late Eocene (Heer, 1883a, 1883b; Koch, 1963, 1964).
17. Kugssininguaq (70°35'N, 54°28'W; syn: Kugsinet and Netluarsuk), Nûgssuaq Peninsula, Ifsorisok Formation, late Eocene (Heer, 1874, 1883b; Koch, 1964).

11.3. Spitsbergen/Faroe Island

1. Southwest Ny-Ålesund, Brögger Peninsula (78°55'N, 12°00'W), Spitsbergen, Firkanten Formation, Josephine Coal seam, early Paleocene (Schloemer-Jäger, 1958; Flood *et al.*, 1971; Schweitzer, 1974, Sveshnikova, 1975b; Harland *et al.,*1976).
2. Festningsodden (78°02'N, 14°10'W; syn: Cape Staratschin), Spitsbergen, Firkanten Formation, early Paleocene (Heer, 1870a; Kvacek *et al.*, 1994; Kvaček & Manum, 1997).
3. Kohlenberg (77°47'N, 15°14'W), Bell Sound, Spitsbergen, probably Firkanten Formation, early Paleocene (Heer, 1868; Kvacek *et al.*, 1994).
4. Near Bunessan (56°19'N 6°14'W), Aredtun Peninsula, Isle of Mull, Scotland, Intrabasaltic "leaf beds", late Paleocene (Gardner, 1886; Crane *et al.*, 1988; Boulter & Kvaček, 1989).
5. Mikines (62°07'N, 7°38'W), Faroe Island, undefined, late Paleocene (Rasmussen & Koch, 1963; Boulter & Kvaček, 1989).
6. Nordenskiöldfjellet (Nordenskiölds Berg) and Lars Hiertafjellet (Lars Hjertas Berg) (78°05'N, 15°36'W), Spitsbergen, Aspelintoppen Formation, early Eocene (Kvaček *et al.*, 1994; Kvaček & Manum, 1997).

7. Renardodden (Cape Lyell) and Scottbreen (Scott Gletcher) (77°30'N, 14°30'W), Spitsbergen, Renardodden Formation, late Eocene (Heer, 1876; Schwarz & Weide, 1962; Kvaček *et al*., 1994).
8. Kaffioyia and Sarsoyra, Forlandsundet Basin (78°40'N, 12°30'W), Spitsbergen, Forlandsundet Formation, late Eocene (Zastawnisk, 1981; Kvaček *et al*., 1994).

11.4. Arctic Canada

1. Mackenzie River 20 miles above Bear Creek (GSC Loc. 4092 [=1552]) and Near Fort Norman (64°55'N, 125°29'W), Northwest Territory, Brackett Coal Basin, Summit Creek Formation, Paleocene (Heer, 1868, 1880b; Dawson, 1889; Berry 1926a; Bell, 1949; Sweet *et al*., 1989).
2. Strathcona Fiord (78°38 to 78°40'N, 81°55 to 81°59'W), Ellesmere Island, upper Expedition Formation, early to middle Paleocene and Strand Bay, middle Paleocene (McIver & Basinger, 1999).
3. Fosheim Anticline West (79°34'N, 84°02'W), Ellesmere Island, upper Expedition Formation, early to middle Paleocene (McIver & Basinger, 1999).
4. Fosheim Anticline West (79°43'N, 84°45'W), Ellesmere Island, Lower member, Iceberg Bay Formation, late Paleocene (McIver & Basinger, 1999).
5. Lake Hazen (81°54'N, 69°40'W), Ellesmere Island, Coal member, Iceberg Bay Formation, early Eocene (McIver & Basinger, 1999).
6. Strand Fiord (US163—79°16'N, 91°26'W; US164—79°14'N, 91°26'W; US165–167, US172, US 175–177—79°15'N, 91°16'W; US168–170, 174—79°15'N, 91°10'W; and US178–180—79°14'N, 91°16'W), Axel Heiberg Island, lower member, Iceberg Bay Formation, late Paleocene (McIver & Basinger, 1999).
7. Oxhead Creek (79°43'N, 85°05'W), Mosquito Creek (79°57'N, 84°43'W), Hot Weather Creek (79°56'N, 84°45'W) and Fosheim Peninsula (79°45'N, 85°01'W), Ellesmere Island, Iceberg Bay Formation, late Paleocene-early Eocene (McIver & Basinger, 1999).
8. Stenkul Fiord (77°22'N, 83°28'W), Ellesmere Island, Nunavut, Iceberg Bay Formation, Eureka Sound Group, late Paleocene-early Eocene (Nathorst, 1915; Sveshnikova, 1975a; LePage, unpublished).
9. Strathcona Fiord (78°40'N, 82°40'W), Ellesmere Island, Nunavut, Iceberg Bay Formation, Eureka Sound Group, late Paleocene-early Eocene (LePage, unpublished).
10. Numerous localities throughout the Fosheim Peninsula (ca. 79°40'N, 84°18'W), Ellesmere Island, Nunavut, Iceberg Bay Formation, Eureka Sound Group, late Paleocene-early Eocene (LePage, unpublished).

11. Fort Conger (81°45'N, 64°45'W), Ellesmere Island, Nunavut, probably Iceberg Bay Formation, Eureka Sound Group, late Paleocene-early Eocene (Heer, 1878a).
12. Strathcona Fiord (78°38'N, 82°52.5'W), Stenkul Fiord (77°52'N, 81°38'W) and Split Lake (77°53.2'N, 83°36'W), Ellesmere Island, Margaret Formation, early to middle Eocene (McIver & Basinger, 1999).
13. Napartulik (79°55'N, 89°02'W), Axel Heiberg Island, Nunavut, Buchanan Lake Formation, Eureka Sound Group, middle Eocene (Basinger, 1991).
14. Duck Hawk Bluffs (71°57'N, 125°40'W), Banks Island, Mary Sachs gravels (=Beaufort Formation), middle Miocene (Hills, 1975; Matthews & Ovenden, 1990; Matthews *et al*., 1986; Matthews, 1987).
15. West River near Horton River (69°12'N, 127°02'W), Northwest Territory, Plateau Cap gravels, middle Miocene (Matthews & Ovenden, 1990).
16. Ballast Brook beds at Ballast Brook (74°19'N, 123°25'W), Banks Island, Canada, unnamed Beaufort Formation equivalent, late Miocene (Heer, 1868; Matthews & Ovenden, 1990; Matthews *et al*., 1986; Matthews, 1987).
17. Numerous localities on Prince Patrick Island (76–77°N, 116–123°W), Beaufort Formation, early late Pliocene (Matthews & Ovenden, 1990; Matthews *et al*., 1990).

11.5. Sakhalin

1. Mgachi and Cape Dui (51°03'N, 142°20'E) and Boshnyakovo (49°35'N, 142°12'E), Savayama Formation, early Campanian (Heer, 1878c, 1878d; Kryshtofovich, 1921a; Vakhrameev, 1988).
2. Avgustovka River near Boshnyakovo (49°35'N, 142°12'E), Boshnyakovskaya and Conglomeratovaya Formations, Paleocene (Ablaev, 1978; Krasilov, 1973, 1979).
3. Kamennaya River near Dui (51°03'N, 142°20'E), Conglomeratovaya Formation, Paleocene (Krasilov, 1973; Ablaev, 1978).
4. Kawakami coal mines (=Sinegorsk coal-mine; 47°13' N; 142°31'E), Anivskiy Region, Naibuchi coal bearing Formation of the Naibuchi Series (=Naibuchinskaya Svita), Eocene (Endo, 1928; Kodrul, 1999).
5. Pilyvo (ca. 50°24'N, 142°14'E) and Borodyazheskaya River (50°35'N, 142°09'E), Conglomerate and Lower Dui Formations, late Eocene-early Oligocene (Borsuk, 1956).

6. Schmidt section (ca. 54°14'N, 142°16'E), Machigarskaya Formation, late Oligocene (Fotyanova, 1988).
7. Khoindzho Promontory near Dui (51°03'N, 142°20'E), Khoindzho Formation, late Oligocene (Fotyanova, 1988).
8. Onnai River near Lesogorsk (49°24'N, 142°10'E), Arakaiskaya Formation, late Oligocene and Kholmsko-Nevefiskaya Formation, early Miocene (Fotyanova, 1988).
9. Shakhtersk Mountain near Shakhtersk (49°11'N, 142°11'E), Naibutinskaya Formation, early Eocene and Shakhterskaya and Verkhneduiskaya Formations, early Miocene (Ablaev, 1978; Fotyanova, 1988).
10. Nadezhdinka River near Lesogorsk (49°24'N, 142°10'E), Shakhterskaya and Verkhneduiskaya Formations, early Miocene (Fotyanova, 1988).
11. Vakhrushev (48°57'N, 142°58'E), Verkhneduiskaya Formation, early Miocene (Pimenov, 1984, 1990; Fotyanova 1988).
12. Korallovka and Gar Rivers near Makarov (48°39'N, 142°45'E), Verkhneduiskaya Formation, early Miocene (Fotyanova, 1988).
13. Novikovo (46°26'N, 143°19'E), Verkhneduiskaya Formation, early Miocene (Fotyanova, 1988).

11.6. China

1. Hunchun, (ca, 43°08'N, 130°04'E) Jilin Province, Hunchun Formation, Senonian (Guo & Li, 1979).
2. Wuyun (49°11'N, 129°08'E), Heilongjinang Province, Wuyun Formation, Wuyun Group, Maastrichtian/Danian (Tao & Xiong, 1986a, 1986b; Liu *et al*., 1999).
3. Tangyuan (46°30'N, 130°08'E), Heilongjinang Province, Wuyun Formation, Wuyun Group, Maastrichtian/Danian (Zhang *et al*., 1990).
4. Jiayin (48°40'N, 130°28'E), Heilongjinang Province, Wuyun Formation, Wuyun Group, Paleocene (Lu *et al.,*1983 Xiong, 1986).
5. Yilan coal mine (46°10'N, 129°15'E), Yilan County, Heilongjiang, undefined, early Eocene and early Oligocene (He & Tao, 1994).
6. Fushun coalfield (ca. 41°51'N, 123°53'E) near Shen-yang, Liaoning Province undefined, late Eocene (Endo, 1926, 1928, 1931, 1933b, 1936, 1942; Hu, 1946; Academic Sinica, 1978).
7. Shenbei coalfield (ca. 41°30'N, 123°33'E), Liaoning, Yangliantun Formation, Oligocene (Jin & Shang, 1998).
8. Gaosongshu and Qiuligou Villages (ca. 43°35'N, 128°23'E), Dunhua County, Jilin Province, Tumenzi Formation, early Miocene (Li & Yang, 1984).

9. Taiyang Coal Mining Company 20 km southeast of Taipei (25°05'N, 121°32'E), Shihti Formation, middle Miocene (Canright, 1972).

11.7. Alaska

1. North shore of the Yukon River ca. 12 miles below Melozi telegraph station (ca. 64°44'N, 156°08'W), undivided marine and non-marine sandstones, shales and conglomerate deltaic deposits, Cenomanian/?Turonian (Hollick, 1930; Patton & Moll-Stalcup, 2000).
2. West shore of the Yukon River ca. 17 miles below Nulato (ca. 64°31'N, 158°27'W), undivided marine and non-marine sandstones, shales and conglomerate deltaic deposits, Cenomanian/?Turonian (Hollick, 1930; Patton & Moll-Stalcup, 2000).
3. Coal Creek (syn: Port Moller and Pointe Divide; ca. 55°53'N, 160°47'W), Herendeen Bay, Alaska Peninsula, Chignik Formation, Late Campanian-Early Maastrichtian (Knowlton, 1896; Hollick, 1930, 1936; Detterman *et al*., 1996).
4. Chignik Bay, Alaska Peninsula (syn: Anchorage Bay; ca. 56°18'N, 158°27'W; USGS Locs. 3519, 3522, 3523), Tolstoi Formation, late Paleocene-early Eocene (Knowlton, 1896; Hollick, 1930, 1936; Wolfe *et al*., 1966; Detterman *et al*., 1996).
5. Chignik River below Long Bay (ca. 56°16'N, 158°42'W), Alaska Peninsula, Chignik Formation, Late Campanian-Early Maastrichtian (However, depending upon the exact location, the deposits could also be assigned to the late Paleocene-early Eocene Tolstoi Formation; Hollick, 1930, 1936; Detterman *et al*., 1996).
6. Sagavanirktok River at Sagwon (69°22.5'N, 148°42'W), Sagavanirktok Formation, Paleocene (Spicer *et al*., 1994).
7. Numerous localities between 61°38.3'–61°48'N, 147°59.5'–149°05'W (USGS Locs. 5892, 9870–9874, 9877, 9881), Chickaloon Formation, late Paleocene-early Eocene (Martin & Katz, 1912; Hollick, 1936; Wolfe, 1966; Wolfe *et al*., 1966; Triplehorn *et al.,*1984).
8. Pavlof Bay south of Settlement Point (55°29'N, 161'29'W), Alaska Peninsula, Tolstoi Formation, late Paleocene-early Eocene (Hollick, 1930; Detterman *et al*., 1996).
9. Ivanof Bay (55°50'N, 159°27'W; USGS Locs. 11411, 11412, 11416), Alaska Peninsula, Tolstoi Formation, late Paleocene-early Eocene (Detterman *et al*., 1996).
10. Cape Douglas (58°51'N, 153°18'W; USGS Loc. 9761), Copper Lake Formation, early Eocene (Knowlton, 1896; Hollick, 1936; Wolfe *et al*., 1966; Detterman *et al*., 1996).

11. Cape Nukshak (syn: Kukak Bay; ca. 58°19'N, 154°01'W), Alaska Peninsula, Hemlock Conglomerate, early Oligocene (Knowlton, 1904; Hollick, 1936; Detterman *et al*., 1996).
12. Port Camden Bay (56°39'N, 134°02'W), Kuiu Island, Kootznahoo Formation, Angoonian stage, late Oligocene (Heer, 1869; Knowlton, 1896; Hollick, 1936).
13. Head of Hamilton Bay (ca. 56°43.5'N, 133°38'W), Kupreanof Island (USGS Locs. 3652, 4389, 4391, 4392, 7474 and 7565), Kootznahoo Formation, Angoonian stage, late Oligocene (Hollick, 1936; Wolfe *et al*., 1966; Muffler, 1966).
14. Little Pybus Bay (syn: Murder Cove; 57°15'N, 134°10'W), Admiralty Island, ? Kootznahoo Formation, Angoonian stage, late Oligocene (Loney, 1964; Lathram *et al*., 1965).
15. Sepphagen mine and De Groff tunnel (ca. 57°35'N, 134°19'W), Kootznahoo Inlet, Admiralty Island, Kootznahoo Formation, Angoonian stage, late Oligocene (Knowlton, 1896; Newberry, 1898; Hollick, 1936).
16. Marvine Glacier, Malaspina District (60°08.8'N, 140°08.25'W; USGS Loc. 11185), Poul Creek Formation, Angoonian stage, late Oligocene (Wolfe, 1977).
17. North shore of Long Island (ca. 57°30'N, 134°20'W; USGS Locs. 9822–9825, 9827), Kootznahoo Inlet, Admiralty Island, Kootznahoo Formation, Angoonian stage, late Oligocene (Wolfe, 1977).
18. Southwest shore of Zarembo Island (56°19'N, 133°14'W), Kootznahoo Formation, Angoonian stage, late Oligocene (Hollick, 1936; Karl *et al*., 1999).
19. Chicken Creek (64°10'N, 141°58'W; USGS Loc. 10031), ? Kenai Formation, Seldovian stage, early to middle Miocene (Foster, 1969).
20. California Creek (ca. 65°24'N, 150°08'W), probably Usibelli Group, Sanctuary Formation, upper Seldovian stage, middle Miocene (Hollick, 1936; Leopold & Liu, 1994).
21. Mission Creek, (65°11'26"N, 151°57'35"W), probably Usibelli Group, Sanctuary Formation, upper Seldovian stage, middle Miocene (Knowlton, 1898b; Leopold & Liu, 1994).
22. Ninilchik (60°03'N, 151°40'W), Kenai Formation, Clamgulchian stage, early Pliocene (Heer, 1869; Newberry, 1883; Knowlton, 1896; Hollick, 1936; Wolfe, 1966).
23. Chuitna River (61°06'N, 151°09'E; USGS Loc. 9844), Kenai Formation, Homerian stage, early to middle Miocene (Wolfe, 1966).
24. North side of Haenke Glacier (60°6.1'N, 139°11.5'W; USGS Loc. 11183), Yakataga Formation, early middle Miocene (Wolfe, 1977).
25. West side of Tsadaka Canyon (61°42.1'N, 149°05.6'W; USGS Loc. 9359), Kenai Formation, lower Seldovian stage, early to middle Miocene (Wolfe *et al*., 1966).

26. Little Susitna River (61°41'N, 149°08'W; USGS Loc. 8380), north bank (61°39.4'N, 149°27.8'W; USGS Loc. 9865) and west bank (61°41.7'N, 149°14.7'W; USGS Loc. 9866), Kenai Formation, lower Seldovian stage, early to middle Miocene (Wolfe *et al*., 1966).
27. Harriet Point (60°33'N, 153°18'W, USGS Locs. 9984 and 9885 and 60°25'N, 152°19'W, USGS Locs. 9886 and 9945) and Redoubt Point (60°18'N, 152°25'W; USGS Locs. 9887 and 9760), Kenai Formation, lower Seldovian stage, early to middle Miocene (Wolfe *et al*., 1966).
28. North side of the entrance to Chinitna Bay (59°53'N, 152°49'W; USGS Loc. 3505), Kenai Formation, lower Seldovian stage, early to middle Miocene (Hollick, 1936; Wolfe *et al*., 1966).
29. 0.6 miles south of Point Pogibshi, Seldovia Point (59°25'N, 151°53.1'W; USGS Loc. 9857) and 0.7 miles east of Seldovia Point (59°28.3'N, 151°40.6'W; USGS Loc. 9858), Kenai Formation, upper Seldovian stage, early to middle Miocene (Wolfe *et al*., 1966; Wolfe & Tanai, 1980).
30. North side of Coal Cove at Port Graham (59°23.7'N, 151°53.7'W; USGS Loc. 9856), Kenai Formation, early to middle Miocene (Heer, 1869; Newberry, 1883; Hollick, 1936; Wolfe, 1966).
31. East bank of Coal Creek at Beluga Lake (61°25.6'N, 151°31.2'W; USGS Loc. 9850), Kenai Formation, upper Seldovian stage, early to middle Miocene (Wolfe *et al*., 1966).
32. South side of Capp's Glacier (61°18.9'N, 151°46.2'W; USGS Loc. 9845) and west side of high hill (61°16.7'N, 151°45.1'W; USGS Loc. 9846), Kenai Formation, upper Seldovian stage, early to middle Miocene (Wolfe *et al*., 1966).
33. 1.5 miles above Cache Creek Mining Company's Camp on Cache Creek (62°30'N, 150°57'W; USGS Loc. 6063), Kenai Formation, upper Seldovian stage, early to middle Miocene (Wolfe *et al*., 1966).
34. South side of Cache Creek (62°29.9'N, 150°56.9'W; USGS Loc. 9868), Kenai Formation, Homerian stage, late Miocene (Wolfe, 1966; Wolfe *et al*., 1966).
35. South bank of Chuitna River, Cook Inlet (61°07.1'N, 151°18.1'W; USGS Loc. 9844), Kenai Formation, Homerian stage, late Miocene (Wolfe *et al*., 1966).
36. Chuitna River 0.5 miles south of Old Tyonek, Cook Inlet (61°02'N, 151°17'W; USGS Loc. 4130), Kenai Formation, Homerian stage, late Miocene (Hollick, 1936; Wolfe, 1966; Wolfe *et al*., 1966).
37. 0.25 miles south of Mutnala Gulch (59°43.2'N, 151°49.4'W; USGS Loc. 9852), Kenai Formation, Homerian stage, late Miocene (Wolfe *et al*., 1966).
38. Entrance to Troublesome Gulch (59°46'N, 151°51'W; USGS Loc. 4129), Kenai Formation, Homerian stage, late Miocene (Hollick, 1936; Wolfe *et al*., 1966).

39. 0.25 miles northwest of Diamond Creek (59°40.3'N, 151°42.4'W; USGS Loc. 9366), Kenai Formation, Homerian stage, late Miocene (Wolfe *et al*., 1966).
40. 1 mile south of Miller's Landing (59°39.4'N, 151°26.3'W; USGS Loc. 9361), Kenai Formation, Homerian stage, late Miocene (Wolfe *et al*., 1966).
41. Entrance to Fritz Creek, Kachemak Bay (59°41'N, 151°22'E; USGS Loc. 4131), Kenai Formation, Homerian stage, late Miocene (Hollick, 1936; Wolfe *et al*., 1966).

11.8. Canada

1. Monkman Pass (54°33'N, 121°15'W; GSC Loc. 3218), British Columbia, Dunvegan Formation, Cenomanian (Bell, 1963).
2. Kistatinaw River (55°51'N, 120°15'W; GSC Loc. 3351), British Columbia, Dunvegan Formation, Cenomanian (Bell, 1963).
3. South Moberly Creek (56°00'N, 121°17'W; GSC Loc. 3618), British Columbia, Dunvegan Formation, Cenomanian (Bell, 1963).
4. East Pine River (55°43'N, 121°13'W; GSC Locs. 4193; 3783 [=3781], 4194, 4197), British Columbia, Dunvegan Formation, Cenomanian (Bell, 1963).
5. North bank of the Kakwa River (54°37'N, 118°27'W; GSC Loc. 5114) about 3 miles below Kapatatik Creek, Alberta, Dunvegan Formation, Cenomanian (Bell, 1963).
6. No. 8 mine dump, Cumberland Coal (1) Ltd. (GSC Loc. 3768), Cumberland (49°37'N, 124°59'W), British Columbia, Comox Formation, Nanaimo Group, Santonian (Bell, 1957, 1962).
7. Port McNeill (50°35'N, 127°06'W; GSC Loc. 3420), British Columbia, undefined Nanaimo Group, Early Campanian (Dawson, 1893; Bell, 1957, 1962).
8. White Rapids Mine (GSC Loc. 3771) and Jingle Pot Mine (GSC Loc. 4210), Nanaimo (49°08'N, 123°58'W), British Columbia, Extension Formation, Nanaimo Group, Early Campanian (Heer, 1865; Dawson, 1882, 1893; Newberry, 1863, 1898; Bell, 1957, 1962; Chaney, 1951).
9. Protection (49°11'N, 123°55'W; GSC Locs. 1580, 3858) and Round (GSC Loc. 3826) Islands, British Columbia, Protection Formation, Nanaimo Group, Late Campanian (Dawson, 1882; Clapp, 1914; Bell, 1957, 1962).
10. Cutbank Creek (53°20'N, 113°53'W; GSC Loc. 3671 [=3669]) 3 miles south of Theresa on the Nose Mountain Trail, Alberta, Wapiti Group, Late Cretaceous (Bell, 1949).

11. Lower reaches of Reynolds Creek along the Great Pacific Railway, near the Parsnip River (54°56'N, 122°39'W), British Columbia, Sustut Group, ? Sifton Formation, Late Cretaceous-early Paleocene (Rouse, 1967).
12. Ravenscrag Butte near Ravenscrag (49°30.4'N, 109°1.2'W), Saskatchewan, Ravenscrag Formation, Paleocene (McIver & Basinger, 1993).
13. Genesee (53°21'N, 114°24'W), Alberta, Scollard member, Paskapoo Formation, Paleocene (Chandrasekharam, 1974).
14. Alexo (52°27'N, 115°48'W; GSC Loc. 3428), Alberta, probably Scollard member, Paskapoo Formation, Paleocene (Bell, 1949).
15. Short Creek (GSC Loc. 1651), Souris River near Roche Percée (49°04'N, 102°48'W), Saskatchewan, Ravenscrag Formation, Paleocene (Dawson, 1881, 1887; Penhallow, 1903; Bell, 1949).
16. Willow Creek (50°10'N, 113°50'W; GSC Loc. 3700), Alberta, Willow Creek Formation, Ravenscrag Formation, Paleocene (Bell, 1949).
17. Lamoral (52°26'N, 115°30'W), Clearwater County, Alberta, Paskapoo Formation, Paleocene (Penhallow, 1903; Allan & Rutherford, 1926; Berry, 1926b).
18. Near Niven River and Thutade Lake (56°56'N, 126°55'W; GSC Locs. 3487, 3488, 3489), British Columbia, Sustut Group, Paleocene (Lord, 1948; Bell, 1949).
19. 2 miles north of François Lake (56°02'N, 125°38'W; GSC Locs. 4072, 3013, 1770), British Columbia, Sustut Group, Paleocene (Armstrong, 1949).
20. 1 mile north of the mouth of T-Allin Creek (56°02'N, 125°58'W; GSC Loc. 4084), British Columbia, Sustut Group, Paleocene (Armstrong, 1949).
21. Ed Bird and Estella Lakes (56°57'N, 125°05'W), British Columbia, Sustut Group, Sifton Formation, Paleocene (Roots, 1954).
22. 6.5 miles southeast of the mouth of the Rapid River (59°10'N, 128°55'W; GSC Loc. 4235), British Columbia, Rapid Formation, Paleocene (Gabrielse, 1963).
23. Fish and Pedley Creeks (53°26'N, 117°36'W), Alberta, Paskapoo Formation, Paleocene (Lang, 1947).
24. Southeast of Goodlands (49°01'N, 100°32'W), Manitoba, Turtle Mountain Formation, Paleocene (Wickenden, 1945).
25. Munce's Hill 3 km northeast of Canyon Ski Quarry and Gao Mine locality (roadcut on the north bank of Highway 593, 14 km east of Red Deer [52°15'N, 113°48'W]) near Red Deer, Alberta, Paskapoo Formation, Paleocene (late Tiffanian Ti_4) (Falder *et al.,*1999).
26. 12 miles east of Ponoka (52°42'N, 113°24'W) and 9 miles east of Red Deer (52°15'N, 113°41'W), Alberta, Paskapoo Formation, Paleocene (Allan & Rutherford, 1926; Berry, 1926b).

27. Porcupine Creek (= Poplar River) west of Maxstone (ca. 49°28'N, 106°02'W) and north of Twelve Mile Lake, Saskatchewan, Ravenscrag Formation, Paleocene (Dawson, 1875; Penhallow, 1903, 1907b, 1908; Berry, 1926a, 1930, 1935; Williams & Dyer, 1930).
28. 3.5 miles east of Ravenscrag (49°30'N, 109°08'W), Saskatchewan, Ravenscrag Formation, Paleocene (Williams & Dyer, 1930).
29. Approximately 10 miles southeast of Willowbunch (49°22'N, 105°39'W), Saskatchewan, Ravenscrag Formation, Paleocene (Berry, 1935; Williams & Dyer, 1930).
30. Approximately 10 to 15 miles southwest of Bengough (49°25'N, 105°10'W), Saskatchewan, Ravenscrag Formation, Paleocene (Berry, 1935; Williams & Dyer, 1930).
31. Approximately 5 miles south of Big Muddy Lake (49°09'N, 105°00'W), Saskatchewan, Ravenscrag Formation, Paleocene (Berry, 1935; Williams & Dyer, 1930).
32. Kneehills Creek on left bank of the Red Deer River (57°30'N, 112°50'W), Edmonton Formation, Paleocene (Williams & Dyer, 1930).
33. Mouth of the Blind Man River (52°22'00"N, 113°46'05"W), Red Deer River Valley, Paskapoo Formation, Paleocene (Penhallow, 1902, 1903, 1906; Allan & Rutherford, 1926; Berry, 1926a).
34. 80 miles SE of Grand Prairie (54°15'N, 118°45'W, Smokey Tower, Alberta, Volcanic Tuff flora, Paleocene (Christophel, 1974).
35. Diamond Vale Coal Company, Quilchena near Nicola (50°08'N, 120°31'W), British Columbia, Kamloops Group, Coldwater beds, middle Eocene (Penhallow, 1906, 1908; Berry, 1926a; Armentrout, 1981; Mathewes & Brooke, 1971).
36. Tranquille River near Kamloops (50°39'N, 120°24'W), British Columbia, Canada, Kamloops Group middle Eocene (Penhallow, 1908; Berry, 1926a).
37. Joseph Creek (51°28'N, 120°08'W; GSC Loc. 7070), British Columbia, Chu Chua Formation, middle Eocene (Berry, 1926a; Campbell & Tipper, 1971; Roddick *et al*., 1976; Armentrout, 1981).
38. Ashnola locality (49°22.7'N, 120°32.7'W) near Princeton, British Columbia, Allenby Formation, middle Eocene (Arnold, 1955; Hills & Baadsgaard, 1967; Rothwell & Basinger, 1979; Basinger, 1981, 1984).
39. 2 to 2.5 miles south of Cache Creek and 4 miles east of Cache Creek (50°50'N, 121°10'W), British Columbia, Coldwater beds, early middle Eocene (Duffell & McTaggart, 1952).
40. 2.5 miles south of Sihwe Creek (50°25'N, 121°43'W), British Columbia, Kamploops Group, middle Eocene (Duffell & McTaggart, 1952).
41. Newhykulston Creek (51°18'N, 120°09'W; GSC Loc. 7069), British Columbia, Chu Chua Formation, middle Eocene (Campbell & Tipper, 1971).

42. Brewery Creek near Stikine River (57°48'N, 131°25'W), British Columbia, undefined, Eocene (Kerr, 1948).
43. Whipsaw and Lamont Creeks (49°23'N, 120°34'W), British Columbia, Princeton Group, Allenby Formation, middle Eocene (Rice, 1947).
44. Vermilion Cliff on the Tulameen River 3 miles west of Princeton (49°27'N, 120°34'W), British Columbia, Princeton Group, Allenby Formation, middle Eocene (Penhallow, 1908; Berry, 1926a; Rice, 1947).
45. Kettle River just north of the US-Canada border approximately 6 miles upstream from Midway (49°02'N, 118°45'W), British Columbia, probably Princeton Group, Allenby Formation, middle Eocene (Penhallow, 1907a, 1908).
46. Nine-mile Creek (49°26'N, 120°18'W), British Columbia, probably Princeton Group, Allenby Formation, middle Eocene (Dawson, 1879).
47. Similkameen River near Princeton (49°25'N, 120°35'W), British Columbia, middle Eocene (Dawson, 1891; Penhallow, 1903, 1908; Berry, 1926a; Armentrout, 1981).
48. Coal Gully near Coutlee (50°08'N, 120°49'W), British Columbia, Kamloops Group, Coldwater beds, middle Eocene (Penhallow, 1906).
49. Miocene Mines, Horsefly River near Horsefly (52°20'N, 121°25'W), British Columbia, Horsefly River beds, middle Eocene (Penhallow, 1902, 1903, 1908; Berry, 1926a; Wilson, 1977).
50. Kitsilano (49°16'N 123.10'W), south side of English Bay, Vancouver, British Columbia, Kitsilano Formation, late Eocene-early Oligocene (Johnson, 1923; Berry, 1926a; Chaney, 1951).
51. 2.6 miles west of the Devil's Thumb (53°35'N, 125°20'W), British Columbia, Endako Group, late Oligocene (Tipper, 1963).
52. West Road (= Blackwater) River (53°19'N, 122°52'W), British Columbia, probably Endako Group, late Oligocene (Dawson, 1877; Penhallow, 1908; Berry, 1926a).
53. Deadman River Valley south of Snohoosh Lake (51°03'N, 120°53'W; GSC Loc. 7067), British Columbia, Deadman Formation, late Miocene (Campbell & Tipper, 1971).

11.9. USA

1. Red Coulée (47°33'N, 110°57'W), Cascade County, Montana, Eagle Sandstone, late Santonian-early Campanian (Bell, 1963).
2. Hunter Wash (36°17N, 108°15'W), 30 miles south of Farmington and 1 mile east of the Reservation line, San Juan County, New Mexico, Fruitland Formation, late Campanian (Knowlton, 1917a).

3. SE 1/4, S. 6, T. 49 N, R. 99 W (44°15'N, 108°48'W; USGS Loc. 6176), Park County, Wyoming, Ferris Formation, Late Cretaceous-early Paleocene (Brown, 1962).
4. Rattlesnake Butte (45°16'31"N, 107°40'08"W), Cheyenne Indian Reservation, Bighorn County, South Dakota, Lance Formation, late Maastrichtian (Knowlton, 1911).
5. Near Lance Creek (43°22'N, 104°16'W), Niobrara County, Wyoming, Lance Formation, late Maastrichtian (Dorf, 1940, 1942).
6. Craig (40°31'N, 107°33'W), Moffat County, Colorado, Medicine Bow Formation, late Maastrichtian (Dorf, 1942).
7. Oakdale mine, northwest of La Veta (37°30'N, 105°00'W), Huerfano County, Colorado, Vermejo Formation, late Maastrichtian (Knowlton, 1917b).
8. McAinlly mine near Walsenburg (37°37'N, 104°46'W), Huerfano County, Colorado, Vermejo Formation, late Maastrichtian (Knowlton, 1917b).
9. Starkville mine, Starkville, (37°07'N, 104°31'W), Las Animas County, Colorado, Vermejo Formation, late Maastrichtian (Knowlton, 1917b).
10. Morley mine, Morley (37°02'N, 104°30'W), Las Animas County, Colorado, Vermejo Formation, late Maastrichtian (Knowlton, 1917b).
11. Vermejo Park (36°53'N, 105°00'W), Colfax County, New Mexico, Vermejo Formation, late Maastrichtian (Knowlton, 1917b).
12. Dawson (36°40'N, 104°46'W), Colfax County, New Mexico, Vermejo Formation, late Maastrichtian (Knowlton, 1917b).
13. Ponil Creek (36°28'N, 104°47'W), Colfax County, New Mexico, Vermejo Formation, late Maastrichtian (Knowlton, 1917b).
14. Bug Creek Anthills near the Fort Peck Reservoir (47°40'N, 106°13'W), McCone County, Montana, Hell Creek Formation, late Maastrichtian (Shoemaker, 1966).
15. Cannonball River 30 miles south of Mandan (46°24'N, 100°53'W), Morton County, North Dakota, Lance Formation, late Maastrichtian (Brown, 1935a).
16. Marmarth (46°17'N, 103°55'W), Slope County, North Dakota, Hell Creek Formation, late Maastrichtian (Brown, 1939; Chaney, 1951).
17. No. 6 mine, Forbes (37°15'23"N, 104°33'47"W), Las Animas County, Colorado, Vermejo Formation, late Maastrichtian (Knowlton, 1917b).
18. Willow Creek ca. 12 miles north of Musselshell Post Office and 1 mile east of road from Junction City to Fort Maginnis (46°41'N, 108°01'W), Fergus County, Montana, ?Judith River Formation, Maastrichtian (Knowlton, 1905).
19. Custro in Tercio Park (37°03'N, 104°59'W), Las Animas County, Colorado, Vermejo Formation, late Maastrichtian (Knowlton, 1917b).

20. S. 31, T. 50 N, R. 99 W (44°16'N, 108°48'W; USGS Loc. 6173), Park County, Wyoming, Ferris Formation, Late Cretaceous-early Paleocene (Brown, 1962).
21. Sand Creek, 7 miles north of Glenrock (42°58'N, 105°51'W; USGS Loc. 8551), Converse County, Wyoming, Fort Union Formation, early Paleocene (Brown, 1962).
22. Bluffs on the west side of the Little Missouri River, 2 miles south of Medora (46°53'N, 103°37'W; USGS Loc. 4264), Billings County, North Dakota, Fort Union Formation, early Paleocene (Brown, 1962).
23. Near the top of Sentinel Butte (46°52'N, 103°50'W; USGS Loc. 8238), Golden Valley County, North Dakota, Fort Union Formation, early Paleocene (Brown, 1962).
24. 3 miles SW of Yule (46°32'N, 103°49'W; USGS Loc. 8240), Golden Valley County, North Dakota, Fort Union Formation, early Paleocene (Knowlton, 1909; Brown, 1962).
25. 6.5 km north of New Salem (46°54'N, 101°25'W), Morton County, North Dakota, Fort Union Formation, early Paleocene (Harr & Ting, 1976).
26. Road cut east-southeast of Medora (46°55'N, 103°32'W), Billings County, North Dakota, Fort Union Formation, early Paleocene (Harr & Ting, 1976).
27. S. 33, T. 37 N, R. 47 E (47°22'N, 104°23'W; USGS Loc. 7005), left bank of the Yellowstone River at Burns, Richland County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
28. 30 miles below Gendive (46°41'N, 104°44'W; USGS Loc. 2420), Dawson County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
29. SW 1/4, NW 1/4, S. 28, T. 31N, R. 19 E, S of Chinook (48°34'N, 109°13'W; USGS Loc. 5595), Blaine County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
30. 10 miles N of Terry in S. 19, T. 13 N, R. 50 E (46°56'N, 105°19'W; USGS Loc. 8556), Prairie County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
31. SW 1/4, S. 27, T. 5 S, R. 50 E, about 6 miles SW of Broadus (45°24'N, 105°28'W; USGS Loc. 8786), Powder River County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
32. Makton coal mine, 7 miles NE of Big Sandy (48°13'N, 109°58'W; USGS Loc. 8885), Chouteau County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
33. 2 miles SW of Edwards (47°07'N, 107°22'W USGS Loc. 8249), Garfield County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
34. East side of Smokey Butte Creek, 14 miles NW of Jordan (47°24'N, 107°10'W; USGS Loc. 9334), Garfield County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).

35. Klonders Ranch 18 miles NE of Miles City (46°35'N, 105°33'W; USGS Loc. 8550), Montana, Fort Union Formation, early Paleocene (Knowlton, 1909; Brown, 1962).
36. 8 miles west of Bridger (45°20'N, 109°01'W), Carbon County, Montana, Fort Union Formation, early Paleocene (Knowlton, 1909).
37. Signal Butte 5 miles east of Miles City (46°23'N, 105°45'W), Custer County, Montana, Fort Union Formation, early Paleocene (Knowlton, 1909).
38. Whetstone Falls, on a tributary of Pacific Creek NE of Moran (43°50'24"N, 110°30'34"W; USGS Loc. 9193), Teton County, Wyoming, Fort Union Formation, early Paleocene (Brown, 1962).
39. Bud Kimball Mine (44°00'N, 107°32'W; USGS Loc. 5063), Washakie County, Wyoming, Fort Union Formation, early Paleocene (Knowlton, 1909; Brown, 1962).
40. SW 1/4, S. 5, T. 45 N, R. 97 W (43°54'N, 108°31'W), Hot Springs County, Wyoming, Fort Union Formation, early Paleocene (Brown, 1962).
41. South Park (43°25'N, 110°47'W), Teton County, Wyoming, Fort Union Formation, early Paleocene (Lesquereux, 1874).
42. Ilo and Gynne Ranch near Grass Creek (43°56'25"N, 108°38'55"W; USGS Locs. 4661, 8899), Hot Springs County, Wyoming, Fort Union Formation, early Paleocene (Knowlton, 1909; Brown, 1962).
43. Little Missouri River, near New Town (syn: Elbowoods; 47°58'54"N, 102°30'49"W Fort Berthold Reservation; USGS Loc. 8212), Mountrail County, North Dakota, Fort Union Formation, early Paleocene (Brown, 1962).
44. Roadcut ESE of Medora (46°51'30"N, 103°25'02"W), Billings County, North Dakota, Fort Union Formation, early Paleocene (Harr & Ting, 1976).
45. 6.5 km north of New Salem (46°54'N, 101°26'W), Morton County, North Dakota, Fort Union Formation, early Paleocene (Harr & Ting, 1976).
46. 3 miles NW of Meeteetse (Black Diamond Mine; ca. 44°11'N, 108°55'W), Park County, Wyoming, Fort Union Formation, early Paleocene (Knowlton, 1909).
47. Shoshone River near Cody (44°32'N, 109°03'W), Park County, Wyoming, Fort Union Formation, early Paleocene (Knowlton, 1909).
48. *Ceratops* beds along Lance Creek (43°14'N, 104°36'W), Converse County, Wyoming, Fort Union Formation, early Paleocene (Knowlton, 1909).
49. Seven Mile Creek (43°23'52"N, 104°25'05"W), Niobrara County, Wyoming, Fort Union Formation, early Paleocene (Knowlton, 1909).
50. SW 1/4, S. 15, T. 15 N, R. 47 E (47°03'10"N, 105°45'56"W; USGS Loc. 8165), Prairie County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).

51. Bison Basin (42°16'31"N, 108°05'58"W), Fremont County, Wyoming, Fort Union Formation, early Paleocene (Gemmill & Johnson, 1997).
52. S. 34, T. 6N, R. 27 E, 6 miles E of Buckley (46°13'44"N, 108°19'50"W; USGS Loc. 4582), Yellowstone County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
53. NE 1/4, SW 1/4, S. 23, T. 5 N, R. 26 E, 2 miles south of Buckley (46°10'20"N, 108°26'01"W; USGS Loc. 4984), Musselshell County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
54. Point of Rocks (41°41'N, 108°47'W), Sweetwater County, Wyoming, Fort Union Formation, early Paleocene (Lesquereux, 1876; Knowlton, 1900a; Chaney, 1951).
55. Near the top of a conical hill, S. 23, T. 2 S, R. 44 E (43°39'22"N, 106°15'45"W; USGS Loc. 8521), Rosebud County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
56. Twisp (48°22'N, 120°07'W), Okanogan County, Washington, Pipestone Formation, Paleocene (Royse, 1965).
57. Route 719 across from the S. 24, T. 143 N, R. 101 W, (47°11'30"N, 103°25'26"W), Billings County, North Dakota, Fort Union Formation, early Paleocene (Harr & Ting, 1976).
58. Carbon (41°51'N, 106°22'W), Carbon County, Wyoming, Fort Union Formation, early Paleocene (Lesquereux, 1873).
59. Farley Creek (44°56'N, 107°08'W) about 2 1/4 miles NE of Ranchester, Sheridan County, Wyoming, Fort Union Formation, early Paleocene (Knowlton, 1909).
60. East side of Bighorn River across from Kirby (43°48'N, 108°10'W), Hot Springs County, Wyoming, Fort Union Formation, early Paleocene (Knowlton, 1909).
61. Rock Springs (41°35'N, 109°12'W), Sweetwater County, Wyoming, Fort Union Formation, early Paleocene (Chaney, 1951).
62. Hodson's coal mine on Meadow Creek (45° 38'N, 110°52'W), 12 miles SE of Bozeman, Gallatin County, Montana, Fort Union Formation, early Paleocene (Knowlton, 1893b).
63. Big Dry Creek (47°30'55"N, 106°16'41"W), ca. 60 miles south of Glasgow, McCone County, Montana, Fort Union Formation, early Paleocene (Knowlton, 1909).
64. 6 miles above the mouth of Sevenmile Creek NE of Glendive (47°06'23"N, 104°42'39"W; USGS Loc. 8196), Dawson County, Montana, Fort Union Formation, early Paleocene (Brown, 1962).
65. Yellowstone River near O'Fallon's Creek (46°50'11"N, 105°08'50"W), Prairie County, Montana Fort Union Formation, early Paleocene (Newberry, 1868, 1898; Chaney, 1951).

66. Lone Butte (47°30'09"N, 103°09'30"W), McKenzie County, North Dakota, Sentinel Butte mudstone, Sentinel Butte Formation, Paleocene (Hoganson, 1997).
67. Medicine Lodge (Sage) Creek (44°59'N, 112°57'W), Beaverhead County, Montana, unknown, probably Paleocene (Lesquereux 1872; Knowlton 1923; Chaney 1951).
68. Numerous localities in Mountrail, Dunn, Mercer, Morton, McKenzie and Stark Counties (between ca. 46°30'N to 48°00'N, 101°30'W to 103°30'W; USNM Locs. 14056, 14059, 14066, 14068, 14074, 14079, 14083, 14085, 14088, 14098, 14108, 14115, 14121, 14122, 14128 and 14142), North Dakota, Bear Den and Camel Butte members, Golden Valley Formation, late Paleocene-early Eocene (Hickey, 1977).
69. SE 1/4, NW 1/4, S. 28, T. 9 N, R. 80 W, 7 miles west of Walden (40°44'N, 106°25'W; USGS Loc. 6000), Jackson County, Colorado, Coalmont Formation, late Paleocene-early Eocene (Brown, 1962; Roberts & Rossi, 1999).
70. Beckler Creek and Foss River Valley (ca. 47°42'N, 121°19'W), Skykomish Basin, Washington, Swauk Formation, late Paleocene-early Eocene (Smith & Duror, 1916).
71. Elko Station (40°50'N, 115°46'W), Elko County, Nevada, Elko Formation, early Eocene (Lesquereux, 1873, 1874; Chaney, 1951; Wing, 1987).
72. Pleasant Bay, SE 1/4 of SE 1/4 section 25, T. 37 N, R 2E (48°39'53"N, 122°29'48"W), Whatcom County, Washington, Chuckanut Formation, early Eocene (Pabst, 1968).
73. Birch Bay (48°55'N, 122°44'W), Whatcom County, Washington, Chuckanut Formation, early Eocene (Newberry, 1863, 1898; Chaney, 1951).
74. Chuckanut Drive on State highway 99A about 1/2 mile northwest of Dogfish Point, Clayton Bay, SE 1/4 of SW 1/4 section 6, T. 36 N, R 2E (48°37'32"N, 122°27'45"W), Skagit County, Washington, Chuckanut Formation, early Eocene (Pabst, 1968).
75. Germer Basin (44°30'N, 114°14'W), Custer County, Idaho, Germer Tuffaceous Member, Challis Volcanics, middle Eocene (Edelman, 1975).
76. Republic (48°39'N, 118°45'W), Ferry County, Washington, Klondike Mountain Formation, middle Eocene (Brown, 1935b; Wolfe & Wehr, 1987).
77. Bear Creek near Pinson (35°30'N, 88°45'W), Madison County, Tennessee, Lagrange Formation, late Eocene (Berry, 1916).
78. South end of the Ruby Reservoir between Mormon and Peterson Creeks (45°12'N, 112°09'W), Ruby Basin, Madison County, Montana, Renova Formation, late Eocene (Becker, 1960, 1961; Armentrout, 1981; Call & Dilcher, 1997).

79. Grant (45°00'N, 113°04'W), Beaverhead County, Montana, Medicine Lodge florule, Beaverhead Basin, Renova Formation, late Eocene (Becker, 1969; Call & Dilcher, 1997).
80. Fossil (45°01'N, 120°11'W), Cove Creek (syn: Knox Ranch and Pentecost Ranch; 44°54'N, 120°23'W) and Iron Mountain (syn: Clarno's Ferry, Chapman Ranch, Dugout Gulch and Slanting leaf beds; 44°41'N, 119°54'W), Wheeler County, Oregon, western facies of the Bridge Creek flora, John Day Formation, early Oligocene (Knowlton, 1902; Mason, 1927; Chaney, 1951; Manchester & Meyer, 1987; Meyer & Manchester, 1997).
81. Twickenham (44°45'N, 120°14'W) and Painted Hills (syn: Allen Ranch, Bridge Creek [*sensu sticto*], Mitchell and Wade Ranch; 44°38'N, 120°17'W), Wheeler County, Oregon, eastern facies of the Bridge Creek flora, John Day Formation, early Oligocene (Lesquereux, 1883; Newberry, 1883, 1898; Knowlton, 1902; Chaney, 1951; Arnold, 1952; Brown, 1959; Meyer & Manchester, 1997).
82. Lost Creek (syn: Post and Gray's Ranch; 44°38'N, 120°17'W) and Crooked River (syn: Gray's Ranch and Post; 44°09'N, 120°19'W), Crook County, Oregon, southern facies of the Bridge Creek flora, John Day Formation, early Oligocene (Newberry, 1898; Chaney, 1927; Mason, 1927; Clements & Chaney, 1936; Arnold, 1947; Chaney, 1951; Meyer & Manchester, 1997).
83. Canal flora near Redmond (44°15'N, 121°11'W), Deschutes County, Oregon, Clarno Formation, middle Oligocene (Ashwill, 1983).
84. 0.8 miles NE of Rujada and 23 miles E of Cottage Grove (43°48'N, 122°35'W), Lane County, Oregon, late Oligocene (Lakhanpal, 1958).
85. Thomas Creek 5 miles southeast of Lyons (44°41'N, 122°31'W), Linn County, Oregon, Little Butte Volcanic Series, Oligocene (Meyer, 1973).
86. Franklin Butte (44°30'N, 122°30'E) near Scio, Linn County, Oregon, Little Butte Volcanic Series, Oligocene (Sanborn, 1949).
87. Hay Fork (40°33'N, 123°13'W), Shock Creek (40°34'35"N, 123°02'33"W), Redding Creek (40°35'N, 123°53'W), Big Bar (40°44'31"N, 123°15'03"W) and Hyampom (40°37'N, 123°27'W), Trinity County, California, Weaverville Formation, Oligocene (MacGinitie, 1937).
88. Warner Mountains (ca. 41°32'N, 120°10'W), Modoc County, California, Lower Cedarville Formation, late Oligocene-early Miocene (Russell, 1928; Chaney 1951).
89. *Metasequoia* Creek on the Columbia River (45°37'12"N, 121°59'13"W), Oregon, Eagle Creek Formation, early Miocene (Krause, 1999).
90. Electric powerhouse on the right bank of the Salmon River near Salmon (45°10'N, 113°53'W), Lemhi County, Idaho, early Miocene (Brown, 1935b; Chaney, 1951).

91. Left side of the road up Potlatch Creek between Arrow Junction and Juliaetta (ca. 46°32'N, 116°43'W), Latah County, Idaho middle Miocene (Brown, 1935b).
92. Good Hope Hill (38°52'04"N, 76°57'45"W), Anacostia River, District of Columbia, Calvert Formation, Miocene (Berry, 1909).
93. 1 mile east of Murphy's Springs and about 4 miles southeast of Ashland (42°10'N, 122°47'W), 3 miles south east of Ashland (42°10'N, 122°45'W) and 5 miles north of Ashland (42°16'N, 122°43'W), Jackson County, Oregon, undefined, Miocene (Knowlton, 1900b; Chaney, 1951).
94. Hog and Alkali Creeks near Weiser (44°15'N, 116°58'W), Washington County, Idaho, Idaho Formation, late Miocene/early Pliocene (Dorf, 1936; Smith, 1938).
95. Clarkia (47°00'N, 116°15'W), Shoshone County, Idaho, Miocene (Smiley *et al.*, 1975; Smiley & Rember, 1985).
96. Picture Gorge (44°31'51"N, 119°38'03"W) to White Hills locality (syn: Van Horn's Ranch or Belshaw Ranch; ca. 44°25'N, 119°14'W) along the east fork of the John Day River, Grant County, Oregon, John Day Formation, early Oligocene, (Knowlton, 1902; Cockerell, 1910; Chaney & Axelrod, 1959; Chaney, 1951).
97. 3.5 miles south of Lone Rock (ca. 44°13'N, 118°15'W), Oregon, John Day Formation, early Oligocene (Knowlton, 1902).
98. Edward's Ranch, Stanley Hill near Coeur D'Alene (47°40'N, 116°47'W), Kootenai County, Idaho, Latah Formation, middle Miocene (Knowlton, 1926).
99. ½ mile above the mouth of Deep Creek (47°45'N, 117°33'W) northwest of Spokane, Spokane County, Washington, Latah Formation, middle Miocene (Knowlton, 1926).
100. Well at Mica (47°33'N, 117°12'W) ca. 10 miles SE of Spokane, Spokane County, Washington, Latah Formation, middle Miocene (Knowlton, 1926).
101. Cut along the Spokane, Portland and Seattle Railway, Spokane (47°39'N, 117°25'W), Spokane County, Washington, Latah Formation, middle Miocene (Knowlton, 1926).
102. Cut ca. 1 miles west of Shelley Lake (47°39'N, 117°12'W) about 10 miles east of Spokane, Washington, Latah Formation, middle Miocene (Knowlton, 1926).

11.10. Korea

1. Keumkwandong near Pohang (36°00'N, 129°36'E), Yeong'il Bay District, Changgi flora, Keumkwandong Formation, Changgi Group, early Miocene (Huzioka, 1972; Chun, 1982).

2. Ung'jeomdong near Yongdong and Myeoncheon ca. 30 northeast of Kilju (40°55'N, 129°21'E), Myeoncheon-Kilju District, Yongdong flora, Yongdong Formation, Yongdong Group, early Miocene (Huzioka, 1972).
3. Tongcheon coal field (Tsusen coal field, Kogen-do; ca. 38°41'N, 128°10'E), Tongcheon District, Kangweon-do, Tongcheon flora, Tongcheon Formation, late early to early middle Miocene (Ichimura, 1928; Endo, 1938b, 1939; Huzioka, 1972).
4. Hamjindong (Kantindô and Hakurokudô (Hugandô) coal mines) and Kilju (40°55'N, 129°21'E), Myeoncheon-Kilju District, Hamjindong flora, Hamjindong Formation, Myeoncheon Group, middle Miocene (Endo, 1936, 1938a, 1939; Huzioka, 1972).
5. Yongpukdong in the Kogeonweon coal field (Kokangen coal mine) located about 40 km northeast of Hoeryeong (42°29'N, 129°45'E), Kyeongweon District of Hamg'yeong-bukdo, Kogeonweon flora, "*Engelhardtia* bed", middle Miocene (Endo, 1938a, 1939; Huzioka, 1972).
6. Aojidong coal field located about 40 km northeast of Hoeryeong (42°29'N, 129°45'E), Kyeongweon District of Hamg'yeong-bukdo, Kogeonweon flora, lower coal-bearing bed, middle Miocene (Endo, 1938a; Huzioka, 1972).
7. Kungshim colliery at Kungshimdong 7.5 km northeast of Hoeryeong (42°29'N, 129°45'E), Hoeryeong District, Kungshim flora, Hoengyeong Formation, early middle Miocene (Ichimura, 1927; Huzioka, 1972).
8. Paektodong located about 10 km southwest of Hoeryeong (42°29'N, 129°45'E), Hoeryeong District, Kungshim flora, Yuseon Formation, early late Miocene (Ichimura, 1927; Huzioka, 1972).

11.11. Japan

11.11.1. Hokkaido

1. Owada coal mines near Rumoi City (43°55'N, 141°38'E), Rumoe District, Tesio, Yudoro Formation, late Eocene (Endo, 1936; Oishi, 1950; Tanai, 1955).
2. Shimizusawa coal mine, Ishikari coal field near Yubari City (43°20'N, 142°10'N), Yubari District, Yubari Formation, Eocene (Endo, 1928; Huzioka & Kobayashi, 1961).
3. Shako and Sarushihorokabetsu, Yubari City (43°11'N, 142°00'E), and Tekkonosawa, Kuriyama-machi, Sarachi District, Ishikari coal field, *Woodwardia* Formation, middle Eocene (Endo, 1968).
4. Kushiro coalfield near Kushiro City (43°10'N, 145°10'E), Harutori, Tenneru, Shakubetsu and Yubetsu Formations, Urahoro Group, late Oligocene (Oishi & Huzioka, 1942; Tanai, 1970; Matsue & Onoe, 1995).

5. Ponbetsu coal mine, near Mikasa City (43°15'N, 141°57'E), Fukagawa-machi, Sorachi District, Naidabu Formation, early to middle Miocene (Endo, 1928; Tanai, 1955).
6. Near Kanasagawa and Miyano (42°20'N, 139°56'E), Wakamatsu flora, Sekinai Formation, middle Miocene (Tanai & Suzuki, 1972).
7. Kayanuma coal mine on the upper course of the Tama River near Kayanuma north of Iwani (43°01'N, 140°32'E), Fukuyama Formation, Miocene (Tanai, 1955, 1961; Tanai & Suzuki, 1963).
8. Yoshioka flora near Yoshioka (41°26'N, 140°54'E), Yoshioka Formation, late early to early middle Miocene (Tanai, 1955, 1961; Tanai & Suzuki, 1963).
9. Wakamatsu coal mine 2 km from Kanegasawa Bridge ca. 15 km south of Higashisetana Station near Wakamatsu (42°20'N, 139°56'E), Kudo coal-bearing member, Kunnui Formation, late early to early middle Miocene (Tanai, 1961; Tanai & Suzuki, 1963).
10. Abura flora near Setana (42°27'N, 139°52'E), Kunnui Formation, late early to early middle Miocene (Tanai, 1955, 1961; Tanai & Suzuki, 1963).
11. Soya-Magaribuchi, Hokutaku-koishi and Horonobe coal mines of the Tempoku coal field near Wakkanai (45°20'N, 142°20'E), Soya coal-bearing Formation, early Miocene (Endo, 1936, 1955; Tanai, 1955, 1961).
12. Cliff in the middle course of the Sakipempetsu River located about 20 km south of Ashibetsu (43°29'N, 142°14'E), Sorachi coal field, Ashibetsu District, Sakipempetsu flora, Sakipembersu/Nokonan Formation, Ishikari Group, early Miocene (Tanai, 1955, 1961, 1971).
13. Asahi coal mine, Ikushumbetsu District, Ishikari coal field near Yubari (43°04'N, 141°59'E), Asahi Formation, early Miocene (Tanai, 1955, 1961).
14. Honjin-no-sawa near Rumoi City (43°57'N, 141°40'E), Urye District, Rumoe coal field, Honjin-no-sawa Formation, late early to early middle Miocene (Tanai, 1955, 1961).
15. Hidaka coal area (ca. 42°50'N, 142°50'E), Niipaku Formation, late Miocene (Tanai, 1961).
16. Utanobori (ca. 44°50'N, 142°40'E), Kitami region, Tachikarabetsu Formation, late Miocene (Tanai, 1961).
17. Konomai mine (44°07'N, 143°30'E), Kitami Province, Shanabuchi Formation, late Miocene (Tanai, 1961).

11.11.2. Honshu

18. Aburato, Kozunohama, Sanze and Iragawa (Tagawa coal mine) near Oyama (38°40'N, 139°40'E), Nishitagawa coal field, Yamagata Prefecture, Atsumi, Aburato and Iragawa Formations, early early

Miocene (Tanai, 1952a, 1955, 1961; Huzioka, 1964; Matsue & Onoe, 1995).

19. Kamigo (38°15'N, 140°08'E) eastern and southern part of the Nishitagawa coal field, Yamagata Prefecture, Kamigo Formation, middle Miocene (Tanai, 1952b, 1961).
20. Oguni (38°03'N, 139°45'E), Yamagata Prefecture, Imaichi and Oguni Formations, middle Miocene (Morita, 1932; Tanai, 1955, 1961; Tokunaga, 1960; Onoe, 1974).
21. Along the Shira River near Yonezawa (ca. 38°00'N, 139°47'E), Okitama lignite field, Yonezawa Basin, Yamagata Prefecture, Takamine and Tenoko Formations, Shirakawa Group, late Miocene (Tokunaga & Tanai, 1954; Tanai, 1961; Uemura, 1988).
22. Shinjo Basin (38°43'N, 140°06'E), Yamagata Prefecture, Oriwata Formation, early Pliocene (Tanai, 1961).
23. Shichiku flora located ca. 8 km west of Yotsukura (36°50'N, 140°45'E), Joban coal field, Fukushima Prefecture, Shichiku Formation, early early Miocene (Tanai & Onoe, 1959; Tanai, 1961; Huzioka, 1964).
24. Koya (37°02'N, 140°49'E), Uchigo City, Fukushima Prefecture, Shichiku flora, Iwake Formation, Oligocene (Nathorst, 1888; Endo, 1963).
25. Shichuku flora near Iwaki City (ca. 37°00'N, 140°53'E), Fukushima Prefecture, Shirasaka Formation, Shiramizu Group, early to middle Miocene (Tanai & Onoe, 1959; Tanai, 1961).
26. Koyanaizu Village (37°31'09"N, 139°44'40"E), Yanaizu-machi, Kawanuma-gun, Aizu Basin, Fukushima Prefecture, Izumi Formation, Yamato Group, late Pliocene (Suzuki, 1961, 1987; Tanai, 1961; Manabe *et al*., 1970).
27. River cliff along the Sakase River ca. 400 m S30°W of Matsuzuka Village (37°29'03"N, 139°46'53.6"E), Niitsura-mura, Oonuma-gun, Aizu Basin, Fukushima Prefecture, Izumi Formation, Yamato Group, late Pliocene (Suzuki, 1961, 1987; Tanai, 1961; Manabe *et al*., 1970).
28. River cliff along the Wasedani River at Wasedani Village (37°41'15.7"N, 139°45'56.4"E), Yamato-machi, Yama-gun, Aizu Basin, Fukushima Prefecture, Izumi Formation, Yamato Group, late Pliocene (Suzuki, 1961, 1987; Tanai, 1961; Manabe *et al*., 1970).
29. Hara River near Obusegawa Village (34°23'N, 135°18'E), Fukushima Prefecture, Nisihaga flora (Shiroko florule), Fujitoge Formation, late Miocene and Izumi Formation, late Pliocene (Suzuki, 1951, 1959; Tanai, 1961).
30. Tennoji (37°48'N, 140°25'E), Fukushima Prefecture, Tennoji flora, Tennoji Formation, late Miocene (Suzuki, 1959; Tanai, 1961).
31. Fukurohara (37°37'N, 139°43'E), Fukushima Prefecture, Fukurohara flora, Maki and Ootezawa floras, Izumi Formation, Yamato Group, Pleistocene (Suzuki, 1959).

32. Koyanaizu (37°31'N, 139°44'E), Fukushima Prefecture, Koyanaizu flora, Fuji-toge and Izumi Formations, Yamato Group, Plio-Pleistocene (Suzuki, 1959).
33. Shiotsubo (37°36'N, 139°45'E), Fukushima Prefecture, Shiotsubo flora, Shiotsubo Formation, Pliocene (Suzuki, 1959).
34. Higashidate (36°52'N, 140°26'E), Fukushima Prefecture, Higashidate flora, Kuroiwa Formation, Pliocene (Suzuki, 1959).
35. Kuji (40°12'N, 141°47'E), Iwate Prefecture, Sawayama Formation, Kuji Group, Senonian (Tanai, 1979).
36. River in Gamono, Mataki Village (38°50'N, 140°13'E), Nisiiwai District, Iwate Prefecture, Plio-Pleistocene (Miki, 1950b).
37. Sehara Cliff, Hiraizumi Village (38°59'N, 141°12'E), Nisiiwai District, Iwate Prefecture, Plio-Pleistocene (Miki, 1950b).
38. Morioka City (39°43'N, 141°08'E), Iwate Prefecture, Gosho flora, Masuzawa Formation, middle Miocene (Murai, 1957a, 1957b; Tanai, 1961).
39. Shin-Suzumeda colliery, Kaji colliery, Dan, Hirabara colliery, Okinoyama colliery, Wakayama colliery, Daini-Fuji colliery, Hagimori colliery, Shin-Suwa colliery, Fujimagari, Kami-Umeda, Motoyama colliery and Ejioike near Ube (33°57'N, 131°16'E), Yamaguchi Prefecture, Okinoyama Formation, Ube Group, late Eocene and possibly middle Eocene (Huzioka & Takahashi, 1970; K. Uemura personal communication, 2001).
40. Yamane, Yuya Village (34°21'N, 131°03E), Yuya Bay, Yamaguchi Prefecture, Hitomaru Formation, Hioki Group, early to middle Miocene (Huzioka, 1974).
41. Lignite bed in Azina (34°11'N, 131°57'E), Huzikawa Village, Kuma District, Yamaguchi Prefecture, Plio-Pleistocene (Miki, 1950b).
42. Ouchiyama-kami in Heki-cho about 14 km west of Nagato City (34°20'N, 131°13'E), Yamaguchi Prefecture, Kiwado Formation, Hioki Group, Oligocene (Uemura *et al.*, 1999).
43. Shiogama City and Saura-machi (38°20'N, 140°59'E) Miyagi District, Miyagi Prefecture, Sauramachi and Ajiri Formations, early and middle Miocene (Endo, 1931, 1933b, 1936, 1954; Tanai, 1955).
44. Near Sendai (38°16'N, 140°52'E), Miyagi Prefecture, Kameoka Formation, Sendai Group, early Pliocene (Endo, 1931, 1933a, 1933b; Tanai, 1961).
45. Akiho Village (ca, 38°15'N, 140°52'E) near Sendai, Miyagi Prefecture, Kameoka Formation, Sendai Group, early Pliocene (Kryshtofovich, 1920).
46. Sarao and Shizuhara near Fukui City (36°06'N, 136°13'E), Hokuriku District, Fukui Prefecture, Asuwa flora, Sarao bed, Paleocene (Matsuo, 1962).

47. Shimoichi and Fukaya (36°13'N, 136°10'E), Fukui, Fukui Prefecture, Kunimi Formation, middle Miocene (Huzioka, 1955; Tanai, 1961).
48. Monzen locality near Monzen (39°56'N, 139°47'E), Oga Peninsula, Akita Prefecture, Monzen Formation, early Miocene (Tanai, 1955; Huzioka, 1964).
49. Yakuya River, a tributary of the Yoneshiro River near Hanawa (ca. 40°15'N, 140°20'E), Akita Prefecture, Senosawa Formation, early Miocene (Huzioka, 1964).
50. Iwadate locality (formerly Hassei coal mine; 40°24'N, 139°43E), Hachimori-machi, Yamamoto District, Akita Prefecture, Iwadate coal-bearing Formation, early Miocene (Tanai, 1955, 1961; Huzioka, 1964).
51. Yokone florule near Honjo (39°23'N, 140°03'E) Akita Prefecture, Yokonetoge Formation, early Miocene (Huzioka, 1964).
52. Moriyoshi-machi (40°06'N, 140°20'E), Tsuyukuma (Arase coal mine), Kayakusa (Kinryuzan coal mine; 39°58'N, 140°24'E), Yunotai, Nekko (Ooani coal mine), Koya, Haginari, Shimo Hinokinai Village (39°44'N, 140°35'E) and Osawagawa localities near Aniai (39°58'N, 140°24'E), Akita Prefecture, Aniai Formation, early Miocene (Yokoyama, 1886; Nathorst, 1888; Kryshtofovich, 1920; Endo, 1963; Huzioka, 1964).
53. Yamakayakusa (39°57'N, 140°22'E), Hadachi, Uttonaizawa, Totorinai, Tachinomatazawa, Onimatazawa and Tsuchikumazawa localities are all situated about 5–40 km southeast of Aniai (40°00'N, 140°26'E), Akita Prefecture, Utto Formation, middle Miocene (Tanai, 1955, 1961; Huzioka, 1963).
54. Omagoshi locality (40°35'N, 139°56'E), Iwasaki Village, Nishi-Tsugaru District, Aomori Prefecture, Iwadate coal-bearing Formation, early Miocene (Huzioka, 1964).
55. Funauchi Mine located in the Nishimeya Mountains about 15 km southwest of Hirosaki (39°22'N, 140°03'E), Aomori Prefecture, Fujikura flora, Kuroishizawa Formation, early Miocene (Huzioka, 1964).
56. Coal mine on the eastern side of Mt. Gozu located about 15 km northeast of Gosen (37°47'N, 139°30'E), Sasaoka Village, Kita-Kambara District, Niigata Prefecture, Yamanokami Formation, early Miocene (Huzioka, 1964).
57. Zenshino, Terabora, Nishikatabira and Higashikatabira all located about 10 km southwest of Minokamo (35°29'N, 137°01'E), Aichi Prefecture, Nakamura Formation, Kani Group, early Miocene (Tanai, 1955; Huzioka, 1964; Ina, 1992).
58. Near Mizumani (35°25'N, 137°16'E), Aichi Prefecture, Toki Formation, Mizunami Group, Miocene (Tokunaga & Onoe, 1969).

59. Near Kouwa (34°44'N, 136°57'E), Chita Peninsula, Aichi Prefecture, Kouwa flora, Kouwa Member, Tokoname Formation, Seto Group, late Miocene (Miki, 1948; Ozaki, 1991).
60. Ueno, Sakashita-cho, Kasugai City (35°15'N, 136°57'E), Aichi Prefecture, Yadagawa Formation, late Miocene-early Pliocene (Miki, 1948, 1950b; Ozaki, 1991).
61. Syurakuen Cliff in Tita District (35°03'N, 135°55'E), Aichi Prefecture, early Pliocene (Miki 1941).
62. Fuchu City 15–20 km west of Tokyo (35°41'N, 139°30'E), Tokyo Prefecture, Minamitama Formation, (Miura Formation), middle Miocene (Ida, 1955).
63. Itoh mine, Obata-machi, Seto (35°08'N, 136°55'E), Aichi Prefecture, Seto porcelain clay Formation, late Miocene (Ozaki, 1991).
64. B bed in Bessyoyama, Hirakata City (34°50'N, 135°40'E), Osaka Prefecture, Plio-Pleistocene (Miki, 1950b; Uemura, personal communication 2003).
65. Itsukaichi (35°44'N, 139°13'E) in Akiruno City near Tokyo, Tokyo Prefecture, Kosho Formation, early Miocene (Endo, 1963; Uemura *et al*., 2001).
66. Kita-asa River in Narahara, Hachioji City (35°40'N, 139°20'E), Tokyo Prefecture, Oyabe Formation, Plio-Pleistocene (Kimura *et al*., 1981; Horiuchi, 1996).
67. Numerous localities near Kobe (ca. 34°40'N, 135°07'E), Hyogo Prefecture, Miocene (Hori 1987).
68. Asiyagawa Cliff (34°43'N, 135°18'E), Hyogo Prefecture, early Pliocene (Miki, 1941).
69. Toyooka (35°35'N, 134°48'E), Hyogo Prefecture, Toyooka and Akeyo Formations, Hokutan Group, Miocene (Tanai, 1961; Onoe, 1978).
70. *Stegodon* beds in Yagi near Akashi (34°38'N, 134°55'E), 25 km west of Kobe, Hyogo Prefecture, Pliocene (Miki, 1936, 1937, 1950a; Endo, 1954, 1955).
71. Nagurayama clay bed, Hayasida-ku (34°55'N, 134°35'E), Hyogo Prefecture, Plio-Pleistocene (Miki, 1950b; Uemura, personal communication 2003).
72. Zyoho Cliff (34°15'N, 134°45'E), Nada Village, Mihara District, Hyogo Prefecture, Plio-Pleistocene (Miki, 1950b).
73. Noboritate clay bed (34°15'N, 134°45'E), Tui-tyo, Mihara District, Hyogo Prefecture, Plio-Pleistocene (Miki, 1950b).
74. Lignite at Hukakusa (34°25'N, 134°52'E), Yamada Village, Tuna District, Hyogo Prefecture, Plio-Pleistocene (Miki , 1950b).

75. Lignite bed in Tamon, Nisimaiko, Akashi City (34°40'N, 135°00'E), Hyogo Prefecture, Plio-Pleistocene (Miki, 1950b; Uemura, personal communication 2003).
76. Kaminotani, Suma District, Kobe (34°41'N, 135°12'E), Hyogo Prefecture, Shirakawa Formation, Kobe Group, Oligocene (Shikama, 1938; Tanai, 1955, 1961).
77. Akashi (34°40'N, 134°58'E), Hyogo Prefecture, Akashi Formation, Osaka Group, early Pleistocene (Itihara, 1961).
78. Kobe (34°44'N, 135°22'E), Hyogo Prefecture, Akashi Formation, Osaka Group, early Pleistocene (Itihara, 1961).
79. Nishinomiya (34°39'N, 135°00'E), Hyogo Prefecture, Koyoen and Koroen members, Akashi Formation, Osaka Group, early Pleistocene (Itihara, 1961).
80. Rokko Highlands near Kobe (34°44'N, 135°22'E), Hyogo Prefecture, Kobe flora, Kobe Group, late Miocene (Hori, 1976, 1987).
81. Koyoen and Gokayama Cliffs and River cliff at Kantengoya, Nishinomiya City (34°45'N, 135°22'E), Hyogo Prefecture, Plio-Pleistocene (Miki, 1950b).
82. Nishiyagi, Okubo Village, Akashi District near Kobe (34°41'N, 134°52'E), Hyogo Prefecture, = Miki's (1937) *Stegodon* Beds, Osaka Group, Pliocene-early Pleistocene (Endo, 1936).
83. Kita-ku, Suma-ku and Nishi-ku (34°41'N, 135°06'E), Kobe, Hyogo Prefecture, Kobe Formation, Shirakawa Group, Oligocene (Kobayashi *et al.*, 1993).
84. Muraoka (35°24'N, 134°44'E), Youfu district, Hyogo Prefecture, Hokutan Formation, Takayanagi Group, middle Miocene (Kobayashi *et al.*, 1993).
85. Kasumi (35°39'N, 134°39'E), Shirosaki district, Hyogo Prefecture, Seto Volcanic Rock Formation, Miocene (Kobayashi *et al.*, 1993).
86. Muraoka (35°29'N, 134°34'E), Mikata distict, Hyogo Prefecture, Toyooka Group, Miocene (Ueji, 1938; Kobayashi *et al.*, 1993).
87. Hokudan-cho (34°31'N, 134°55'E), Tuna district, Hyogo Prefecture, Osaka Formation, Tomishima Group, Pliocene (Kobayashi *et al.*, 1993).
88. Miyamachi (34°27'N, 134°50'E), Tsuna district, Hyogo Prefecture, "lignite bed", Pliocene (Kobayashi *et al.*, 1993).
89. Seidan-cho (34°19'N, 134°43'E), Mihara district, Hyogo Prefecture, Pliocene (Kobayashi *et al.*, 1993).
90. Nandan-cho (34°14'N, 134°48'E), Mihara district, Hyogo Prefecture, Nada Formation, Pliocene (Kobayashi *et al.*, 1993).
91. Onsen-cho (35°29'N, 134°46'E), Mikata district, Hyogo Prefecture, Teragi Formation, late Miocene–Pliocene (Kobayashi *et al.*, 1993).
92. Shimotoda (34°59'N, 134°59E), Nishiwaki, Hyogo Prefecture, "*Metasequoia* bed", Plio-Pleistocene (Miki, 1950b; Kobayashi *et al.*, 1993).

93. Hagiwara (34°52'N, 135°24'E), Kawanishi, Hyogo Prefecture, "*Metasequoia* bed", Plio-Pleistocene (Kobayashi *et al*., 1993).
94. Nonoike-chosuichi (34°41'N, 134°57'E), Akashi, Hyogo Prefecture, Kawanishi-clay, early Pleistocene (Kobayashi *et al*., 1993).
95. Ookubo-cho (34°41'N, 134°57'E), Akashi, Hyogo Prefecture, lower Osaka Formation, early Pleistocene (Kobayashi *et al*., 1993).
96. Nishi-ku (34°42'N, 135°06'E), Kobe, Hyogo Prefecture, lower Osaka Formation, Plio-Pleistocene (Kobayashi *et al*., 1993).
97. Nagata-ku (34°41'N, 135°10'E), Kobe, Hyogo Prefecture, lower Osaka Formation, early Pleistocene (Kobayashi *et al*., 1993).
98. Hibarigaoka (34°49'N, 135°26'E), Takarazuka, Hyogo Prefecture, "*Pinus koraiensis* bed" middle-late Pleistocene (Kobayashi *et al*., 1993).
99. Gokayama, Shyurinji and Yama-Ashiyamachi (34°46'N, 135°20'E), Nishinomiya and Ashiya, Hyogo Prefecture, lower Osaka Formation, early Pleistocene (Kobayashi *et al*., 1993).
100. Tarumi-ku, Kobe and Ohkuraya, Akashi (34°39'N, 135°03'E), Hyogo Prefecture, lower Osaka Formation, Plio-Pleistocene (Kobayashi *et al*., 1993).
101. Kigo (35°33'N, 135°12'E), Kyoto Prefecture, Seya Formation, early early Miocene (Tokunaga & Onoe, 1969; Onoe, 1978).
102. Okukaizi clay bed (34°55'N, 135°43'E), Kaizi Village, Otokuni District, Kyoto Prefecture, Plio-Pleistocene (Miki, 1950b).
103. Fukakusa (34°56'N, 135°46'E), southeast of Kyoto, Kyoto Prefecture, Izumi Formation, Osaka Group, Pliocene (Fukakusa Research Group, 1962).
104. Miyazu City (35°33'N, 135°12'E), Kyoto Prefecture, Yosa Group, Seya Formation, early to middle Miocene (Tanai, 1961).
105. Yasaka (35°43'N, 135°02'E), Kyoto Prefecture, Seya Formation, early early Miocene (Onoe 1978).
106. Near Takaya and Orito (37°30'N, 137°15'E), Noto Peninsula, Ishikawa Prefecture, Yanagida Formation (= Higashi Innai Formation, Orito Member), early early Miocene (Ishida & Masuda, 1956; Tanai, 1961; Ishida, 1970).
107. Ningyo Pass (35°27'N, 133°52'E), Tottori Prefecture, Ningyo-Toge Formation, late Miocene (Tokunaga & Onoe, 1969).
108. Saji River located 200 m east-northeast of Tatsumi Pass (35°14'N, 134°07'E), Tottori Prefecture, Tochiwara Formation, late Miocene (Ozaki, 1979; Matsue & Onoe, 1995).
109. Fuganji, Takakubo and Dogo (34°13'N, 132°35'E), Tottori and Shimane Prefectures, Honshu, Suki and Fuganji Formations, Tottori Group, Miocene (Hojo, 1973).
110. Huke (34°19'N, 135°10'E) and Tsutimaru (34°22'N, 135°20'E) clay beds in Sennan District, Osaka Prefecture, early Pliocene (Miki, 1941).

111. Tannowa clay bed (34°20'N, 135°15'E), Sennan District, Osaka Prefecture, Plio-Pleistocene (Miki, 1950b).
112. Singe clay bed (34°20'N, 135°15'E), Higasitotori Village, Sennan District, Osaka Prefecture, Plio-Pleistocene (Miki, 1950b).
113. Clay bed in riverside (34°28'N, 135°42'E), Nisigori Village, Minamikawati District, Osaka Prefecture, Plio-Pleistocene (Miki, 1950b).
114. Hamuro clay bed (34°28'N, 135°42'E), Sinaga Village, Minamikawati District, Osaka Prefecture, Plio-Pleistocene (Miki, 1950b).
115. Kitahurue (34°57'N, 135°25'E), Hosokawa Village, Toyono District, Osaka Prefecture, Plio-Pleistocene (Miki, 1950b).
116. Lignite bed in Baba (34°53'N, 135°40'E), Kiyotani Village, Mishima District, Osaka Prefecture, Plio-Pleistocene (Miki, 1950b).
117. Near Kishiwada (34°27'N, 135°22'E), Osaka Prefecture, Sennan Formation, Osaka Group, late Pliocene, Kokubu Formation, Osaka Group, early Pleistocene (Momohara, 1992).
118. Suita-Ibaragi, Senriyama (34°48'N, 135°40'E), Osaka Prefecture, Senriyama Formation, Osaka Group, early Pleistocene (Itihara, 1961).
119. Hirakata-Sinkori, Hirakata near Osaka (34°48'N, 135°40'E), Osaka Prefecture, Senriyama Formation, Osaka Group, early Pleistocene (Itihara, 1961).
120. Izumisunagawa, Sennan near Osaka (34°29'N, 135°40'E), Osaka Prefecture, Senriyama Formation, Osaka Group, early Pleistocene (Itihara, 1961).
121. Lignite bed at Koda (34°12'N, 135°17'E), Arakawa Village, Naka District, Wakayama Prefecture, Plio-Pleistocene (Miki, 1950b).
122. Toge clay bed (34°20'N, 135°42'E), Hasimoto City, Ito District, Wakayama Prefecture, Plio-Pleistocene (Miki, 1950b; Oishi, 1950).
123. Kinokawa River, Hashimoto City (34°20'N, 135°36'E), Wakayama Prefecture, Shobudani Formation, Osaka Group, late Pliocene-early Pleistocene (Miki, 1941, 1950b; Momohara *et al*., 1990).
124. Hashimoto clay (34°05'N, 135°15'E), Wakayama Prefecture, Plio-Pleistocene (Miki 1941, 1950b).
125. Sidatani clay bed (34°48'N, 136°10'E), Simagahara, Ayama District, Mie Prefecture, early Pliocene (Miki, 1941, 1950b).
126. Near Inabe-cho (35°10'N, 136°28'E), Inabe area, Mie Prefecture, Tokai Group, Kono and Ichinohara Formations, Pliocene, Oizumi Formation, late Pliocene-early Pleistocene and Komeno Formation, Pleistocene (Takemura, 1984).
127. Lignite bed in Sabutani (34°48'N, 136°10'E), Nii Village, Ayama District, Mie Prefecture, Plio-Pleistocene (Miki, 1950b).
128. Tarusaka clay bed, Ooyati Village (34°48'N, 136°10'E), Mie District, Mie Prefecture, Plio-Pleistocene (Miki, 1950b).

129. Yamanoisiki clay bed (35°03'N, 136°30'E), Mie Village, Mie District, Mie Prefecture, Plio-Pleistocene (Miki, 1950b).
130. Syukuno clay bed (35°03'N, 136°30'E), Komono-tyo, Mie District, Mie Prefecture, Plio-Pleistocene (Miki, 1950b).
131. Tyayagami clay bed (34°48'N, 136°10'E), Komono-tyo, Mie District, Mie Prefecture, Plio-Pleistocene (Miki, 1950b).
132. Lignite bed at Hagasikaino, Toyashiro Village (35°10'N, 136°28'E), Inabe District, Mie Prefecture, Plio-Pleistocene (Miki, 1950b).
133. Tadogawa clay bed (35°10'N, 136°33'E), Todo Village, Kuwana District. Mie Prefecture, Plio-Pleistocene (Miki, 1950b).
134. Kono clay bed (35°10'N, 136°33'E), Komi Village, Kuwana District, Mie Prefecture, Plio-Pleistocene (Miki, 1950b).
135. Hanataka lignite beds near Takasaki City (36°20'N, 139°06'E), Gunma Prefecture, early Pliocene (Miki, 1941, 1950).
136. Annaka City 9 km west of Takasaki (36°19'N, 138°55'E), Gunma Prefecture, Itahana Formation, late Miocene (Ozaki *et al*., 1981; Ozaki, 1991; Horiuchi, 1996).
137. Yoshigayatsu Pass south of Annaka City (36°12'N, 138°50'E), Gunma Prefecture, Itahana and Akima Formations, late Miocene-early Pliocene (Horiuchi, 1996).
138. Akima near Annaka City (36°20'N, 139°00'E), Gunma Prefecture, Akima Formation, early Pliocene (Horiuchi, 1996).
139. Kaorizawa Valley, Katashina Village (ca. 36°47'N, 139°37'E), Tone District, Gunma Prefecture, Okunikko Rhyolites, Ohamami Formation, Maastrichtian (Kimura & Okawara, 1986).
140. Lignite bed in Okamidani (34°50'N, 133°50'E), Mayagami Village, Mitu District, Okayama Prefecture, Plio-Pleistocene (Miki, 1950b).
141. Lignite bed in Kosoku (34°30'N, 136°01'E), Nakayumon Village, Uda District, Nara Prefecture, Plio-Pleistocene (Miki, 1950b).
142. Lignite bed in Nishiada (34°28'N, 135°53'E), Ooada Village, Uda District, Nara Prefecture, Plio-Pleistocene (Miki, 1950b).
143. Ayamegaike Cliff (34°40'N, 135°40'E), Husimi Village, Ikoma District, Nara Prefecture, Plio-Pleistocene (Miki, 1950b).
144. Southeastern part of Nara City (35°53'N, 137°30'E), Nara Prefecture, Fujiwara Formation, Pliocene (Kokawa, 1954, 1955).
145. Numerous localities near Mt. Mikasa and Mt. Kasuga (34°41'N, 135°51'E), Nara Prefecture, Shirakawaike and Saho Formations, Plio-Pleistocene (Kokawa, 1954).
146. Nisinotanda clay bed (ca. 34°53'N, 136°12'E), Ohara Village, Koga District, Shiga Prefecture, Plio-Pleistocene (Miki, 1950b).
147. Somakawa clay bed (ca. 34°53'N, 136°12'E), Kibukawa-cho, Koga District, Shiga Prefecture, Plio-Pleistocene (Miki, 1950b).

148. Lignite bed in Nisidera (ca. 34°53’N, 136°12’E), Isebe-cho, Koga District, Shiga Prefecture, Plio-Pleistocene (Miki, 1950b).
149. Lignite bed in Hata (ca. 34°53’N, 136°12’E), Mikumo Village, Koga District, Shiga Prefecture, Plio-Pleistocene (Miki, 1950b).
150. Hara clay bed (35°02’N, 136°14’E), Higasisakuradani Village, Gamo District, Shiga Prefecture, Plio-Pleistocene (Miki, 1950b).
151. Lignite bed in Keikake Village (35°02N, 136°14’E), Gamo District, Shiga Prefecture, Plio-Pleistocene (Miki, 1941, 1950b).
152. Kozuhata clay bed (35°02’N, 136°14’E), Itihara Village, Gamo District, Shiga Prefecture, Plio-Pleistocene (Miki, 1950b).
153. Lignite bed in Shida, Taga Village (35°13’N, 136°17’), Inukami District, Shiga Prefecture, Plio-Pleistocene (Miki, 1950b).
154. Minamigaito and Fukuzawa located about 10 km north of Mizunami City (35°22’N, 137°15’E), Gifu Prefecture, Nakamura Formation, Kani Group, early Miocene (Tanai, 1955; Huzioka, 1964; Ina, 1992).
155. Ishibora, Kamitoge and Maki located about 5 km north of Akechi (35°19’N, 137°22’E), Gifu Prefecture, Nakamura Formation, Kani Group, early Miocene (Tanai, 1955; Huzioka, 1964; Ina, 1992).
156. Nakagumi, Ueno, Yabasama, Miyasaki, Fushima, Seta, Wagata, Hirakaido, Tani and Mikasa located within 10 km to the northeast, east and southeast of Minokamo (35°29’N, 137°01’E), Gifu Prefecture, Nakamura Formation, Kani Group, early Miocene (Tanai, 1955; Huzioka, 1964; Ina, 1992).
157. Lignite bed at Matuo (35°20’N, 136°29’E), Sekigahara, Gifu Prefecture, Plio-Pleistocene (Miki, 1950b).
158. Hagihara Cliff (35°17’N, 136°30’E), Makita Village, Yoro District, Gifu Prefecture, Plio-Pleistocene (Miki, 1950b).
159. River cliff in Simotara (35°17’N, 136°30’E), Tara Village, Yoro District, Gifu Prefecture, Plio-Pleistocene (Miki, 1950b).
160. Simoyama clay bed (35°17’N, 136°30’E), Toki Village, Yoro District, Gifu Prefecture, Plio-Pleistocene (Miki, 1950b).
161. Inkyoyama near the Tokishi Railway Station, Toki City (35°20’N, 137°11’E), Gifu Prefecture, Yamanouchi, Kujiri and Shukunohora facies, Akeyo Formation, Mizunami Group, early late Miocene (Ozaki, 1974; Ina, 1992).
162. Hachiya (35°30’N, 137°03’E), Minokamo District, Gifu Prefecture, Hachiya flora, Hachiya and Nakamura Formations, Kani Group, early Miocene (Tanai, 1955; Ina *et al*., 1983, 1985; Ina, 1992).
163. Tarui-cho (35°21’N, 136°31’E), Fuwa District, Gifu Prefecture, Tokai Group, early Pleistocene (Tsukagoshi *et al*., 1997).
164. Osusawa clay bed, Tokitutyo near Mt. Mikuni (35°15’N, 137°12’E), Toki District, Gifu Prefecture, early Pliocene (Miki, 1941, 1950a, 1950b).

165. Mizunami and Toki district (35°22'N, 137°15'E), Toki (35°22'N, 137°13'E) and Kani district (35°27'N, 137°11'E), Gifu Prefecture, Nakamura and Hiramaki Formations, Kani and Mizunami Groups, early to middle Miocene (Tanai, 1955, 1961; Ina, 1981, 1992).
166. Nakagumi locality near Minokamo (35°29'N, 137°01'E) and Fukazawa locality near Mizunami (35°25'N, 137°16'E), Gifu Prefecture, Toki Coal-bearing Formation, Mizunami Group, early early Miocene (Tanai, 1961; Ina, 1992).
167. Mizunami (35°20'N, 137°15'E), Gifu Prefecture, Akeyo Formation, Mizunami Group, early Miocene, 16–17 Ma (Ina, 1974, 1992).
168. Mizunami (35°20'N, 137°15'E), Oidawara Formation, Mizunami Group, middle Miocene, 14.5–15.5 Ma (Ina, 1974; 1992).
169. Sayado clay bed (36°33'N, 140°03'E), Masikotyo, Haga District, Tochigi Prefecture, Plio-Pleistocene (Miki, 1941, 1950b).
170. Lignite bed in Koike (37°50'N, 140°50'E), Kasimatyo, Soma District, Fukushima Prefecture, Plio-Pleistocene (Miki, 1941, 1950b).
171. Cliff in Kodakohara (37°30'N, 139°45'E), Kawanisi Village, Kanuma District, Fukushima Prefecture, Plio-Pleistocene (Miki, 1950b).
172. Tozawa (39°11'N, 140°10'E), Takano Village, Nishi-Shirakawa District, Fukushima Prefecture, undefined, probably late early to early middle Miocene (Endo, 1954, 1955).
173. Nagai (37°37'N, 139°48'E), Kawanisi Village, Kawanuma District, Fukushima Prefecture, Izumi Formation, Pliocene (Endo, 1936).
174. Ara River near Kumagaya (36°08'N, 139°22'E), Saitama Prefecture, Yagii Formation, late Miocene (Ozaki, 1991).
175. Iruma River at Sasai (35°49'N, 139°20'E), Iruma City, Saitama Prefecture, Bushi Clay Member, Plio-Pleistocene (Kimura *et al.*, 1981; Sasai Fossil Forest Research Group, 1984; Horiuchi, 1996).
176. Ogawa (36°03'N, 139°11'E), Saitama Prefecture, Kanisawa Formation, late early-early middle Miocene (Horiuchi, 1996).
177. Kawamoto Town (36°07'N, 139°16'E), Saitama Prefecture, Yagii Formation, late middle Miocene (Horiuchi, 1996).
178. Sayama Hills (35°45'N, 139°22'E), Saitama Prefecture, Yatsu clay, Sayama Formation, Miura Group, Mio-Pliocene (Saitama Research Group & Kanto Quaternary Research Group, 1970).
179. Near Saigo (36°12'N, 133°19'E), Oki Island, Shimane Prefecture, Suki Formation, Tottori Group, Miocene (Hojo, 1973).
180. Hamada City (34°52'30"N, 132°03'43"E), Shimane Prefecture, Fukui flora, Kokubu Volcanics, Kokubu Group, early to middle Miocene and Tsunozu Formation, late Pliocene (Imamura, 1957; Tanai, 1961).
181. Izumo City (35°23'N, 132°43'E), Shimane Prefecture, Takakubo shale member, Nabeyama Formation, late early Miocene (middle Miocene in Tanai, 1961).

182. Yatsuka (35°30'N, 133°04'E), Shimane Prefecture, Koura Formation, early Miocene (Matsue & Onoe, 1995).
183. Yunotsu (34°57'N, 132°15'E), Shimane Prefecture, Tonotsu Formation, Plio-Pleistocene (Sakanoue & Fujita, 1981).
184. Kitago (ca. 36°40'N, 137°50'E), northwest part of Nagano Prefecture, Kitago Formation, late Pliocene-early Pleistocene (Tomizawa, 1958).
185. Omori, Azano (35°20'N, 137°40'E), Chiyo, Kamome and Ohira near Iida City (35°35'N, 137°50'E), Anan-cho, Nagano Prefecture, Oshimojo Formation, Tomikusa Group, early Miocene (Yokoyama, 1886; Kryshtofovich, 1920; Endo, 1963; Ina, 1988; 1992).
186. Kita-Aiki Village (36°02'N, 138°35'E) 10 km northeast of Yatsugadake, Minami-saku, Nagano Prefecture, Kita-Aiki Formation, Miocene (Nathorst, 1888; Kryshtofovich, 1920, 1930; Endo, 1963).
187. Ozamita and Muroga (ca. 36°25'N, 138°27'E), Chiisagata, Nagano Prefecture, undefined, probably Mio-Pliocene (Kryshtofovich, 1930).
188. Ussawa near Iida City (35°35'N, 137°50'E), Ysasuoka Village, Nagano Prefecture, Awano Formation, Tomikusa Group, early Miocene (Ina, 1988, 1992).
189. Chigisawa River near Iida City (35°35'N, 137°50'E), Anan-cho, Shimoina District, Nagano Prefecture, Nukuta Formation, Tomikusa Group, early Miocene (Ina, 1988, 1992).
190. Ogawa (35°53'N, 138°33'E), Nagano Prefecture, Sashikiri Member, Omi (Ogawa) Formation, middle Miocene (Kryshtofovich, 1930; Kon'no, 1931; Tanai, 1961; Ozaki, 1991).
191. Chausu-yama (35°22'N, 137°08'E), Shinonoi-machi, Nagano Prefecture, probably equivalent to Omi (Ogawa) Formation, middle Miocene (Tanai, 1961).
192. Kamikanezawa, Daigo Town approximately 30 km north of Omiya (36°46'N, 140°17'E), Ibaraki Prefecture, Asakawa and Kitatake Formations, late early to early middle Miocene (Nathorst, 1888; Oyama, 1960; Tanai, 1961; Endo, 1963; Horiuchi, 1996).
193. Hitachi-omiya (36°33'N, 140°24'E), Ibaraki Prefecture, Sakuramoto Formation, late early Miocene (Akutsu, 1952; Huzioka & Uemura, 1979; Horiuchi, 1996).
194. Inube Pass (36°37'N, 140°25'E), Yamagata Town, Ibaraki Prefecture, Asakawa Formation, late early to early middle Miocene (Horiuchi & Takimoto, 2001).
195. Kanasogo Town, Osato area 20 km north of Mito City (36°22'N, 140°29'E), Ibaraki Prefecture, Kume Formation, early Pliocene (Takimoto *et al.*, 1998).

11.11.3. Shikoku

196. Imoo clay bed (34°08'N, 133°45'E). Kamisaita, Saita Village, Kagawa Prefecture, Plio-Pleistocene (Miki, 1950b).
197. Sinme Cliff (34°12'N, 133°40'E), Sogo Village, Nakatado District, Kagawa Prefecture, Plio-Pleistocene (Miki, 1950b).
198. Lignite bed in Teradani (34°00'N, 134°15'E), Sanzi, Moriyama Village, Oe District, Tokushima Prefecture, Plio-Pleistocene (Miki, 1941, 1950b).
199. Numerous localities on Awaji Island (34°11'25"-34°32'48"N, 134°44'01"-134°59'05"E), Yudani, Atago and Goshikihama Formations, Osaka Group, late Pliocene (Momohara & Mizuno 1999).
200. Mizuwakare in the eastern part of Uwajima City (33°03'N, 132°43E), Ehime Prefecture, Takanoko Formation, late Pliocene-early Pleistocene (Mizuno, 1980).
201. Niihama City, Iyo-gun, Ehime Prefecture, undefined (Yagi, 1955).

11.11.4. Kyushu

202. Minami-Arima-cho (32°38N, 130°16'E; syn: Oe), Shimabara Peninsula, Minami-Arima-Village, Minami-Takaki District, Nagasaki Prefecture, Kuchinotsu Group, early Pleistocene (Endo, 1936; Takahashi, 1954).
203. Mogi near Nagasaki (32°42'N, 129°55'E), Nagasaki Prefecture, Mogi plant-bearing Formation, late Pliocene (Nathorst, 1883; Florin, 1920; Tanai, 1961, 1976; Endo, 1963).
204. Kazusa (ca. 32°50'N, 130°00'E), Shimabara, Nagasaki Prefecture, Sasebo Group, Oya Formation, Pliocene (Takahashi, 1954; Matsue & Onoe, 1995).
205. Oshima Colliery, Sasebo City (33°29'N, 129°32'E), Oshima Island, Nagasaki Prefecture, Sakito Formation, Matsushima Group, early Oligocene (Tanai, 1952a; Matsuo, 1970).
206. Kuchinotsu (32°28'N, 130°10'E), Nagasaki Prefecture, Oya and Kitaarima Formations, Kuchinotsu Group, early Pleistocene (Otsuka, 1966).
207. Lignite bed in Yunoso, Kodaragi Village, Kurume City (33°15'N, 130°31'E), Mizuma District, Fukuoka Prefecture, Pliocene (Miki, 1950b; Miki & Kokawa, 1962).
208. Lignite bed in Uchikoshi west of Kuroki Station (33°14'N, 130°39'E), Kitakawachi Village, Yame District, Fukuoka Prefecture, Pliocene (Miki, 1950b; Miki & Kokawa, 1962).
209. Near Nagano and Lake Imuta (31°47'N, 130°28'E; syn: Hiwaki), Kagoshima Prefecture, Nagano flora, Nagano, Koriyama and Tabira

Formations, late Pliocene (Onoe, 1972; Takayama & Hayasaka, 1975; Matsue & Onoe, 1995).

210. Iriki-cho near Yoshida Village (31°36'N, 131°00'E), Kagoshima Prefecture, Yamanokuchi Formation, early Pleistocene (Hase & Hatakana, 1976).
211. Locality about 10 km southwest of Sendai (31°50'N, 130°17'E) and another locality situated about 15 km south of Okuchi (31°43'N, 129°02'E), Kagoshima Prefecture, Daiwa Member, Koriyama Formation and Nagano Formation, late Pliocene (Hase & Hatanaka, 1984).
212. Koriyama Village, Gamou-cho and Hiwaki Village (ca. 31°48'N, 130°25'E), Satsuma Village (ca. 31°55'N, 130°27'E) and Kaseda City (31°20'N, 130°20'E), Kagoshima Prefecture, Kajiki, Gamou and Hayato Formations, Kokubu Group, early Pleistocene (Takaki, 1985, 1986).
213. Yunohara and Shitabarai (32°20'N, 130°45'E), Hitoyoshi City, Kumamoto Prefecture, Hitoyoshi Formation, Pliocene (Miki & Kokawa, 1962).
214. Hoshiwara, Kahoku-cho (33°10'N, 130°45'E), Kumamoto Prefecture, Hoshiwara flora Hoshiwara Member, Tsue Group, Pliocene (Iwao, 1981; Iwao & Matsuo, 1982).
215. Kujyu Village (33°13'N, 131°12'E), Ohita Prefecture, Nogami flora, Hosenji Member, Kusu Formation, Pleistocene (Endo, 1963; Iwao, 1981).
216. Kida, Shinminato, Hino and Nittetsu-Emukae coal mines of the Sasebo coal field near Sasebo (33°10'N, 129°42'E), Nagasaki Prefecture, Ainoura, Yunoki and Fukui Formations, Sasebo Group, early Miocene (Tanai & Onoe, 1956; Tanai, 1961).
217. Higashimatsuura Peninsula (33°32'N, 129°52'E), Saga Prefecture, Hachinokubo gravel bed, Miocene (Matsue & Onoe, 1995).

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