

THE SIERRA REDWOOD (*SEQUIADENDRON*) FOREST: END OF A DYNASTY

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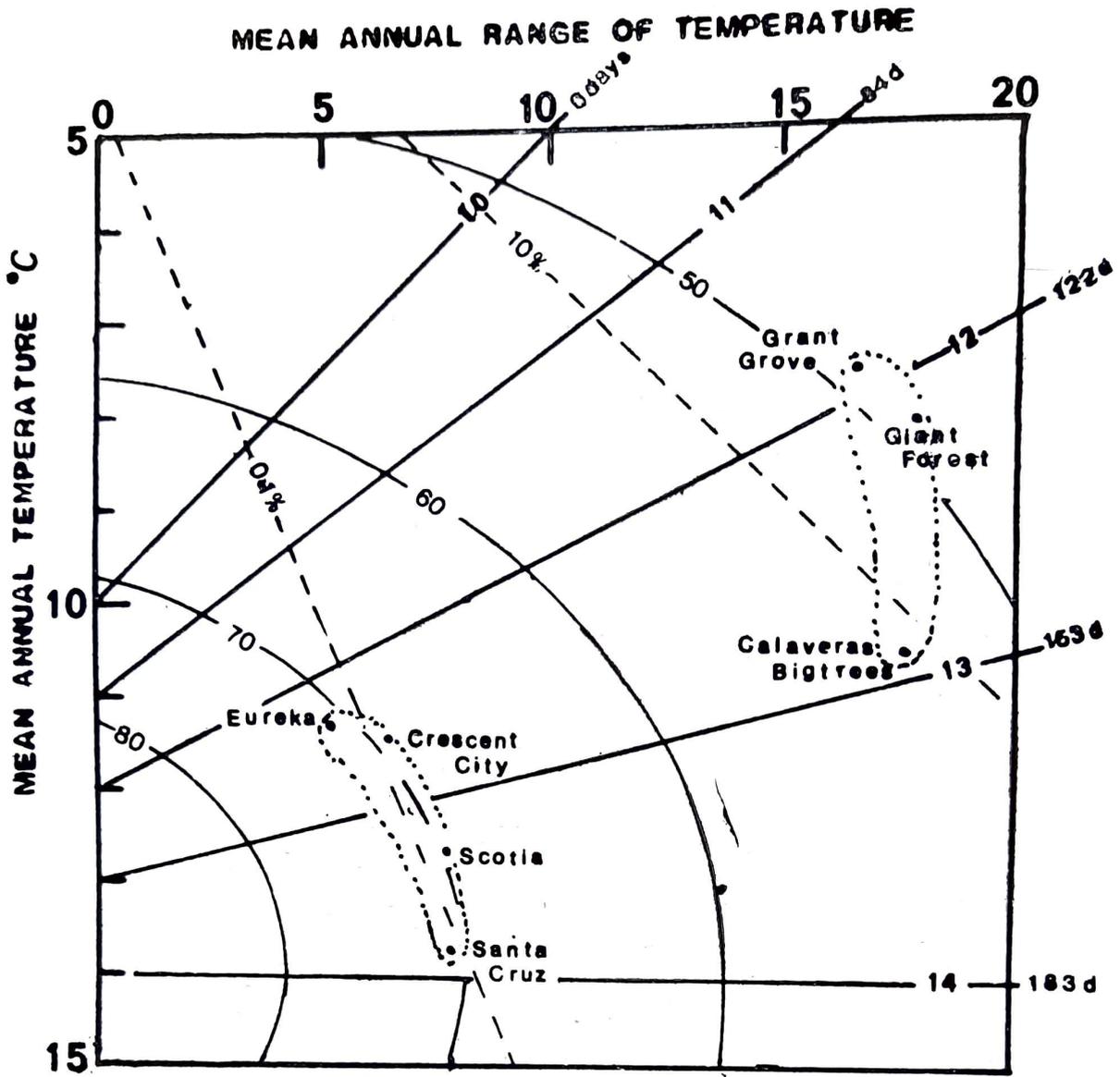
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Paleobotanists have been especially interested in the history of conifers. This derives from their long fossil record that illustrates trends and rates of evolution of taxa, as well as their shifting distribution and changes in their associates during time. Although many conifer genera have a good geological record, for the most part it is preserved in older rocks and usually in areas distant from their nearest living derivatives. *Ginkgo*, restricted now to a few isolated areas in China where it reportedly is in a natural state (Wang, 1961), is scarcely known from Tertiary rocks of the entire region of China. *Metasequoia*, which also has a long Cretaceous and Tertiary record in high and middle latitudes, is recorded from only a couple of fossil localities in China where it survives in a few isolated valleys south of the Yangtze gorge (Bartholomew *et al.*, 1983). The coast redwood (*Sequoia*) of California also has a fair fossil record in older rocks, yet its later history is highly fragmentary in the western United States. On the other hand, Sierra redwood (*Sequoiadendron*) is known from the Late Cretaceous and Early Tertiary rocks of high latitudes and is in the Neogene of western Europe as well as in the western United States (see Florin, 1963). In the middle and later Miocene (18-6 m.y. ago) it is recorded at a dozen localities now in the Nevada desert and on its borders, sites scarcely 100 miles (160 km) from the relict stands now on the western slope of the Sierra Nevada (Text-fig. 1). In the light of new fossil records of the species, and a better understanding of the nature of terrain and climate during the Miocene and later, it is appropriate to update the later history of this relict tree (Axelrod, 1959).

The Present Forest

Sequoiadendron occupies the western humid middle slopes of the Sierra Nevada where it locally dominates the mixed conifer forest. The trees prefer moister flats and swales where evaporation is generally low. Its regular associates include *Abies concolor*, *Calcedrus decurrens*, *Pinus ponderosa*, *P. lambertiana* and, at the north, *Pseudotsuga menziesii* and (rarely) western yew, *Taxus brevifolia*. Common associated trees and shrubs include *Acer glabrum*, *Alnus rhombifolia*, *Chrysolepis* (*Castanopsis*) *sempervirens*, *Lithocarpus densiflora* var. *echinoides*, *Quercus chrysolepis*, *Q. kelloggii*, *Q. vaccinifolia*, *Rosa* spp., *Salix lemmonii*, *S. nuttallii*, *Ceanothus integerrimus*, *Chamaebatia foliolosa* and *Cornus nuttallii*.

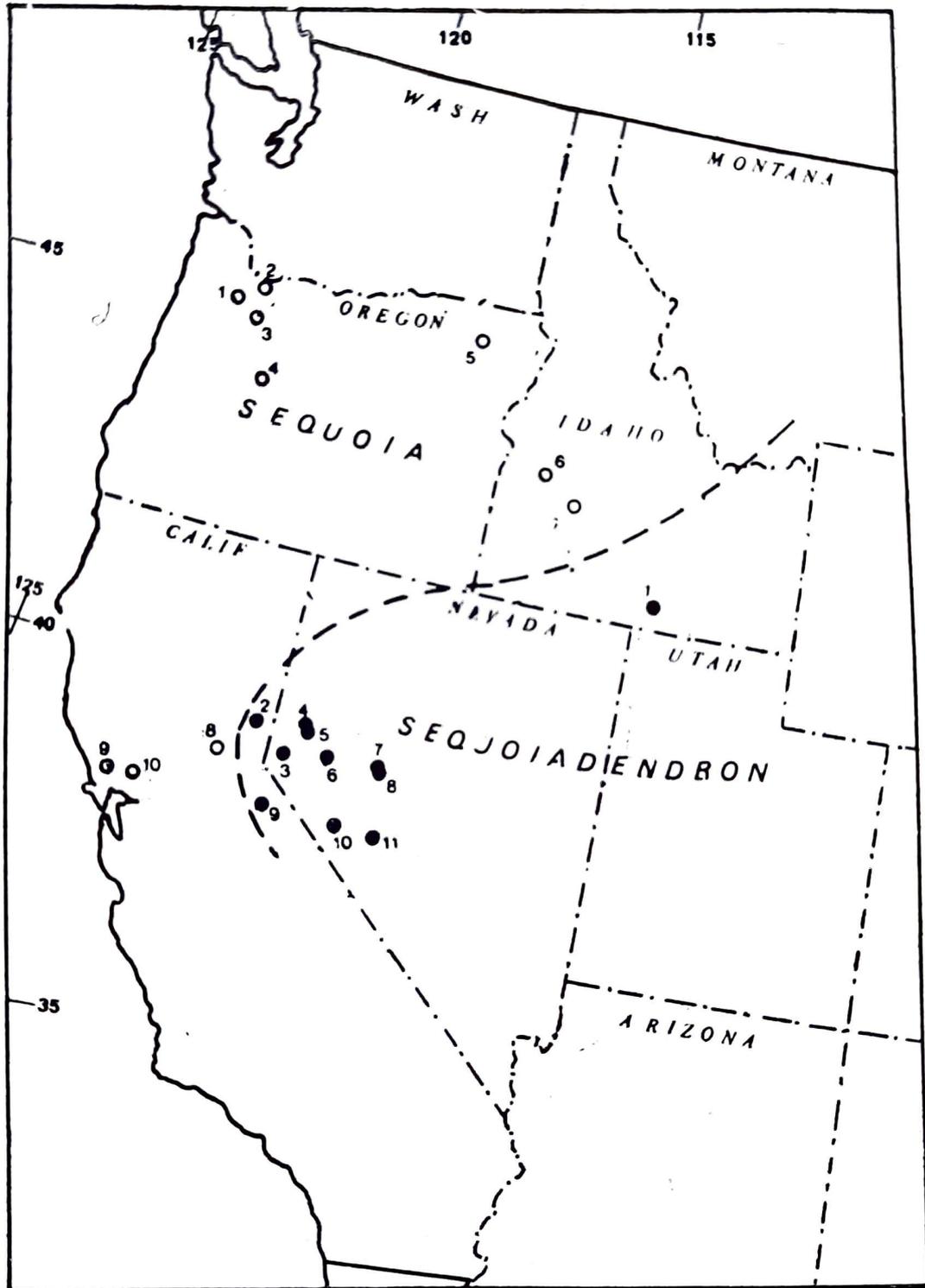
At higher elevations the mixed forest with *Sequoiadendron* merges into fir forest, composed of *Abies magnifica*, *A. concolor*, and with *Pinus murrayana*, *Populus tremuloides*, *Sorbus sitchensis* in cold pockets. Common associated shrubs in this zone include *Chrysolepis sempervirens*, *Ceanothus cordulatus*, *Quercus vaccinifolia*, and *Ribes viscosissimum*. At lower elevations, especially in the south, *Sequoiadendron* is associated with broad-leaved sclerophyll vegetation that includes *Ceanothus cuneatus*, *Cercis occidentalis*, *Cercocarpus betuloides*, *Quercus chrysolepis* and *Torreya californica*.



Text-fig. 1—Comparison of the thermal fields of *Sequoia* and *Sequoiadendron*. Radiating lines indicate warmth of climate, defined by the number of days(d) equal to or warmer than the stipulated temperature. Arcs represent a measure of the equability of climate. Dashed lines indicate forest frequency as % of the hours of the year subject to freezing.

Precipitation occurs chiefly in winter. Although there are occasional summer thunderstorms in the southern Sierra Nevada, they add little moisture to the soil owing to the high evaporation rate. Winter precipitation is chiefly as snow though winters are not severe. The lowest recorded temperatures are -4 to -6°F (-20° to -21°C) and the mean January temperatures range from 32°F (0°C) at Giant Forest to 37°F (2.8°C) in the Calaveras Bigtrees. Temperatures are somewhat lower where it meets fir forest and snow persists longer at the higher level. The species occupies a climate that is less equable than that of coast redwood (*Sequoia*) of the foggy coastal strip where the range of temperature is much lower (Text-fig. 1). Although the temperature regimes of these areas are very different, the forests have generally similar warmth values. *Sequoiadendron* occupies an area between W 12-13 $^{\circ}\text{C}$ (121 to 153 days with these mean temperatures or higher), whereas warmth in the area of *Sequoia* ranges from W 11.3 to W 13.8 $^{\circ}\text{C}$ (97-177 days equal to or warmer than those temperatures). Judging from their separate distri-

butions in the Miocene (Text-fig. 2), *Sequoiadendron* situated farther in the interior and south of *Sequoia* was in a more extreme climatic region. As a result it had fewer associated exotic taxa, fewer mesic species, and more numerous sclerophyllous taxa from sub-humid sites.



Text-fig. 2—During the Neogene the areas occupied by *Sequoia* and *Sequoiadendron* were mutually exclusive. *Sequoia* lived farther north and coastward, in a region of moister, milder climate.

Sequoia localities are 1. Collawash, 2. Troutdale, 3. Mollala, 4. Hidden Lake, 5. Blue Mountains, 6. Payette, 7. Thorn Creek, 8. Remington Hill, 9. Sonoma, 10. Napa. *Sequoiadendron* localities are 1. Trapper Creek, 2. Webber Lake, 3. Chalk Hills, 4. Peterson Canyon, 5. Purple Mtn., 6. Fallon, 7. Middlegate, 8. Eastgate, 9. Mt. Reba, 10. Aldrich Station, 11. Fingerrock.

Cretaceous-Paleogene history

Sequoiadendron has been recorded at numerous sites in high latitudes in rocks of Upper Cretaceous and Paleocene-Eocene age (Florin, 1962). However, those species (*S. reichenbachii*, *S. couttsiae*) differ sufficiently from the living *S. giganteum* to indicate that they are not directly ancestral to it. These older fossil species regularly have smaller cones and their foliage is more lax than that of the present tree. Also, most of the associates of these older big trees differed considerably from those of the present community. They included numerous deciduous hardwoods, distributed in species of *Acer*, *Alnus*, *Betula*, *Castanea*, *Cercididphyllum*, *Diospyros*, *Fagus*, *Liquidambar*, *Tilia* and others that occur now in eastern North America or eastern Asia, areas with ample summer rainfall. Many of the hardwoods produced larger leaves than their nearest modern relatives which occur now in middle latitudes. This may be attributed to the long photoperiod to which they were adapted and that encouraged ample growth, much as cultivated crops (e.g. cabbage, strawberries, etc.) respond to those conditions at high latitudes today (i.e. Matanuska Valley, Alaska). The associated conifers were chiefly those of mild temperature requirements, notably *Ginkgo*, *Metasequoia* and *Taxodium*. Montane conifers, as *Abies*, *Picea*, *Pinus* and others were also present, but apparently lived chiefly on cooler, bordering slopes as judged from their rarity in the deposits.

Miocene and later history

As cooler climate spread over higher latitudes following the Late Eocene *Sequoiadendron* shifted into middle latitudes. Its associates in the Miocene of western Europe were largely similar to those that occurred with it in the Eocene to the north, though the species are more nearly allied to present day taxa. These included numerous deciduous hardwoods and mesic lowland conifers (e.g. *Glyptostrobus*, *Metasequoia*, *Taxodium*) that occur today in areas where there is ample summer rainfall and winters are relatively mild. By the Miocene, *Sequoiadendron* was in western Europe but evidently was rare in eastern Asia; at least records of it there are not common. Its latest occurrence in Asia appears to be in the Pliocene of Japan.

In the western United States, *Sequoiadendron* is now known from the Late Oligocene of south-central Idaho, and from the Miocene of southern Idaho and western Nevada. The latter records from the Miocene provide evidence of its later history, notably its shift to the Sierra Nevada and the segregation of the modern community from the richer Neogene forest. The gradual rise of the modern forest from that of the Miocene appears explicable on the basis of the responses of plants (changing physiologic-genetic relations) to modifications in climate. In the western United States, following the wide occurrence of moist, marginal tropical to temperate climates of Paleocene and Eocene times, there was a secular trend to a gradual reduction in total rainfall, a shift in seasonal distribution from ample summer rain early in the period to its progressive reduction and elimination over much of the region at the end of the Tertiary. This was accompanied by an increase in the frequency and amount of winter precipitation. In concert with this there was a gradual development of hotter summers with a higher evaporation rate and winters shifted from mild and essentially frostless over wide areas early in the Cenozoic to colder at the close of the period. These progressive changes appear to account for the shift of the *Sequoiadendron* community from the western interior to the Sierra Nevada by the later Miocene; for the elimination from the late Tertiary community of a number of species whose ranges of tolerance for summer rain, or summer heat, or winter cold, were exceeded; for the

persistence in the Sierra Nevada of part of the flora as the new Mediterranean climate developed; and for the gradual rise to dominance during the late Cenozoic of conifers that formerly had a subordinate place in the ancestral forest.

In terms of their composition, the Miocene floras of Nevada and border areas with *Sequoiadendron* represent two different groups. They provide evidence of the gradual emergence of the modern community associated with Sierra redwood. The floras of Middle Miocene age (18-14 m.y.) have more numerous exotic taxa than do the younger floras. They are also more mesic in their indications as judged from the taxa associated with them. Representative exotics in these older floras include:

Trapper Creek, southern Idaho : *Halesia*, *Hydrangea*, *Ilex*, *Nyssa*, *Parthenocissus*, *Pterocarya*, *Sassafras*, *Sophora*, *Ulmus*, *Zelkova*.

Eastgate-Midlegate, western Nevada: *Aesculus*, *Cedrela*, *Diospyros*, *Eugenia*, *Gymnocladus*, *Hydrangea*, *Platanus*, *Robinia*.

Fingerrock, southwestern Nevada : *Carya*, *Diospyros*, *Eugenia*, *Gymnocladus*, *Robinia*, *Ulmus*, *Zelkova*.

Golddyke, southwestern Nevada : *Aesculus*, *Carya*, *Eugenia*, *Malus*, *Magnolia*, *Robinia*, *Ulmus*, *Zelkova*.

These floras have fewer exotic genera than floras of similar age farther north, as the Mascall, Latah, Grand Coulee and others with fully 60% exotics. For the most part this reflects their more northerly position in a moister climate, and especially one with ample summer rainfall. In addition to the exotic genera, some fossil species in these floras are also exotic, allied to taxa now in the eastern United States or eastern Asia. These are distributed in *Acer* (*pictum*, *rubrum*, *saccharinum*), *Betula* (*luminifera*, *papyrifera*), *Crataegus*, *Populus* (*heterophylla*), *Quercus* (*prinus*) and *Sorbus* (*aucuparia*). Associates of these exotics in the floras with *Sequoiadendron* also include a number of species now in the forests of California, Oregon and Idaho but no longer contribute to the Sierra redwood community. They are represented by fossil species allied to *Abies grandis*, *Chamaecyparis lawsoniana*, *Larix occidentalis*, *Picea breweriana*, *Tsuga mertensiana*, *Paxistima myrsinites*, *Populus balsamifera*, *Rhamnus purshiana* and *Mahonia aquifolium*.

Also present in these floras are a few taxa whose nearest descendants are now in the Rocky Mountains, notably species allied to *Acer grandidentatum*, *A. diffusum*, *Betula fontinalis*, *Populus angustifolia*, and *P. balsamifera*. There also are records in Nevada of a Douglas fir more nearly allied to the Rocky Mountain *Pseudotsuga glauca* than to *P. menziesii* of the Pacific slope. In addition, a few taxa are similar to species now in southern California (i.e. *Lyonothamnus*) or northern Mexico (*Populus brandegeei*).

These Middle Miocene floras of Idaho and Nevada do have a number of species similar to those now in the *Sequoiadendron* forest. These include *Abies concolor*, *A. shastensis*, *Calocedrus decurrens*, *Pinus ponderosa*, *Lithocarpus densiflorus*, *Quercus chrysolepis*, *Q. kelloggii*, as well as diverse shrubs similar to *Amelanchier alnifolia*, *Chrysolepis sempervirens*, *Cercocarpus betuloides*, *Ceanothus integerrimus*, *Cornus nuttallii*, *Prunus demissa*, *P. emarginata*, *Populus hastata*, *P. tremuloides*, *Salix lemmonii*, and *S. scouleriana*. It is amply clear that the Middle Miocene *Sequoiadendron* floras were much richer in taxa than the modern forest.

By contrast, the Late Miocene floras, radiometrically dated (K/Ar) at 13-12 m.y., have few or no exotic genera:

Aldrich Station, west-central Nevada : *Ulmus*, *Zelkova*

Fallon, west-central Nevada : *Sophora*

Chalk Hills, western Nevada : *Carya*

Purple Mountain, western Nevada : (none)

Chloropagus, west-central Nevada : *Robinia*

Exotic species in these younger floras are distributed in the Pacific Coast region, but in areas well removed from *Sequoiadendron* :

Abies bracteata : Santa Lucia Mountains

Aesculus palmeri : northern Baja California

Chamaecyparis lawsoniana : Klamath Mountains

Fraxinus velutina : South California-Southwest United States

Lyonothamnus asplenifolius : insular South California

Populus angustifolia : eastern Nevada-Colorado

Populus brandegeei : northern Mexico

These younger floras have more numerous species related to those in the forest today (see above), as well as taxa from warmer sites on its margins:

Acer macrophyllum

Cercis occidentalis

Arbutus menziesii

Cercocarpus betuloides

Chrysolepis chrysophylla

Lithocarpus densiflorus

Quercus chrysolepis

It is apparent that there was a major shift in the nature of the associates of *Sequoiadendron* between 18-14 and 13-12 m.y. ago and later. This may be attributed to the rapid decrease in summer rainfall as implied by the drastic reduction of taxa now in summer-rain areas of the eastern United States, eastern Asia, or Mexico. The marked shift in composition, although recognized many years ago (Axelrod, 1973, fig. 2), was then unexplained. The change appears to have resulted from the spread of the East Antarctic ice-sheet which rapidly chilled the ocean basins. With colder water upwelling along the west coasts, summer rainfall would decrease, as indicated by the rainfall trend (Text-fig. 3). This resulted since air moving over the colder water onto the warmer land would be inherently stable, resulting in decreased summer precipitation. Marine air now moving onto land would provide coastal strips with summer fog, an environment in which a number of taxa persisted much longer than in the interior. This is shown by the late occurrence of genera such as *Ilex*, *Magnolia*, *Nyssa*, *Persea*, *Trapa* and *Ulmus* into the Pliocene of coastal California and also along the margins of the Central Valley of California where *Magnolia*, *Persea*, *Sapindus* and others are recorded (Axelrod, 1944a, 1944b, 1980).

During the time 13-12 m.y. ago, vegetation over the lowlands of western Nevada was more nearly like that now in the southern *Sequoiadendron* groves at their lower elevation where sclerophyllous taxa of warmer requirements are more abundant. These were allied to species of *Ceanothus*, *Cercocarpus*, *Cercis*, *Fraxinus*, *Lyonothamnus*, and *Quercus*. Some conifers associated with these younger Miocene floras with *Sequoiadendron* are allied to species now in the more mesic parts of the mixed conifer forest or in its more equable areas, among these may be noted :

Abies bracteata, in the Santa Lucia Mts. bordering the coast.

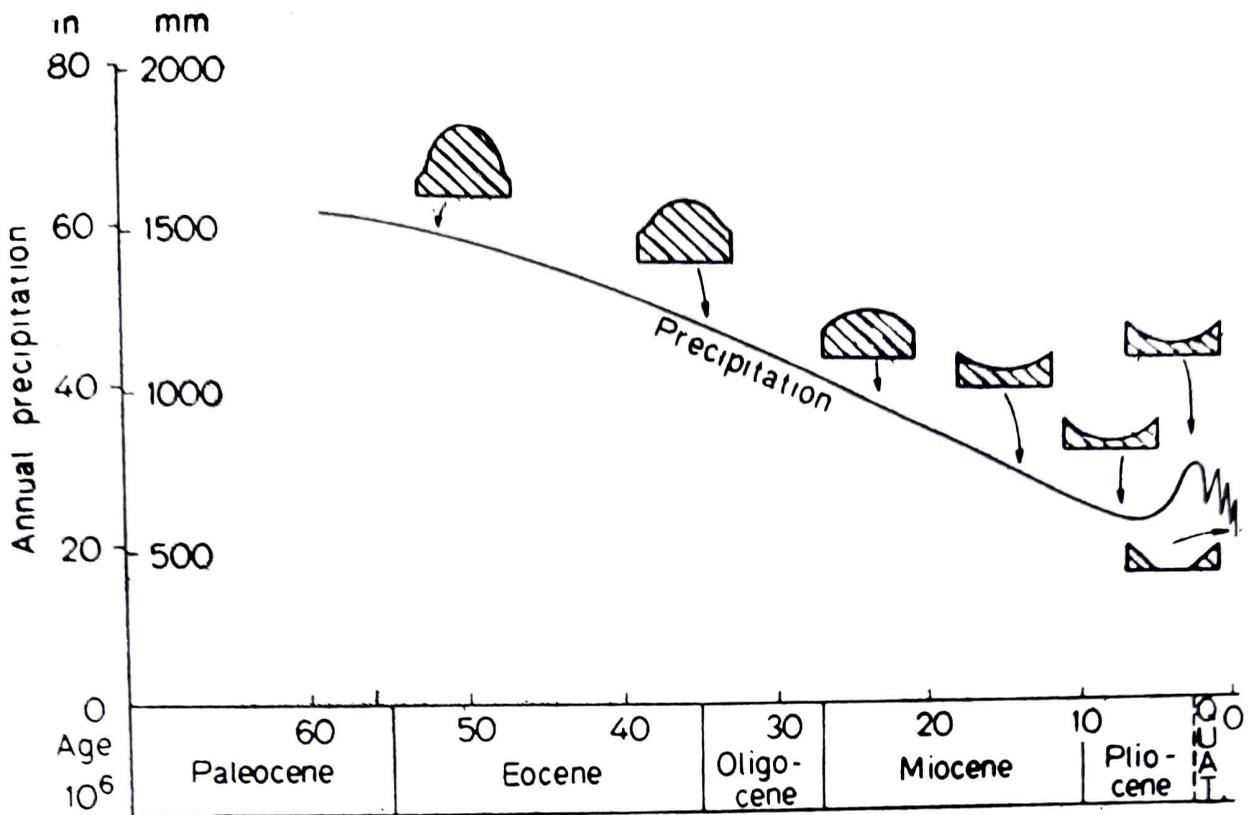
Chamaecyparis lawsoniana, in the Klamath Mountain region, northwestern California.

Picea breweriana, in the Klamath Mountain region.

Pinus balfouriana, in the Klamath Mountain region and the southern Sierra Nevada.

Abies shastensis, in the Klamath Mountain region and the southern Sierra Nevada.

All these conifers were associated with *Sequoiadendron* in the Purple Mountain flora, situated in the Truckee River canyon 25 miles east of Reno, Nevada. The flora



Text-fig. 3—Rainfall trend in California and border areas. Note the marked decrease in summer precipitation in the later Miocene, now closely dated at 13 m.y. Duration of the Miocene has now been extended up to 5 m.y. (from Axelrod, 1973).

also includes sclerophyllous taxa, notably species of *Quercus* (cf. *chrysolepis*), *Cercocarpus* (cf. *betuloides*), *Chrysolepis* (cf. *chrysophylla*) and others that lived in this now-desert region where yearly precipitation totals scarcely 5 inches.

The youngest Neogene record of *Sequoiadendron* now known is in the Mt. Reba flora, at 8,600 ft. (2,625 m) near timberline in the central Sierra Nevada (Axelrod, 1980). The deposit is 6-7 m.y. old on the basis of K/Ar dating of the associated andesite mudflow breccia. The flora represents a forest much like that now on the lower slopes of the central to northern Sierra Nevada. Broadleaved sclerophyll taxa, notably tan-oak (*Lithocarpus densiflorus*) and maul oak (*Quercus chrysolepis*) dominate the flora together with Douglas fir (*Pseudotsuga menziesii*). Mixed conifer forest taxa are exceedingly rare for only 7 specimens were recovered from a total of over 1,000 examined. These include *Abies concolor*, 1 cone scale, 2 needles; *Sequoiadendron*, 2 small twigs; *Pinus lambertiana* and *P. ponderosa*, 1 fascicle each. The vegetation at Mt. Reba was much like that now in the drainage of the Yuba River below Camptonville. There the mixed conifer forest lives on slopes above sclerophyll vegetation at an altitude near 2,500 ft (760 m), and most of the nearest living allies of the fossil species are there. Since the deposition of the structures representing the flora, which is overlain by a giant-boulder conglomerate on the ridge crest scarcely 10 feet (3 m) above the fossil flora, the Mokelumne River gorge has been entrenched fully 4,500 ft (1,370 m), chiefly since 4-5 m.y. ago.

Although we find a near-modern *Sequoiadendron* forest in the Sierra Nevada about 6 m.y. ago, there were important differences as compared with the modern community. Among its exotics were cypresses allied to a species now in Mexico, and an elm (*Ulmus*) related to species now in the eastern United States. Both imply some summer rainfall

was still in the area. This agrees with the occurrence of *Magnolia*, *Persea*, *Ulmus* and other relicts in the coastal region at this time as well as on the low Sierran piedmont where *Persea*, *Sapindus* and others are recorded (Axelrod, 1944a, 1980). Comparable taxa had largely disappeared from western Nevada by this later date. The evidence suggests that following accumulation of the Mt. Reba flora, the Sierra Nevada in this area was elevated fully 6,000-7,000 ft. This was chiefly in the later Pliocene and Quaternary as judged from glacial tills displaced over 4,000 ft in the Mammoth region, and by comparable amounts in the area from Lake Tahoe southward to Sonora Pass. Progressive uplift of the Sierran block formed an increasingly more effective rainshadow over areas to the east. This gradually eliminated forest cover from the Nevada lowlands, restricting it to the east Sierran slope for the most part. Uplift and the concurrent decrease in precipitation favoured the spread over the Nevada lowlands of the pinon-juniper woodland that was already in the area in the late Miocene, when it was confined chiefly to more exposed, drier slopes. Relict sites for the mixed forest no doubt occurred in the rising ranges over the Great Basin wherever there was still adequate moisture. Stated another way, communities earlier on the drier borders of the mixed conifer forest commenced to spread as the mesic forest taxa retreated in response to the trend to drier climate. The trend to aridity, although in part attributable to uplift of the Sierran block, also reflects the driest part of the Tertiary. At this time, sequences of floras both to the east and west of the range show a similar trend to drier conditions, and then a return to moister climate in the late Pliocene (Axelrod, 1957; 1980). The marked shift to drier climate, recorded also in the High Plains (see Axelrod, 1980), may be related to the spread of the West Antarctic ice cap. With the introduction of additional cold water into the ocean basins the resultant decrease in summer rainfall in areas where it was already somewhat deficient for exotic genera and species would have accentuated aridity over the region, as recorded in the sequences of fossil floras.

The trend to drier climate 5-6 m.y. ago resulted in a near-modern east slope flora, as indicated by the composition of the Verdi flora from the east front of the Carson Range a few miles west of Reno, Nevada (Axelrod, 1958). Dated at 5 m.y., it still has a few taxa that are now on the milder, west slope of the Sierra Nevada, or in near-coastal areas, notably species similar to *Pinus attenuata*, *Acer macrophyllum*, *Ceanothus cuneatus*, *Quercus wislizenii*, *Populus trichocarpa* var. *trichocarpa*, and *Salix gooddingii*. Typical members of the east-side forest include fossils allied to *Pinus lambertiana*, *P. ponderosa*, *Arctostaphylos nevadensis*, *Populus tremuloides*, *Prunus emarginata*, *Ribes roezlii*, and *Salix scouleriana*. In addition, *Populus angustifolia* represents a taxon now in the eastern Great Basin and Rocky Mountains, and an aspen is allied to *P. tremula* of eastern Asia.

The subsequent history of the forest is largely conjectural. As the forest was confined to the Sierra Nevada it probably was well distributed at moister levels where it was associated with most of its present species. Taxa now in the moister phase of the forest to the north (e.g. *Pseudotsuga*), or on its margins at lower, warmer levels (i.e. *Acer macrophyllum*, *Arbutus menziesii*, *Chrysolepis chrysophylla*, *Lithocarpus densiflorus*) probably were more widespread then since there was some summer rainfall into the close of the Tertiary, and temperatures were moderate. As winter temperatures were lowered taxa of the sclerophyll forest gradually were confined to lower levels. Species that earlier were in the forest, but are represented by species now in the Kalmath Mountain region noted above, probably were restricted northward as summer precipitation decreased and as yearly precipitation was generally lowered during the Pliocene; any relicts probably were eliminated as the range was glaciated. It seems likely that *Sequoiadendron* was then, as today, confined chiefly to moister swales and broad, well-watered valleys together with its present associates

that prefer moister sites, and with the pines on drier, more exposed slopes together with oaks and their usual associates.

As suggested earlier by John Muir (1876), glaciation greatly affected the distribution of the groves. As he noted, the present stands are situated in the rolling uplands away from the deep valleys of the Tule, Kern, Kaweah, San Joaquin, Merced, Tuolumne, and Stanislaus rivers down which the glacial tongues reached to middle altitudes. While this no doubt disrupted the continuity of the forest, it does not wholly explain the present discontinuous and patchy occurrence of the groves (Text-fig. 4). There are numerous sites—open meadows in the forest, broad open swales with ample moisture (seepages, springs)—where conditions appear adequate for these forest giants but they are not there. By contrast, their regular associates, white fir, yellow pine, sugar pine, incense cedar, black oak, etc. have an essentially continuous distribution throughout the range. The present disjunct groves in the rolling uplands of the central and southern Sierra may have developed in response to the drier, warmer climate of the Xerothermic period, some 8,000–4,000 years ago.

As judged from its effect on vegetation elsewhere in California, this warmer, drier period probably had an important role in restricting the groves to the most favourable sites. Many plant communities and their diagnostic taxa were disrupted by warmer, drier climate following the last glacial. Among the examples previously noted (Axelrod, 1960, 1981), we recall the following.

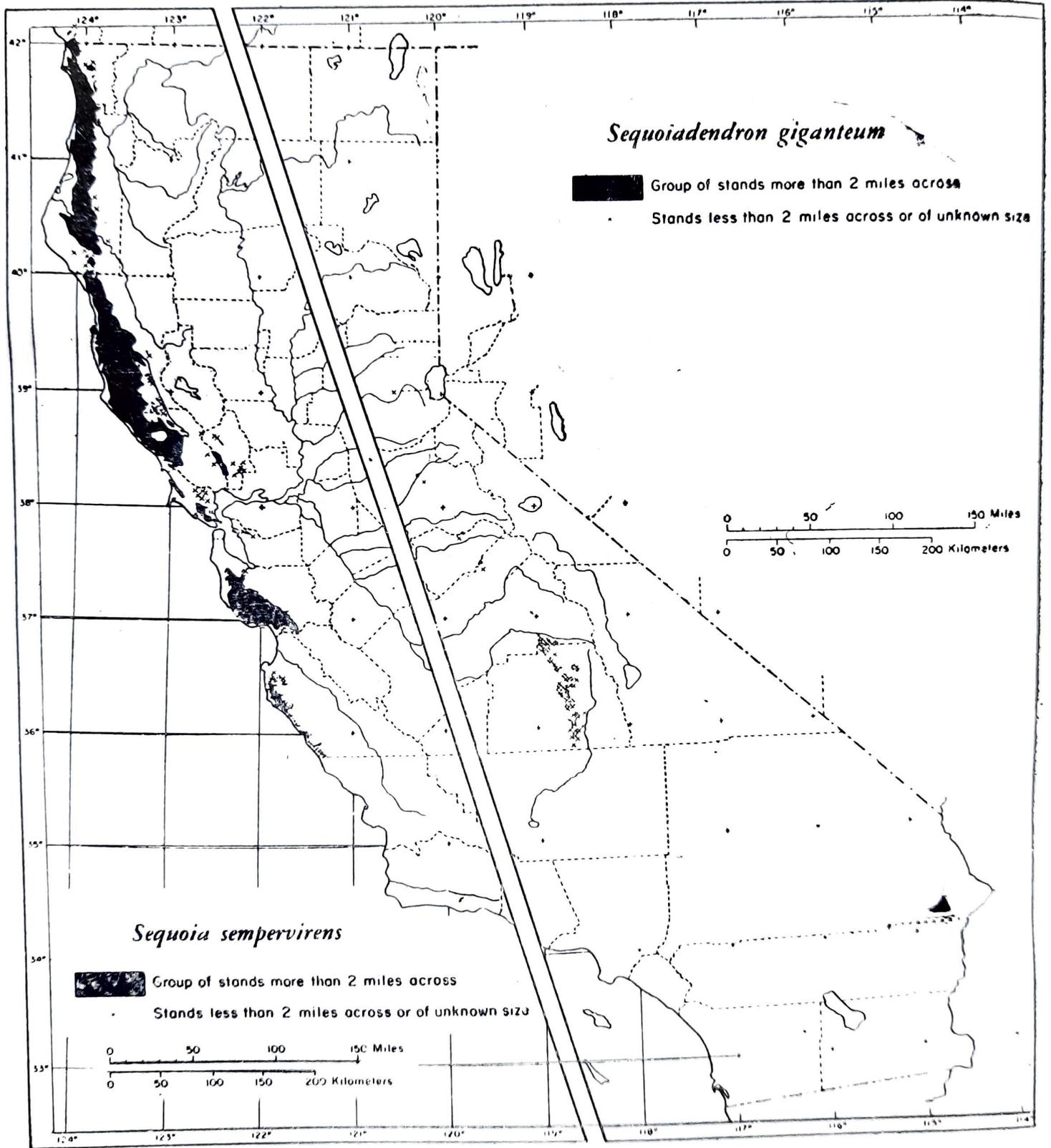
Desert taxa—A number of shrubs and semi-shrubs of the present Mohave Desert are widespread in the southern San Joaquin valley, as are several animals also typical of the desert area. Among these are kit fox (*Vulpes macrotis*), yucca night lizard (*Xantusia vigilis*) and desert scaly lizard (*Sceloporus magister*).

Juniper woodland—There is an isolated patch of *Juniperus californica* in the foothills between San Bernardino and Redlands, well removed from the main population on the desert slopes of the San Bernardino Mountains. Juniper and many of its associates also range well north in the inner Coast Ranges to Mount Hamilton and Mount Diablo, a distribution of post-glacial age. The isolated stand on Figueroa Mountain north of Santa Barbara is also a relict of this distribution.

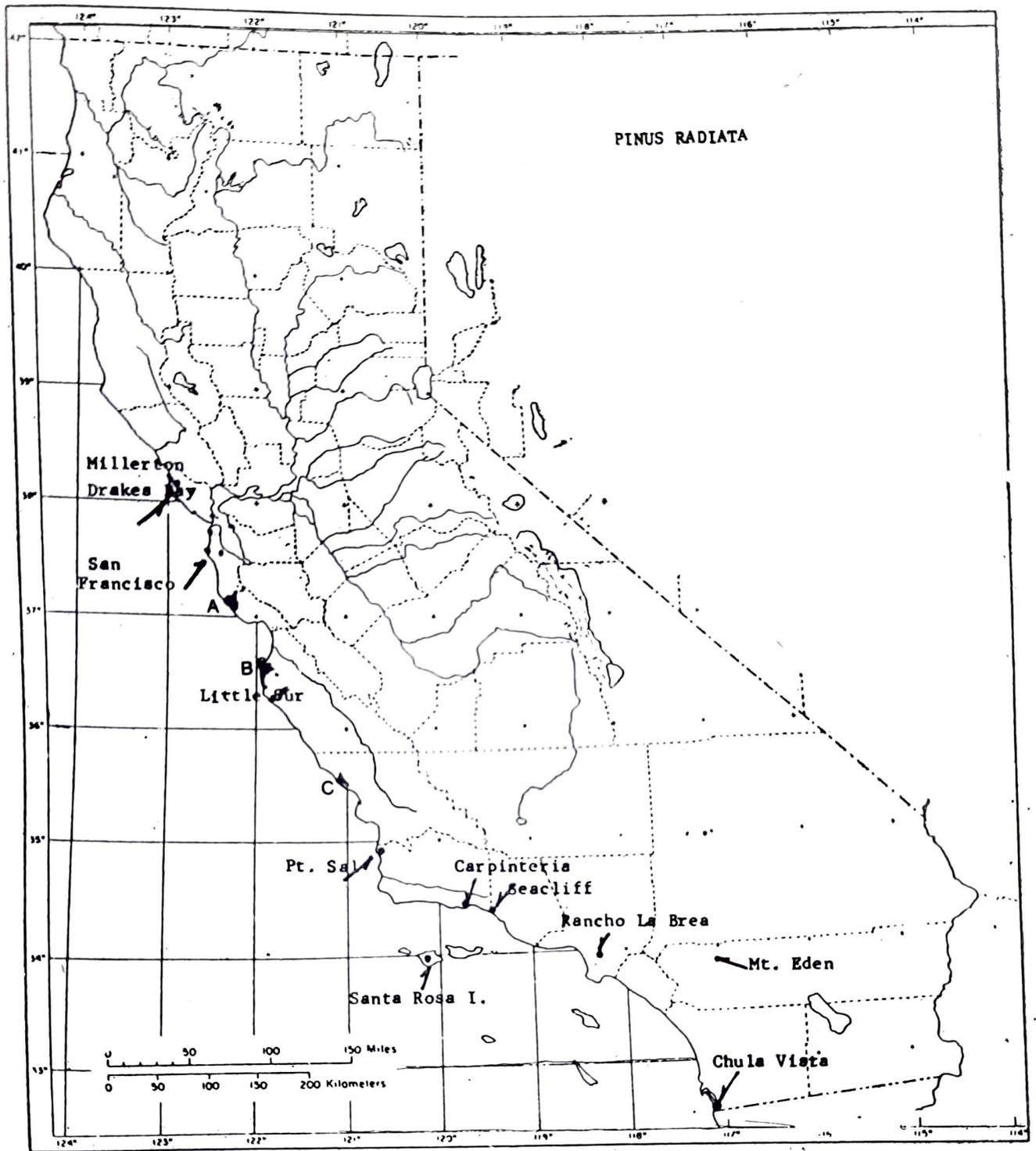
Digger pine woodland—This distinct woodland, dominated by *Pinus sabiniana*, *Quercus douglasii* and *Q. wislizenii*, has an isolated occurrence in Santa Ynez valley some 30 miles south of its normal distribution in the south Coast Range. It commonly disjunct in the Sierra Nevada, in sites wholly surrounded by mixed conifer forest. There is a large stand on Hat Creek north of Mount Lassen, isolated from the community in the Central Valley by fully 40 miles of mixed conifer forest. There also are isolated stands in the Trinity River gorge, well removed from the main area of woodland in the Central Valley by a broad stretch of mixed conifer forest. Although digger pine is chiefly of interior occurrence in an area characterized by very hot summers, it also occurs on the mild, equable coastal slope of the Santa Lucia range near Gorda, within sound of the pounding surf of the Pacific.

Closed-cone pine forest—*Pinus radiata* and *P. muricata* had a more continuous distribution on the central and southern California coast into the last glacial as judged from deposits of their cones dated in the range of 15,000–12,000 year B.P. At present there are only 3 groves of Monterey pine (*P. radiata*) in coast-central California. Yet its late Pleistocene sites occur widely along the coast (Text-fig. 5), as do those of bishop pine.

Mixed conifer forest—There are numerous isolated stands of this forest in the central and south Coast Ranges and in southern California. Their outstanding feature is that the



Text-fig. 4—Comparison of the present areas of *Sequoia* and *Sequoiadendron* (from Griffin & Critchfield, 1972).



Text-fig. 5—*Pinus radiata* occurs today in California at A. Año Nuevo, B. Monterey, and C. Cambria. Its Late Pleistocene and Pliocene (Chula Vista, Mount Eden) localities indicate a much wider distribution in the past. Its post-glacial restriction probably resulted from the warm, dry xerothermic climate.

species differ from area to area, yet conditions seem adequate for all of the regular species of this mixed forest. The disjunct taxa can not be explained by a long distance dispersal. Judging from the Pleistocene records of the forest, which certainly was widely spread over the lowlands, the present disjunctions probably reflect the upward restriction of the forest as drier climate spread over lower altitudes, and different forest species were eliminated from various ranges (Axelrod, 1981).

In view of these and other disjunct occurrences (see Griffin & Critchfield, 1972 for distribution maps) that appear to be explicable as a result of the Xerothermic period, it is

concluded tentatively that the present restriction of Sierra redwood to isolated sites may also have occurred during the Xerothermic. That its present state is a precarious one is amply clear.

The future

Under present conditions, the scattered stands of Sierra redwood (Text-fig. 4) are certainly on the road to extinction. This is the result of continued fire suppression by the U. S. Forest Service and National Park Service. With few or no natural fires, which clear the forest floor and let in ample light, the associated trees and shrubs continue to grow and produce progressively denser shade and deeper litter. This applies especially to white fir (*Abies concolor*) which produces sufficient shade so that it outcompetes pine and also eliminates *Sequoiadendron* seedlings that require ample light and shallow soil with little litter to germinate and grow (Fowells, 1965). Since they are intolerant of shade, at present there is little or no natural reproduction of these forest giants. Today abundant reproduction is found only about the margins of some meadows, or along forest roads where the soil has been disturbed and there is ample light. Unless the forest groves are opened by clearing, or controlled burning, these forest giants--some of which are over 3,000 years old, and whose ancestry reaches back fully 70 million years--will all be gone within a few hundred years, or possibly less. If the groves are to be perpetuated for future generations to enjoy, something drastic must be done, and immediately.

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