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Tertiary Floras and Topographic History of the Snake River Basin, Idaho

Abstract: During Eocene time a volcanic field was built up on a north-south axis that had persisted since mid-Cretaceous in the region from central Idaho into Nevada. Eocene subalpine conifer forest recovered from the higher parts of the axis implies a minimum altitude near 4000 ft. and structural evidence suggests that locally some peaks may have been 2000 ft higher. The successive appearance of conifer-deciduous hardwood forest, mixed deciduous hardwood forest, and evergreen broadleaved forest to the east and west of the central axis indicates lower altitudes and warmer climates there.

Cross-collapse of the axis at the site of the Snake River Plain probably commenced during the Oligocene because the basin was present by Miocene time. This is shown by Miocene floras from the trough that represent deciduous hardwood forest, whereas those on its flanks comprise conifer-hardwood forest, indicating higher altitudes and cooler climates there.

The Snake River basin appears to be a tensional rift that widened and deepened as the Idaho batholith drifted northward (Hamilton and Myers, 1966). This movement, which presumably initiated collapse of the Cretaceous-Eocene divide during Oligocene time and has continued down to the present, was accompanied by uplift of the bordering highlands of approximately one mile.

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INTRODUCTION

The Snake River basin is an arcuate trough 400 miles long and 100 to 150 miles wide that stretches across southern Idaho from Wyoming into eastern Oregon (Fig. 1). The central part of the basin, the Snake River Plain, has an altitude near 6000 ft in the east and 2100 ft in the west, and lies from 5000 to 6000 ft below the bordering highlands. These include the highest ranges in the region, most with peaks exceeding 11,000 ft in altitude. Since the Snake River Plain represents a major tectonic depression, considerable information has been assembled concerning it. Nonetheless, two important general questions relating to its history remain

unanswered: When did the basin come into existence? What was the general altitude and topography of the region prior to subsidence? Provisional answers to these questions are suggested by the altitudinal relations of Eocene and Miocene floras preserved in sedimentary rocks associated with volcanic sequences exposed in and around the Snake River basin. Prior to discussing them, we should recall certain salient geologic features of the region that relate to an interpretation of its early history.

ACKNOWLEDGMENTS

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Science Foundation (Grants GI 4926).

The manuscript has been criticized by Harry P. Bailey, Ralph W. Ch. Hamilton, and Harry D. MacC. whom have offered constructive criticisms that have improved it.

GENERAL GEOLOGIC SETTING

Regional tectonic (Cohée and Stose, 1932) and geologic (Stose, 1932) maps of the Snake River basin coincide with the east end of a V-shaped Cenozoic trough that widens to the west, spreading into northwestern Nevada and California, and northward into Oregon. This volcanic field, dotted with recently active cones, rests on igneous rocks of pre-Tertiary age. In the northwest is the Idaho batholith; to the west are tenuous metamorphic rocks flanked by upper Precambrian to upper Mesozoic geosynclinal rocks. Correlative but more extensive metamorphic complexes occur to the west in Oregon, Nevada, and California, and are bordered to the east in the Snake River Basin by eugeosynclinal and then by geosynclinal rocks that range in age from Cambrian into upper Mesozoic.

Early geologic reconnaissance of the Snake River Basin is a major feature that deepens to the west. The Tertiary sequence is thickest (L. Russell, 1902; Kirkham, 1931). The record continues through intertonguing and subsidence, with nearly all units separated by conformities (for example, Malde and Powers, 1962; Kittleman, 1965). The northern and southern parts of the plain are terminated by west-trending faults, whereas the eastern half is a late Cenozoic depression that cuts across older basins and ranges into the trough (Cohée and others). The eastern end is marked by the Centinias on the north and by the Snake River on the southeast, both active. Structural relations on the north side of the western Snake River Plain suggest a massive vertical displacement by high totals at least 9000 ft since the lower Pliocene Idavada. Volcanic activity progressively decreasing around the younger formations (Malde and others; physical studies (Bonini, 1963; Joesting, 1964; Hill, 1963) indicate

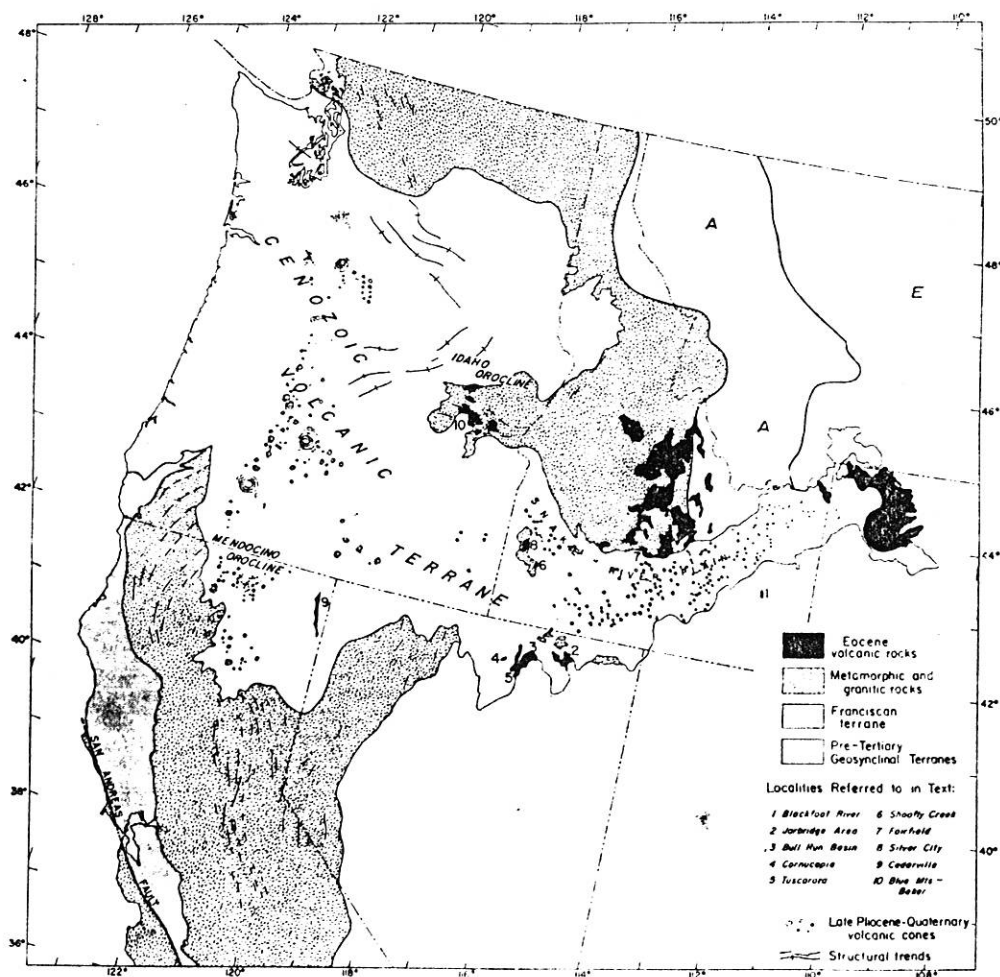


Figure 1. Regional geologic setting of Snake River Basin (data from Cohée, 1960; Stose, 1932; Hamilton and Myers, 1966).

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The manuscript has been critically reviewed by Harry P. Bailey, Ralph W. Chaney, Warren Hamilton, and Harry D. MacGinitie, all of whom have offered constructive suggestions that have improved it.

GENERAL GEOLOGIC SETTING

Regional tectonic (Cohce and others, 1962) and geologic (Stose, 1932) maps show that the Snake River basin coincides with the narrow east end of a V-shaped Cenozoic volcanic field that widens to the west, spreading southward into northwestern Nevada and adjacent California, and northward into Oregon and Washington. This volcanic field, dotted with numerous recently active cones, rests on diverse basement rocks of pre-Tertiary age (Fig. 1). To the northwest is the Idaho batholith and its contiguous metamorphic rocks flanked on the east by upper Precambrian to upper Mesozoic miogeosynclinal rocks. Correlative batholithic and metamorphic complexes occur to the southwest in Oregon, Nevada, and California, and are bordered to the east in the northern Great Basin by eugeosynclinal and thence by miogeosynclinal rocks that range in age from lower Cambrian into upper Mesozoic.

Early geologic reconnaissance showed that the Snake River Basin is a major structural feature that deepens to the west where the Tertiary sequence is thickest (Lindgren, 1898; Russell, 1902; Kirkham, 1931). The formations record continuing though intermittent subsidence, with nearly all units separated by unconformities (for example, Malde, 1965; Malde and Powers, 1962; Kirtleman and others, 1965). The northern and southern flanks of the west part of the plain are terminated by northwest-trending faults, whereas most of the eastern half is a late Cenozoic downwarp that cuts across older basins and ranges that strike into the trough (Cohce and others, 1962). The eastern end is marked by the Centennial Mountains on the north and by the Teton Range on the southeast, both active fault blocks. Structural relations on the northern margin of the western Snake River Plain show that relative vertical displacement by high-angle faulting totals at least 9000 ft since extrusion of the lower Pliocene Idavada Volcanics, with progressively decreasing amounts recorded by the younger formations (Malde, 1959). Geophysical studies (Bonini, 1963; Wollard and Joesting, 1964; Hill, 1963) indicate that a broad

gravity maximum extends along the axis of the basin, that several *en echelon* gravity highs are in the western half, and that the plain and the highlands are in approximate isostatic equilibrium. The relations imply that the western part of the plain is not underlain by depressed crustal ("granitic") rocks like those in the mountains to the north and south, but by a thick, denser, high-velocity ("basaltic") crust, an inference seemingly consistent with the composition of the Snake River Basalt (Powers, 1960).

All these features support the suggestion that the Snake River Plain may be a lava-filled tensional rift that formed in the lee of the northwestward-drifting Idaho batholith (Hamilton, 1963; Hamilton and Myers, 1966). Present evidence indicates that the continental plate probably has been sundered in the western part of the Snake River Plain, and thinned in the east. Hamilton and Myers (1966) present additional evidence to support Carey's (1958) hypothesis that the arcs of pre-Tertiary rocks of the Klamath Mountains of California and the Blue-Wallowa Mountains of northeastern Oregon and adjacent Idaho, respectively termed the "Mendocino Orocline" and "Idaho Orocline" by Carey (1958), were originally part of a relatively straight orogenic belt. As this belt was deformed, the Snake River basin appears to have opened up as a rift behind the Idaho orocline. That this event probably occurred in Oligocene time is suggested by the topographic indications of Eocene as compared with Miocene floras of the region.

BASIS FOR ANALYSIS

The most striking fact about the fossil floras is that they represent samples of forest zones that existed under different climates (Table 1). Some Eocene floras (for example, Comstock, Tipperary) are evergreen broadleaved forests like those now in regions with frostless warm temperate climate; others (Yellowstone, Lower Cedarville, Gernert) represent mixed deciduous hardwood forests similar to communities living in areas with mild temperate climate; some (Copper Basin, Coal Creek, Lower Bull Run) are conifer-hardwood forests that resemble communities in regions with cool temperate climate; and a few (Upper Bull Run, Thunder

¹In the place of "orocline," Albritton (1967) proposes the term "orocline" for mountain ranges with arcuate trends that result from tectonic bending of the crust.

TABLE 1. FOREST ZONES AND CLIMATES REPRESENTED BY SOME EOCENE AND MIOCENE FLORAS OF THE SNAKE RIVER BASIN AND BORDERING REGION

Forest Zones	Eocene Floras	Miocene Floras	Climate Type ET* 50.0°F
Subalpine conifer	Upper Bull Run Bullion Gulch Thunder Mt.	(in Trapper Cr.)	cold temperate 52.9°F —
Conifer-deciduous hardwood	Lower Bull Run Copper Basin Coal Creek Salmon	Trapper Cr. Trout Cr. Blue Mts. Thorn Cr.	cool temperate 54.5°F —
Mixed-deciduous hardwood	Germer Yellowstone Lower Cedarville	Mascall Stinking Water Succor Cr. Horseshoe Bend Latah-Grand Coulee	mild temperate 59.9°F —
Broadleaved evergreen forest	Clarno Tipperary Comstock Chalk Bluffs	not present†	warm temperate 64.4°F —
Tropical rainforest and savanna	not in region	not in region	tropical

* ET = Effective temperature (see text; also Bailey, 1960).

† A few relicts of the forest (*Exbucklandia*, *Machilis*, *Persea*, *Magnolia*, and so on) were present on the outer coast, extending up major valleys.

Mt., Bullion Gulch) represent subalpine conifer forests like those that occur today in areas with cold temperate climate. Similarly, some Miocene floras (Succor Creek, Horseshoe Bend) are mixed deciduous hardwood forests; others represent conifer-hardwood forests (Trout Creek, Thorn Creek, Blue Mountains); and one (Trapper Creek) lived marginal to subalpine conifer forest and cold temperate climate.

The co-existence of markedly different, yet essentially contemporaneous forests in this region during Eocene and Miocene times was the result of climatic zonation: the forests that required cooler climate must have lived at higher levels. Forest zonation similar to that shown by Eocene floras occurs today in the mountainous sections of southern China and southeastern Mexico. The Miocene floras resemble forest zones in the eastern and western United States, central-to-northern Japan, and the Yangtze Basin. The climatic conditions under which these comparable living forests occur provide a basis for estimating the altitudes at which the Eocene and Miocene forests lived, and thus afford a means for reconstructing the topographic history of the Snake River basin.

DETERMINATION OF ALTITUDE

The altitudes at which Tertiary floras lived may be estimated from the temperature conditions under which similar forests occur today. The temperature requirements of forests should be appraised in terms of effective temperature (ET) and equability (M).

Effective temperature is a measure of the warmth and duration of summer (Bailey, 1960). It is determined from the mean temperatures (°F) of the warmest month (WM) and the coldest month (CM), either by nomogram or by the equation:

$$ET = \frac{64.4 \text{ WM} - 50.0 \text{ CM}}{\text{WM} - \text{CM} + 14.4}$$

ET 64.4° F marks the edge of tropical climate, where all months of the year have a mean temperature above 64.4° F. The margin of polar climate coincides with ET 50° F, where no month has a mean temperature above 50° F. Between them, where ET is 57.2° F (14° C), there are six months (163 days) in which mean temperatures are above 57.2° F. Figure 2 shows the ET (radii) of stations at the margin of

tropical climate (ET 64.4° F), at cold temperate climate (ET 50° F), and some with an intermediate (ET 57.2° F). The stations have been selected so that with the same ET occur at different latitudes (ET lines), with those far right having a greater range of temperature. This is, in part, an expression of the equability (M) of climate.

Equability (or temperateness) is a thermal regime in terms of its departure from the mean (ET 57.2° F), which is midway between ET 64.4° F and ET 50° F, approximately the mean temperature at the earth's surface (Bailey, 1960). A climate that has a uniform temperature of 57.2° F has an ideal rating of M 100. Annual temperature is warmer or cooler than 57.2° F, or if seasonal fluctuation the departure from M 100 is in inverse scale (arcs) of lower values (M 90, 80, etc.) as equability decreases. Figure 2 shows that equability lines form arcs nearly perpendicular to ET lines, with stations of the same M at different points along the radii corresponding to their M values (read from the outer scale).

The temperature conditions under which forests live can be expressed in terms of M (see Axelrod, 1965, Figs. 4-6). Figure 2 shows the ET and M for stations of some representative forests (statistical Appendix). The fossil floras of the Snake River basin and border areas that resemble modern forests are assumed to have had generally similar temperature requirements. However, the former climates of higher equability (M 100) were more widespread than today. Smaller range of annual temperature, and hence higher M (see Fig. 2) would have resulted from general tectonic conditions, from the absence of continental topographic barriers like the Alps, the American Cordillera, and from the extreme climates of broad extent: tundra, steppe, and desert climates yet in existence over the lowland.

The areas where the Tertiary floras of Idaho, and bordering region nearest living analogues best develop climates of high equability (Appendix, pp. 54-59; 1965, Fig. 8), chiefly implying an essential absence of topographic barriers (Fig. 3). The role of controlling forest composition is illustrated by comparing the forests of the United States and central Japan

tropical climate ($ET\ 64.4^\circ F$), at the edge of cold temperate climate ($ET\ 52.9^\circ F$), and some with an intermediate ($ET\ 58^\circ F$) value. The stations have been selected so that those with the same ET occur at different points on the radii (ET lines), with those farthest to the right having a greater range of annual temperature. This is, in part, an expression of the equability (M) of climate.

Equability (or temperateness) rates the thermal regime in terms of its departure from $ET\ 57.2^\circ F$, which is midway between $ET\ 64.4^\circ F$ and $ET\ 50^\circ F$, and is also approximately the mean temperature of the earth's surface (Bailey, 1960, 1964). A climate that has a uniform temperature of $57.2^\circ F$ has an ideal rating of $M\ 100$. If mean annual temperature is warmer or colder than $57.2^\circ F$, or if seasonal fluctuations occur, then the departure from $M\ 100$ is indicated by a scale (arcs) of lower values ($M\ 90, 80, 70, \dots$) as equability decreases. Figure 2 shows that the equability lines form arcs nearly normal to the ET lines, with stations of the same ET spaced at different points along the radii (ET) according to their M values (read from arcs).

The temperature conditions under which forests live can be expressed in terms of ET and M (see Axelrod, 1965, Figs. 4-9). Figure 3 shows the ET and M for stations (dots) in some representative forests (stations listed in Appendix). The fossil floras of the Snake River basin and border areas that resemble them are assumed to have had generally similar ET requirements. However, the former lived under the climates of higher equability (M) that apparently were more widespread in the Tertiary than today. Smaller range of annual temperature, and hence higher M (see Figs. 2 and 3), would have resulted from generally lower continents, from the absence of continuous high topographic barriers like the Alpine belt or the American Cordillera, and from the lack of extreme climates of broad extent: regional polar, tundra, steppe, and desert climates were not yet in existence over the lowlands.

The areas where the Tertiary floras of Nevada, Idaho, and bordering regions find their nearest living analogues best developed all have climates of high equability (Axelrod, 1964, pp. 54-59; 1965, Fig. 8), chiefly above $M\ 60$, implying an essential absence of frost (diagonal dotted lines, Fig. 3). The role of equability in controlling forest composition can be illustrated by comparing the forests of the eastern United States and central Japan. Broadleaved



Figure 2. Nomogram showing relations of effective temperature (radii), ET (lines), and equability (M arcs), as illustrated by stations with $ET\ 64.4$, $ET\ 58.0$, and $ET\ 52.9^\circ F$ (Nomogram by H. P. Bailey).



Figure 3. Effective temperature and equability of stations (dots) in living forests analogous to those represented in Eocene and Miocene floras (Appendix lists stations).

evergreen trees are very rare at Washington, D. C., where *ET* is 56.7° F; yet at Tokyo—which is at the same latitude and also has *ET* 56.7—they are abundant. The difference probably is due to the lower equability at Washington (*M* 49.7), as compared with Tokyo (*M* 53.8). This is inferred from the greater total number of hours of freezing at Washington (7456 hours in the period 1951–1960) as contrasted with the number at Tokyo (4599 hours in the same period), and during this decade Washington had 10,334 hours with temperature above 80° F as compared with 5683 hours at Tokyo (Bailey, 1967). In the eastern United States, forests comparable to those near Tokyo occur well to the south (in Georgia and South Carolina); yet the forests there are not as rich in species or in life forms as those near Tokyo, even though the climate is considerably warmer (*ET* 59 to 60° F).

Owing to greater equability, Tertiary forests were able to live under lower *ET* than they do today in most areas of their distribution, a relation still present in relict areas characterized by high *M*. For example, the evergreen broad-leaved forest in the uplands of southern China (Wang, 1961, Chap. VI, Table 14) thrives under an equability near *M* 63, and *ET* is comparatively low (as, *ET* 57.5 to 58.2° F, at Kunming and Tengchung; Fig. 4). But where the forest occurs in the lowlands, *ET* is near 59.5° F and *M* is lower (as, *M* 47 to 48 at Kweilin, Chanting, and Wenchow; Fig. 4). The importance of equability also becomes apparent if the forest at New Orleans (*ET* 61.4° F) is compared with that at Huauchinango, Mexico (*ET* 58.4° F). Whereas only a few broadleaved evergreens contribute to the forest at New Orleans, they dominate it at Huauchinango, where there are also many of the same deciduous hardwoods that occur at New Orleans (Miranda and Sharp, 1950). Even though *ET* is 3° F lower, the forest at Huauchinango has a decidedly tropical aspect as compared with that at New Orleans. The relation is due to the higher equability at Huauchinango (*M* 69) than at New Orleans (*M* 49). Freezing is essentially unknown at Huauchinango, but it occurs regularly at New Orleans, and extreme low temperatures there dip to 4° F (see Fig. 4).

The relation is further emphasized if we compare the temperature data for New Orleans with that in two other areas with similar *ET* but with very different vegetation. As shown in Figure 4, stations (Orizaba, Huatusco, Jala-

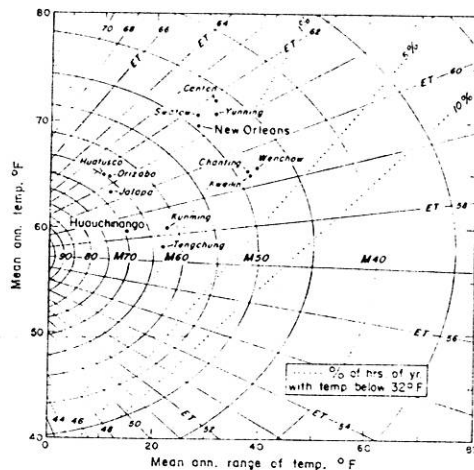


Figure 4. Illustration of changing relations of effective temperature (*ET*) of forests in regions with different equability (*M*); the higher the *M*, the lower the *ET* (see text).

pa) on the eastern escarpment (altitude 4000 to 5000 ft) of southern Mexico and along the south China coast (Canton, Swatow, Yunnan) near sea level are located in evergreen broad-leaved forest. The tropical aspect of this forest as compared with the dominantly deciduous forest at New Orleans results chiefly from the more severe cold that affected the Gulf Coast area in the later Cenozoic. It eliminated numerous broadleaved evergreens from the forest there, and its continuing presence militates against their re-establishment in the region. It is apparent that basing reconstructions of Tertiary climate or altitude on temperatures for the Gulf Coast area would be highly misleading. As for climate, the Gulf Coast area has an effective temperature that is too high for similar Tertiary forests: they lived under conditions of lower *ET* and higher *M*.

As for altitude, the preceding examples indicate that at times of high equability (*M*), as in the early and middle Tertiary, *ET* was as much as two to three points lower than it is today in some modern forests that resemble Tertiary floras. For this reason, if climatic data selected for a Tertiary flora are based on stations of medium (*M* 45 to 50) instead of high (*M* 60 to 65+) equability, estimates of altitude will be too high. This principle is illustrated in Figure 5 by the *ET* lines (radii) that diverge with departure from mean annual temperature

57.2° F and with increasing annual temperature. As equability decreases (right in Fig. 5), points (Fig. 5, A'-B') on any two lines of *ET*—which are considered to represent the temperature requirements of lowland (A, A') (B, B') floras—become farther apart as they are separated by a greater mean annual temperature. As shown in Fig. 5, the theoretical floras represented by high equability (*M* 60+) and separated by 12° F of mean annual temperature (left margin). Using a lapse rate (1° F decrease in temperature per 278 ft), the floras at A and B are separated by 3336 ft ($12^\circ \times 278 = 3336$). On the other hand, if the floras lived under low equability (*M* 46 to 47), as shown in Fig. 5, then they are separated by 19° F of mean annual temperature, or 5282 ft ($19^\circ \times 278 = 5282$ ft). By using the latter (incorrect) computed altitude of the upland, the altitude is nearly 2000 ft too high ($5282 - 3336 = 1946$ ft).

From the principles that have been discussed (also see Axelrod, 1965), it is feasible to estimate the temperature requirements of Tertiary floras, and to estimate their altitudes from the *ET* of a flora in the coastal

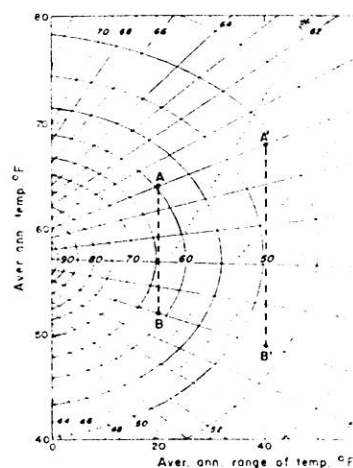


Figure 5. Importance of equability in estimating altitude from effective temperature. With decreasing *M*, the mean annual temperature (and altitude) that separates two stations of different *ET* becomes greater (that is, A'-B').

57.2° F and with increasing annual range of temperature. As equability decreases (to the right in Fig. 5), points (Fig. 5, A-B versus A'-B') on any two lines of *ET*—which may be considered to represent the temperature requirements of lowland (A, A') and upland (B, B') floras—become farther apart because they are separated by a greater difference in mean annual temperature. As shown in Figure 5, the theoretical floras represented at A and B have high equability ($M 60^+$) and are separated by 12° F of mean annual temperature (read temperature scale, left margin). Using a normal lapse rate (1° F decrease in temperature per 278 ft), the floras at A and B are found to be separated by 3336 ft ($12^\circ \times 278 = 3336$ ft). On the other hand, if the floras lived under medium equability ($M 46$ to 47), as shown for A' and B', then they are separated by 19° F of mean annual temperature, or 5282 ft ($19^\circ \times 278 = 5282$ ft). By using the latter (incorrect) data, the computed altitude of the upland flora (B') is nearly 2000 ft too high ($5282 - 3336 = 1946$ ft).

From the principles that have been reviewed (also see Axelrod, 1965), it is feasible to infer the temperature requirements of Tertiary floras, and to estimate their altitudes. Using the *ET* of a flora in the coastal strip which

serves as a base for sea level, the altitude of *ET* inferred for a contemporaneous flora away from the coast can be inferred because the difference in mean annual temperature provides a measure of their altitudinal separation, as exemplified by either A - B (12°) or A' - B' (19° F) in Figure 5.

ALTITUDES OF EOCENE AND MIOCENE FOREST ZONES

The Eocene and earlier Oligocene floras of the coastal strip and adjacent valleys that represent evergreen broadleaved forest include the Goshen (Chaney and Sanborn, 1933), Comstock (Sanborn, 1935), La Porte (Potbury, 1935), and Clarno (Knowlton, 1902; Scott, 1954); their regional relations are discussed by Chaney (1940, 1948) and also by MacGinitie (1937, 1941). In the interior, the mixed deciduous hardwood forest represented by the Yellowstone flora is under revision (Dorf, 1960), and MacGinitie (1966) is describing several new lowland floras in the region farther east that represent evergreen broadleaved forest. Axelrod (1966a) described an upland Eocene conifer-hardwood forest at Copper Basin in northeastern Nevada, and discussed Eocene conifer-hardwood and subalpine conifer forests at Bull Run basin in the adjacent area. Axelrod (1966a, 1966b) has also reviewed the relations between several upland floras that represent mixed deciduous hardwood forest (Republic, Lower Cedarville, Weaverlyville), conifer-hardwood forest (Salmon), and subalpine forest (Thunder Mountain), some of which were formerly considered to be Miocene (Brown, 1937). During the past two summers four new floras (Bullion Gulch, Democrat Creek, Coal Creek, Germer) were collected from the Challis Volcanics in south-central Idaho, and they are included in the present analysis. The Eocene forest zones and the floras that contributed to them are depicted in Figure 6A. They included species of the following genera:

1. SUBALPINE CONIFER FOREST

TREES

CONIFERS: (Specimens total over 80 percent of entire flora.)

**Abies*, *Larix*, **Picea*, **Pinus*, *Pseudolarix*, *Pseudotsuga*, *Tsuga*, *Chamaecyparis*, *Thuja*, *Sequoiadendron*.

DECIDUOUS HARDWOODS: (Abundance may depend on altitude; also on seral relations,

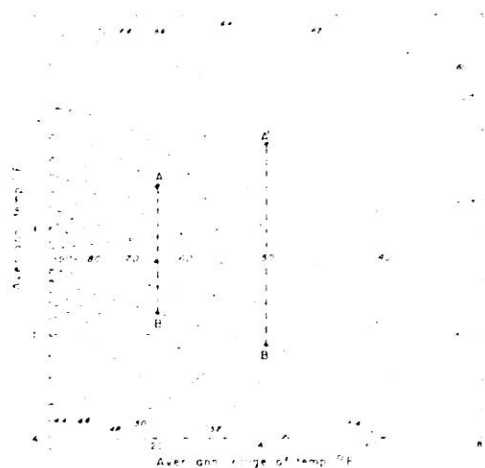


Figure 5. Importance of equability (M) in estimating altitude from effective temperature (ET). With decreasing M , the mean annual temperature (and altitude) that separates two stations with different ET becomes greater (that is, A-B versus A'-B').

for example, fire, ash falls, and so forth.)²
Acer, Alnus, Betula, Populus, Ulmus,
Zelkova.

SHRUBS

Acer, Betula, Berberis, Comptonia, Cra-
taegus, Micromeles, Holodiscus, Mahonia,
Prunus, Rhododendron, Ribes, Salix, Sorbus,
Vaccinium, Viburnum.

(*Genera represented by two to four species
each, allied to modern high montane conifers)

II. CONIFER-HARDWOOD FOREST

TREES

CONIFERS: (Remains comprise 30 percent or
more of entire flora.)

*Abies, *Picca, *Pinus, Pseudotsuga,
Pseudolarix, Cephalotaxus, Tsuga, Cha-
maecyparis, Thuja, Sequoia, Sequoiaden-
dron, Metasequoia.

DECIDUOUS HARDWOODS

Acer, Alnus, Aesculus, Betula, Carya,
Euonymus, Cercidiphyllum, Koeleria,
Pterocarya, Quercus, Ulmus, Zelkova.

EVERGREENS

Arbutus, Lithocarpus.

SHRUBS

Acer, Amelanchier, Crataegus, Holodiscus,
Mahonia, Prunus, Rhododendron, Ribes,
Rosa, Sassafras, Sorbus, Spiraea.

(*Genera represented by two to four species each,
allied to living high montane conifers)

² Following destruction of modern forests by ash falls
or by fires, the dominant (climax) forest gradually be-
comes re-established through a series of successional
stages. Similar changes have their counterparts in the
Tertiary record. For example, in the Eocene Bull Run
flora, northeastern Nevada, pure subalpine conifer forest
is replaced temporarily by conifer-hardwood forest at the
level where ash falls first appear in the sedimentary se-
quence, and then the pure conifer forest becomes re-
established at slightly higher stratigraphic levels. Com-
parable changes occur in the Eocene Germer and the
Miocene Carson Pass and Purple Mountain floras. They
show that certain species (that is, sycamore, poplar,
lingnut, oak) are predominant at particular stratigraphic
levels, but that at higher or lower horizons these pre-
sumed successional species are rare, or subordinate to
plants that evidently represent a climax forest composed
of numerous genera, the common species of which differ
from the "successional" forms. It is apparent that floras
in volcanic sequences may show important changes that
reflect only successional relations, not major forest mod-
ifications imposed by secular change of climate, or by a
change of altitude.

III. MIXED DECIDUOUS HARDWOOD FOREST

TREES

CONIFERS: (Remains comprise less than 25
percent, excluding those of hydric require-
ments, for example, Taxodium, Metase-
quoia, Glyptostrobus.)

Abies, Chamaecyparis, Glyptostrobus,
Keteleeria, Metasequoia, Pseudolarix,
Torreya.

DECIDUOUS HARDWOODS

Acer, Alnus, Betula, Carya, Castanea,
Cercidiphyllum, Dalbergia, Diospyros,
Dipterocarpus, Fraxinus, Hydrangea, Ilex,
Juglans, Liriodendron, Nyssa, Pterocarya,
Quercus, Tilia, Ulmus, Zelkova.

BROADLEAVED EVERGREENS

Alangium, Calyptranthes, Ficus, Ilex,
Inga, Machilus, Magnolia, Ocotea, Persea,
Quercus, Sterculia.

SHRUBS

Amelanchier, Berchemia, Cassia, Compto-
nia, Cornus, Mahonia, Rhamnus, Rhus,
Rosa, Salix, Styxax.

VINES

Actinidia, Tetracera.

IV. EVERGREEN BROADLEAVED FOREST

FERNS

Dennstaedtia, Hemitelia, Lastraea, Lygo-
dium.

TREES

GYMNOSPERMS

Cycas, Dioon, Glyptostrobus, Metase-
quoia, Taxodium (Ginkgo, Pinus, Fokie-
nia, and so forth, very rare to absent).

BROADLEAVED EVERGREENS

Alangium, Annona, Astronium, Calyp-
tranthes, Cedrela, Chamaedorea, Chaetop-
telea, Cinnamomum, Cordia, Cryptocarya,
Cupania, Dillenia, Engelhardtia, Eupte-
lea, Ficus, Gordonia, Litsea, Lonchocarpus,
Magnolia, Mallotus, Meliosma, Nectan-
dra, Persea, Quercus, Rhamnidium, Sabal,
Sapindus, Sapium, Siparuna, Symplocos,
Terminalia.

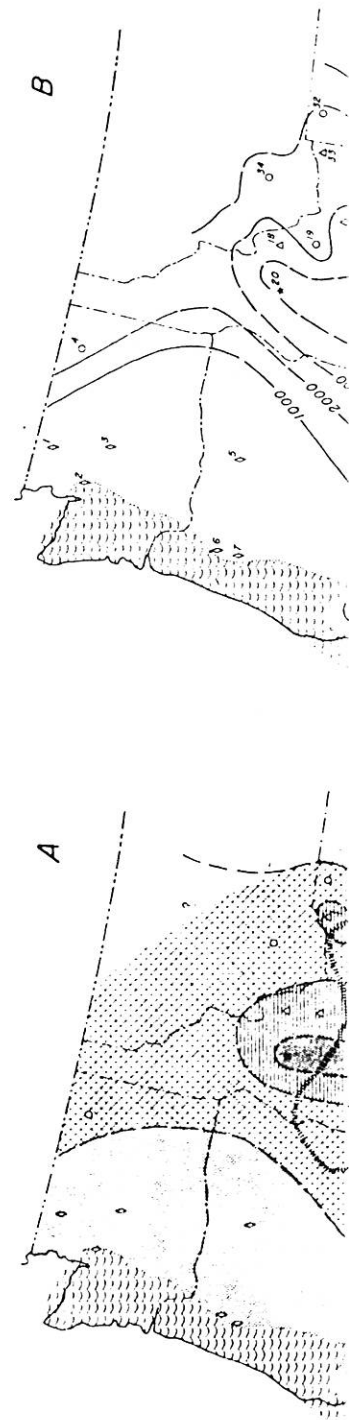
DECIDUOUS HARDWOODS

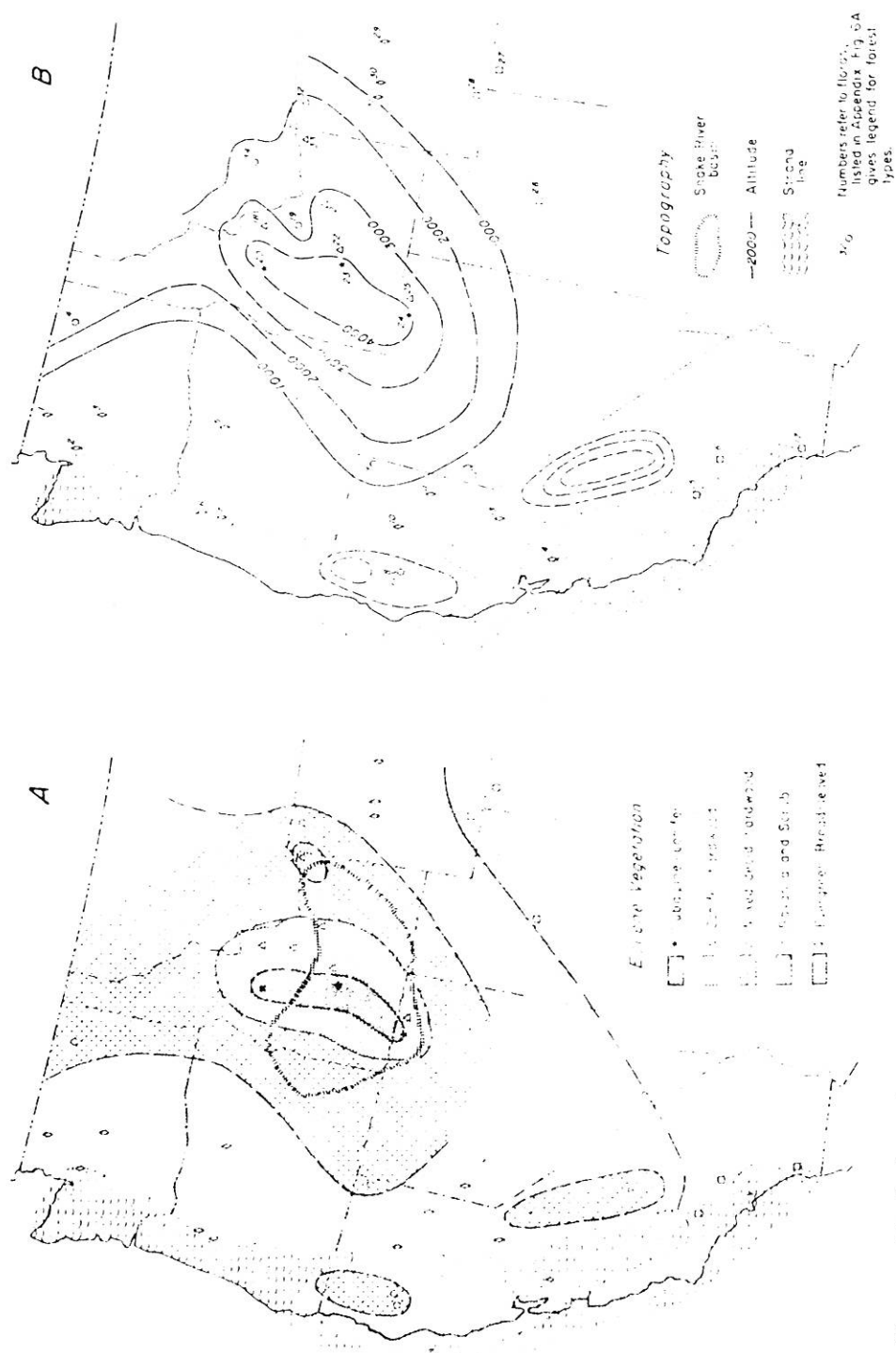
(Generally rare except for hydric plants,
for example, Alnus, Platanus, Salix.)

Acer, Ailanthus, Alnus, Carya, Cer-
cidiphyllum, Cladrastis, Idesia, Inga,
Koeleria, Platanus, Zelkova.

SHRUBS

Hydrangea, Ilex, Rhamnus, Rhus, Pterosper-
mum, Viburnum.





VINES

Actinidia, Aristolochia, Cissus, Cissampelos, Callichlamys, Davilla, Hyperbaena, Holmskioldia, Petrea, Smilax, Tetracera.

The Miocene floras of the Snake River Basin and border areas have been discussed in numerous papers. Since references to all of them can be found in recent monographs (Chaney, 1959; Axelrod, 1964) they need not be reviewed here. The major forest zones of the region, and the floras that represent them, are shown in Figure 7A. Typical plants (genera) recorded in the floras of these vegetation zones include:

I. SUBALPINE CONIFER FOREST*

TREES

CONIFERS

Abies, Larix, Picea, Pinus, Tsuga, Thuja, Chamaecyparis, Sequoiadendron.

DECIDUOUS HARDWOODS:

Acer, Alnus, Betula, Populus.

SHRUBS

Acer, Alnus, Betula, Amelanchier, Prunus, Salix, Sorbus, Vaccinium.

(*Miocene floras with 80 percent or more montane conifers have not been described. Paleogeologic data suggest that some of the plants in floras having from 30 to 65 percent montane conifers probably contributed to subalpine forests [see Chaney, 1959; Axelrod, 1964].)

II. CONIFER-HARDWOOD FOREST

TREES

CONIFERS

Abies, Picea, Pinus, Thuja, Tsuga, Chamaecyparis, Larix, Sequoia, Sequoiadendron, Keteleeria, Pseudotsuga.

DECIDUOUS HARDWOODS

Acer, Alnus, Ailanthus, Betula, Carpinus, Cercidiphyllum, Cornus, Carya, Fagus, Fraxinus, Gymnocladus, Halesia, Liquidambar, Nyssa, Populus, Pterocarya, Quercus, Sophora, Tilia, Ulmus, Zelkova.

BROADLEAVED EVERGREENS

Arbutus, Cedrela, Ilex, Persea, Quercus, Lithocarpus.

SHRUBS

Alnus, Acer, Amelanchier, Betula, Crataegus, Holodiscus, Lindera, Mahonia, Ostrya, Prunus, Rhus, Rosa, Salix, Sassafras, Sorbus, Rhamnus, Symphoricarpos.

VINES

Parthenocissus, Smilax.

III. MIXED DECIDUOUS HARDWOOD FOREST

TREES

CONIFERS*

Cephalotaxus, Keteleeria, Pinus, Fokienia, Taxodium, Glyptostrobus, Metasequoia.

DECIDUOUS HARDWOODS

Acer, Ailanthus, Alnus, Albizzia, Carpinus, Carya, Castanea, Cercidiphyllum, Diospyros, Exbucklandia, Fagus, Fraxinus, Halesia, Liquidambar, Liriodendron, Magnolia, Nyssa, Platanus, Populus, Pterocarya, Quercus, Sophora, Tilia, Ulmus, Zelkova.

BROADLEAVED EVERGREENS

Arbutus, Castanopsis, Cedrela, Machilus, Magnolia, Oropanax, Persea, Quercus.

SHRUBS

Amelanchier, Celtis, Comptonia, Cornus, Crataegus, Euonymus, Hydrangea, Ilex, Gaultheria, Mahonia, Lindera, Ostrya, Philadelphus, Paliurus, Rosa, Salix, Sassafras, Vaccinium, Viburnum.

VINES

Cocculus, Vitis, Smilax.

(*Species of *Abies*, *Picea*, *Tsuga*, *Thuja*, and so forth occur in these floras in small number. They probably were scattered and represented members of conifer-hardwood forest that lived in cooler sites in these lowland basins.)

EOCENE AND MIOCENE TOPOGRAPHY

Using the altitudes inferred for the sedimentary basins in which the Eocene and Miocene floras occur, it is feasible to construct a crude topographic map for each epoch. It is realized that the "benchmarks" (floras) are not as numerous as might be desired, and that actual relief was far more diverse than can possibly be reconstructed from evidence available today. It is also granted that other paleobotanists, using quite different methods to estimate altitude,³ probably would assign dif-

³ A frequently used method interpolates the altitudes of similar modern forests into those of the past. The chief weaknesses of this method are: (1) Climates that now control the altitudes of forest zones are not the same as those of the Tertiary. (2) Even at the same latitude, the altitude of a forest zone varies in different parts of the continent. For example, at lat 42° N. the lower margin of subalpine forest is at 4500 ft in northwestern California, at 7000 ft in northeastern California, at 8000 ft in northeastern Nevada, and at 3000 ft in central New York. In northern Honshu it is at 2500 ft at lat 42° N. Since Tertiary subalpine forests show relationship to all these forests, the present altitudes of the living forests cannot directly indicate the altitudes of related fossil forests.





Figure 7: Distribution of $N(\text{occ})$, for $\alpha = 0.01$, $\sigma^2(\lambda)$ and the general divides that they indicate (74). Numbers near to 0 (not listed in Appendix).

ferent (chiefly higher) levels to the fossil floras. Irrespective of the altitudes that might be inferred by any other method, the conclusion with respect to general Eocene and Miocene topography in the Snake River basin region would agree with the results reached here (Figs. 6B and 7B). The evidence suggests that, whereas an upland occupied the present area of the Snake River basin during the Eocene, a lowland basin coincided with it by Miocene time. This implies that the trough was probably initiated during the Oligocene. Although subsidence may have commenced in the western sector (for example, Oregon) during the later part of the Eocene, available evidence suggests that the axis in south-central Idaho was not affected until later. Growth of the trough may be portrayed as an eastward-moving rent whose north flank moved slowly northward during the rest of the Cenozoic. This is inferred from pattern of folded volcanic rocks north of the Idaho orocline (see Cohee and others, 1960; also Fig. 1), by the downwarping in the east half of the basin that affects Pliocene and younger rocks, by active faulting at the eastern margin of the basin (Hamilton and Myers, 1966), and by geophysical evidence which indicates that the area from the western half of the basin westward into Oregon is floored by high density ("basaltic") rocks (see references in Hamilton and Myers, 1966, p. 537).

The paleobotanic relations which suggest that an upland occupied the present site of the Snake River basin during Eocene is supported by three additional lines of geologic evidence:

(1) Geologic data indicate that central Idaho and Nevada formed an upland source area for sediments of the Cretaceous Rocky Mountain and Pacific Coast geosynclines (Gilluly, 1949, 1963; King, 1959). The central part of the source region was close to the axis in which the Eocene montane forests occur (Fig. 8), an area that includes the Idaho batholith and related plutonic bodies to the south in Idaho (Owyhee Mts.-Ruby Hills) and Nevada (Bull Run Mts.-Jarvis Mts.-Contact) which were emplaced during the middle and later Cretaceous (Jaffe and others, 1959; Coats and others, 1965). The region was uplifted and eroded sufficiently during later Cretaceous and Paleocene times to expose plutonic and metamorphic rocks because they are covered by Eocene volcanic sequences (see below). That uplift and erosion continued into early Tertiary is also inferred

from the absence of late Cretaceous and Paleocene sedimentary rocks on the northern and southern flanks of the Snake River Plain.

(2) Similar Eocene volcanic sequences rest on basement rocks on opposite sides of the Snake River Plain. To the north, Eocene floras (Salmon, Germer, Thunder Mountain, Democrat Creek, Bullion Gulch) occur in tuffaceous sedimentary rocks interbedded with the Challis Volcanics. These rocks (Fig. 1) extend to the margin of the plain, where they are truncated by faults or disappear under a cover of younger formations. On the south side of the trough, about 20 miles southeast of Blackfoot, there is a patch of volcanic rocks (basalt, andesite, rhyolite) similar to the Challis (Mansfield, 1927). Farther west, on the south side of the Snake River basin in northeastern Nevada, the Deadhorse Tuff in the Jarvis area (Coats, 1964) and the Frost Creek Volcanics in the Bull Run region (Decker, 1964) are only slightly (5 m.y.) younger than the Challis. Coats (oral commun., 1966) states that rocks of this sequence are widespread in the Mountain City-Jarvis region. They also occur in the Cornucopia mining district west of the Bull Run basin, as well as in the Tuscarora Mountains to the south (Fig. 1).

Examination of thin sections of volcanic rocks from these areas on opposite sides of the Snake River Plain reveals identical types. In addition, the biotite rhyolite 20 miles south-southwest of Grandview, Idaho, in the upper drainage of Shoofly Creek (Littleton and Crosswaite, 1957) is very similar to rhyolite exposed near Fairfield on the north side of the basin. The rhyolite welded tuff and lower basalt in the Silver City district (Lindgren, 1904; Piper and Laney, 1926) may also belong to this volcanic sequence; the rhyolite resembles that in the Challis Volcanics near Thunder Mountain. The volcanic rocks with which the Yellowstone flora is associated are similar in composition and age to the lower Challis, and appear to represent the eastern border of the Eocene volcanic field (Fig. 1).

There are volcanic rocks in northeastern California and north-central Oregon that lie on a granitic-metamorphic terrain on opposite sides of the Tertiary volcanic field that may represent part of this Eocene sequence (Fig. 1). In northeastern California, the lower part of the Lower Cedarville Volcanics (Russell, 1928), representing andesite flows, tuffs, and mudflow breccias and some associated rhyolite, is upper Eocene (Axelrod, 1966b). The sequence is



Figure 8. Land-sea relations during Eocene; sediments transported to bordering sea (Axelrod, 1963).

more than 5000 ft. thick, and its upper parts are Oligocene. In the Tains, eastern Oregon, Pardee (1914) mapped an andesite mud 1800 ft thick that rests on crystalline. It extends east into the Baker quadrangle (Luly, 1937) and is there associated with banded red andesite and Dool Breccia that rest on a granitic-

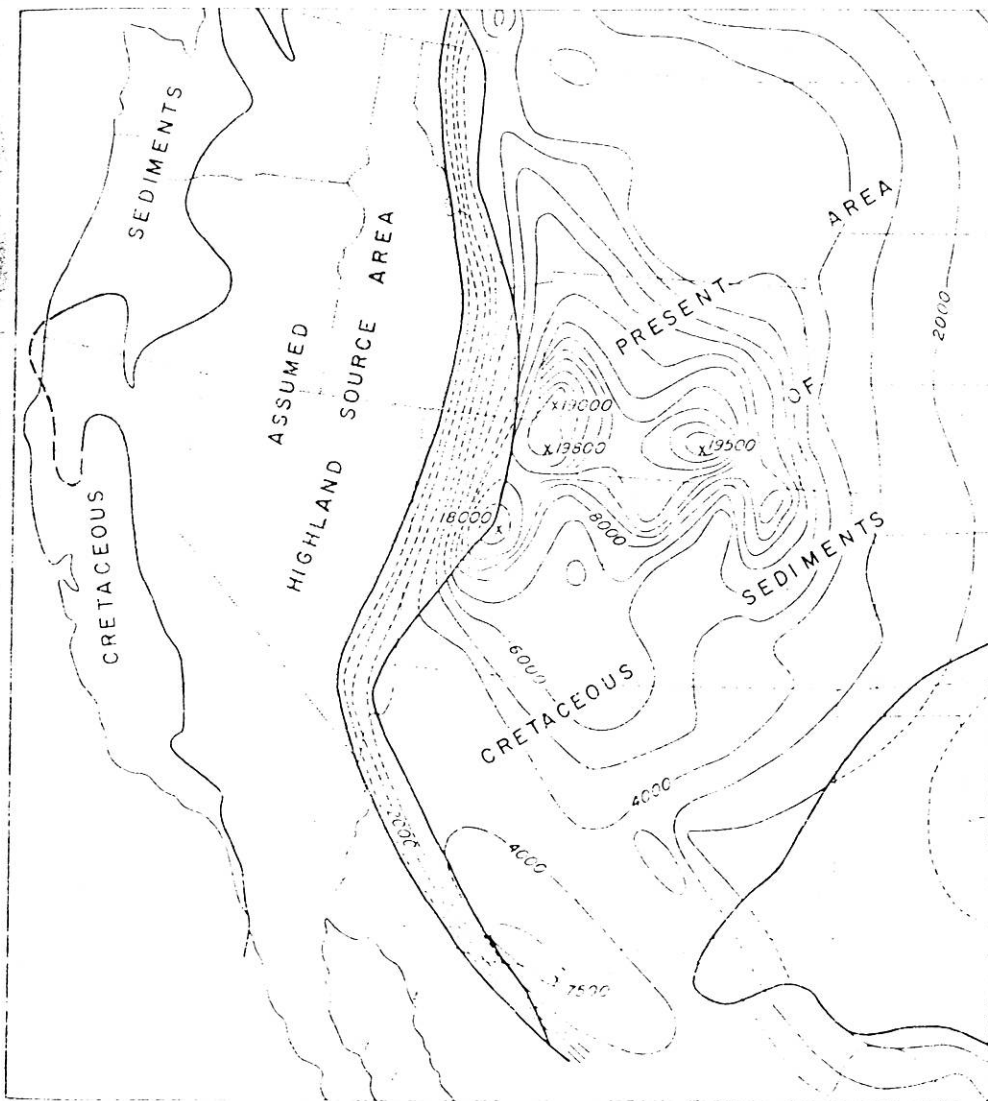


Figure 8. Land-sea relations during early Late Cretaceous, showing presumed upland source area for sediments transported to bordering geosynclines. Isopachs indicate thickness of sediments (from Gilluly, 1963).

more than 5000 ft. thick, and its middle and upper parts are Oligocene. In the Blue Mountains, eastern Oregon, Pardee and Hewett (1914) mapped an andesite mudflow breccia 1800 ft thick that rests on crystalline basement. It extends east into the Baker quadrangle (Gilluly, 1937) and is there associated with flow-banded red andesite and Dooley Rhyolite Breccia that rest on a granitic-metamorphic

complex much like that in northern California. These volcanic rocks have not been dated closely, but underlie Miocene rocks and could be Eocene.

All these rocks seem referable to the same episode of volcanism, one which radiometric evidence indicates extended from early (50 m.y.) into latest (35 m.y.) Eocene (Ross, 1962, p. 101; Axelrod, 1966b). The inferred con-

tinuity of similar volcanic rocks across the present basin area during the Eocene is paralleled by the distribution of the Succor Creek and Payette Formations in the Miocene, by the Idavada Volcanics in the late Miocene and early Pliocene, by the Banbury Formation

plants that require a pronounced dry season evidently were not present on bordering slopes in Wyoming-adjacent Colorado during earlier Eocene and Paleocene times, judging from the fossil floras of that region. However, they were present in savanna areas to the south and south-

TABLE 2. CORRELATION OF EOCENE FORMATIONS BORDERING THE SNAKE RIVER BASIN*

REGION		SNAKE RIVER BASIN AREA					
		North Flank	IDAHO		South Flank	NE NEVADA	East Border
AGE			SW Sector	SE Sector	Jarbridge	Bull Run	Yellowstone
EOCENE	late				Meadowfork Fm.	Chicken Creek Fm.	
					Deadhorse Tuff	I L Fm.	
		Challis Volcanics			Copper Basin	Morr. Road Fm.	
	mid		Rhyolite and basalt at Silver City.	Rhyolite, basalt, andesite, SSE of Blackfoot		Frost Creek Volcanics	
		* Salmon • Bullion Gulch • Germar • Coal Cr. • Democrat Cr. • Thunder Mt.	Rhyolite on Shoofly Creek				early acid breccia
early	Wasatchian						early basic breccia

* References to areas in the text. K-Ar dates indicated by *.

during middle Pliocene, and by the upper Pleistocene Snake River Basalt, which forms a visible ligament across the basin today. If the suggested Eocene correlations are substantially correct (Table 2), then the postulated Eocene volcanic field was of considerable extent (Fig. 1), it was thick (2000 to 3000 ft, locally 5000 ft) and was constructed throughout Eocene (mid-Wasatchian through Duchesnean) time, judging from radiometric dates of volcanic rocks.

(3) The Eocene floral sequence of southwestern Wyoming-adjacent Colorado reveals a very rapid change from evergreen broadleaved forest (Tipperary, Kisinger Lakes floras) of early middle Eocene age to drier savanna and scrub (type Green River, Little Mountain floras) of late middle Eocene and late Eocene age (MacGinitie, 1966). The environmental change, occurring within a few hundred feet stratigraphically, is too rapid to attribute to the secular climatic trend. Furthermore, conditions suited to the evolution of these distinctive

west during those times, and probably in the Cretaceous as well (Axelrod, 1958, Fig. 2). Furthermore, palynological study of the lower Eocene (Capay) Del Mar Member of the La Jolla Formation near San Diego indicates the presence of dry tropic forest and thorn forest vegetation (Ting, 1967, oral commun.) These data support the suggestions that (1) the distinctive Green River plants probably migrated from dry regions in the south as suitable conditions spread over the lowlands in northwest Colorado-Wyoming, and that (2) drier conditions rapidly developed in the lee of an upland which evidently reached its maximum altitude near the close of middle Eocene (Green River) time.

EOCENE VOLCANIC PLATEAU

General Topography

The Eocene volcanic sequences, from 2000 to 5000 ft thick, largely buried an older terrain,

leaving only a few peaks of basalt standing above the general level of the plateau. The surface on which the volcanic rocks are now preserved on both sides of the basin.

On the north, in the Casto quadrangle west of Challis, Idaho, the contact between the Challis Volcanics and the basement is marked by a gentle relief, with most local hills rising only a few hundred feet (Ross, 1934, pp. 10-11). The relatively flat erosion surface extends to the east to the Custer quadrangle where it is about 20 miles in the Salmon River (Ross, 1937). Low relief over most of the region is also suggested by the general absence of glomerate in the associated sections. By contrast, in the adjacent region to the east, large-boulder conglomerates are present, and they accumulate on slopes that were confined to the pre-Challis surface now between 5000 and 6000 ft (Ross, 1937, p. 88). Ross emphasizes that the pre-Challis surface now between 5000 and 6000 ft is much less dissected than the present surface. The contrast is so marked, and the gentle topography so broad, as to suggest (1) the east part of the region was in a late mature stage of erosion, and rejuvenation, deep valleys were carved into it just prior to burial by the Challis Volcanics (Ross, 1937, p. 88).

The highs on the pre-Challis surface respond with those of the present topography. They were appreciably lower (Ross, 1937, p. 88) than the relief on the basement now rises near it was less during Eocene time. The region has been warped and faulted (Fig. 7). The base of the Challis Volcanics in Round Valley near Challis is at about 5000 ft in altitude, and it has been uplifted in the mountains a few miles west. The Challis Volcanics have fully 5000 ft of thickness expressed by a structural terrace. The broad folds to the west, including the region. In that area the highest peaks, Castle Peaks) rise about 2500 ft above the Challis Volcanics, and the basement high—some of which is due to the Challis Volcanics extend up to the Lost River Range to the south. The Challis Volcanics extend up to the Lost River Range to the south, indicating that only an occasional peak, 12,600 ft; Mt. Leatherman,

* Many major faults in the region were mapped by Ross and his contemporaries. As a result, the highs can not be determined with certainty. The topography has been mapped more accurately.

leaving only a few peaks of basement rock standing above the general level of aggradation. The surface on which the volcanics accumulated is now preserved on both sides of the basin.

On the north, in the Casto quadrangle northwest of Challis, Idaho, the contact between the Challis Volcanics and the basement shows low relief, with most local hills rising only a few hundred feet (Ross, 1934, pp. 83-84). The relatively flat erosion surface extends south into the Custer quadrangle where it is exposed for 20 miles in the Salmon River Canyon (Ross, 1937). Low relief over most of this region is also suggested by the general absence of conglomerate in the associated sedimentary sections. By contrast, in the adjoining Bayhorse region to the east, large-boulder conglomerates are present, and they accumulated near steep slopes that were confined to deeper valleys (Ross, 1937, p. 88). Ross emphasizes that the pre-Challis surface now between 7500 and 9000 ft is much less dissected than parts of the pre-Challis surface now between 5000 and 5600 ft. The contrast is so marked, and the areas of gentle topography so broad, as to suggest that (1) the east part of the region had reached a late mature stage of erosion, and that, (2) due to rejuvenation, deep valleys were being carved into it just prior to burial by Challis Volcanics (Ross, 1937, p. 88).

The highs on the pre-Challis surface correspond with those of the present day, although they were appreciably lower (Ross, 1937). Relief on the basement now rises nearly a mile, but it was less during Eocene time, because the region has been warped and faulted (Ross, 1937, Fig. 7). The base of the Challis Volcanics under Round Valley near Challis is at or below 4000 ft in altitude, and it has been uplifted to 9500 ft in the mountains a few miles west. The volcanics have fully 5000 ft of structural relief, expressed by a structural terrace flanked by broad folds to the west, including the Sawtooth region. In that area the highest peaks (for example, Castle Peaks) rise about 2500 ft above the volcanics, and the basement has 4500 ft of relief—some of which is due to deformation.⁴ In the Lost River Range to the south (Ross, 1917), Challis Volcanics extend up to 10,500 ft, showing that only an occasional peak (Borah Peak, 12,600 ft; Mt. Leatherman, 12,200 ft) rose

above the volcanic field. Inasmuch as the highest peaks in the region are either composed of Challis Volcanics (for example, Rainbow Mt., 9300 ft; Sheldon Mt., 9200 ft; Boulder Mt., 10,500 ft; near Galena Peak, 10,500 ft), or have remnants of it high on their flanks (Sawtooth Range, Lost River Range, White Cloud Peaks, Ramshorn Peak), very few summits escaped burial.

Although the relations suggest that the pre-volcanic surface may locally have had as much as 2000 ft of relief, it probably had less in most of the higher parts of the region. More detailed field work will be required to determine the pre-volcanic topography with greater accuracy, although it is nonetheless clear that the highs were local in extent, and that relief over broad areas was subdued and low. Assuming that subsidence generally kept pace with the outpouring of the volcanics, and that the general level of the central axis of the plateau was near 4000 ft, as implied by the plant evidence (Fig. 6B), then most of the higher peaks that rose above the volcanic plain probably had altitudes near 5000 to 6000 ft, with an occasional summit possibly reaching 7000 ft. The relations suggest uplift of fully a mile, since the Eocene, which is consistent with the structural evidence as now known.

Southward from the Salmon River Mountains, the contact between Challis Volcanics and the underlying basement is well exposed along the north margin of the Snake River Plain. The pre-volcanic surface has generally low relief with highs of granitic and metamorphic rocks rising locally. Similar relations may be observed south of the structural trough in Idaho, both to the east (near Blackfoot) and to the west (Shoofly Creek, Silver City). In the Jarbidge region of northeastern Nevada (Coats, 1964), Eocene volcanic rocks (Deadhorse Tuff) accumulated on a surface of moderate relief, with local basement highs providing pebble-cobble conglomerates to the volcanic sequence. Similar relations are indicated for the Eocene Bull Run Mountains 40 miles west. The highest part of the range probably rose about 1000 ft above the basin, and the northern end of the adjacent Independence Range was also an area of low relief, largely blanketed by Eocene volcanic rocks.

The preceding evidence suggests that schematic north-south sections across the western part of the Snake River basin area during the Eocene as compared with today may have been essentially as shown in Figure 9. The present

⁴ Many major faults in the region were not recognized by Ross and his contemporaries. As a result, pre-volcanic highs can not be determined with certainty until structure has been mapped more accurately.

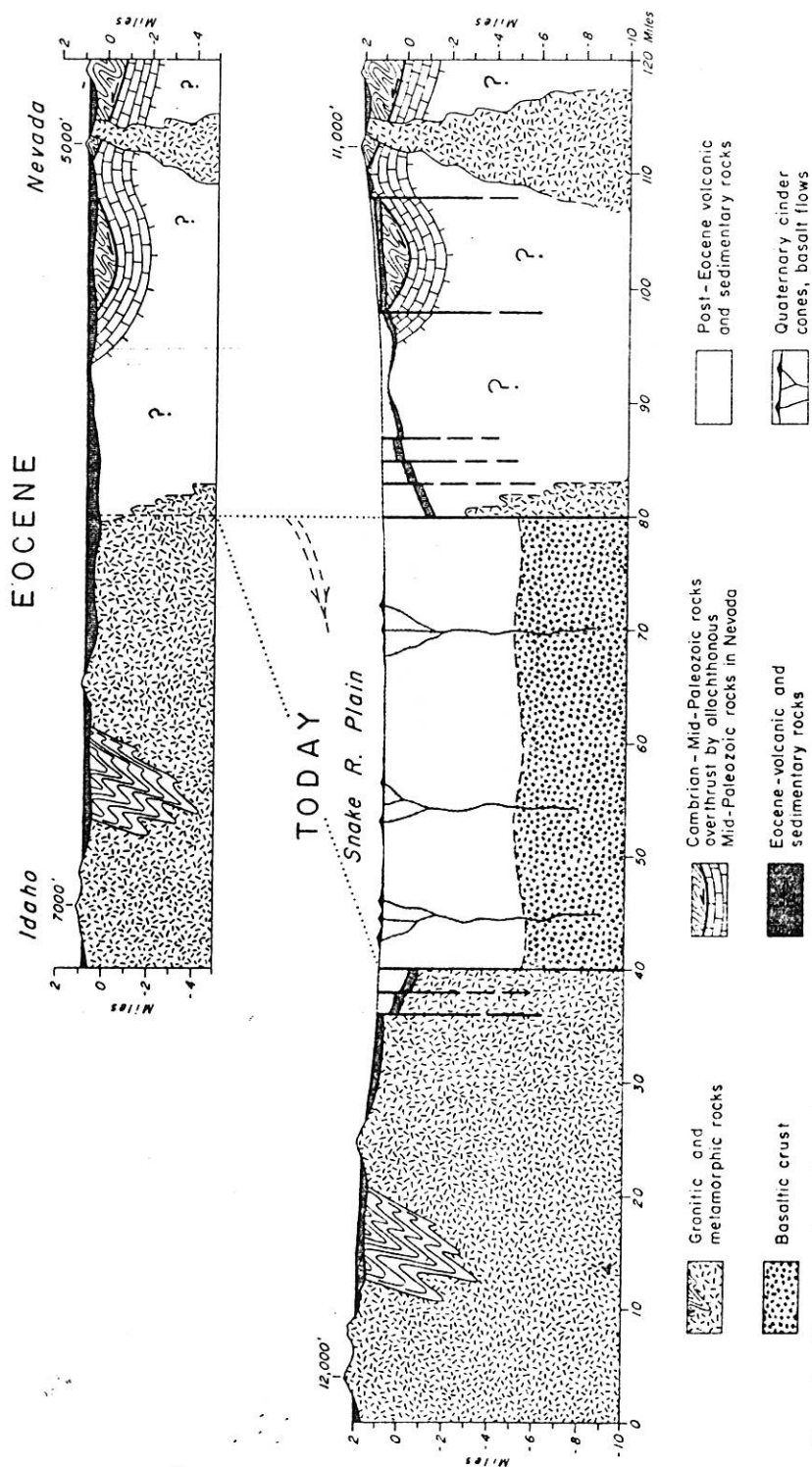


Figure 9. Diagrammatic north-south cross-section of western half of Snake River Plain in Eocene and today. Current structural and geophysical data suggest that the basin may be a "pull-apart," with about 40 miles of northward movement. Altitude of bordering highlands has increased approximately one mile since Eocene time.

Snake River Plain probably is a trough that filled with volcanic and sedimentary rocks as the Idaho basin subsided about 40 miles northward following the Eocene time (see Hamilton and Myers, 1961). Paleobotanical evidence implies that the bordering highlands to the north have been elevated about one mile since Eocene time.

Regional Setting

With respect to the regional setting, the Idaho-Nevada Eocene plateau, which had an altitude decreased to the east, was a part of the Cretaceous divide that trended northward into central Nevada into Idaho (Figure 10). From plant evidence, this axis probably formed in the Eocene, at which time the general regional setting may have been essentially as shown in Figure 10. To the east, along the present Rocky Mountains, the Tertiary orogeny had already produced moderate altitude separated by the divide, in which extensive lacustrine and fluvial deposits accumulated (King, 1961; Houten, 1961). There is no marked change in topography between Eocene-Eocene time, as many of the records continue deposition. There is no evidence for major tectonic activity. Paleocene floras (Brown, 1961) at localities that straddle the present divide show humid lowland conditions much like those of the late Cretaceous. Late Cretaceous and Paleocene hardwood or subalpine conifer floras are recorded in the region. Where the known early Eocene, Paleocene, and Cretaceous floras probably lived at or near sea level, they now occur in the Snake River Plain near 5000 ft on the western Great Plains. Thus it seems probable that the divide axis formed only a low, broad continental divide during the Late Tertiary, a divide that was lower than the Nevada-Idaho divide at that time.

The Eocene lakes (Figure 10) probably formed by earlier Laramide uplift in basins that received Late Paleocene sediments, or both, from the Great Plains province. The divide was elevated sufficiently—probably a few hundred feet—to undergo erosion and drainage systems for the two basins suggested by the dotted line.

Snake River Plain probably is a deep structural trough that filled with volcanic and sedimentary rocks as the Idaho batholith drifted about 40 miles northward following Eocene time (see Hamilton and Myers, 1966, Fig. 9). Paleobotanical evidence implies that the bordering highlands to the north and south have been elevated about one mile since that time.

Regional Setting

With respect to the regional setting of the Idaho-Nevada Eocene plateau, it is recalled that altitude decreased to the east and west of a Cretaceous divide that trended northward from central Nevada into Idaho (Fig. 8). To judge from plant evidence, this axis persisted into the Eocene, at which time the general topographic setting may have been essentially as shown in Figure 10. To the east, along the trace of the present Rocky Mountains, the Laramide orogeny had already produced local ranges of moderate altitude separated by broad basins in which extensive lacustrine and fluvio-lacustrine deposits accumulated (King, 1958, 1959; Van Houten, 1961). There is no evidence for a marked change in topography during Paleocene-Eocene time, as many of the major basins record continuing deposition. Furthermore, there is no evidence for major changes in altitude. Paleocene floras (Brown, 1962) from localities that straddle the present Continental Divide show humid lowland environments much like those of the late Cretaceous. Significantly, Late Cretaceous and Paleocene conifer-hardwood or subalpine conifer forests are not recorded in the region. Whereas nearly all of the known early Eocene, Paleocene, and Late Cretaceous floras probably lived within 1000 ft of sea level, they now occur in rocks at altitudes near 5000 ft on the western Great Plains, and at 7000 to 9000 ft close to the Continental Divide. Thus it seems probable that the Rocky Mountain axis formed only a low, indefinite continental divide during the Late Cretaceous and early Tertiary, a divide that evidently was lower than the Nevada-Idaho axis during those times.

The Eocene lakes (Fig. 10) express continued ponding by earlier Laramide events. They occur in basins that received Late Cretaceous and Paleocene sediments, or both, but were removed from the Great Plains province, which was then elevated sufficiently probably only a few hundred feet to undergo erosion. The possible drainage systems for the two principal axes, suggested by the dotted lines (Fig. 10), are

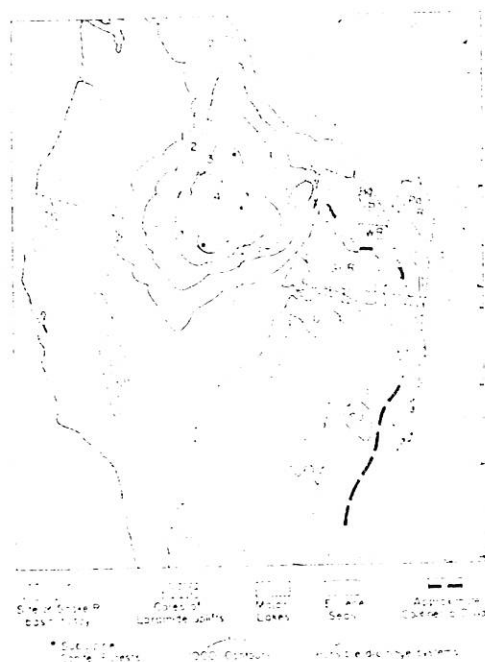


Figure 10. General Eocene paleogeography, showing area of Eocene volcanic plateau, imaginary river systems, and major basins of deposition. Figure 6A shows Eocene forest zones of the region.

imaginary rivers. The geologic work necessary to determine their existence and plot their course has not been done, and further, the record has been removed from much of the region or else is buried. Nonetheless, if we accept two major drainage divides for the Eocene, then the principal drainage systems of that time appear to have persisted to the present, at least in their broad features.

SUMMARY

Geologic and paleobotanic evidence suggest that the following major events were involved in the topographic history of the Snake River basin:

(1) An upland source area that supplied sediments to the Pacific Coast and Rocky Mountain geosynclines during the Cretaceous was aligned north-south through central Idaho and Nevada. Spanning the site of the Snake River basin, this upland axis persisted into the Eocene.

(2) During Eocene time a major episode of volcanism buried the north-south axis, a terrain then characterized by broad areas of low to moderate relief with local highs. The Eocene

volcanic plateau apparently stretched from north-central Idaho into Nevada, and from western Wyoming possibly to northern California and eastern Oregon.

(3) The high central part of the plateau axis was covered with subalpine conifer and conifer-hardwood forests. The former implies an average minimum altitude near 4000 ft, and structural evidence suggests that locally the highest peaks probably stood near 6000 ft.

(4) The conifer-hardwood forest graded east and west to deciduous hardwood and thence to evergreen broadleaved forest near the margins of the volcanic plateau at an altitude of about 1500 ft in Wyoming and central Oregon.

(5) The Snake River basin evidently formed during Oligocene time, apparently as a tensional rift in the lee of the Idaho batholith, which began to drift north (Hamilton and Myers, 1966). Subsidence may have begun earlier in the west, with the basin opening up as an ever-widening rent, floored with denser ("basaltic") rock in its western half.

(6) Miocene floras show that the basin had formed. Mixed deciduous hardwood forest in the Miocene Snake River basin suggests a minimum altitude near 1000 to 1500 ft in the western half, whereas conifer-hardwood forest on its adjacent flanks was at least 1000 to 2000 ft higher, grading into subalpine conifer forest at higher levels farther north and south.

(7) As subsidence continued, remnants of the Eocene volcanic plateau were left perched on the flanks of the basin. The subsiding central part was progressively buried by younger formations that accumulated as the trough continued to subside and widen during the rest of the Cenozoic, while the Idaho batholith appears to have continued to drift slowly northward.

(8) Subsidence of the Snake River basin was accompanied by uplift of the bordering highlands, which now stand at 11,000 to 12,000 ft as compared with about 6000 to 7000 ft in the Eocene.

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Meteorological stations providing some major forest types (see Fig.

SUBALPINE CONIFER FOREST

CALIFORNIA. Soda Springs, South Lake, Huntington Lake. NEW ENGLAND. First Connecticut. Eastport. GREAT LAKES. Harbor, Mich.; Humboldt, O'Lakes, Wisc. OREGON-W. Crater Lake, Mt. Rainier National Park, Ranger Stations, Steens Pass, Steens Pass, Steens Pass, Steens Pass. JAPAN-KUR. Sikka.

CONIFER-HARDWOOD FOREST

VERMONT. St. Albans. MASS. Adams. NEW HAMPSHIRE. Chatham Expt. Farm, Stanc. MICHIGAN. Mackinaw City. SIN. Rheinlander, Minocqua, hauser, Dodgeville. NEW. Placid, Indian Lake. PEN. Coudersport, Somerset. WEST VIRGINIA. Shady Side. Oiwake, Otiai. CHINA. Ilmienpo, Kungchuling.

REDWOOD FOREST

CALIFORNIA. Scotia, Santa Crescent City.

DECIDUOUS BROADLEAF FOREST

CHINA. Chaoyang, Peking, T. MARYLAND. Cumberland. DELAWARE. Milford, C. INDIANA. Rockville, Wason. ILLINOIS. Mt. Vernon. UANIA. Ephrata, Belefonte. WEST VIRGINIA. Cairo.

MIXED MESOPHYTIC FOREST (TZE BASIN)

CHINA. Engshih, Nanking, I.

EVERGREEN BROADLEAF FOREST

JAPAN. Kagoshima, Osaka, N. Chanting, Yungkia, chung, Kunming.

TEMPERATE RAINFOREST

GUATEMALA. Coban (above Huatusco, Jalapa, Orizaba, C. Swatow, Wuchow, Yunnan. TAIWAN. Taipei.