An Analysis of Present-Day Terrestrial Lapse Rates in the Western Conterminous United States and Their Significance to Paleoaltitudianal Estimates

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By JACK A. WOLFE

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An Analysis of Present-Day Terrestrial Lapse Rates in the Western Conterminous United States and Their Significance to Paleoaltitudinal Estimates

By Jack A. Wolfe

Abstract

Compilation of temperature data from stations throughout the western conterminous United States and calculations of terrestrial lapse rates relative to the Pacific Coast indicate that terrestrial lapse rates for most stations are significantly less than the putative worldwide mean of 5.0–6.0 °C/km. Terrestrial lapse rates for stations in specific physiographic provinces typically decrease with decreasing latitude for a given altitude and decrease with decreasing altitude for a given latitude. The major exception to these decreases is in terrestrial lapse rates for intramontane basins within the Rocky Mountains, which show basically no latitudinal or altitudinal change in rate.

Terrestrial lapse rates are typically highest for stations on the windward slopes of mountains. Intermontane plateaus leeward of the Cascade Range and Sierra Nevada have markedly lower terrestrial lapse rates for a given altitude than stations at comparable altitudes on the windward slopes of these mountains. Intramontane basins also have significantly lower terrestrial lapse rates than adjacent mountains, although this differential lessens southward.

Present-day terrestrial lapse rates in the western United States probably are affected most strongly by incursions of frigid arctic air, the influence of which decreases southward and decreases toward lower altitudes. This overlay tends to mask elemental (and lower) terrestrial lapse rates that are probably more applicable to most of the Tertiary. Comparison of elemental lapse rates for the western United States with lapse rates for other regions of the world (especially Asia and South America) indicates that areally extensive high plateaus and mountain ranges such as the Tibetan Plateau and Andean region have markedly lower terrestrial lapse rates of about 2.0–3.0 °C/km, a range that includes the suggested elemental lapse rates for much of the western conterminous United States. Most previous paleoaltitudinal estimates for specific assemblages in the western North America are based on a much higher lapse rate and thus consistently underestimate altitude. A consideration of where fossil plant assemblages most likely accumulate also leads to the suggestion that most previous paleoaltitudinal estimates are too low.

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INTRODUCTION

The solutions to many paleotectonic interpretations depend on the use of valid and reproducible terrestrial lapse rates (Molnar and England, 1990), which are the rates by which temperature decreases along the Earth's surface as altitude increases. If mean annual temperature can be estimated for a fossil assemblage in an area of unknown altitude and also for an isochronous coastal assemblage, then a simple calculation using the appropriate terrestrial lapse rate should provide a paleoaltitudinal estimate for the area of unknown altitude; this is the basis for the methodology developed by Axelrod (1966). One problem with this methodology, however, is the assumption that in almost all instances a terrestrial lapse rate of 5.5 °C/km is valid.

As emphasized by Meyer (1986), terrestrial lapse rates can significantly vary from the putative worldwide mean of 5.5 °C/km, especially relative to the increase in mean annual temperature on large massifs. Meyer's (1986) approach to paleoaltitudinal estimates introduces complexities such as calculating a hypothetical sea-level temperature in the area of the unknown altitude. This approach, which also ignores data from regions such as the Columbia Plateaus and Great Basin, is perhaps overly complicated and provides little assurance that a local terrestrial lapse rate in a particular mountainous area can be extended back into the Tertiary.

My analysis covers much of the same ground as does Meyer's (1986) analysis but with significant differences. Whereas Meyer derived local terrestrial lapse rates by calculating temperature differences between stations in the same area, I derived lapse rates by calculating temperature differences between coastal and upland and (or) interior areas, which is the basis for the methodology proposed by Axelrod (1966). I have, moreover, included all lower altitude, interior stations, most of which were excluded by Meyer (1986); such sites probably are present in topographic analogues of Tertiary depositional basins, which are basic to paleoaltitudinal estimates.

For discussions of various aspects of the topics discussed and for offering comments and suggestions on the manuscript, I thank Peter Molnar (Massachusetts Institute of Technology), Judith Totman Parrish (University of Arizona), and Robert A. Spicer (Oxford University).

METHODOLOGY

The basis for my derivation of modern terrestrial lapse rates is (1) estimation of coastal temperatures by smoothing the actual data set from stations (see next section), (2) calculating the difference in mean annual temperature between an interior and (or) upland station and the coast at the same latitude, and (3) dividing the temperature difference (in degrees Celsius) by the altitudinal difference (in kilometers). I converted the temperature data, which are given in various publications of the National Oceanic and Atmospheric Administration's Climatic Data Center (or its predecessors), from degrees Fahrenheit. Stations that recorded temperatures for 10 years or less were generally excluded, although, because of the sparsity of high-altitude data, data from some high-altitude stations that recorded temperatures for 8–10 years were included. Grouping of the stations into physiographic subdivisions (plate 1) generally follows Lobeck (1950). Some minor differences between Lobeck's subdivisions and those employed here are noted in the following discussions; for example, I extended the Cascade-Sierra boundary southward to about lat 40° N., from near lat 42° N.

PRESENT-DAY TERRESTRIAL LAPSE RATES

Coastal Temperatures

Calculation of a terrestrial lapse rate partly depends on coastal temperature at the same latitude as the interior station, and determination of coastal temperature is not as simple as might be thought. Along the coast of Oregon and Washington, temperature does not increase at an absolutely uniform rate if stations are ordered from north to south (appendix 1). If temperatures are plotted against latitude, temperature generally increases from north to south (fig. 1). A best-fit line drawn through the plots indicates that temperature increases 2.3 °C from north to south; that is, a latitudinal temperature gradient of approximately 0.33 °C per degree of latitude. Data from outer coastal stations of British Columbia also fit this gradient, but data from outer coastal southeastern Alaskan stations (north of lat 55° N.) indicate a higher gradient of about 0.50 °C per degree of latitude.

Between lat 38° and 42° N., coastal temperature apparently is unrelated to latitude; a best fit, based on only eight stations, suggests a constant temperature of about 11.8 °C. Between lat 37° and 38° N., temperature increases to about 13.6 °C and then very gradually increases to about 14.0 °C just north of Point Arguello and Point Concepcion. Another marked increase occurs just southeast of Point Concepcion; excluding urban airport temperature data, temperature levels off at about 15.8 °C from just north of Los Angeles to the Mexican border. Note that temperatures from land forming points extending into the Pacific Ocean are anomalously low.

The stepwise pattern of the gradient in mean annual temperature along the California coast is not mirrored by data from more interior stations. Stations at given altitudes in the Sierra Nevada, for example, have temperatures that increase at a uniform rate from north to south. If, however, the latitudinal temperature gradient that was suggested between lat 42° and 55° N. is extended southward (fig. 1), the gradient intersects the actual best-fit lines at two points and would intersect the line again just south of the Mexican border. This extension smooths irregularities in coastal California temperature caused, at least partly, by the irregular width of the continental shelf and by upwelling. This smoothed latitudinal temperature gradient is used in this report for calculating terrestrial lapse rates in the western conterminous United States.

Embayments and Large Valleys Opening to the Coast

Mean annual temperatures in embayments and large valleys near the coast are uniformly higher than temperatures on the coast (table 1), and thus some terrestrial lapse rates are negative. Although winter temperatures are somewhat lower than on the coast, markedly warmer summer temperatures result in a net increase in mean annual temperature. Values of negative lapse rates are highly dependent on altitude; on plate 1, the actual difference in mean annual temperature between the coast and interior stations for stations that are warmer than the coast is given rather than the lapse rate.

In the Pacific Northwest, mean annual temperatures are elevated more along the shores of the Puget Sound than in the Willamette Valley relative to coastal temperature. Although the Willamette Valley is heated more than the Puget Sound area in the summer, temperatures in the Puget Sound area are relatively higher in the winter. In near-

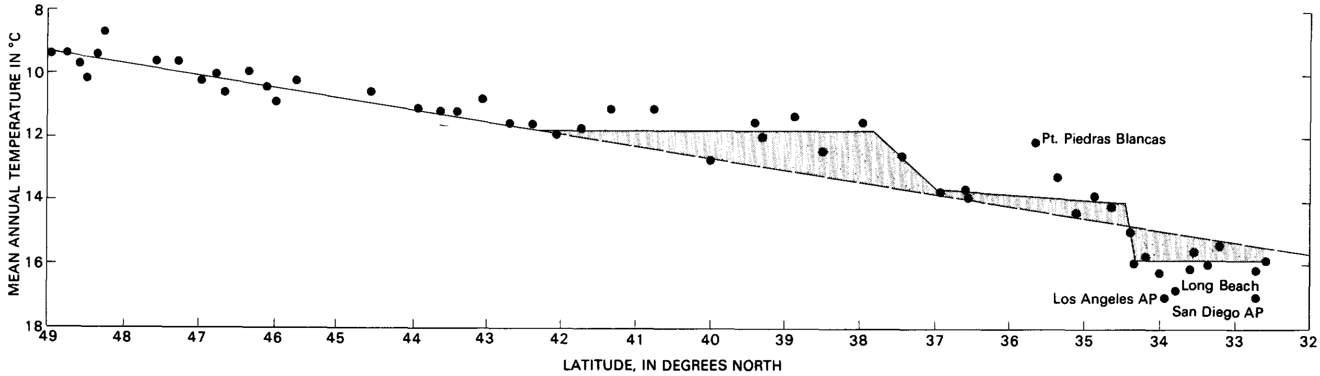

Figure 1. Plots of mean annual temperature and latitude for stations listed in appendix 1 along the Pacific Coast of the western conterminous United States. The solid line represents a best-fit for actual mean annual temperature, and the dashed line represents the inferred latitudinal temperature gradient south of lat 42° N.

Table 1. Terrestrial lapse rates and temperatures for areas around marine embayments and for large coastal valleys

Altitude (meters)	Lapse rate (°C/km)	Station	Mean annual temperature (°C) Station	Coastal
		Puget Sound, Washington		
81	-0.7	Tacoma	10.7	10.1
37	0	Quilcene 2SW	9.9	9.9
30	-2.8	Everett	10.1	9.8
7	0	Shelton	10.1	10.1
6	-150.0	Grapeview	11.0	10.1
4	-350.0	Seattle AP	11.4	10.0
		Willamette Valley, Oregon		
198	1.5	Cottage Grove	11.0	11.3
148	-1.4	Fern Ridge Dam	11.4	11.2
125	-0.8	Estacada	10.9	10.8
111	-4.5	Eugene	11.4	10.9
69	-1.4	Corvallis	11.1	11.0
59	-3.4	Salem	11.1	10.9
51	-27.5	Oregon City	12.2	10.8
45	-6.7	McMinnville	11.1	10.8
		Valleys of southwestern Oregon		
533	1.5	Ashland	11.1	11.9
396	-0.3	Medford	12.0	11.9
282	-2.1	Grants Pass	12.5	11.9
207	-2.4	Riddle	12.2	11.7
142	-3.5	Roseburg	12.1	11.6
89	-3.4	Drain	11.7	11.4
70	-1.4	Powers	11.8	11.7
37	-24.3	Elkton	12.3	11.4
		San Francisco Bay, California		
105	-4.8	Berkeley	14.0	13.5
17	-52.9	Richmond	14.4	13.5
8	-21.2	Palo Alto	14.0	13.6
2	-100.0	San Francisco AP	13.7	13.5

coastal basins, presence of a significant marine embayment increases mean annual temperature more than in nonmarine basins. A similar relation occurs between stations around San Francisco Bay and stations in the Los Angeles basin relative to actual coastal temperatures, although urban heating in these two areas makes conclusions based on temperature data from these areas somewhat uncertain.

The Sacramento and San Joaquin Valleys (here collectively referred to as the Great Valley) are more distant from the coast than the basins just discussed and are isolated from the coast by almost continuous mountain ranges whose divides are about 800 m high. Summer heating in the Great Valley is great and results in mean annual temperatures 3–4 °C higher than smoothed coastal mean annual temperatures. Mean annual temperatures are at or above sea-level temperatures (and hence terrestrial lapse rates are negative) to an altitude of about 800 m on slopes above the Great Valley. During most of the Tertiary the Great Valley was at least partially inundated by marine waters through various straits. By analogy with the Puget Sound–Willamette Valley relation, these shallow extensions of marine waters may have resulted in an even greater elevation of mean annual temperature than today. During high stands of sea level, however, the Coast Ranges would have stood relatively lower, and summer heating in interior valleys was perhaps not as great as today.

Coastal Mountains

Except east of San Diego, meteorological data from even moderate altitudes in coastal mountains are sparse (appendix 2); most stations are in valleys within the Coast Ranges and generally have mean annual temperatures higher than the coastal mean annual temperatures and thus have negative terrestrial lapse rates (table 2). From the

Table 2. Mean annual temperatures for valleys of the Coast Ranges

[Mean amount that valley mean annual temperature is higher (or lower) than coastal mean annual temperature is in °C. Number in brackets is number of stations. Leaders (--) indicate not applicable]

Altitude (meters)	Latitude (degrees north) >42	40–42	38–40	35–37	32–35
400–600	-1.4 [2]	-1.3 [2]	-0.6 [4]	--	1.8 [2]
200–400	0.3 [2]	1.3 [2]	1.7 [1]	1.3 [3]	0.7 [1]
<200	0.5 [4]	1.4 [2]	1.0 [7]	0.7 [3]	2.1 [2]

limited data, valleys within the Coast Ranges have mean annual temperatures that reflect primarily latitude; temperature generally increases as latitude decreases but decreases with altitude only in the north and then only slightly. The southward increase in mean annual temperature is more than would be expected from the southward increase in mean annual temperature along the coast; that is, the farther south the valley, the more mean annual temperature increases relative to coastal mean annual temperature.

The very limited data from altitudes greater than 800 m in the Coast Ranges show no significant differences in terrestrial lapse rates as compared with stations of similar altitudes in the Cascade Range and Sierra Nevada (table 3). However, the obvious decrease in terrestrial lapse rates from north to south is probably related to the increase in mean annual temperatures in the valleys of the Coast Ranges.

Cascade Range and Sierra Nevada

The Cascade Range forms an almost continuous north-south barrier northward from lat 40 °N. to north of lat 49° N., where the range merges with the British Columbia Coast Ranges. The only gaps in the Cascades are formed by the westward-flowing Columbia River between Oregon and Washington and the southwestward-flowing Klamath and Pit Rivers in northern California. Although two peaks are slightly higher than 4,000 m altitude, most are about 2,700–3,400 m high. These peaks are typically widely separated, and the divides between are about 1,200–1,500 m high. Except for three stations, the Cascade stations are at or below the divides (table 4, appendix 3).

North of lat 46° N. (most of the Washington Cascades), terrestrial lapse rates are uniformly high for altitudes greater than 700 m on both windward and leeward slopes of the Cascades (appendix 3). On the windward side, the seven Washington stations at altitudes greater than 900 m have a mean lapse rate of 4.7 °C/km in contrast to 4.3 °C/km for the four Oregon stations at altitudes greater than 900 m and north of lat 43° N. On the leeward slope the relation is similar: the 13 Washington stations at altitudes greater than 500 m have a mean lapse rate of 4.4 °C/km in contrast to 3.8 °C/km for the 6 Oregon stations. South of lat 43° N., lapse rates on both windward and leeward slopes of the Cascade Range are lower than those north of lat 43° N. Thus, terrestrial lapse rates on both the windward and leeward sides decrease as latitude decreases, and leeward lapse rates generally are lower than windward lapse rates.

The Sierra Nevada markedly increase in altitude from north to south. The divides in the northern part are at about 1,400 m altitude, and, at the latitude of Yosemite (about 38° N.), the divides are at about 2,900 m. To the south, the Sierra Nevada divides are higher than 3,000 m, and peaks include Mt. Whitney (4,417 m). Many of the stations are in valleys cut into the the western slope, but some stations are at or near the crest of the Sierra; no data are available for the highest parts of the Sierra south of Yosemite.

The pattern of southward decline of terrestrial lapse rates continues in the Sierra Nevada. Only two stations have a lapse rate that exceeds 3.8 °C/km (appendix 4), and one of these (Lodgepole) is in a small basin that apparently traps cold winter air (the winter temperatures at Lodgepole are consistently lower than those at nearby Grant Grove at about the same altitude). Lapse rates markedly decrease at altitudes of less than 1,800 m, and, as noted previously, negative lapse rates generally prevail below 800 m.

The Cascade-Sierra data indicate that terrestrial lapse rates on both windward and leeward sides decline from north to south, but the decline is greater on descending the leeward slopes of the ranges (table 5). With an altitudinal decrease of only 200 m, some lapse rates decline by more than 1.0 °C/km, and the rate of decrease continues to decline at an even greater rate as altitude decreases. A basin to the leeward of a mountain range and only a few hundred meters lower in altitude than the divides of the range will have mean annual temperatures significantly higher than at the same altitude on the windward side. Lapse rates can, however, increase immediately leeward of the divides of a range before markedly declining. This phenomenon occurs, for example, immediately east of the Cascade Range in Washington (compare summit lapse rates of Snoqualmie and Stevens Passes with the lapse rate of Lake Keechelus) and immediately east of the Sierra Nevada in California (compare near-summit lapse rates of Sierraville RS and Ellery Lake with lapse rates of Boca and Bodie, respectively).

Table 3. Comparison of mean terrestrial lapse rates between the Coast Ranges and the interior (Cascade Range and Sierra Nevada) at the same latitude

[North Coast Ranges are north of lat 43° N., and Central Coast Ranges are between lat 37° and 43° N. Terrestrial lapse rate in °C/km. Number in brackets is number of stations. Leaders (--) indicate not applicable]

Altitude (meters)	North Coast Ranges	Interior	Central Coast Ranges	Interior
1,200–1,400	--	--	1.2 [1]	1.7 [3]
1,000–1,200	3.6 [1]	3.5–4.1	2.6 [1]	2.7 [2]
800–1,000	--	--	2.0 [2]	2.5 [1]
600–800	--	--	2.7 [1]	2.2 [3]
400–600	3.6 [1]	2.9 [2]	-0.9 [5]	-2.0 [4]

Table 4. Decline of terrestrial lapse rates along windward slopes of the Cascade Range and Sierra Nevada southward and as altitude decreases

[Lapse rate in °C/km. Number in brackets is number of stations. Leaders (--) indicate not applicable]

Altitude	Latitude (degrees north)				
(meters)	46–49	43–46	40–43	38–40	35–38
2,800–3,000	--	--	--	--	3.7 [1]
2,600–2,800	--	--	--	--	3.0 [1]
2,400–2,600	--	--	--	3.7 [3]	--
2,000–2,200	--	--	--	4.1 [1]	3.5 [3]
1,800–2,000	--	4.3 [1]	--	3.5 [3]	--
1,600–1,800	4.1 [1]	--	3.0 [1]	2.6 [3]	--
1,400–1,600	--	4.3 [2]	2.9 [4]	2.8 [4]	2.1 [3]
1,200–1,400	4.5 [3]	4.1 [1]	3.0 [3]	--	1.7 [3]
1,000–1,200	--	--	2.7 [2]	2.4 [3]	1.4 [1]
800–1,000	4.8 [4]	--	2.5 [1]	0.7 [6]	-1.1 [2]
600–800	--	3.5 [3]	2.0 [2]	-2.7 [1]	1.6 [2]
400–600	3.7 [3]	2.9 [2]	1.5 [1]	0.3 [1]	-4.9 [2]
200–400	2.7 [6]	2.5 [4]	-3.5 [2]	-6.3 [1]	-13.9 [1]
100–200	0.7 [5]	0.4 [4]	--	-22.8 [1]	-23.5 [6]

Rocky Mountains

The Rocky Mountains almost meet the northern part of the Cascade Range in northern Washington and from there extend markedly southeastward. They comprise a series of ranges that generally increase in altitude from near the Canadian border to a maximum altitude in Colorado. South of Colorado, the Rockies decrease in altitude and lose their identity in New Mexico. The Central and Southern Rockies are separated by a large intramontane basin in southern Wyoming.

Divides in the Northern Rockies are 1,500–2,000 m high but are as high as 2,400 m in the Central Rockies. Similarly, few peaks in the Northern Rockies are higher than 3,000 m, but in the Central Rockies some peaks are 4,000 m high. In the Southern Rockies of Colorado, divides typically are higher than 3,000 m and many peaks are higher than 4,000 m. In northern New Mexico, the Rockies are generally lower; only one peak of the Sangre de Cristo Range is 4,000 m high, and south of Albuquerque none of the peaks east of the Rio Grande is as high as 3,000 m. The Continental Divide is west of the Rio Grande in the northern part of New Mexico and some peaks are as high as 3,000 m. The high ranges are, however, interrupted by an extension of the Colorado Plateau between lat 35° and 36° N., where the Continental Divide is about 2,200 m high. The divide then follows a series of mountain ranges in the western New Mexico, where a few peaks are more than 3,000 m high. South of lat 33° N., the altitude decreases sharply, and the Continental Divide is less than 1,400 m high.

The Rocky Mountain data (appendix 5), similar to the Cascade-Sierra data, indicate a decline in terrestrial lapse rates from north to south (table 6); note that appendix 5 excludes all stations in intramontane basins (which section see later). Also excluded are data from the adjacent inter-montane plateaus such as the Columbia Plateau, Snake

Table 5. Comparison of terrestrial lapse rates between stations at or near windward mountain passes and leeward stations
[Data indicate a sharp increase in mean annual temperature to leeward and thus a marked decrease in lapse rate compared to windward flanks of mountains]

Windward station	Altitude (meters)	Mean annual temp. (°C)	Lapse rate (°C/km)	Leeward station	Altitude (meters)	Mean annual temp. (°C)	Lapse rate (°C/km)
Stevens Pass, Wash.	1,245	4.3	4.5	Waterville, Wash.	794	7.2	3.4
Snoqualmie Pass, Wash.	920	5.4	5.0	Ellensburg AP, Wash.	526	8.4	3.4
Stampede Pass, Wash.	1,206	4.1	5.0	Wilson Creek, Wash.	389	9.6	1.0
Government Camp, Oreg.	1,213	5.8	4.1	Madras, Oreg.	680	9.1	2.8
				Kent, Oreg.	829	8.9	2.3
Fish Lake, Oreg.	1,475	6.5	3.7	Klamath Falls 2SSW, Oreg.	1,249	8.8	2.5
Mineral, Calif.	1,485	7.4	3.5	Susanville, Calif.	1,264	9.3	2.6
				Sand Pass, Nev.	1,189	10.9	1.4
Sierraville RS, Calif.	1,516	7.5	3.6	Reno, Nev.	1,342	9.7	2.4
				Fallon Exp. Stat., Nev.	1,209	10.9	1.7
Tahoe City, Calif.	1,899	6.0	3.6	Carson City, Nev.	1,425	10.1	2.0
				Yerington, Nev.	1,334	10.7	1.8
Twin Lakes, Calif.	2,438	4.3	3.6	Woodfords, Calif.	1,753	9.7	2.0
Ellery Lake, Calif.	2,926	2.7	3.7	Bishop, Calif.	1,252	13.3	0.3

River Plain, and Colorado Plateau. At the higher altitudes, lapse rates in the Rocky Mountains are generally similar to those at the same latitudes and altitudes in the Cascade Range and Sierra Nevada. The Northern Rockies have uniformly high lapse rates throughout their altitudinal range, but lapse rates for the Central Rockies are lower at lower altitudes as are those for the Southern Rockies. Note, however, that lapse rates apparently also are low for the highest altitudes in the Southern Rockies.

Intermontane Plateaus

An extensive area between the Cascade Range and Sierra Nevada on the west and the Rocky Mountains on the east is occupied by plateaus. In the Pacific Northwest, these mostly comprise the Columbia Plateaus, which can be further subdivided into smaller physiographic units; most of these plateaus are about 1,000 m high, but that part of the Snake River Plain near the Northern and Central Rockies is more than 1,500 m high. The northern edge of the Great Basin is in southern Oregon and Idaho; although not normally called a plateau because of its predominantly internal drainage and many mountain ranges, the core of the Great Basin (see plate 2) is basically a high (1,800–2,000 m) and rugged plateau that extends south to about lat 36° N.; this plateau is flanked on both its western and eastern sides by low basins that have altitudes of less than 1,300 m. To the east of the southern half of the Great Basin, the low basin is flanked by the rugged, mountainous western margin of the northern part of the Colorado Plateau in Utah. The main part of the Colorado Plateau is at altitudes of about 1,800–2,200 m and extends into northern Arizona and New Mexico.

Relative to the surrounding montane areas, the Walla Walla Plateau of eastern Washington, adjacent Idaho, and northeastern Oregon has low terrestrial lapse rates (appendix 6, table 7). At higher altitudes of the plateau, the lapse rate is half that for the same altitudes on the windward side of the Cascade Range, although lapse rates for stations in the mountains that rise from the plateau (Ochoco, Blue, and Wallowa Mountains, appendix 7) are comparable with those for the Cascades. Altitudes of less than 400 m on the Walla Walla Plateau generally have mean annual temperatures near or higher than mean annual temperatures on the coast. The Snake River Plain of the Columbia Plateaus similarly has lower lapse rates than at comparable altitudes on the windward slopes of the Oregon Cascades; the lower part of the Snake River Plain has particularly low lapse rates. Comparing data from the more northern Walla Walla Plateau with data from the Snake River Plain, lapse rates decline at comparable altitudes from north to south. In both regions lapse rates also decline as altitude decreases.

In the Great Basin, as on the Columbia Plateaus, terrestrial lapse rates decrease southward and as altitude decreases (table 8, appendix 8). In the central plateau region of the Great Basin, however, the decrease as altitudes decrease is not pronounced or even certain. Stations at altitudes of 1,600–2,200 m in the northern half of the Great Basin have a mean lapse rate of 2.7 °C/km and in the

Table 6. Decline of terrestrial lapse rates in the Rocky Mountains southward and as altitude decreases

[Lapse rate and standard deviation in °C/km. Latitude (degrees north) in parentheses. Number in brackets is number of stations. Leaders (--) indicate not applicable

Altitude (meters)	Northern (43–49)	Central (41–45)	Southern (37–41)	Southern (<37)
>3,000	–	–	3.7±0.2[3]	3.5 [1]
2,800–3,000	–	–	3.7±0.2[3]	–
2,600–2,800	–	3.9 [1]	4.0±0.4[10]	3.5±0.4[3]
2,400–2,600	–	–	4.2±0.3[5]	3.7±0.2[5]
2,200–2,400	4.2±0.2[2]	4.4±0.3[4]	4.4 [1]	3.3±0.4[4]
2,000–2,200	4.5±0.2[4]	4.4±0.4[10]	3.9±0.4[2]	3.2±0.3[7]
1,800–2,000	4.2±0.3[6]	4.1±0.4[22]		
1,600–1,800	4.4±0.3[7]	3.5±0.5[5]	Colorado Plateau	
1,400–1,600	4.1±0.4[6]			
1,200–1,400	4.4±0.4[7]	Snake River Plain		
1,000–1,200	4.7±0.4[4]			
800–1,000	4.5±0.4[9]			
600–800	4.2±0.3[7]			
400–600	4.2+0.2 [2]			
	Columbia Plateau			

Table 7. Comparison of terrestrial lapse rates between subdivisions of the Columbia Plateaus and the windward slope of the Cascade Range

[Lapse rate and standard deviation in °C/km. Number in brackets is number of stations. Leaders (--) indicate not applicable. Lapse rate values of less than -1°C/km were arbitrarily assigned a value of -1 °C/km; the apparent decrease in standard deviations at low altitudes is a function of this convention]

Altitude (meters)	Walla Walla Plateau	Harney section	Snake River Plain	Cascades Oregon	Cascades Washington
1,600–1,800	–	–	3.4±0.3 [2]	–	–
1,400–1,600	–	2.2±0.3 [2]	3.6±0.4 [7]	3.9 [4]	
1,200–1,400	–	2.4±0.2 [2]	2.5±0.5 [14]	3.5 [4]	
1,000–1,200	–	1.8 [1]	1.9±0.2 [4]	2.7 [4]	
800–1,000	2.3±0.6 [13]	–	1.7±0.3 [4]	3.2 [2]	4.6 [4]
600–800	2.5±1.0 [13]	1.2 [1]	0.7±0.9 [17]	3.1 [4]	–
400–600	1.0±1.1 [19]	–	–	–	3.5 [4]
200–400	-0.4±1.0 [15]	–	–	–	2.1 [3]
100–200	-1.0±0.0 [8]	–	–	–	–

southern half 2.2 °C/km. Contrasted to lapse rates at the same altitudes on the windward slopes of the Sierra Nevada and southern part of the Cascade Range, lapse rates in the Great Basin are substantially lower.

As with other north to south comparisons, stations in the northern (Utah and Colorado) part of the Colorado Plateau generally have higher terrestrial lapse rates at the same altitudes than stations in the southern (Arizona and New Mexico) part of the plateau (table 9). Lapse rates on the Colorado Plateau decrease as altitude decreases, but the rate of decrease is very low in the interval from 1,600 to 2,400 m, the general altitude of most of the plateau. The southern part of the Great Basin and the northern part of the Colorado Plateau are at about the same latitude and have similar lapse rates for the same altitudinal intervals.

Major River Canyons and Valleys

The two major rivers of the west—the Columbia and the Colorado—flow from deep within the North American continent and cut into the Columbia and Colorado Plateaus,

Table 8. Comparison of terrestrial lapse rates between northern and southern parts of the Great Basin and windward slopes of mountain ranges

[Lapse rate in °C/km. Number in brackets is number of stations. Leaders (--) indicate not applicable. Lapse rate values of less than -1 °C/km were arbitrarily assigned value of -1 °C/km]

Altitude (meters)	Cascade-Sierra (>lat 39.5° N.)	Great Basin: Northern (>lat 39.5° N.)	Great Basin: Southern (<lat 39.5° N.)	Sierra Nevada (<lat 39.5° N.)
2,200–2,400	--	--	2.6 [1]	3.7 [3]
2,000–2,200	4.1 [1]	2.2 [1]	2.4±0.4 [3]	3.7 [4]
1,800–2,000	--	2.5±0.3 [6]	2.5±0.8 [10]	3.5 [3]
1,600–1,800	3.0 [1]	2.8±0.6 [11]	2.2±0.4 [9]	2.6 [3]
1,400–1,600	2.9 [4]	2.1±0.9 [16]	1.9±0.4 [9]	2.5 [7]
1,200–1,400	3.0 [3]	1.9±0.6 [32]	1.1±0.6 [12]	1.7 [3]
1,000–1,200	2.7 [2]	1.7±0.3 [2]	-0.4±0.7 [4]	2.2 [4]

Table 9. Comparison of terrestrial lapse rates for intermontane plateaus in the western conterminous United States

[Lapse rate in °C/km. Number in brackets is number of stations. Lapse rate values of less than -1 °C/km were arbitrarily assigned value of -1 °C/km; the apparent decrease in standard deviations at low altitudes is a function of this convention]

Altitude (in meters)	Columbia Plateaus	Northern Great Basin	Southern Great Basin	Northern Colorado Plateau	Southern Colorado Plateau
2,400–2,600	--	--	--	3.7±0.2 [2]	3.1 [1]
2,200–2,400	--	--	2.6 [1]	2.9± 0.4 [3]	2.6±0.5 [4]
2,000–2,200	--	2.2 [1]	2.4±0.4 [3]	2.9±0.5 [9]	2.5±0.5 [20]
1,800–2,000	--	2.5±0.3 [7]	2.5±0.8 [10]	2.5±0.3 [9]	2.3±0.5 [8]
1,600–1,800	3.4±0.3 [2]	2.8±0.6 [11]	2.2±0.4 [9]	2.4±0.5 [11]	1.7±0.3 [10]
1,400–1,600	3.6±0.5 [9]	2.1±0.9 [16]	1.9±0.4 [9]	0.9±0.3 [4]	1.3±0.6 [11]
1,200–1,400	2.6±0.5 [16]	1.9±0.6 [32]	1.1±0.6 [12]	0.8±1.0 [6]	--
1,000–1,200	1.9±0.2 [5]	1.7±0.3 [2]	-0.4±0.7 [4]	-1.0 [1]	
800–1,000	2.2±0.7 [14]	--	-1.0±0.0 [3]	--	-1.0 [1]
600–800	1.5±1.2 [30]	--	-1.0±0.0 [2]	--	-1.0 [1]
400–600	0.9±1.2 [18]	--	--	--	--
200–400	-0.4±1.0 [13]	--	-1.0 [1]	--	--
<200	-1.0±0.0 [6]	--	--	--	--

respectively. Along much of the rivers' courses, mean annual temperatures are high and are the same or higher than sea-level mean annual temperatures along the coast (table 10). For the Columbia and its major tributary the Snake River, sea-level mean annual temperatures are at altitudes of more than 700 m and almost 600 km from the coast. For the Colorado River, sea-level mean annual temperatures are at altitudes of almost 1,500 m and 1,000 km from the coast. Mean annual temperatures are very high within deep canyons (for example, stations such as Richland, Oregon, and Inner Canyon USGS, Arizona), but the farthest inland extent of sea-level mean annual temperatures listed in table 10 is not in deep canyons. All these stations are, of course, in topographically low parts of their regions and are logical places for the deposition of fossil plants (see later discussion of paleoaltitudinal estimates).

Intramontane Basins

In the initial stages of this study, many stations in the Rocky Mountains appeared to have anomalously low terrestrial lapse rates. For example, some stations in the Northern Rockies of western Montana, an area for which lapse rates are generally greater than 4.0 °C/km, have lapse rates as low as 2.3 and 2.5 °C/km. When the topographic settings of these anomalous stations were investigated in detail, they invariably were in basins and (or) river valleys within the mountains. Large, obvious intramontane basins (for example, Bighorn, Shoshone, and Wyoming Basins) produce similarly anomalously low lapse rates (table 11, appendix 10).

Analysis of the terrestrial lapse rates in these intramontane basins (table 11) produced two surprising

Table 10. Mean annual temperature along the Columbia and Colorado Rivers

[Temperature in brackets is that for coast at same latitude]

Station	Distance to coast (kilometers)	Annual temperature (°C)		Altitude (meters)
Columbia River and tributaries				
Astoria AP, Oreg.	0	10.4		2
Clatskanie, Oreg.	50	10.5	[10.5]	7
Longview, Wash.	70	10.8	[10.5]	4
Portland AP, Oreg.	100	11.7	[10.7]	6
Bonneville Dam, Oreg	150	11.2	[10.6]	20
The Dalles, Oreg.	200	12.3	[10.7]	31
Arlington, Oreg.	290	12.5	[10.6]	87
Kennewick, Wash.	480	12.0	[10.5]	120
Wenatchee, Wash.	310	10.2	[10.0]	193
Chelan, Wash.	340	9.9	[9.9]	341
Coulee Dam 1SW, Wash.	260	9.6	[9.8]	519
Yakima River				
Prosser, Wash.	340	11.2	[10.5]	206
Sunnyside, Wash.	310	10.8	[10.4]	228
Wapato, Wash.	290	11.3	[10.4]	259
Yakima AP, Wash.	280	9.9	[10.3]	324
Okanogan River				
Oroville 3NW, Wash.	350	9.9	[9.5]	323
Snake River				
Wawawai 2NW, Wash.	540	12.7	[10.3]	212
Lewiston, Idaho	570	10.9	[10.4]	431
Orofino, Idaho	630	10.7	[10.4]	313
Kooskia, Idaho	650	10.3	[10.5]	384
Richland, Oreg.	530	10.8	[11.0]	675
Huntington, Oreg.	675	11.8	[11.1]	655
Weiser, Idaho	540	10.7	[11.2]	646
Payette, Idaho	540	10.4	[11.2]	643
Ontario KSRV, Oreg.	540	10.9	[11.3]	654
Nyssa, Oreg.	540	10.6	[11.3]	663
Swan Falls PH, Idaho	570	12.8	[11.5]	708
Grand View, Idaho	580	11.1	[11.6]	719
Glenns Ferry, Idaho	620	11.0	[11.7]	786
Colorado River and tributaries				
Boulder City, Nev.	350	19.4	[14.2]	770
Overton, Nev.	450	19.2	[14.0]	372
St. George PH, Utah	550	15.6	[13.8]	823
Zion NP, Utah	650	16.4	[13.8]	1,234
Inner Canyon USGS, Ariz.	550	20.4	[14.2]	783
Lees Ferry, Ariz.	670	16.8	[13.9]	957
Wupataki NM, Ariz.	670	14.3	[14.4]	1,496
Hite, Utah	1,000	15.7	[13.5]	1,058
Moab 4NW, Utah	1,100	12.7	[13.2]	1,209
Thompsons, Utah	1,110	11.6	[13.1]	1,570
Grand Jct. AP, Colo.	1,200	11.4	[13.1]	1,478
Palisade, Colo.	1,220	12.3	[13.1]	1,463

inferences. Unlike the lapse rates of the adjoining mountains and the intermontane plateaus, the lapse rates in the intramontane basins neither decrease as altitude decreases nor decrease from north to south. Within a given basin, moreover, no obvious correlation of lapse rate with altitude is apparent (table 12), although some stations at the lower altitudes within a basin have a relatively high lapse rate (presumably because of trapping of cold air).

Not all definite intramontane basins have low terrestrial lapse rates. For example, a few western Montana stations (Lincoln RS and Drummond AP, appendix 5), some stations in the Gunnison River Valley of Colorado (Cochetopa Creek and Gunnison, appendix 5), and the single station in North Park, Colorado (Fraser, appendix 5), have lapse rates as high as those of stations in nearby mountains. However, the proximal surrounding mountains are only a few hundred meters higher than the basins.

A high degree of protection afforded by the surrounding mountains probably is the critical factor in the development of anomalously high mean annual temperatures and consequently low lapse rates, as shown in the following examples.

1. In the Gunnison River Valley, a third station, Sapinero 9W, is situated 400 m higher than Cochetopa Creek and Gunnison in a tributary valley on the north side of the Gunnison Valley; Sapinero 9W has a lapse rate of 3.5 °C/km, compared with 4.4 °C/km for the other two stations.
2. The broad San Luis Valley of southern Colorado has a high mean terrestrial lapse rate compared with the adjacent upper Rio Grande Valley at Taos, New Mexico. The only significant physiographic differences between the two basins, which are at almost the same altitude, are (a) the Taos area is slightly farther south and (b) an east-west spur of the Sangre de Cristo Mountains extends across the valley separating the two basins and adding protection for the Taos area from arctic air masses.

Table 11. Mean terrestrial lapse rates for some intramontane basins and river valleys in the western conterminous United States

[Lapse rate and standard deviation in °C/km]

Basin	Number of stations	Mean lapse rate
Flathead Lake, Mont.	6	3.1±0.5
Bitterroot Valley, Mont.	4	3.0±0.3
Beaverhead-Madison, Mont.	8	2.9±0.5
Salmon River, Idaho	6	3.2±0.2
Bighorn, Mont. and Wyo.	12	3.0±0.6
Shoshone (Wind River), Wyo.	8	3.0±0.4
Wyoming, Wyo.	12	3.1 ± 0.3
Uinta-Piceance, Utah and Colo.	14	3.4±0.2
Estes Park, Colo.	1	3.0
San Luis Valley, Colo.	6	3.5±0.3
Rio Grande (upper), N. Mex.	5	3.0±0.3
Vermejo Park, N. Mex.	1	2.8
San Agustin Plain, N. Mex.	4	2.9±0.1

Table 12. Latitudinal and altitudinal distributions of mean terrestrial lapse rates for intramontane basins of the western conterminous United States

[Lapse rates in °C/km. Number in brackets is number of stations. Leaders (--) indicate not applicable. Analysis is based on 140 stations, which have a mean lapse rate of 3.06 °C/km and a standard deviation of 0.44]

Altitude (in meters)	Latitude (degrees north) 45–49		41–45		37–41		33–37	
2,400–2,600	--		3.2	[1]	3.1	[4]	3.1	[2]
2,200–2,400	--		2.9	[1]	3.2	[12]	3.0	[6]
2,000–2,200	--		3.1	[9]	2.9	[4]	2.9	[6]
1,800–2,000	2.7	[1]	2.9	[8]	3.3	[8]	--	
1,600–1,800	3.2	[5]	3.0	[7]	3.0	[11]	--	
1,400–1,600	2.8	[5]	2.7	[8]	3.3	[4]	--	
1,200–1,400	3.0	[2]	3.1	[7]	--		--	
1,000–1,200	2.9	[5]	3.4	[3]	--		--	
800–1,000	3.0	[10]	--		--		--	
600–800	3.2	[6]	--		--		--	
400–600	3.1	[4]	--		--		--	
200–400	3.1	[1]	--		--		--	
All altitudes	3.0	[39]	3.0	[44]	3.1	[43]	3.0	[14]
2,000–2,600	3.1	[11]	3.1	[20]	3.0	[14]	--	
1,400–2,000	2.9	[11]	2.9	[23]	3.2	[23]	--	
800–1,400	3.0	[17]	3.2	[10]	--		--	
<800	3.2	[11]	--		--		--	

3. Within the San Luis Valley, the lowest terrestrial lapse rate (3.0 °C/km) is based on Great Sand Dunes NM. This station is nestled against the northwest-trending Sangre de Cristo Mountains, which provide protection from north winds, and it probably receives adiabatically heated winds that come over the mountains.

4. Ouray, Colorado (2,390 m), is within a narrow, deep valley, in contrast to the considerably more open valley in which Aspen, Colorado (2,412 m), is located. Ouray has a lapse rate of 2.7 °C/km in contrast to the lapse rate of 3.4 °C/km for Aspen.

5. In the Flathead Lake valley of northwestern Montana, Kalispell AP is on the western side of the valley in the path of a northeast-southwest-oriented gap between the Whitefish and Swan Ranges, whereas Bigfork 12S is 40 km southeast and on the eastern side of the valley. Kalispell AP has a terrestrial lapse rate of 4.1 °C/km in contrast to 2.3 °C/km for Bigfork 12S.

These examples strongly indicate that a barrier that blocks arctic air masses is the critical factor in elevating mean annual temperature and thus lowering lapse rate.

Throughout the Rocky Mountains, terrestrial lapse rates of stations in intramontane basins are significantly lower than lapse rates in adjacent mountains (table 13). Although montane lapse rates decrease as latitude decreases, montane and intramontane lapse rates are less different and have almost the same values in the western New Mexico. The four stations on the San Agustin Plain (table 11), which is east of the Continental Divide, have a mean lapse rate of 2.9 °C/km in contrast to a mean of 3.2 °C/km for five high-altitude stations near or west of the Continental Divide.

High Plains

In Montana the High Plains slope from the eastern foot of the Rocky Mountains at an altitude of about 1,200 m east to the North Dakota State line at about 700 m. The western margin of the High Plains bends southeastward in southern Montana and Wyoming at an altitude of about

Table 13. Comparison of mean terrestrial lapse rates for intramontane basins and adjacent mountains

[Lapse rate in °C/km]

	Latitude (degrees north) 45–49	41–45	37–41	33–37
Intramontane	3.1	3.0	3.1	3.0
Mountains	4.2	4.1	4.2	3.6

1,400–1,500 m, then trends north-south through Colorado at an altitude of about 1,600–1,700 m. At the Colorado-New Mexico State line, the High Plains are interrupted by the east-trending Raton Mesa, which extends east into the High Plains for about 150 km and is more than 2,400 m high. On the southern side of Raton Mesa, the plains continue, sloping both easterly and southerly from an altitude of 2,000 m in the north near Raton to 900 m near the southeastern corner of New Mexico.

Although altitudinally low, the northeastern corner of Montana has the highest terrestrial lapse rates calculated in this study. Lapse rates clearly and markedly decline in a southwesterly direction. A similar trend is present in the lapse rates in the drainages of the Powder, Little Powder, and Belle Fourche Rivers of northeastern Wyoming and adjacent Montana; that is, lapse rates are higher in the altitudinally lowest parts of the drainages. Through Colorado, lapse rates markedly decrease southward but decrease very little, if at all, toward lower altitudes (toward the east). In northern New Mexico, lapse rates sharply decrease between lat 35°30' and 37° N. but decrease very little, if at all, relative to either decreasing latitude or altitude.

Summary of Terrestrial Lapse Rates

On plate 2, highly diagrammatic profiles of altitude and mean annual temperature are shown for several latitudes in the western conterminous United States. The scales were selected to exaggerate topography and, at the same time, to illustrate the departure in terrestrial lapse rate in the western United States from a "standard" lapse rate of 5.0 °C/km. If a rate of 5.0 °C/km is basic to the western United States, then the altitude and mean annual temperature profiles should coincide; a higher lapse rate would result in the temperature profile plotting above the altitude profile.

The profiles on plate 2 show that, except for the High Plains of northeastern Montana, terrestrial lapse rates only approach 5.0 °C/km in the mountains just south of the Canadian border. Even for this northernmost profile, significant divergence of the altitude and the temperature profiles are in the Puget Sound, Walla Walla Plateau, intramontane basins of the Rocky Mountains, and the eastern part of the High Plains. In the more southern profiles, divergence of the altitude and temperature profiles is progressively greater. Land areas that have mean annual temperatures higher than coastal temperatures at the same latitude also are progressively larger to the south; for the majority of the land along the most southerly profile mean annual temperature is higher than coastal temperature.

INTERPRETATION

Factors Affecting Present-Day Terrestrial Lapse Rates

The trends in terrestrial lapse rates for the High Plains data can be readily correlated with greater incursions of frigid arctic air during the winter relative to incursions of warm air from the Gulf of Mexico or incursions of air masses from the Pacific, which may be cool but are rarely frigid. Because the altitude of the High Plains varies little, latitude is the controlling factor in mean annual temperature and thus lapse rate. In mountains and intermontane plateaus (and their major rivers), the influence of arctic air masses is greatest to the north and at higher altitudes. The intramontane basins, however, typically are shielded from arctic air incursions and thus show little (or no) altitudinal or latitudinal change in lapse rate.

As noted previously, basins to the leeward of mountains that extend only a few hundred meters above the basin have lower terrestrial lapse rates relative to comparable altitudes on the windward slope of the mountains. The summer heating in these basins results in a net gain in mean annual temperature that more than compensates for the blocking of incursions of milder maritime air during the winter. This relation is not peculiar to the western conterminous United States. Preliminary analysis of data from Asia show a similar relation (table 14). Both the Asian and North American data suggest that leeward basins heat so much that areas at altitudes of less than about 1,000 m have mean annual temperatures higher than temperatures at sea level at the same latitude. The Asian data also suggest that, at the same altitude, the farther into the interior of the continent the greater the heating in terms of mean annual temperature. The Asian data, similar to the U.S. data, are almost certainly influenced by the frigid air masses from Siberia and the Arctic.

Table 14. Comparison of terrestrial lapse rates for stations leeward and windward of mountain ranges of northern China

[Most leeward stations are in Mongolia, Inner Mongolia, and Sinkiang. Lapse rate in °C/km. Number in brackets is number of stations. Many values are based on observations of less than five years]

Altitude (meters)	Windward		Mongolia and Inner Mongolia		Sinkiang	
1,600–1,700	–		2.8	[2]	–	
1,200–1,500	–		2.0	[2]	-1.5	[2]
1,000–1,200	5.7	[1]	2.8	[5]	-1.7	[2]
800–1,000	6.4	[2]	-0.2	[2]	-0.9	[3]

The elemental terrestrial lapse rate for the intermontane plateaus in the western conterminous United States is certainly less than 3.0 °C/km; lapse rates for all the stations except a few on the highest parts of the Snake River Plain are below this value. A value of about 2.0–2.5 °C/km is probably the best estimate for the elemental lapse rate and today is more common in the more southern and (or) lower parts of the intermontane plateaus; that is, where arctic air masses are least influential. In the most southern areas of the intermontane plateaus, where air masses from the Gulf of California and adjacent Pacific Ocean are more dominant, a lapse rate of 1.5–2.0 °C/km may be more appropriate.

As emphasized by Meyer (1986), areally extensive mountain masses can markedly lower terrestrial lapse rates from the "normal" rate of 5.5 °C/km. These major massifs can be either in the interior of a continent, as in the instances of the Rocky Mountains and adjoining plateaus and the Tibetan and adjoining plateaus, or at the the western margin of a continent, as in the instance of the Andes (table 15). Almost all the stations in such areas are in river valleys; lapse rates on mountains proximal to these stations are unknown, but at the very least the Asian and South American lapse rates are consistent with the low lapse rates obtained for Rocky Mountain intramontane basins.

The mean terrestrial lapse rate of 3.06 °C/km calculated for intramontane basins of the Rocky Mountains may be somewhat too high. Although all obvious contaminants (data from basins that are strongly influenced by arctic air masses) were removed from the basis for this calculation, some contamination may remain such as, for example, some of the sites in exposed locations in the San Luis Valley of Colorado and especially stations in more exposed river valleys in the northern part of the study area. If these stations are removed from the intramontane database, the mean lapse rate is 2.95 °C/km. This value is probably close to the elemental lapse rate for the Rocky Mountain region. It is also slightly lower than the lapse rate for the highest altitudes in the Rocky Mountains south of lat 36° N., where arctic air masses are least influential.

The elemental terrestrial lapse rate for mountains in the Pacific States may also be about 3.0 °C/km. The influence of arctic air masses on the highest altitude Sierran stations is shown by data for Bodie (4.2 °C/km, altitude 2,551 m) and Boca (4.2 °C/km, altitude 1,699 m), both of which are on mountains just east of the Sierra Nevada divide. In contrast, lapse rates for many higher altitude, windward-slope stations in the Sierra Nevada are less than 3.0 °C/km; these stations are sufficiently distant from the Sierran divide to be little influenced by arctic air masses, except for the rare arctic air masses that move down over Alaska and along the Pacific Coast.

Mean annual range of temperature is low on the windward side of the Washington Cascades (about 15–18 °C), where lapse rates are high. On the other hand, mean annual range of temperature is high on the High Plains of Montana just east of the Rocky Mountains, where lapse rates are low. Lapse rates are consistently high in coastal eastern Asia, whether north of lat 40° N. (mean annual range of more than 30 °C) or on Taiwan (mean annual range of less than 10 °C). Thus, mean annual range of temperature probably has no correlation with terrestrial lapse rates, although such a correlation has been previously suggested (Axelrod, 1966).

Table 15. Comparison of terrestrial lapse rates for stations on and near the Tibetan Plateau, in the Andes, and in eastern Asia

[Eastern Asian stations include stations south of lat 40° N. and east of the Tibetan and related plateaus. Lapse rate in °C/km. Number in brackets is number of stations. Some values are based on observations of less than five years]

Altitude (meters)	Eastern Asia		Tibetan Plateau		Andes	
3,500–4,000	5.0	[1]	1.4	[2]	3.2	[2]
3,000–3,500	–		2.9	[2]	2.4	[2]
2,500–3,000	–		2.8	[2]	2.6	[1]
2,000–2,500	5.7	[2]	1.5	[7]	2.1	[1]
1,500–2,000	5.0	[6]	2.2	[7]	–	
1,000–1,500	5.3	[12]	1.7	[5]	–	

Application to Paleoaltitudinal Estimates

My primary concern in this report is to provide the basis for calculating valid estimates of paleoaltitudes for the many Tertiary leaf assemblages in the western North America. That the influence of arctic air masses has a major influence on present-day lapse rates in the western United States is clear. How far back into the Tertiary is this influence applicable?

The primary factor in producing frigid arctic air and its movement out of the Arctic is a frozen Arctic Ocean. All evidence indicates that the Arctic Ocean had no ice cover until perhaps the late Pliocene (Clark, 1982). Prior to that time, low-pressure systems probably developed during the winter over the Arctic. A secondary but still significant factor is the development of the "Siberian Express," a high-pressure system that develops over Siberia during the winter and is blocked by the Tibetan Plateau from moving south in Asia, thus breaking out over the Arctic and southward into North America. Until the collision of the Indian and Asian plates and subsequent uplift of the Himalayas and Tibetan Plateau (Miocene and Pliocene?), cold Siberian air would have gradually flowed south over

Asia and not over North America. Thus, the major factors that contribute to present-day high terrestrial lapse rates in the western conterminous United States probably were not operative until the late Tertiary. Using present-day terrestrial lapse rates significantly increases previous paleoaltitudinal estimates for Tertiary plant assemblages known from the western United States, whereas using the terrestrial lapse rate of about 3 °C/km suggested here as basic to the western United States would increase these estimates by a factor of about two.

A major boundary condition that influences the climates of the western United States is upwelling along the Pacific Coast. In part, strong upwelling is a function of the latitudinal position of the continental shelf and the narrower the shelf the more upwelling influences land climate. Since the North Atlantic rifted apart during the Cretaceous, the continental shelf on the Pacific side has been in a position favorable for upwelling (Parrish and Curtis, 1982) and, being the leading edge of the continent, probably was narrow. Marine diatomaceous sediments, evidence for significant upwelling, are found in California in rocks of latest Cretaceous age and throughout most of the Tertiary section (Hein and Parrish, 1987). Thus, the boundary condition of significant upwelling along the Pacific Coast was probably present throughout most, if not all, of the Tertiary.

That the western conterminous United States has had at least moderate altitude (and hence low terrestrial lapse rates) since at least some time in the early Tertiary is highly probable. If the estimates of mean annual temperatures given by MacGinitie (1953) for the interior Florissant assemblage (18 °C, about 35 million years old) and by Potbury (1935) for the near-coastal La Porte assemblage (24 °C, about 33 million years old) are accepted as valid, then the altitudinal difference between these two assemblages was about 2,000 m because the Florissant lake beds were clearly deposited in an intramontane basin. Application of the recently developed multivariate physiognomic analysis (Wolfe, 1990a, b) results, however, in mean annual temperature estimates of about 20 °C and about 12 °C for the La Porte and Florissant assemblages, respectively; an altitudinal difference of about 2,700 m is more probable (or even 2,900 m if sea-level differences are factored in); a minimum altitude of 2,700–2,900 m for the Florissant is somewhat higher than the altitude of 2,450 m inferred by Meyer (1986) but is basically indistinguishable from the present-day altitude of 2,600 m.

The Cascade Range has been an active area of volcanism since at least the Eocene (Peck and others, 1964); although the range was undoubtedly lower than now during much of the Tertiary, even low ranges will increase leeward mean annual temperatures. The presence of Eocene and younger gravels in the Sierra Nevada indicates some altitude for this range as well. Whether, however, the Sierra Nevada were the the western flank of an upland region or extended somewhat above the upland has not been determined. Note the major difficulty created if the Great Basin were at an altitude of less than 1,000 m during the Miocene. If coastal mean annual temperatures were 2–3 °C or more above present-day levels and even if the Sierra Nevada were considerably lower than present, the low altitude of the Great Basin combined with the increase in mean annual temperature resulting from a leeward positioning would create an area of intense heating, much as the Sonoran Desert is heated today. Mean annual temperature in the Great Basin at altitudes lower than 1,000 m would certainly have been at least as high as coastal mean annual temperature (about 15 °C) and could have approached 20 °C!

Another point that I emphasize is that most post-Paleocene Tertiary plant assemblages from the noncoastal western conterminous United States represent deposition in areas that today have terrestrial lapse rates significantly lower than the "normal" lapse rate of 5.5 °C/km. This is particularly true for assemblages from the Neogene of Nevada (Great Basin) and the Columbia Plateaus. Many of the Columbia Plateaus Neogene assemblages, moreover, are from deposits associated with large rivers, along which lapse rates may even have been negative despite altitudes of several hundreds of meters. Many of the interior Paleogene assemblages are from obvious intramontane basins, some small (Republic and Ruby) and some large (Powder River, Green River, and Bighorn). Application of a "normal" terrestrial lapse rate will significantly underestimate paleoaltitudes, even if valid mean annual temperatures are inferred for both coastal and interior assemblages.

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APPENDIXES 1—10

Appendixes 1-10. Stations in the western conterminous United States from which data were used to calculate terrestrial lapse rates

[All altitudes are in meters, terrestrial lapse rates in degrees Celsius per kilometer, and mean annual temperatures in degrees Celsius. The abbreviations used in the station names are those used in the official station names assigned by the National Ocean and Atmospheric Administration (or its predecessors)]

Appendix 1. Coastal stations arranged from north to south

Altitude	Lapse rate	Station	Mean annual temperature
14	0	Blaine 1E, Wash.	9.4
34	0	Bellingham 2N, Wash.	9.4
24	0	Olga 2SE, Wash.	9.7
9	0	Anacortes, Wash.	10.2
31	0	Tatoosh Island, Wash.	9.4
9	0	Clallam Bay 1NE, Wash.	8.7
23	0	Clearwater, Wash.	9.6
30	0	Point Greenville, Wash.	9.6
4	0	Aberdeen, Wash.	10.2
3	0	Grayland 2S, Wash.	10.0
46	0	Willapa Harbor, Wash.	10.6
8	0	Long Beach Exper. Stat., Wash.	9.9
2	0	Astoria AP, Oreg.	10.4
3	0	Seaside, Oreg.	10.9
5	0	Tillamook, Oreg.	10.2
24	0	Cloverdale 1NW, Oreg.	10.9
38	0	Newport, Oreg.	10.6
35	0	Honeyman SP, Oreg.	11.1
17	0	Reedsport, Oreg.	11.2
6	0	North Bend AP, Oreg.	11.2
6	0	Bandon 2NNE, Oreg.	10.8
89	0	Port Orford, Oreg.	11.6
15	0	Gold Beach RS, Oreg.	11.6
37	0	Brookings, Oreg.	11.9
12	0	Crescent City 1N, Calif.	11.7
49	0	Orick Prairie Cr. SP, Calif.	11.1
18	0	Eureka, Calif.	11.1
42	0	Scotia, Calif.	12.1
126	0	Shelter Cove Aviation, Calif.	12.7
50	0	Fort Bragg 1E, Calif.	11.5
30	0	Point Arena, Calif.	11.3
34	0	Fort Ross, Calif.	12.4
155	0	Point Reyes, Calif.	11.5
11	0	Half Moon Bay, Calif.	12.5
40	0	Santa Cruz, Calif.	13.7
117	0	Monterey, Calif.	13.6
12	0	Del Monte, Calif.	12.8
10	0	Point Piedras Blancas, Calif.	12.1
35	0	Morro Bay Fire Dept., Calif.	13.2
24	0	Pismo Beach, Calif.	14.3
77	0	Santa Maria AP, Calif.	13.8
29	0	Lompoc, Calif.	14.1

Appendix 1. Coastal stations arranged from north to south—Continued

Altitude	Lapse rate	Station	Mean annual temperature
2	0	Santa Barbara, Calif.	15.9
3	0	Santa Barbara AP, Calif.	14.9
15	0	Oxnard, Calif.	15.7
4	0	Santa Monica Pier, Calif.	16.2
30	0	Los Angeles AP, Calif.	17.0
8	0	Avalon Pleasure Pier, Calif.	15.9
10	0	Long Beach, Calif.	16.8
3	0	Newport Beach Harbor, Calif.	16.1
11	0	Laguna Beach, Calif.	15.5
3	0	Oceanside Marina, Calif.	15.3
4	0	San Diego AP, Calif.	17.0
92	0	Point Loma, Calif.	16.1
17	0	Chula Vista, Calif.	15.8

Appendix 2. Stations in Coast Ranges arranged by decreasing altitude

Altitude	Lapse rate	Station	Mean annual temperature
1,783	0.8	Mount Wilson, Calif.	13.4
1,692	1.1	Palomar, Calif.	13.4
1,414	1.5	Cuyamaca, Calif.	11.7
1,282	1.2	Mount Hamilton, Calif.	12.2
1,169	2.6	Sexton Summit, Oreg.	8.8
1,113	1.9	Julian Wynola, Calif.	13.2
1,094	3.6	Laurel Mountain, Oreg.	7.0
969	1.1	Warner Springs, Calif.	14.1
829	2.4	Fort Jones RS, Calif.	10.2
823	1.7	Henshaw Dam, Calif.	13.8
802	1.6	Yreka, Calif.	10.9
802	1.1	Campo, Calif.	14.5
713	2.7	Forest Glenn, Calif.	10.7
625	1.1	Weaverville RS, Calif.	11.8
579	0.2	Lake Pillsbury, Calif.	12.8
533	1.5	Ashland, Oreg.	11.1
522	3.6	Elk Valley, Calif.	10.1
579	1.2	Willits Howard RS, Calif.	12.3
529	-4.2	Alpine, Calif.	17.5
442	-3.2	Ramona Fire Dept., Calif.	16.7
411	-1.7	Upper Lake RS, Calif.	13.7
409	-1.5	Lakeport, Calif.	13.7
405	-2.7	Clearlake Park, Calif.	14.2
398	-4.4	Pinnacles NM, Calif.	15.7
396	-0.5	Medford, Oreg.	12.0
343	-7.6	Sierra Madre, Calif.	17.5
332	-3.7	Happy Camp RS, Calif.	13.3
320	-3.4	Hunter Liggett, Calif.	15.3
309	-5.5	Potter Valley PH, Calif.	14.7
244	-3.7	Paso Robles AP, Calif.	15.2

Appendix 2. Stations in Coast Ranges arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
235	-3.8	Nacimiento Dam, Calif.	15.2
218	-3.2	Escondido Church Ranch	16.0
213	-6.1	Paso Robles, Calif.	15.6
190	-7.4	Ukiah, Calif.	14.4
183	-15.8	El Capitan Dam, Calif.	18.2
165	-7.9	El Cajon Yale Ranch	16.7
122	-12.3	Orleans, Calif.	13.8
104	-13.5	Cloverdale 3SSE, Calif.	14.6

Appendix 3. Stations in Cascade Range arranged by decreasing altitude

Altitude	Lapse rate	Station	Mean annual temperature
		Western slope of Cascade Range	
1,974	4.3	Crater Lake NP, Oreg.	3.2
1,753	3.2	Manzanita Lake, Calif.	6.9
1,692	4.1	Rainier Paradise, Wash.	3.4
1,485	3.5	Mineral, Calif.	7.4
1,475	3.7	Fish Lake, Oreg.	6.5
1,461	4.4	Odell Lake, Oreg.	4.9
1,447	4.2	Santiam Pass, Oreg.	4.8
1,392	3.7	Howard Prairie Dam, Oreg.	6.7
1,265	4.0	Mt. Baker, Wash.	4.5
1,245	4.5	Stevens Pass, Wash.	4.3
1,213	4.1	Government Camp, Oreg.	5.8
1,206	5.0	Stampede Pass, Wash.	4.1
1,091	2.7	Mt. Shasta AP, Calif.	9.4
1,000	2.7	McCloud, Calif.	9.6
988	5.0	Spirit Lake, Wash.	5.6
960	5.3	Parkway 6S, Wash.	5.1
954	3.8	Burney, Calif.	8.8
920	5.0	Snoqualmie Pass, Wash.	5.4
919	2.5	Hat Creek PH, Calif.	10.1
842	3.9	Rainier Longmire, Wash.	7.0
767	0.7	Montague AP, Calif.	11.6
757	2.4	Prospect 2SW, Oreg.	9.9
754	4.2	Marion Forks Fish Hatch., Oreg.	7.9
732	3.0	Sundown Ranch, Oreg.	8.7
661	1.5	Dunsmuir, Calif.	11.3
656	3.4	Belknap Springs 8N, Oreg.	8.8
529	4.5	Rainier Carbon River, Wash.	7.8
527	4.2	Electron Headworks, Wash.	8.0
475	2.3	Cedar Lake, Wash.	8.9
450	1.6	McKenzie Bridge RS, Oreg.	10.3
411	4.1	Silver Creek Falls SP, Oreg.	9.3
399	2.3	Mud Mountain Dam, Wash.	9.2
389	-0.5	Oak Ridge Fish Hatch., Oreg.	11.4
372	4.6	Detroit Dam, Oreg.	9.3

Appendix 3. Stations in Cascade Range arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
		Western slope of Cascade Range—Continued	
350	4.9	Wind River, Wash.	8.9
341	3.2	Three Lynx, Oreg.	9.8
286	3.8	Glacier RS, Wash.	8.4
273	1.5	Palmer 3SE, Wash.	9.7
272	1.8	Diablo Dam, Wash.	9.1
250	2.8	Dorena Dam, Oreg.	10.6
236	1.7	Kosmos, Wash.	10.0
198	1.5	Cottage Grove, Oreg.	11.0
168	3.0	Darrington RS, Wash.	9.2
163	1.8	Landsburg, Wash.	9.7
160	-3.1	Newhalem, Wash.	10.1
148	0.0	Fern Ridge Dam, Oreg.	11.2
131	1.5	Snoqualmie Falls, Wash.	10.2
125	-0.8	Estacada, Oreg.	10.9
82	-12.2	Concrete, Wash.	10.6
		Eastern slope of Cascade Range	
1,451	4.3	Chemult, Oreg.	5.3
1,341	3.1	Alturas RS, Calif.	8.1
1,328	3.8	Wickiup Dam, Oreg.	6.4
1,264	2.6	Susanville, Calif.	9.3
1,249	2.5	Klamath Falls 2SSW, Oreg.	8.8
1,241	2.9	Blewett Pass, Wash.	6.4
1,230	3.2	Tulelake, Calif.	8.1
1,116	3.1	Bend, Oreg.	7.7
1,049	5.1	Bumping Lake, Wash.	4.8
1,018	2.5	Fall River Mills, Calif.	9.9
981	4.2	Holden Village, Wash.	5.5
933	3.0	Redmond, Oreg.	8.4
832	4.1	Rimrock Tieton Dam, Wash.	6.9
796	3.8	Satus Pass, Wash.	7.4
754	5.4	Lake Keechelus, Wash.	6.0
741	4.3	Friend 1W, Oreg.	7.6
695	3.6	Tieton Intake, Wash.	7.8
692	4.8	Lake Kachess, Wash.	6.8
687	4.1	Lake Cle Elum, Wash.	7.3
671	6.4	Stockdill Ranch, Wash.	5.4
597	4.0	Mt. Adams RS, Wash.	8.1
535	5.2	Winthrop 1WSW, Wash.	6.9
530	4.0	Parkdale, Oreg.	8.6
518	2.9	White Salmon, Wash.	9.1

Appendix 4. Stations in Sierra Nevada arranged by decreasing altitude
[All stations are in California unless otherwise noted]

Altitude	Lapse rate	Station	Mean annual temperature
2,926	3.7	Ellery Lake	2.7
2,743	3.0	Lake Sabrina	5.6
2,457	3.8	Tamarack	3.7
2,438	3.6	Twin Lakes	4.3
2,438	3.6	Marlette Lake, Nev.	4.3
2,140	3.2	Huntington Lake	6.7
2,057	4.1	Soda Springs	4.4
2,053	4.4	Lodgepole	4.8
2,012	3.0	Grant Grove	7.7
1,899	3.6	Tahoe City	6.0
1,827	3.5	Truckee RS	6.4
1,810	3.5	Donner Memorial SP	6.4
1,753	3.0	Manzanita Lake	6.9
1,635	2.0	Bowman Dam	9.6
1,609	1.7	Blue Canyon WSMO	10.2
1,572	2.7	Lake Spaulding	8.7
1,561	2.4	South Entrance Yosemite NP	9.9
1,548	3.2	Westwood	7.7
1,516	3.6	Sierraville RS	7.5
1,494	1.0	Big Creek PH 1	12.3
1,478	3.7	Portola	7.4
1,469	1.1	Inskip Inn	11.1
1,431	2.5	Calaveras Big Trees	9.8
1,421	1.5	Lake Eleanor	11.4
1,390	3.2	Canyon Dam	8.2
1,379	2.1	Chester	9.7
1,234	2.2	Springerville Tule Headworks	11.4
1,224	1.7	Tehachapi	12.4
1,209	1.3	Yosemite NP	12.0
1,180	1.4	Hetch Hetchy	11.8
1,161	1.4	Strawberry Valley	11.3
1,128	2.7	Deer Creek PH	9.9
1,039	3.0	Quincy	9.6
980	2.1	West Branch	10.7
957	2.1	Glenville	12.3
945	1.1	North Bloomfield	12.0
914	2.3	Dudley's	11.5
889	2.3	Downieville	10.9
848	1.9	Nevada City	11.4
823	-0.1	De Sabla	12.9
821	-2.2	Grass Valley	14.8
812	-0.6	North Fork RS	14.2
735	-2.7	Colfax	15.1
718	-0.6	Tiger Creek PH	13.7
652	-2.6	Auberry 1NW	15.5
576	0.3	Placerville	13.0
533	-3.6	Sonora RS	15.4
521	-6.1	Ash Mountain	17.2

Appendix 4. Stations in Sierra Nevada arranged by decreasing altitude—Continued
[All stations are in California unless otherwise noted]

Altitude	Lapse rate	Station	Mean annual temperature
394	-6.3	Auburn	15.6
328	-6.5	Shasta Dam	16.6
201	-13.9	Camp Pardee	16.2
158	-22.8	Centerville PH	16.4
156	-19.9	Lemon Cove	17.2
131	-20.6	Orange Cove	16.7
128	-20.3	Lindsay	16.7
125	-22.4	Friant Government Camp	16.6
120	-26.7	Porterville	17.4
100	-31.0	Fresno AP	17.0
		East of Sierra Nevada	
2,551	4.2	Bodie, Calif.	2.7
1,699	4.4	Boca, Calif.	5.6

Appendix 5. Stations in Rocky Mountains arranged by decreasing altitude

Altitude	Lapse rate	Station	Mean annual temperature
		Northern Rockies	
2,225	4.3	Conway Ranch, Mont.	1.3
2,225	4.0	Kings Hill, Mont.	1.3
2,103	4.5	Obsidian 4N, Idaho	1.8
2,094	4.6	Obsidian 3SSE, Idaho	1.7
2,076	4.2	Cobalt Blackbird Mine, Idaho	2.1
2,045	4.7	Lakeview, Mont.	1.4
1,978	4.4	Hebgen Dam, Mont.	2.2
1,871	4.3	Chilly Barton Flat, Idaho	3.3
1,859	4.6	Grouse, Idaho	2.8
1,846	4.6	Wisdom, Mont.	2.3
1,836	3.9	Mullan Pass, Idaho	2.8
1,829	3.4	Atlanta RS, Idaho	5.1
1,795	3.9	Mt. Spokane Summit, Wash.	2.9
1,793	4.1	Spencer RS, Idaho	3.8
1,774	4.7	Sun Valley, Idaho	3.1
1,733	4.4	Big Creek 1S, Idaho	3.3
1,710	4.7	Dixie, Idaho	2.7
1,686	4.1	Butte AP, Mont.	3.7
1,638	4.6	Deadwood Dam, Idaho	3.6
1,589	4.8	Summit, Mont.	2.1
1,544	4.1	Fairfield RS, Idaho	5.1
1,532	4.3	McCall, Idaho	4.3
1,494	3.6	Sherburne Lake, Mont.	4.1
1,483	4.2	Cascade 1NW, Idaho	4.9
1,423	3.7	Prairie, Idaho	6.2
1,384	4.4	Lincoln RS, Mont.	4.1
1,292	4.6	Drummond AP, Mont.	4.4
1,265	3.6	Roland West Portal, Idaho	5.6

Appendix 5. Stations in Rocky Mountains arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
		Northern Rockies—Continued	
1,250	5.0	Ovando 1SW, Mont.	3.9
1,248	4.3	Burke 2ENE, Idaho	4.6
1,228	4.2	Seeley Lake, RS, Mont.	4.9
1,219	4.4	Elk City, Idaho	5.2
1,186	4.0	Lowman, Idaho	6.4
1,180	4.9	New Meadows RS, Idaho	5.1
1,097	4.9	Pleasant Valley, Mont.	4.4
1,097	5.1	Polebridge, Mont.	3.9
975	4.4	Chesaw 1NW, Wash.	5.5
968	4.1	Pierce RS, Idaho	6.4
963	4.2	Hungry Horse Dam, Mont.	5.7
961	4.2	West Glacier, Mont.	5.6
960	4.3	Haugan, Mont.	5.9
930	4.5	Deception Creek, Idaho	5.7
914	4.6	Fortine 1NNE, Mont.	5.3
853	5.5	Upper Yak River, Mont.	4.8
811	4.6	Republic, Wash.	5.9
757	4.5	Trout Creek 2W, Mont.	6.5
725	4.4	Priest River Ext. Stn., Idaho	6.5
692	3.8	Conconully, Wash.	7.0
682	4.7	Herron 2 NW, Mont.	6.6
651	4.3	Newport, Wash.	7.0
644	4.0	Deer Park 2E, Wash.	7.2
634	4.1	Libby 1 NE RS, Mont.	7.1
549	4.4	Porthill, Idaho	7.1
498	4.0	Chewelah 2S, Wash.	7.7
		Central Rockies	
2,379	4.5	South Pass City, Wyo.	1.2
2,366	4.6	Lake Yellowstone, Wyo.	0.2
2,336	4.6	Kendall, Wyo.	0.9
2,195	4.4	Yellowstone NE Entrance	1.3
2,192	4.4	Pinedale, Wyo.	2.0
2,120	3.7	Kemmerer, Wyo.	4.3
2,098	4.6	Snake River, Wyo.	1.5
2,091	3.9	Evanston 1E, Wyo.	4.2
2,079	4.9	Big Piney, Wyo.	1.6
2,072	4.8	Moran, Wyo.	1.3
2,031	4.7	West Yellowstone, Mont.	1.4
2,020	4.5	Moose, Wyo.	2.3
2,009	4.4	Farson, Wyo.	3.1
1,978	4.4	Hebgen Dam, Mont.	2.2
1,972	4.6	Lamar RS, Wyo.	1.8
1,960	3.7	Alta 1NNW, Wyo.	4.1
1,933	4.4	Woodruff, Utah	3.7
1,928	4.1	Bedford 2SE, Wyo.	3.7
1,927	4.4	Sage 4NNW, Wyo.	3.7
1,920	4.0	Belcher River, Wyo.	3.6
1,920	4.3	Island Park Dam, Idaho	2.8

Appendix 5. Stations in Rocky Mountains arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
		Central Rockies—Continued	
1,920	3.8	Gray, Idaho	4.4
1,910	4.4	Tower Falls, Wyo.	2.5
1,903	4.4	Jackson, Wyo.	3.2
1,902	3.7	Yellowstone NP HQ, Wyo.	3.9
1,890	3.7	Conda, Idaho	4.7
1,890	3.8	Tetonia, Idaho	4.2
1,890	4.4	Blackfoot Dam, Idaho	3.3
1,865	4.6	Border 3N, Wyo.	3.4
1,864	4.6	Afton 2N, Wyo.	3.2
1,864	4.6	Grover 2S, Wyo.	3.2
1,858	3.9	Driggs, Idaho	4.1
1,825	3.5	Laketown, Utah	5.7
1,817	3.6	Montpelier RS, Idaho	5.3
1,806	3.7	Lifton Pump. Stat., Idaho	5.4
1,646	3.5	Grace, Idaho	6.0
1,645	3.3	Palisades Dam, Idaho	6.1
1,615	3.7	Irwin 2SE, Idaho	5.5
1,455	2.2	Logan USU, Utah	8.9
1,438	2.9	Preston 2SE, Idaho	7.9
1,366	3.2	Lewiston, Utah	7.6
1,347	3.0	Malad City, Idaho	7.9
		Bighorn Mountains	
2,689	3.9	Dome Lake, Wyo.	0.5
2,256	3.9	Hunters Station, Wyo.	2.3
		Southern Rockies	
3,460	4.0	Summitville, Colo.	-0.1
3,254	3.5	Sandia Crest, N. Mex.	3.1
3,129	3.6	Lake Moraine, Colo.	2.0
3,109	3.5	Leadville, Colo.	2.1
2,873	3.6	Wolf Creek Pass 4W, Colo.	3.4
2,835	3.5	Sapinero 9W, Colo.	3.5
2,826	4.0	Silverton, Colo.	2.1
2,763	4.0	Dillon 1E, Colo.	1.9
2,761	4.2	Foxpark, Wyo.	0.8
2,743	4.6	Hermit 7ESE, Colo.	1.0
2,730	3.5	Longs Peak, Colo.	3.0
2,701	4.2	Crested Butte, Colo.	1.8
2,697	3.5	Fremont Exp. Stat., Colo.	3.8
2,682	3.4	Telluride, Colo.	4.3
2,658	4.1	Grand Lake 1NW, Colo.	1.7
2,652	3.0	Cloudcroft RS, N. Mex.	7.3
2,649	3.8	Lee Ranch, N. Mex.	4.3
2,644	3.7	Red River, N. Mex.	4.1
2,609	4.7	Fraser, Colo.	0.5
2,600	3.7	Pole Mountain Nursery, Wyo.	2.8
2,591	4.3	Wagon Wheel Gap 3N, Colo.	1.9
2,580	4.0	Elizabethtown, N. Mex.	3.6
2,545	3.9	Spicer 2NE, Colo.	2.8

Appendix 5. Stations in Rocky Mountains arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
		Southern Rockies—Continued	
2,526	4.2	Grand Lake 6SSW, Colo.	2.2
2,512	3.9	Eagle Nest, N. Mex.	4.3
2,484	3.9	Wolf Canyon, N. Mex.	4.5
2,475	3.4	Tres Piedras, N. Mex.	5.5
2,473	4.1	Walden, Colo.	2.3
2,438	3.5	Alpine, Ariz.	6.4
2,438	4.4	Cochetopa Creek, Colo.	2.6
2,384	3.4	Chama, N. Mex.	5.9
2,345	4.4	Gunnison, Colo.	3.0
2,332	3.3	Vallecito Dam, Colo.	5.9
2,270	3.0	Regina, N. Mex.	7.3
2,260	3.8	Gavilan, N. Mex.	5.4
2,255	2.9	Jewett RS, N. Mex.	8.3
2,166	3.7	Pagosa Springs, Colo.	5.7
2,164	2.7	Star Lake, N. Mex.	8.3
2,149	3.4	Luna RS, N. Mex.	7.6
2,134	3.7	McGaffey 4SE, N. Mex.	6.5
2,124	3.5	Lookout 14NE, Wyo.	4.7
2,118	3.4	Dulce, N. Mex.	6.6
2,063	4.3	Steamboat Springs, Colo.	3.7
2,059	3.0	Ruidoso, N. Mex.	9.1
2,038	3.1	Aragon, N. Mex.	8.7
2,033	3.2	Beaverhead RS, N. Mex.	8.5

Appendix 6. Stations on Columbia Plateau arranged by decreasing altitude

Altitude	Lapse rate	Station	Mean annual temperature
1,665	3.1	Dubois Ext. Stat., Idaho	6.1
1,615	3.7	Arco 3NW, Idaho	5.4
1,524	4.3	Hill City, Idaho	4.9
1,514	3.6	St. Anthony, Idaho	5.9
1,504	3.9	Idaho Falls 46W, Idaho	5.6
1,490	3.9	Sugar City, Idaho	5.5
1,460	4.1	Idaho Falls 42NW, Idaho	5.3
1,460	3.8	Hamer 4NW, Idaho	5.8
1,442	3.1	Idaho Falls AP, Idaho	7.0
1,440	3.1	Wagon Tire, Oreg.	6.9
1,420	2.7	Squaw Butte Ext. Stat., Oreg.	7.7
1,370	3.1	Blackfoot 2SSW, Idaho	7.4
1,359	2.8	Fort Hall Indian Agency, Idaho	7.8
1,355	2.4	Pocatello AP, Idaho	8.4
1,347	3.1	Springfield, Idaho	7.4
1,341	3.2	Aberdeen Ext. Stat., Idaho	7.4
1,340	2.6	Danner, Oreg.	8.2
1,316	2.7	American Falls 1SW, Idaho	8.2
1,312	3.3	Richfield, Idaho	7.3

Appendix 6. Stations on Columbia Plateau arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
1,305	2.1	Minodoka Dam, Idaho	9.0
1,281	2.4	Rupert, Idaho	8.7
1,265	2.5	Burns, Oreg.	8.2
1,251	2.8	Malheur Refuge HQ, Oreg.	8.0
1,274	1.8	Burley, Idaho	9.5
1,237	1.7	Hazelton, Idaho	9.7
1,207	2.5	Shoshone 1WNW, Idaho	8.7
1,204	3.1	Winchester 1SE, Idaho	6.7
1,183	1.9	Anderson Dam, Idaho	9.3
1,154	1.7	Jerome, Idaho	9.7
1,149	2.2	Twin Falls 2NNE, Idaho	9.3
1,067	1.8	Buhl, Idaho	9.9
1,022	1.8	Warm Springs Reservoir, Oreg.	9.6
996	1.6	Bliss, Idaho	10.1
989	3.1	Gooding 1E, Idaho	8.6
987	2.0	Arrowrock Dam, Idaho	9.4
981	3.1	Nez Perce, Idaho	7.4
969	2.0	Mountain Home 1SE, Idaho	9.7
945	2.3	Cove 1ENE, Oreg.	8.6
933	3.0	Redmond AP, Oreg.	8.4
914	2.2	Bickleton, Wash.	8.5
874	3.5	Prineville, Oreg.	8.1
873	2.4	Condon, Oreg.	8.7
866	1.2	Boise AP, Idaho	10.4
866	1.6	Antelope, Oreg.	9.5
843	2.4	Union Exper. Stat., Oreg.	8.8
840	1.2	LaGrande, Oreg.	9.8
836	1.4	Mitchell, Oreg.	9.9
829	2.3	Kent, Oreg.	8.9
818	1.7	Kuna 2NNE, Idaho	10.0
811	2.2	Moscow, Idaho	8.5
808	2.7	Fossil, Oreg.	8.7
799	1.6	Meridian 1W, Idaho	10.1
794	3.4	Waterville, Wash.	7.2
786	0.9	Glenns Ferry, Idaho	11.0
776	4.6	Pullman 2NW, Wash.	6.7
768	2.7	Potlatch, Idaho	8.1
765	1.4	Deer Flat Dam, Idaho	10.3
762	0.7	Emmett 2E, Idaho	10.8
762	3.3	Metolius 1W, Oreg.	8.6
747	2.9	Davenport, Wash.	7.7
742	0.9	Dayville, Oreg.	10.4
732	1.0	Owyhee Dam, Oreg.	11.3
731	2.3	Rosalia, Wash.	8.4
722	1.7	Caldwell, Idaho	10.2
719	0.7	Grand View, Idaho	11.1
718	1.7	Spokane, Wash.	8.8
708	1.8	Swan Falls PH, Idaho	12.8

Appendix 6. Stations on Columbia Plateau arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
693	1.3	Parma Ext. Stat., Idaho	10.4
689	1.2	Malheur Br. Exp. Stn., Oreg.	10.5
683	0.9	Vale, Oreg.	10.7
680	2.8	Madras, Oreg.	9.1
680	0.9	Adrian, Oreg.	10.8
675	0.3	Richland, Oreg.	10.8
663	1.1	Nyssa, Oreg.	10.6
659	3.2	Wilbur, Wash.	7.8
655	1.1	Huntington, Oreg.	11.8
654	0.5	Ontario KSRV, Oreg.	11.0
646	0.8	Weiser, Idaho	10.7
643	1.2	Payette, Idaho	10.4
634	2.5	Saint Maries, Idaho	8.5
601	1.8	Colfax 1NW, Wash.	9.1
587	1.7	Sprague, Wash.	9.1
582	1.4	Hartline, Wash.	9.1
575	0.9	Heppner, Oreg.	10.3
570	2.5	Moro, Oreg.	9.3
556	1.3	Ritzville, Wash.	9.4
550	2.0	Pomeroy, Wash.	10.3
549	-1.5	Riggins RS, Idaho	11.6
524	0.4	Pilot Rock, Oreg.	10.5
519	0.4	Coulee Dam 1SW, Wash.	9.6
498	3.0	Goldendale, Wash.	9.1
495	0.6	Lind 3NE, Wash.	9.9
475	0.0	Dayton 1WSW, Wash.	10.4
472	-0.4	Mikkalo 6W, Oreg.	10.9
471	1.1	LaCrosse 3ESE, Wash.	9.8
469	1.5	Odessa, Wash.	9.4
455	-1.5	Pendleton AP, Oreg.	11.4
439	0.5	Ruff 3SW, Wash.	9.9
414	0.7	Hatton 8E, Wash.	10.0
405	2.7	Dufur, Oreg.	9.6
389	1.0	Wilson Creek, Wash.	9.6
389	-3.1	Ephrata, Wash.	11.2
388	0.8	Quincy 1S, Wash.	9.8
384	0.5	Kooskia, Idaho	10.3
368	2.4	Moses Lake, Wash.	9.2
341	0.0	Chelan, Wash.	9.9
335	-2.1	Sixprong, Wash.	11.3
313	-1.3	Orofino, Idaho	10.7
296	-5.7	Milton Freewater, Oreg.	12.2
289	-5.5	Walla Walla City, Wash.	12.1
259	-3.5	Wapato, Wash.	11.3
228	-1.8	Sunnyside, Wash.	10.8
212	-11.3	Wawawai 2NW, Wash.	12.7
206	-3.4	Prosser, Wash.	11.2
201	-6.5	Echo, Oreg.	11.9

Appendix 6. Stations on Columbia Plateau arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
193	-1.0	Wenatchee, Wash.	10.2
190	-4.7	Hermiston 2S, Oreg.	11.5
169	-8.9	Trinidad 2SSE, Wash.	11.6
135	-5.9	Touchet, Wash.	11.3
127	-17.3	Wahluke, Wash.	12.5
120	-13.3	Kennewick, Wash.	12.0
117	-12.0	Hanford, Wash.	11.7
87	-21.8	Arlington, Oreg.	12.5
31	-51.6	The Dalles, Oreg.	12.3

Appendix 7. Stations in Blue, Wallowa, Ochoco, and Strawberry Mountains arranged by decreasing altitude

Altitude	Lapse rate	Station	Mean annual temperature
1,505	5.4	Granite 4WSW, Oreg.	3.9
1,420	4.8	Seneca, Oreg.	4.4
1,321	4.3	Austin, Oreg.	5.4
1,229	4.0	Unity, Oreg.	6.2
1,211	4.2	Ochoco RS, Oreg.	6.0
1,146	3.8	Enterprise, Oreg.	6.3
1,122	3.8	Meacham AP, Oreg.	6.4
1,094	3.0	Anatone, Wash.	7.2
1,027	3.3	Baker AP, Oreg.	7.6
1,023	2.6	Grangeville, Idaho	7.9
981	3.1	Nez Perce, Idaho	7.4
979	4.7	Ukiah, Oreg.	6.3
945	2.3	Cove 1ENE, Oreg.	8.6
891	3.6	Wallowa, Oreg.	7.5
843	2.4	Union Exp. Stat., Oreg.	8.8
814	3.8	Halfway, Oreg.	7.8
809	2.5	Elgin, Oreg.	8.7

Appendix 8. Stations in Great Basin arranged by decreasing altitude

Altitude	Lapse rate	Station	Mean annual temperature
2,210	2.6	Kimberley, Nev.	7.3
2,182	3.0	Snowball Ranch, Nev.	6.5
2,080	2.1	Lehman Caves NM, Nev.	8.8
2,012	2.2	Austin, Nev.	8.5
1,996	2.3	Alunite, Utah	8.7
1,993	2.4	Eureka, Nev.	8.1
1,981	3.3	Sheldon, Nev.	5.5
1,966	2.4	Mono Lake, Calif.	8.7

Appendix 8. Stations in Great Basin arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
1,935	2.5	Glenbrook, Nev.	8.2
1,932	2.5	McGill, Nev.	8.2
1,917	2.6	Lamoille PH, Nev.	7.6
1,906	3.3	Ely, Nev.	6.8
1,905	2.2	Adavan, Nev.	9.2
1,881	2.0	Bingham Canyon, Utah	8.8
1,875	2.9	Jarbidge, Nev.	6.7
1,862	1.7	Pioche, Nev.	10.4
1,844	4.0	Fish Creek Ranch, Nev.	5.7
1,832	2.7	Ruby Lake, Nev.	7.7
1,821	2.1	Parowan, Utah	9.6
1,803	1.4	Rattlesnake, Nev.	10.7
1,786	2.9	Beaver, Utah	8.3
1,754	2.2	Emigrant Pass HS, Nev.	8.6
1,753	2.0	Woodfords, Calif.	9.7
1,734	1.7	Goldfield, Nev.	10.6
1,731	1.9	Cedar City PH, Utah	10.3
1,715	3.2	Wells, Nev.	6.8
1,715	2.0	Smokey Valley, Nev.	9.7
1,713	2.2	Park Valley, Utah	8.3
1,712	3.1	Hart Mtn. Refuge, Oreg.	6.5
1,702	3.6	Mala Vista Ranch, Nev.	6.2
1,664	2.7	Modena, Utah	9.0
1,654	1.7	Tonopah, Nev.	10.6
1,652	3.3	Three Creek, Idaho	6.5
1,645	2.6	Owyhee, Nev.	7.7
1,617	2.7	Scipio, Utah	8.6
1,615	2.3	Levan, Utah	9.2
1,615	2.8	Jess Valley, Calif.	7.8
1,609	3.2	Ibapah, Utah	7.6
1,608	2.7	Strevell, Idaho	7.6
1,600	1.2	Fillmore, Utah	11.2
1,591	1.7	Santaquin PH, Utah	10.1
1,585	3.4	San Jacinto, Nev.	6.7
1,565	1.2	Nephi, Utah	10.9
1,547	1.3	Oak City, Utah	10.1
1,547	2.9	Elko, Nev.	7.9
1,537	1.0	Lwr American Fork PH, Ut	11.1
1,533	2.4	Milford AP, Utah	9.6
1,518	2.0	Dyer 4SE, Nev.	10.5
1,512	0.2	Cottonwood Weir, Utah	12.2
1,512	1.2	Lwr. Miller Cr. PH, Utah	10.7
1,501	3.5	Thistle 3N, Utah	7.5
1,487	2.8	Montello, Nev.	8.1
1,469	1.4	Tooele, Utah	10.5
1,463	1.7	Wellington, Nev.	10.7
1,451	1.9	Delta AP, Utah	10.3
1,450	2.8	Lakeview, Oreg.	7.9
1,448	2.4	Smith 1N, Nev.	9.7

Appendix 8. Stations in Great Basin arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
1,448	2.0	Partoun, Utah	10.0
1,440	3.1	Wagon Tire, Oreg.	6.9
1,436	1.1	Spanish Fork PH, Utah	11.1
1,433	2.4	Minden, Nev.	9.7
1,431	2.1	Beowawe, Nev.	9.5
1,430	1.9	Elberta, Utah	10.1
1,425	2.0	Carson City, Nev.	10.1
1,423	1.9	Cedarville, Calif.	9.5
1,396	1.7	Adel, Oreg.	9.4
1,388	0.8	Mina, Nev.	12.2
1,384	2.5	Deseret, Utah	9.5
1,381	2.8	Battle Mountain, Nev.	8.6
1,371	2.5	Utah Lake Lehi, Utah	9.2
1,362	2.3	Provo KOVO, Utah	9.5
1,361	1.9	McDermitt 26N, Oreg	9.1
1,359	2.6	Orr Ranch, Utah	9.0
1,345	2.6	Lucin AP, Utah	8.7
1,342	2.4	Reno, Nev.	9.7
1,342	1.3	Caliente, Nev.	11.9
1,341	1.1	Ogden Pioneer PH, Utah	10.8
1,341	3.1	Alturas RS, Calif.	8.1
1,339	2.2	Golcanda, Nev.	9.4
1,338	1.5	Riverdale PH, Utah	10.3
1,334	1.8	Yerington, Nev.	10.7
1,329	2.0	Paisley, Oreg.	9.0
1,323	1.7	Midvale, Utah	10.3
1,321	1.4	Brigham City, Utah	10.3
1,319	2.7	Valley Falls, Oreg.	8.2
1,317	2.1	Tremonton, Utah	9.4
1,311	2.1	Orovada, Nev.	9.4
1,310	2.4	Winnemucca, Nev.	9.3
1,305	1.5	Ogden Sugar Factory, Utah	10.4
1,301	1.5	Farmington, Utah	10.5
1,299	0.5	Silverpeak, Nev.	12.9
1,291	0.7	Wendover AP, Utah	11.6
1,290	2.2	Corinne, Utah	9.3
1,286	1.3	Salt Lake City AP, Utah	10.7
1,284	1.2	Saltair, Utah	10.8
1,283	1.4	Bear River Refuge, Utah	10.4
1,283	1.7	Imlay, Nev.	10.3
1,280	0.3	Thorne, Nev.	12.8
1,278	2.2	Summer Lake 1S, Oreg.	8.8
1,274	1.0	Hawthorne Babbit, Nev.	12.0
1,267	0.6	Lahontan Dam, Nev.	12.2
1,260	1.8	Rye Patch Dam, Nev.	10.3
1,257	1.4	Schurz, Nev.	11.3
1,233	1.5	Sulphur, Nev.	10.3
1,225	0.2	Sarcobatus, Nev.	13.5
1,213	1.0	Empire, Nev.	11.3

Appendix 8. Stations in Great Basin arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
1,212	1.5	Lovelock, Nev.	10.9
1,209	1.7	Fallon Exper. Stat., Nev.	10.9
1,189	1.4	Sand Pass, Nev.	10.9
1,189	1.9	Nixon, Nev.	10.6
1,158	0.6	Leeds 4NE, Utah	14.4
1,079	-2.9	Searchlight, Nev.	17.5
1,049	0.0	Alamo, Nev.	13.7
1,010	-1.4	Beatty, Nev.	15.3
956	-2.1	Indian Springs, Nev.	16.0
890	-3.1	Desert Game Reserve, Nev.	16.8
823	-2.6	St. George PH, Utah	15.6
770	-6.8	Boulder City, Nev.	19.4
611	-7.0	Las Vegas, Nev.	18.7
372	-14.0	Overton, Nev.	19.2

Appendix 9. Stations on Colorado Plateau arranged by decreasing altitude

Altitude	Lapse rate	Station	Mean annual temperature
2,560	3.1	Bright Angel RS, Ariz.	6.1
2,530	3.8	Clear Creek, Utah	3.3
2,426	3.5	Bryce Canyon NP, Utah	5.1
2,377	2.9	Hickman, N. Mex.	7.7
2,390	2.7	Ouray, Colo.	7.1
2,316	3.4	Fort Lewis, Colo.	5.9
2,231	3.0	McNary, Ariz.	8.1
2,221	1.8	Betatakin, Ariz.	9.8
2,204	2.5	Hiawatha, Utah	7.4
2,200	2.6	El Moro NM, N. Mex.	8.7
2,195	2.2	Gobernador 7W, N. Mex.	9.1
2,179	2.5	Lybrook, N. Mex.	8.6
2,169	1.8	Mesa Verde NP, Colo.	10.0
2,164	2.7	Star Lake, N. Mex.	8.3
2,164	3.1	Datil, N. Mex.	8.2
2,154	2.6	Monticello, Utah	7.9
2,150	2.8	Fence Lake, N. Mex.	8.6
2,147	3.4	Loa, Utah	5.9
2,141	2.8	Augustine, N. Mex.	8.8
2,140	3.1	Norwood, Colo.	6.7
2,135	2.7	Chevlon RS, Ariz.	8.9
2,134	2.1	Fort Wingate, N. Mex.	10.0
2,134	3.7	McGaffey 4SE, N. Mex.	6.5
2,132	3.3	Flagstaff AP, Ariz.	7.4
2,128	3.0	Alton, Utah	7.3
2,127	1.8	Crownpoint, N. Mex.	10.5
2,126	2.6	La Sal, Utah	7.8
2,123	2.6	Springerville, Ariz.	9.3
2,100	2.4	Grand Canyon HQ, Ariz.	9.2

Appendix 9. Stations on Colorado Plateau arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
2,097	2.2	Otis, N. Mex.	9.4
2,073	1.5	Tohatchi, N. Mex.	11.2
2,073	2.7	Bluewater 3WSW, N. Mex.	8.8
2,057	2.7	Gamerco, N. Mex.	8.8
2,057	2.3	Williams, Ariz.	9.8
2,057	2.0	Window Rock, Ariz.	10.1
2,048	3.7	Panguitch, Utah	6.0
2,036	3.0	Northdale, Colo.	7.3
2,012	2.7	Durango, Colo.	8.2
2,012	2.5	Gallup 5E, N. Mex.	9.3
1,987	2.6	Grants AP, N. Mex.	9.4
1,981	2.7	Pinedale, Ariz.	9.4
1,966	2.7	Black Rock, N. Mex.	9.1
1,963	2.3	Zuni AP, N. Mex.	9.9
1,958	2.8	Ignacio 1N, Colo.	8.3
1,945	1.3	Copper Mine TP, Ariz.	11.5
1,935	2.8	Colbran, Colo.	7.6
1,935	2.6	Ganado, Ariz.	9.3
1,919	2.6	Tropic, Utah	8.7
1,903	1.9	Cedaredge, Colo.	9.4
1,898	2.3	Cortez, Colo.	9.3
1,893	2.6	Watson 3SW, Utah	7.9
1,890	2.8	Emery, Utah	7.8
1,867	2.1	Chaco Canyon NM, N. Mex.	10.3
1,859	2.0	San Fidel 3E, N. Mex.	10.8
1,840	2.1	Blanding, Utah	9.7
1,807	2.2	Paonia 1S, Colo.	9.2
1,798	2.3	Piute Dam, Utah	9.2
1,772	1.5	Laguna, N. Mex.	11.9
1,766	1.8	Bloomfield 3SE, N. Mex.	10.8
1,763	2.2	Montrose 2, Colo.	9.4
1,762	1.2	Colorado NM, Colo.	11.0
1,753	2.6	Escalante, Utah	8.9
1,747	1.7	Saint Johns, Ariz.	11.8
1,731	3.2	Castle Dale, Utah	7.5
1,730	1.3	Kayenta, Ariz.	11.7
1,720	2.2	Snowflake, Ariz.	10.9
1,719	1.9	Aztec Ruins NM, N. Mex.	10.7
1,702	2.7	Manti, Utah	8.4
1,701	2.1	Price Game Farm, Utah	9.4
1,699	1.6	Newcomb, N. Mex.	11.3
1,688	1.9	Chinle, Ariz.	10.9
1,684	2.7	Moroni, Utah	8.4
1,675	1.7	Farmington AP, N. Mex.	11.1
1,664	1.3	Petrified Forest NM, Ariz.	12.4
1,663	2.1	Bonanza Pump. Stn., Utah	9.2
1,622	2.8	Rifle, Colo.	8.3
1,618	2.3	Richfield KSVC, Utah	9.4

Appendix 9. Stations on Colorado Plateau arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
1,591	1.6	Seligman, Ariz.	11.9
1,574	1.7	Fruitland, N. Mex.	11.2
1,570	1.0	Thompsons, Utah	11.6
1,567	1.3	Ash Fork, Ariz.	12.4
1,545	1.6	Holbrook, Ariz.	12.2
1,527	1.0	Kanab PH, Utah	12.2
1,516	1.4	Shiprock 1E, N. Mex.	11.8
1,504	0.9	Tuba City, Ariz.	12.8
1,496	1.0	Wupataki NM, Ariz.	14.3
1,487	1.3	Winslow, Ariz.	12.7
1,478	1.2	Grand Junction AP, Colo.	11.4
1,463	0.5	Palisade, Colo.	12.3
1,455	-0.3	Tuweep, Ariz.	14.6
1,433	1.6	Leupp, Ariz.	12.2
1,425	1.8	Fredonia, Ariz.	11.3
1,366	2.1	Fruita 1W, Colo.	10.1
1,358	1.4	Hanksville AP, Utah	11.4
1,315	0.5	Bluff, Utah	13.0
1,241	1.4	Green River Aviation, Utah	11.4
1,234	-2.1	Zion NP, Utah	16.4
1,209	0.4	Moab 4NW, Utah	12.7
1,058	-2.1	Hite, Utah	15.7
957	-3.0	Lees Ferry, Ariz.	16.8
783	-7.9	Inner Canyon USGS, Ariz.	20.4

Appendix 10. Stations in intramontane basins and river valleys of Rocky Mountains arranged by decreasing altitude

Altitude	Lapse rate	Station	Mean annual temperature
2,475	3.0	Great Sand Dunes NM, Colo.	6.2
2,461	3.2	Centennial, Wyo.	4.4
2,446	2.8	Truchas, N. Mex.	7.3
2,417	2.7	Buena Vista, Colo.	6.6
2,412	3.4	Aspen, Colo.	4.7
2,402	3.2	Del Norte, Colo.	6.0
2,396	3.1	Westcliffe, Colo.	6.0
2,390	2.7	Ouray, Colo.	7.1
2,377	2.9	Hickman, N. Mex.	7.7
2,370	3.1	Cerro 5NE, N. Mex.	6.6
2,367	3.1	Tierra Amarilla 6SSE, N. Mex.	6.7
2,355	3.1	Bailey, Colo.	5.7
2,348	3.5	Manassa, Colo.	5.5
2,345	3.2	Saguache, Colo.	5.8
2,339	3.6	Center 4SSW, Colo.	5.1
2,336	3.0	Cerro, N. Mex.	6.8
2,332	3.3	Vallecito Dam, Colo.	5.9

Appendix 10. Stations in intramontane basins and river valleys of Rocky Mountains arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
2,309	3.7	Garnett, Colo.	5.0
2,303	2.9	Idaho Springs, Colo.	6.2
2,301	2.8	Vermejo Park, N. Mex.	7.4
2,297	3.7	Alamosa AP, Colo.	5.1
2,294	3.0	Estes Park, Colo.	5.8
2,256	3.1	Lake Maloya, N. Mex.	6.7
2,252	2.9	Encampment 10ESE, Wyo.	5.7
2,204	2.5	Hiawatha, Utah	7.4
2,195	3.2	Laramie, Wyo.	5.3
2,164	3.1	Datil, N. Mex.	8.2
2,149	2.7	Salida, Colo.	7.6
2,147	3.4	Loa, Utah	5.9
2,147	2.8	Cuba, N. Mex.	8.1
2,140	2.8	Augustine, N. Mex.	8.8
2,128	2.5	Taos, N. Mex.	8.6
2,108	3.4	Dubois, Wyo.	4.3
2,096	2.6	Cheesman, Colo.	7.6
2,084	2.7	Seminoe Dam, Wyo.	6.3
2,083	3.4	Sunshine 3SW, Wyo.	4.3
2,077	3.3	Wamsutter 1N, Wyo.	5.3
2,073	2.9	Ervay, Wyo.	5.6
2,073	2.7	Birmingham Ranch, N. Mex.	9.5
2,068	3.3	Saratoga, Wyo.	5.4
2,059	3.0	Rawlins AP, Wyo.	5.9
2,057	3.3	El Vado Dam, N. Mex.	7.3
2,055	3.1	Rock Springs AP, Wyo.	5.9
2,012	2.7	Durango, Colo.	8.2
1,999	2.7	Mystic Lake, Mont.	5.4
1,998	1.9	Magdalena, N. Mex.	11.2
1,963	3.7	Hayden, Colo.	5.4
1,958	2.8	Ignacio IN, Colo.	8.3
1,942	3.0	Manila, Utah	6.5
1,938	3.7	Dixon, Wyo.	5.2
1,913	2.5	Middle Fork, Wyo.	6.9
1,910	3.7	Lima, Mont.	3.9
1,904	3.6	Craig, Colo.	5.7
1,903	3.4	Meeker, Colo.	6.2
1,871	3.6	Little Hills, Colo.	5.9
1,859	3.0	Altamont, Utah	7.0
1,856	3.1	Green River, Wyo.	6.4
1,829	3.1	Leo 6SW, Wyo.	6.2
1,825	3.5	Laketown, Utah	5.7
1,814	3.5	Snake Creek PH, Utah	6.2
1,807	2.4	Pathfinder Dam, Wyo.	7.5
1,797	3.1	Mackay RS, Idaho	5.7
1,786	3.6	Sunbeam 7SW, Colo.	6.1
1,779	3.0	Virginia City, Mont.	5.4
1,775	2.6	Glenwood Springs, Colo.	8.2

Appendix 10. Stations in intramontane basins and river valleys of Rocky Mountains arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
1,754	3.1	Soldier RS, Idaho	6.1
1,705	3.4	Heber, Utah	6.8
1,702	2.7	Manti, Utah	8.4
1,702	3.0	Fort Washakie, Wyo.	6.5
1,699	3.5	Red Lodge, Mont.	4.9
1,699	2.9	Diversion Dam, Wyo.	6.7
1,696	2.9	Lander AP, Wyo.	6.9
1,692	3.3	Coalville, Utah	6.8
1,684	2.7	Moroni, Utah	8.4
1,681	3.5	Duchesne, Utah	6.8
1,680	2.7	East Anaconda, Mont.	6.0
1,676	2.6	Mountain Dell Dam, Utah	8.1
1,676	2.9	Echo Mountain Dam, Utah	7.5
1,658	2.7	Pavilion, Wyo.	7.1
1,648	3.6	Divide 2NW, Mont.	4.7
1,624	3.2	Hailey RS, Idaho	6.2
1,618	2.3	Richfield KSVC, Utah	9.4
1,609	3.3	Philipsburg RS, Mont.	5.1
1,609	3.4	Vernal AP, Utah	7.1
1,593	2.8	Dillon W.M.C.E., Mont.	6.4
1,576	2.9	Challis, Idaho	6.5
1,572	1.8	Buffalo Bill Dam, Wyo.	8.3
1,556	2.9	Roosevelt, Utah	8.1
1,551	2.9	Cody AP, Wyo.	6.6
1,545	3.2	Morgan, Utah	7.4
1,544	3.5	May RS, Idaho	5.7
1,521	3.7	Fort Duchesne, Utah	7.0
1,510	3.1	Ennis, Mont.	6.1
1,510	3.6	Riverton, Wyo.	6.2
1,506	3.1	Pineview Dam, Utah	7.6
1,480	3.4	Bozeman AC, Mont.	5.7
1,455	2.2	Logan U.S.U., Utah	8.9
1,441	1.9	Norris-Madison PH, Mont.	7.9
1,439	3.5	Jensen, Utah	7.6
1,415	2.0	Boysen Dam, Wyo.	8.6
1,401	3.0	Whitehall, Mont.	6.4
1,387	3.5	Snowville, Utah	7.2
1,372	2.0	Clark 4WNW, Wyo.	8.1
1,366	3.2	Lewiston, Utah	7.6
1,338	2.9	Powell, Wyo.	7.1
1,315	2.9	Thermopolis, Wyo.	7.6
1,251	3.4	Deaver, Wyo.	6.6
1,238	3.7	Worland, Wyo.	6.7
1,230	2.4	Trident, Mont.	7.6
1,204	3.6	Salmon, Idaho	6.5
1,187	3.5	Helena AP, Mont.	6.3
1,183	2.8	Darby, Mont.	7.2
1,177	2.9	Basin, Wyo.	7.7

Appendix 10. Stations in intramontane basins and river valleys of Rocky Mountains arranged by decreasing altitude—Continued

Altitude	Lapse rate	Station	Mean annual temperature
1,166	3.6	Lovell, Wyo.	6.8
1,158	3.6	Spencer 10NE, Wyo.	7.3
1,122	2.5	Bridger, Mont.	8.0
1,076	2.5	Hamilton, Mont.	7.8
1,027	3.3	Stevensville, Mont.	7.0
967	2.2	Missoula 2WNW, Mont.	7.1
939	2.9	Columbia Falls 5SW, Mont.	7.0
933	2.3	Bigfork 12S, Mont.	7.8
904	4.1	Kalispell AP, Mont.	6.0
899	3.2	Wallace Woodland Park, Idaho	7.1
894	2.9	Polson AP, Mont.	7.3
884	3.2	Saint Ignatius, Mont.	7.3
876	2.9	Lonepine 1WNW, Mont.	7.4
844	2.8	Wallace, Idaho	7.6
826	2.9	Superior, Mont.	7.7
760	2.4	Avery RS, Idaho	8.3
742	3.5	Thompson Falls PH, Mont.	7.4
703	2.6	Kellogg, Idaho	8.2
642	3.3	Metaline Falls, Wash.	7.4
640	3.6	Sandpoint Ext. Stat., Idaho	7.4
631	4.0	Bayview Model Basin, Idaho	7.3
568	2.6	Colville, Wash.	8.1
552	3.6	Bonners Ferry, Idaho	7.6
501	3.4	Laurier, Wash.	7.8
410	2.9	Northport, Wash.	8.3
351	3.1	Stehekin 3NW, Wash.	8.6

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