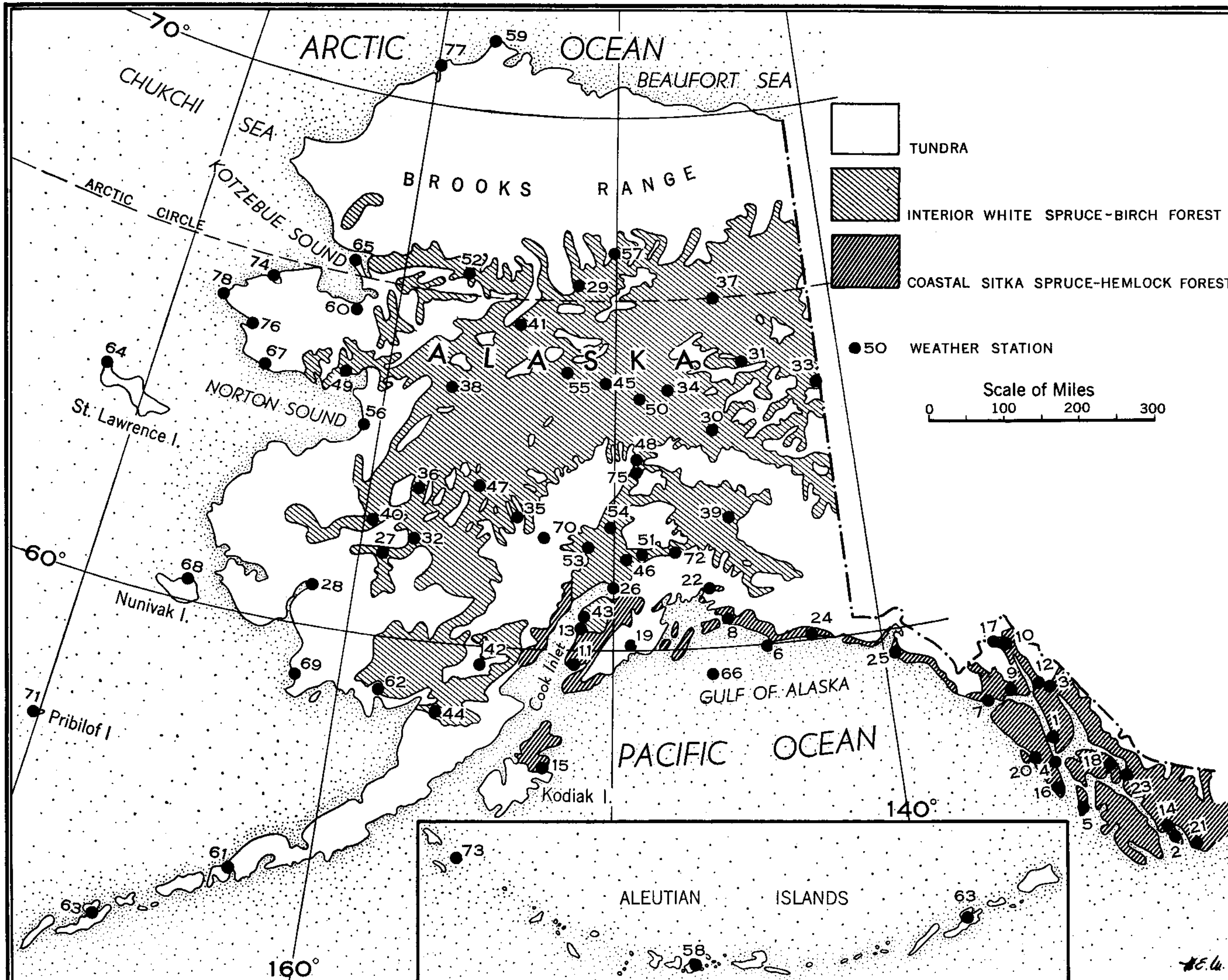

Fig. 1. Index map of Alaska

SOME CHARACTERISTICS OF THE CLIMATE IN FOREST AND TUNDRA REGIONS IN ALASKA*

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THE present-day vegetation of Alaska consists of three major types: the coastal Sitka spruce-hemlock forest of southeastern and south-central Alaska; the interior white spruce-birch forest of central Alaska; and the treeless tundra of western and northern Alaska (Sigafoos 1958). All three vegetation types are represented by assemblages of fossil plant remains found in different strata of late Cenozoic age in western Alaska (Hopkins and Benninghoff 1953). A desire to assess the palaeoclimatic significance of these fossil plant assemblages led to the results that are presented here.

The coastal forest extends a few tens of miles inland along the coast of southeastern and southern Alaska westward to Cook Inlet and northeastern Kodiak Island (Fig. 1); the interior forest is distributed through most of central Alaska north of the coastal mountains and south of the Brooks Range; and the tundra is found beyond the continental limits of forest in central and western Alaska and in highland areas above the altitudinal limits of forest in central and southern Alaska.

Both forest types contain several species of trees in addition to those employed here to characterize them (Sigafoos 1958), and the tundra is a mosaic of many different sorts of vegetation, some of which are limited to either southern or northern tundra regions (Griggs 1936, Hanson 1953, Britton 1957).

The detailed boundary between forest and tundra is intricate and is determined by small differences in the character of the soil, drainage conditions, intensity of frost action, and perhaps microclimate (Sigafoos 1953). The detailed boundary between coastal and interior forest no doubt reflects similar minor variations in environmental conditions. In a few places in Alaska the boundaries between major vegetation units appear to be shifting actively and rapidly in response to recent small climatic changes (Griggs 1934). However, the data presented here suggest that in much of Alaska the gross boundaries between the three major vegetation types reflect regional or altitudinal differences in the annual temperature regime.

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It has long been recognized that the gross boundary between forest and tundra is related to some threshold value for summer warmth. Köppen (1936) and many others have pointed out a fair world-wide correspondence between the northern limit of trees and the 50°F. isotherm for the warmest month; Nordenskjöld's Arctic Limit (Nordenskjöld and Mecking 1928), which takes the mean temperature of the coldest month into account, coincides with the northern tree line about equally well; but both lines diverge grossly from the forest-tundra boundary in western Alaska (see Hare 1955, Fig. 21).

The relationships between cumulative summer warmth and the distributions of both individual species and larger vegetational units have been analyzed by many investigators concerned primarily with more temperate regions (cf. Merriam 1894, Livingston and Shreve 1921). Hare (1950) reviews the numerous studies that have indicated that mid-summer temperatures control the growth rates of the coniferous trees composing the boreal forest and shows that there is a close correspondence in northeastern Canada between zonal forest divisions and Thornthwaite's thermal efficiency index, an accumulating logarithmic function of monthly mean temperatures (Thornthwaite 1948).

This paper attempts to establish a more faithful correspondence between a temperature parameter and the forest-tundra boundary in Alaska using summations of cumulative summer warmth, and it attempts to characterize the differences between the temperature regimes of the region of the interior white spruce-white birch forest and the region of the coastal Sitka spruce-hemlock forest. The temperature records for 78 Alaskan weather stations that have been in operation for 10 years or more furnished the data for the study (Table 1).

After several other approaches had failed a good correspondence was discovered between the vegetation at the station and the number of degree-days above 50°F. on one hand and the mean temperature of the coldest month on the other (Fig. 2). Degree days are normally computed by calculating the sum of the departure of mean *daily* temperatures from an adopted reference temperature during a chosen interval. For this study the number of degree-days above 50°F. was approximated by multiplying the amount by which the mean temperature of the warmer *months* exceeded 50°F. times the number of days in the warm months. For example, a station reporting a mean July temperature of 55°F., a mean August temperature of 51°F. and mean temperatures below 50°F. for the other 10 months would be computed as follows:

$$5 \times 31 + 1 \times 31 = 186 \text{ degree-days above } 50°\text{F.}$$

All weather stations in either the coastal or the interior forest record more than 130 degree-days above 50°F., and nearly all weather stations beyond or above the limit of forest record less than 130 degree-days above 50°F. (Fig. 2). Similar but less sharply defined results were obtained by comparing the number of degree-days above 45°F. with the vegetation at the station, but no correspondence was found between the number of degree-days above 40°F. or 32°F. and the local vegetation. The coastal Sitka spruce-hemlock forest and the interior white spruce-birch forest evidently have similar summer heat requirements; neither forest is found in areas having less than a critical amount of heat above a threshold value in the high 40's (°F.).

Several tundra stations in southern and southwestern Alaska report as much summer warmth as do stations in forested regions elsewhere. Treeless Middleton Island and Dutch Harbor (*66* and *63* on Figs. 1 and 2)

Table 1. Temperature data for 78 Alaskan weather stations that have been in operation 10 years or more (U. S. Weather Bureau 1947-1957)

Station	*Years of record*	*Degree-days above 50°F.*	*Temp. (°F.) of coldest month*
Coastal Sitka spruce-hemlock forest			
1. Angoon	33	302	29.3
2. Annette	15	581	34.6
3. Annex Creek	31	363	23.4
4. Baranof	15	476	29.2
5. Cape Decision	10	228	33.9
6. Cape St. Elias	15	431	33.1
7. Cape Spencer	19	161	32.2
8. Cordova WB	14	207	25.0
9. Gustavus	18	351	27.1
10. Haines CAA	29	590	23.2
11. Homer CAA	20	171	23.2
12. Juneau WB	15	384	26.2
13. Kasilof	14	279	13.4
14. Ketchikan	45	556	35.3
15. Kodiak	49	276	30.2
16. Little Pt. Walter	20	382	33.1
17. Moose Valley	10	528	10.0
18. Petersburg	24	470	28.6
19. Seward	34	401	24.2
20. Sitka Magnetic	72	488	33.3
21. Tree Point	18	656	34.8
22. Valdez	38	149	19.2
23. Wrangell	29	659	30.2
24. Yakataga	13	176	27.0
25. Yakutat	11	171	26.5
Interior white spruce-birch forest			
26. Anchorage	35	511	13.0
27. Aniak	13	328	-1.9
28. Bethel	34	301	6.8
29. Bettles	14	411	-12.5
30. Big Delta	14	613	-2.1
31. Circle Hot Sprs.	16	668	-13.1
32. Crooked Creek	11	485	0.4
33. Eagle	37	629	-12.4
34. Fairbanks WB	28	791	-9.8
35. Farewell	13	192	1.6
36. Flat	21	433	-2.0
37. Fort Yukon	30	776	-19.1
38. Galena	14	720	-9.3
39. Gulkana	15	406	-5.9
Interior white spruce-birch forest (cont.)			
40. Holy Cross	44	506	2.2
41. Hughes	13	577	-8.8
42. Iliamna	15	266	14.1
43. Kenai CAA	18	214	11.5
44. King Salmon	24	328	14.1
45. Manley Hot Sprs.	23	603	-10.1
46. Matanuska	33	563	13.1
47. McGrath	16	550	-8.7
48. McKinley Park	31	245	4.6
49. Moses Point	15	133	-0.5
50. Nenana	28	740	-8.0
51. Palmer 1N	15	513	13.4
52. Shungnak	10	396	-4.6
53. Skwentna	16	580	5.9
54. Talkeetna	36	497	8.5
55. Tanana	47	554	-9.5
56. Unalakleet	15	178	2.5
57. Wiseman	17	413	-9.9
Tundra			
58. Adak	14	40	32.8
59. Barrow	15	0	-17.9
60. Candle	21	90	-9.4
61. Cold Bay	13	65	28.4
62. Dillingham	16	340	15.9
63. Dutch Harbor	28	164	31.8
64. Gambell	17	0	3.4
65. Kotzebue	15	103	-21.0
66. Middleton Island	15	213	33.7
67. Nome WB	41	0	5.6
68. Nunivak	12	0	10.9
69. Platinum	13	93	14.6
70. Puntilla	10	65	3.4
71. St. Paul	38	0	23.8
72. Sheep Mountain	15	129	7.2
73. Shemya	10	0	30.9
74. Shishmaref	24	0	-4.3
75. Summit	15	74	2.3
76. Teller	15	31	-0.3
77. Wainwright	11	0	-17.9
78. Wales	13	0	0.8

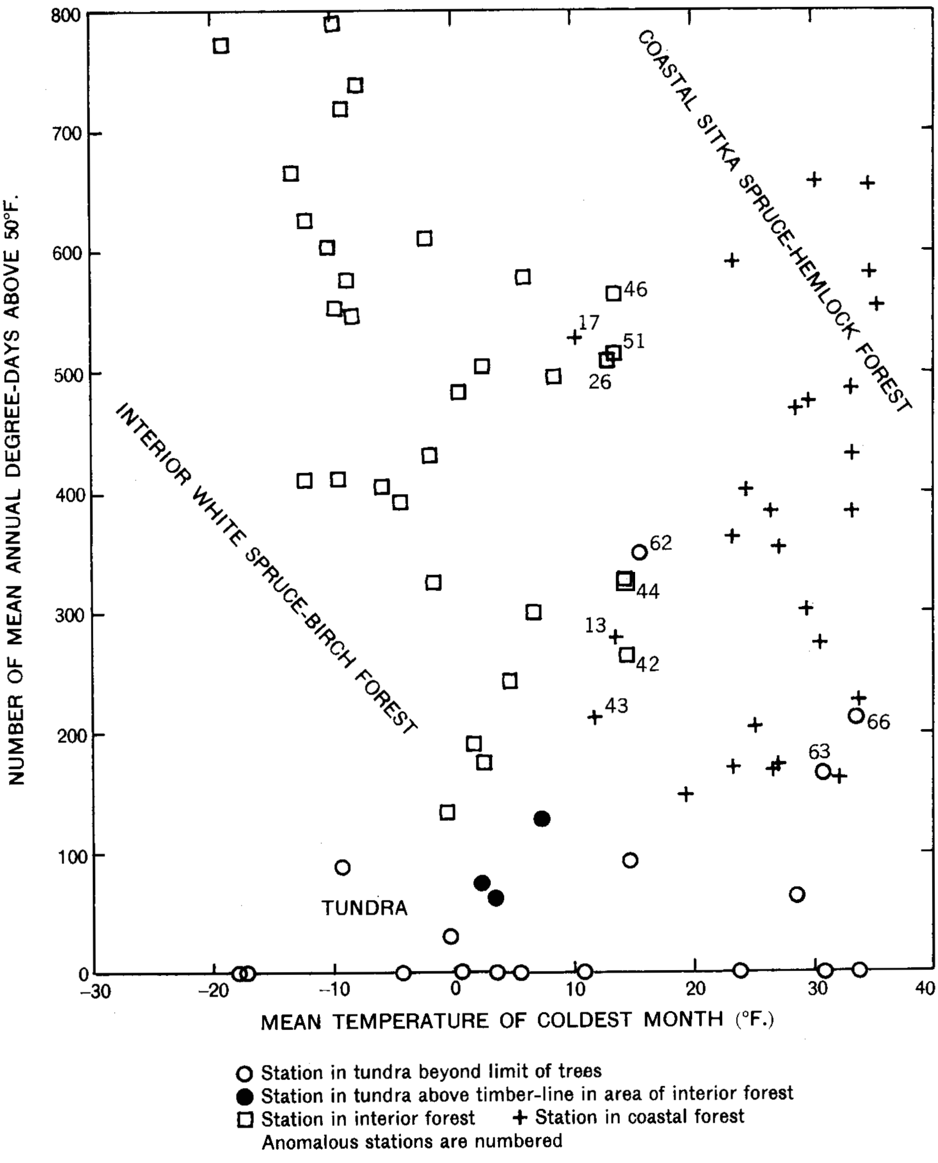

Fig. 2. Temperature conditions compared with vegetation at 77 Alaskan weather stations. Anomalous stations: *13,* Kasilof; *17,* Moose Valley; *26,* Anchorage; *42,* Iliamna; *43,* Kenai; *44,* King Salmon; *46,* Matanuska; *51,* Palmer; *62,* Dillingham; *63,* Dutch Harbour; *66,* Middleton Island.

Note added in proof: The symbol for Dutch Harbor, numbered *63,* has been misplaced and should be farther to the right to indicate that the temperature of the coldest month is 31.8°F.

are remote from sources of seed, but Sitka spruce has been successfully introduced on Unalaska Island near Dutch Harbor (Griggs 1936, p. 413). The other tundra stations having exceptionally warm summers (Dillingham — *62* on Figs. 1 and 2 — and several weather stations on Kodiak Island that were occupied too briefly to be included in this study) lie in a region in which both the coastal and the interior forest are reported to be vigorously expanding into the tundra (Griggs 1934).

The climates of the areas of the coastal forest and of the interior forest differ chiefly in the severity of the winters. Nearly all weather stations within the interior forest report at least one winter month during which the mean temperature is lower than 10° F., and nearly all stations in the coastal forest report no winter month having a mean temperature as low as 15°F. Tundra appears indifferently in areas having mild winters and in areas having cold winters.

Three stations in the coastal forest near the boundary with the interior forest (Kasilof, *13;* Kenai, *43;* and Moose Valley, *17,* on Figs. 1 and 2) and five stations in the southern part of the interior forest (Matanuska, *46;* Palmer, *51,* Anchorage, *26,* King Salmon, *44;* and Iliamna, *42*) report coldest winter months having temperatures between 10°F. and 15°F. The stations clustered about the head of Cook Inlet lie in a transitional zone in which the two forest types intergrade; along the line on the map separating the two types, the forest is a mixture of Sitka spruce, white spruce, and hybrids between Sitka and white spruce (Sigafoos 1958, p. 177; Benninghoff, written communication 1958). The other three stations lie in areas where the interior and coastal forests are isolated from one another by mountain ranges bearing only tundra vegetation, so that opportunities for mixing and hybridization are at a minimum.

Assemblages of fossil plants furnish part of the evidence on which palaeoclimatic interpretations must rely. Attempts to reconstruct ancient climates using the evidence of fossil plants rest on the assumption that the ancient forms had nearly the same ecological requirements as their living representatives. The reliability of the assumption improves with increasing size of the fossil flora, with increasingly close taxonomic relationship between the individual fossil forms and their living representatives, and with decreasing time separation between the age of the fossil flora and its living equivalent. Unfortunately, fossil plant assemblages generally represent only a small part of the plant community from which they were derived, and commonly the identity of the individual forms with living forms cannot be proved; but this difficulty is minimized for many fossil floras by the availability of collateral pedologic, stratigraphic, or geomorphic evidence concerning the nature of the climate in which the floras lived.

It is reasonable to assume that the assemblages of species making up the major vegetation types in Alaska have had approximately the same climatic requirements during much of late Cenozoic time, and that fossil assemblages clearly assignable to these major vegetation types may be used as evidence in palaeoclimatic reconstructions. Fossil remains of coastal Sitka spruce-hemlock forest suggest past periods of warm summers and mild winters; fossil remains of interior white spruce-birch forest suggest past periods of warm summers and severe winters; and fossil remains of tundra vegetation suggest past periods of cold summers and either mild or severe winters.

I have benefited greatly by discussing the ideas presented here with R. S. Sigafoos and W. S. Benninghoff.

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