NEOGLACIATION IN THE MOUNTAINS OF THE SOUTHWESTERN UNITED STATES

by

Donald R. Currey

B.S., University of Wyoming, 1957
M.A., University of Wyoming, 1959

Submitted to the Department of Geography and Meteorology and the Faculty of the Graduate School of the University of Kansas in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Dissertation Committee:

Chairman

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CHAPTER I

INTRODUCTION

Neoglaciation[1] is both an interval of time, approximately the last 3,000 years, and the conditions, highlighted locally and intermittently by glaciation, that have characterized that time. Unlike previous, Pleistocene glaciations, Neoglaciation did not generate continental glaciers. Mountain glaciers, however, generally attained greater sizes and were more numerous during Neoglaciation than during the warm interval[2] that preceded it.

Paradoxically, of the geomorphic systems active during and conspicuously conditioned by Neoglaciation, those involving glacial and periglacial activity in mountain environments are among the least known. Despite compelling relevance to many fields of environmental and historical inquiry, the distribution of high-altitude geomorphic systems in Neoglacial time and space has received little study, even in the relatively accessible mountain areas of the conterminous United States.

The purpose of this study is to view Neoglaciation through its effects in mountainous areas. This is undertaken by outlining the planimetric, altitudinal, and temporal dimensions of glacial and periglacial systems in the mountains of the southwestern United States. In general, answers are sought to the following basic questions.

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[1]Superscript numbers refer to Notes, pages 21 and 22.

(1) How many major episodes of intensified glacial and periglacial activity and, concomitantly, how many major episodes of diminished activity occurred in the Southwest during Neoglaciation? How many lesser episodes occurred during each of the major episodes?

(2) In terms of relative chronology and in terms of absolute chronology, when did the various episodes occur?

(3) Viewing each of several study areas in planimetric and altitudinal perspective, how extensive were active glacial and periglacial systems during each of the Neoglacial episodes? What comparisons can be made between Neoglacial systems and pre-Neoglacial systems?

(4) How were glacial systems and various types of periglacial systems spatially related? How were glacial and periglacial systems related to other high-altitude environmental systems?

High-altitude Geomorphic Systems

Active geomorphic systems consist of materials that are operated upon by energy transformations, or processes, to produce characteristic landforms. Geomorphic systems tend to be in equilibrium with the system complexes, or environments, of which they are a part. As changes occur in associated geologic, climatic, and biotic systems, new geomorphic systems evolve and older ones become inactive. Inactive geomorphic systems consist of erosional landforms or depositional landforms, or both, that are progressively modified by subsequent systems.

Glacial and periglacial systems are the zonal geomorphic systems of the high-latitude and high-altitude environments. The dominant material in active glacial systems is glacier ice. Active periglacial systems, on the other hand, include seasonally and in some cases perennially frozen water, but are dominated by materials other than glacier ice. The following types of geomorphic systems have been active in the high-altitude environments of the Southwest during Neoglaciation.

Glacial systems. The glacier ice of active glacial systems contains accumulation layers and ablation unconformities, undergoes visco-plastic flow, and is superficially broken by crevasses. Entrained on and in the ice is rubble added by rockfalls and rockslides, and debris produced by glacial plucking and abrasion. The principal erosional form resulting from mountain glaciation is the cirque basin or amphitheater, which may open downvalley into a U-shaped trough. The headward and lateral limits of glacier ice in cirques and troughs are marked by Schrund lines and trim lines,[3] below which striated, grooved, polished, and quarried bedrock surfaces are likely to be evident following deglaciation. Depositional forms resulting from mountain glaciation include lateral moraines and end moraines, which may be ice-cored,[4] and sparsely distributed erratic boulders.

Transitional rock glaciers. Composite glacial-periglacial systems in which the glacial systems grade downvalley into rock glaciers are termed transitional rock glaciers.[5] The components of active, partially active, and inactive transitional rock glaciers are summarized in Table 1.

Rock glaciers. Long an enigma, many of the properties of rock glaciers are now known, largely through the definitive work of Wahrhaftig and Cox (1959). Active rock glaciers consist of rubble and interstitial ice, the latter making possible viscous-like deformation in response to topographic gradients and in response to loading imposed by addition of rubble. Rubble is added to the headward and lateral margins of rock glaciers by rockslides from adjacent talus cones and talus aprons, and by rockfalls and avalanches from higher slopes. The interstitial ice, for

TABLE 1. Downvalley sequence of zones in (1) active, (2) partially active, and (3) inactive transitional rock glaciers.

Downvalley direction →

	Ice-glacier zone	Ice-cored moraine zone	Ice-cored rock-glacier zone	Rock-glacier zone	Terminus zone
(1)	Exposed firn and glacier ice; downvalley motion	Glacier ice thinly veneered by ablation moraine and talus; downvalley motion	Glacier ice deeply buried by ablation moraine and talus with interstitial matrix of secondary ice; downvalley motion	Morainic debris and talus with interstitial ice, but little or no glacier ice; downvalley motion	Lower part of terminus face at angle of repose, upper part steeper than angle of repose; terminus advancing
(2)	Wastage of glacier ice, leaving basin	Ice-cored moraine on downvalley side of basin; little motion	As above; retarded wastage of subsurface ice	As above; retarded wastage of subsurface ice	As above
(3)	Basin filling with talus, bog	Thaw-collapsed moraine; no appreciable motion	Thaw-collapsed rock glacier; no appreciable motion	Thaw-collapsed rock glacier; no appreciable motion	All terminus slopes less than angle of repose; terminus stationary

Source: compiled by the author.

the most part, is not buried glacier ice, but is secondary ice, resulting from the metamorphism of snow sifted downward from the surface, contained in avalanche deposits, and buried by rockslides and rockfalls, and the freezing of downward-percolating water in interstices maintained at subfreezing temperatures by Balch ventilation.[6]

Lobate, tongue-shaped, or spatulate in plan, rock glaciers range from a few hundred feet to a mile or more in length. Longitudinal and transverse ridges and furrows are common surface features. Successively younger rock glaciers are sometimes superimposed, imbricate fashion. Active rock glaciers may exceed 100 feet in thickness, but inactive rock glaciers are seldom more than half that thick, the rubble having settled due to melting of the interstitial ice. Active rock glaciers terminate abruptly, in faces as steep as or steeper than the repose angle of the constituent rubble, whereas inactive rock glaciers terminate in rounded slopes less steep than the angle of repose.

Protalus lobes. Lobate prolongations of talus slopes, smaller than rock glaciers but more massive than protalus ramparts, have been termed protalus lobes (Richmond, 1962, p. 20). Although periglacial systems intermediate between rock glaciers and protalus ramparts can and do exist, in this study such systems are regarded as rock glaciers if there are indications of present or past motion and as protalus ramparts if the indications are of exterior accretion without internal motion.

Protalus ramparts. Ridges of rubble that are parallel to but a short distance away from the base of talus slopes and bedrock cliffs are termed protalus ramparts.[7] The troughs upslope from the ramparts are as much as 30 feet deep and 300 feet wide, may be many hundreds of feet long, and during episodes of intensified periglacial conditions contain late-lying snowbanks and even small firn patches. Under such conditions rubble dislodged from above rolls and slides over the snow-filled troughs and comes to rest at the lower margins of the snowbanks, where the ramparts develop by accretion. During episodes of diminished periglacial conditions, in the absence of persistent snowbanks, rubble comes to rest at the very base of talus slopes and bedrock cliffs, precluding development of protalus ramparts and obscuring inactive trough-and-rampart systems.

Other high-altitude geomorphic systems. Many other types of geomorphic systems occur at high altitudes in the Southwest and could be enumerated here. Two that in a strict sense are not necessarily periglacial, but which warrant consideration because they so commonly occupy the headwalls and valley sides adjacent to the glacial and periglacial systems described above, are talus slopes and colluvium sheets.[8] Talus accrues most rapidly during periods of active frost weathering; during times of less intensive frost weathering, when chemical weathering and slope wash are relatively more important, talus is likely to become mantled with colluvium. Talus and colluvium, together with the glacial and periglacial systems described, can be viewed within the framework of a high-altitude depositional continuum, outlined in Figure 1.

Neoglacial Chronology

In stratigraphic terms, Neoglaciation is a geologic-climate unit of glaciation rank, subdividable into hemicycles of relatively intense glacial and periglacial activity, termed stades, and hemicycles of relatively diminished glacial and periglacial activity, termed interstades (American Commission on Stratigraphic Nomenclature, 1961, p. 660).[9] As indicated in Table 2, episodes of lesser rank, informally termed substades and intersubstades, and phases and interphases, are recognized in this study.

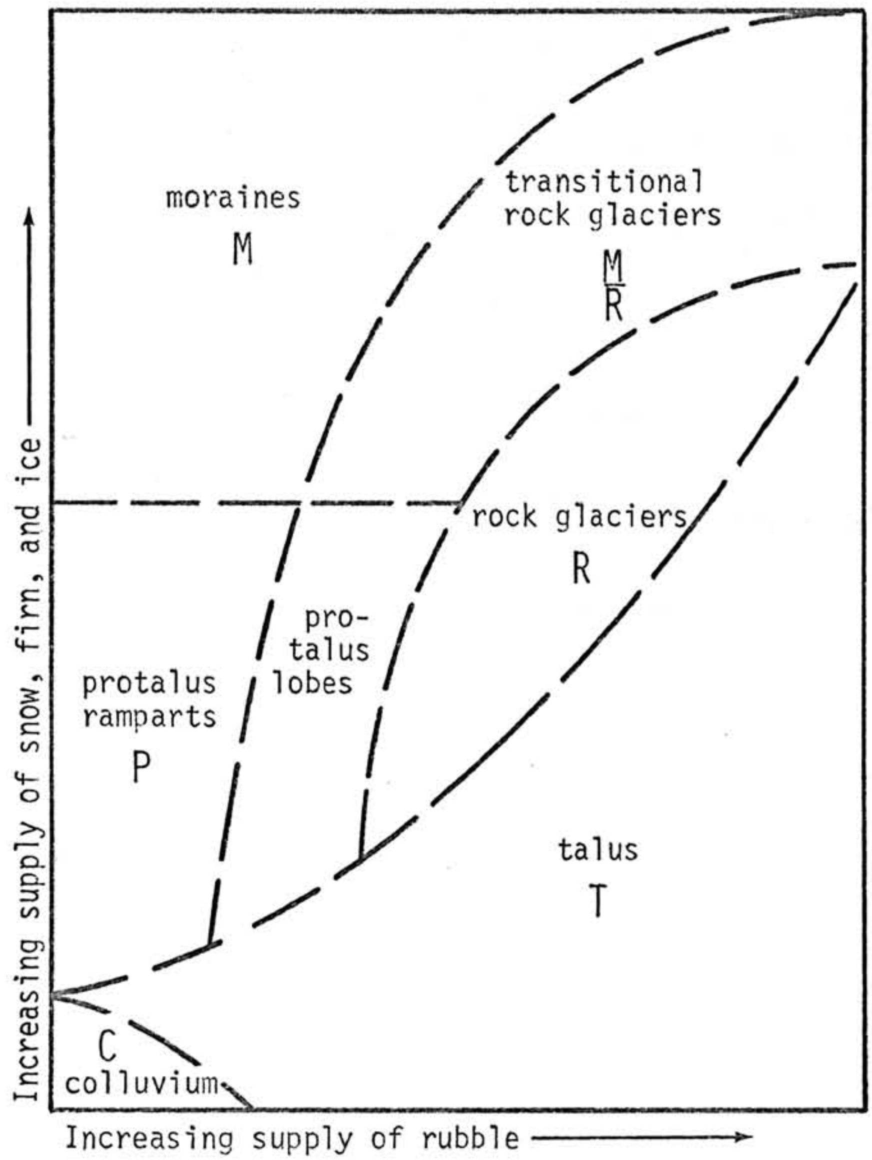

FIGURE 1. Alpine depositional facies, arranged schematically in terms of increasing supply of constituent materials. Upper case letter symbols used in tables in Chapter 2.

TABLE 2. Geologic-climate units in order of decreasing rank.

Hemicycles of relatively intense glacial and periglacial activity	Hemicycles of relatively diminished glacial and periglacial activity
Glaciation[a]	Interglaciation[a]
Stade[a]	Interstade[a]
Substade[b]	Intersubstade[b]
Phase[b]	Interphase[b]

[a]Codified by American Commission on Stratigraphic Nomenclature (1961, p. 660).

[b]Not codified; used informally in this study.

In any region, the discrimination of Neoglacial stades, interstades, and lesser episodes is a matter both of relative dating and absolute dating. Relative dating, or chronological ordering, of episodes is based on the superposition of features having geologic-climate significance, cross-cutting relationships involving such features, and the degree to which such features have been modified by subsequent geomorphic activity. Absolute dates, in years, of geologic-climate events are obtained by radiometry, particularly radiocarbon dating, and biometrics, particularly tree-ring dating and lichenometry.

Stades of Neoglaciation have been discriminated in several regions, with three stadial patterns reported (Table 3). A two-stade model of Neoglaciation, the earlier stade dating from approximately the first millennium B.C. and the later stade dating from the second millennium A.D., is reported in a majority of studies. The subdivision of Neoglacial stades into units of substade rank has been undertaken in a few studies, notably those indicated in Table 4. Minor pulsations, or phases, of glacial activity are relatively well known from the latter part of the latest stade (Table 5), but are only sketchily known from earlier times.

Previous studies have employed a variety of proper names to designate Neoglacial geologic-climate units. Much of this nomenclature is redundant, overlapping, or vaguely defined. In this study, rather than assigning a proper name to each stade and lesser episode, geologic-climate units are provisionally designated by chronologically descriptive terms, such as earlier and later, and first, second, third, et cetera.

Methods of Study

The collection and organization of information in this study is aimed at discriminating episodes of glacial and periglacial activity, and

TABLE 3. Patterns of Neoglacial stades reported in previous studies.

Neoglacial stades[a]			Study
Earlier		Later	
1	2	3	New Zealand (McGregor, 1967)
2		1	N. Hemisphere (Ahlmann, 1953, p. 41)
2		1	N. Hemisphere (Porter and Denton, 1967, p. 201)
2		1	Europe (Lamb, 1959)
2		1	Norway (Liestöl, 1960, p. 485)
1		2	Norway (Østrem, 1961)
1	2	3	Brooks Range, Alaska (Porter, 1966, p. 96)
1		2	Kenai Peninsula, Alaska (Karlstrom, 1964, p. 41)
2		1	St. Elias Mts., Canada (Denton and Stuiver, 1966)
1		2	Mt. Rainier, Wash. (Crandell and Miller, 1964)
1	2	3	Trinity Alps, Calif. (Sharp, 1960, p. 323)
1	2	3	Sierra Nevada, Calif. (Harrison, 1956)
1	2	3	Sierra Nevada, Calif. (Birman, 1964, p. 45)
1		2	Rocky Mts., U. S. A. (Richmond, 1965, p. 224, 225)

[a]Number 1 denotes stade having most extensive glacial systems, 2 denotes stade having second most extensive glacial systems, etc.

TABLE 4. Number of Neoglacial substades reported in previous studies.

Earlier Neoglacial stade	Later Neoglacial stade	Study
4	3	World; Europe (Schove, 1966; 1961)
3	2	Cook Inlet region, Alaska (Karlstrom, 1964, plate 7)
2	2	Rocky Mountain National Park, Colo. (Richmond, 1960, p. 1372)

TABLE 5. Dated advances of mountain glaciers during the most recent stade of Neoglaciation.

Europe[a]	Mt. Rainier, Washington[b]
A.D. 1875-1895 (max. ca. 1890)	A.D. 1895
1838-1860 (max. ca. 1850)	1835-1850
1814-1825 (max. ca. 1820)	
1770-1778	
1743-1750	1745
1719	
1678-1681	
1640-1644	1635
1595-1620	

[a]Historical records compiled by Matthes (1942a, p. 190-208).

[b]Tree-ring dating by Sigafoos and Hendricks (1961, p. A-19).

establishing the dimensions of glacial and periglacial systems. Although the principal focus is Neoglaciation, information regarding glacial and periglacial systems judged to have been active during the latest pre-Neoglacial stade[10] is included, for use as a bench mark with which Neoglaciation can be compared. In addition, data pertaining to a high-altitude biotic system, specifically, the uppermost observed occurrences of presently living trees, are included as a reference surface for comparison with the distribution of high-altitude geomorphic systems.

Sources of data. The information in this study has been collated from four kinds of sources: previous studies, aerial photographs, topographic maps, and observations in the field.

Previous studies, given brief citations where appropriate in the text and complete citations in the bibliography (References Cited), have provided useful information, to the extent that published work is available and sufficiently detailed.

Vertical aerial photographs have served as base maps for areas lacking adequate topographic map coverage and, viewed stereoscopically, have been an indispensible source of substantive data for some areas and an important supplementary source for others. The aerial photographs used in this study are described in Appendix A.

Topographic maps have served as planimetric and hypsimetric indexes for many of the aerial photographs, as base maps for information plotting, and as control in the mensuration of high-altitude systems. The topographic maps used in this study are described in Appendix B.

Field work was undertaken in selected areas to acquire familiarization with high-altitude systems and to collect data for this study. Field observations were particularly important in checking aerial photograph interpretations in the earlier stages of the study, when skills essential to accurate photo-interpretation of glacial and periglacial features were being acquired. The summers of 1963 and 1964, and parts of the summers of 1965 and 1966 were devoted to field studies in mountain areas, including 14 areas encompassed by this study.

Geomorphic feature notation. A system of notation by which salient geomorphic features and groups of features are characterized concisely is employed in succeeding sections of this study and is outlined in Table 6.

System parameters. Spatial dimensions of glacial and periglacial systems are described in this study in terms of four parameters: the direction (azimuth) of exposure, the axial length (downvalley distance), the areal extent (area), and the lowest elevation (terminus altitude) attained by each system. Transitional rock glacier systems are described by two sets of these parameters, one set pertaining to the glacial component and the other to the rock glacier component.

The dominant or average direction toward which a system is exposed is expressed to the nearest 5^{o} of azimuth, with values ranging clockwise from 000^{o} (north-facing) to 355^{o}. Glacial, transitional rock glacier, and rock glacier systems in many cases have azimuths that closely parallel the trends of enclosing cirques; some rock glaciers and most talus and protalus systems have azimuths that are normal to the valley sides on and below which they occur.

Downvalley distance is measured in planimetric perspective from the cirque headwall or, where appropriate, valley sidewall to the most distal part of a particular system and is expressed to the nearest 0.01 mile. The most distal part of a glacial system is taken as the crest of the terminal moraine, whereas the most distal parts of periglacial

TABLE 6. Notation denoting geomorphic features.

Notation[a]	Geomorphic feature
M	end moraine ridge
$\frac{M}{R}$	transitional rock glacier (morainic material grading downvalley into rock glacier); activity of rock glacier component denoted as with rock glaciers, below
R"	conspicuously active rock glacier, clearly exhibiting marginal slopes steeper than the repose angle of the constituent rubble
R'	probably active rock glacier, with marginal slopes of unstable rubble at approximately the angle of repose
R	inactive rock glacier, with marginal slopes of stabilized rubble at less than the angle of repose
P	protalus rampart
T	talus apron or talus cone
C	colluvium-mantled slope
*	comparatively massive feature, with respect to other features of the same type in the near vicinity
+	multiple, very closely spaced end moraine ridges (M+), rock-glacier transverse ridges (R+), or protalus ramparts (P+)
!	overlap of an older feature by a younger feature
F	firn existing between 1945 and 1966, when the aerial photography and field work for this study took place
G	glacier ice existing between 1945 and 1966
	separation between crests of successive end moraine ridges or protalus ramparts, or between moraine crest and other specified feature upvalley, expressed semi-quantitatively, in terms of ridge widths[b]:
x	features distinct, but with separation of less than one ridge width
xx	separation of one to 2 ridge widths
xxx	separation of 3 to 10 ridge widths
xxxx	separation greater than 10 ridge widths

Source: compiled by the author.

[a]Where a sequence of features is denoted, the notation is ordered from the oldest feature on the left to the youngest feature on the right.

[b]Ridge widths are roughly equivalent to hundreds of feet.

systems are the toes of the distal slopes.

Following delineation of a particular system on a topographic map or aerial photograph, area was measured with a compensating polar planimeter and is expressed to the nearest 0.01 square mile. Glacial systems are bounded upvalley by Schrund lines and trim lines, and downvalley by lateral and terminal moraine crests. A rock glacier system is bounded upvalley by the toes of tributary talus slopes and downvalley by the toes of its own marginal slopes. A protalus rampart system encompasses the area between the distal toe of the rampart and the toe of the headward talus or the base of the headward cliff. The areas of talus slopes and colluvium-mantled slopes were not measured.

Terminus altitudes were determined from the largest scale topographic maps available and are expressed in feet above sea level. The terminus altitude of a glacial system is taken as the lowest altitude attained by glacier ice, whereas the terminus altitudes of periglacial systems are the lowest altitudes occupied by constituent rubble.

The altitudes of the uppermost observed trees, expressed in feet above sea level in succeeding sections of this study, are the highest known occurrances of plants having tree life form, in this study defined as having a woody main stem more than 8 feet tall (after Hanson, 1962, p. 353), as determined by field observations or by the interpretation of stereoscopic images and shadows on aerial photographs.

<u>Relative dating: the modification index</u>. The relative ages of inactive geomorphic systems have been determined in this study primarily on the basis of three criteria previously mentioned: superposition of forms, cross-cutting forms, and modification of forms. Superposition of geomorphic forms may be stratigraphic superposition, but more frequently

is topographic superposition, wherein younger forms occur upslope or upvalley from older forms. Cross-cutting relationships, in which older forms are truncated or breached by younger forms, are not common.

As an index of the relative ages of glacial and periglacial systems, repeated reference is made in this study to the progressive modification of depositional forms. Evaluation of the degree to which exterior form has been modified is based on five subjectively quantified variables, which in turn are summarized in a coefficient termed the modification index. The modification index ranges from 0.00, for forms that are fresh and essentially unmodified, to 1.00, for forms that have been very largely effaced, and is given by

$$\text{modification index} = \frac{v + d + s - c - b + 8}{20}$$

where v, d, s, c, and b are, respectively: vegetation cover, dissection, slope stability, crestal sharpness, and boulder prominence. Each variable is evaluated as: imperceptible = 0, slight = 1, moderate = 2, great = 3, and very great = 4.

The variables comprising the modification index tend to be time dependent, either directly or inversely, and are probably exponential rather than linear functions of time. Vegetation cover reflects plant succession and soil development, and tends to be directly related to the age of the substratum. Dissection of form, by rills, gullies, and in some cases by beach erosion, tends to be directly related to the age of the form. Slope stability, which increases as slope declines from an initially unstable or metastable angle, tends to be directly related to the age of the slope. On the other hand, the crestal sharpness of a moraine ridge, the brow or surface ridges of a rock glacier, or a protalus rampart tends to be inversely related to age; crestal sharpness is not applicable to talus slopes and colluvium.[11] Boulder prominence, a combination of the microrelief due to boulders and the frequency of boulders, likewise tends to be inversely related to the age of a particular surface. Evaluation of these variables was accomplished by field observations and by the stereoscopic examination of aerial photograph. A complete tabulation of the values from which the modification indexes in this study have been derived is presented in Appendix C.

Other procedures for assigning values to the relative ages of glacial and periglacial forms have been employed in previous studies (Nelson, 1954, p. 335), but, for use with aerial photographs over broad areas, are generally less suitable than the modification index employed in this study. Studies of soil profiles, which have been shown by Richmond (1962) to be an effective method of relative dating in high-altitude areas, produced erratic results when applied by the author, probably owing to a lack of requisite expertise.

Absolute dating. At sites below the upper limit of trees the most feasible method of absolute dating has been the use of tree-rings; other potentially useful methods of absolute dating could not be immediately undertaken within the resources available to this study. By means of increment borers, radial cores up to 28 inches long were taken from the oldest woody plants (Pinaceae) at a number of glacial and periglacial localities. Tree-rings at high altitudes in the Southwest are unmistakably annual in character and ring series are not unduly complicated by false rings and missing rings. But even with a complete tree-ring record, the date of the oldest ring in the oldest tree merely provides a minimum substrate age, to which must be added an estimate of ecesis time[12]. The period of glacial or periglacial activity, which preceded the adjusted minimum date, can sometimes be bracketed by a maximum date provided by substantially older trees at downslope or downvalley sites. The later episodes of Neoglaciation are well within the life span of presently living trees of several species and even the earlier episodes are spanned by living specimens of bristlecone pine (Currey, 1965).

Study Areas

The southwestern United States, for the purposes of this study, comprises the area between 31 and 42 degrees north latitude, and between 101 and 125 degrees west longitude, and includes California, Nevada, Utah, Arizona, southern Wyoming, Colorado, and New Mexico. Data pertaining to Neoglaciation in these states have been assembled from 27 study areas in three major physiographic regions: eight areas in the Pacific mountain system, seven areas in the intermountain region, and 12 areas in the Rocky Mountain system (Figure 2). Most of the study areas include several study localities, usually cirques, that are designated with reference to the nearest readily identifiable topographic prominences.

Several factors were considered in selecting areas for inclusion in this study: most of the mountain areas in the Southwest that have been the subject of previous study relating to Neoglaciation are included; most of the areas known to contain glaciers or remnant glacier ice at the present time are included; several areas were included to ensure a relatively even distribution of areas; and several of the more accessible high-altitude areas were included because of their suitability for field study.

Basic data concerning glacial and periglacial systems of Neoglacial and latest pre-Neoglacial age are summarized by study area, and locality, in Chapter 2. A synthesis of these data and conclusions regarding Neoglaciation in the southwestern United States are presented in Chapter 3.

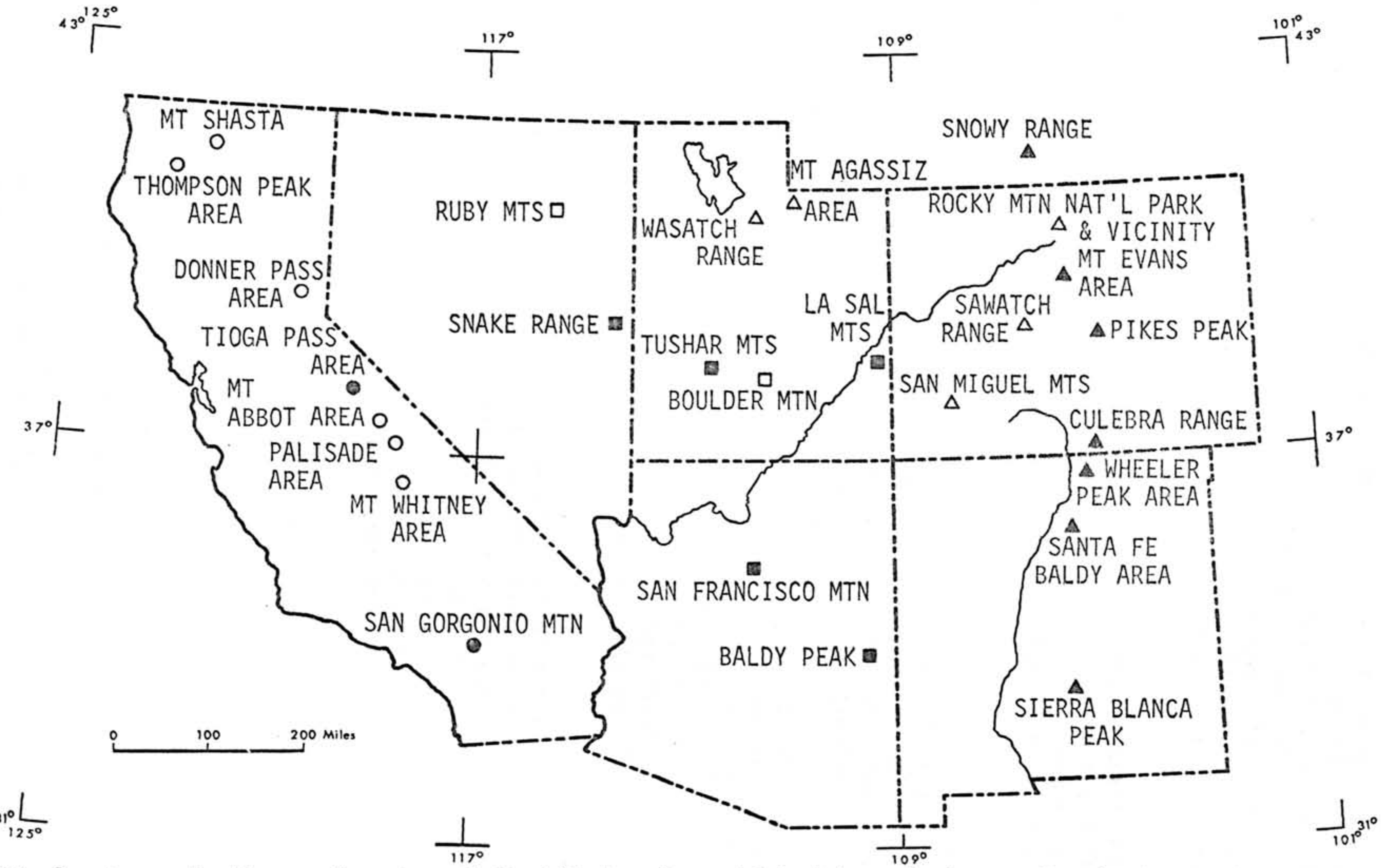

FIGURE 2. Areas in the southwestern United States from which data relating to Neoglaciation have been assembled in this study. Circles denote study areas in the Pacific mountain system, squares denote study areas in the intermontane provinces, and triangles denote study areas in the Rocky Mountain system. Solid symbols denote areas that the author studied in the field and by means of aerial photographs. Open symbols denote areas for which data were obtained from reports by other workers and from aerial photographs or maps.

Notes

[1]The term Neoglaciation was originally applied to cirque moraines in the Wind River Mountains of Wyoming by Moss (1951, p. 62), wherein it is written Neo-glaciation. As subsequently applied to a variety of regions, it invariably is written Neoglaciation and has largely superceded the term "little ice-age," introduced by Matthes in 1939 (p. 520) to describe the last 4,000 years. Information summarized by Porter and Denton in 1967 (p. 201) suggests that Neoglaciation began about 3,000 years ago.

[2]The warm interval preceding Neoglaciation has been described by several terms, including Altithermal, originally applied to the interval between 5000 and 2500 B.C. (Antevs, 1948, p. 176), and Hypsithermal, originally applied to the interval between 7000 and 600 B.C. (Deevey and Flint, 1957).

[3]A Schrund line is described by Sharp (1960a, p. 336-337) as defining the upper limit of ice adjacent to the Bergschrund. Trim lines, as described by Birman (1964, p. 32), occur on trough walls that are too steep to retain lateral moraines, and are traceable downvalley to the crests of the highest lateral moraines of a particular glacial advance.

[4]Many Neoglacial moraines are composed largely of ice that is protected from wastage by a cover of morainic debris. Ice-cored moraines generally are more massive and have steeper slopes than comparable moraines without ice cores. Snowbanks near the distal ends of glaciers have been covered to form ice-cored moraines in Scandanavia (Østrem, 1964). The distal ends of the glaciers, themselves, have been covered to form ice-cored moraines in California (Matthes, 1940, p. 399) and Alaska (Foster and Holmes, 1965).

[5]Rock glaciers that grade into true glaciers at their upper ends were first reported by Capps (1910, p. 360) from Alaska. The term transitional rock glacier was introduced for such a feature, also in Alaska, by Foster and Holmes (1965). The term cirque-floor rock glacier has been applied to identical features in Colorado (Outcalt and Benedict, 1965), but is inexact because some of the rock glaciers that occur on cirque floors have never been connected with ice glaciers.

[6]The tendency for the coldest winter air to drain into and resist displacement from depressions having restricted ventilation was advanced by Balch (1900) to explain subterranean ice in "taluses, boulder heaps, wells, mines, tunnels, and caves." For this process, by which perennially subfreezing cryptoclimates can be maintained even in regions otherwise lacking permafrost, Thompson (1962, p. 214) has introduced the very appropriate term Balch ventilation.

[7]As indicated by Bryan's (1934) generally accepted term for this type of periglacial system, protalus ramparts occur most frequently and are best developed near the base of talus cones and talus aprons. Similar but more diminutive ramparts may, nevertheless, occur near the base of bedrock cliffs.

[8]Talus and colluvium both consist of poorly sorted, poorly stratified, angular to subangular rock debris, predominantly boulder size in the former and comprising relatively even proportions of fine through coarse sizes in the latter. Talus occurs in cones that have their apexes in or beneath high-angle gullies through which rockfalls and avalanches have been repeatedly funneled, and in aprons of juxtaposed, coalescing cones. Colluvium generally occurs in relatively thin sheets of surficial mantle, frequently overlying preexisting detrital materials, such as inactive talus.

[9]Strict interpretation of the Code of Stratigraphic Nomenclature would indicate that Neoglaciation is not a valid name because it is not taken from a geographic feature or a geographically named stratigraphic unit, as stipulated in Articles 13 and 40 (American Commission on Stratigraphic Nomenclature, 1961, p. 653 and 660). A more appropriate name, possessing implicit priority but never formally proposed in the writings of Matthes (1916; 1942b, p. 383), would be Sierran Glaciation. The name Neoglaciation is, however, retained in this study.

[10]The latest stade prior to Neoglaciation, and immediately preceding the Altithermal, or Hypsithermal interval, is widely recognized in the Rocky Mountains as the late stade of Pinedale Glaciation, dating from ca. 8000 to 4500 B.C. (Richmond, 1965, p. 227). A correlative in the mountains of California remains to be adequately described. Correlative stades in other parts of North America include the Tanya in south-central Alaska, dating from ca. 7000 to 4000 B.C. (Karlstrom, 1964, plate 7); the Cochrane in southeastern Canada, dating from ca. 7000 to 4500 B.C. (Karlstrom, 1956); and the Cockburn in northeastern Canada, dating from ca. 7000 to 6000 B.C. (Falconer et al., 1965).

[11]Where crestal sharpness is not relevant the modification index $= \frac{v + d + s - b + 4}{16}$.

[12]The ecesis time required for persisting seedlings to become established following deglaciation has been estimated at from less than 2 to more than 30 years, depending on factors such as distance to seed source, nature of surface materials, and climate (Meier, 1965, p. 801).

CHAPTER II

AREAS STUDIED

Summary descriptions of the study areas indicated in Figure 2 (page 20) are presented in this chapter. The order of presentation is from north to south and from west to east, beginning with the northernmost study area in California and ending with the southernmost study area in New Mexico. Individual localities within a given study area also are treated in north-to-south and west-to-east order.

Mt. Shasta, California

One of the large composite volcanoes of the Cascade Range, Mt. Shasta is the highest peak in northern California. Although it presently has more glacier-covered area than any other mountain in the Southwest, the glacial and periglacial systems on Mt. Shasta have never been studied in detail. The information presented here is from aerial photograph and topographic map sources.

The most recent end moraine loops, which locally approach the proportions of transitional rock glaciers, are well developed, fresh in appearance, and occur approximately 0.5 mile downslope from the present glacier termini. These moraines were deposited by six semi-independent glaciers and appear to be the result of at least four nearly equal glacial advances during the latest stade of Neoglaciation. The moraine loops are clearly delineated on a topographic map (Shasta Special Map) surveyed in 1884, when the glacier termini were last standing near their late stade maximum positions. The dimensions of the late stade glaciers on Mt. Shasta, based on the 1884 survey, are summarized in Table 7.

Neither rock glaciers nor protalus ramparts were noted in the aerial photographs. The identification of older moraines in the photographs is complicated by numerous gullies and mudflows that have developed in the pyroclastic slope materials, and was not undertaken. The uppermost trees noted in the photographs are growing on the west-southwest side of Shastina, a subsidiary cone, at an altitude of 9,500 feet.

Thompson Peak Area, California

Midway between Mt. Shasta and the coast of California, on plutonic rocks within the Klamath Mountains, the Trinity Alps culminate in a group of horns centered around Thompson Peak. Two small glaciers in the Thompson Peak area are presently the most seaward and the lowest altitudinal occurrences of glacier ice in the Southwest. A brief description of these and other Neoglacial features appears in a previous study (Sharp, 1960a). The information presented here, and summarized in Table 8, is primarily from aerial photographs.

Evidence of two stades of Neoglaciation is visible in the photographs. The later stade is represented by crevassed ice that occurs in two broad cirques, one on the north side of Thompson Peak and the other on the northeast side of Peak 8966. Fresh moraine loops with multiple crests lie in front of the present glacierets and enclose glacierized areas 3.1 and 3.4 times as large as the present ice-covered areas. Fresh talus of the later stade is evident on nearby peaks, but no other periglacial features were noted.

An earlier stade of Neoglaciation is represented by conspicuously

TABLE 7. Glacierization during the later stade of Neoglaciation, Mt. Shasta (14,162), California.

Locality	Azimuth, downvalley Distance, Area, Terminus altitude			
	Az (°)	D (mi)	A (mi^2)	T (ft)
Whitney Glacier	335	2.0	0.5	9,550
Bolam Glacier	340	1.8	0.8	9,500
Hotlum Glacier, west lobe	025	1.8	0.9	9,500
Hotlum Glacier, east lobe	065	1.8	0.6	8,950
Wintun Glacier	095	2.1	0.5	8,250
Konwakiton Glacier	155	0.9	0.3	11,000

Source: Shasta Special Map (scale 1:62,500, contour interval 100 feet), surveyed in 1884 and published in 1897 by the U. S. Geological Survey. Moraines at margins of later stade glaciers shown by stippled pattern.

TABLE 8. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Thompson Peak area, California.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi^2)	T (ft)
NE of Peak 8,966						
Later stade	M*+xxxG	0.05	015	0.15	0.07	7,800
Earlier stade	M+	0.40	015	0.5	----	7,200
Latest pre-Ng[a]	M+	----	005	3.0	----	4,200
N of Thompson Peak (9,002)						
Later stade	M+xx4M+xxxxG	0.10	005	0.35	0.10	7,700
Earlier stade	M+	0.40	005	0.55	0.30	7,200
Latest pre-Ng[a]	M+	----	325	4.0	----	4,500
NW of Peak 8,913						
Later stade	T	0.06	---	----	----	-----
Earlier stade	MxM	0.30	340	0.15	0.03	8,100
Latest pre-Ng[a]	M+	----	290	1.9	----	5,300
NW of Peak 8,911						
Later stade	T	----	---	----	----	-----
Earlier stade	M+	----	330	0.11	0.02	7,900
Latest pre-Ng[a]	M+	----	305	1.9	----	5,300

Sources: aerial photograph interpretation by the author and, where denoted by [a], data from Sharp (1960a).

Features: M = end moraine ridge, T = talus, G = existing glacier ice, * = comparatively massive feature, + = several end moraine ridges, x = separation of less than one ridge width, xx = separation of one to 2 ridge widths, xxx = separation of 3 to 10 ridge widths, xxxx = separation of more than 10 ridge widths.

modified moraines with multiple crests that terminate 0.20 and 0.35 mile downvalley from the later stade moraines. Similar earlier stade moraines occur in cirques on nearby peaks that were not glacierized during the later stade. No evidence was noted of a possible third stade of Neoglaciation suggested by Sharp (ibid., p. 323).

Still farther downvalley, the late pre-Neoglacial moraine sequence, which Sharp (ibid., p. 308-314) termed the Morris Meadow substage, is quite complex. The data in Table 8 that ostensibly pertain to the latest pre-Neoglacial stade are derived from Sharp's maps and may in fact pertain instead to episodes earlier than the latest pre-Neoglacial stade. For lack of suitable aerial photograph coverage, a survey of pre-Neoglacial moraines was not undertaken in this study.

The uppermost trees noted in the photographs are growing at altitudes approaching 9,000 feet.

Donner Pass Area, California

Glacial and proglacial features in the section of the northern Sierra Nevada that includes Donner Pass are described in a study by Birkeland (1964), which is the source of the information presented here.

Only one feature of Neoglacial age, a little-modified protalus rampart that occurs at an altitude of 8,400 feet on a northeast-facing cirque headwall, is reported by Birkeland, with no suggestion as to which stade or stades of Neoglaciation it may represent. No perennial snowfields are known at present in the Donner Pass area.

Late pre-Neoglacial deglaciation in the Donner Pass area was marked by several stillstands followed shortly by a slight readvance from the cirques, an episode that Birkeland termed the Frog Lake advance. Five reported glaciers (Table 9) of this latest pre-Neoglacial stade terminated

TABLE 9. Latest pre-Neoglacial glacial deposits[a] reported by Birkeland (1964, fig. 4) from the Donner Pass area, California.

Locality	Azimuth (°)	Terminus altitude (ft)
NE of Frog Lake Cliff (8,640)	085	7,400
E of Peak 8,597	095	7,650
NE of Squaw Peak (8,885)	065	7,450
SE of Squaw Peak (8,885)	105	7,600
upper Bear Creek canyon (8,400+)	060	7,600

[a]Termed by Birkeland the Frog Lake Till.

at altitudes ranging from 7,400 to 7,650 feet; all terminated within 0.625 mile of their cirque headwalls.

The highest peaks in the Donner Pass area are wooded to their summits and, therefore, are lower than the potential uppermost occurrence of trees.

Tioga Pass Area, California

High-altitude geomorphic systems, including three existing glaciers, are relatively accessible where the crest of the Sierra Nevada forms the eastern boundary of Yosemite National Park near Tioga Pass. Glacial and periglacial features in the Tioga Pass area are described here, and summarized in Table 10, on the basis of field observations and aerial photograph interpretation by the author. Twelve localities, each heading in a cirque, were observed in a distance of 10 miles along the south-southeast-trending Sierra Nevada crest; six of the localities are on the west side of the crest and six are on the east. Two stades of Neoglaciation, the earlier marked by more extensive glacierization than the later, are consistently evident at these localities.

The later stade of Neoglaciation is represented by three existing glaciers, including Conness Glacier and Dana Glacier, that terminate upvalley from massive, multiple-crested, ice-cored moraines that remain essentially unmodified. These later stade moraine loops formerly enclosed glaciers having areas 1.8, 2.5, and 4.0 times as large as the existing glaciers. Two other cirques contain moraines that are fresh and undisturbed, but are now devoid of glacier ice. No later stade transitional rock glaciers were observed, although the ice-cored moraines locally approach the transitional form. Later stade rock glaciers, probably still active, occupy two cirques, and five cirques are occupied

TABLE 10. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Tioga Pass area, California.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi^2)	T (ft)
SW of Peak 12,015						
Later stade	T	0.00	---	---	----	------
Earlier stade	M!M	0.20	350	0.4	0.09	10,500
Latest pre-Ng		no observations				
NE of Sheep Peak (11,840+)						
Later stade	R'	0.00	000	0.2	----	10,400
Earlier stade	M	0.30	355	0.3	0.12	10,300
Latest pre-Ng		no observations				
NE of North Peak (12,242)						
Later stade	4MxxG	0.00	025	0.2	0.04	11,100
Earlier stade	M+!M+xM+	0.25	045	0.7	0.4	10,300
Latest pre-Ng[a]	M+	0.65	090	5.6	---	9,520
NE of Mt. Conness (12,590)						
Later stade	*M+!*M+!*M+xxG[b]	0.00	020	0.5	0.2	11,300
Earlier stade	M!M+xxM+	0.30	055	1.6	0.8	10,200
Latest pre-Ng[a]	M+	0.65	090	6.0	---	9,520
SE of Mt. Conness (12,590)						
Later stade	T	0.00	---	----	----	------
Earlier stade	MxxxM	0.25	100	0.65	0.15	11,000
Latest pre-Ng[a]	M+	0.65	090	4.3	----	9,520
N of White Mountain (12,000+)						
Later stade	M+	0.00	010	0.1	0.02	11,200
Earlier stade	MxxxMxxMxM	0.25	085	0.9	0.36	10,200
Latest pre-Ng[a]	M+	0.65	090	4.2	----	9,520

TABLE 10, continued.

E of White Mountain (12,000+)						
Later stade	M+	0.00	040	0.15	0.03	11,250
Earlier stade	MxxxMxxMxM	0.30	040	1.2	0.8	10,150
Latest pre-Ng[a]	M+	0.65	090	3.8	---	9,520
SE of White Mountain (12,000+)						
Later stade	T	0.05	---	---	----	------
Earlier stade	*M+	0.25	130	0.2	0.05	11,300
Latest pre-Ng	M+	0.55	225	1.9	----	9,800
N of Peak 11,255						
Later stade	R'!R'	0.00	005	0.2	----	10,300
Earlier stade	*M+	0.15	350	0.3	0.05	10,250
Latest pre-Ng		no observations				
NW of Peak 12,002						
Later stade	T	0.00	---	---	---	------
Earlier stade	MxM+	0.15	295	0.3	0.1	10,900
Latest pre-Ng	M+	0.50	185	1.9	---	10,300
SE of Peak 12,002						
Later stade	T	0.00	---	---	---	------
Earlier stade	MxxM	0.25	045	0.3	0.1	10,400
Latest pre-Ng	M+xxxxM+	0.55	215	2.5	---	9,900
NE of Mt. Dana (13,053)						
Later stade	*Mx*M+!*Mx*M+xxxG[c]	0.00	025	0.35	0.10	11,200
Earlier stade	*M+x*Mx*M+x*M+	0.20	355	0.85	0.32	11,000
Latest pre-Ng[a]	M+	0.65	090	3.5	----	9,520

Source: field observations and aerial photograph interpretation by author.

Features: M = end moraine ridge, R' = probably active rock glacier,
T = talus, G = existing glacier, * comparatively massive feature,
+ = several end moraine ridges or rock glacier transverse ridges,

TABLE 10, continued.

! = overlap of older feature (left) by younger (right), x = separation of less than one ridge width, xx = separation of one to 2 ridge widths, xxx = separation of 3 to 10 ridge widths, xxxx = separation of over 10 ridge widths.

[a]Glaciers confluent. Former ice margin is marked by pitted ground moraine and discontinuous end moraine remnants.

[b]Conness Glacier.

[c]Dana Glacier.

by actively accruing talus.

All 12 of the observed cirques in the Tioga Pass area contained glaciers during the earlier stade of Neoglaciation. The earlier stade end moraines occur between 0.5 and 1.1 mile downvalley from those of the later stade, and characteristically consist of two, three, or four distinct end moraine ridges within a downvalley interval of less than 0.1 mile. None of the earlier stade moraines is ice cored and all have been externally modified; the mean modification index of the 12 sets of earlier stade moraines is 0.24 ± 0.05 (standard deviation). At least one of the earlier stade moraines was wooded throughout the later stade; the oldest living tree (Pinus contorta) cored on the earlier stade terminal moraine NE of Mt. Conness began growing ca. A.D. 1300.

The latest pre-Neoglacial stade was marked by valley glaciers, generally fed by two or more confluent cirque glaciers, that terminated between 1.6 and 4.9 miles downvalley from the positions subsequently attained by the glaciers of the earlier Neoglacial stade. The latest pre-Neoglacial end moraines are irregular and pitted, reflecting stagnation little affected by stillstand or readvance, and have been considerably modified by subsequent high-altitude systems; the mean modification index of the four sets of latest pre-Neoglacial moraines observed in the Tioga Pass area is 0.56 ± 0.06.

The uppermost observed trees in the Tioga Pass area are growing on the south slope of Mt. Dana at an altitude of approximately 11,100 feet.

Mt. Abbot Area, California

The glacial history of an area straddling the Sierra Nevada crest in the vicinity of Mt. Abbot, 40 miles southeast of Tioga Pass, has been treated in detail by Birman (1964), wherein three stades of Neoglaciation are described and mapped (ibid., plate 1). Birman's map is the source of the information presented here, and summarized in Table 11.

During the latest Neoglacial stade, which Birman termed the Matthes glaciation, eight cirques or parts of compound cirques west of the crest and one cirque east of the crest were occupied or partially occupied by cirque glaciers. The Matthes moraine loops, comprising as many as eight closely spaced ridges, occur a short distance downvalley from remnant glacierets and perennial snow masses that now exist in those localities.

Moraine loops deposited by cirque glaciers during an earlier Neoglacial stade, which Birman termed the Recess Peak glaciation, have been mapped at eight localities in the Mt. Abbot area. The Recess Peak loops consist of two, three, and four distinct end moraine ridges and terminate between 0.3 and 0.9 mile downvalley from the Matthes terminal moraines.

Moraines deposited by valley glaciers during what Birman has termed the Hilgard glaciation, which he regards as probably being of earliest Neoglacial age, have been mapped in the two main valleys of the Mt. Abbot area, one on either side of the Sierra Nevada crest. The Hilgard moraines west of the crest terminate 2.3 miles downvalley from the Recess Peak terminal moraines and on the east they terminate 5.5 miles from the Recess Peak moraines. Other workers in the Sierra Nevada are inclined to regard Hilgard as the latest pre-Neoglacial, rather than the earliest Neoglacial, stade (R. J. Janda, 1965, oral communication).

Rock glaciers attained altitudes as low as 10,000 feet during the latest (Matthes) stade and altitudes as low as 9,680 feet during the earlier (Recess Peak) stade.

TABLE 11. Neoglacial glacierization reported by Birman (1964, plate 1) from the Mt. Abbot area, California.

Locality	Azimuth, downvalley Distance, Area, Terminus altitude			
Episode[a]	Az (°)	D (mi)	A (mi²)	T (ft)
N of Recess Peak (12,836)				
Matthes	000	0.25	0.08	11,600
Recess Peak	345	0.8	0.30	11,200
Hilgard	not mapped			
E of Recess Peak (12,836)				
Matthes	045	0.25	0.03	11,800
Recess Peak	040	0.55	0.15	11,200
Hilgard	not mapped			
E of Peak 12,692				
Matthes	000	0.25	0.08	11,800
Recess Peak	000	1.0	0.50	10,900
Hilgard	not mapped			
N of Mt. Hilgard (13,361)				
Matthes	020	0.25	0.07	11,800
Recess Peak	350	1.1	0.60	11,100
Hilgard	not mapped			
NW of Mt. Gabb (13,711)				
Matthes	010	0.35	0.07	11,800
Recess Peak[b]	345	1.1	0.4	11,100
Hilgard	not mapped			
NE of Mt. Gabb (13,711)				
Matthes	030	0.5	0.11	11,800
Recess Peak[b]	345	1.3	0.5	11,100
Hilgard	not mapped			

TABLE 11, continued.

E of Peak 12,691				
Matthes	345	0.25	0.03	11,600
Recess Peak	355	0.7	0.20	11,100
Hilgard[c]	345	3.0	----	9,300
N of Mt. Mills (13,468)				
Matthes	000	0.4	0.10	11,800
Recess Peak	not mapped			
Hilgard[c]	345	4.7	----	9,300
NE of Mt. Abbot (13,715)				
Matthes	050	0.6	0.4	12,000
Recess Peak	040	1.5	1.9	11,100
Hilgard	025	7.0	11.0	9,300

[a]Birman's "glaciations."

[b, c]Glaciers confluent.

Palisade Area, California

The southernmost active glaciers and glacierets in the Southwest occur in the Palisade section of the Sierra Nevada, about 30 miles southeast of Mt. Abbot. Palisade Glacier, with an area of 0.50 square mile, is presently the largest body of glacier ice in the Sierra Nevada and except for three of the glaciers on Mt. Shasta is the largest glacier in the Southwest. The only previous study relating to Neoglaciation in the Palisade area is a 1946 survey and description of Palisade Glacier (Heald, 1946). As described here and in Table 12 on the basis of information extracted primarily from aerial photographs, the Palisade area comprises four miles of Sierra Nevada crest, including one cirque locality on the west slope and seven cirque and compound cirque localities on the east slope.

Two stades of Neoglaciation are evident in aerial photographs of the Palisade area. In five of the observed localities the later stade is represented by bodies of glacier ice, four of which occur upvalley from massive, apparently ice cored end moraine loops, and one which occurs at the head of a transitional rock glacier. The later stade end moraine complex in front of the Palisade Glacier encloses an area about 1.2 times as large as the present glacier and consists of approximately 16 closely spaced and overlapping end moraine ridges, the greatest number of later stade moraine ridges observed at a single locality in this study. The areas enclosed by other later stade moraine loops in the Palisade area are from two to three times as large as the present glaciers. All of the later stade moraines are virtually unmodified, except where they seem to have undergone, and may still be undergoing, a certain amount of rock glacier motion. The transitional rock glacier is similarly

TABLE 12. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Palisade area, California.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
NE of Mt. Agassiz (13,891)						
Later stage	R"!$\overset{*}{M}$+xG / $\overset{*}{R}$"+	0.00	035	0.25 / 0.90	0.05 / 0.30	12,300 / 11,700
Earlier stade	M+	0.10	035	1.25	0.4	11,300
Latest pre-Ng[a]	M+	0.55	090	3.60	---	9,600
N of Mt. Winchell (13,768)						
Later stade	$\overset{*}{M}$x$\overset{*}{M}$+!$\overset{*}{M}$x$\overset{*}{M}$+xxxG	0.00	060	0.35	0.1	12,450
Earlier stade[b]	M+	0.30	030	2.30	0.4	10,200
Latest pre-Ng[a]	M+	0.55	090	3.50	---	9,600
N of North Palisade (14,242)						
Later stade	$\overset{*}{M}$+!3$\overset{*}{M}$+!$\overset{*}{M}$+!$\overset{*}{M}$+xxxMxxG[c]	0.00	030	1.1	0.6	12,000
Earlier stade[b]	M+	0.30	030	2.3	1.9	10,200
Latest pre-Ng[a]	M+	0.55	090	3.5	---	9,600
NNE of Temple Crag (12,999)						
Later stade	R"	0.00	330	0.35	---	10,800
Earlier stade	$\overset{*}{R}$+xR	0.25	330	1.00	---	10,000
Latest pre-Ng[a]	M+	0.55	090	2.10	---	9,600
NE of Mt. Gayley (13,510)						
Later stade	R'	0.00	065	0.1	----	12,500
Earlier stade	M+	0.15	065	0.3	0.03	12,100
Latest pre-Ng		no observations				
E of Isosceles Peak (12,280+)						
Later stade	R"	0.00	005	0.15	----	11,700
Earlier stade	M+xxx$\overset{*}{M}$+	0.30, 0.15	005	0.4	0.10, 0.09	11,400
Latest pre-Ng		no observations				

TABLE 12, continued.

E of Mt. Sill (14,162)						
Later stade	5$\overset{*}{M}$+xxxG	0.00	045	0.36	0.06	12,250
Earlier stade	MxM+	0.20	045	0.62	0.20	12,000
Latest pre-Ng		no observations				
E of Peak 13,390						
Later stade	$\overset{*}{M}$x$\overset{*}{M}$+!$\overset{*}{M}$x$\overset{*}{M}$+xxxG	0.05	040	0.2	0.11	11,950
Earlier stade	MxM+xxM+xxxM+	0.30	040	0.9	0.43	10,900
Latest pre-Ng		no observations				

Source: aerial photograph interpretation by the author.

Features: M = end moraine ridge, $\frac{M}{R}$ = transitional rock glacier, R" = active rock glacier, R' = probably active rock glacier, R = inactive rock glacier, G = existing glacier ice, * = comparatively massive feature, + = several end moraine ridges or rock glacier transverse ridges, ! = overlap of older feature (left) by younger (right), x = separation of less than one ridge width, xx = separation of one to 2 ridge widths, xxx = separation of 3 to 10 ridge widths.

[a, b]Glaciers confluent.

[c]Palisade Glacier. A total of approximately 16 later stade end moraine ridges is discernible.

unmodified and appears to be actively advancing. A number of later stade rock glaciers, most of which are probably still active, were observed at altitudes as low as 10,800 feet in the Palisade area, and at altitudes as low as 10,500 feet near Kearsarge Pass, midway between the Palisade and Mt. Whitney areas. Later stade protalus ramparts were not observed in the Palisade area, but near Kearsarge Pass have been observed at altitudes as low as 10,000 feet.

Seven of the localities observed in the Palisade area were glacierized during the earlier stade of Neoglaciation. Earlier stade moraines occur between 0.26 and 1.95 miles downvalley from the later stade moraines and are less massive and consequently less conspicuous than the later moraines. The earlier stade moraines appear to lack ice cores and since glaciation have been externally modified to the extent that the mean modification index of the seven sets of moraines is 0.21 ± 0.09 (standard deviation). As is common in other areas of the Sierra Nevada, three or four phases of glacierization during a single earlier Neoglacial stade are clearly recorded by moraines in a compound cirque east of Peak 13390. A rather different pattern, not observed at any other locality in the Sierra Nevada, appears in the cirque east of Isosceles Peak, where two earlier moraines having distinctly different degrees of post-glacial modification suggest the possibility of two earlier Neoglacial stades, rather than one. The lowest observed earlier stade rock glacier in the Palisade area terminates at an altitude of 10,000 feet.

The latest pre-Neoglacial moraine system in the valley of Big Pine Creek, at the eastern margin of the Palisade area, terminates between 1.2 and 2.4 miles farther downvalley than the moraines of the earlier Neoglacial stade and, with a modification index of 0.55, is far more subdued than the Neoglacial moraines. The latest pre-Neoglacial moraines in other parts of the Palisade area were not traced to their termini. In Sawmill Canyon, between the Palisade area and Kearsarge Pass, the latest pre-Neoglacial moraines terminate at an altitude of 9,700 feet, 2.4 miles downvalley from the canyon head (Dalrymple, 1964, fig. 1).

On both slopes of the Sierra Nevada, the uppermost observed trees in the Palisade area are growing at altitudes of approximately 11,600 feet.

Mt. Whitney Area, California

Several of the highest peaks, and perhaps the southernmost bodies of perennial snow, in the Southwest occur in the vicinity of Mt. Whitney, 40 miles southeast of the Palisade area. Previously unstudied in terms of Neoglaciation, the area that is described here, and in Table 13, was examined by means of aerial photographs encompassing 6 miles of the Sierra Nevada crest, including six cirque and compound cirque localities to the west of the crest and nine to the east.

Two stades of Neoglaciation, an earlier stade marked by cirque glaciation and a later stade marked by periglacial systems, are evident in the Mt. Whitney area. The later stade is represented by a transitional rock glacier in the cirque SE of Mt. Whitney, by rock glaciers at 11 localities, and by protalus ramparts at three localities. Continuing rock glacier activity and small firn banks are in evidence at a number of the localities. A mean modification index of 0.03 ± 0.03 (standard deviation), representing those localities observed stereoscopically (N = 14), is indicative of the slight degree to which the later stade features have been modified. Tripartite structure of the transitional

TABLE 13. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Mt. Whitney area, California.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi^2)	T (ft)
N of Peak 13,211						
Later stade	P	----	010	0.15	----	11,800
Earlier stade	M+	----	010	0.23	0.06	11,700
Latest pre-Ng		no observations				
NW of Tunnabora Peak (13,565)						
Later stade	R*"!R*"+	0.00	010	0.44	----	11,500
Earlier stade	M+	0.20	010	0.66	0.16	11,300
Latest pre-Ng		no observations				
N of Peak 13,355						
Later stade	R*"	0.05	000	0.33	----	11,600
Earlier stade	MxM	0.20	025	0.55	0.11	11,550
Latest pre-Ng		no observations				
NW of Mt. Russell (14,086)						
Later stade	P	0.10	350	0.10	----	13,000
Earlier stade	M*xM+	0.40	350	0.23	0.07	12,900
Latest pre-Ng		no observations				
NE of Mt. Russell (14,086)						
Later stade	P	0.05	050	0.10	----	12,850
Earlier stade	MxM+	0.20	050	0.37	0.09	12,800
Latest pre-Ng		no observations				
SE of Mt. Russell (14,086)						
Later stade	R'	0.05	000	0.10	----	12,000
Earlier stade	M+	0.25	090	0.43	0.06	11,900
Latest pre-Ng	M+	0.55	110	1.03	0.19	11,300

TABLE 13, continued.

NE of Mt. Hale (13,440+)						
Later stade	$\overset{*}{R}$"+	0.00	350	0.4	----	11,750
Earlier stade	M+	0.20	350	0.7	0.18	11,700
Latest pre-Ng		no observations				
N of Mt. Young (13,177)						
Later stade	R"!$\overset{*}{R}$"+	0.00	005	0.20	----	11,500
Earlier stade	M+	0.15	005	0.25	0.10	11,450
Latest pre-Ng		no observations				
NE of Mt. Whitney (14,495)						
Later stade	R'!R'	0.05	065	0.14	----	12,600
Earlier stade[a]	MxM+	0.30	090	0.80	0.10	11,900
Latest pre-Ng[b]	M+	0.50	090	1.60	0.20	10,900
SE of Mt. Whitney (14,495)						
Later stade	R"+!$\frac{M+}{R''+}$xxR"+	0.00	090	0.3 / 0.5	0.04 / 0.08	12,300 / 12,050
Earlier stade[a]	MxM+	0.30	090	0.7	0.16	11,900
Latest pre-Ng[b]	M+	0.50	090	1.6	0.32	10,900
NE of Mt. Muir (14,015)						
Later stade	R"	0.05	075	0.23	----	12,300
Earlier stade	MxM!MxMxM+	0.20	075	0.53	0.20	12,200
Latest pre-Ng	M+	0.50	085	1.50	0.50	10,800
SE of Mt. Muir (14,015)						
Later stade	$\overset{*}{R}$"xR"+	0.05	080	0.34	----	12,150
Earlier stade	M+	0.20	080	0.47	0.07	12,000
Latest pre-Ng[c]	M+	0.55	070	1.70	----	10,700
E of Discovery Pinnacle (13,680+)						
Later stade	R"!R"	0.00	005	0.29	----	12,500
Earlier stade	M	0.20	005	0.34	0.05	12,400
Latest pre-Ng[c]	M+	0.55	070	1.65	----	10,700

TABLE 13, continued.

N of Mt. Chamberlin (13,169)						
Later stade	$\overset{*}{R}$"	0.05	010	0.2	----	11,350
Earlier stade	M!3$\overset{*}{M}$x3M	0.20	010	0.3	0.12	11,300
Latest pre-Ng		no observations				
N of Mt. Pickering (13,485)						
Later stade	R'+	0.00	045	0.3	----	12,000
Earlier stade	M+	0.15	045	0.8	0.22	11,900
Latest pre-Ng		no observations				

Source: aerial photograph interpretation by the author.

Features: M = end moraine ridge, $\frac{M}{R}$ = transitional rock glacier, R" = active rock glacier, R' = probably active rock glacier, R = inactive rock glacier, P = protalus rampart, * = comparatively massive feature, + = several end moraine ridges or rock glacier transverse ridges, ! = overlap of older feature (left) by younger (right), x = separation of less than one ridge width, xx = separation of one to 2 ridge widths.

[a, b, c]Glaciers confluent.

rock glacier appears to record three main episodes of glacial or near-glacial conditions during the later stade.

Moraine loops representing the earlier Neoglacial stade occur at each of the 15 observed localities, between 0.05 and 0.66 mile downvalley from the termini of the later stade features. The earlier Neoglacial moraines are visibly modified, with a mean modification index, based on observations of 14 localities, of 0.23 ± 0.07. Three main episodes of earlier stade glacierization appear to be recorded by end moraines N of Mt. Chamberlin, and five earlier stade episodes may be recorded by moraines NE of Mt. Muir.

End moraines of the latest pre-Neoglacial stade were observed in four valleys east of the Sierra Nevada crest, where they occur between 0.6 and 1.3 mile farther downvalley and are considerably more modified, with a mean modification index of 0.52 ± 0.03, than the moraines of the subsequent Neoglacial stade. Latest pre-Neoglacial moraines were observed on the west slope of the Sierra Nevada but were not traced to their termini.

The uppermost trees in the Mt. Whitney area, observed at several south- and southwest-facing sites, are growing at altitudes of approximately 11,800 feet.

San Gorgonio Mountain, California

The highest peak in southern California, San Gorgonio Mountain is situated in the culminating section of the San Bernardino Mountains, an east-trending fault block complex of crystalline rocks, which is the only section of southern California to have been extensively glaciated (Sharp et al., 1959). Observations made in the field and from aerial photographs are summarized here and in Table 14.

TABLE 14. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, San Gorgonio Mountain, California.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (^{o})	D (mi)	A (mi^2)	T (ft)
NE of San Gorgonio Mountain (11,502)						
Later stade	T	0.00	---	---	----	------
Earlier stade	T	0.12	---	---	----	------
Latest pre-Ng	M	0.40	045	0.4	0.06	10,200

Source: field observations and aerial photograph interpretation by author.
Features: M = end moraine ridge, T = talus.

Large volumes of little-modified and actively accumulating Neoglacial talus are present in 10 cirques on the north slopes of the San Bernardino Mountains. From the highly dissected condition of the cirque walls, it appears that none of the cirques was glaciated during Neoglaciation and that few were glaciated as recently as the latest pre-Neoglacial stade. The clearest example of a very late pre-Neoglacial moraine is at the mouth of the cirque NE of San Gorgonio Mountain, where a single well defined moraine ridge, breached by a gully and partly overlapped by Neoglacial talus, marks what well may have been the last stand of glacier ice in southern California. The oldest observed plant (Pinus flexilis) on this moraine indicates that deglaciation occurred prior to A.D. 1150.

The uppermost trees on San Gorgonio Mountain were observed on the south slope at an altitude of 11,300 feet; krummholz extends to the summit.

Ruby Mountains, Nevada

Glacial and periglacial features at four localities in the central portion of the Ruby Mountains, a southwest-trending fault block of crystalline rocks that is the highest range in the northern part of the Great Basin, are described here, and summarized in Table 15, on the basis of observations made by means of aerial photographs.

Although the localities observed in the Ruby Mountains do not appear to have been occupied by glacier ice during Neoglaciation, two stades of Neoglacial rock glacier development are clearly evident at the head of Lamoille Creek canyon, where a later stade rock glacier that is essentially unmodified and probably still active partially overlaps an earlier stade rock glacier that is now modified and stabilized. Two distinct episodes of earlier stade rock glacier activity appear to be represented at the

TABLE 15. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Ruby Mountains, Nevada.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi^2)	T (ft)
W of Thomas Point (11,316)						
Later stade	T	----	---	---	---	-----
Earlier stade	T	----	---	---	---	-----
Latest pre-Ng	MxMxM	0.65	355	1.7	---	8,700
NE of Peak 11,133						
Later stade	T	----	---	---	---	-----
Earlier stade	T	----	---	---	---	-----
Latest pre-Ng	M+	0.60	065	0.9	---	9,000
upper Lamoille Creek canyon (10,865)						
Later stade	R"	0.00	310	0.1	---	9,900
Earlier stade	R	0.25	310	0.2	---	9,800
Latest pre-Ng	M+	0.70	025	0.7	---	9,200
upper Box Canyon (10,960+)						
Later stade	T	----	---	---	---	-----
Earlier stade	R!R	0.30	345	0.3	---	9,900
Latest pre-Ng		no observations				

Source: aerial photograph interpretation by the author.

Features: M = end moraine ridge, R" = active rock glacier, R = inactive rock glacier, T = talus, + = several end moraine ridges, ! = overlap of older feature (left) by younger (right), x = intercrestal separation of less than one ridge width.

head of Box Canyon. The mean modification index of the earlier stade rock glaciers in Lamoille and Box canyons is 0.28 ± 0.04 (standard deviation).

End moraines of the latest pre-Neoglacial stade, which in a previous study of the Ruby Mountains (Sharp, 1938, p. 305-306) is referred to as the last phase of the Angel Lake substage, were observed at three localities, between 0.5 and 1.6 mile downvalley from the Neoglacial features at the valley heads. The latest pre-Neoglacial moraines are quite subdued, support what appear to be mature stands of bristlecone pine, and have a mean modification index of 0.65 ± 0.05.

The uppermost observed trees in the Ruby Mountains are growing on south-facing slopes near the head of Lamoille Creek canyon at an altitude of 10,950 feet.

Snake Range, Nevada

The highest altitudes in the eastern part of the intermontane Southwest, and the only body of glacier ice presently existing in the intermontane region, occur in the Snake Range, a south-trending fault-block range composed largely of quartzite. Information pertaining to glacial and periglacial systems in the Snake Range is presented here, and in Table 16, on the basis of observations made in the field and from aerial photographs. Eight localities, one cirque on the west slope and seven on the east, were observed in the highest part of the range.

Two stades of Neoglaciation are recognizable in the Snake Range. The later stade is represented by a small body of glacier ice at the head of an active transitional rock glacier in the cirque NE of Wheeler Peak, by an active rock glacier in the cirque NE of Baker Peak, and by a relatively unmodified protalus rampart in the cirque N of Wheeler Peak. Later stade talus is in evidence at other localities. The mean modification

TABLE 16. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Snake Range, Nevada.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (^{o})	D (mi)	A (mi^{2})	T (ft)
SE of Point 11,024						
Later stade	T	----	---	----	----	------
Earlier stade	T	----	---	----	----	------
Latest pre-Ng	M	0.65	070	0.15	0.05	10,400
N of Wheeler Peak (13,063)						
Later stade	P	0.05	015	0.1	----	10,700
Earlier stade	R'	0.20	015	0.2	----	10,600
Latest pre-Ng	*MxxxMxxxMxR	0.50	015	0.8	0.25	10,150
NE of Wheeler Peak (13,063)						
Later stade	M+xG / *R"+	0.00	025	0.1 / 0.3	0.01 / 0.04	11,200 / 10,950
Earlier stade	M+ / *R'+	0.15	025	0.4 / 0.5	0.04 / 0.07	10,900 / 10,700
Latest pre-Ng	*MxxxMxxxMxx*R+	0.50	025	1.8	0.6	9,700
NE of Baker Peak (12,298)						
Later stade	*R"+	0.05	055	0.2	---	10,800
Earlier stade	M(?)[a] / *R'+	0.20	055	<0.2 / 0.3	---	>10,800 / 10,700
Latest pre-Ng	M!MxMxM	0.55	055	0.5	0.4	10,200
SE of Baker Peak (12,298)						
Later stade	T	0.12	---	---	---	------
Earlier stade	R'	0.20	065	0.2	---	10,600
Latest pre-Ng	M+	0.60	065	0.4	0.1	10,600
S of Pyramid Peak (11,921)						
Later stade	T	----	---	---	---	------
Earlier stade	R	0.30	075	0.1	---	10,650
Latest pre-Ng	M+	0.60	075	0.3	---	10,500

TABLE 16, continued.

NW of Peak 11,804						
Later stade	T	----	---	---	---	------
Earlier stade	T	----	---	---	---	------
Latest pre-Ng	M+	----	005	0.2	---	10,200
NE of Peak 11,562						
Later stade	T	----	---	---	---	------
Earlier stade	T	----	---	---	---	------
Latest pre-Ng	MxxxMxxMxM	----	050	0.3	---	10,000

Source: field observations and aerial photograph interpretation by author.

Features: M = end moraine ridge, $\frac{M}{R}$ = transitional rock glacier, R" = active rock glacier, R' = probably active rock glacier, R = inactive rock glacier, P = protalus rampart, T = talus, G = existing glacier ice, * = comparatively massive feature, + = several end moraine ridges or rock glacier transverse ridges, x = separation of less than one ridge width, xx = separation of one to 2 ridge widths, xxx = separation of 3 to 10 ridge widths.

[a]Site of possible earlier stade glacier is now occupied by later stade rock glacier.

index of later stade periglacial features, as observed in detail at four localities, is 0.06 ± 0.05 (standard deviation). Spruce (Picea engelmanni) has grown on the protalus rampart N of Wheeler Peak since ca. A.D. 1880. Later stade rock glaciers were observed in the Snake Range at altitudes as low as 9,800 feet; later stade protalus ramparts were observed as low as 9,200 feet.

The earlier stade of Neoglaciation is represented at two localities by transitional rock glaciers that are inactive or nearly so, at three localities by rock glaciers that are inactive or comparatively inactive, and by stabilized talus at other localities. Only 0.1 to 0.2 mile in front of the later stade features, the earlier stade features are in large part overlapped by the younger features. The mean modification index of the five earlier stade transitional rock glaciers and rock glaciers is 0.21 ± 0.05. Spruce had become established on the earlier stade rock glacier N of Wheeler Peak by A.D. 1430.

The latest pre-Neoglacial stade is represented at each of the observed localities by terminal moraines and recessional features that occur between 0.1 and 1.3 mile downvalley from the termini of the oldest Neoglacial features. Inactive rock glaciers, similar to but larger than the Neoglacial transitional rock glaciers, mark the final phase of the latest pre-Neoglacial stade in the cirques N and NE of Wheeler Peak. A stand of bristlecone pine (Pinus aristata) which includes individuals that began growing at least as early as 1500 B.C. occurs on the latest pre-Neoglacial deposits NE of Wheeler Peak. Based on detailed observations at six localities, the mean modification index of the latest pre-Neoglacial moraines is 0.57 ± 0.06.

Engelmann spruce are the uppermost trees observed in the Snake Range, in several places growing at altitudes as high as 11,400 feet.

Mt. Agassiz Area, Utah

Neoglacial features in a large cirque north of Mt. Agassiz, a quartzite peak near the western end of the Uinta Mountains, were observed by means of aerial photographs. Those observations are summarized here and in Table 17. Two stades of Neoglaciation are apparent in the Mt. Agassiz area. The later stade is represented by active, little-modified rock glacier lobes and talus aprons; later stade protalus ramparts were not observed.

Earlier stade terminal moraine ridges, marking the maximum extent of two formerly juxtaposed glaciers that occupied the southwestern part of the cirque, occur about 0.1 mile downvalley from the later stade periglacial features. The terminal moraines, together with two recessional moraines, are locally overlapped by later stade features and have a mean modification index of 0.25 ± 0.07 (standard deviation).

Except to note the presence of patchy ground moraine downvalley from the Neoglacial moraines, observations of pre-Neoglacial moraines were not made. The uppermost observed trees in the Mt. Agassiz area are growing on south- and southwest-facing slopes at altitudes of up to 11,300 feet.

Wasatch Range, Utah

Information pertaining to Neoglaciation in two areas in the Wasatch Range is presented here and summarized in Table 18. Glacial and periglacial features at two cirque localities on Mt. Timpanogos, a peak of gently dipping sedimentary rocks that is the highest summit in the range, are described on the basis of aerial photograph observations by the author. Glacial and periglacial features in Little Cottonwood and Bells Canyons, an area of granitic rocks 12 miles north of Mt. Timpanogos, have been

TABLE 17. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Mt. Agassiz area, Utah.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi^2)	T (ft)
NW of Mt. Agassiz (12,435)						
Later stade	*R"	0.00	040	0.20	----	10,950
Earlier stade	M	0.20	040	0.25	0.15	10,900
Latest pre-Ng		no observations				
NE of Mt. Agassiz (12,435)						
Later stade	T	0.12	035	----	----	10,700
Earlier stade	MxMxxM	0.30	035	0.30	0.15	10,600
Latest pre-Ng		no observations				

Source: aerial photograph interpretation by the author.

Features: M = end moraine ridge, R" = active rock glacier, T = talus, * = comparatively massive feature, x = intercrestal separation of less than one ridge width, xx = intercrestal separation of one to 2 ridge widths.

described by Richmond (1964).

Mt. Timpanogos. Evidence of two Neoglacial stades is observable on Mt. Timpanogos. The later stade is represented by rock glaciers that are unmodified and still active, and by protalus ramparts that are similarly unmodified; the former were observed at altitudes as low as 8,900 feet and the latter at altitudes as low as 8,400 feet.

During the earlier Neoglacial stade a glacier occupied part of the cirque N of Mt. Timpanogos, where several closely spaced end moraine ridges and numerous ground moraine furrows are well developed and not greatly modified. The cirque E of Mt. Timpanogos, now largely overrun by a later stade rock glacier, also was probably glacierized during the earlier stade. Earlier stade rock glaciers appear to have been active at altitudes as low as 8,700 feet.

No observations were made of moraines representing the latest pre-Neoglacial stade, or of the uppermost trees now growing on Mt. Timpanogos.

Little Cottonwood and Bells Canyons. Richmond has identified two stades of Neoglaciation in the N-trending cirques and valleys tributary to Little Cottonwood and Bells Canyons. The later stade is represented by 15 reported rock glaciers that terminate at altitudes as low as 9,300 feet, and by one reported protalus rampart that terminates at 9,750 feet.

The earlier stade is represented by till deposited by 10 reported cirque glaciers that terminate at altitudes between 9,160 and 10,120 feet. Twenty earlier stade rock glaciers are reported as terminating at altitudes as low as 9,250 feet, and four earlier stade protalus ramparts are reported at altitudes as low as 9,700 feet.

The latest pre-Neoglacial stade is represented by moraines deposited

TABLE 18. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Wasatch Range, Utah.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
N of Mt. Timpanogos (11,750)[a]						
Later stade	R"*	0.00	005	0.3	----	10,200
Earlier stade	M+	0.15	005	0.6	0.14	10,150
Latest pre-Ng		no observations				
E of Mt. Timpanogos (11,750)[a]						
Later stade	R"*+	0.00	015	0.6	0.08	10,350
Earlier stade	M(?)[b]	----	015	<0.6	<0.08	>10,350
Latest pre-Ng		no observations				
Little Cottonwood and Bells Canyons (11,489)[c]						
Later stade[d]		----	---	---	----	-----
Earlier stade[e]	M+	----	000	0.9	1.55	9,800
Latest pre-Ng[f]	M+	----	000	1.8	6.45	9,200

Features: M = end moraine ridge, R" = active rock glacier, * = comparatively massive feature, + = several end moraine ridges or rock glacier transverse ridges.

[a]Source: field observations and aerial photograph interpretation by author.

[b]Site of possible earlier stade glacier is now occupied by later stade rock glacier.

[c]Source: Richmond (1964). Locality is 12 miles N of Mt. Timpanogos.

[d]Termed the historic stade by Richmond, no moraines reported.

[e]Termed the Temple Lake Stade by Richmond, 10 glaciers reported. Data presented here are approximate average azimuth, downvalley length of longest glacier (Hogum Fork), total glacierized area, and average terminus altitude.

[f]Termed the late stade of Pinedale Glaciation by Richmond, 13 glaciers reported. Data presented here are approximate average azimuth, downvalley length of longest glacier (Hogum Fork), total glacierized area, and average terminus altitude.

by 13 reported cirque glaciers and small valley glaciers that terminated at altitudes between 6,560 and 9,840 feet.

According to Richmond, timberline occurs just below the summits of the highest peaks, which attain altitudes of up to 11,489 feet.

La Sal Mountains, Utah

Three groups of laccolithic peaks that comprise the La Sal Mountains include the highest summits in the Colorado Plateau province of the intermontane region. Glacial and periglacial features on the three mountain groups have been studied in detail by Richmond (1962) and those on the middle mountain group were examined in the field and by means of aerial photographs in this study. The information presented here, and in Table 19, pertains to the middle mountain group and was collected by the author; data collected by Richmond from all three mountain groups are summarized in Table 20.

The author's observations at four cirque localities tend to confirm Richmond's identification of two stades of Neoglaciation in the La Sal Mountains. A later stade is represented in the four cirques by little-modified rock glaciers (mean modification index = 0.05) that for the most part are still active. Later stade rock glaciers were observed at altitudes as low as 10,100 feet; later stade protalus ramparts are poorly developed and were not observed systematically.

An earlier Neoglacial stade is not so clearly expressed, except in the cirque N of Mt. Peale, where a closely spaced pair of end moraines is somewhat more modified (modification index = 0.25) than the later stade rock glaciers, one of which is presently advancing onto the moraines. Earlier stade moraines may also have been deposited in the cirques N and NE of Mt. Tukuhnikivatz, but if so have been buried completely by later

TABLE 19. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, La Sal Mountains, Utah.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
N of Mt. Tukuhnikivatz (12,483)						
Later stade	*R"	0.05	030	0.5	----	10,500
Earlier stade		not observed[a]				
Latest pre-Ng	MxxMxMxM	0.50	030	0.8	0.20	10,300
NE of Mt. Tukuhnikivatz (12,483)						
Later stade	R'	0.05	000	0.4	----	10,600
Earlier stade		not observed[a]				
Latest pre-Ng	M+	0.60	000	0.7	0.18	10,400
NW of Peak 12,230						
Later stade	*R'	0.05	250	0.1	----	10,750
Earlier stade	T	0.38	---	---	----	10,750
Latest pre-Ng	*M	0.65	340	0.5	0.15	10,750
N of Mt. Peale (12,721)						
Later stade	*R"	0.05	015	0.3	---	11,500
Earlier stade	MxM	0.25	015	0.4	0.1	11,500
Latest pre-Ng	M	0.50	060	1.4	0.5	10,450

Source: field observations and aerial photograph interpretation by author.

Features: M = end moraine ridge, R" = active rock glacier, R' = probably active rock glacier, T = talus, * = comparatively massive feature, + = several end moraine ridges, x = intercrestal separation of less than one ridge width, xx = intercrestal separation of one to 2 ridge widths.

[a]Earlier stade features obscured or buried by later stade rock glaciers.

TABLE 20. Neoglacial glaciers and rock glaciers reported by Richmond (1962, p. 76-77, 101-103) from the La Sal Mountains, Utah.

Stade or interstade	Number of		Total area of glaciers and rock glaciers[a] (mi^2)	Average lower limit of glaciers and rock glaciers[a] (ft)
	Glaciers	Rock glaciers		
Present	none	inactive	---	------
Later stade[b]	1	8	0.2	11.130
Interstade[c]	none	inactive	---	------
Earlier stade[d]	11	23	1.5	11,100

[a]Glaciers and rock glaciers grouped together in Richmond's data.
[b]Late Gold Basin time of Richmond.
[c]Spanish Valley time of Richmond.
[d]Early Gold Basin time of Richmond.

stade rock glaciers.

Moraines representing the latest pre-Neoglacial stade, which is apparently what Richmond has described as late Beaver Basin time, occur in the valleys below each of the four observed localities. In the valley N of Mt. Peale the latest pre-Neoglacial terminal moraine is 1.0 mile downvalley from the terminus subsequently attained during the earlier Neoglacial stade. The latest pre-Neoglacial moraines are densely forested, have been notched by axial streams, and at the four observed localities have a mean modification index of 0.56 ± 0.07 (standard deviation).

The uppermost trees, observed at several sites on the southwest slopes of the middle mountain group, are growing at altitudes of approximately 11,600 feet.

One of the few places in the Southwest where the radiocarbon age of a Neoglacial stade has been obtained is on the lower west slope of the La Sal Mountains, where charcoal from hearth sites in early Gold Basin (earlier stade) outwash alluvium has provided an average C^{14} date of 2,800 ± 200 years B.P. (ca. 850 B.C.) (ibid., p. 102).

Tushar Mountains, Utah

The highest peaks in southwestern Utah occur in the Tushar Mountains, a south-trending range of extrusive igneous rocks. Two of the more prominent cirques were examined in the field and by means of aerial photographs, and information pertaining to Neoglaciation at those localities is summarized here and in Table 21.

Although there is no evidence of Neoglacial moraines in the Tushar mountains, a number of rock glaciers developed during Neoglaciation. The latest stade of rock glacier development is represented by unmodified, active rock glaciers at both of the observed localities. Other late stade

TABLE 21. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Tushar Mountains, Utah.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
NE of Mt. Belknap (12,139)						
Later stade	*R"	0.00	065	0.2	---	11,100
Earlier stade	*R!*R	0.20	065	0.5	---	10,700
Latest pre-Ng		not observed[a]				
N of Delano Peak (12,173)						
Later stade	*R"	0.00	040	0.3	---	10,700
Earlier stade		not observed[b]				
Latest pre-Ng		not observed[a]				

Source: field observations and aerial photograph interpretation by author.

Features: R" = active rock glacier, R = inactive rock glacier,
* = comparatively massive feature, ! = overlap of older feature (left) by younger (right).

[a]Latest pre-Neoglacial moraines very poorly developed or nonexistent.

[b]Earlier stade features obscured or buried by later stade rock glaciers.

rock glaciers were observed at altitudes as low as 10,250 feet; similarly unmodified protalus ramparts were observed as low as 9,750 feet.

In the cirque NE of Mt. Belknap an active late stade rock glacier overlaps a moderately modified (modification index = 0.20), inactive rock glacier that has been wooded at least since A.D. 1400. Tandem lobes within the earlier rock glacier appear to reflect two significant episodes of earlier Neoglacial rock glacier development.

Moraines assignable to the latest pre-Neoglacial stade are either not present at the observed localities or are very poorly developed. The uppermost trees observed in the Tushar Mountains are growing on the east slope of Delano Peak at an altitude of 11,400 feet.

Boulder Mountain, Utah

Rock glaciers are the principal Neoglacial features identified by Flint and Denny (1958, p. 131-133, plate 6) at Boulder Mountain, which is a large mesa capped by volcanic rocks. A total of 24 rock glaciers has been mapped at the base of the northwest-, northeast-, and east-facing mesa sides. The rock glaciers have not been differentiated as to stade, but in part are clearly quite fresh, with terminal slopes of 38^0 to 42^0 and terminal heights of up to 110 feet, a paucity of fine debris, and little vegetation except lichen. Some of the rock glaciers overlap pre-Neoglacial deposits and some consist of two members, one lobe lapping onto another. The observations of Flint and Denny are summarized in Table 22. Boulder Mountain is presently wooded to the summit (Gould, 1939).

San Francisco Mountain, Arizona

The volcanic peaks that comprise San Francisco Mountain are the highest summits in the southern part of the intermontane Southwest.

TABLE 22. Neoglacial rock glaciers reported by Flint and Denny (1958, plate 6) from Boulder Mountain, Utah.

Locality	Azimuth (°)	Number of rock glaciers	Terminus altitude (ft)		
			Min	Mean	Max
WNW of Bluebell Knoll (11,328)	285	5	10,100	10,520	10,700
NNE of Bluebell Knoll (11,328)	040	12	10,200	10,275	10,300
E of Bluebell Knoll (11,328)	050	7	10,100	10,215	10,300
All rock glaciers	020	24	10,100	10,315	10,700

Glacial and periglacial features on the San Francisco peaks were first studied in detail by Sharp (1942). In the light of Sharp's observations, Neoglacial features at two localities in the head of an east-facing compound cirque were examined in the field and on aerial photographs, and are summarized here and in Table 23.

San Francisco Mountain apparently was not glacierized during Neoglaciation. Accretion of relatively fresh talus (modification index = 0.06) has been the most recent periglacial activity, with the rate of accretion diminishing markedly ca. A.D. 1885, when many of the present generation spruce became established on the talus slopes.

At both of the observed localities a substantially older episode of periglacial activity, probably correlative with the earlier Neoglacial stade noted in other areas, produced rock glaciers that are now overlapped by the younger talus, are largely forested and stabilized, and have a mean modification index of 0.22 ± 0.04 (standard deviation). A minimum age of the rock glacier that occupies much of the cirque S of Humphreys Peak is provided by a bristlecone pine that began growing on the feature ca. A.D. 350.

Moraines that Sharp (1958) regards as representing recessional phases of late Wisconsin glaciation are breached by streams 0.2 mile downvalley from the rock glacier termini and are partly overlapped by the rock glacier S of Humphreys Peak. The mean modification index of the latest pre-Neoglacial moraines is 0.52 ± 0.04.

The uppermost observed trees on San Francisco Mountain are bristlecone pines that grow on the southwest ridge of Humphreys Peak at an altitude of 12,000 feet.

TABLE 23. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, San Francisco Mountain, Arizona.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi^2)	T (ft)
S of Humphreys Peak (12,611)						
Later stade	T	0.06	---	---	----	------
Earlier stade	*R	0.25	070	0.5	----	10,750
Latest pre-Ng	*MxMxxxMxM	0.55	070	0.7	0.25	10,550
E of Agassiz Peak (12,340)						
Later stade	T	0.06	---	---	----	------
Earlier stade	R	0.20	000	0.2	----	11,200
Latest pre-Ng	*MxM	0.50	040	0.4	0.15	10,600

Source: field observations and aerial photograph interpretation by author.

Features: M = end moraine ridge, R = inactive rock glacier, T = talus, * = comparatively massive feature, x = intercrestal separation of less than one ridge width, xxx = intercrestal separation of 3 to 10 ridge widths.

Baldy Peak, Arizona

The White Mountains, an irregular volcanic plateau that is the second highest mountain group in Arizona, culminate in Baldy Peak. Summarized here, and in Table 24, are field and aerial photograph observations pertaining to Neoglacial features at four localities near the heads of shallow cirques on the east slope of the Baldy Peak crest.

There is no indication that the White Mountains were glacierized during Neoglaciation, or during the latest pre-Neoglacial stade, although evidence of earlier episodes of Pleistocene glaciation has been reported (Melton, 1961) from the lower slopes of Baldy Peak. Relatively recent periglacial conditions, however, are indicated by protalus ramparts at each of the observed localities. The ramparts, which have a mean modification index of 0.28 ± 0.18 (standard deviation), appear to reflect intermittent periglacial activity that may date in part from late pre-Neoglacial time, that was probably relatively intense during early Neoglacial time, and that appears to have been relatively insignificant during later Neoglacial time.

East-facing sites immediately below the Baldy Peak crest receive large quantities of drifted snow in winter; tree-ring studies indicate that the present spruce forest, which extends to the summit of the peak, has been able to colonize such sites in substantial numbers only since ca. A.D. 1860.

Snowy Range, Wyoming

The northernmost Rocky Mountain area included in this study is the Snowy Range, a southwest-trending ridge of metamorphic rocks that is the crest of the Medicine Bow Mountains in southern Wyoming. Observations pertaining to glacial and periglacial features, particularly at Lookout

TABLE 24. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Baldy Peak, Arizona.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (^{o})	D (mi)	A (mi^2)	T (ft)
N of Baldy Peak (11,590)						
Later stade	P	0.20^a	055	0.1	0.01	11,200
Earlier stade	P					
Latest pre-Ng		not observed				
NE of Baldy Peak (11,590)						
Later stade	P	0.20^a	045	0.1	0.01	11,000
Earlier stade	P					
Latest pre-Ng		not observed				
SSE of Baldy Peak (11,590)						
Later stade	C	----	---	---	----	------
Earlier stade	P	0.55	050	0.1	0.01	11,200
Latest pre-Ng		not observed				
SE of Baldy Peak (11,590)						
Later stade	P	0.15^a	005	0.1	0.01	11,100
Earlier stade	P					
Latest pre-Ng		not observed				

Source: field observations and aerial photograph interpretation by author.

Features: P = protalus rampart, C = colluvium (mainly slope wash)

[a]Later stade features are superimposed upon, partially concealing and modifying, earlier stade features. Parameters cannot be assigned to a particular stade.

Lake, a locality one mile S of Medicine Bow Peak, were made in the field and by means of aerial photographs (Table 25).

Evidence of two main stades of Neoglaciation, each comprising two substades, was noted in the Snowy Range. Although the area does not appear to have been glacierized during the later stade, existing firn patches attest to near-glacial conditions during the latest phase of the later stade. In aerial photographs taken in September, 1955, and October, 1956, 19 firn patches can be identified with certainty (Table 26 and Figure 3). The firn patches are as large as 0.01 square mile in area, range from 10,620 to 11,600 feet in altitude, and in a number of cases contain well defined layers that are probably annual. The mean exposure azimuth of the patches is 075 ± 53 (standard deviation) degrees, distinctly downwind from the WNW mean direction of the fastest winds observed during November through April at Cheyenne (50 years of record, U. S. Dept. of Commerce, 1964); the two largest patches are directly downwind from the fastest winter winds. These relationships suggest that the Snowy Range firn patches result largely from wind drift accumulation, as do many of the present glaciers in Colorado (Outcalt and MacPhail, 1965). Firn patches that persist in the landscape for a period of years, but which fail to generate glacier ice, are undoubtedly common at near-glacial altitudes in many areas of the Southwest, but are seldom noted because of the restricted intervals during which they are identifiable as firn rather than snow.

An earlier substade of the later Neoglacial stade is represented at Lookout Lake by a large rock glacier. What appear to have been three distinct phases of the substade are indicated by prominent transverse ridges. The rock glacier has been slightly modified by subaerial processes

TABLE 25. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Snowy Range, Wyoming.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
S of Medicine Bow Peak (12,013)						
Later stade	R*'+	0.05	080	0.3	----	10,620
Earlier stade	M!4M	0.35, 0.15	080	0.5	0.16	10,600
Latest pre-Ng[a]	M+	0.65	150	3.0	----	9,600

Source: field observations and aerial photograph interpretation by author.

Features: M = end moraine ridge, R' = probably active rock glacier, * comparatively massive feature, + = several end moraine ridges or rock glacier transverse ridges, ! = overlap of older feature (left) by younger (right).

[a] S-trending outlet glacier from small ice cap; N- and E-trending outlet glaciers may have been larger.

TABLE 26. Existing firn patches in the Snowy Range, Wyoming, in order of decreasing altitude.

Azimuth (^{o})	Area (mi^2)	Terminus altitude (ft)
065	<0.01	11,600
000	<0.01	11,500
065	<0.01	11,500
120	<0.01	11,480
130	<0.01	11,480
355	<0.01	11,460
135	<0.01	11,370
080	<0.01	11,360
070	<0.01	11,350
345	<0.01	11,320
050	<0.01	11,300
350	<0.01	11,300
130	<0.01	11,180
120	<0.01	11,130
125	0.01	11,100
055	<0.01	10,980
090	<0.01	10,980
100	<0.01	10,750
110	0.01	10,620

Source: aerial photograph interpretation by the author; photos taken Sept. 30, 1955, and Oct. 14, 1956.

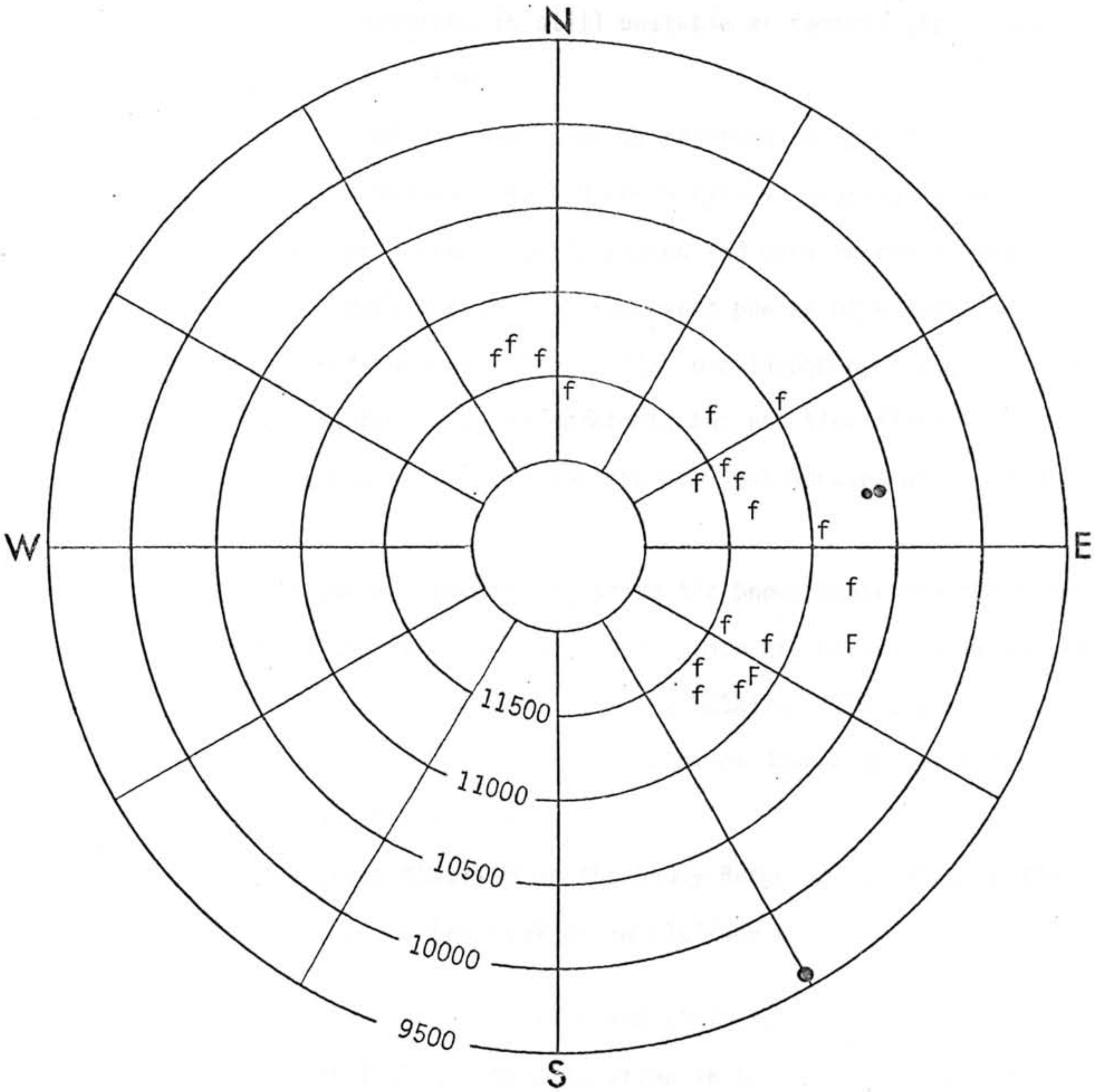

FIGURE 3. Azimuth and altitude (ft) of features in the Snowy Range, Wyoming. F denotes existing firn patch with area of 0.01 square mile, f denotes existing firn patch with area <0.01 square mile. Mean azimuth of firn patches = 075°. Largest dot denotes latest pre-Neoglacial terminal moraine, medium dot denotes earlier Neoglacial terminal moraine, and smallest dot denotes later Neoglacial rock glacier.

and has supported scattered clumps of fir (<u>Abies lasiocarpa</u>) since ca. A.D. 1700, but the terminus is still unstable at several places and one lobe appears to be advancing.

The earlier stade of Neoglaciation is represented by end moraines that partially enclose Lookout Lake and are partially overlapped by the later stade rock glacier. Four closely spaced end moraine ridges that are only moderately modified appear to represent phases of a later substade. A single end moraine ridge, partly overlapped by and considerably more modified than the four younger moraines, but not significantly greater in extent, appears to represent the earliest Neoglacial substade in the Snowy Range.

During the latest pre-Neoglacial stade the Snowy Range was the site of a waning ice cap, the receding margins of which are marked by relatively subdued moraines that have been identified by McCallum (1962, fig. 3). The latest pre-Neoglacial moraines occur 2.5 miles downvalley from the Neoglacial moraines at Lookout Lake.

The uppermost trees observed in the Snowy Range are growing on the southwest ridge of Medicine Bow Peak at an altitude of 11,350 feet.

Rocky Mountain National Park and Vicinity, Colorado

Information pertaining to Neoglaciation in two areas in the Front Range, a south-trending crystalline range that is presently the most glacierized section of Colorado, is presented here. Glacial and periglacial features at nine cirque localities in the Indian Peaks area are described on the basis of aerial photograph observations by the author and are summarized in Table 27. Glacial episodes on the east slope of Rocky Mountain National Park, 10 miles north of the Indian Peaks, have been described by Richmond (1960) and are summarized in Table 28.

TABLE 27. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Indian Peaks area[a], Colorado.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
NW of Peak 12,799						
Later stade	*MxG[b]	0.05	010	0.3	0.05	11,400
Earlier stade	M+	0.35	010	0.6	0.12	10,700
Latest pre-Ng		no observations				
N of Mt. George (12,876)						
Later stade	*MxG[c] / *R"+	0.00	020	0.3 / 0.6	0.07 / 0.12	11,350 / 10,900
Earlier stade	*MxxM	0.25	020	0.7	0.24	10,900
Latest pre-Ng		no observations				
NE of Apache Peak (13,441)						
Later stade	MxMxxG[d]	0.00	075	0.3	0.05	11,950
Earlier stade	M+	0.25	110	0.6	0.15	11,400
Latest pre-Ng		no observations				
N of Navajo Peak (13,409)						
Later stade	MxG[e]	0.00	050	0.2	0.02	12,400
Earlier stade	M+	0.25	050	0.4	0.07	12,100
Latest pre-Ng		no observations				
NW of Arikaree Peak (13,150)						
Later stade	MxMxG[f]	0.00	045	0.15	0.03	12,400
Earlier stade	M / *R	0.30	045	0.3 / 0.5	0.06 / 0.08	12,300 / 12,200
Latest pre-Ng		no observations				
SE of Arikaree Peak (13,150)						
Later stade	M+xF	0.05	075	0.1	0.04	11,600
Earlier stade	M+	0.30	075	0.5	0.18	11,200
Latest pre-Ng[g]	*M+	0.60	090	3.7	----	10,100

TABLE 27, continued.

NE of North Arapaho Peak (13,502)						
Later stade	MxxG[h]	0.00	090	0.2	0.04	12,200
Earlier stade	M / *R	0.25	090	0.4 / 0.6	0.08 / 0.12	12,100 / 12,000
Latest pre-Ng[g]	*M+	0.60	090	4.2	----	10,100
NE of South Arapaho Peak (13,397)						
Later stade	*Mx*M+xxG[i]	0.00	090	0.5	0.14	12,100
Earlier stade[j]	MxM+xxM	0.30	065	1.2	0.3	11,300
Latest pre-Ng[g]	*M+	0.60	090	4.4	---	10,100
E of South Arapaho Peak (13,397)						
Later stade	MxF / *R"+	0.00	055	0.1 / 0.6	0.02 / 0.10	12,100 / 11,800
Earlier stade[j]	MxM+xxM	0.30	065	1.1	0.1	11,300
Latest pre-Ng[g]	*M+	0.60	090	4.3	---	10,100

Source: aerial photograph interpretation by the author.

Features: M = end moraine ridge, $\frac{M}{R}$ = transitional rock glacier, R" = active rock glacier, R = inactive rock glacier, G = existing glacier, F = existing firn patch, * = comparatively massive feature, + = several end moraine ridges or rock glacier transverse ridges, x = separation of less than one ridge width, xx = separation of one to 2 ridge widths.

[a]Approximately 8 miles S of Rocky Mountain National Park.

[b]Peck Glacier.

[c]Fair Glacier.

[d]Isabelle Glacier.

[e]Navajo Glacier.

[f]Arikaree Glacier.

[g]Glaciers confluent.

[h]Henderson Glacier.

[i]Arapaho Glacier.

[j]Glaciers confluent.

TABLE 28. Terminus altitudes of Neoglacial and latest pre-Neoglacial moraines in Rocky Mountain National Park, Colorado.

Locality Stade[a]	Terminus altitude (ft)
Fall River	
Later stade (historic stade)[b]	------
Earlier stade (Temple Lake Stade)	11,400
Latest pre-Ng (late stade of Pinedale Glaciation)	10,600
Sprague Glacier	
Later stade (historic stade)	11,850
Earlier stade (Temple Lake Stade)	11,750
Latest pre-Ng (late stade of Pinedale Glaciation)[c]	9,100
Spruce Canyon	
Later stade (historic stade)	11,100
Earlier stade (Temple Lake Stade)	10,800
Latest pre-Ng (late stade of Pinedale Glaciation)[c]	9,100
Fern Creek	
Later stade (historic stade)	11,600
Earlier stade (Temple Lake Stade)	10,925
Latest pre-Ng (late stade of Pinedale Glaciation)	9,525
Glacier Creek	
Later stade (historic stade)	10,750
Earlier stade (Temple Lake Stade)	10,600
Latest pre-Ng (late stade of Pinedale Glaciation)	9,500

Source: Richmond, 1960, p. 1376.

[a]Names used by Richmond in parentheses.

[b]No moraines reported.

[c]Glaciers confluent.

Indian Peaks area. Along a 5-mile segment of the Indian Peaks divide, observations were made of two localities on the west slope and seven on the east. Evidence of two stades of Neoglaciation was noted at each locality. At seven of the localities the later stade is represented by existing cirque glaciers and at the other two localities it is represented by firn bodies; one of the glaciers and one of the firn bodies belong to active transitional rock glacier systems. Formerly greater dimensions of the later stade glaciers are indicated by essentially unmodified end moraine loops, most of them probably ice-cored, that are situated slightly beyond the present termini. At its later stade maximum, presumably ca. A.D. 1860, the area covered by Arapaho Glacier, presently the largest glacier in Colorado, was 1.5 times as large as in 1960 (Waldrop, 1964, p. 1); the later stade maximum areas of other glaciers in the Indian Peaks area were larger than at present by a similar factor. Pairs of end moraine loops at three of the localities suggest two main episodes of later stade glacierization. Two prominent unconformities in the layering within Fair Glacier, however, are regarded by Ives (1953, p. 246-247) as suggestive of three important glacial episodes during the later stade. Rock glaciers and protalus ramparts, little modified and assignable to the later stade, were observed at altitudes as low as 10,700 and 10,300 feet, respectively.

A cirque glacier or small valley glacier occurred at each of the observed localities during the earlier stade of Neoglaciation. Two of the glaciers belonged to transitional rock glacier systems and the others terminated at end moraine loops, between 0.2 and 0.7 mile downvalley from the later stade moraines. Moraines of the earlier stade have a mean modification index of 0.28 ± 0.04 (standard deviation) and locally appear to represent at least three distinct phases or substades of glacierization.

A phase in the recession of the earlier stade glacier E of South Arapaho Peak has been dated at 510 ± 100 B.C. by means of C^{14} in organic colluvium overlying proglacial pond deposits (Benedict, 1967, p. 829).

Although observations are incomplete, it is clear that during the latest pre-Neoglacial stade four of the localities on the east slope of the Indian Peaks divide were tributary to a valley glacier that terminated near the present Silver Lake dam, between 3.2 and 3.8 miles farther downvalley than the positions subsequently attained by glaciers of the earlier Neoglacial stade. The latest pre-Neoglacial end moraines that partially impound Silver Lake are densely forested and have a modification index of 0.60.

Rocky Mountain National Park. Glacial deposits assignable to two stades of Neoglaciation have been identified by Richmond (1960, fig. 1) in 35 cirques at the heads of the five eastward-draining basins entered in Table 28. Later stade glaciers, of which 13 small glaciers and stagnant ice bodies remain, were less than 0.5 mile long and probably underwent at least two secondary pulsations. Earlier stade glaciers were at most one mile long and also underwent at least two secondary pulsations. Prior to the Altithermal interval, during which glaciers probably disappeared entirely from Rocky Mountain National Park, glaciers of the latest pre-Neoglacial stade were 2 to 5 miles long and moraines were deposited that now bear zonal soils, which are not present on the Neoglacial moraines. At the northwest edge of the Park, the base of a thick peat section that overlies till of the latest pre-Neoglacial stade has been dated at 4220 ± 240 B.C. by means of C^{14} (ibid., p. 1380).

The uppermost trees observed by the author in Rocky Mountain National Park are growing on the south slope of Trail Ridge at an altitude of approximately 11,600 feet.

Mt. Evans Area, Colorado

Glacial and periglacial features were observed at four cirque localities in the Mt. Evans area, a crystalline massif that is one of the most accessible high altitude areas in the Southwest. The observations, which appear to indicate two Neoglacial stades, were made in the field and by means of aerial photographs, and are summarized here and in Table 29.

The later Neoglacial stade is marked at two of the localities by rock glaciers that are still active and at several places by talus that is still unstable. No evidence of later stade glacierization was noted in the area, although firn bodies have been present at a number of sites, including the cirque N of Mt. Evans, where a small firn patch still occurs. The lowest altitude at which an active rock glacier was observed in the Mt. Evans area is 11,700 feet; protalus ramparts assignable to the later stade were observed at altitudes as low as 11,000 feet.

During the earlier Neoglacial stade small cirque glaciers occurred at two of the observed localities. End moraines at those localities appear to reflect at least two distinct episodes of earlier stade glacierization. The earlier stade moraines have a mean modification index of 0.35 ± 0.07 (standard deviation).

During the latest pre-Neoglacial stade all four of the observed localities were occupied by glacier ice. The glacier heading in the cirque N of Mt. Evans during that stade terminated 2.0 miles farther downvalley than did the glacier subsequently occurring at that locality during the earlier Neoglacial stade. The latest pre-Neoglacial moraines observed at three localities have a mean modification index of 0.55 ± 0.10.

The uppermost trees observed in the Mt. Evans area are growing on the southeast ridge of Rogers Peak at an altitude of 11,950 feet.

TABLE 29. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Mt. Evans area, Colorado.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
NE of Rogers Peak (13,391)						
Later stade	T	0.00	---	---	---	------
Earlier stade	T	0.19	---	---	---	------
Latest pre-Ng	M+*	0.45	110	0.8	0.2	11,500
N of Mt. Evans (14,258)						
Later stade	T	0.00	---	---	---	------
Earlier stade	M+xxM	0.30	355	0.3	0.1	13,200
Latest pre-Ng	M+	0.65	025	2.3	---	11,300
SE of Mt. Bierstadt (14,060)						
Later stade	R"	0.05	035	0.1	----	12,900
Earlier stade	M+	0.40	070	0.2	0.05	12,900
Latest pre-Ng		no observations				
N of Rosalie Peak (13,575)						
Later stade	R"	0.05	035	0.2	---	12,000
Earlier stade	T	0.25	---	---	---	------
Latest pre-Ng	M+	0.55	060	0.8	0.3	11,500

Source: field observations and aerial photograph interpretation by author.

Features: M = end moraine ridge, R" = active rock glacier, T = talus, * = comparatively massive feature, + = several end moraine ridges, xx = intercrestal separation of 3 to 10 ridge widths.

Sawatch Range, Colorado

The culminating unit of the Rocky Mountains is the crystalline, south-trending Sawatch Range. Data pertaining to glacial and periglacial features in several areas within a 16-mile radius of Independence Pass, in the central part of the range, are summarized here.

Lincoln Creek area. Five cirque localities near the head of the Lincoln Creek drainage basin, approximately 6 miles southwest of Independence Pass, were studied by means of aerial photographs (Table 30). Two stades of Neoglaciation are evident in the area. The later stade is represented at each of the observed localities by rock glaciers that are still active and have a mean modification index of 0.04 ± 0.04 (standard deviation). The earlier stade is represented at four of the localities by end moraine loops that have a mean modification index of 0.32 ± 0.10; these moraines, which occur between 0.1 and 0.2 mile downvalley from and are partially overlapped by the rock glaciers, appear to reflect two distinct substades of glacierization. Between 0.7 and 1.8 mile farther downvalley, the end moraines of the latest pre-Neoglacial stade have been much more conspicuously modified since deposition (mean modification index = 0.63 ± 0.03).

The uppermost trees observed in the Sawatch Range are growing on the southwest slope of Peak 13631 at an altitude of 12,100 feet.

Peak 13220 area. An area including Peak 13220, 16 miles southeast of Independence Pass, was also observed by means of aerial photographs (Table 30). Two stades of Neoglaciation are evident in the cirque to the east of the peak, where a closely spaced series of earlier stade end moraine ridges (modification index = 0.20) is largely overlapped by an unmodified, active rock glacier of the later stade. The latest pre-Neoglacial end moraines (modification index = 0.55) occur 1.2 mile farther

TABLE 30. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Sawatch Range, Colorado.

Locality[a]		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi^2)	T (ft)
NE of Peak 13,300						
Later stade	R"*	0.05	000	0.2	----	12,000
Earlier stade		not observed[b]				
Latest pre-Ng	MxMxM	0.65	005	1.7	----	11,250
NW of Truro Peak (13,282)						
Later stade	R"*	0.00	320	0.15	----	12,200
Earlier stade	M	0.20	000	0.3	0.05	12,200
Latest pre-Ng	M	0.60	050	1.0	0.29	11,300
NE of Peak 13,505						
Later stade	R'*	0.10	045	0.2	----	12,700
Earlier stade	MxxM	0.40	045	0.4	0.05	12,550
Latest pre-Ng	M+	0.65	070	1.6	----	11,300
E of Peak 13,505						
Later stade	R"+*	0.05	030	0.2	----	12,350
Earlier stade	MxxM	0.30	030	0.3	0.05	12,300
Latest pre-Ng	M+	0.65	050	1.3	----	11,350
E of Peak 13,631						
Later stade	R"*	0.00	050	0.2	----	12,200
Earlier stade	MxxxM	0.40	050	0.4	0.10	12,200
Latest pre-Ng	MxM+	0.60	350	2.2	----	11,000
E of Peak 13,220						
Later stade	R"*	0.00	035	0.2	----	12,500
Earlier stade	M+	0.20	035	0.25	0.05	12,400
Latest pre-Ng	M	0.55	355	1.4	----	11,200

Source: aerial photograph interpretation by the author.

Features: M = end moraine ridge, R" = conspicuously active rock glacier,

TABLE 30, continued.

R' = probably active rock glacier, * = comparatively massive feature,
+ = several end moraine ridges or rock glacier transverse ridges,
x = intercrestal separation of less than one ridge width,
xx = intercrestal separation of one to 2 ridge widths,
xxx = intercrestal separation of 3 to 10 ridge widths.

[a]Except for Peak 13,220, which is 16 miles SE of Independence Pass, localities are approximately 6 miles SW of Independence Pass.

[b]Earlier stade features obliterated by later stade rock glaciers.

downvalley.

Areas studied previously. At four localities on the east slope of the Sawatch Range, immediately east of Independence Pass, the latest pre-Neoglacial terminal moraines have been mapped by Richmond (1965b, p. 124) at altitudes averaging approximately 11,000 feet. Richmond did not differentiate between moraines and rock glaciers in mapping Neoglacial deposits.

At a locality 8 miles northwest of Independence Pass, end moraines that probably represent the latest pre-Neoglacial stade have been mapped at an altitude of 11,400 feet by Nelson (1954), who assigned them to what he termed the Chapman Gulch glaciation; on the basis of post-glacial modification, he estimated that the moraines date from ca. 3800 B.C. Nelson reported observing no Neoglacial moraines.

Pikes Peak, Colorado

By far the highest summit rising from the granite platform of the Rampart Range, Pikes Peak is the easternmost area included in this study. Field and aerial photograph observations of glacial and periglacial features on Pikes Peak are summarized here, and in Table 31.

High altitude geomorphic activity on Pikes Peak during later Neoglacial time was limited to periglacial processes that promoted mobility in talus, colluvium, and rock glacier systems. An unmodified rock glacier that is probably still active occurs in a deep cirque on the east face of the peak. The lowest altitude at which a later Neoglacial rock glacier was observed on the peak is 11,250 feet; protalus ramparts were not noted.

The only evidence of possible glacierization during Neoglaciation occurs on the north face of the peak, where what appear to be earlier

TABLE 31. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Pikes Peak, Colorado.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
NE of Point 12,792						
Later stade	T	0.19[a]	---	---	---	------
Earlier stade	T		---	---	---	------
Latest pre-Ng	M*	0.50	005	0.4	0.1	11,600
NNE of Point 13,363						
Later stade	T	0.19[a]	---	---	---	------
Earlier stade	T		---	---	---	------
Latest pre-Ng	M*	0.45	025	0.9	0.2	11,000
N of Pikes Peak (14,109)						
Later stade	T	0.00	350	---	---	------
Earlier stade	M[b]	0.15	350	0.6(?)	0.06(?)	12,000(?)
Latest pre-Ng	M*	0.40	020	1.3	0.4	11,100
SE of Pikes Peak (14,109)						
Later stade	R'	0.00	045	0.1	---	11,850
Earlier stade	R	0.15	135	0.3	---	11,600
Latest pre-Ng	M*	0.40	100	0.8	0.2	11,800
S and SW of Pikes Peak (14,109)						
Later stade	C	0.25[a]	---	---	---	------
Earlier stade	C		---	---	---	------
Latest pre-Ng[c]	M+	0.45	180	1	2	11,700

Source: field observations and aerial photograph interpretation by author.

Features: M = end moraine ridge, R' = probably active rock glacier, R = inactive rock glacier, T = talus, C = colluvium, * = comparatively massive feature, + = several end moraine ridges.

[a]Modification index reflects accretion and modification during both stades of Neoglaciation and cannot be assigned to either stade.

[b]Right-lateral moraine or moraines poorly preserved in high-angle trough.

[c]Small ice cap, dimensions not determined precisely.

Neoglacial moraine ridges (modification index = 0.15) terminate at an altitude of approximately 12,000 feet. At other localities earlier Neoglacial time is marked by talus, colluvium, and rock glaciers that are now relatively stable.

During the latest pre-Neoglacial stade all of the observed localities were occupied by glacier ice, the terminus margins of which are marked by moraines that have a mean modification index of 0.44 ± 0.04 (standard deviation). Several episodes in the waning of a small ice cap are clearly expressed by the latest pre-Neoglacial moraines on the south slope of the peak.

At several sites on Pikes Peak, trees were observed at altitudes as high as 12,250 feet.

San Miguel Mountains, Colorado

The culminating portion of the San Miguel Mountains, an east-trending crest of igneous and sedimentary rocks that is one of the principal units within the larger San Juan Mountains, was examined by means of aerial photographs. Glacial and periglacial features assignable to two stades of Neoglaciation were noted at each of four observed cirque localities (Table 32). Later stade rock glaciers that are little modified and presently active occur at each of the localities; rock glaciers of the later stade were observed at altitudes as low as 10,900 feet. Partially overlapped by later stade rock glaciers at two of the localities, and perhaps completely buried at the other two, are single, undissected end moraine ridges (mean modification index = 0.25) of the earlier stade. Between 0.5 and 1.2 mile farther downvalley are the latest pre-Neoglacial end moraines, which are conspicuously dissected and have a mean modification index of 0.50 ± 0.13 (standard deviation).

TABLE 32. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, San Miguel Mountains, Colorado.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
NW of Wilson Peak (14,017)						
Later stade	R"+ *	0.05	325	0.6	----	11,900
Earlier stade		not observed[a]				
Latest pre-Ng	M *	0.35	325	0.8	0.22	11,700
N of Gladstone Peak (13,913)						
Later stade	R"+	0.00	030	0.3	----	12,600
Earlier stade	M[b]	(?)	030	0.3(?)	0.06(?)	12,600(?)
Latest pre-Ng[c]	MxxM	0.55	070	1.5	----	11,050
NE of Peak 13,097						
Later stade	R'+	0.05	000	0.1	----	11,900
Earlier stade	M/R	0.25	035	0.2/0.3	0.04/0.05	11,900/11,700
Latest pre-Ng[c]	MxxM	0.55	070	0.8	----	11,050
E of Gladstone Peak (13,913)						
Later stade	R"	0.00	100	0.2	----	12,500
Earlier stade	M	0.25	100	0.5	0.13	12,150
Latest pre-Ng	M[d]	0.60	090	1.2	----	11,400

Source: aerial photograph interpretation by the author.

Features: M = end moraine ridge, R" = conspicuously active rock glacier, R' = probably active rock glacier, R = inactive rock glacier, M/R = transitional rock glacier, * = comparatively massive feature, + = several rock glacier transverse ridges, xx = intercrestal separation of one to 2 ridge widths.

[a]Earlier stade feature completely obscured by later stade rock glacier.

[b]Earlier stade moraine or moraines largely obscured by later stade rock glacier.

[c]Glaciers confluent.

[d]Kame moraine.

On the south slope of the San Miguel Mountains trees were observed at altitudes as high as 12,000 feet.

Culebra Range, Colorado

Four cirque localities, two on either side of a 7-mile segment of the south-trending, crystalline-cored Culebra Range, were examined in the field and in aerial photographs. Information pertaining to glacial and periglacial features at those localities is summarized here and in Table 33.

Two stades of Neoglaciation are in evidence at each of the observed localities. In the cirque ESE of Peak 13,010 a closely-spaced pair of scarcely-modified end moraine ridges marks a site that appears to have been occupied by a later stade glacieret. At other localities the later stade is represented by active rock glaciers, which were observed at altitudes as low as 10,700 feet, and aprons of unstable talus. Four imbricate lobes, all presently active, in one rock glacier system and several prominent transverse ridges in another appear to reflect a series of later stade episodes, each of which was marked by periglacial activity of renewed intensity.

Moderately modified end moraine loops, each comprising two moraine ridges, at three localities and an inactive rock glacier system with two imbricate lobes at the other locality suggest that the earlier Neoglacial stade comprised two distinct glacial episodes. The earlier stade features, which have a mean modification index of 0.23 ± 0.08 (standard deviation), terminate between 0.2 and 0.6 mile downvalley from and are in each case partially overlapped by later stade features. A somewhat more modified (modification index = 0.35) earlier stade end moraine N of Culebra Peak apparently represents the earliest observed substade of the earlier Neoglacial stade.

TABLE 33. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Culebra Range, Colorado.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
ESE of Peak 13,010						
Later stade	*MxM*	0.05	060	0.1	0.03	12,500
Earlier stade	*MxM	0.20	060	0.4	0.1	12,100
Latest pre-Ng		no observations				
SSW of Peak 13,010						
Later stade	*R'!R"!R"!R"	0.05	335	0.4	---	12,000
Earlier stade	*R!*R	0.20	335	1.0	---	11,300
Latest pre-Ng	*M+	0.55	335	1.7	1.0	11,200
N of Culebra Peak (14,069)						
Later stade	*R"+	0.05	015	0.3	---	12,400
Earlier stade	*M!M	0.35, 0.25	015	0.5	0.2	12,300
Latest pre-Ng	M+	0.65	335	2.0	1.0	11,300
NE of Purgatoire Peak (13,719)						
Later stade	T	0.00	---	---	---	------
Earlier stade	MxM	0.15	070	0.3	0.1	12,200
Latest pre-Ng		no observations				

Source: field observations and aerial photograph interpretation by author.

Features: M = end moraine ridge, R" = conspicuously active rock glacier, R' = probably active rock glacier, R = inactive rock glacier, T = talus, * = comparatively massive feature, + = several end moraine ridges or rock glacier transverse ridges, x = intercrestal separation of less than one ridge width, ! = overlap of older feature (left) by younger (right).

End moraines of the latest pre-Neoglacial stade are considerably more modified (mean modification index = 0.60 ± 0.07) than the most modified Neoglacial moraine. The latest pre-Neoglacial moraines terminate 1.5 mile beyond the earliest Neoglacial moraine in the valley N of Culebra Peak and at comparable downvalley positions in other localities.

Wheeler Peak Area, New Mexico

In the section of the south-trending, predominantly crystalline core of the Sangre de Cristo Mountains that includes Wheeler Peak, the highest summit in New Mexico, an area comprising two cirque localities was studied in the field and by means of aerial photographs. Information relating to those localities is presented here, and in Tables 34 and 35. An adjacent area, on the west side of Wheeler Peak, has been studied by Richmond (1963, fig. 213.1) and information pertaining to that locality is summarized in Table 36.

Evidence of two Neoglacial stades was observed at both of the localities studied by the author. The later stade is represented at each locality by rock glaciers that are presently active and little modified. At other sites in the Wheeler Peak area rock glaciers and protalus ramparts of similar apparent age were observed at altitudes as low as 10,900 and 10,400 feet, respectively.

During the earlier stade part of each locality was occupied by a small glacieret, the sites of which are now marked by an end moraine ridge and an inactive transitional rock glacier that have a mean modification index of 0.22 ± 0.04 (standard deviation) and are largely overlapped by later stade rock glaciers.

Densely forested, partially dissected end moraines (modification index = 0.55) assignable to the latest pre-Neoglacial stade terminate

TABLE 34. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Wheeler Peak area, New Mexico.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
SE of Wheeler Peak (13,173)						
Later stade	*R"	0.05	035	0.2	----	12,150
Earlier stade	M+ / *R+	0.25	035	0.3 / 0.5	0.03 / 0.1	12,100 / 12,000
Latest pre-Ng[a]	M+	0.55	045	1.2	0.3	11,200
NE of Simpson Peak (13,113)						
Later stade	*R"	0.05	000	0.2	----	11,900
Earlier stade	M	0.20	055	0.2	0.02	12,050
Latest pre-Ng[a]	M+	0.55	045	0.8	0.2	11,200

Source: field observations and aerial photograph interpretation by author.

Features: M = end moraine ridge, M/R = transitional rock glacier, R" = conspicuously active rock glacier, R = inactive rock glacier, * = comparatively massive feature, + = several end moraine ridges or rock glacier transverse ridges.

[a]Glaciers confluent.

TABLE 35. Surface characteristics of moraines and rock glaciers in the cirque southeast of Wheeler Peak, New Mexico.

Stade and feature	Boulder frequency[a] (per acre)	Steepest slope angle[b] (°)
Later stade rock glacier	8,000	38
Earlier stade transitional rock glacier	3,300	31
Latest pre-Ng moraines	800	23

Source: field observations by the author.

[a]Boulders with diameter > 1 ft, based on counts in 800-ft^2 field areas.

[b]Determined by repeated measurements with hand level.

TABLE 36. Neoglacial and latest pre-Neoglacial moraines reported by Richmond (1963, p. E122) from the Wheeler Peak area[a], New Mexico.

Stade[b]	Average altitudes of end moraines (ft)
Later stade (Gannett Peak Stade)	12,000
Earlier stade (Temple Lake Stade)	11,850
Latest pre-Ng (late stade of Pinedale Glaciation)	11,000

[a]Valley of Rio Hondo, W of Wheeler Peak (13,173).

[b]Name used by Richmond in parentheses.

0.6 and 0.9 mile beyond the limits subsequently attained by the Neoglacial glacierets. The contrasting degrees of post-depositional modification that have been incurred by progressively older features SE of Wheeler Peak are clearly reflected in Table 35.

Aerial photograph observations by the author suggest that the Neoglacial moraines reported by Richmond (ibid.), the average terminus altitudes of which are summarized in Table 36, are in most, if not all, cases rock glaciers rather than moraines. The author concurs with Richmond's identification of late Pinedale moraines in Rio Hondo valley at altitudes of approximately 11,000 feet.

Santa Fe Baldy Area, New Mexico

Two cirque localities on the east slope of the Sangre de Cristo Mountains at Santa Fe Baldy, 50 miles south of Wheeler Peak, were studied in the field and by means of aerial photographs, and are briefly described here and in Table 37.

Neither of the cirques shows evidence of having been occupied by glacier ice during Neoglacial time, but both contain two generations of well-developed protalus ramparts. The younger ramparts, unmodified and generally draped over the older ones, appear to represent a later stade of Neoglaciation. The older, partially buried protalus ramparts (modification index = 0.20) clearly represent an earlier stade. Within the greater Santa Fe Baldy area, incipient rock glaciers that appear to have been active during later Neoglacial time were observed at altitudes as low as 11,500 feet; relatively fresh protalus ramparts were identified at sites as low as 10,950 feet.

Terminal moraines, and at least two recessional moraines, assignable to the latest pre-Neoglacial stade occur at both of the studied localities;

TABLE 37. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Santa Fe Baldy area, New Mexico.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi²)	T (ft)
NE of Santa Fe Baldy (12,622)						
Later stade	P	0.00	---	---	----	------
Earlier stade	P	0.20	---	---	----	------
Latest pre-Ng	*M+xxMxM	0.50	090	0.5	0.11	11,450
SE of Santa Fe Baldy (12,622)						
Later stade	P	0.00	---	---	----	------
Earlier stade	P	0.20	---	----	----	------
Latest pre-Ng	*M+xxxMxM	0.45	110	0.6	0.09	11,400

Source: field observations and aerial photograph interpretation by author.

Features: M = end moraine ridge, P = protalus rampart, * = comparatively massive feature, + = several end moraine ridges, x = intercrestal separation of less than one ridge width, xx = intercrestal separation of one to 2 ridge widths, xxx = intercrestal separation of 3 to 10 ridge widths.

these moraines, which have a mean modification index of 0.48 ± 0.04 (standard deviation), terminate 0.5 and 0.6 mile from the cirque heads. On the northeast side of Lake Peak, 2 miles south of Santa Fe Baldy, the latest pre-Neoglacial terminal moraine has been identified at an altitude of 11,250 feet (Richmond, 1963, p. E124).

Trees are growing on the summit ridge of Santa Fe Baldy at altitudes of up to 12,400 feet.

Sierra Blanca Peak, New Mexico

A cirque opening into a trough on the northeast face of Sierra Blanca Peak, the highest summit in the igneous Sierra Blanca massif, is the southernmost locality in the Southwest at which evidence of Quaternary glacierization has been observed. Field study and aerial photograph interpretation indicate that during Neoglaciation, and the latest pre-Neoglacial stade, the cirque on Sierra Blanca Peak was subjected to periglacial, rather than glacial, activity (Table 38).

Colluvium, apparently accrued during recent centuries, has stabilized markedly since ca. A.D. 1880, when the present generation of spruce began to colonize the cirque floor and walls. A pair of protalus ramparts, slightly weathered and partially covered by colluvium, occur in the cirque and apparently date from earlier Neoglacial time (modification index = 0.15). The ramparts overlie a substantially more weathered deposit (modification index = 0.50) that appears to be a small rock glacier of the latest pre-Neoglacial stade. Earlier pre-Neoglacial stades are represented by moraines that occur downvalley from the cirque.

Sierra Blanca Peak currently is sparsely wooded to the summit.

TABLE 38. Features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade, Sierra Blanca Peak, New Mexico.

Locality		Modification index, Azimuth, downvalley Distance, Area, Terminus altitude				
Stade	Feature	Mod	Az (°)	D (mi)	A (mi^2)	T (ft)
NE of Sierra Blanca Peak (12,003)						
Later stade	C	----	---	---	----	------
Earlier stade	PxP	0.15	050	0.1	<0.01	11,300
Latest pre-Ng	R*	0.50	050	0.1	0.01	11,250

Source: field observations and aerial photograph interpretation by author.

Features: R = inactive rock glacier, P = protalus rampart, C = colluvium (mainly slope wash), * = comparatively massive feature, x = intercrestal separation of less than one ridge width.

CHAPTER III

PATTERNS OF NEOGLACIATION: A SYNTHESIS

On the basis of the information presented in the preceding chapter, consideration is given in this chapter to the questions posed initially (page 2), viz., (1) how many major and lesser episodes occurred during Neoglaciation, (2) when did they occur, (3) how extensive were glacial and periglacial systems during each of the episodes, and (4) how were glacial, periglacial, and other high-altitude systems spatially related.

Episodes

Neoglaciation, as a stratigraphic unit, is resolvable into subdivisions of successively lower rank. The geologic-climate units, or episodes, that comprise Neoglaciation are assigned in this study to three ranks: stade/interstade, substade/intersubstade, and phase/interphase (Table 2, page 8).

Episodes of stade/interstade rank. Available information strongly suggests that in the Southwest Neoglaciation comprised two distinct stades (Table 39) and an intervening interstade. An earlier stade and a quite separate later stade appear to be clearly represented at 96 of the 135 localities for which data have been assembled in this study. However, end moraine loops partially overlapped by and considerably more modified than moraines assignable to the earlier stade were observed by the author at three localities (Table 39 footnote) and may represent a possible third, or earliest, stade of Neoglaciation; possible earliest

TABLE 39. Neoglacial stades represented by glacial and periglacial features at study areas in the Southwest.

STUDY AREA	Later stade	Earlier stade	Possible earliest stade	Stades undivided
MT. SHASTA, CALIF.	glacial	no observations	no observations	---
THOMPSON PEAK AREA, CALIF.	glacial	glacial	none observed	---
DONNER PASS AREA, CALIF.	---	---	---	periglacial
TIOGA PASS AREA, CALIF.	glacial	glacial	none observed	---
MT. ABBOT AREA, CALIF.	glacial	glacial	glacial[a]	---
PALISADE AREA, CALIF.	glacial	glacial	glacial[b]	---
MT. WHITNEY AREA, CALIF.	glacial	glacial	none observed	---
SAN GORGONIO MTN., CALIF.	periglacial	periglacial	none observed	---
RUBY MTS., NEV.	periglacial	periglacial	none observed	---
SNAKE RANGE, NEV.	glacial	glacial	none observed	---
MT. AGASSIZ AREA, UTAH	periglacial	glacial	none observed	---
WASATCH RANGE, UTAH	periglacial	glacial	none observed	---
LA SAL MTS., UTAH	periglacial	glacial	none observed	---
TUSHAR MTS., UTAH	periglacial	periglacial	none observed	---
BOULDER MTN., UTAH	---	---	---	periglacial
SAN FRANCISCO MTN., ARIZ.	periglacial	periglacial	none observed	---
BALDY PEAK, ARIZ.	---	---	---	periglacial
SNOWY RANGE, WYO.	periglacial	glacial	glacial[c]	---
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY, COLO.	glacial	glacial	none observed	---

TABLE 39, continued.

MT. EVANS AREA, COLO.	periglacial	glacial	none observed	---
SAWATCH RANGE, COLO.	periglacial	glacial	none observed	---
PIKES PEAK, COLO.	periglacial	glacial	none observed	---
SAN MIGUEL MTS., COLO.	periglacial	glacial	none observed	---
CULEBRA RANGE, COLO.	glacial	glacial	glacial[d]	---
WHEELER PEAK AREA, N. M.	periglacial	glacial	none observed	---
SANTA FE BALDY AREA, N. M.	periglacial	periglacial	none observed	---
SIERRA BLANCA PEAK, N. M.	periglacial	periglacial	none observed	---

[a]Hilgard moraines are probably latest pre-Neoglacial, rather than earliest Neoglacial.

[b]End moraine loop E of Isosceles Peak may be assignable to possible earliest Neoglacial stade.

[c]End moraine loop S of Medicine Bow Peak may be assignable to possible earliest Neoglacial stade.

[d]End moraine loop N of Culebra Peak may be assignable to possible earliest Neoglacial stade.

Neoglacial moraines mapped by Birman (1964, plate 1) at two localities are regarded as pre-Neoglacial by other workers. At 34 of the localities Neoglacial features are not sufficiently diagnostic or have not been studied sufficiently to permit differentiation of stades.

Episodes of lesser rank. End moraine sequences and rock glacier structures were examined in an effort to ascertain the number of substades and phases comprising each of the Neoglacial stades. The results of this enumeration (Table 40) are subjective and probably incomplete. In many cases, for example, the differentiation of moraines representing an important recession followed by an important readvance from moraines representing a slight recession followed by stillstand is a matter of judgement, rather than measurement. Because moraine ridges and rock glacier lobes of earlier episodes are likely to have been buried or removed during subsequent episodes, the record is almost certainly incomplete.

Both stades of Neoglaciation included several phases of intensified glacial and periglacial activity. The phases comprising the later stade appear to have been of approximately equal intensity, a characteristic also noted by Harrison (1960, p. 14), and do not group readily into geologic-climate units of substade rank. In Rocky Mountain National Park and vicinity, where perhaps the greatest amount of Neoglacial research has been carried out by other workers, Richmond (1960, p. 1381) noted evidence of at least two secondary phases of later stade activity, Ives (1953, p. 246-247) observed three main stratigraphic units in Fair Glacier, and Outcalt and Benedict (1965, p. 851) have clearly identified four phases of later stade transitional rock glacier development. The author noted four generations of later stade rock glaciers in the Culebra Range and indications of four later stade phases in the Snowy Range and at three

TABLE 40. Substades and phases of Neoglaciation, inferred on the basis of end moraine and rock glacier morphology at study areas in which Neoglacial moraines and rock glaciers are particularly well developed.

STUDY AREA	Later stade	Earlier stade	
		Later substade	Earlier substade
	Number of phases[a]	Number of phases	Number of phases
THOMPSON PEAK AREA, CALIF.	2	X	X
TIOGA PASS AREA, CALIF.	4	3	X
PALISADE AREA, CALIF.	4	2	2
MT.WHITNEY AREA, CALIF.	4	3	X
RUBY MTS., NEV.	X	X	X
SNAKE RANGE, NEV.	X	3	X
MT. AGASSIZ AREA, UTAH	X	X	X
WASATCH RANGE, UTAH	X	X[a]	
LA SAL MTS., UTAH	X	X	X
SNOWY RANGE, WYO.	4	4	X
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY, COLO.	4	X	X
MT. EVANS AREA, COLO.	X	X	X
SAWATCH RANGE, COLO.	X	X	X
SAN MIGUEL MTS., COLO.	X	X[a]	
CULEBRA RANGE, COLO.	4	X	X
WHEELER PEAK AREA, N. M.	X	X	X

Source: field observations and aerial photograph interpretation by the author. X denotes evidence of at least one phase of glacial or periglacial activity.

[a]Little or no indication of multiple substades.

areas in the Sierra Nevada. Although the maximum number of later stade phases reported here is four, it is clear that some or all of those phases were themselves compound. This is especially well shown by the end moraines at Palisade Glacier, where at least 16 oscillations of the terminus are marked by closely spaced, yet discrete, ridges.

Two glacial episodes of substade rank appear to be represented by the moraines of the earlier Neoglacial stade. The maximum extent of the earlier stade glaciers seems generally to have occurred during the earlier substade and is typically marked by a single, outermost moraine ridge that is either clearly in advance of (e.g., east of Peak 13631 in the Sawatch Range) or distinctly more massive than (e.g., north of Mt. George near Rocky Mountain National Park), and at some localities slightly more modified than, the moraines of the later substade. As many as four phases of successively diminished glacial activity are indicated by the latter.

Chronology

The temporal distribution of Neoglacial episodes is in this study viewed both in relative and absolute terms.

Relative chronology. As an indication of relative age, post-depositional changes in the surface morphology of glacial and periglacial deposits have been summarized in a subjective measure termed the modification index (page 17). In conjunction with the criteria of superposition and cross-cutting relations, modification index values have provided the basis for a relative chronology, within which other dimensions of glacial and periglacial systems have been ordered. The sensitivity of the modification index is most appropriate to the description and discrimination of episodes of stade/interstade rank.

Modification index values of features assignable to stades of

Neoglaciation and to the latest pre-Neoglacial stade are summarized by study area in Table 41. The extreme and mean values for a particular stade in a particular area are based on observations of depositional features at from one to 14 localities in the area. Differences between means assignable to successively older stades in a particular area are also tabulated. The absolute extremes, means of the means, and means of the differences appear in the last rows of the table.

With modification index values ranging from 0.00 to 0.12 and an overall mean index of 0.03 ± 0.03 (standard deviation), the 89 features produced by later stade glacial and periglacial activity, which is still in progress at many localities, are clearly the least modified. In contrast, the 85 features attributable to activity during the earlier stade have index values ranging from 0.10 to 0.40 and an overall mean index of 0.24 ± 0.07, and the 51 features attributed to latest pre-Neoglacial activity have values ranging from 0.35 to 0.70 and a mean index of 0.55 ± 0.08. A greater difference in degree of modification, perhaps reflecting a greater span of time, exists between the pre-Neoglacial and earlier Neoglacial features (mean index difference = 0.31 ± 0.04) than between features of the earlier and later Neoglacial stades (mean difference = 0.21 ± 0.05).

A graphic summary of the basic relative chronology perceived in this study is provided by Figure 4, where index values of the 225 features for which modification data were collected are displayed with respect to frequency. There are suggestions in this display, as in Tables 39 and 40, of a possible earliest Neoglacial stade within what appears to be overlap between the earlier stade and latest pre-Neoglacial stade values, and of two substades within the main part of the earlier stade.

TABLE 41. Summary of modification index values for features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade.

STUDY AREA Stade	Number of features N	Modification index			
		Max.	Min.	Mean	Dif.
MT. SHASTA, CALIF.		no observations			
THOMPSON PEAK AREA, CALIF.					
Later stade	3	0.10	0.05	0.07	0.30
Earlier stade	3	0.40	0.30	0.37	----
Latest pre-Ng		no observations			
DONNER PASS AREA, CALIF.		no observations			
TIOGA PASS AREA, CALIF.					
Later stade	12	0.05	0.00	0.00	0.24
Earlier stade	12	0.30	0.15	0.24	0.32
Latest pre-Ng	4	0.65	0.50	0.56	
MT. ABBOT AREA, CALIF.		no observations			
PALISADE AREA, CALIF.					
Later stade	8	0.05	0.00	0.00	0.22
Earlier stade	8	0.30	0.10	0.22	0.33
Latest pre-Ng	1	0.55	0.55	0.55	
MT. WHITNEY AREA, CALIF.					
Later stade	14	0.10	0.00	0.03	0.19
Earlier stade	13	0.40	0.15	0.22	0.30
Latest pre-Ng	4	0.55	0.50	0.52	
SAN GORGONIO MTN., CALIF.					
Later stade	1	0.00	0.00	0.00	0.12
Earlier stade	1	0.12	0.12	0.12	0.28
Latest pre-Ng	1	0.40	0.40	0.40	
RUBY MTS., NEV.					
Later stade	1	0.00	0.00	0.00	0.28
Earlier stade	2	0.30	0.25	0.28	0.37
Latest pre-Ng	3	0.70	0.60	0.65	
SNAKE RANGE, NEV.					
Later stade	4	0.12	0.00	0.05	0.16
Earlier stade	5	0.30	0.15	0.21	0.36
Latest stade	6	0.65	0.50	0.57	
MT. AGASSIZ AREA, UTAH					
Later stade	2	0.12	0.00	0.06	0.19
Earlier stade	2	0.30	0.20	0.25	----
Latest pre-Ng		no observations			
WASATCH RANGE, UTAH					
Later stade	2	0.00	0.00	0.00	0.15
Earlier stade	1	0.15	0.15	0.15	----
Latest pre-Ng		no observations			
LA SAL MTS., UTAH					
Later stade	4	0.05	0.05	0.05	0.27
Earlier stade	2	0.38	0.25	0.32	0.24
Latest pre-Ng	4	0.65	0.50	0.56	

TABLE 41, continued.

TUSHAR MTS., UTAH					
Later stade	2	0.00	0.00	0.00	0.20
Earlier stade	1	0.20	0.20	0.20	
Latest pre-Ng		no observations			----
BOULDER MTN., UTAH		no observations			
SAN FRANCISCO MTN., ARIZ.					
Later stade	2	0.06	0.06	0.06	0.16
Earlier stade	2	0.25	0.20	0.22	0.30
Latest pre-Ng	2	0.55	0.50	0.52	
BALDY PEAK, ARIZ.	values not assignable to a particular stade				
SNOWY RANGE, WYO.					
Later stade	1	0.05	0.05	0.05	0.20
Earlier stade	2	0.35	0.15	0.25	0.40
Latest pre-Ng	1	0.65	0.65	0.65	
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (INDIAN PEAKS AREA), COLO.					
Later stade	9	0.05	0.00	0.01	0.27
Earlier stade	8	0.35	0.25	0.28	0.32
Latest pre-Ng	1	0.60	0.60	0.60	
MT. EVANS AREA, COLO.					
Later stade	4	0.05	0.00	0.02	0.26
Earlier stade	4	0.40	0.19	0.28	0.27
Latest pre-Ng	3	0.65	0.45	0.55	
SAWATCH RANGE, COLO.					
Later stade	6	0.10	0.00	0.03	0.27
Earlier stade	5	0.40	0.20	0.30	0.31
Latest pre-Ng	6	0.65	0.55	0.61	
PIKES PEAK, COLO.					
Later stade	2	0.00	0.00	0.00	0.15
Earlier stade	2	0.15	0.15	0.15	0.29
Latest pre-Ng	5	0.50	0.40	0.44	
SAN MIGUEL MTS., COLO.					
Later stade	4	0.05	0.00	0.02	0.23
Earlier stade	2	0.25	0.25	0.25	0.26
Latest pre-Ng	4	0.60	0.35	0.51	
CULEBRA RANGE, COLO.					
Later stade	4	0.05	0.00	0.04	0.19
Earlier stade	5	0.35	0.15	0.23	0.37
Latest pre-Ng	2	0.65	0.55	0.60	
WHEELER PEAK AREA, N. M.					
Later stade	2	0.05	0.05	0.05	0.17
Earlier stade	2	0.25	0.20	0.22	0.33
Latest pre-Ng	1	0.55	0.55	0.55	
SANTA FE BALDY AREA, N. M.					
Later stade	2	0.00	0.00	0.00	0.20
Earlier stade	2	0.20	0.20	0.20	0.28
Latest pre-Ng	2	0.50	0.45	0.48	

TABLE 41, continued.

SIERRA BLANCA PEAK, N. M.					
Later stade		no observations			----
Earlier stade	1	0.15	0.15	0.15	0.35
Latest pre-Ng	1	0.50	0.50	0.50	
ALL STUDY AREAS	ΣN	Max.	Min.	$\overline{\text{Mean}}$	$\overline{\text{Dif.}}$
Later stade	89	0.12	0.00	0.03	0.21
Earlier stade	85	0.40	0.10	0.24	0.31
Latest pre-Ng	51	0.70	0.35	0.55	

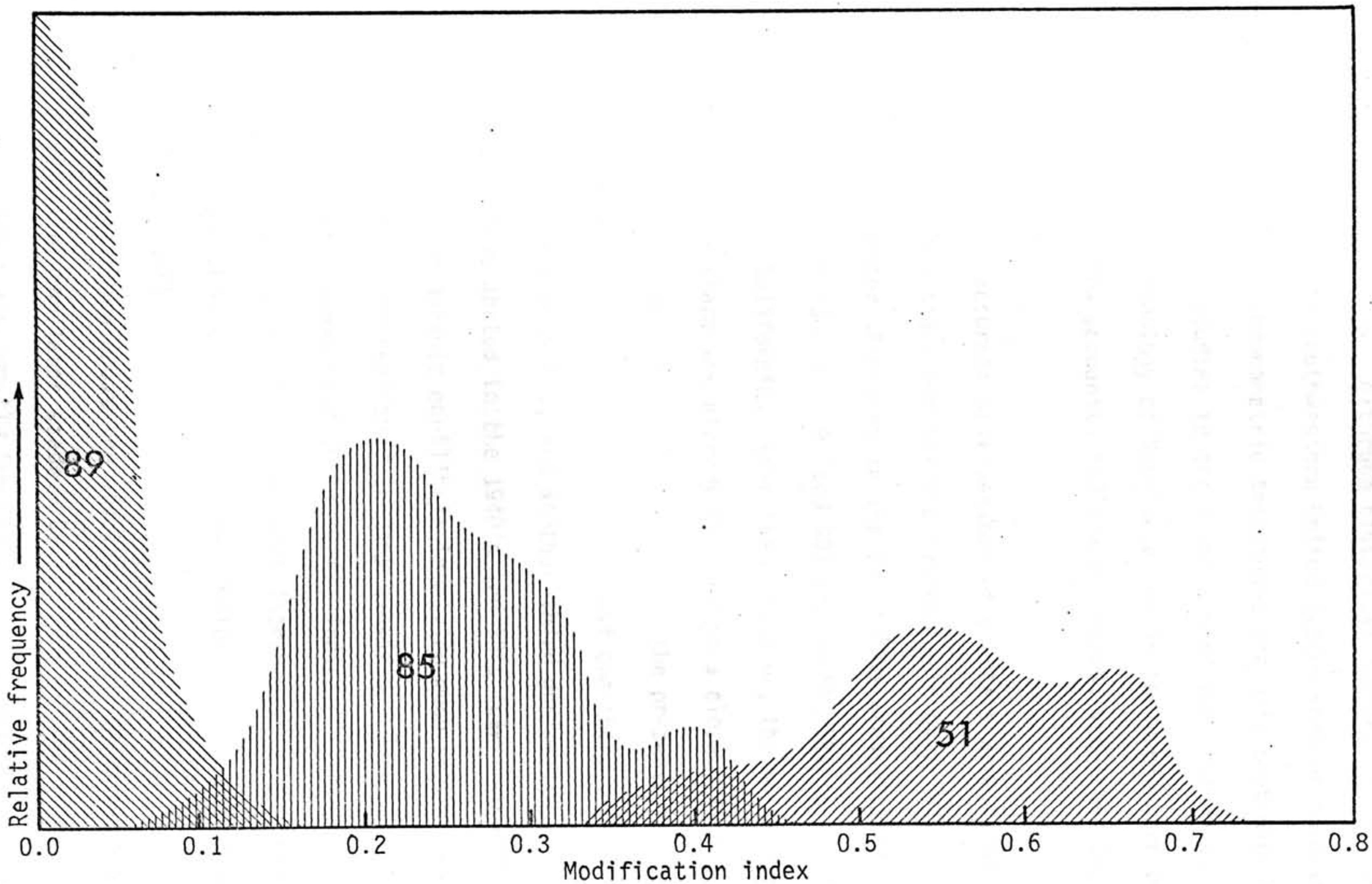

FIGURE 4. Relative frequency of modification index values of 89 features assignable to the later stade of Neoglaciation, 85 features assignable to the earlier stade of Neoglaciation, and 51 features assignable to the latest pre-Neoglacial stade.

Absolute chronology. Although historical accounts pertaining to glacial activity in the southwestern United States span no more than a century, and absolute chronometric techniques are only beginning to be applied to geomorphic studies in the mountains of the Southwest, a skeleton absolute chronology of Neoglaciation in the region can be fashioned from the few accounts, radiocarbon dates, and tree-ring data that are available.

In 1883, when accurate observations of glaciers were first made in the Southwest, later stade end moraine systems were brim-full of ice, or nearly so, at a number of places in the Tioga Pass area (Russell, 1885, p. 322 and plates 35, 36, 37, 39, and 40) and on Mt. Shasta (ibid., plates 44 and 50), California. Even then, however, the most recent phase of the later stade was already drawing to a close. It has been estimated (Kesseli, 1941, p. 223) that during the present interphase that followed, glaciers in the Tioga Pass area lost one-third of their volume between the 1880's and 1930's, and another third during the 30's. That trend seems to have abated in the 1940's and 50's (Lawrence and Lawrence, 1961, p. 341), when dynamic equilibria involving much reduced budgets appear to have been reestablished in many glaciers. Tree-ring studies by the author, in part summarized in Table 42, indicate that the transition from the most recent phase to the present interphase was accompanied by widespread establishment of conifers on previously uninhabitable sites between 1860 and 1885.

Far less is known about the absolute chronology of earlier phases and interphases of the later stade. Cores taken by the author from approximately 100 trees, mostly Engelmann spruce, near the upper limit of trees in the Snake Range, Nevada, suggest that climatic and periglacial

TABLE 42. Dates pertaining to features assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade.

STUDY AREA Locality: feature dated	Year Later stade	 Earlier stade	 Latest pre-Ng
TIOGA PASS AREA, CALIF.			
NE of Mt. Conness: oldest observed tree (Pinus contorta) on terminal moraine		A.D. 1390	
SAN GORGONIO MTN., CALIF.			
NE of San Gorgonio Mtn.: oldest observed tree (Pinus flexilis) on terminal moraine			A.D. 1150
SNAKE RANGE, NEV.			
N of Wheeler Peak: oldest observed tree (Picea engelmanni) on protalus rampart	A.D. 1880		
N of Wheeler Peak: oldest observed tree (Picea engelmanni) on rock glacier		A.D. 1430	
NE of Wheeler Peak: oldest observed tree (Pinus aristata) on rock glacier			1500 B.C.
LA SAL MTS., UTAH			
N of Mt. Mellenthin: oldest observed tree (Picea engelmanni) on rock glacier		A.D. 1400	
NW of Mt. Tukuhnikivatz: radiocarbon date from charcoal in outwash terrace		850±200 B.C.[a]	
TUSHAR MTS., UTAH			
NE of Mt. Belknap: oldest observed tree (Picea engelmanni) on rock glacier		A.D. 1400	
SAN FRANCISCO MTN., ARIZ.			
S of Humphreys Peak: oldest observed tree (Picea engelmanni) on talus	A.D. 1885		
S of Humphreys Peak: oldest observed tree (Pinus aristata) on rock glacier		A.D. 350	
BALDY PEAK, ARIZ.			
SSE of Baldy Peak: oldest observed tree (Picea engelmanni) on cirque headwall	A.D. 1860		
SNOWY RANGE, WYO.			
S of Medicine Bow Peak: oldest observed tree (Abies lasiocarpa) on rock glacier	A.D. 1700		
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY, COLO.			
Long Draw, NW edge of Park: radiocarbon date from peat overlying ground moraine			4220±240 B.C.[b]

ROCKY MOUNTAIN NATIONAL PARK AND VICINITY, COLO. (cont.)	
ESE of South Arapaho Peak: radiocarbon date from base of organic colluvium overlying proglacial lake sediments	510±100 B.C.[c]
SAWATCH RANGE, COLO.	
Frying Pan River basin: estimate based on degree to which glacial deposits have been modified	3800 B.C.[d]
CULEBRA RANGE, COLO.	
SE of Peak 13,010: oldest observed tree (Pinus aristata) on protalus rampart	A.D. 700
SIERRA BLANCA PEAK, N. M.	
NE of Sierra Blanca Peak: oldest observed tree (Picea engelmanni) on cirque headwall	A.D. 1880

Sources: tree-ring dates determined by the author; other dates from sources cited below.

[a]Richmond, 1962, p. 102.

[b]Richmond, 1960, p. 1380.

[c]Benedict, 1967, p. 829.

[d]Nelson, 1954, p. 339.

geomorphic stresses on trees and shrubs intensified in the decades following A.D. 1430 (Figure 5). Those stresses appear to have been relaxed temporarily ca. 1710, perhaps during an interphase, then reimposed, and then relaxed again during the present interphase. The stratigraphy of ice and firn within existing glaciers is another promising key, as yet little utilized in the Southwest, to the history of the later stade. More than 400 annual bands were counted in the face of Fair Glacier, Colorado, in 1932 by Ives (1938, p. 1064), and over 300 layers of ice and firn, interrupted by several unconformities, were observed at the surface of Conness Glacier, California, near the end of the 1964 ablation season by the author. This line of evidence suggests that the formation of later stade glaciers began in the late 1400's or early 1500's, A.D.

Very few dates pertaining to the earlier Neoglacial stade are known from the mountain areas of the Southwest. The interstade between the earlier and later stades had begun by A.D. 350, when a bristlecone pine, still living and quite undeformed, began to grow on the intricately furrowed surface of the earlier stade rock glacier south of Humphreys Peak, Arizona. It is to be anticipated that additional precision in dating the end of the earlier stade will be provided by bristlecone pines at other localities within the range of the species (Figure 6). Glacier recession during what was probably the last phase of the earlier stade resulted in the drainage of a proglacial lake east of Arapaho Peak, Colorado; radiocarbon dates averaging 510 ± 100 B.C. have been reported for the transition from lacustrine to colluvial sedimentation at that site (Benedict, 1967, p. 829). In the La Sal Mountains, Utah, outwash alluvium of the earlier stade, perhaps correlative with the culmination of the later substade, has yielded an average radiocarbon date of 850

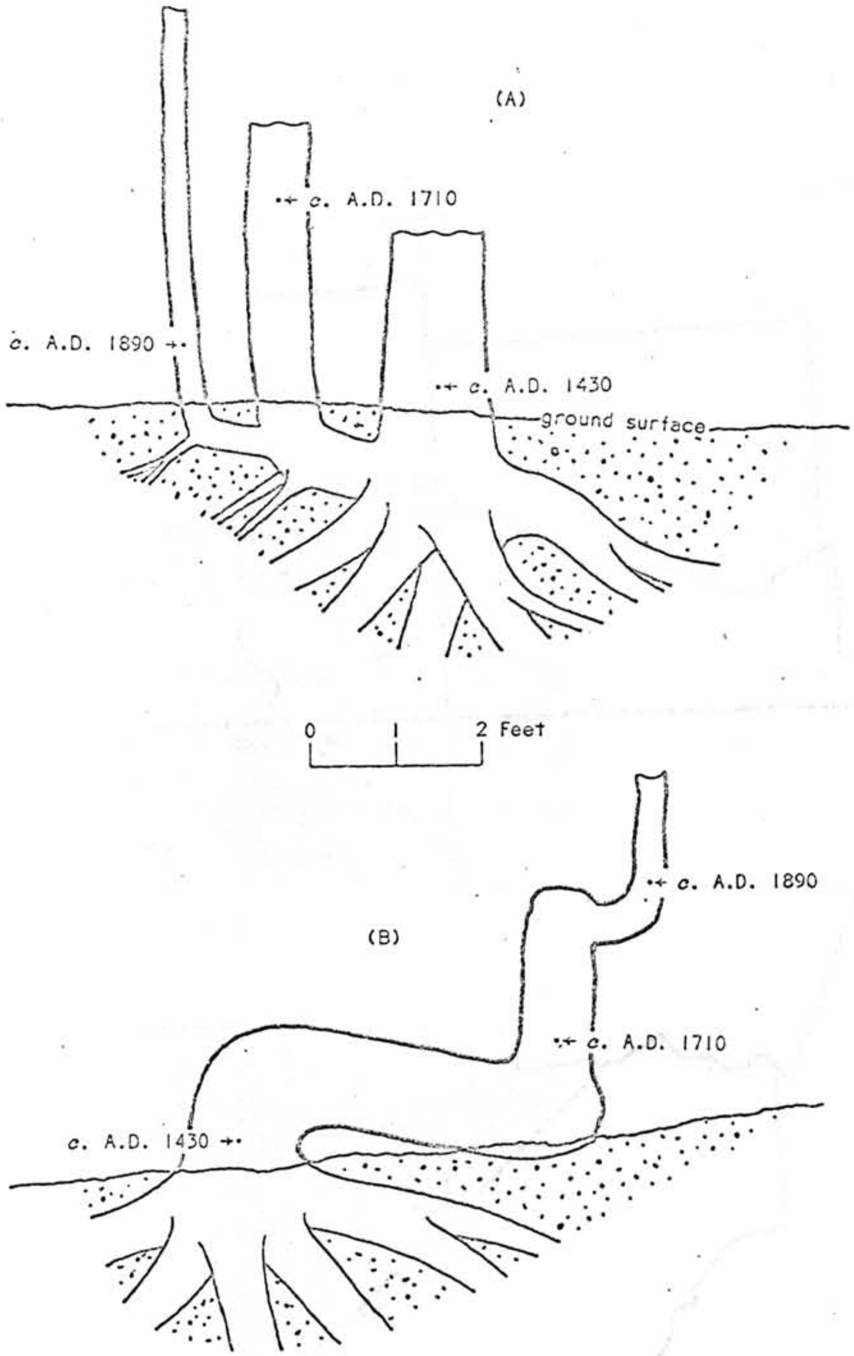

FIGURE 5. Stem structure and age relations typical in deformed Engelmann spruce growing on earlier stade deposits in the Snake Range, Nevada. (A) Successively younger daughter stems rising from lower branches partially buried by intermittent debris accretion. (B) Trellis branching resulting from snow-pack loading and avalanche shearing. Many of the earliest stems date from ca. A.D. 1430; subsequent periods of regeneration began in many stems shortly before 1710 and 1890.

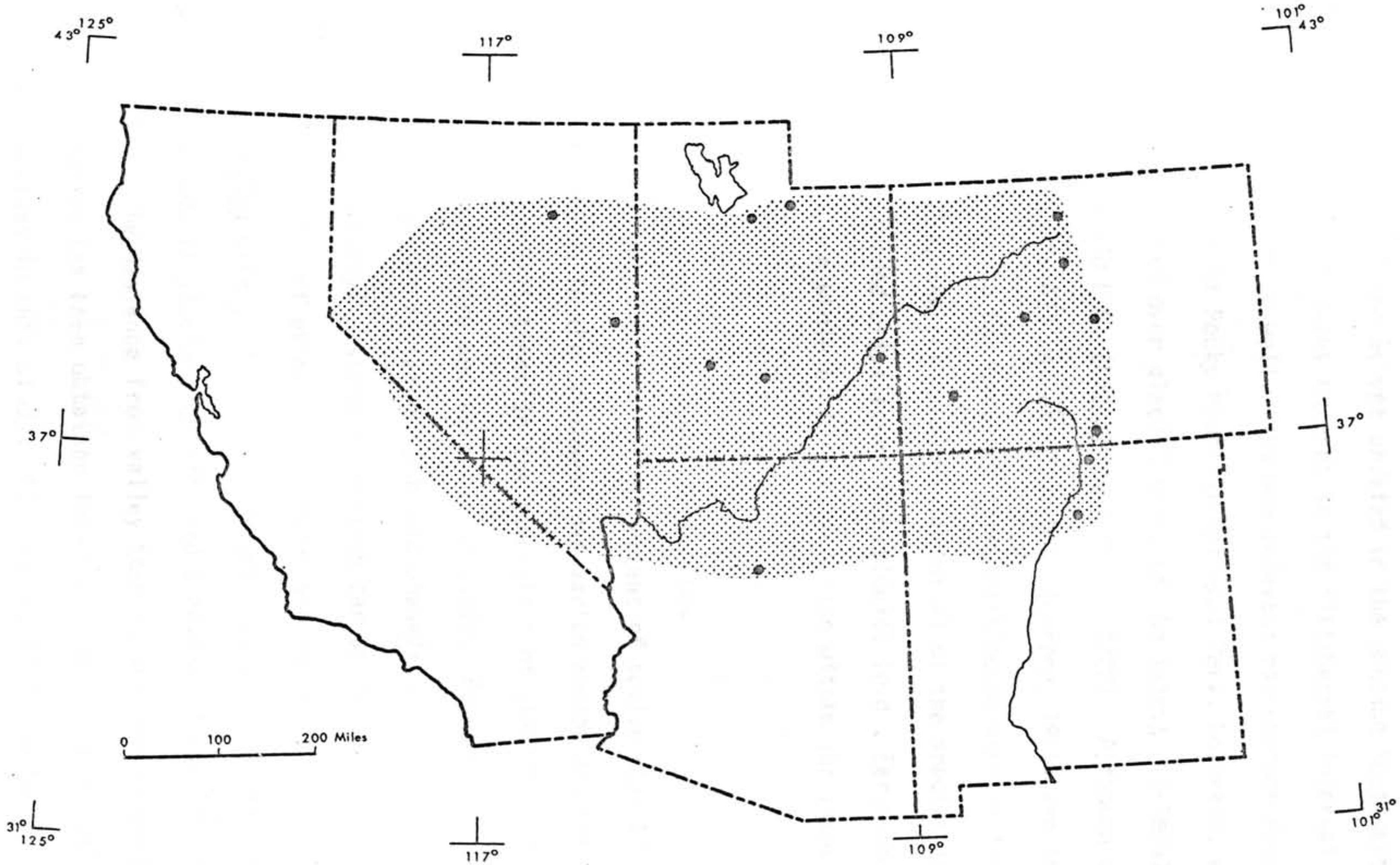

FIGURE 6. Generalized range of bristlecone pine, discontinuous in stands limited to the subalpine zone within the stippled area (adapted from Collingwood et al., 1964, p. 19). Dots indicate areas included in the present study.

± 200 B.C. (Richmond, 1962, p. 102). The beginning and earlier episodes of the earlier stade are as yet undated in the montane Southwest.

This paucity of dates extends to the Altithermal interval and latest pre-Neoglacial stade as well. The one relevant radiocarbon date has come from the north edge of Rocky Mountain National Park, Colorado, where peat began to be deposited over glacial drift of the latest pre-Neoglacial stade ca. 4220 ± 240 B.C. (Richmond, 1960, p. 1380). Although dates of ca. 1500 B.C. (Table 42) and ca. 2900 B.C. (Currey, 1965) are the oldest that the author has so far obtained from bristlecone pine on features of pre-Neoglacial age, the chronometric potential of the species is considerably greater; extended bristlecone chronologies (e.g., Ferguson, 1968) promise to place the whole of Altithermal time within the range of tree-ring dating.

Extent of Systems

The planimetric and altitudinal extent of active glacial and periglacial systems in the Southwest has varied appreciably through Neoglacial time. Variations in the dimensions of glacial systems are particularly instructive and amenable to study. Because of uncertainty regarding the substade/intersubstade and phase/interphase levels of Neoglacial chronology, systems dimensions can be feasibly assigned only to the culminations of principal episodes and to the present interphase.

Downvalley extent of glacial systems. At the culmination of each stade every body of glacier ice attained a maximum downvalley dimension, measurable as the distance from valley head to terminal moraine crest. This measurement has been obtained for one or more stadial culminations at 114 localities in this study. At a number of those localities downvalley distances assignable to consecutive stadial culminations were determined, permitting direct comparisons (Table 43) of the downvalley extent of glacial systems during successive stades.

At the culmination of the Altithermal Interval, preceding Neoglaciation, glacier ice probably disappeared from every peak in the Southwest, with the possible exception of Mt. Shasta (Matthes, 1942a, p. 212-213; Antevs, 1948, p. 178; Richmond, 1960, p. 1381; Richmond, 1962, p. 101; Richmond, 1964, p. D40). The glaciers that reappeared during the earlier stade of Neoglaciation consistently attained downvalley dimensions smaller than those of the glaciers that had previously occurred at the same localities during the latest pre-Neoglacial stade. At 40 localities for which comparative dimensions are known (Table 43) the mean downvalley extent of the earlier Neoglacial glaciers was only 28 ± 12 (standard deviation) per cent as great as that of their latest pre-Neoglacial predecessors. Significant areal variation of this percentage is not identifiable from available data.

During the interstade that followed the earlier Neoglacial stade most cirques in the Southwest probably were largely, if not completely, deglacierized. This is clearly indicated in the Sierra Nevada, where Matthes (1941) observed talus beneath recently wasting cirque glaciers and the author observed what appears to be an interstadial protalus rampart imbedded in the sole of Conness Glacier, and over which the basal layers of Conness Glacier are draped.

Glaciers that were regenerated during the later stade of Neoglaciation consistently attained downvalley dimensions less than those of the earlier Neoglacial glaciers that had previously occurred at the same localities. At 32 localities for which comparative dimensions are known (Table 43) the mean downvalley extent of later Neoglacial glaciers was

TABLE 43. Downvalley distance of terminal moraines assignable to the later stade of Neoglaciation, relative to terminal moraines assignable to the earlier stade of Neoglaciation, and downvalley distance of earlier stade terminal moraines, relative to terminal moraines assignable to the latest pre-Neoglacial stade.

STUDY AREA	Number of localities	$D_{younger}/D_{older}$		
Stades	N	Max.	Min.	Mean
MT. SHASTA, CALIF.				
Later stade/earlier stade		no observations		----
Earlier stade/latest pre-Ng		no observations		----
THOMPSON PEAK AREA, CALIF.				
Later stade/earlier stade	2	0.64	0.30	0.47
Earlier stade/latest pre-Ng		data not verified		----
DONNER PASS AREA, CALIF.				
Later stade/earlier stade		none reported		----
Earlier stade/latest pre-Ng		none reported		----
TIOGA PASS AREA, CALIF.				
Later stade/earlier stade	5	0.41	0.11	0.25
Earlier stade/latest pre-Ng	9	0.32	0.11	0.19
MT. ABBOT AREA, CALIF.				
Later stade/earlier stade	8	0.45	0.23	0.34
Earlier stade/latest pre-Ng	2	0.23	0.21	0.22
PALISADE AREA, CALIF.				
Later stade/earlier stade	5	0.58	0.15	0.33
Earlier stade/latest pre-Ng	2	0.66	0.35	0.50
MT. WHITNEY AREA, CALIF.				
Later stade/earlier stade	1	0.43	0.43	0.43
Earlier stade/latest pre-Ng	6	0.50	0.21	0.37
SAN GORGONIO MTN., CALIF.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
RUBY MTS., NEV.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
SNAKE RANGE, NEV.				
Later stade/earlier stade	1	0.25	0.25	0.25
Earlier stade/latest pre-Ng	1	0.22	0.22	0.22
MT. AGASSIZ AREA, UTAH				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		no observations		----
WASATCH RANGE (MT. TIMPANOGOS AREA), UTAH				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		no observations		----
WASATCH RANGE (LITTLE COTTONWOOD CANYON), UTAH				
Later stade/earlier stade		none reported		----
Earlier stade/latest pre-Ng	1	0.50	0.50	0.50

TABLE 43, continued.

LA SAL MTS., UTAH				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng	1	0.29	0.29	0.29
TUSHAR MTS., UTAH				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
BOULDER MTN., UTAH				
Later stade/earlier stade		none reported		----
Earlier stade/latest pre-Ng		none reported		----
SAN FRANCISCO MTN., ARIZ.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
BALDY PEAK, ARIZ.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
SNOWY RANGE, WYO.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng	1	0.17	0.17	0.17
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (INDIAN PEAKS AREA), COLO.				
Later stade/earlier stade	9	0.50	0.09	0.40
Earlier stade/latest pre-Ng	4	0.27	0.10	0.19
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (WITHIN THE PARK), COLO.				
Later stade/earlier stade		data not reported		----
Earlier stade/latest pre-Ng		data not reported		----
MT. EVANS AREA, COLO.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng	1	0.13	0.13	0.13
SAWATCH RANGE, COLO.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng	5	0.30	0.18	0.23
PIKES PEAK, COLO.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng	1	0.46	0.46	0.46
SAN MIGUEL MTS., COLO.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng	3	0.42	0.20	0.29
CULEBRA RANGE, COLO.				
Later stade/earlier stade	1	0.25	0.25	0.25
Earlier stade/latest pre-Ng	1	0.25	0.25	0.25
WHEELER PEAK AREA, N. M.				
Later stade/earlier stade		none observed		----
Earlier stade/	2	0.25	0.25	0.25
SANTA FE BALDY AREA, N. M.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----

TABLE 43, continued.

SIERRA BLANCA PEAK, N. M.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
ALL STUDY AREAS	ΣN	Max.	Min.	Mean
Later stade/earlier stade	32	0.44	0.23	0.34
Earlier stade/latest pre-Ng	40	0.33	0.23	0.28

only 34 ± 9 per cent as great as that of their earlier Neoglacial counterparts. Later stade glaciers attained lengths about 10 per cent as great as those attained during the latest pre-Neoglacial stade. Again, significant areal variation in these percentages is not discernible from available data.

Downvalley distances of terminal moraines assignable to consecutive stades at particular localities are summarized graphically in Figure 7, where latest pre-Neoglacial distances with respect to earlier Neoglacial distances at 40 localities fall along a trend line with a slope of 3.5, earlier Neoglacial distances with respect to themselves describe a line with slope 1.0, and later Neoglacial distances with respect to earlier Neoglacial distances at 32 localities fall along a trend line with a slope of 0.3. Localities having latest pre-Neoglacial glaciers less than 0.5 mile long were in no known case reoccupied by glaciers during Neoglaciation and localities having earlier Neoglacial glaciers less than 0.25 mile long were in no known case reoccupied by glaciers during the later Neoglacial stade.

Areal extent of glacial systems. At the culmination of each stade every body of glacier ice attained a maximum areal extent, measurable as an area delimited partly by trim lines and partly by outermost moraines. This measurement has been obtained for one or more stadial culminations at 106 localities in this study. At a number of those localities glacierized areas assignable to consecutive stadial culminations were determined, permitting direct comparisons (Table 44) of the areal extent of glacial systems during successive stades.

Glaciers that reappeared during the earlier stade of Neoglaciation, following deglacierization during the Altithermal Interval, consistently attained areal dimensions smaller than those of the glaciers that had

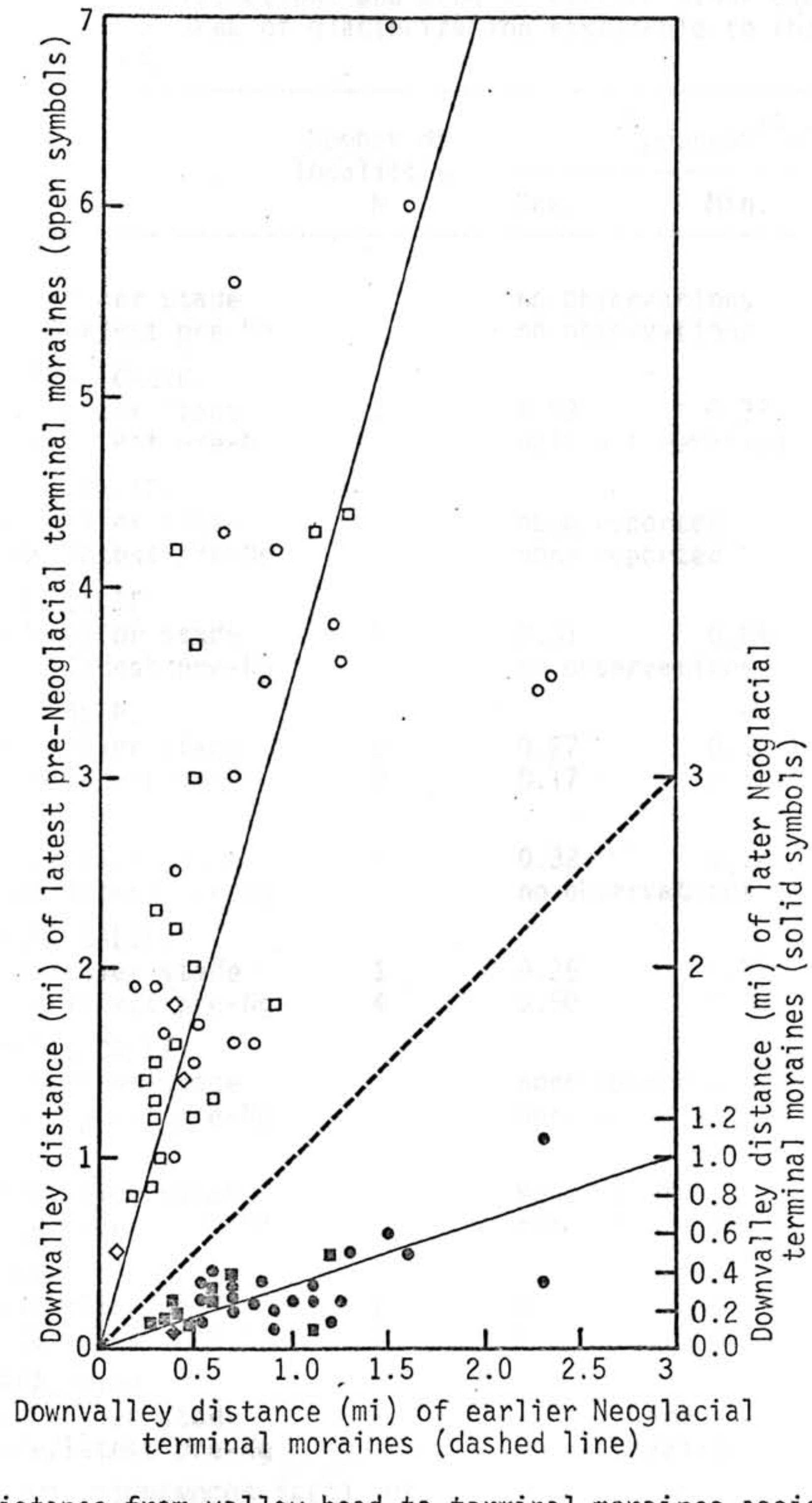

FIGURE 7. Distance from valley head to terminal moraines assignable to the latest pre-Neoglacial stade and the later stade of Neoglaciation, with respect to the distance from valley head to terminal moraines assignable to the earlier stade of Neoglaciation. Circles denote localities in the Pacific mountain system, diamonds denote localities in the intermontane provinces, and squares denote localities in the Rocky Mountain system.

TABLE 44. Area of glacierization assignable to the later stade of Neoglaciation, relative to area of glacierization assignable to the earlier stade of Neoglaciation, and area of earlier stade glacierization, relative to area of glacierization assignable to the latest pre-Neoglacial stade.

STUDY AREA / Stades	Number of localities N	$A_{younger}/A_{older}$ Max.	Min.	Mean
MT. SHASTA, CALIF.				
Later stade/earlier stade		no observations		----
Earlier stade/latest pre-Ng		no observations		----
THOMPSON PEAK AREA, CALIF.				
Later stade/earlier stade	1	0.33	0.33	0.33
Earlier stade/latest pre-Ng		data not verified		----
DONNER PASS AREA, CALIF.				
Later stade/earlier stade		none reported		----
Earlier stade/latest pre-Ng		none reported		----
TIOGA PASS AREA, CALIF.				
Later stade/earlier stade	5	0.31	0.04	0.15
Earlier stade/latest pre-Ng		no observations		----
MT. ABBOT AREA, CALIF.				
Later stade/earlier stade	8	0.27	0.12	0.19
Earlier stade/latest pre-Ng	1	0.17	0.17	0.17
PALISADE AREA, CALIF.				
Later stade/earlier stade	5	0.32	0.12	0.25
Earlier stade/latest pre-Ng		no observations		----
MT. WHITNEY AREA, CALIF.				
Later stade/earlier stade	1	0.25	0.25	0.25
Earlier stade/latest pre-Ng	4	0.50	0.32	0.43
SAN GORGONIO MTN., CALIF.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
RUBY MTS., NEV.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
SNAKE RANGE, NEV.				
Later stade/earlier stade	1	0.25	0.25	0.25
Earlier stade/latest pre-Ng	1	0.07	0.07	0.07
MT. AGASSIZ AREA, UTAH				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		no observations		----
WASATCH RANGE (MT. TIMPANOGOS AREA), UTAH				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		no observations		----
WASATCH RANGE (LITTLE COTTONWOOD CANYON), UTAH				
Later stade/earlier stade		none reported		----
Earlier stade/latest pre-Ng	1	----	----	0.24

TABLE 44, continued.

LA SAL MTS., UTAH				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng	1	0.20	0.20	0.20
TUSHAR MTS., UTAH				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
BOULDER MTN., UTAH				
Later stade/earlier stade		none reported		----
Earlier stade/latest pre-Ng		none reported		----
SAN FRANCISCO MTN., ARIZ.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
BALDY PEAK, ARIZ.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
SNOWY RANGE, WYO.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		no observations		----
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (INDIAN PEAKS AREA), COLO.				
Later stade/earlier stade	9	0.50	0.20	0.36
Earlier stade/latest pre-Ng		no observations		----
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (WITHIN THE PARK), COLO.				
Later stade/earlier stade		data not reported		----
Earlier stade/latest pre-Ng		data not reported		----
MT. EVANS AREA, COLO.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		no observations		----
SAWATCH RANGE, COLO.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng	1	0.17	0.17	0.17
PIKES PEAK, COLO.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng	1	0.15	0.15	0.15
SAN MIGUEL MTS., COLO.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		no observations		----
CULEBRA RANGE, COLO.				
Later stade/earlier stade	1	0.30	0.30	0.30
Earlier stade/latest pre-Ng	1	0.20	0.20	0.20
WHEELER PEAK AREA, N. M.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng	2	0.10	0.10	0.10
SANTA FE BALDY AREA, N. M.				
Later stade/earlier stade		none observed		----
Earlier stade/ latest pre-Ng		none observed		----

TABLE 44, continued.

SIERRA BLANCA PEAK, N. M.				
Later stade/earlier stade		none observed		----
Earlier stade/latest pre-Ng		none observed		----
ALL STUDY AREAS	ΣN	$\overline{\text{Max.}}$	$\overline{\text{Min.}}$	$\overline{\text{Mean}}$
Later stade/earlier stade	31	0.32	0.20	0.26
Earlier stade/latest pre-Ng	13	0.20	0.17	0.19

previously occurred at the same localities during the latest pre-Neoglacial stade. At 13 localities for which comparative areas are known (Table 44) the mean areal extent of the earlier Neoglacial glaciers was only 19 ± 10 (standard deviation) per cent as great as that of their latest pre-Neoglacial predecessors. Significant areal variation in this percentage is not identifiable from the data that are available.

Glaciers that were regenerated during the later stade of Neoglaciation, following deglacierization during the mid-Neoglacial interstade, consistently attained areal dimensions less than those of the earlier Neoglacial glaciers that had previously occurred at the same localities. At 31 localities for which comparative areas are known (Table 44) the mean areal extent of later Neoglacial glaciers was only 26 ± 7 per cent as great as that of their earlier Neoglacial counterparts. Later stade glaciers attained areas about 5 per cent as great as those attained during the latest pre-Neoglacial stade. Again, significant areal variation in these percentages is not discernible from available data.

The diminishing glacierized areas that have attended the present interphase of the later Neoglacial stade were measured at 14 localities in four study areas. Two glaciers in the Thompson Peak area, California, have diminished by an average of 69 per cent of their later stade maximum area; three glaciers in the Tioga Pass area, California, have diminished by an average of 64 per cent; four glaciers in the Palisade area, California, have diminished by an average of 54 per cent; and five glaciers south of Rocky Mountain National Park, Colorado, have diminished by an average of 33 per cent. The mean remaining area of these glaciers is 48 ± 18 per cent of their maximum later stade area. On the basis of this small sample, there is a suggestion of areal variation in this percentage, with the greater net wastage of glacier ice during the present interphase being associated with decreasing continentality and increasing latitude.

Glacierized areas assignable to consecutive stades at particular localities are summarized graphically in Figure 8, where latest pre-Neoglacial areas with respect to earlier Neoglacial areas at 13 localities fall along a trend line with a slope of 5.2, earlier Neoglacial areas with respect to themselves describe a line with slope 1.0, and later Neoglacial areas with respect to earlier Neoglacial areas at 31 localities fall along a trend line with a slope of 0.26. Some localities having latest pre-Neoglacial glaciers as large as 0.30 square mile were not reoccupied by glaciers during Neoglaciation (margin of Figure 8) and no localities having latest pre-Neoglacial glaciers smaller than 0.20 square mile are known to have been reoccupied. Similarly, some localities having earlier Neoglacial glaciers as large as 0.22 square mile were not glacierized during the later Neoglacial stade and no localities having earlier stade glaciers smaller than 0.05 square mile are known to have been glacierized later.

By combining information on the downvalley and areal extent of glacial systems, proportionally correct schematic plans of composite glaciers, representing the latest pre-Neoglacial, earlier Neoglacial, and later Neoglacial stadial culminations, and the present interphase, have been compiled in Figure 9.

Altitudinal extent of glacial systems. At the culmination of each stade every body of glacier ice, or at least the vast majority of those considered here, which were too small to have been seriously affected by kinematic waves, attained a lowest limit of glacierization, or minimum terminus altitude. Although the altitudinal extent of glacial systems

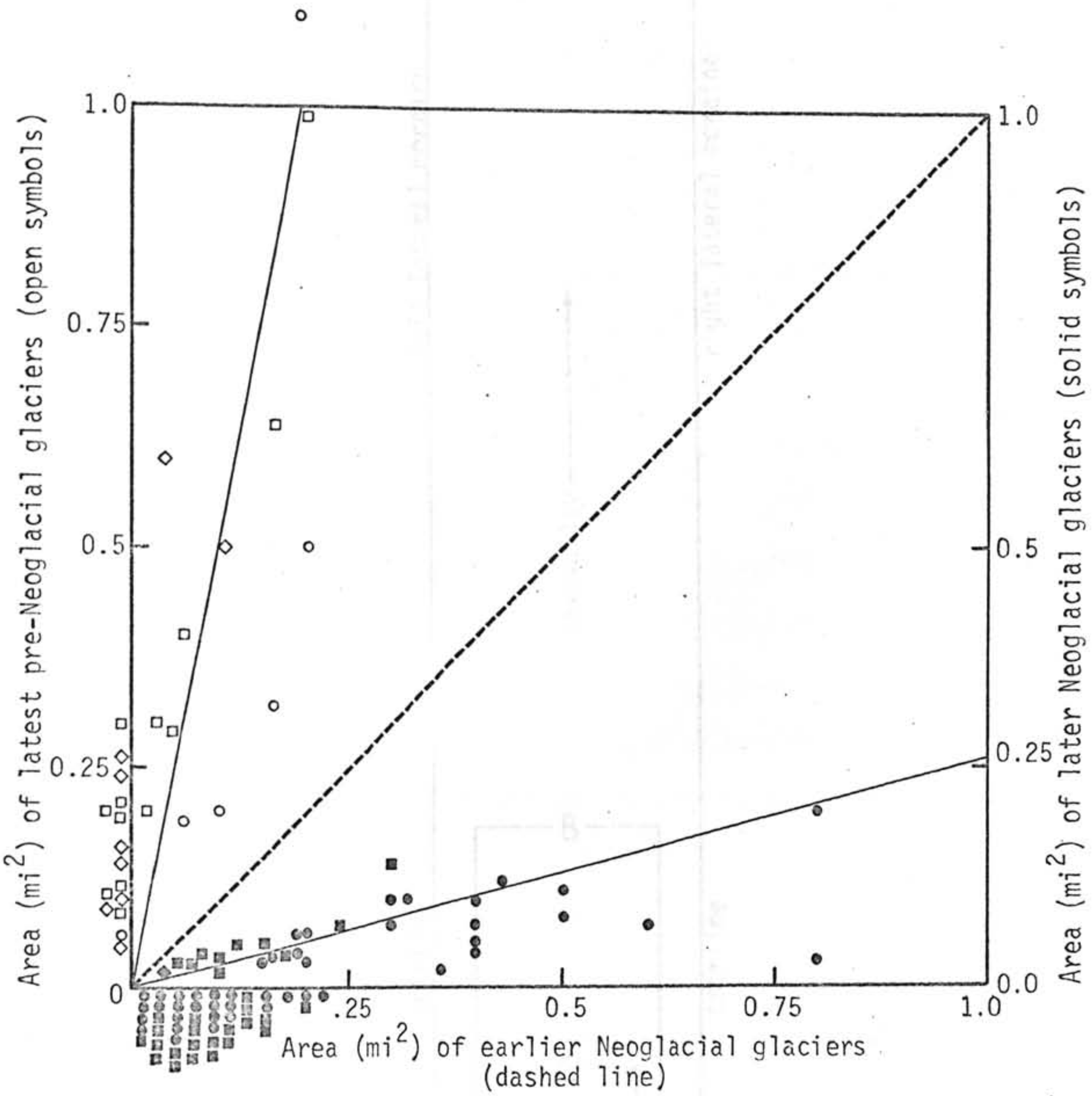

FIGURE 8. Area of glacierization assignable to the latest pre-Neoglacial stade and the later stade of Neoglaciation, with respect to the area of glacierization assignable to the earlier stade of Neoglaciation. Circles denote localities in the Pacific mountain system, diamonds denote localities in the intermontane provinces, and squares denote localities in the Rocky Mountain system.

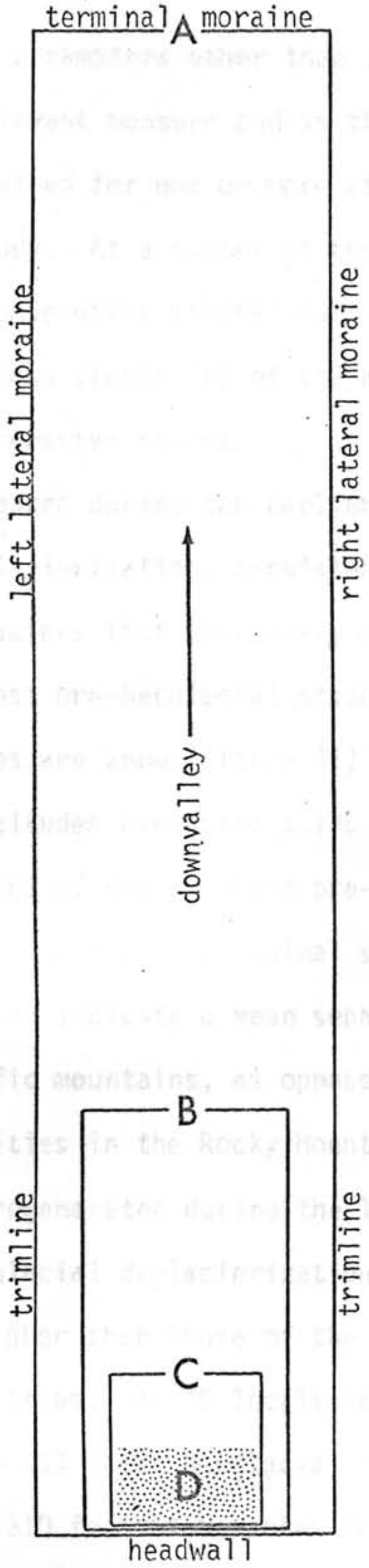

FIGURE 9. Schematic composite plans of (A) latest pre-Neoglacial, (B) earlier Neoglacial, (C) later Neoglacial, and (D) existing glaciers in the Southwest. Planimetric dimensions are to scale proportionally.

is sometimes described by parameters other than terminus altitude, the latter is the simplest relevant measure and is the one used here. This measurement has been obtained for one or more stadial culminations at 124 localities in this study. At a number of those localities terminus altitudes assignable to consecutive stadial culminations were determined, permitting direct comparisons (Table 45) of the altitudinal extent of glacial systems during successive stades.

Glaciers that reappeared during the earlier stade of Neoglaciation, following Altithermal deglacierization, consistently terminated at higher altitudes than had the glaciers that previously occurred at the same localities during the latest pre-Neoglacial stade. At 52 localities for which comparative altitudes are known (Table 45) earlier Neoglacial glaciers terminated at altitudes averaging 1,175 ± 340 (standard deviation) feet higher than the termini of their latest pre-Neoglacial predecessors. Possible regional variation in this altitudinal separation is suggested by the available data, which indicate a mean separation of 1,270 feet at 18 localities in the Pacific mountains, as opposed to a mean separation of 1,140 feet at 32 localities in the Rocky Mountains.

Glaciers that were regenerated during the later stade of Neoglaciation, following mid-Neoglacial deglacierization, consistently attained terminus altitudes even higher than those of the earlier Neoglacial glaciers at the same localities. At 36 localities for which comparative altitudes are known (Table 45) later Neoglacial glaciers terminated at altitudes averaging 580 ± 310 feet higher than the termini of their earlier Neoglacial counterparts. Significant regional variation in this altitudinal separation is suggested by the available data, which indicate a mean separation of 750 feet at 21 localities in the Pacific mountains,

TABLE 45. Altitudinal separation between terminal moraines assignable to the later stade and the earlier stade of Neoglaciation and between terminal moraines assignable to the earlier stade of Neoglaciation and the latest pre-Neoglacial stade.

STUDY AREA / Stades	Number of localities N	Altitudinal separation (ft) Max.	Min.	Mean
MT. SHASTA, CALIF.				
Later stade-earlier stade		no observations		---
Earlier stade-latest pre-Ng		no observations		---
THOMPSON PEAK AREA, CALIF.				
Later stade-earlier stade	2	600	500	550
Earlier stade-latest pre-Ng		data not verified		---
DONNER PASS AREA, CALIF.				
Later stade-earlier stade		none reported		---
Earlier stade-latest pre-Ng		none reported		---
TIOGA PASS AREA, CALIF.				
Later stade-earlier stade	5	1,100	200	840
Earlier stade-latest pre-Ng	9	1,500	500	925
MT. ABBOT AREA, CALIF.				
Later stade-earlier stade	8	900	400	675
Earlier stade-latest pre-Ng	2	1,800	1,800	1,800
PALISADE AREA, CALIF.				
Later stade-earlier stade	5	2,250	250	1,270
Earlier stade-latest pre-Ng	2	1,700	600	1,150
MT. WHITNEY AREA, CALIF.				
Later stade-earlier stade	1	400	400	400
Earlier stade-latest pre-Ng	5	1,700	600	1,200
SAN GORGONIO MTN., CALIF.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng		none observed		---
RUBY MTS., NEV.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng		none observed		---
SNAKE RANGE, NEV.				
Later stade-earlier stade	1	300	300	300
Earlier stade-latest pre-Ng	1	1,200	1,200	1,200
MT. AGASSIZ AREA, UTAH				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng		no observations		---
WASATCH RANGE (MT. TIMPANOGOS AREA), UTAH				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng		no observations		---
WASATCH RANGE (LITTLE COTTONWOOD CANYON), UTAH				
Later stade-earlier stade		none reported		---
Earlier stade-latest pre-Ng	10	2,600	100	600

TABLE 45, continued.

LA SAL MTS., UTAH				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng	1	1,150	1,150	1,150
TUSHAR MTS., UTAH				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng		none observed		---
BOULDER MTN., UTAH				
Later stade-earlier stade		none reported		---
Earlier stade-latest pre-Ng		none reported		---
SAN FRANCISCO MTN., ARIZ.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng		none observed		---
BALDY PEAK, ARIZ.				
Later stade-earlier stade		none observed		---
Earlier stade-latest stade		none observed		---
SNOWY RANGE, WYO.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng	1	1,000	1,000	1,000
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (INDIAN PEAKS AREA), COLO.				
Later stade-earlier stade	9	800	100	470
Earlier stade-latest pre-Ng	3	2,000	1,100	1,430
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (WITHIN THE PARK), COLO.				
Later stade-earlier stade	4	675	100	310
Earlier stade-latest pre-Ng	5	2,650	800	1,530
MT. EVANS AREA, COLO.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng	1	1,900	1,900	1,900
SAWATCH RANGE, COLO.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng	5	1,250	900	1,100
PIKES PEAK, COLO.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng	1	900	900	900
SAN MIGUEL MTS., COLO.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng	3	1,550	750	1,050
CULEBRA RANGE, COLO.				
Later stade-earlier stade	1	400	400	400
Earlier stade-latest pre-Ng	1	1,000	1,000	1,000
WHEELER PEAK AREA, N. M.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng	2	900	850	875
SANTA FE BALDY AREA, N. M.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng		none observed		---

TABLE 45, continued.

SIERRA BLANCA PEAK, N. M.				
Later stade-earlier stade		none observed		---
Earlier stade-latest pre-Ng		none observed		---

ALL STUDY AREAS	ΣN	$\overline{\text{Max.}}$	$\overline{\text{Min.}}$	$\overline{\text{Mean}}$
Later stade-earlier stade	36	825	295	580
Earlier stade-latest pre-Ng	52	1,550	950	1,175

in contrast to a mean separation of 400 feet at 14 localities in the Rocky Mountains.

Terminus altitudes assignable to consecutive stades at particular localities are summarized graphically in Figure 10, where later Neoglacial termini and latest pre-Neoglacial termini are plotted with respect to earlier Neoglacial termini. At 36 localities later Neoglacial terminal moraines fall along a trend line 580 feet above the earlier Neoglacial termini and at 52 localities latest pre-Neoglacial terminal moraines fall along a trend line 1,175 feet below the earlier Neoglacial termini. Terminus altitudes assignable to the later Neoglacial stade average approximately 1,750 feet higher than those assignable to the latest pre-Neoglacial stade at the same localities.

The mean terminus altitudes, and the extreme terminus altitudes, attained by glaciers during the stades in question are summarized by study area in Table 46. Altitudes assignable to a particular stade in a particular area are based on observations of terminal moraines at from one to 14 localities in the area. To ensure that these altitudes, especially the mean terminus altitudes, reflect regional variation in the lower limit of glacierization, at least insofar as sample sizes permit, and that variability introduced by differences in exposure is held to a minimum, only those localities having exposure azimuths in the 120-degree sector between 345 and 105 degrees are included for each area.

The mean terminus altitudes in Table 46 provide a basis, directly and by extrapolation using the altitudinal separation information developed above (Table 45 and Figure 10), for mapping surfaces describing the lower altitudinal limits of glacierization. As inferred from observed altitudes at 18 areas and extrapolated altitudes at five areas, the mean lower limit

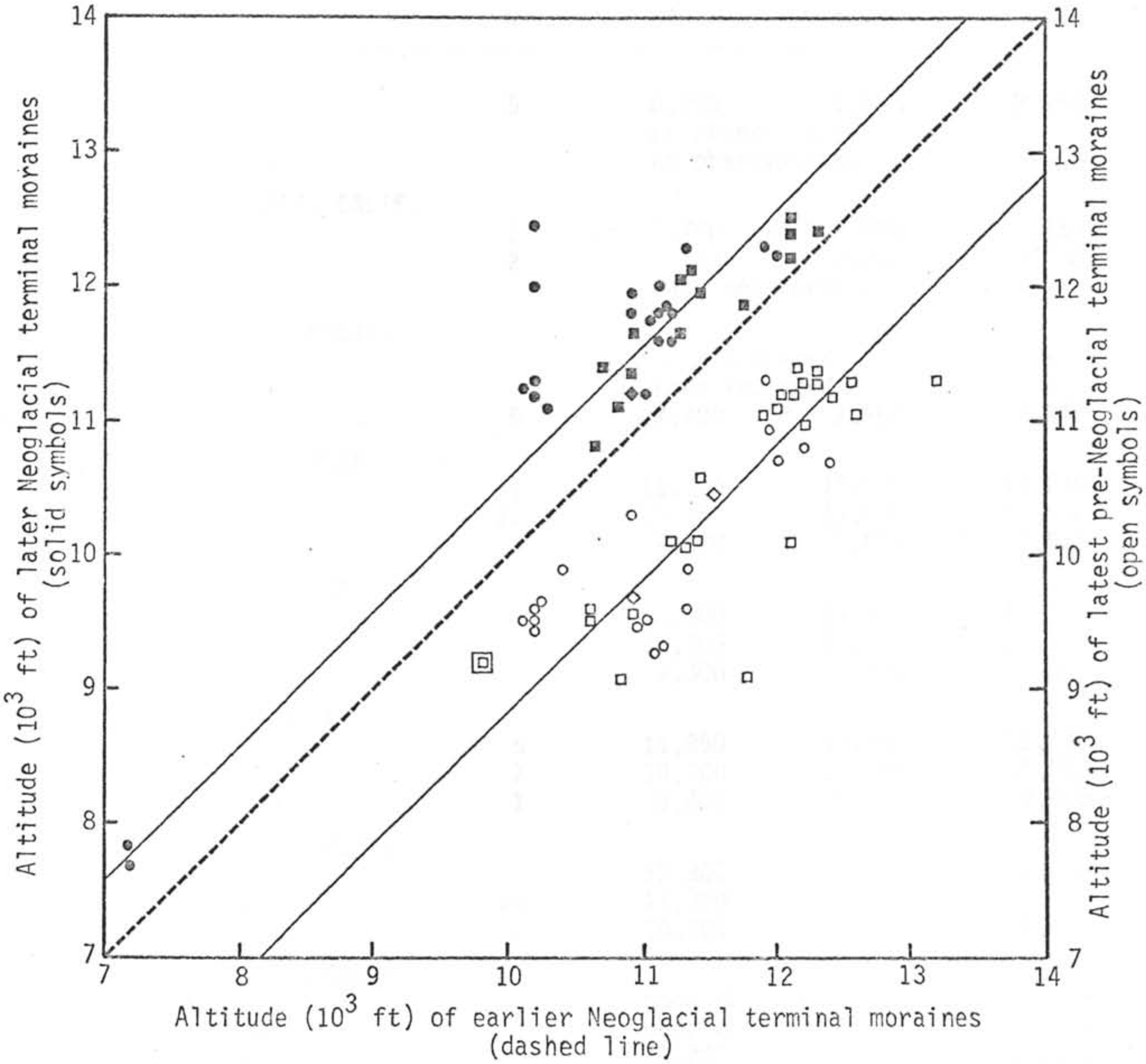

FIGURE 10. Altitude of terminal moraines assignable to the later stade of Neoglaciation and the latest-pre-Neoglacial stade, with respect to the altitude of terminal moraines assignable to the earlier stade of Neoglaciation. Circles denote localities in the Pacific mountain system, diamonds denote localities in the intermontane provinces, and squares denote localities in the Rocky Mountain system. Double square represents 10 localities in the Wasatch Range, Utah.

TABLE 46. Summary of altitudes of terminal moraines assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade. Azimuths are in the 120° sector centered on 045°.

STUDY AREA Stade	Number of localities N	Altitude (ft) Min.	Max.	Mean
MT. SHASTA, CALIF				
Later stade	5	8,250	9,550	9,150
Earlier stade		no observations		-----
Latest pre-Ng		no observations		-----
THOMPSON PEAK AREA, CALIF.				
Later stade	2	7,700	7,800	7,750
Earlier stade	2	7,200	7,200	7,200
Latest pre-Ng		data not verified		-----
DONNER PASS AREA, CALIF.				
Later stade		none reported		-----
Earlier stade		none reported		-----
Latest pre-Ng	5	7,400	7,650	7,540
TIOGA PASS AREA, CALIF.				
Later stade	5	11,100	11,300	11,210
Earlier stade	10	10,150	11,000	10,430
Latest pre-Ng	1	9,520	9,520	9,520
MT. ABBOT AREA, CALIF.				
Later stade	9	11,600	12,000	11,780
Earlier stade	7	10,900	11,200	11,100
Latest pre-Ng	2	9,300	9,300	9,300
PALISADE AREA, CALIF.				
Later stade	5	11,950	12,450	12,190
Earlier stade	7	10,200	12,100	11,320
Latest pre-Ng	1	9,600	9,600	9,600
MT. WHITNEY AREA, CALIF.				
Later stade	1	12,300	12,300	12,300
Earlier stade	14	11,300	12,900	11,930
Latest pre-Ng	3	10,700	10,900	10,800
SAN GORGONIO MTN., CALIF.				
Later stade		none observed		------
Earlier stade		none observed		------
Latest pre-Ng	1	10,200	10,200	10,200
RUBY MTS., NEV.				
Later stade		none observed		------
Earlier stade		none observed		------
Latest pre-Ng	3	8,700	9,200	8,970
SNAKE RANGE, NEV.				
Later stade	1	11,200	11,200	11,200
Earlier stade	1	10,900	10,900	10,900
Latest pre-Ng	8	9,700	10,600	10,220

TABLE 46, continued.

MT. AGASSIZ AREA, UTAH				
Later stade		none observed		------
Earlier stade	2	10,600	10,900	10,750
Latest pre-Ng		no observations		------
WASATCH RANGE (MT. TIMPANOGOS AREA), UTAH				
Later stade		none observed		------
Earlier stade	1	10,150	10,150	10,150
Latest pre-Ng		no observations		------
WASATCH RANGE (LITTLE COTTONWOOD CANYON), UTAH				
Later stade		none reported		-----
Earlier stade	10	9,160	10,120	9,800
Latest pre-Ng	13	6,560	9,840	9,200
LA SAL MTS., UTAH				
Later stade		none observed		------
Earlier stade	1	11,500	11,500	11,500
Latest pre-Ng	3	10,300	10,450	10,380
TUSHAR MTS., UTAH				
Later stade		none observed		------
Earlier stade		none observed		------
Latest pre-Ng		none observed		------
BOULDER MTN., UTAH				
Later stade		none reported		------
Earlier stade		none reported		------
Latest pre-Ng		data not verified		------
SAN FRANCISCO MTN., ARIZ.				
Later stade		none observed		------
Earlier stade		none observed		------
Latest pre-Ng	2	10,550	10,600	10,575
BALDY PEAK, ARIZ.				
Later stade		none observed		------
Earlier stade		none observed		------
Latest pre-Ng		none observed		------
SNOWY RANGE, WYO.				
Later stade		none observed		------
Earlier stade	1	10,600	10,600	10,600
Latest pre-Ng		no observations		------
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (INDIAN PEAKS AREA), COLO.				
Later stade	9	11,350	12,400	11,940
Earlier stade	8	10,700	12,300	11,500
Latest pre-Ng	1	10,100	10,100	10,100
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (WITHIN THE PARK), COLO.				
Later stade	4	10,750	11,850	11,325
Earlier stade	5	10,600	11,750	11,095
Latest pre-Ng	4	9,100	10,600	9,680
MT. EVANS AREA, COLO.				
Later stade		none observed		------
Earlier stade	2	12,900	13,200	13,050
Latest pre-Ng	2	11,300	11,500	11,400

TABLE 46, continued.

SAWATCH RANGE, COLO.				
Later stade		none observed		------
Earlier stade	5	12,200	12,550	12,330
Latest pre-Ng	6	11,000	11,350	11,230
PIKES PEAK, COLO.				
Later stade		none observed		------
Earlier stade	1	12,000	12,000	12,000
Latest pre-Ng	4	11,000	11,800	11,375
SAN MIGUEL MTS., COLO.				
Later stade		none observed		------
Earlier stade	3	11,900	12,600	12,220
Latest pre-Ng	2	11,050	11,400	11,225
CULEBRA RANGE, COLO.				
Later stade	1	12,500	12,500	12,500
Earlier stade	3	12,100	12,300	12,200
Latest pre-Ng		no observations		------
WHEELER PEAK AREA, N. M.				
Later stade		none observed		------
Earlier stade	2	12,050	12,100	12,075
Latest pre-Ng	1	11,200	11,200	11,200
SANTA FE BALDY AREA, N. M.				
Later stade		none observed		------
Earlier stade		none observed		------
Latest pre-Ng	2	11,400	11,450	11,425
SIERRA BLANCA PEAK, N. M.				
Later stade		none observed		------
Earlier stade		none observed		------
Latest pre-Ng		none observed		------

of glacierization during the latest pre-Neoglacial stade is represented in Figure 11; the comparable surface during the earlier Neoglacial stade, inferred from observations at 17 areas and from extrapolations at six areas, appears in Figure 12; and that for the later Neoglacial stade, inferred from observations at nine areas and extrapolations at 14 areas, is shown in Figure 13. Apart from obvious differences in altitude, the surfaces depicted in these maps are nearly identical in form, with the most striking aspects in each being the pronounced seaward descent of the mean lower limits of glacierization in the Pacific mountains, i.e., in California, and the more gradual northward descent of those surfaces inland from the Pacific mountains.

Extent of periglacial systems. As glacial systems diminished in extent with successive stadial culminations, periglacial systems assumed relatively greater extent during succeeding stades, completely supplanting the glacial systems at some localities and occupying formerly glacierized tracts adjacent to much diminished glaciers at other localities. Of the 70 cirques and valley heads included in this study that show evidence of having been occupied by bodies of glacier ice during the earlier stade of Neoglaciation, only one-third were reoccupied by glaciers or transitional rock glaciers during the later Neoglacial stade. The other 46 localities were later occupied by periglacial systems, in the proportions indicated in Figure 14.

Of the 29 cirques and valley heads included in this study that appear to have been occupied by periglacial, rather than glacial, systems during the earlier stade, none was subsequently occupied by a glacier. The later stade periglacial systems that succeeded those of the earlier stade at those localities are indicated in Figure 15.

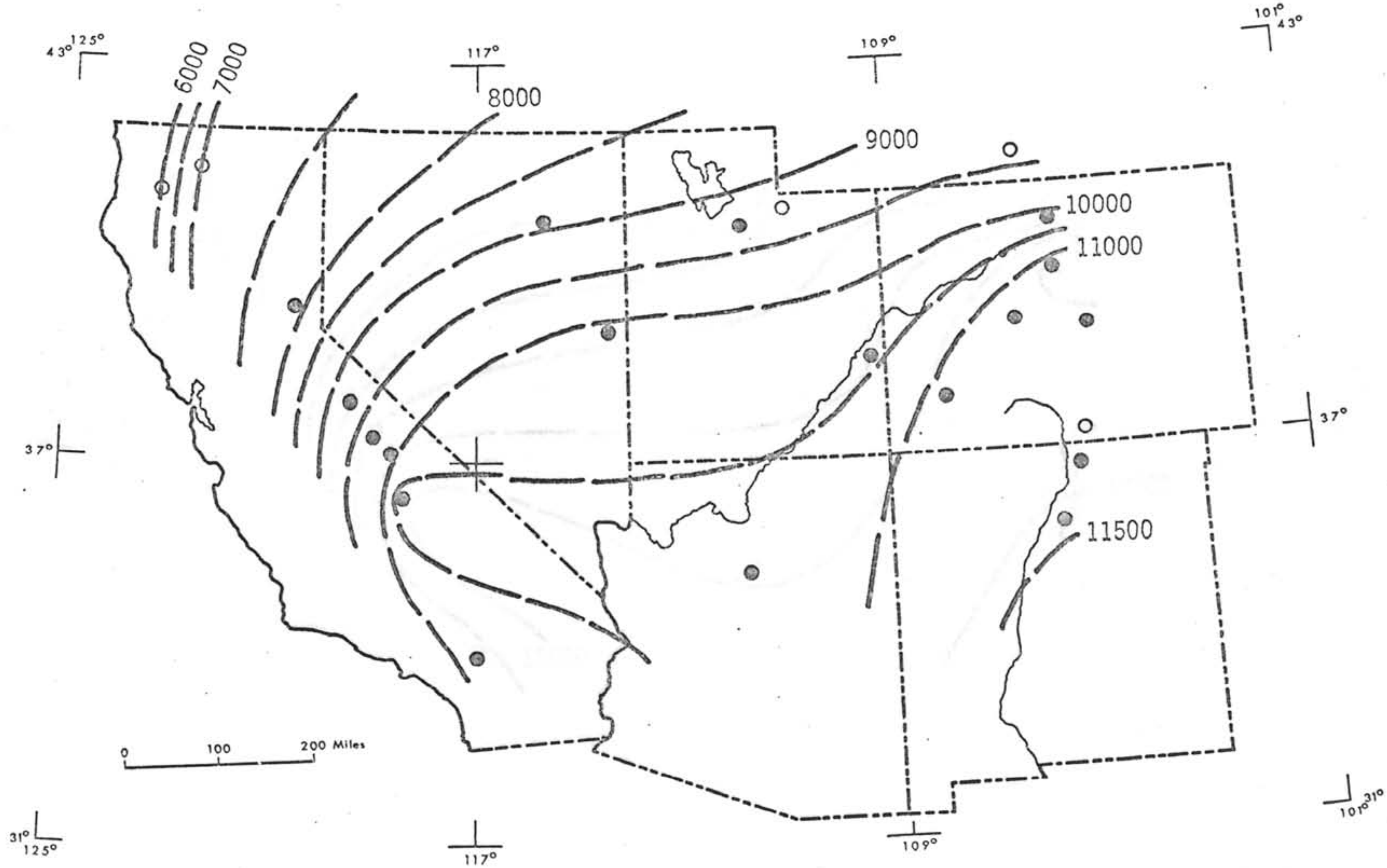

FIGURE 11. Altitudes of terminal moraines assignable to the latest pre-Neoglacial stade. Contour interval 500 feet. Solid dots denote study areas for which data are available (Table 46). Open dots denote study areas for which altitudes are estimated by extrapolation from Neoglacial terminal moraines.

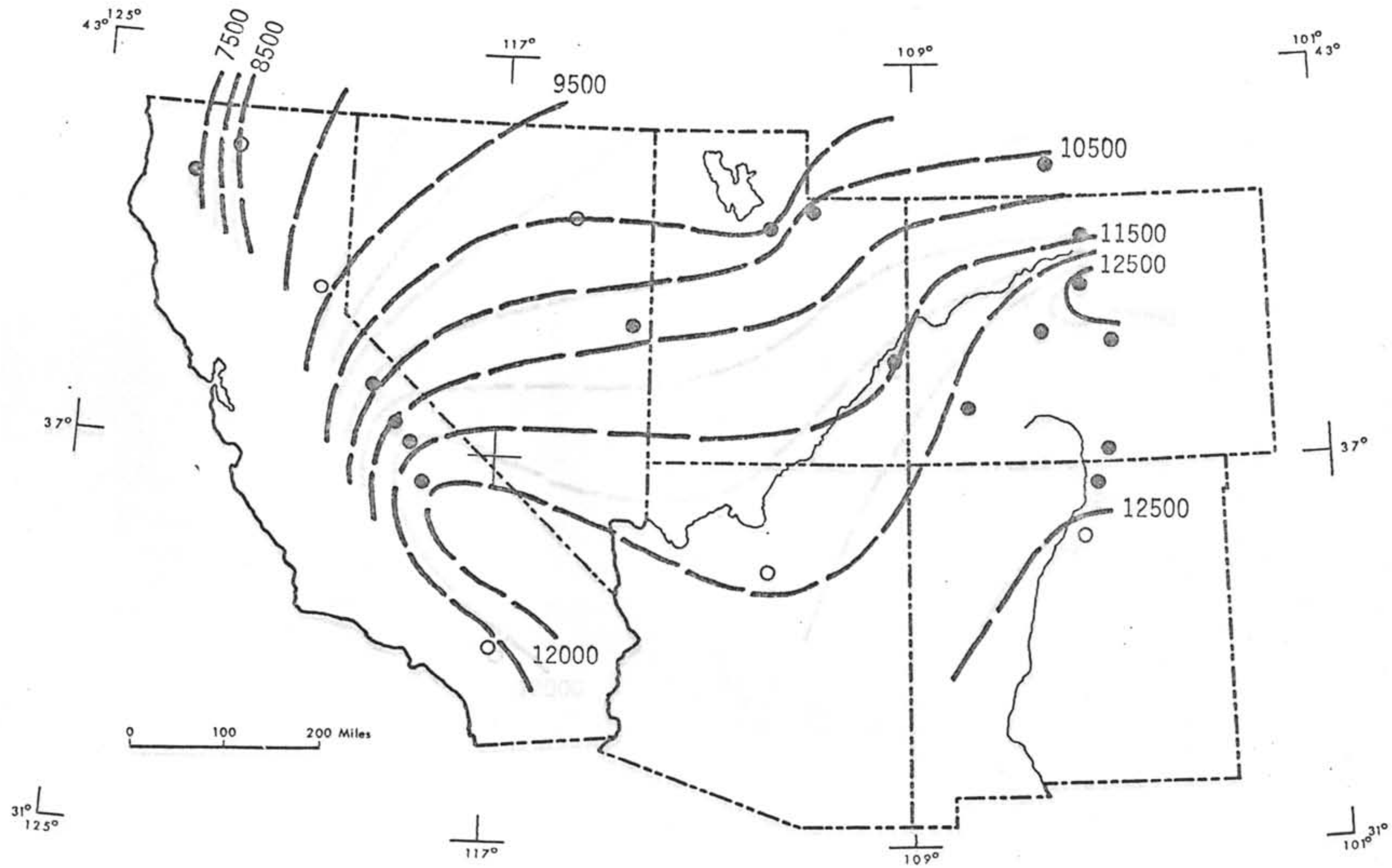

FIGURE 12. Altitudes of terminal moraines assignable to the earlier stade of Neoglaciation. Contour interval 500 feet. Solid dots denote study areas for which data are available (Table 46). Open dots denote study areas for which altitudes are estimated by extrapolation from terminal moraines of the latest pre-Neoglacial stade and the later stade of Neoglaciation.

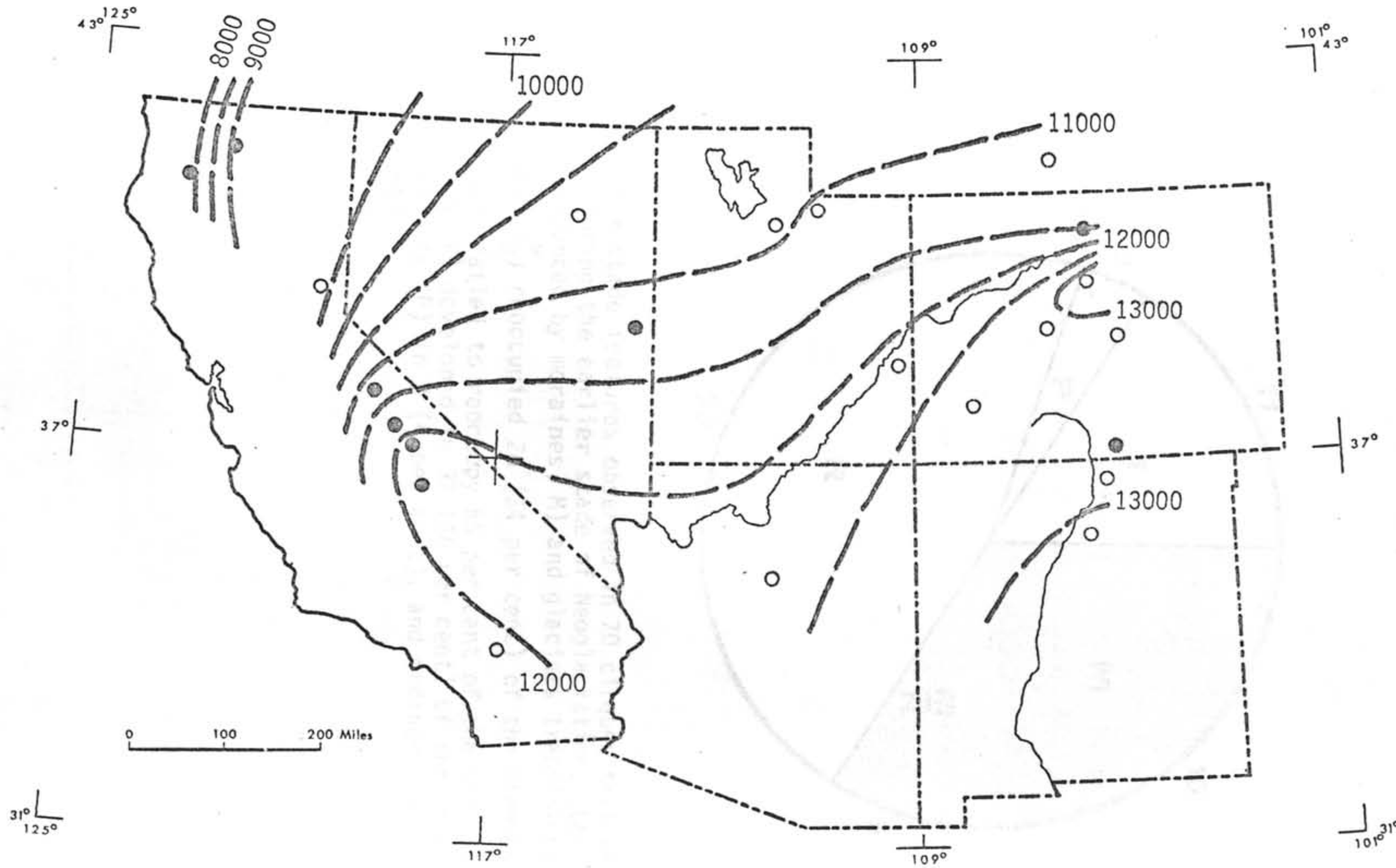

FIGURE 13. Altitudes of terminal moraines assignable to the later stade of Neoglaciation. Contour interval 500 feet. Solid dots denote study areas for which data are available (Table 46). Open dots denote study areas for which altitudes are estimated by extrapolation from terminal moraines of the earlier stade of Neoglaciation and the latest pre-Neoglacial stade.

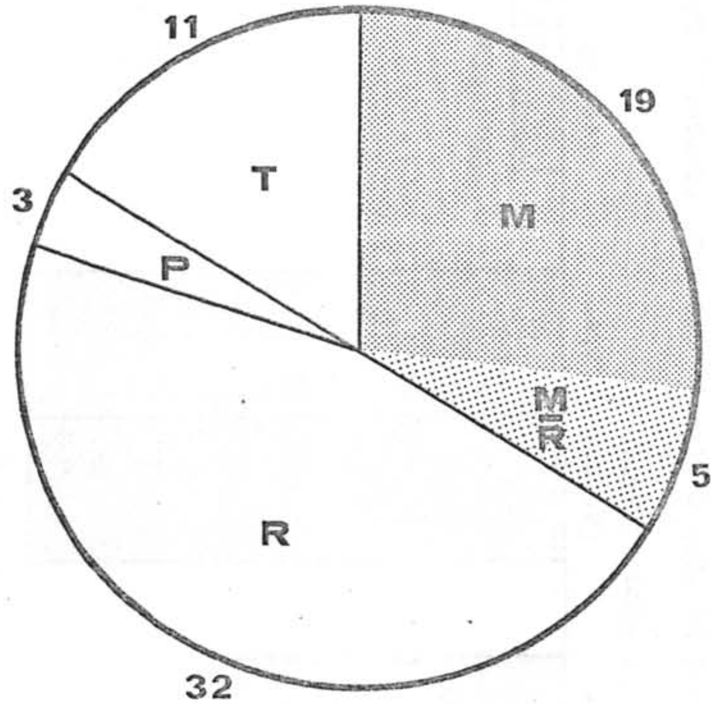

FIGURE 14. Later stade features observed in 70 cirques that were occupied by glaciers during the earlier stade of Neoglaciation. Later stade glaciers (evidenced by moraines, M) and glaciers transitional into rock glaciers ($\frac{M}{R}$) reoccupied 24 (34 per cent) of the cirques. Later stade glaciers failed to reoccupy 66 per cent of the cirques. Instead, rock glaciers (R) developed in 32 (46 per cent) of the cirques, protalus ramparts (P) in 3 (4 per cent), and ordinary talus (T) in 11 (16 per cent).

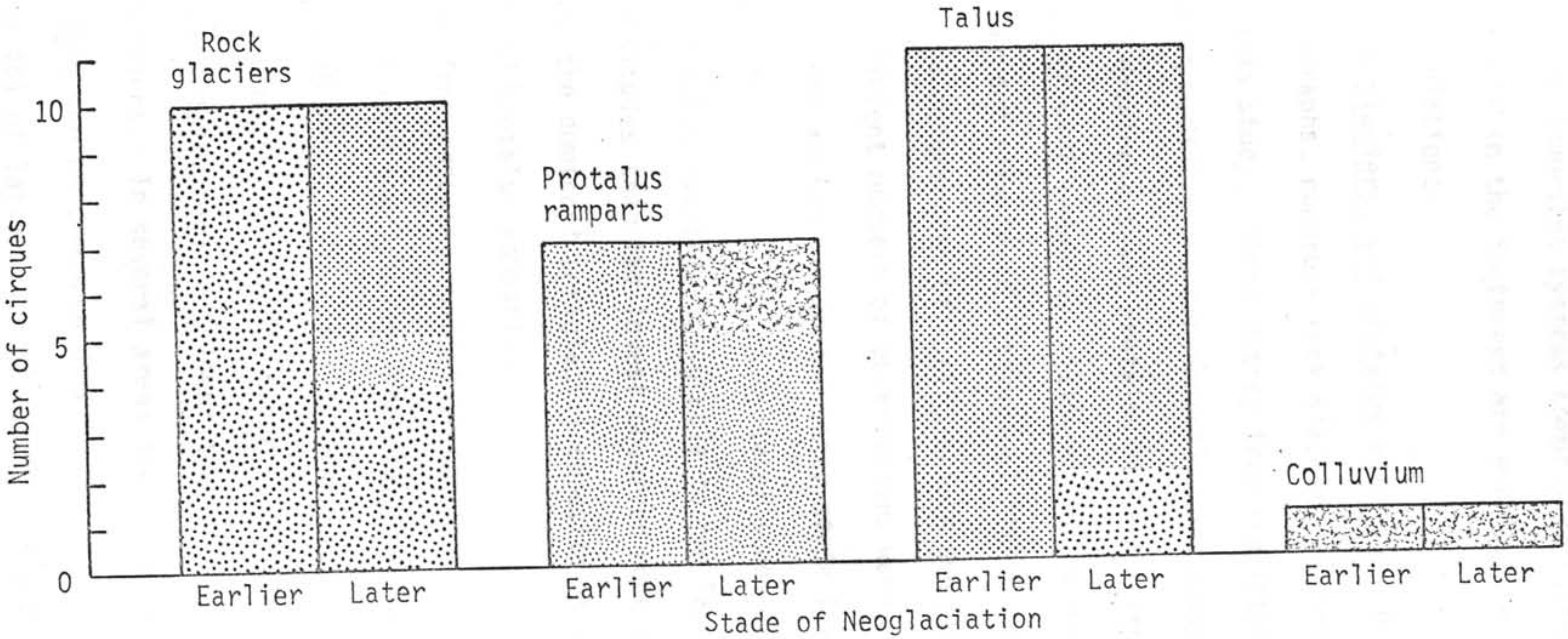

FIGURE 15. Later stade features in cirques occupied by rock glaciers, protalus ramparts, talus, and colluvium during the earlier stade of Neoglaciation.

Interrelations of Systems

Some of the more important systems comprising high-altitude Neoglacial environments in the Southwest are examined here in terms of their spatial interrelations.

<u>Glaciers, rock glaciers, and protalus ramparts</u>. Both in the field and in aerial photographs, numerous rock glaciers and protalus ramparts were observed in this study. Those dating from the later stade of Neoglaciation are least modified and consequently most conspicuous. Later stade rock glacier development and protalus rampart accretion appear to have operated through wide ranges of altitudes in individual areas, but always above rather definite lower altitudinal limits marked by one or more lowest observed occurrences of rock glaciers and protalus ramparts. In areas where sufficient numbers of observations were made, the lowest observed rock glaciers assignable to the later stade invariably terminate at altitudes lower than those attained by later stade glaciers, and the lowest observed protalus ramparts assignable to the later stade invariably occur at lower altitudes than the lowest observed rock glaciers. Talus and colluvium are the dominant periglacial deposits at altitudes below the lowest observed protalus ramparts.

Where known from adequate numbers of observations, the lower limits of later Neoglacial rock glaciers and protalus ramparts are indicated in Table 47. In the 10 areas where observations permit direct comparisons, the lowest observed protalus ramparts occur at altitudes averaging 495 ± 110 (standard deviation) feet lower than the termini of the lowest observed rock glaciers. In several areas the lower limits of these periglacial systems can be compared directly with the mean terminus altitudes (Table 46) of later stade glaciers. In seven areas the lowest

TABLE 47. Altitude of lowest observed rock glacier, R, assignable to the later stade of Neoglaciation, altitude of lowest observed protalus rampart, P, assignable to the later stade of Neoglaciation, altitudinal separation between R and P, and altitudes of R and P relative to mean altitude of terminal moraines, $\overline{M}$, (Table 46) assignable to the later stade of Neoglaciation.

STUDY AREA	Altitude (ft) R	Altitude (ft) P	Altitudinal separation (ft) R-P	Altitudinal separation (ft) $\overline{M}$-R	Altitudinal separation (ft) $\overline{M}$-P
MT. SHASTA, CALIF.	-----	-----	---	-----	-----
THOMPSON PEAK AREA, CALIF.	-----	6,500	---	-----	1,250
DONNER PASS AREA, CALIF.	-----	-----	---	-----	-----
TIOGA PASS AREA, CALIF.	9,400	-----	---	1,810	-----
MT. ABBOT AREA, CALIF.	10,000	-----	---	1,780	-----
PALISADE AREA, CALIF.	10,500	10,000	500	1,690	2,190
MT. WHITNEY AREA, CALIF.	10,400	10,000	400	1,900	2,300
SAN GORGONIO MTN., CALIF.	-----	-----	---	-----	-----
RUBY MTS., NEV.	9,900	9,600	300	-----	-----
SNAKE RANGE, NEV.	9,800	9,200	600	1,400	2,000
MT. AGASSIZ AREA, UTAH	-----	-----	---	-----	-----
WASATCH RANGE (MT. TIMPANOGOS AREA), UTAH	8,900	8,400	500	-----	-----
WASATCH RANGE (LITTLE COTTONWOOD CANYON), UTAH	9,300	-----	---	-----	-----
LA SAL MTS., UTAH	10,100	-----	---	-----	-----
TUSHAR MTS., UTAH	10,250	9,750	500	-----	-----
BOULDER MTN., UTAH	-----	-----	---	-----	-----
SAN FRANCISCO MTN., ARIZ.	-----	-----	---	-----	-----
BALDY PEAK, ARIZ.	-----	-----	---	-----	-----
SNOWY RANGE, WYO.	10,620	-----	---	-----	-----
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (INDIAN PEAKS AREA), COLO.	10,700	10,300	400	1,240	1,640
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (WITHIN THE PARK), COLO.	-----	-----	---	-----	-----
MT. EVANS AREA, COLO.	11,700	11,000	700	-----	-----
SAWATCH RANGE, COLO.	10,850	-----	---	-----	-----
PIKES PEAK, COLO.	11,250	-----	---	-----	-----
SAN MIGUEL MTS., COLO.	10,900	-----	---	-----	-----
CULEBRA RANGE, COLO.	10,700	-----	---	1,800	-----

TABLE 47, continued.

WHEELER PEAK AREA, N. M.	10,900	10,400	500	-----	-----
SANTA FE BALDY AREA, N. M.	11,500	10,950	550	-----	-----
SIERRA BLANCA PEAK, N. M.	-----	-----	---	-----	-----
			R-P	$\overline{M}$-R	$\overline{M}$-P
ALL STUDY AREAS			495	1,660	1,875
Number of areas			10	7	5

observed rock glaciers terminate at altitudes averaging 1,660 ± 240 feet lower than those attained by the glaciers, and in five areas the lowest observed protalus ramparts occur at altitudes averaging 1,875 ± 430 feet below the terminal moraines. Significant regional variation in these altitudinal separations is not identifiable from available data.

Lower altitudinal limits of glacial and periglacial systems in particular areas during the later Neoglacial stade are displayed graphically in Figure 16, where the mean lower limits of glaciers and the extreme lower limits of protalus ramparts are plotted with respect to the extreme lower limits of rock glaciers. In seven areas the mean terminus altitudes of glaciers fall along a trend line 1,660 feet above the lowest rock glacier termini, and in 10 areas the lowest protalus ramparts fall along a trend line 495 feet below the lowest rock glaciers. Although these samples are small, it is clear that the periglacial systems operated under climates significantly less severe than those which sustained the glacial systems.

Azimuths describing direction of exposure (p. 14) have been noted for many glacial and periglacial features in this study. The possibility that distinctive preferred orientations were assumed by different types of features is examined here. Data pertaining to exposure of glacial and periglacial systems are displayed graphically in Figure 17, where the lowest observed later stade terminal moraine, rock glacier, protalus rampart, and the lowest observed earlier stade terminal moraine in each area is plotted with respect to azimuth and altitude. The mean azimuth of the later stade moraines in 11 areas is 048 ± 39 (standard deviation) degrees, of the rock glaciers in 20 areas is 348 ± 50 degrees, of the protalus ramparts in 11 areas is 358 ± 46 degrees, and of the earlier

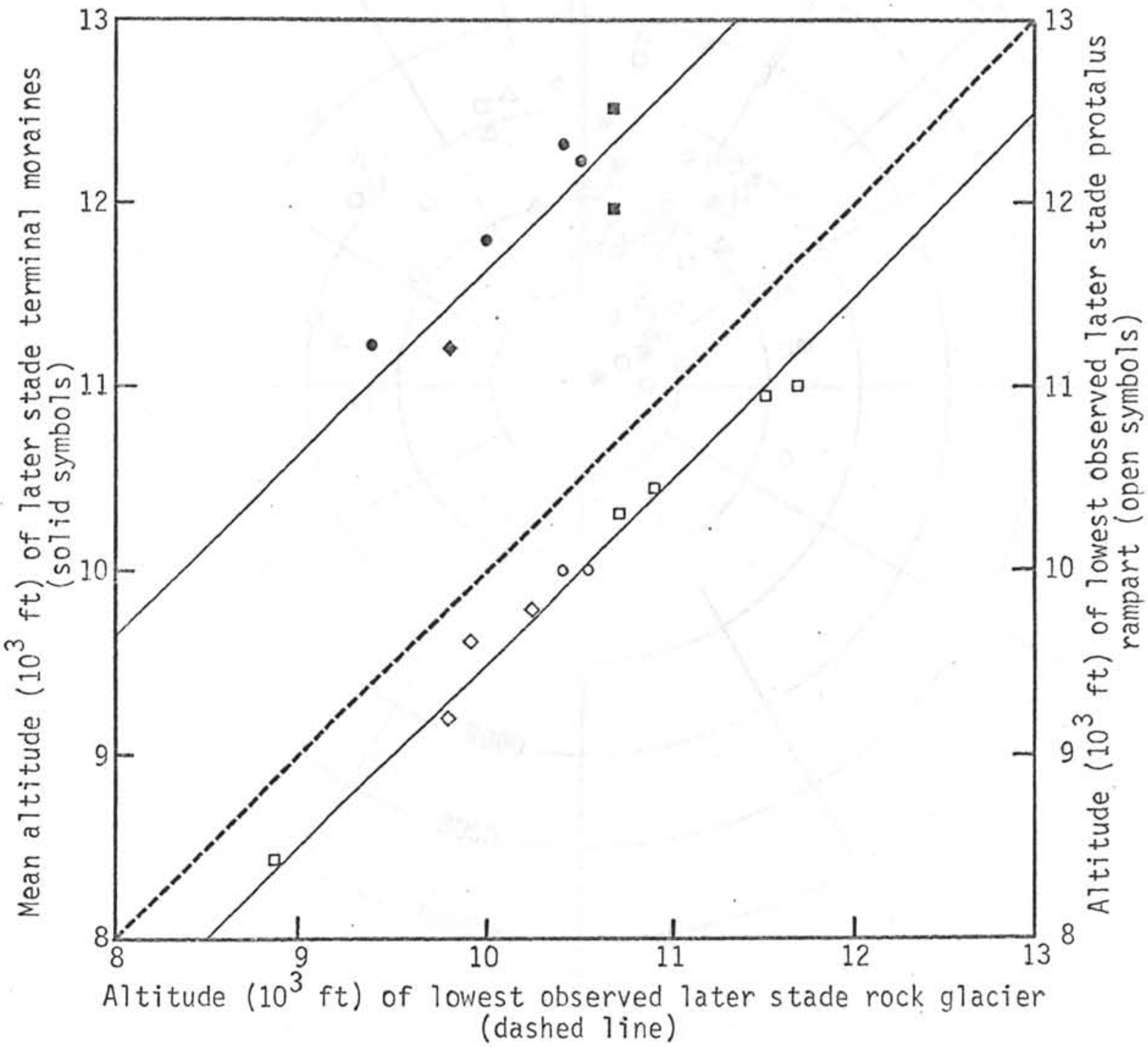

FIGURE 16. Mean altitude of terminal moraines assignable to the later stade of Neoglaciation and altitude of lowest observed protalus rampart assignable to the later stade of Neoglaciation, with respect to the altitude of the lowest observed rock glacier assignable to the later stade of Neoglaciation. Circles denote study areas in the Pacific mountain system, diamonds denote study areas in the intermontane provinces, and squares denote study areas in the Rocky Mountain system.

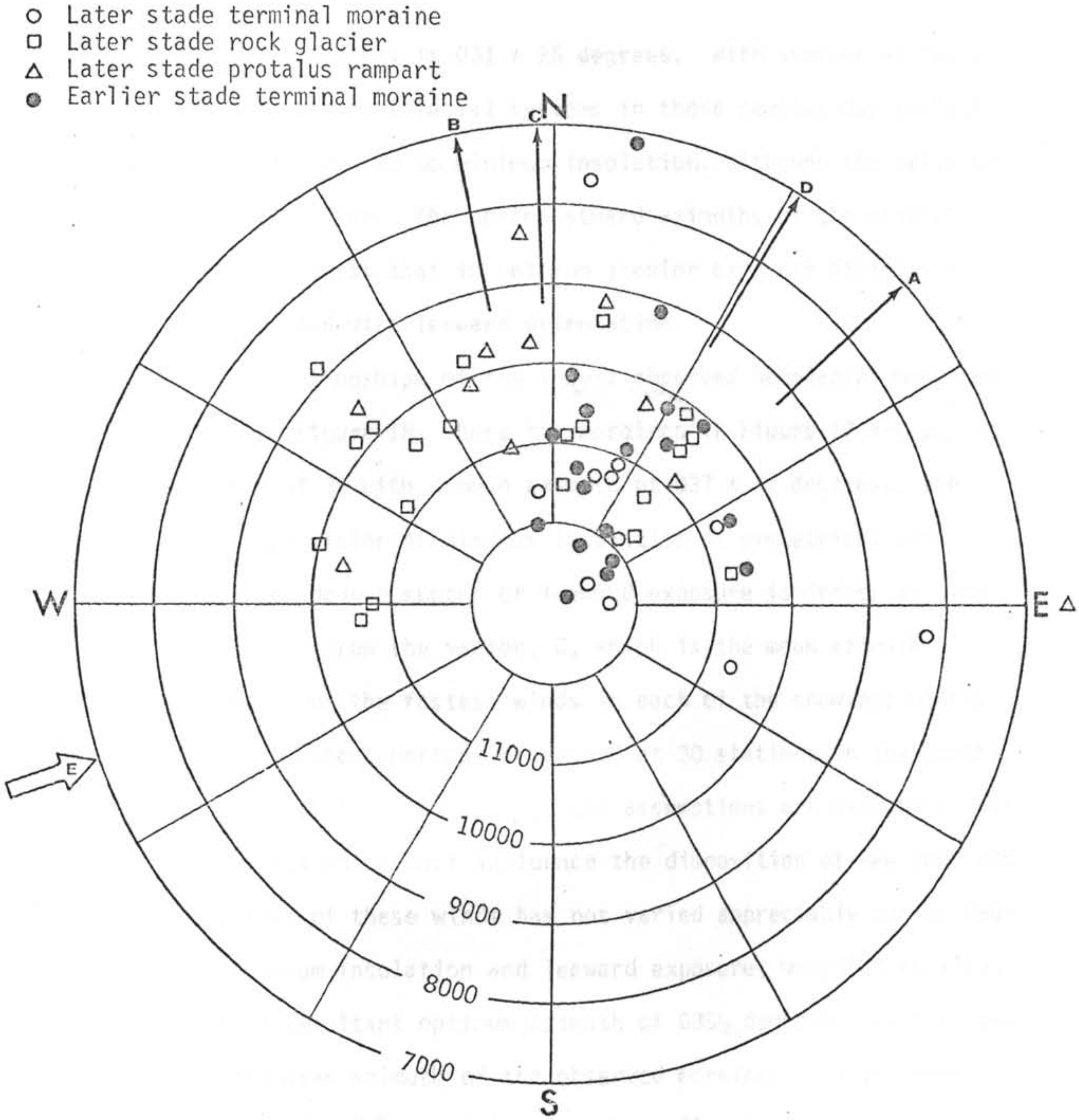

FIGURE 17. Azimuth and altitude (ft) of lowest observed Neoglacial features in each study area. A, mean azimuth of lowest later stade terminal moraines = 048° (11 areas). B, mean azimuth of lowest later stade rock glaciers = 348° (20 areas). C, mean azimuth of lowest later stade protalus ramparts = 358° (11 areas). D, mean azimuth of lowest earlier stade terminal moraines = 031° (19 areas). E, mean azimuth of fastest mile of wind, November through April, at 30 stations in the Southwest = 251° (U. S. Dept. of Commerce, 1964).

stade moraines in 19 areas is 031 ± 25 degrees. With average exposures toward the north, the periglacial systems in these samples may reflect optimum conditions related to minimum insolation, although the relationships are far from clear. The northeastward azimuths of the glacial systems strongly suggest that in optimum glacier exposure diminished insolation is coupled with leeward orientation.

Exposure relationships of the lowest observed Neoglacial moraines are elaborated in Figure 18, where the moraines in Figure 17 are pooled to make a sample of 30 with a mean azimuth of 037 ± 32 degrees. The 180-degree azimuth sector of minimum insolation is symmetrical about true north. A 180-degree sector of leeward exposure is indicated symmetrically downwind from the vector, C, which is the mean azimuth (251 ± 61 degrees) of the fastest winds in each of the snowiest months during relatively recent periods of record at 30 stations in the Southwest (U. S. Dept. of Commerce, 1964); the assumptions are made here that these are the winds which most influence the disposition of new snow and that the direction of these winds has not varied appreciably during Neoglaciation. Minimum insolation and leeward exposure, weighted equally, interact along a resultant optimum azimuth of 035½ degrees, which agrees closely with the mean azimuth of the observed moraines. In and near Rocky Mountain National Park, Colorado, where 28 existing glaciers have a mean azimuth of 051 degrees, the importance of topography that permits minimum summer insolation and maximum winter snow drift has been stressed by Outcalt and MacPhail (1965, p. 8 and 37).

Glaciers and biotic systems. Occurring with glacial and periglacial systems in high-altitude environments are distinctive biotic systems, with their own peculiar spatial distributions. Some biotic systems, such as

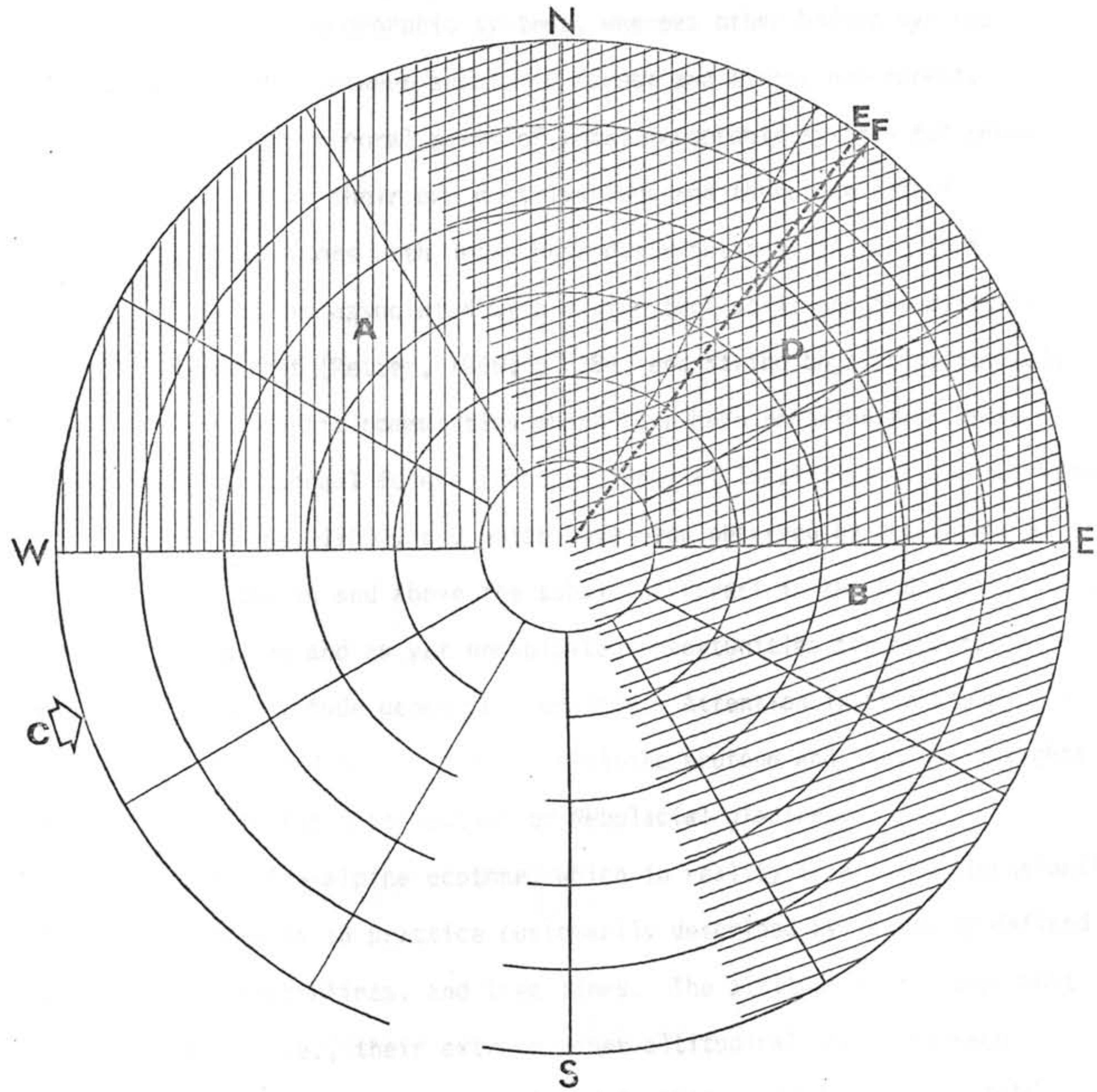

FIGURE 18. Exposure relationships of lowest observed Neoglacial moraines. A, 180° sector of minimum insolation; B, 180° sector of maximum snow drift, leeward with respect to C, the mean azimuth of fastest wind (Figure 17); D, 109° sector of maximum accumulation and minimum ablation; E, azimuth of optimum exposure = 035½°, resultant of A and B; and F, mean azimuth of lowest observed terminal moraines = 037° (30 moraines).

alpine turf vegetation and string bogs, are integral parts of certain zonally distributed geomorphic systems, whereas other biotic systems, such as the ecotone between subalpine forest and alpine non-forest, ordinarily are not integral parts of zonal geomorphic systems but nevertheless are zonal in their own distributions and therefore afford instructive comparisons with geomorphic distributions. Alpine turf vegetation, which is associated with alpine turf soils and the distribution of permafrost (Retzer, 1965, p. 38), and string bogs, distinctively structured hygrophytic communities which have been reported from areas in and north of the boreal forest (Henoch, 1960) at localities having degraded permafrost (Schenk, 1963), and which have been observed by the author at a number of sites in and above the subalpine forest in the Southwest, present intriguing and as yet unexploited opportunities for more fully exploring high-altitude geomorphic systems. Attention in this study, however, is directed to the subalpine-alpine ecotone and possible insights it provides into the distribution of Neoglacial glaciers.

The subalpine-alpine ecotone, which in reality is a three-dimensional transition zone, is in practice customarily described by variously defined forest lines, timberlines, and tree lines. The altitude of the uppermost observed trees, i.e., their extreme upper altitudinal limit, in each observed area is the parameter employed in this study (page 16). This limit is summarized by study area in Table 48. Adequate information is not available for three areas and four are clearly not high enough to intercept an upper tree limit. In 21 of the areas, however, the upper limit of trees was determined through innumerable observations, both in the field and by stereoscopic examination of large-scale aerial photographs. The uppermost observed trees in most areas occur on slopes having southerly

TABLE 48. Altitude of uppermost observed trees[a] and altitudinal separation between the mean altitude of terminal moraines assignable to the later stade of Neoglaciation (Table 46) and the altitude of uppermost observed trees.

STUDY AREA	Altitude (ft) of uppermost observed trees	Altitudinal separation (ft) between later stade moraines and uppermost trees
MT. SHASTA, CALIF.	9,500	-350
THOMPSON PEAK AREA, CALIF.	9,000	-1,250
DONNER PASS AREA, CALIF.	>8,885	---
TIOGA PASS AREA, CALIF.	11,100	+110
MT. ABBOT AREA, CALIF.	no observations	---
PALISADE AREA, CALIF.	11,600	+590
MT. WHITNEY AREA, CALIF.	11,800	+500
SAN GORGONIO MTN., CALIF.	11,300	---
RUBY MTS., NEV.	10,950	---
SNAKE RANGE, NEV.	11,400	-200
CHARLESTON PEAK, NEV.	11,550	---
MT. AGASSIZ AREA, UTAH	11,300	---
WASATCH RANGE, UTAH	no observations	---
LA SAL MTS., UTAH	11,600	---
TUSHAR MTS., UTAH	11,400	---
BOULDER MTN., UTAH	>11,328	---
SAN FRANCISCO MTN., ARIZ.	12,000	---
BALDY PEAK, ARIZ.	>11,590	---
SNOWY RANGE, WYO.	11,350	---
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY, COLO.		
Within the Park	11,600	-275
Indian Peaks area	11,600	+340
MT. EVANS AREA, COLO.	11,950	---
SAWATCH RANGE, COLO.	12,100	---
PIKES PEAK, COLO.	12,250	---
SAN MIGUEL MTS., COLO	12,000	---
CULEBRA RANGE, COLO.	no observations	---
WHEELER PEAK AREA, N. M.	12,350	---
SANTA FE BALDY AREA, N. M.	12,400	---
SIERRA BLANCA PEAK, N. M.	>12,003	---

Source: field observations and aerial photograph interpretation by author.

[a]Woody plants with single main stems more than 8 ft tall (Hanson, 1962, p. 353).

exposure and in every area belong to the family Pinaceae. The uppermost trees at each of several localities within a particular area are generally found at remarkably accordant altitudes.

As inferred from the altitudes in Table 48, the present upper limit of trees in the Southwest is represented in Figure 19. The basic configuration of the tree limit surface is quite similar to that of the surfaces describing the mean lower limits of glacierization, depicted in Figures 11, 12, and 13. However, that the former and the latter are by no means coincident or parallel is evident from the altitudinal separations in Table 48. This is indicated even more clearly in Figure 20, where the mean lower limits of glacierization in seven areas during the later Neoglacial stade and in 14 areas during the earlier stade are plotted with respect to the present upper limits of trees in those areas. Trend lines describing glacier termini lie above tree limit at higher altitudes and below that limit at lower altitudes.

A spatial comparison of the lower limit of glaciers and the upper limit of trees, inferred from data in Tables 46 and 48, and by algebraic subtraction of the surfaces depicted in Figures 13 and 19, appears in Figure 21, where the mean altitudes of actual and inferred later stade terminal moraines are described with respect to the uppermost altitudes of the present trees. Four main patterns stand out in this comparison of glacial and biotic systems in the Southwest: (1) lower glacier limit and upper tree limit both decline poleward and seaward; (2) lower glacier limit generally declines more steeply in each direction; (3) the most abrupt decline of lower glacier limit relative to upper tree limit is in areas of greatest oceanicity; and (4) the most abrupt rise of lower glacier limit relative to upper tree limit is in central Colorado.

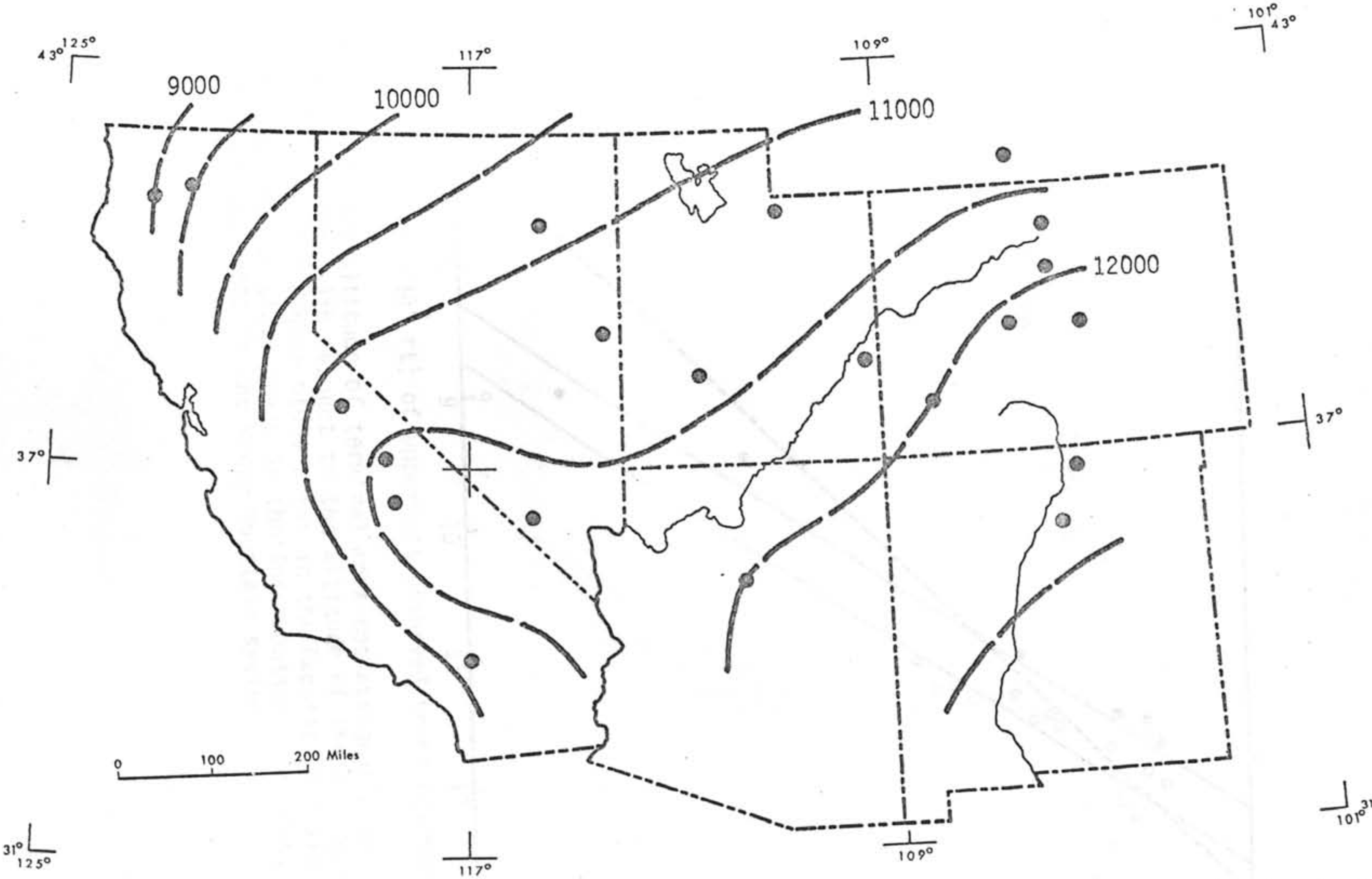

FIGURE 19. Altitudes of uppermost observed trees. Contour interval 500 feet. Dots denote study areas for which data are available (Table 48).

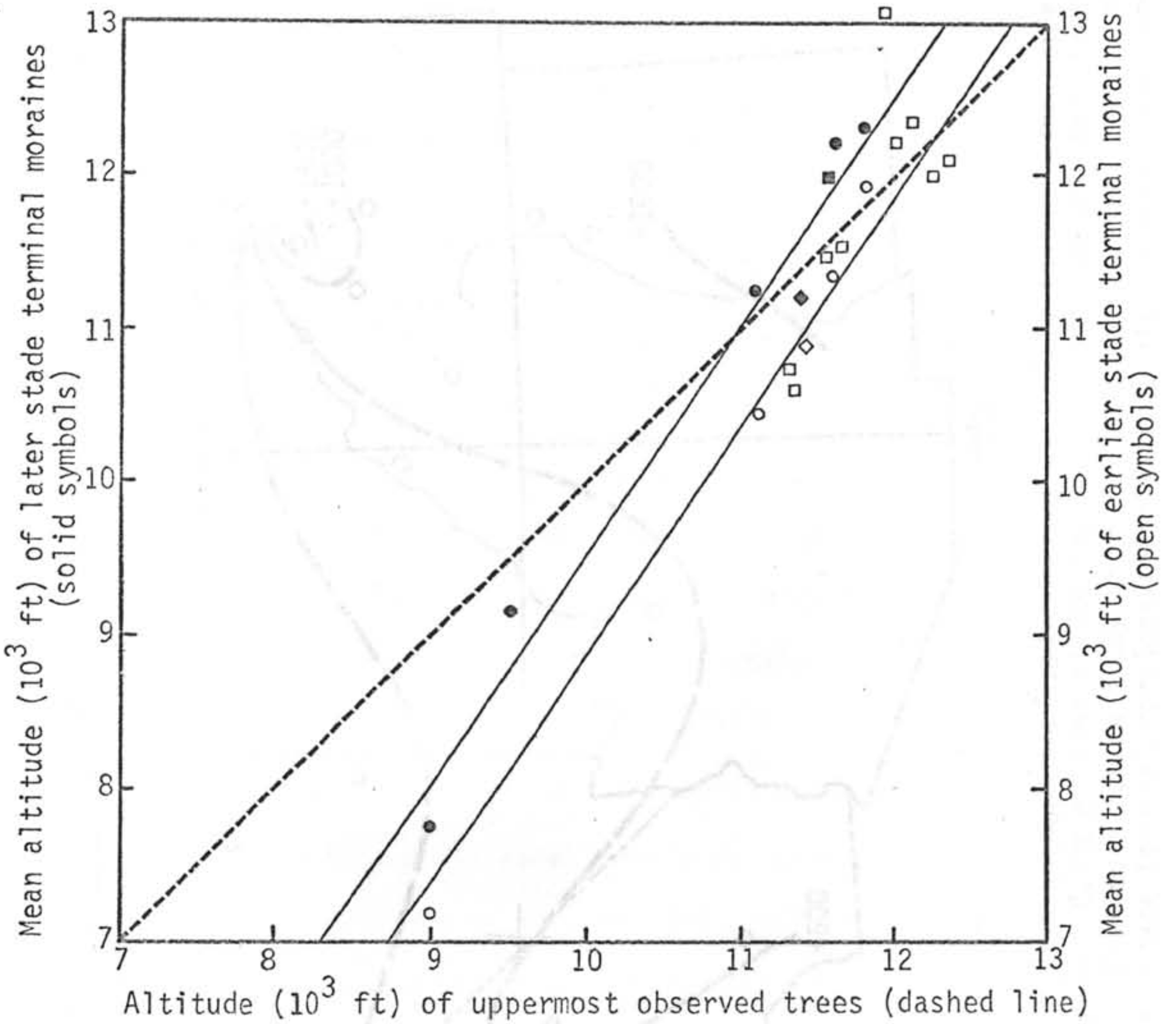

FIGURE 20. Mean altitude of terminal moraines assignable to stades of Neoglaciation, with respect to the altitude of the uppermost observed trees. Circles denote study areas in the Pacific mountain system, diamonds denote study areas in the intermontane provinces, and squares denote study areas in the Rocky Mountain system.

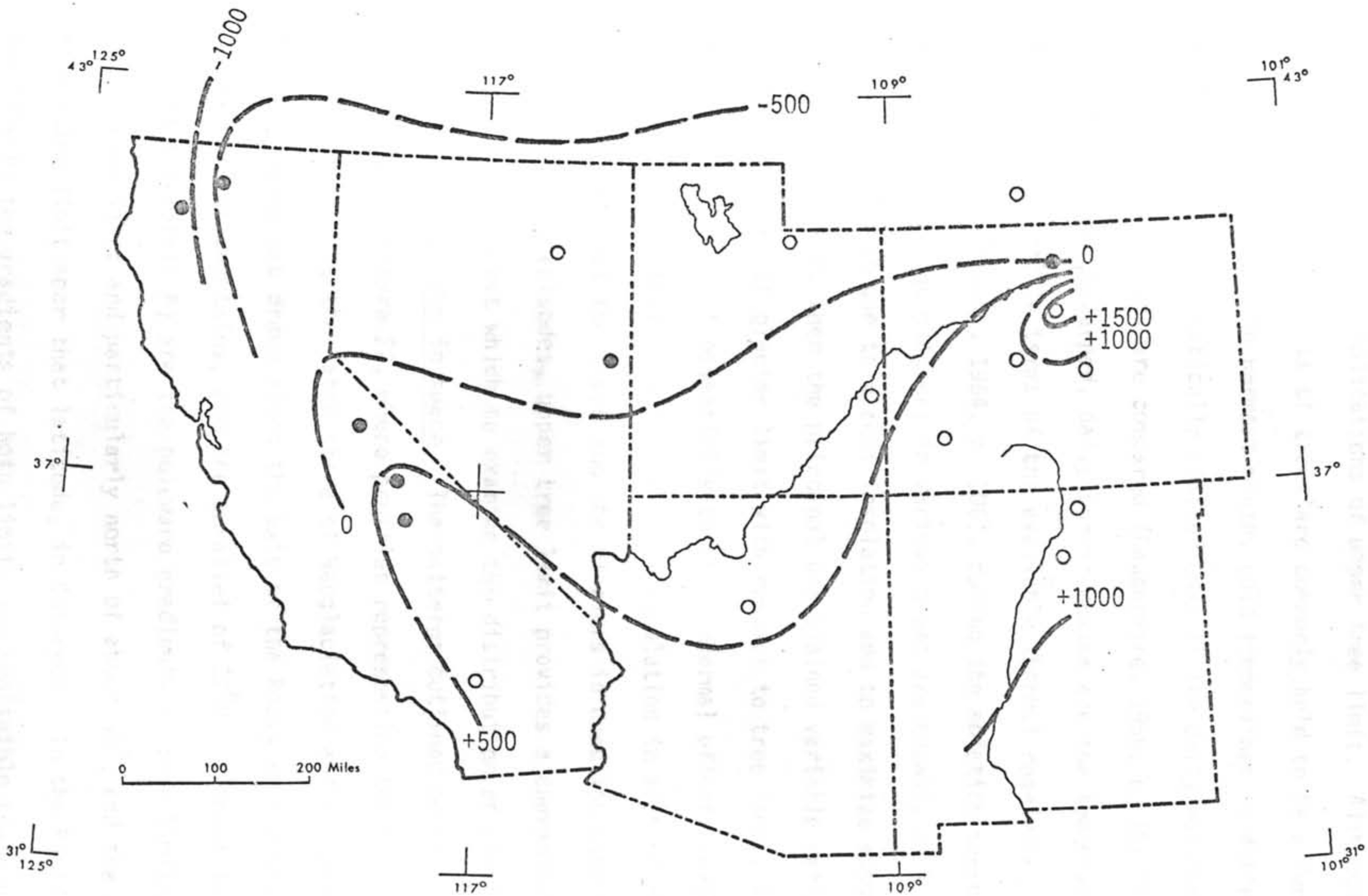

FIGURE 21. Altitudinal separation between terminal moraines assignable to the later stade of Neoglaciation and uppermost observed trees. Contour interval 500 feet. Solid dots denote study areas for which data are available (Table 48). Open dots denote study areas for which altitudinal separation is estimated, the altitudes of the later stade terminal moraines being extrapolated from earlier terminal moraines.

More complete interpretation of Figure 21 requires consideration of the glacio-climatic implications of upper tree limit. Although polar and upper altitudinal limits of trees are commonly held to be a function of the temperature of the warmest month, cold timberlines in different parts of the world are climatically similar only if the daily maximum temperatures of the warmest months are compared (Daubenmire, 1959, p. 182-183). Insofar as glaciers are concerned, daily summer maxima are the temperatures that are most critical in terms of the available thermal reservoir, or thermal effectiveness (Marcus, 1964, p. 106), during the ablation season. Assuming that on the average glaciers in various areas are equally well oriented to minimize ablation due to direct insolation and to maximize accumulation due to wind drift, then the principal unexplained variable reflected in regional changes of glacier limit with respect to tree limit, i.e., with respect to a level of essentially constant thermal effectiveness, is the amount of precipitation available for accumulation in each of the areas. To the extent that the trees and the glaciers in question stem from comparable climatic episodes, upper tree limit provides a convenient and meaningful datum against which to examine the distribution of glacial systems.

Glacial systems in space. The patterns outlined on page 153 are conspicuous in Figure 22, where profiles representing the mean lower limit of glaciers during the later stade of Neoglaciation and the present upper limit of trees are drawn along the axis of the Rocky Mountains, the axis of the Pacific mountains, and the parallel of 37°N. Evident in the Rocky Mountains (profile A) are the poleward gradients of both limits, particularly the glacier limit and particularly north of about 39°, and the abrupt rise of glacier limit near that latitude, in Colorado. In the Pacific mountains (profile B) the gradients of both limits are negligible south of about 36°

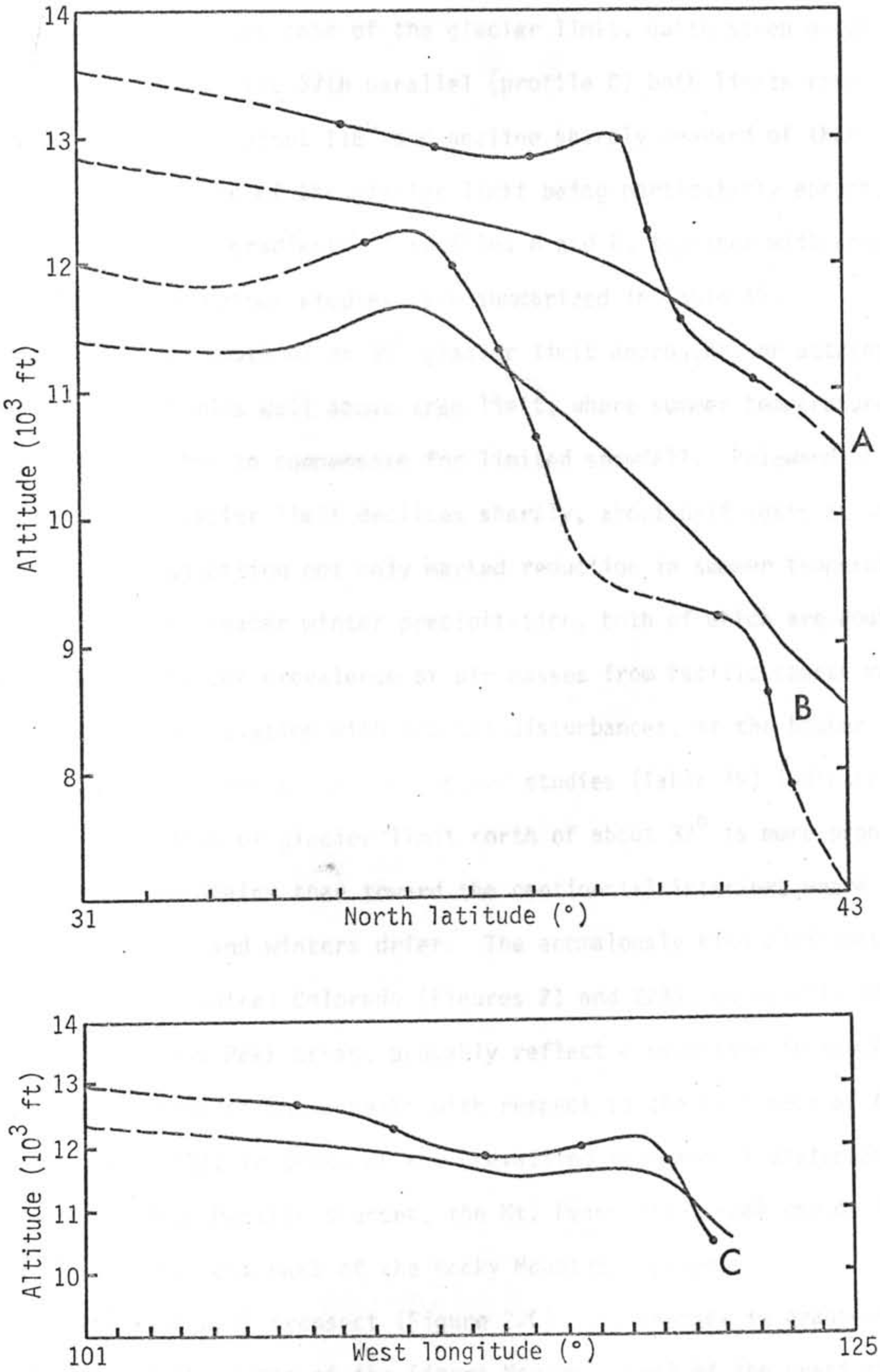

FIGURE 22. Latitudinal profiles in the Rocky Mountain system (A) and Pacific mountain system (B), and E-W profiles at 37°N (C), showing mean altitudes of terminal moraines (beaded lines) and altitudes of uppermost observed trees. Data from Figures 13 and 19.

and, particularly in the case of the glacier limit, quite steep north of that latitude. Along the 37th parallel (profile C) both limits rise gradually inland from about 118^{O} and decline sharply seaward of that longitude, the decline of the glacier limit being particularly abrupt. The average poleward gradients of profiles A and B, together with comparable data from previous studies, are summarized in Table 49.

In latitudes south of 36-39^{O} glacier limit approaches or attains a plateau at altitudes well above tree limit, where summer temperatures are sufficiently low to compensate for limited snowfall. Poleward of those latitudes glacier limit declines sharply, about half again as steeply as tree limit, suggesting not only marked reduction in summer temperatures, but substantially greater winter precipitation, both of which are doubtless related to the greater prevalence of air masses from Pacific source regions, particularly in association with frontal disturbances, at the higher latitudes. The results of this and other studies (Table 49) indicate that the poleward decline of glacier limit north of about 37^{O} is more pronounced in the Pacific mountains than toward the continental interior, where summers are warmer and winters drier. The anomalously high altitudes of glacier limit in central Colorado (Figures 21 and 22A), especially in the Mt. Evans and Pikes Peak areas, probably reflect a reduction in snowfall due to the position of those peaks with respect to the main mass of the Rockies (Figure 23); in terms of the prevailing movement of disturbances involving air from Pacific sources, the Mt. Evans-Pikes Peak region is in the lee of the highest part of the Rocky Mountain system.

In the east-west transect (Figure 22C), the changes in gradients near 118^{O}W mark the crest of the Sierra Nevada. East of the crest the seaward gradient (in feet per degree of longitude) of glacier limit is

TABLE 49. Approximate latitudinal gradients (ft per ^{o}lat) of Neoglacial and pre-Neoglacial altitudinal surfaces.

Altitudinal surface	Pacific mountain system		Rocky Mountain system	
	33^{o}N to 37^{o}N	37^{o}N to 42^{o}N	33^{o}N to 37^{o}N	37^{o}N to 42^{o}N
Mean altitude of later Neoglacial terminal moraines (this study, Figure 22)	0	-770	-120	-370
Uppermost observed trees (this study, Figure 22)	0	-480	-80	-240
Mean altitude of existing glaciers <0.5 km^2 (Meier, 1961, p. 422, 423)	---	-660	---	-380
Mean altitude of latest pre-Neoglacial terminal moraines (Richmond, 1965, p. 224)	---	---	-150	-460
Latest pre-Neoglacial orographic snowline[a] (Richmond, 1965, p. 225)	---	---	0	-200
Pre-Neoglacial climatic firn limit[b] (Wahrhaftig and Birman, 1965, p. 304, 309)	---	-900	---	---
Mean altitude of floors of lowest pre-Neoglacial cirques (Flint, 1957, p. 309)	0	-800	0	-300
Alpine timberline[c] (Daubenmire, 1954, p. 126)	---	-460	-160	-260

[a]Based on average median altitude between terminal moraine and cirque headwall.

[b]Based on summit altitudes of lowest peaks to have glaciers on their S-facing sides.

[c]Altitude midway between upper edge of continuous forest and uppermost stunted tree.

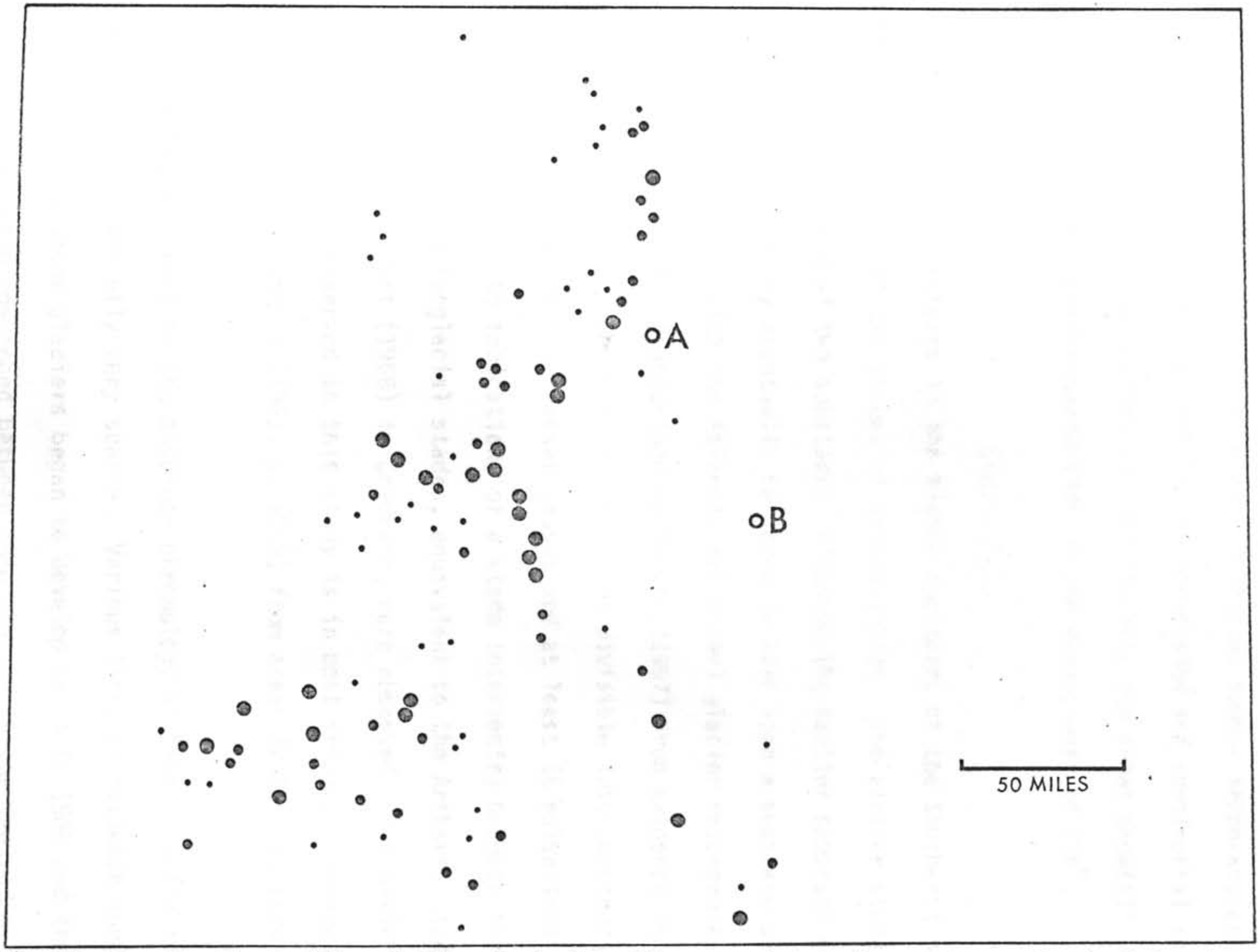

FIGURE 23. Mt. Evans (A) and Pikes Peak (B) with respect to other major peaks in Colorado. Summit altitudes of 12,000-12,999 feet are denoted by small dots, of 13,000-13,999 feet by medium dots, and of 14,000 feet and over by large dots. (Adapted from World Aeronautical Chart sheets 306, 361, and 362.)

-50 and that of tree limit is -40, whereas to the west the seaward gradient of the former is -600 and that of the latter is -330. These gradients reflect well known tendencies toward increasing summer temperatures and diminished winter precipitation in the rainshadow and continental interior, and the quite opposite tendencies, particularly the great snowfall, that prevail on the windward-seaward side of the range, west of 118°.

Conclusions

Geomorphic features in the higher mountains of the Southwest present abundant evidence of two stades of Neoglaciation. The earlier stade probably consisted of two substades, although the earlier substade of the earlier stade may eventually be shown to have been a separate stade, perhaps correlative with the Atlantic/sub-Boreal glacier resurgence (ca. 3200 to 2600 B.C.) described by Mercer (1967) from evidence in many parts of the world. The later stade is not divisible into substades, but did comprise three or four lesser phases and at least 16 pulsations of glacial activity. No indications of a stade intervening between the earlier and later Neoglacial stades, equivalent to the Arikaree Stade described by Benedict (1968) in Colorado, were observed. The basic pattern of Neoglaciation observed in this study is in most respects comparable to that reported by Beschel (1961, p. 1058) from areas in Africa, Europe and Greenland.

Data pertaining to the absolute chronology of Neoglaciation in the Southwest are presently very sparse. Various lines of evidence suggest that the later stade glaciers began to develop ca. A.D. 1500 and that the present interphase commenced between 1860 and 1885. The few radiocarbon dates that are available suggest that the later substade of the earlier stade occurred during the first half of the first millennium B.C. It is to be anticipated that more adequate data will be forthcoming from detailed stratigraphic studies of firn and ice in existing glaciers, including paleotemperature studies of the ice by the oxygen-isotope method (Sharp, 1960b, p. 69-73); from many more radiocarbon age determinations of organic materials associated with glacial and periglacial features, including ice cores within moraines (Østrem, 1961) and rock glaciers; and from increasing use of tree-ring chronologies extending even into pre-Neoglacial times, perhaps in conjunction with paleotemperature studies based on oxygen isotopes in xylem of known age.

Neoglacial glaciers attained diminishing sizes during successive stades and were much less extensive than those of the latest pre-Neoglacial

TABLE 50. Average linear, areal, and altitudinal extent of glacial systems during Neoglaciation, relative to their extent at the same localities during the latest pre-Neoglacial stade.

Episode	Downvalley distance	Area	Terminus altitude (ft)
Modern interphase	0.06	0.024	>1750
Later Neoglacial stade	0.10	0.05	1750
Mid-Neoglacial interstade	0.00	0.00	----
Earlier Neoglacial stade	0.28	0.19	1175
Altithermal interglaciation	0.00	0.00	----
Latest pre-Neoglacial stade (datum)	1.00	1.00	0

stade. Glacier ice probably disappeared from the Southwest during the Altithermal and mid-Neoglacial intervals, and many glaciers that had been of less than certain critical minimum sizes prior to those intervals failed to reappear subsequently. Although satisfactory measurement of sequential periglacial parameters is yet to be accomplished, it is clear that during succeeding stades periglacial systems assumed successively higher altitudes, occupying sites that previously had been occupied by glaciers or periglacial systems of higher rank.

The model introduced in Figure 1 (page 7), in which high-altitude geomorphic systems constitute a spatial continuum, related in part to abundance of constituent materials, is consistent with information developed in this study. Average altitudinal amplitudes of those systems, relative to one another, emerge from numerous observations of later stade features in the Southwest: the lowest limit of rock glacier activity occurs about 1,660 feet below the mean lower limit of glacierization, a relationship comparable to that in central Alaska, where the lowest active rock glaciers terminate about 1,300 feet below the mean lower limit of existing glaciers (Wahrhaftig and Cox, 1959, p. 410-411); the lowest limit of protalus rampart development occurs about 500 feet below the lowest rock glaciers; and at still lower altitudes talus and colluvium are the dominant periglacial deposits. The optimum exposure of glacial systems is northeastward, reflecting a balance between minimum insolation and maximum snow drift, whereas that of rock glaciers and protalus ramparts is northward, apparently reflecting a greater dependence on minimum temperatures than on snow accumulation. Comparisons between the lower limit of glaciers and the upper limit of trees underscore (a) the importance of daily summer maximum temperatures on both and (b) the effects of regional variation in winter snowfall on the former, particularly where glacier limit is sharply depressed by heavy snowfall, as in the Pacific mountains, or abruptly elevated by light snowfall, as in central Colorado. Additional studies of existing firn patches, of the type begun in the Snowy Range, Wyoming (Figure 3, page 71) will be essential to a fuller understanding of the transition between glacial and periglacial environments.

APPENDIX A

SOURCES OF DATA: AERIAL PHOTOGRAPHS

STUDY AREA	Agency[a] holding neg.	Date flown	Contact print scale	Project symbol, film roll, and frame numbers
MT. SHASTA, CALIF.	USFS	7-27-61	1:15840	EJG-1-178 to 183
		7-28-61		EJG-2-130 and 131, 154 to 161, 169 to 177
THOMPSON PEAK AREA, CALIF.	USFS	8-20-64	1:15840	ENU-16-23 to 28
TIOGA PASS AREA, CALIF.	USFS	8-24-63	1:15840	EMH-3-24 to 30, 70 to 76, 84 to 91
PALISADE AREA, CALIF.	USFS	8-7-62	1:15840	ELI-4-123 to 128
		8-18-62		ELI-5-58 to 63
		8-29-62		ELI-4-190 to 194
MT. WHITNEY AREA, CALIF.	USGS	10-6-48	1:53000	HP-1-89 to 91
	USFS	8-19-62	1:15840	ELI-5-244 and 245
		7-16-64		FPC-26-6 to 12
				FPC-27-5 to 11
		7-17-64		FPC-25-9 to 14
SAN GORGONIO MTN., CALIF.	ASCS	2-22-53	1:20000	AXL-47K-182 to 185
				AXL-48K-9 to 11
RUBY MTS., NEV.	USFS	10-16-61	1:15840	EIW-6-78 to 83
SNAKE RANGE, NEV.	USGS	10-2-45	1:39200	BW-1-64 to 69, 74 to 79
	USFS	7-7-62	1:15840	EIW-16-72 to 81
		7-8-62		EIW-17-68 to 75, 83 to 94
		8-25-62		EIW-16-160 to 162
MT. AGASSIZ AREA, UTAH	USFS	9-29-56	1:20000	EBW-16-49 to 55
		8-9-57		EBW-20-115 to 119
		9-14-57		EBW-25-165 to 170
WASATCH RANGE, UTAH	USGS	7-10-46	1:51000	CV-4-38 and 39

LA SAL MTS., UTAH	USFS	8-6-62	1:15840	EIV-4-12 to 15, 50 to 53
TUSHAR MTS., UTAH	ASCS	6-26-58	1:20000	DIF-5V-104 and 173 DRZ-5V-105 to 110, 174 to 179
SAN FRANCISCO MTN., ARIZ.	USFS	9-3-59	1:15840	EGE-3-15 to 19 EGE-4-54 to 58
		10-22-59		EGE-28-130 to 136
BALDY PEAK, ARIZ.	USFS	6-25-60	1:15840	EGX-16-184 to 187
SNOWY RANGE, WYO.	USFS	9-30-55	1:20000	DZV-6-22 to 27, 109 to 114
		10-14-56		DZV-18-122 to 129
ROCKY MTN. NAT'L. PARK AND VICINITY, COLO.	USFS	9-26-56	1:20000	DZZ-1-49 to 56
		9-24-57		DZZ-17-16 to 18 ECB-23-184 to 186
MT. EVANS AREA, COLO.	USFS	9-15-56	1:20000	ECB-8-80 to 85
		9-17-56		ECB-12-10 to 17
SAWATCH RANGE, COLO.	USFS	10-20-56	1:20000	DZZ-15-39 to 43
		9-21-58		DZZ-21-63 to 68
PIKES PEAK, COLO.	USFS	9-4-56	1:20000	ECB-4-38 to 43, 147 to 153
		10-20-56		ECB-22-152 and 153
SAN MIGUEL MTS., COLO.	USFS	10-13-64	1:20000	ENP-10-55 to 61, 137 to 143
		10-22-64		ENP-18-253 to 259
CULEBRA RANGE, COLO.	USGS	10 Oct 53	1:53000	133AU-1687 to 1692
		17 June 54		133AU-3460 to 3462
	USFS	9-29-56	1:20000	ECA-1-01 to 16
		10-14-56		ECA-1-148 and 149
WHEELER PEAK AREA, N. M.	USFS	10-22-58	1:15840	EEB-4-146 to 151
		10-23-58		EEB-5-86 to 90
		9-23-59		EEB-10-51 to 55
SANTA FE BALDY AREA, N. M.	USGS	25 Oct 48	1:43200	EN-4-12 and 13
	USFS	7-23-58	1:15840	EEB-2-29 to 34
		10-3-58		EEB-2-176 to 182
		6-10-59		EEB-8-54 to 56
SIERRA BLANCA PEAK, N. M.	USFS	11-9-58	1:15840	EDF-2-156 to 158 EDF-3-11 to 13

[a]ASCS = Agricultural Stabilization and Conservation Service, USFS = United States Forest Service, USGS = United States Geological Survey.

APPENDIX B

SOURCES OF DATA: TOPOGRAPHIC MAPS[a]

STUDY AREA	Name of sheet	Scale	C.I. (ft)	Publ'n year
MT. SHASTA, CALIF.	Shasta Special Map	1:62500	100	1897
	Shasta	1:62500	80	1954
THOMPSON PEAK AREA, CALIF.	Cecilville	1:62500	80	1955
	Helena	1:62500	100	1951
DONNER PASS AREA, CALIF.	Donner Pass	1:62500	80	1955
	Granite Chief	1:24000	40	1953
TIOGA PASS AREA, CALIF.	Mono Craters	1:62500	80	1953
	Tuolumne Meadows	1:62500	80	1956
MT. ABBOT AREA, CALIF.	Mt. Abbot	1:62500	80	1953
	Mt. Tom	1:62500	40	1949
PALISADE AREA, CALIF.	Mt. Goddard	1:62500	40	1948
	Big Pine	1:62500	40	1950
MT. WHITNEY AREA, CALIF.	Mt. Whitney	1:62500	80	1956
	Mt. Pinchot	1:62500	80	1953
SAN GORGONIO MTN., CALIF.	San Gorgonio Mtn.	1:62500	80	1954
RUBY MTS., NEV.	Lamoille	1:62500	80	1962
SNAKE RANGE, NEV.	Wheeler Peak	1:62500	50	1948
	Sacramento Pass	1:62500	80	1959
MT. AGASSIZ AREA, UTAH	Hayden Peak	1:125000	100	1901
WASATCH RANGE, UTAH	Timpanogos Cave	1:24000	40	1948
	Dromedary Peak	1:24000	40	1955
LA SAL MTS., UTAH	La Sal	1:62500	80	1952
	La Sal Junction	1:62500	80	1952
TUSHAR MTS., UTAH	Delano Peak	1:62500	50	1937
BOULDER MTN., UTAH	Grover	1:62500	80	1952
	Loa 4 NE[b]	1:24000	20	1952

SAN FRANCISCO MTN., ARIZ.	Flagstaff	1:125000	100	1908
BALDY PEAK, ARIZ.	Clifton	1:250000	200	1954-62
SNOWY RANGE, WYO.	Medicine Bow Peak	1:24000	40	1961
	Morgan	1:24000	20	1961
	Sand Lake	1:24000	20	1961
ROCKY MTN. NAT'L. PARK AND VICINITY, COLO.	Monarch Lake	1:24000	40	1958
	Ward	1:24000	40	1957
	Rocky Mtn. N. P.	1:62500	80	1961
MT. EVANS AREA, COLO.	Georgetown	1:62500	80	1957
SAWATCH RANGE, COLO.	New York Peak	1:24000	40	1960
	Independence Pass	1:24000	40	1960
	Mt. Harvard	1:62500	80	1955
PIKES PEAK, COLO.	Pikes Peak	1:24000	20	1951
SAN MIGUEL MTS., COLO.	Dolores Peak	1:24000	40	1953
	Mt. Wilson	1:62500	40	1953
CULEBRA RANGE, COLO.	Trinidad	1:250000	200	1954-62
WHEELER PEAK AREA, N. M.	Eagle Nest SW[c]	1:24000	40	1965
SANTA FE BALDY AREA, N. M.	Aspen Basin	1:24000	40	1953
	Cowles	1:24000	40	1961
SIERRA BLANCA PEAK, N. M.	Sierra Blanca Peak	1:62500	50	1950

[a]Published by the U. S. Geological Survey.

[b]Advance sheet, black and white.

[c]Advance proof, blue line.

APPENDIX C

MODIFICATION INDEX DATA

Data used to compute modification index values (p. 17, tables in Chapter 2, and Table 41) of features (@)[a] assignable to stades of Neoglaciation and to the latest pre-Neoglacial stade. Data include vegetation cover (+v), dissection (+d), slope stability (+s), crestal sharpness (-c), and boulder prominence (-b).

STUDY AREA	Later stade		Earlier stade		Latest pre-Ng	
Locality	@	+v+d+s-c-b	@	+v+d+s-c-b	@	+v+d+s-c-b
MT. SHASTA, CALIF.		no obs.		no obs.		no obs.
THOMPSON PEAK AREA, CALIF.						
NE of Peak 8,966	M	0 0 1 4 4	M	2 1 2 2 3		no obs.
N of Thompson Peak	M	1 1 0 4 4	M	2 3 1 3 3		no obs.
NW of Peak 8,913	T	0 0 1 - 4	M	2 1 1 3 3		no obs.
NW of Peak 8,911		no obs.		no obs.		no obs.
DONNER PASS AREA, CALIF.		no obs.		no obs.		no obs.
TIOGA PASS AREA, CALIF.						
SW of Peak 12,015	T	0 0 0 - 4	M	1 0 1 4 2		no obs.
NE of Sheep Peak	R	0 0 0 4 4	M	2 0 1 3 2		no obs.
NE of North Peak	M	0 0 0 4 4	M	2 1 1 3 4	M[b]	3 2 3 1 2
NE of Mt. Conness	M	0 0 0 4 4	M	2 1 1 3 3	M[b]	3 2 3 1 2
SE of Mt. Conness	T	0 0 0 - 4	M	1 1 1 3 3	M[b]	3 2 3 1 2
N of White Mtn.	M	0 0 0 4 4	M	2 1 1 3 4	M[b]	3 2 3 1 2
E of White Mtn.	M	0 0 0 4 4	M	2 1 1 3 3	M[b]	3 2 3 1 2
SE of White Mtn.	T	0 0 0 - 3	M	1 0 1 3 2	M	3 1 3 2 2
N of Peak 11,255	R	0 0 0 4 4	M	1 0 1 4 3		no obs.
NW of Peak 12,002	T	0 0 0 - 4	M	1 0 1 3 4	M	2 1 3 2 2
SE of Peak 12,002	T	0 0 0 - 4	M	1 1 1 3 3	M	3 1 3 2 2
NE of Mt. Dana	M	0 0 0 4 4	M	1 0 1 3 3	M[b]	3 2 3 1 2
MT. ABBOT AREA, CALIF.		no obs.		no obs.		no obs.
PALISADE AREA, CALIF.						
NE of Mt. Agassiz	MR	0 0 0 4 4	M	0 0 1 3 4	M[c]	2 2 2 1 2
N of Mt. Winchell	M	0 0 0 4 4	M[d]	2 1 1 3 3	M[c]	2 2 2 1 2
N of North Palisade	M	0 0 0 4 4	M[d]	2 1 1 3 3	M[c]	2 2 2 1 2
N of Temple Crag	R	0 0 0 4 4	R	2 1 1 4 3	M[c]	2 2 2 1 2
NE of Mt. Gayley	R	0 0 0 4 4	M	0 0 1 2 4		no obs.
E of Isosceles Peak	R	0 0 0 4 4	M M	0 0 1 3 3 1 0 1 1 3		no obs.
E of Mt. Sill	M	0 0 0 4 4	M	1 0 1 2 4		no obs.
E of Peak 13,390	M	0 1 0 4 4	M	2 1 1 3 3		no obs.

MT. WHITNEY AREA, CALIF.						
N of Peak 13,211		no obs.		no obs.		no obs.
NW of Tunnabora Peak	R	0 0 0 4 4	M	1 1 1 3 4		no obs.
N of Peak 13,355	R	0 0 0 3 4	M	1 0 1 3 3		no obs.
NW of Mt. Russell	P	0 0 0 3 3	M	1 1 2 2 2		no obs.
NE of Mt. Russell	P	0 0 0 3 4	M	1 1 1 4 3		no obs.
SE of Mt. Russell	R	0 0 0 3 4	M	1 1 1 3 3	M	2 1 3 1 2
NE of Mt. Hale	R	0 0 0 4 4	M	1 1 1 3 4		no obs.
N of Mt. Young	R	0 0 0 4 4	M	0 0 1 4 2		no obs.
NE of Mt. Whitney	R	0 0 0 4 3	M[e]	1 0 1 2 2	M[f]	2 1 2 1 2
SE of Mt. Whitney	MR	0 0 0 4 4	M[e]	1 0 1 2 2	M[f]	2 1 2 1 2
NE of Mt. Muir	R	0 0 0 3 4	M	1 0 1 3 3	M	2 1 2 1 2
SE of Mt. Muir	R	1 0 0 4 4	M	1 0 1 3 3	M[g]	2 2 2 1 2
E of Discovery Pinnacle	R	0 0 0 4 4	M	0 0 1 3 2	M[g]	2 2 2 1 2
N of Mt. Chamberlin	R	0 0 0 4 3	M	1 0 2 4 3		no obs.
N of Mt. Pickering	R	0 0 0 4 4	M	1 0 1 3 4		no obs.
SAN GORGONIO MTN., CALIF.						
NE of San Gorgonio Mtn.	T	0 0 0 - 4	T	1 0 1 - 4	M	2 2 2 3 3
RUBY MTS., NEV.						
W of Thomas Point	T	0 0 0 - 4		no obs.	M	3 2 3 2 1
NE of Peak 11,133	T	0 0 0 - 4		no obs.	M	2 3 3 2 2
upper Lamoille Creek	R	0 0 0 4 4	R	2 0 1 3 3	M	3 2 3 1 1
upper Box Canyon	T	0 0 0 - 4	R	2 1 1 3 3		no obs.
SNAKE RANGE, NEV.						
SE of Point 11,024		no obs.		no obs.	M	3 1 3 1 1
N of Wheeler Peak	T	1 0 0 - 4	R	1 0 1 3 3	M	3 1 2 2 2
NE of Wheeler Peak	MR	0 0 0 4 4	MR	1 0 1 3 4	M	3 1 2 2 2
NE of Baker Peak	R	1 0 0 4 4	R	2 0 1 4 3	M	3 1 2 1 2
SE of Baker Peak	T	1 0 0 - 3	R	2 0 1 3 4	M	3 1 3 1 2
S of Pyramid Peak		no obs.	R	2 1 1 3 3	M	3 1 3 1 2
NW of Peak 11,804		no obs.		no obs.		no obs.
NE of Peak 11,562		no obs.		no obs.		no obs.
MT. AGASSIZ AREA, UTAH						
NW of Mt. Agassiz	R	0 0 0 4 4	M	1 0 1 3 3		no obs.
NE of Mt. Agassiz	T	0 1 0 - 3	M	2 1 1 3 3		no obs.
WASATCH RANGE, UTAH						
N of Mt. Timpanogos	R	0 0 0 4 4	M	1 0 1 3 3		no obs.
E of Mt. Timpanogos	R	0 0 0 4 4		no obs.		no obs.
LA SAL MTS., UTAH						
N of Mt. Tukuhnikivatz	R	1 0 0 4 4		no obs.	M	3 1 2 2 2
NE of Mt. Tukuhnikivatz	R	1 0 0 4 4		no obs.	M	4 2 2 2 2
NW of Peak 12,230	R	1 0 0 4 4	T	2 1 2 - 3	M	3 3 3 2 2
N of Mt. Peale	R	1 0 0 4 4	M	2 1 1 3 4	M	3 2 1 2 2
TUSHAR MTS., UTAH						
NE of Mt. Belknap	R	0 0 0 4 4	R	2 0 1 4 3		no obs.
N of Delano Peak	R	0 0 0 4 4		no obs.		no obs.
BOULDER MTN., UTAH		no obs.		no obs.		no obs.
SAN FRANCISCO MTN., ARIZ.						
S of Humphreys Peak	T	1 0 0 - 4	R	2 1 1 3 4	M	3 2 2 2 2
E of Agassiz Peak	T	1 0 0 - 4	R	2 0 1 3 4	M	2 2 2 2 2

BALDY PEAK, ARIZ.			
N of Baldy Peak		P[h] 1 0 2 3 4	no obs.
NE of Baldy Peak		P[h] 2 0 1 3 4	no obs.
SSE of Baldy Peak		CP[h] 2 1 3 2 1	no obs.
SE of Baldy Peak		P[h] 1 0 1 3 4	no obs.
SNOWY RANGE, WYO.			
S of Medicine Bow Peak	R 1 0 0 4 4	M 1 1 1 4 4 M 2 1 2 3 3	M 3 2 3 1 2
ROCKY MOUNTAIN NATIONAL PARK AND VICINITY (INDIAN PEAKS AREA), COLO.			
NW of Peak 12,799	M 0 1 0 4 4	M 2 0 1 2 2	no obs.
N of Mt. George	MR 0 0 0 4 4	M 2 0 1 3 3	no obs.
NE of Apache Peak	M 0 0 0 4 4	M 1 1 1 3 3	no obs.
N of Navajo Peak	M 0 0 0 4 4	M 1 0 1 2 3	no obs.
NW of Arikaree Peak	M 0 0 0 4 4	MR 1 0 1 2 2	no obs.
SE of Arikaree Peak	M 0 0 0 4 3	M 2 1 1 3 3	M[i] 4 2 2 2 2
NE of North Arapaho Peak	M 0 0 0 4 4	MR 1 0 1 2 3	M[i] 4 2 2 2 2
NE of South Arapaho Peak	M 0 0 0 4 4	M[j] 2 1 1 3 3	M[i] 4 2 2 2 2
E of South Arapaho Peak	MR 0 0 0 4 4	M[j] 2 1 1 3 3	M[i] 4 2 2 2 2
MT. EVANS AREA, COLO.			
NE of Rogers Peak	T 0 0 0 - 4	T 1 0 1 - 3	M 3 1 2 2 3
N of Mt. Evans	T 0 0 0 - 4	M 1 0 2 2 3	M 3 1 3 1 1
SE of Mt. Bierstadt	R 1 0 0 4 4	M 2 0 2 2 2	no obs.
N of Rosalie Peak	R 1 0 0 4 4	T 2 0 1 - 3	M 3 1 2 2 1
SAWATCH RANGE, COLO.			
NE of Peak 13,300	R 1 0 0 4 4	no obs.	M 3 2 3 2 1
NW of Truro Peak	R 0 0 0 4 4	M 1 1 1 3 4	M 3 2 2 1 2
NE of Peak 13,505	R 1 0 0 4 3	M 1 1 3 3 2	M 3 2 3 1 2
E of Peak 13,505	R 1 0 0 4 4	M 1 0 2 2 3	M 3 2 3 2 1
E of Peak 13,631	R 0 0 0 4 4	M 1 1 3 4 1	M 3 2 3 2 2
E of Peak 13,220	R 0 0 0 4 4	M 0 0 1 3 2	M 3 2 2 2 2
PIKES PEAK, COLO.			
NE of Point 12,792		T[h] 1 1 1 - 4	M 3 1 3 2 3
NNE of Point 13,363		T[h] 1 1 1 - 4	M 3 1 2 2 3
N of Pikes Peak	T 0 0 0 - 4	M 0 1 1 3 4	M 3 1 2 3 3
SE of Pikes Peak	R 0 0 0 4 4	R 2 1 0 4 4	M 3 1 2 3 3
S and SW of Pikes Peak		C[h] 2 1 1 - 4	M 3 1 3 3 3
SAN MIGUEL MTS., COLO.			
NW of Wilson Peak	R 0 0 0 4 3	no obs.	M[k] 1 2 1 3 2
N of Gladstone Peak	R 0 0 0 4 4	no obs.	M[k] 2 2 2 2 1
NE of Peak 13,097	R 0 0 0 4 3	MR 1 0 1 3 2	M[k] 2 2 2 2 1
E of Gladstone Peak	R 0 0 0 4 4	M 1 1 1 3 3	M 2 2 3 2 1
CULEBRA RANGE, COLO.			
ESE of Peak 13,010	M 1 0 0 4 4	M 1 0 1 3 3	no obs.
SSW of Peak 13,010	R 1 0 0 4 4	R 2 0 1 3 4	M 3 2 2 2 2
N of Culebra Peak	R 1 0 0 4 4	M 1 0 2 2 4 M 1 1 2 3 2	M 3 2 3 1 2
NE of Purgatoire Peak	T 0 0 0 - 4	M 2 0 1 4 4	no obs.

WHEELER PEAK AREA, N. M.			
SE of Wheeler Peak	R 1 0 0 4 4	MR 2 0 1 3 3	M[l] 3 2 2 2 2
NE of Simpson Peak	R 0 0 0 3 4	M 1 0 1 3 3	M[l] 3 2 2 2 2
SANTA FE BALDY AREA, N. M.			
NE of Santa Fe Baldy	P 0 0 0 4 4	P 1 0 1 3 3	M 3 1 2 2 2
SE of Santa Fe Baldy	P 0 0 0 4 4	P 1 0 1 3 3	M 3 0 2 2 2
SIERRA BLANCA PEAK, N. M.			
NE of Sierra Blanca Peak	no obs.	P 1 0 1 3 4	R 2 1 3 2 2

Source: aerial photograph interpretation, in some study areas supplemented by field observations, by the author.

[a]Features: M = moraine, MR = transitional rock glacier, R = rock glacier, P = protalus rampart, T = talus, CP = colluvium over protalus rampart, C = colluvium.

b, c, d, e, f, g, i, j, k, l Glaciers confluent.

[h]Data not assignable to a particular stade.

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