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## PLEISTOCENE GLACIATION IN THE TRINITY ALPS OF NORTHERN CALIFORNIA\*

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**ABSTRACT.** The glacial sequence of the Trinity Alps has good development, significant location, and value as a reference datum for other Pleistocene events. The principal glacial episodes identified are Late (Morris Meadow), Middle (Rush Creek), Early (Alpine Lake) and Ancient (Swift Creek). The three youngest are judged Wisconsin, the oldest pre-Wisconsin. Other evidence suggests possibly still older glaciations, and youthful moraines at high elevations may be Neoglacial (post-Hypsithermal).

During the Late (Morris Meadow) glaciation the Trinity Alps contained at least 30 valley glaciers. Maximum lengths and lowest elevations attained are: Late, 7.8 miles and 3350 feet; Middle, 9.3 miles and 2800 feet; Early, 11.3 miles and 2500 feet; Ancient, 13.7 miles and 2450 feet. Length was more variable than terminal elevation.

Where the glacial detritus was derived largely from serpentine, numerous debris flows extended down-valley from glacier snouts. Deposits of flow debris, almost indistinguishable from till, complicate interpretation of glacial relations on lower Deer and Swift creeks.

The rock floors of stream terraces, well exposed in abandoned placer workings along Canyon Creek, lie at 10, 20, 40, 90, 160 and 300 feet above the stream. Direct tracing to terminal-moraine positions suggests that the 10-, 20- and 40-foot rock-terrace levels are chronologically, but perhaps not genetically, related to the Late, Middle, and Early phases of Wisconsin glaciation. The 90-foot terrace may be a time-equivalent of the Ancient glaciation (pre-Wisconsin), and the 160- and 300-foot terrace could be chronologically related to still earlier Pleistocene glaciations.

In the high country, carapaces of ice formed on sloping valley walls above the level of the ice streams partly filling the valleys. Two vestigial glacierets remain at elevations of 8200-8400 feet on the north side of the Thompson Peak ridge. Wisconsin orographic snow-line lay at 6500 feet, climatic snowline at about 8000 feet. Corresponding figures for the present are judged to be about 7500 and 9000 feet. Wisconsin orographic snowline rose inland 18 feet per mile judging from data obtained on Mt. Lassen, 85 miles to the east-southeast.

### INTRODUCTION

The Pleistocene glaciation of the Trinity Alps was studied for the following reasons: (1) The location is intermediate between coastal and interior environments and midway between the two major glaciated ranges of far-western United States, the Cascades and Sierra Nevada. (2) Although glaciation has long been known in this area (Hershey, 1900), no detailed investigation of it had been made. The nearest well-studied sequence lies 300 miles to the southeast (Blackwelder, 1931; Matthes, 1930; and Birman, 1954, 1957). Evidence of glaciation has been reported in nearby parts of the Coast Range (Davis, 1958) and in the Siskiyou Range to the northwest (Maxson, 1933, p. 128). (3) Preliminary reports (Hershey, 1900, 1903b) suggested that Pleistocene glaciers in the Trinity Alps were of such number and size as to have left a good record. (4) The possibility of tracing and correlating stream-terraces along the relatively large, long rivers draining from the Trinity Alps, offered a hope of extending the glacial chronology into the surrounding country. (5)

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It appeared that a moraine→stream terrace→marine terrace correlation might establish a chronological relation between mountain glaciation and West Coast Pleistocene marine history.

The procedure followed in this paper is to present basic data by means of maps and tabulations. Highlights and significant points are summarized, and matters of special interest are discussed. Mapping of glaciated sites within the limits of the Trinity Alps is reasonably complete. Some small, remote areas of possible glaciation, for example the headwaters of the East Fork of the North Fork of Trinity River, have not been visited. No attempt has been made to extend the study into obviously glaciated neighboring regions such as the north-side tributaries of Coffee Creek, the Etna area, and the country east of upper Trinity River.

A start on the problem was made by one month of field work in 1950, followed by two months in 1955 and one month in 1956.

#### PHYSICAL SETTING

The Trinity Alps comprise a small but striking area of alpine terrain (plate 3) in the southern part of the rugged Klamath Mountains of northern California (inset fig. 1). The core of the "Alps" has many jagged peaks, narrow ridges, cirques, lakes, U-shaped canyons, bedrock steps, waterfalls, areas of ice-scoured bedrock, meadows, perennial snow banks, and two glacierets (plate 3). Thompson Peak at 8936 feet is the highest point, lowest elevations are between 2000 and 2500 feet, and maximum local relief is about 4000 feet.

Drainage of the area is almost entirely through tributaries of the Trinity River, the few exceptions lying in the headwaters of the South Fork of Salmon River. The Trinity and the Salmon are major branches of the Klamath, and the upper Trinity encircles the "Alps" on the northeast, east, and south sides.

The perimeter of the "Alps" is accessible through a network of mountain roads, and the high country is reached by converging trails. Weaverville is the only nearby town of much size; smaller settlements include Helena, Junction City, Dedrick, Minersville, Trinity Center, Carrville, and Cecilville.

About two-thirds of the area studied is covered by excellent modern topographic maps at a 1/62,500 scale, specifically the Helena (1951), Minersville (1950) and Schell Mountain (1952) quadrangles. The remainder appears on the Etna (1934) and Sawyers Bar (1923) quadrangles at a scale of 1/125,000. Good vertical air photographs taken in 1944 are available from the U. S. Forest Service in San Francisco.

#### BEDROCK RELATIONS

Much of the bedrock has not been mapped in detail, but major units are known from an early report by Hershey (1901), later work of Hinds (1932, 1933, 1935, 1940), and a recent study by Cox (1956). Formations of principal interest to glaciation are listed in table 1. Other recognized units including the Copley meta-andesite, Bragdon formation, and some Eocene sedimentary rocks are peripheral to the principal glaciated areas.

The areal distribution of bedrock units is fortunate. The high core of the "Alps", from which glaciers flowed, consists chiefly of stocks of quartz diorite,

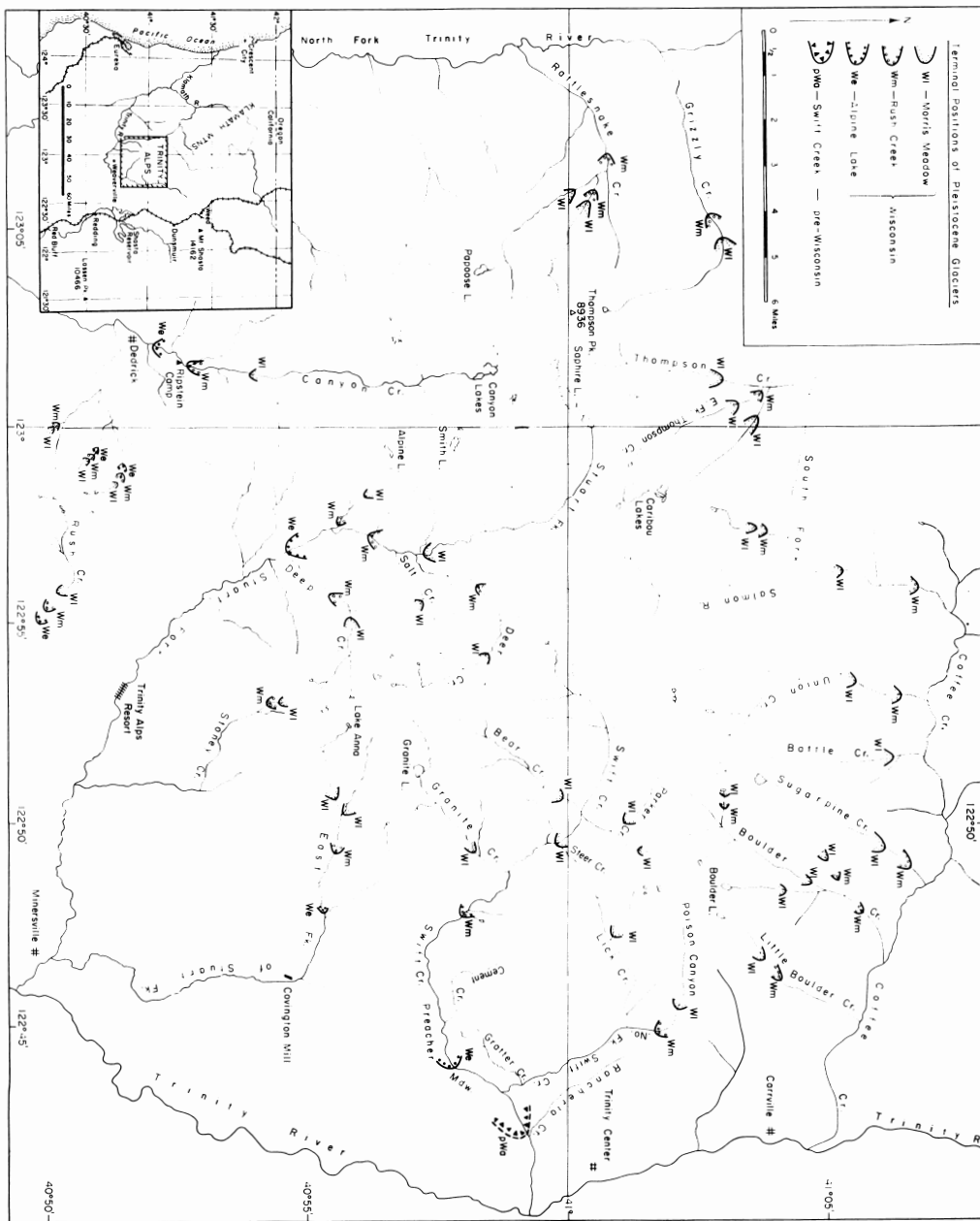


Fig. 1. Location of Trinity Alps and terminal position of Trinity Alps glaciers.

granodiorite, and quartz monzonite<sup>1</sup>. The glaciers carried detritus from these relatively light-colored, easily identified intrusive bodies onto the surrounding

<sup>1</sup> For sake of brevity these intrusive rocks will be referred to as dioritic.

terrane of dark-colored metamorphic rocks. The color and lithologic contrast greatly facilitated identification and mapping of glacial deposits. Many of the stocks are individually distinctive, and the exact source of glacial material can be defined. Associated aplite and lamprophyre dikes also provide local distinctive indicators. Although some of the stocks may be composite, they nonetheless yield a relatively homogeneous type of detritus that affords a good medium for comparisons of weathering undergone by glacial deposits of different age.

TABLE 1

Principal bedrock units in Trinity Alps significant to the glacial geology

Age	Unit	Lithology	Principal areas of exposure
Late Jurassic or Early Cretaceous	Dioritic stocks	Small stocks of quartz diorite, granodiorite, and quartz monzonite	In central core of Trinity Alps
Late Paleozoic (?)	Serpentine	Serpentinized massive intrusive peridotite, locally sheared	Between Stuart Fork and upper Trinity River, on Deer and Swift creeks
Carboniferous (Pennsylvanian)	Chanchellulla formation	Meta-chert with greenstone lenses, thin-bedded; thick beds of blue-gray marble; minor beds of slate and quartzite	North Fork of Trinity River
Paleozoic (?) or	Salmon schist	Principally hornblende and chlorite schist, locally migmatized, some quartzite stringers	Canyon Creek and west side of Stuart Fork
Pre-Cambrian	Abrams schist	Principally quartz-biotite-muscovite schist, some quartzite, coarsely crystalline marble, and hornblende schist	East side of Stuart Fork, head of South Fork Salmon River and Coffee Creek

#### PRINCIPAL EPISODES OF GLACIATION

Within the Trinity Alps the major glaciated areas are in the drainages of Coffee, Swift and Canyon creeks and the Stuart Fork. Less extensive glaciers occupied parts of the drainages of the South Fork of Salmon River, East Fork of Stuart Fork, Rush Creek, and the North Fork of Trinity River (fig. 1).

Four episodes of glaciation are recognized (table 2). The three youngest are probably Wisconsin, and the oldest is presumably pre-Wisconsin. Evidence suggesting still younger and possibly considerably older glaciations is treated in following sections.

#### *Late Substage (Morris Meadow)*

This substage is well represented at most of the glaciated sites. The evidence is best on Stuart Fork below Morris Meadow (fig. 2), in various south-side tributaries of Coffee Creek (figs. 5-7), and on the North Fork of Swift

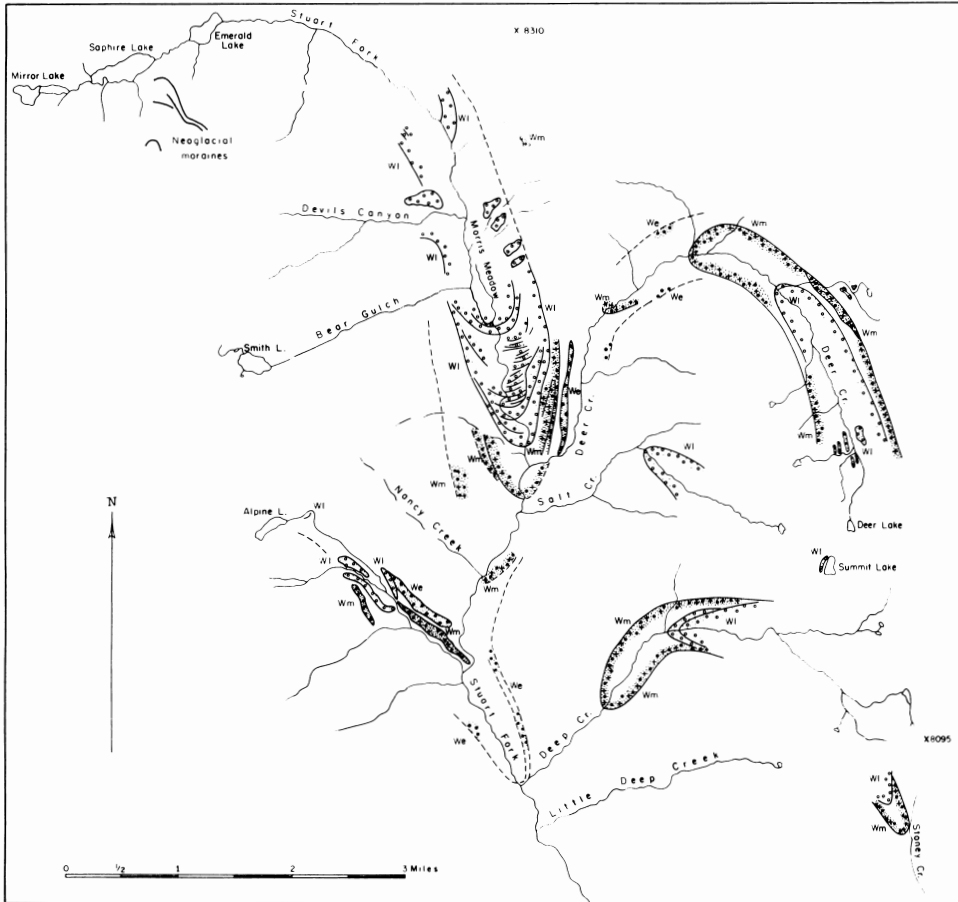


Fig. 2. Moraines of the Stuart Fork drainage. Wl—Late (Morris Meadow) substage, Wm—Middle (Rush Creek) substage, We—Early (Alpine Lake) substage.

Creek (fig. 8). In these places it has formed a terminal moraine and a succession of recessionals, which number 15 on Union Creek, 20 on Sugarpine Creek, 16 on Boulder Creek, 11 on Boulder Lake Creek, and 22 on Stuart Fork. In

TABLE 2

Principal Episodes of Pleistocene Glaciation in Trinity Alps

Age	Symbol	Time Designation	Local Name
Wisconsin	Wl	Late	Morris Meadow
	Wm	Middle	Rush Creek
	We	Early	Alpine Lake
Pre-Wisconsin	pWa	Ancient	Swift Creek

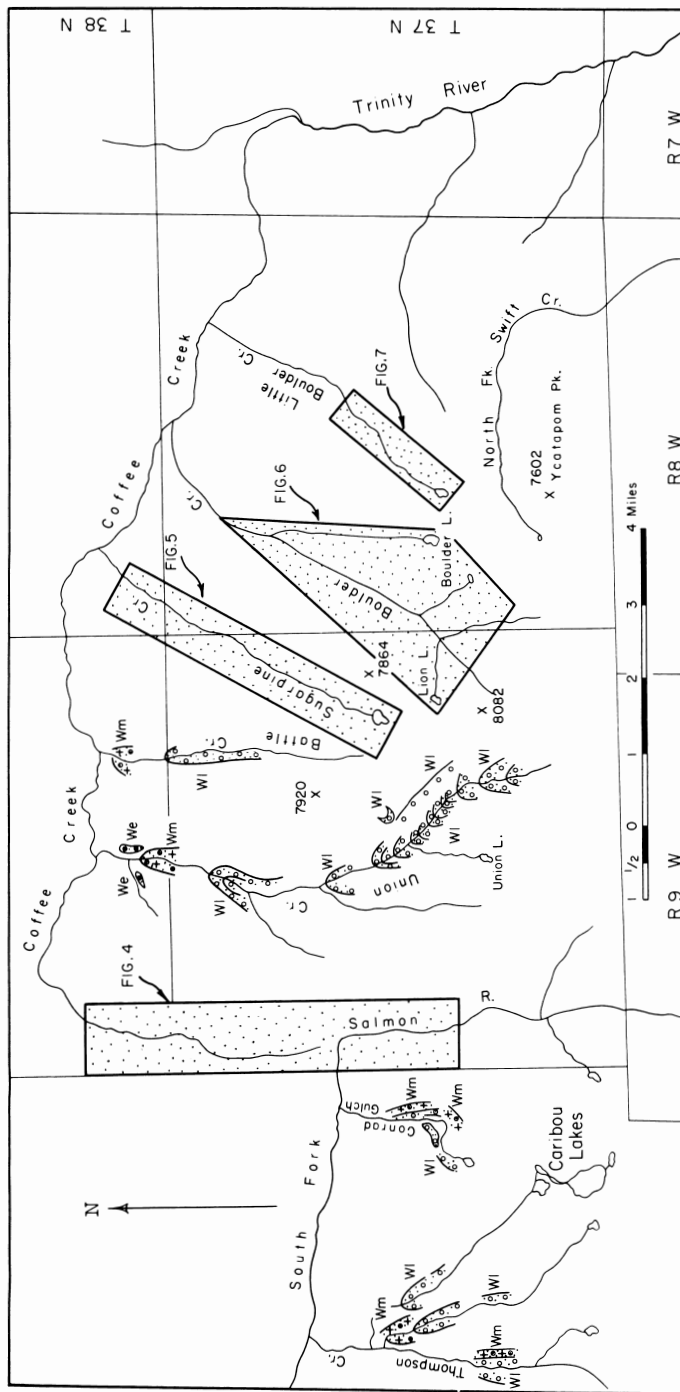


Fig. 3. Glacial deposits of South Fork of Salmon River and Coffee Creek. Details of specific areas shown on figs. 4 to 7 as indicated.

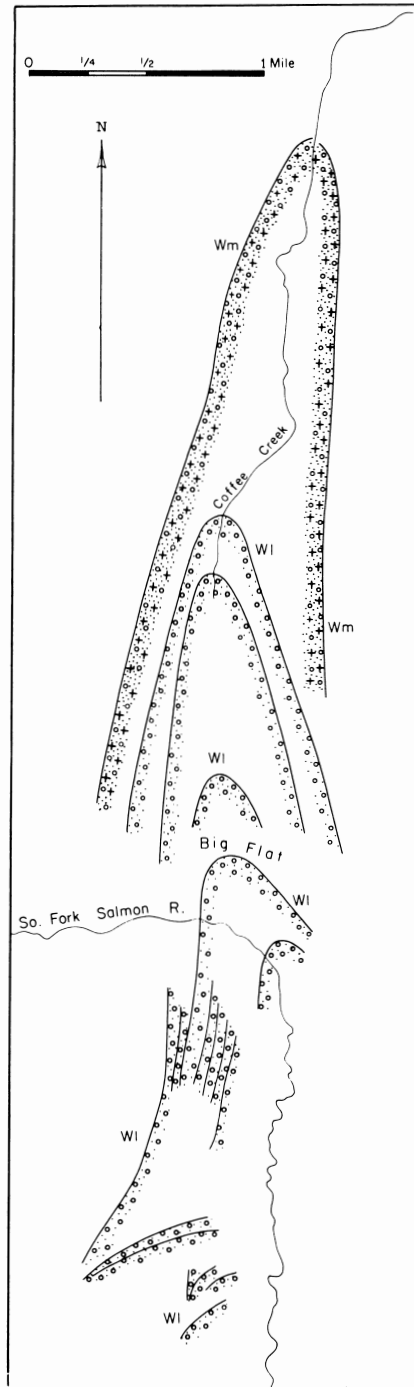


Fig. 4. Moraines of upper Coffee Creek—Salmon River area.

some canyons the terminal is a double ridge, and in others it is smaller and less distinct than some of the recessional moraines. Plotting of the recessionals did not reveal any consistent pattern of spacing, clustering, or size from canyon to canyon. Strong lateral moraines of this substage form prominent benches on the walls of many canyons, and multiple lateral moraine ridges were mapped locally (fig. 4).

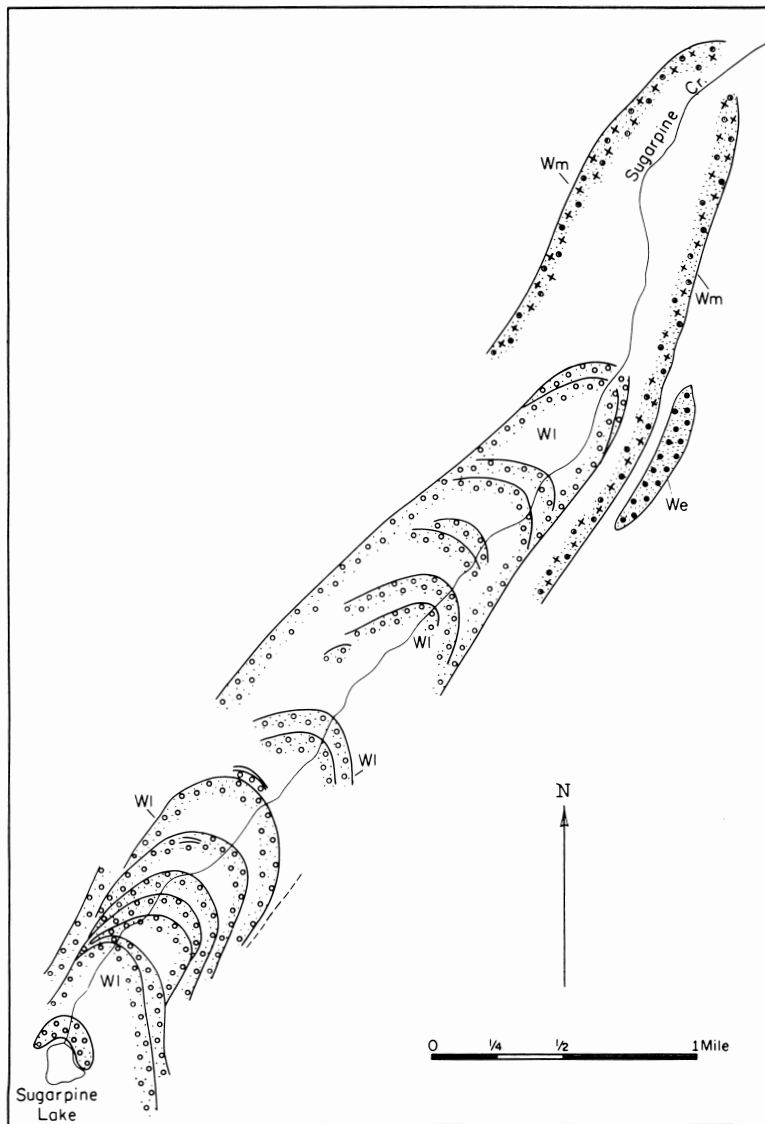


Fig. 5. Moraines on Sugarpine Creek.

A strong recessional moraine suggestive of readvance has been found well upstream from the terminal position on Sugarpine, Union, and Boulder Lake creeks and on Stuart Fork. Boulder counts also suggest a two-phase develop-

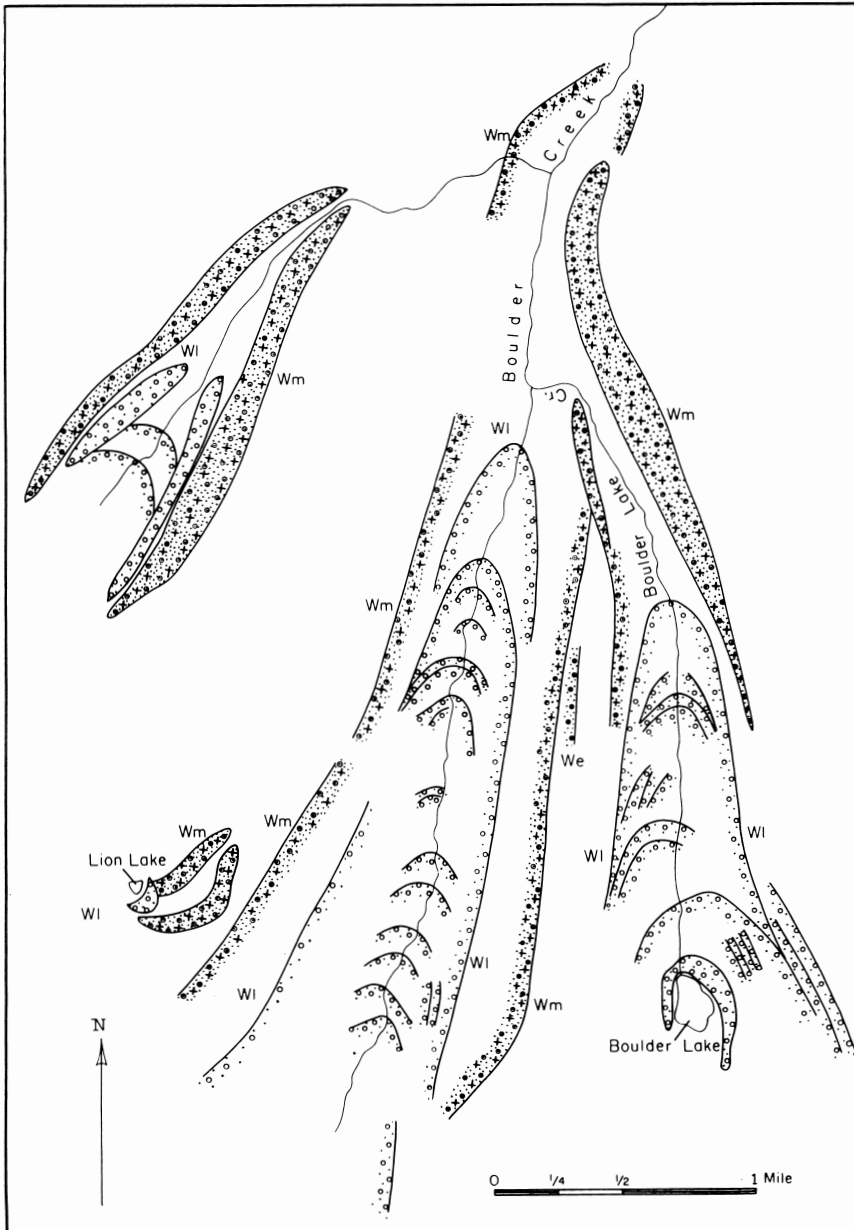


Fig. 6. Moraines of Boulder Creek drainage.

ment within the recessional sequence, which is further supported by discordant trends in overlapping morainal ridges on Sugarpine Creek.

#### *Middle Substage (Rush Creek)*

The terminal and recessional moraines of this substage, although recognizable, are usually neither strong nor well preserved. The terminals do not have multiple ridges as in the Late substage. In places the laterals are large, well-developed and comprise some of the more prominent moraines of the area. Good examples are on Canyon, Rush, Granite, North Fork of Swift, and Alpine Lake creeks. The lateral on the east side of Granite Creek is three quarters of a mile long and rises abruptly 100 feet above a fosse on its outer side.

#### *Early Substage (Alpine Lake)*

This glaciation is represented mostly by small patches of till and scattered lateral-moraine remnants. A few large well-preserved laterals still exist in protected ridge-top localities, for example on Granite Creek (fig. 8) and Alpine Lake Creek (fig. 2). Deposits of this substage are extensive on lower Swift Creek (fig. 8), but the relationships are complicated by debris flows. Patches of Early substage till were mapped on Boulder, Sugarpine, Union, East Fork of Stuart Fork, Rush (fig. 9), Big East Fork of Canyon (fig. 11), Deer, Stuart Fork, and Canyon creeks.

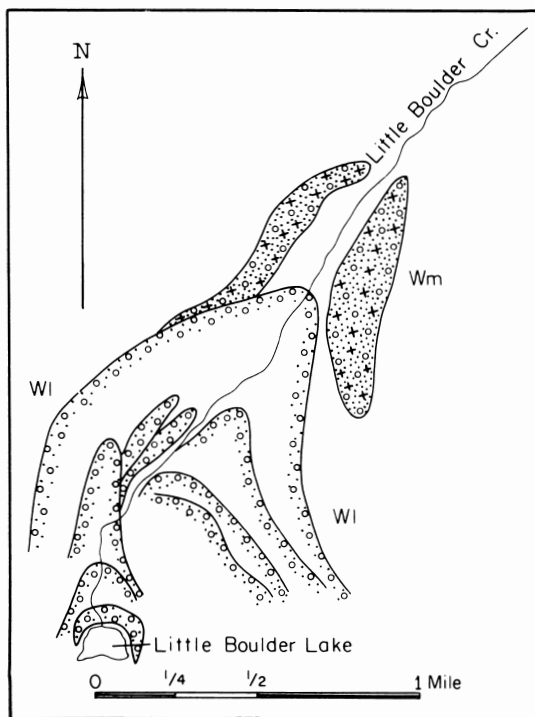
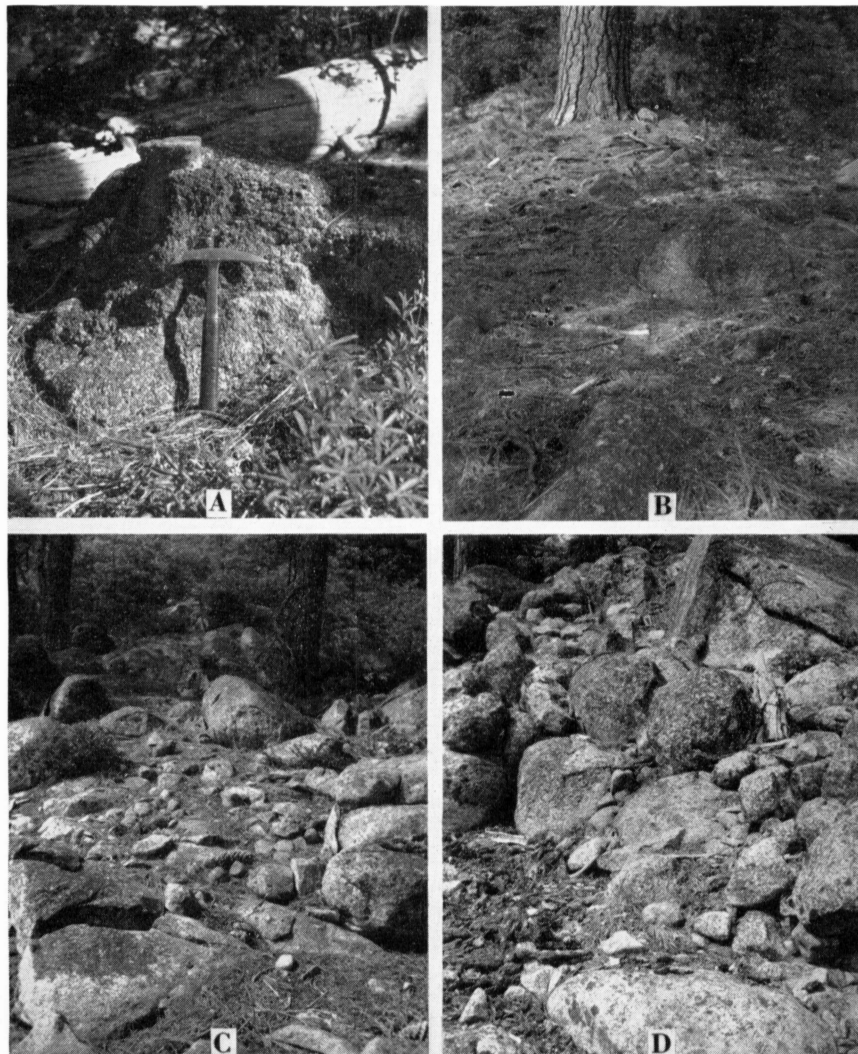


Fig. 7. Moraines on Little Boulder Creek.

PLATE 1



A. Deeply weathered dioritic boulder with fine-grained inclusion projecting 2 inches; crest of Early substage lateral on Canyon-Bear Creek ridge.

B. Crest of Early substage lateral moraine, northeast side of Alpine Lake Creek (fig. 2); compare with C and D.

C. Crest of Middle substage lateral moraine, northeast side of Alpine Lake Creek.

D. Crest of Late substage lateral moraine, northeast side of Alpine Lake Creek; compare with B and C.

*Ancient Stage*

Reliable evidence for this glaciation is recognized only on lower Swift Creek (fig. 8) and even here relations are confusing because of debris-flow deposits. This stage appears to be several times older than the preceding glaciations.

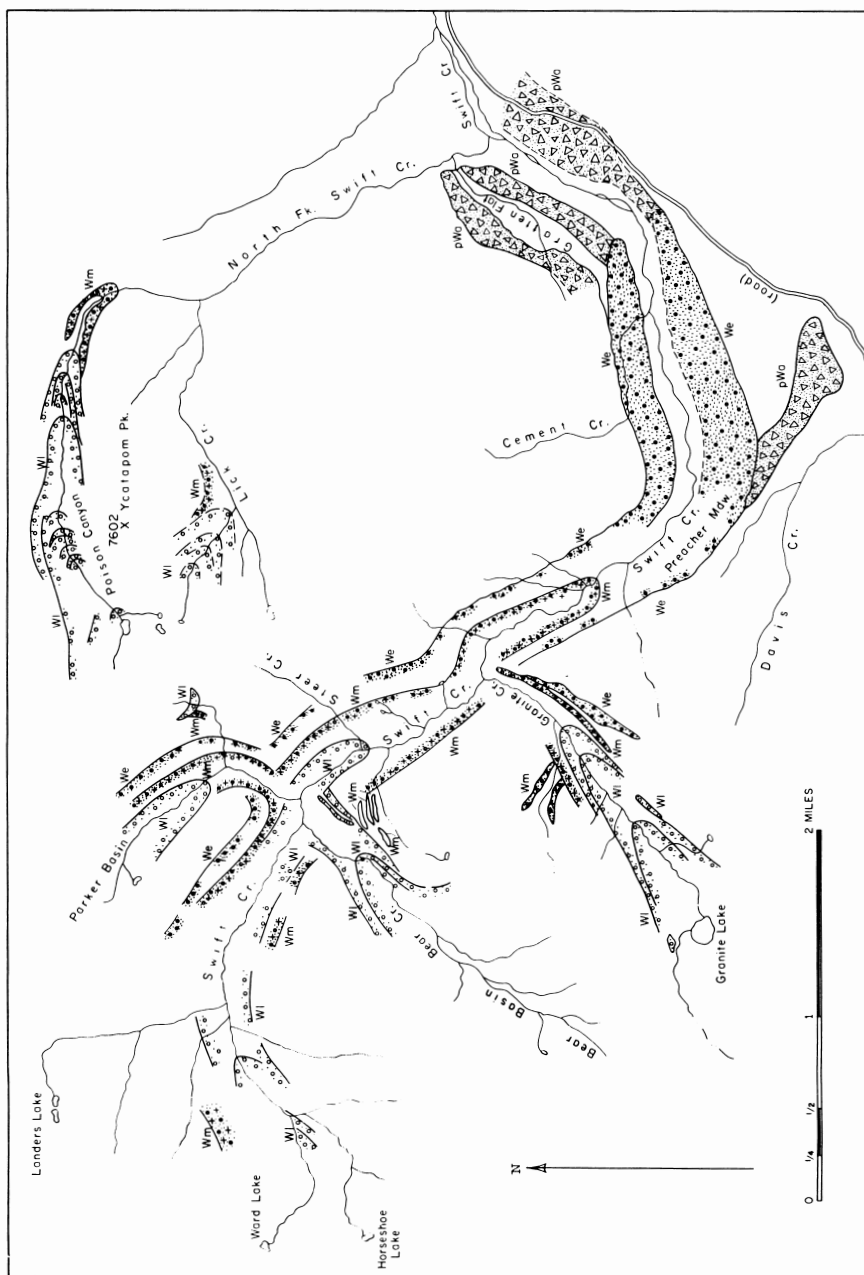


Fig. 8. Glacial deposits of Swift Creek area, pWa—Ancient (Swift Creek) stage.

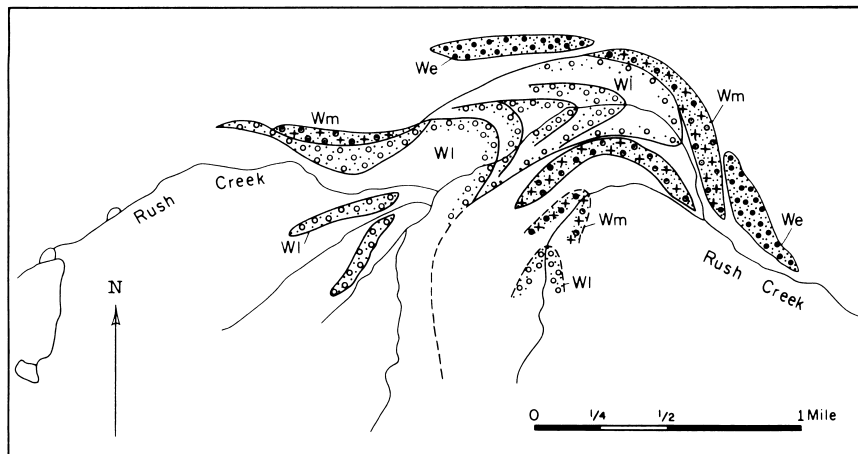


Fig. 9. Moraines on Rush Creek.

#### OTHER LESS CERTAIN OR MINOR PHASES OF GLACIATION

##### *Older Pleistocene Glaciation?*

The Trinity Alps were probably glaciated during Pleistocene stages still earlier than those described, but compelling evidence for this has not been found. Coarse gravels mantling Pleistocene stream terraces, older and higher than terraces perhaps chronologically related to recognized glacial episodes, have been attributed to earlier glaciations (Hershey, 1903a; 1904; MacDonald, 1910, p. 49-50; Diller, 1911, p. 17; 1914, p. 17-18). This proposition is difficult to support with direct evidence and is not advanced as a general argument, but relations at one informative locality are described as they afford an evaluation of the possibilities.

Rock terraces and the overlying deposits are well exposed in abandoned placer workings at the mouth of the Big East Fork of Canyon Creek. On the spur north of the Big East Fork is a rock terrace 330 feet above Canyon Creek mantled by about 100 feet of deposits (fig. 13). The lower 40 feet of this mantle is gravel resting on bedrock and containing subangular to rounded 6-inch to 1-foot boulders, mostly amphibole schist with some diorite. Layering is crude, and sorting is modest. The overlying 25-30 feet of gravel consists almost wholly of diorite boulders, many 3-5 feet in diameter and some 12 feet across, set in a sparse matrix of gruss. The indistinct layering is expressed mostly by differences in boulder size. Sorting is poor, and the boulder to matrix ratio is locally as great as 9 to 1. The distinctive diorite composing the boulders shows that they came down the Big East Fork from Weaver Bally Mountain and not down Canyon Creek. Overlying the gravel is a coverhead of slopewash at least 45 feet thick consisting of 3 distinctive layers, each the product of separate genetic episodes.

These deposits are clearly of some antiquity. The slopewash has a deep-red, clay-rich soil, 10 to 12 feet thick, that contains abundant ironstone pellets of the type found in laterites. The thickness and deeply weathered condition of

this soil may be in part a result of downslope movement and accumulation of weathered debris. Nonetheless, it exceeds anything seen on glacial deposits in this area, except possibly Ancient stage materials on lower Swift Creek. The gravel beneath the slopewash is deeply oxidized to a rich-orange brown in the upper 50 feet and to a yellowish brown in the matrix, 65 feet below the top of the gravel. The degree of disintegration of the diorite boulders is impressive. They are loose enough to be picked apart by bare fingers, and all weather flat

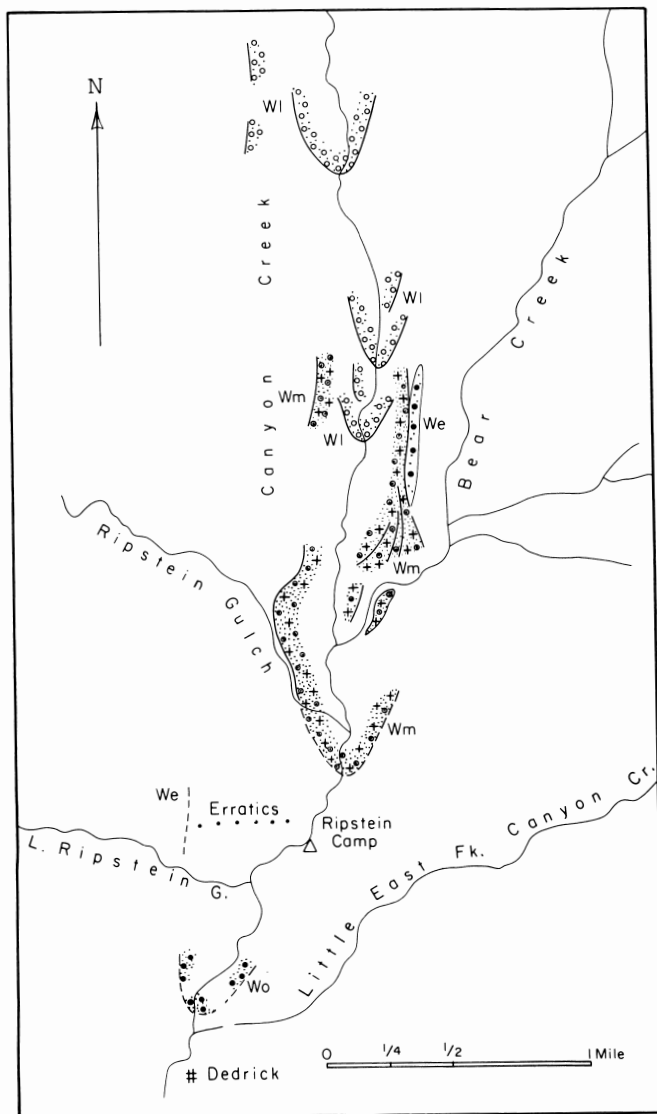
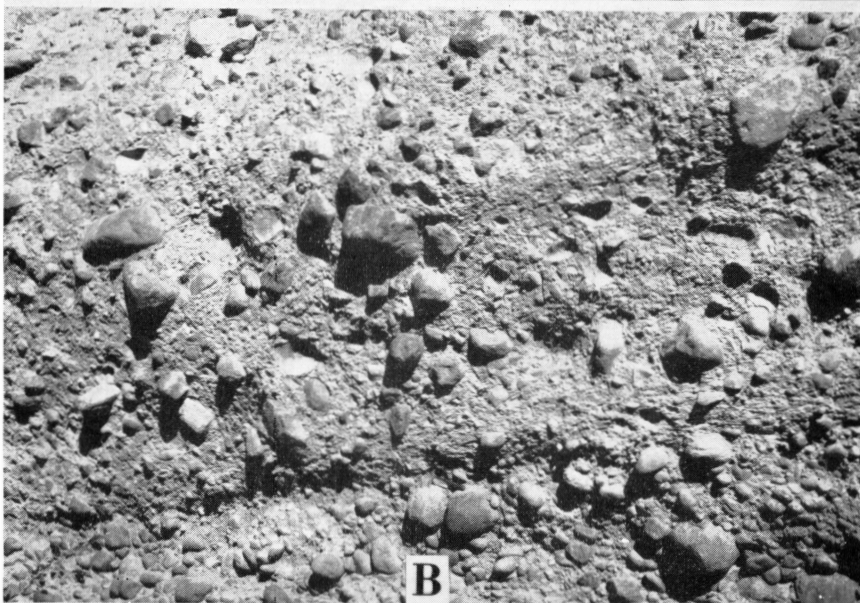
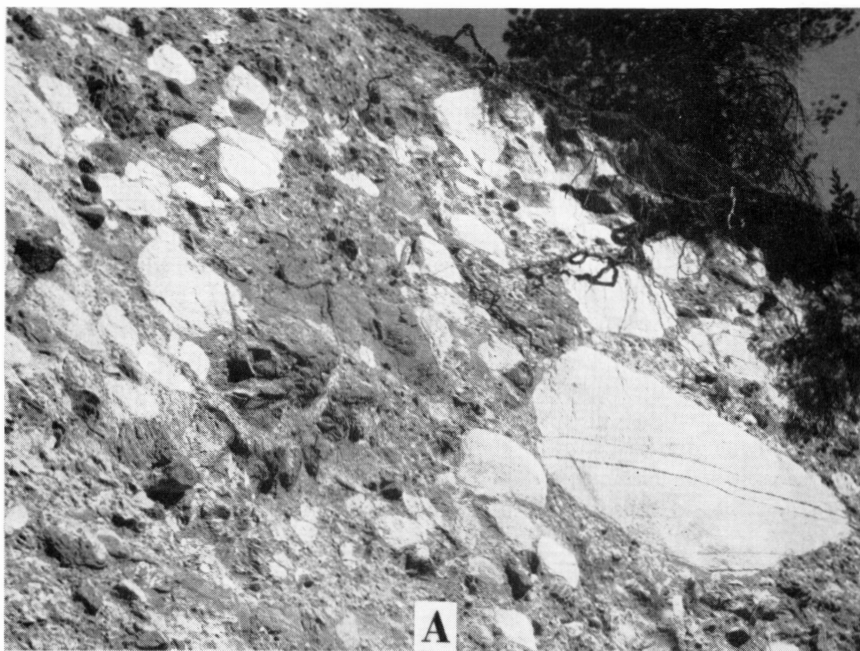


Fig. 10. Moraines on Canyon Creek.

PLATE 2



A. Flat-to-the-face weathering of dioritic boulders in old gravel at mouth of Big East Fork of Canyon Creek. Largest boulder 12 feet across.  
B. Debris-flow deposit along lower Swift Creek; detritus is almost wholly serpentine. Rounded boulders at base are in layer of glacialfluvial material. Largest stones 2-3 feet across.

to the face of the bank (plate 2A). Even the largest, 12 feet across, has no residual core. Metamorphic boulders also show considerable decomposition 50 feet below the top of the gravel where a number weather flat to the face. These relations indicate that the gravel is considerably older than deposits of the Early substage glaciation farther up Canyon Creek. Canyon Creek has cut down nearly 400 feet, 330 feet in hard bedrock, since deposition of the gravel, a further testimony of considerable antiquity.

An outstanding feature is the sudden appearance of large dioritic boulders which must have come down the Big East Fork. At the head of this stream are excellent sets of moraines representing the Late, Middle and Early substages (fig. 11). If the dioritic gravel at the mouth of the Big East Fork were laid down directly by ice, the glacier would have been more than 3 times as long as any of its recognized predecessors. This seems unlikely, and a more reasonable possibility is that the gravels are glacial outwash. The sudden influx of coarse dioritic boulders could be caused by glaciation, and the steep narrow canyon of the Big East Fork provides a good avenue of fluvial transport. It is a reasonable speculation that these coarse dioritic gravels represent glacial outwash, but the proof is neither direct nor compelling. If they are glacial, the

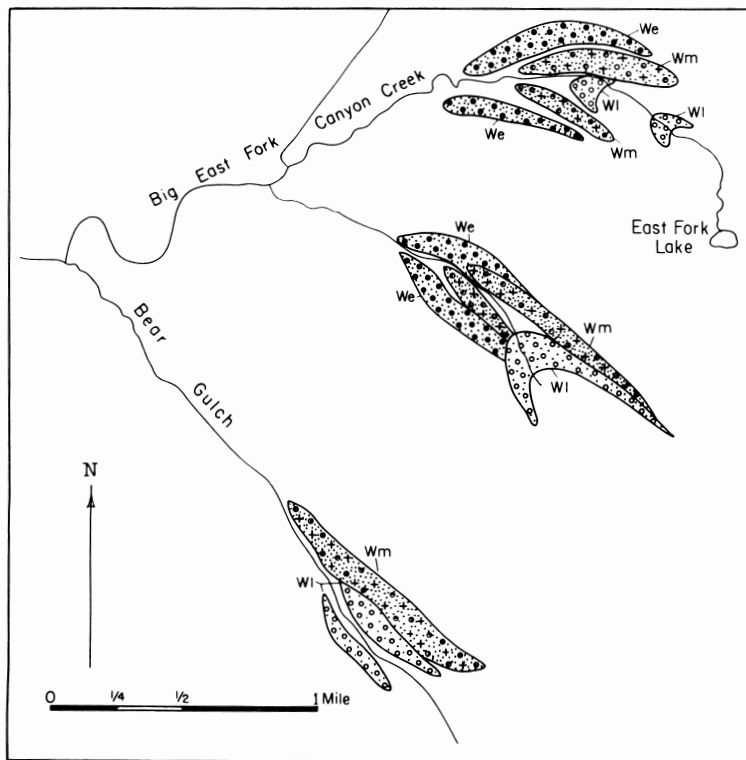


Fig. 11. Moraines on Big East Fork of Canyon Creek.

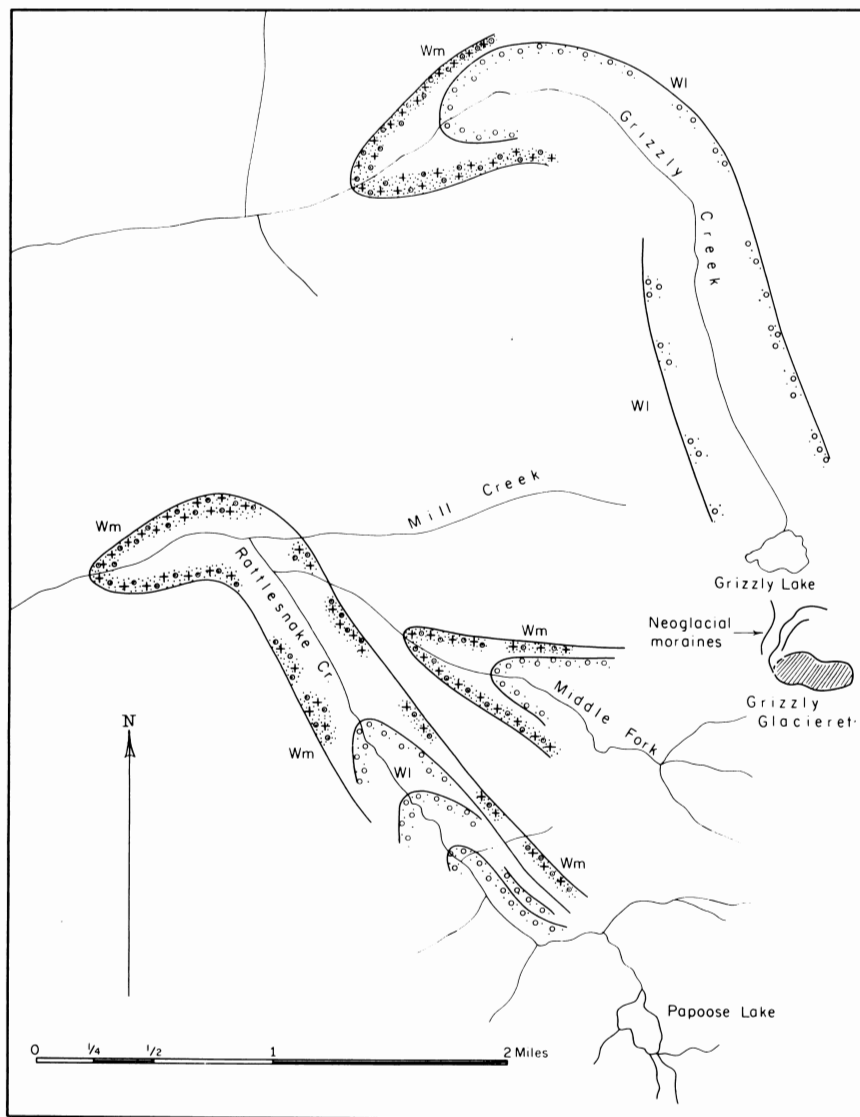


Fig. 12. Moraines of Grizzly—Rattlesnake creeks area.

evidence of antiquity suggests that they are no younger than the Ancient stage on lower Swift Creek and indeed may be considerably older.

#### *Neoglaciation<sup>2</sup>*

Small, fresh, well-defined moraines in the higher parts of the Trinity Alps

<sup>2</sup> This term is used simply as a short convenient designation for a readvance of ice subsequent to shrinkage during the Hypsithermal interval. Cooper (1958, p. 943) suggests the term Hypothermal for this post-Hypsithermal phase and perhaps Hypothermal glaciation would be a preferable term.

may be the product of a post-Hypsithermal glaciation rather than a recessional phase of the late Wisconsin. Such moraines have been mapped on parts of valley walls formerly covered by carapaces of ice, around the margins of existing ice and snow bodies, and on the floors of small cirques. They are mostly

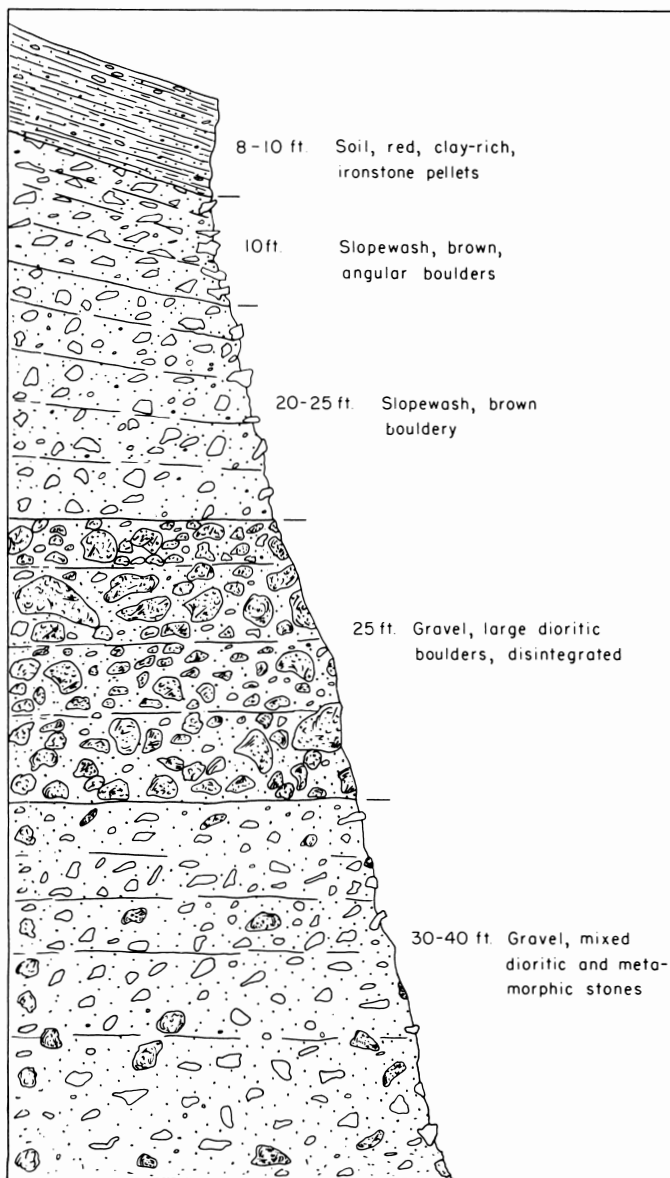


Fig. 13. Sketch of deposits on 330-foot rock terrace at mouth of Big East Fork of Canyon Creek.

20 to 30 feet high, sharp crested, essentially unmodified by erosion, and composed at least superficially of coarse angular blocks. In plan view they are conformable in shape and location to existing ice and snow bodies or to earlier ice masses. On the south (north-facing) wall of Stuart Fork above Sapphire Lake is a succession of 3 such moraines (fig. 2), and a similar sequence was mapped in a zone peripheral to Grizzly glacieret (fig. 12). The outermost moraine of the Stuart Fork group was formed by an ice body about 0.9 mile long that attained a minimum elevation of 6800 feet. The corresponding parameters at the Grizzly glacieret are 0.6 mile and about 7500 feet.

The possibility that these moraines are Neoglacial (Matthes, 1939, p. 519-520; 1940, p. 398-403; 1942, p. 212-214) and therefore formed by an ice advance occurring in the post-Hypsithermal interval is supported by the following points. The innermost moraine is exceedingly youthful and fresh. It bears only a scattered growth of grass, flowers and low bushes, many of the component blocks are not yet stable, and the location is only 200 to 300 yards beyond the edge of existing snowbanks and ice masses. It may correspond to the "1850" moraines of the Sierra Nevada (Matthes, 1940, p. 400). The intermediate moraine is clearly older. Its boulders are stable and the vegetative cover, although sparse, is more dense with conifers 30 feet high and possibly 50 to 100 years old. The outermost moraine is several times older judging from the density of its vegetative cover and the size of trees growing on it.

A further indication of the recency of this glacial episode is the light color of the glaciated dioritic rock surfaces inside the moraines as compared to the distinctly grayish cast of glaciated bedrock outside the moraines. The location and size of other Neoglacial ice bodies which did not form moraines can be determined in some instances by this striking and sharply limited contrast in

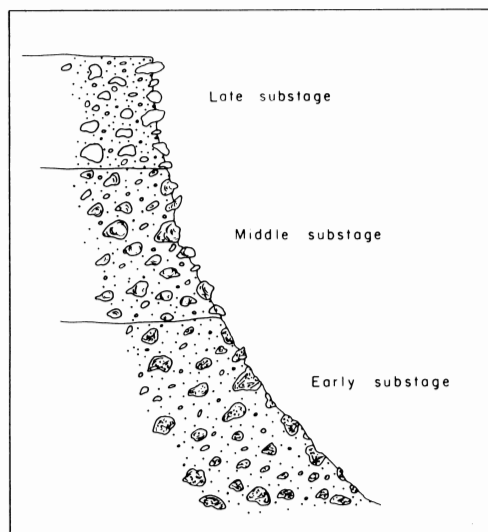


Fig. 14. Weathering behavior of boulders in glacial till as exposed in steep banks.

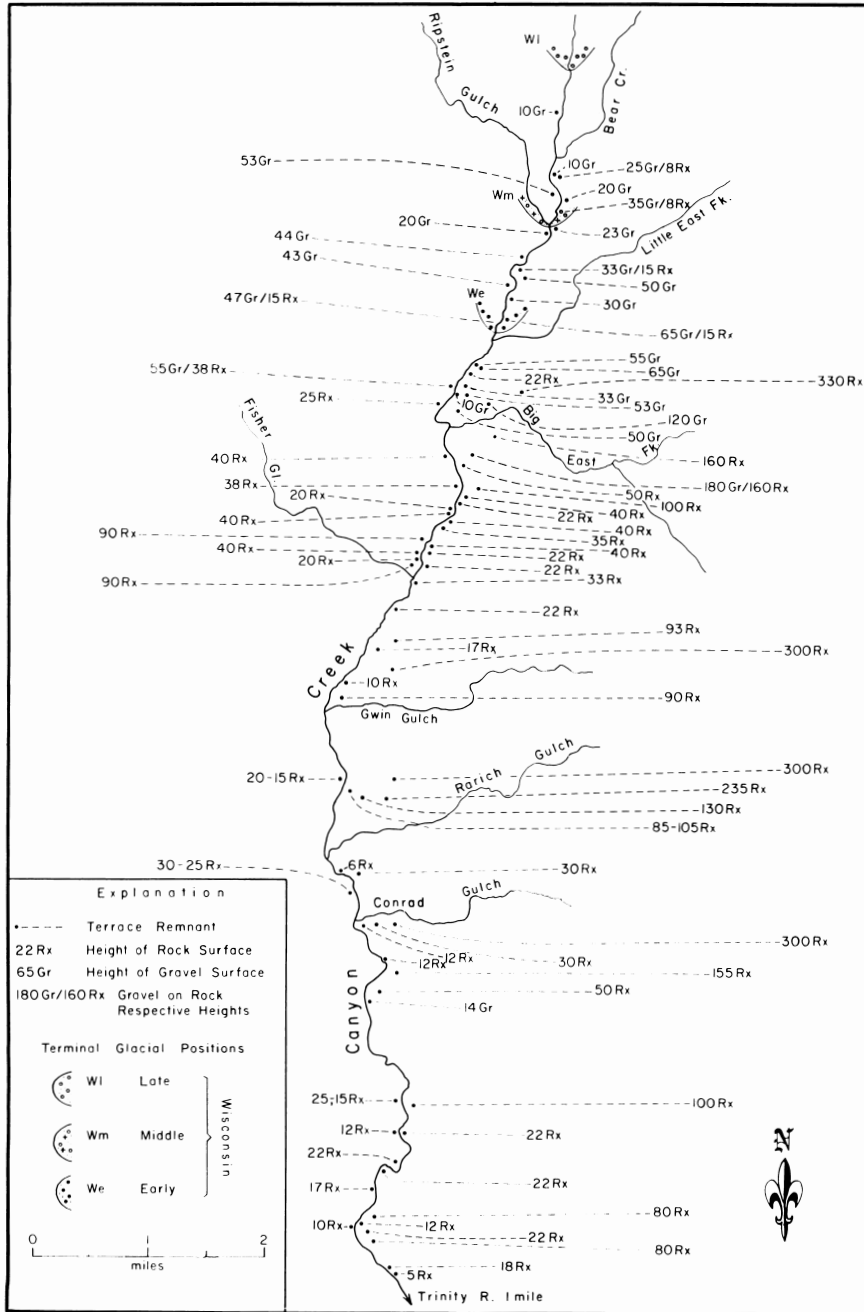


Fig. 15. Canyon Creek terraces.

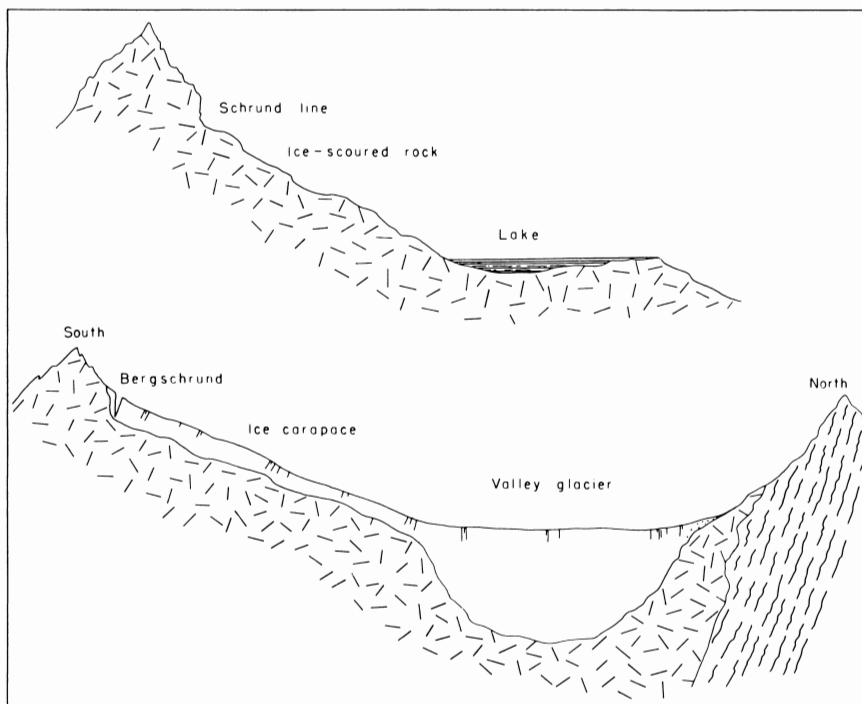


Fig. 16. Diagrammatic sketches of; A—Trinity Alps-type cirque; B—ice carapace relation on valley wall.

bedrock coloration. On this basis, some Neoglacial ice bodies are judged to have attained a length of nearly two miles.

The moraines are estimated to range in age from about 100 years to at least several hundred and possibly 2 or 3 thousand years. That the ice which formed them was regenerated during the post-Hypsithermal interval is not directly demonstrable but seems likely for reasons advanced by Matthes (1939, 1940). Birman (1957, p. 152-179) recognized and mapped 3 Neoglacial sub-stages in the central Sierra Nevada.

#### CHRONOLOGICAL DIFFERENTIATION OF GLACIAL DEPOSITS

Differentiation of drift deposits on a basis of age, both relative and absolute, remains a major problem in mountain glaciation. Criteria are needed for expressing relative time relationships in a quantitative manner. The following is a list of criteria, with brief explanatory notes, used for chronological differentiation in this work (table 3). Many of these features and others not utilized here have been discussed by Blackwelder (1931, p. 870-880), Nelson (1954, p. 334-338), and Birman (1957, p. 60-87) among others.

#### *Local Value of Specific Criteria*

A few of the items listed (table 3) are new, different, or special in their application. Some are dependent on particular aspects of the local environment

and cannot be freely applied in other areas.

Topographic position nearly always affords the primary basis for initial segregation of glacial deposits in a single canyon. The older deposits are mostly higher on canyon walls or farther downstream, for each successively younger ice advance destroys the surface features of earlier glaciations in the area invaded. Weathering of surface stones has progressed to such an extent here even on Late substage moraines that no easily expressed significant distinction could be made between weathered and unweathered boulders. Attention was therefore focused on boulder frequency rather than weathering ratios (Blackwelder, 1931, p. 877; Birman, 1957, p. 67-74). Counts were made on stones of comparable lithology, usually diorite, in corresponding topographic situations. The counting procedure involves quick judgments of such matters as width of the strip (10 feet), size of boulders near the one-foot limit, the size of partly buried boulders, and whether fragments of a fractured boulder are to be counted separately. The procedure is admittedly crude and in part subjective. However, with experience and practice an individual observer produces surprisingly consistent results.

TABLE 3

## Criteria used for chronological differentiation of glaciations in Trinity Alps

1. Topographic position of moraines	Successively older moraines are progressively higher on valley wall or increasingly farther downstream.
2. Topographic expression of moraines	Late (Morris Meadow) moraines have conspicuously sharper, more irregularly jumbled topographic features. Smoothed and subdued forms, degree of gullying and extent of removal of loop moraines by axial streams increase with age.
3. Topographic unconformity	Involves discordance in trend of morainal ridges where deposits of younger phase rest against or overlap older moraines (see fig. 10).
4. Preservation of lateral moraines	Depends strongly upon local topographic situation. Early (Alpine Lake) laterals are preserved only in ridge-crest locations. Well-defined laterals of Middle and Late substages remain only on valley walls that are not too steep or too severely washed.
5. Boulder frequency	Measured by counting number of boulders one foot or more in diameter in strip 100 feet long by 10 feet wide on crest of morainal ridge. See plate 1 for pictorial representation.
6. Condition of surface boulders	Remnants of mechanically worn surfaces found on boulders on Late substage moraines, rare ever there. Spalling and fracturing along joints are marked on Late substage boulders, seen to small degree on Middle substage, almost entirely lacking on Early substage. Loss of rounding on boulder because of differential weathering most noticeable on Early substage moraines. Disintegration first becomes dominant apparent mode of weathering in dioritic surface boulders of Early substage.

TABLE 3 (Continued)

	Differential weathering along cracks etches them 1 inch deep in Middle substage and to 4 inches deep in Early substage.
	Inclusions etched into relief by differential weathering project 1-2 inches on Middle substage and more than 2 inches on Early substage boulders.
	Pitting and differential weathering give Early substage boulders wholly different appearance than younger boulders.
	Ground-level weathering platforms a few inches wide are relatively common on Early substage boulders.
	Some dioritic boulders weather flat-to-the-ground on Early substage moraines but not on younger moraines.
	A distinctive nodular weathering occurs in Early substage boulders to much greater degree than in younger deposits.
	Early substage boulders are more extensively covered by lichen and discolored by a dark weathering coat.
7. Color of drift	Strongly influenced by lithology. Deep red colors on finely ground serpentine of Early and Ancient glaciations. Yellowish-brown common on Middle substage till containing considerable metamorphic detritus. Dioritic material shows noticeable yellow or brown colors only when older than Middle substage.
8. Soils	Dark-red, clay-rich soil with abundant ironstone pellets found on serpentine-rich glacial debris of Ancient stage on lower Swift Creek. Brownish-red soil of similar character, also with ironstone pellets on serpentine detritus of Early substage on Swift Creek. Soils not widely useful.
9. Surface mantle	Burial of surface boulders by disintegrated dioritic guss significant only on Early substage or earlier materials, except in swales or other depressions. Properly situated glacial deposits receive a mantle of "coverhead", largely slopewash increasing in thickness, complexity, and degree of weathering with age.
10. Cut-bank exposures	In Late substage deposits all boulders project from face of steep cut banks. In Middle substage materials about 90 percent of boulders project to some degree. Many are sound enough to ring to a hammer blow. Some dioritic boulders show disintegration and spheroidal weathering with sound cores. In Early substage materials 90-100 percent of dioritic boulders weather flat-to-the-face, at least in upper 15-20 feet of the cut. All are deeply disintegrated and crumble under hammer blow (pl. 2A; also fig. 14).
11. Secondary incrustations	Buried near-surface stones and buried parts of surface stones of Middle and Early substages have dense incrustations of clay and iron oxides.
12. Stratigraphic relationships	Superposition of deposits of one glaciation upon another although rarely seen in this area are extremely useful.
13. Vegetative cover	Middle and Early substage moraines tend to support good stands of timber in comparison with dense brush cover on many Late substage moraines. Does not hold along canyon bottoms where all are forested.

The counts are not the same from canyon to canyon (table 4), but within a single canyon they afford a basis for differentiation of glacial episodes. Among other things, they suggest that the Late (Morris Meadow) substage may consist of two distinct phases, a relationship already inferred from other criteria. From boulder counts it is inferred that the time interval between the Early and Middle substages is greater than between the Middle and Late substages.

A useful chronological criterion in the Trinity Alps was the behavior of boulders on steep cut banks, item 10 (table 3). It was applied chiefly to dioritic boulders and is primarily a function of the degree of subsurface weathering. Middle and Early substage deposits were distinguished by this means on Canyon Creek. The weathering "flat-to-the-face" of nearly all dioritic boulders, even several feet in diameter, in the Early substage deposits is striking and contrasts with projecting boulders in cuts through younger deposits.

TABLE 4  
Boulder counts on glacial moraines in the Trinity Alps\*

Location	Moraine type	Boulder count			
		Late (Wl)	Middle (Wm)	Early (We)	Ancient (pWa)
Sugarpine Creek	Terminal	162			
	Recessional	177			
	Recessional		73		
	Lateral		109		
	Lateral			15	
Boulder Lake	Recessional	125			
	Lateral	110			
Boulder Creek	Recessional	125-130			
	Lateral	80			
	Lateral	100-105			
	Lateral		46		
Little Boulder Lake	Lateral	135			
Alpine Lake Creek	Lateral	180			
	Lateral		135-140		
	Lateral			90	
Swift Creek	Lateral			115	
	Lateral				10-20

\* Figures represent numbers of surface boulders 1 foot or more in diameter in a strip 100 feet long by 10 feet wide on the crest of a morainal ridge. In all locations cited boulders were dioritic except on Swift Creek where they were serpentine.

#### DATA ON THE PLEISTOCENE GLACIERS

During the Late (Morris Meadow) phase of glaciation, the area mapped contained at least 30 separate valley glaciers and a few cirque glaciers. Three large composite ice streams occupied Swift and Canyon creeks and the Stuart Fork. Lengths and terminal elevations of all glaciers during the 4 principal phases of glaciation are given in table 5, and a summary presentation is made in table 6.

TABLE 5  
Data on Pleistocene glaciers of Trinity Alps

Glaciated Drainage	Elevation of headwater divide (in feet)	W1	Elevation of terminal moraine and length of glacier at indicated stages	Wm	We	pWa	General direction of exposure in headwaters	Location
<b>SOUTH FORK OF SALMON RIVER DRAINAGE</b>								
Conrad Gulch	7500	5400 1.2 mi 3800	5100 1.5 mi	—	—	—	N	T 37 N, R 10 W
Caribou Lakes	7500	4 mi 3900	— 3500	—	—	—	N	T 37 N, R 10 W
East Fork Thompson Creek	7600	3.1 mi 3800	3.9 mi	—	—	—	N	T 37 N, R 10 W
Thompson Creek	8500	3.1 mi	—	—	—	—	N	T 36 N } T 37 N }
<b>COFFEE CREEK DRAINAGE</b>								
Little Boulder Creek	6800	4800 1.2 mi 4500	4300 1.8 mi 3150	—	—	—	NE	T 37 N, R 8 W
Boulder Lake	7000	2.4 mi 3750	4.0 mi 3150	—	—	—	N	T 37 N, R 8 W
Boulder Creek	7200 to 7500	3.8 mi 4200	5 mi 3600	—	—	—	N and NE	T 37 N } R 8 W } R 9 W }
Sugarpine Creek	7500	3.2 mi 4600	4.1 mi 4100	—	—	—	NNE	T 37 N } R 8 W } R 9 W }
Battle Creek	7500	2.6 mi 4950	3.2 mi 4500	—	—	—	N	T 37 N, R 9 W
Union Creek	7000 to 7500	5.0 mi	6.0 mi	Into Coffee Creek	—	—	NW	T 37 N } T 38 N }

TABLE 5 (Continued)

Glaciated Drainage	Elevation of headwater divide (in feet)	Elevation of terminal moraine (in feet) and length of glacier (in miles) at indicated stages			General direction of exposure in headwaters	Location
		Wl	Wm	W <sub>a</sub>		
Coffee Creek (South Fork Salmon River)	7000 to 8000	4950 6.5 mi	4750 7.8 mi	—	N	T 36 N } T 37 N } R 9 W T 38 N }
<b>SWIFT CREEK DRAINAGE</b>						
Parker Creek	8000	5900 1.5 mi	Tributary to Swift Creek glacier		SE	T 37 N, R 9 W
Bear Creek	7200 to 7900	5600 2.8 mi	Tributary to Swift Creek glacier		NNE	T 36 N, R 9 W
Granite Creek	8000	4800 4 mi	Tributary to Swift Creek glacier		NE	T 36 N, R 9 W
North Fork of Swift Creek	7400	4400 3.4 mi	4000 4.0 mi	—	E	T 37 N, R 8 W
Lick Creek	7600	5600 1 mi	—	—	E	T 36 N } T 37 N } R 8 W
Swift Creek	7500 to 8000	4800 4.8 mi	3700 7.5 mi	2750 11.3 mi	E	T 36 N } T 37 N } R 8 W T 37 N } R 9 W
<b>EAST FORK OF STUART FORK DRAINAGE</b>						
Long Canyon	8000	4800 2.2 mi	East Fork Gl. 3900 3.4 mi		ESE	T 36 N, R 9 W
Bowman Meadows	7750 to 8000	5100 2.0 mi	3900 3.5 mi	3200 4.6 mi	ENE	T 35 N, R 9 W
<b>STUART FORK DRAINAGE</b>						
Deer Creek	7500 to 8000	5500 2.5 mi	4750? 4.2 mi	3200 4.7 mi	N	T 36 N, R 9 W

TABLE 5 (Continued)

Glaciated Drainage	Elevation of headwater divide (in feet)	Elevation of terminal moraine and length of glacier (in miles) at indicated stages			General direction of exposure in headwaters	Location
		W1	Wm	We		
Salt Creek	8000	5200 1.5 mi	—	—	W	T 36 N, R 9 W
Alpine Lake Creek	8000	4900 2.0 mi	3600 2.8 mi	Tributary to Stuart Fork Gl.	E and SE	T 36 N, R 10 W
Deep Creek	7500 to 8000	4800 2.6 mi	4300 3.1 mi	—	W	T 35 N } T 36 N } R 9 W
Stoney Creek	7400	6900 0.2 mi	6500 0.4 mi	—	S	T 35 N, R 9 W
Stuart Fork	8000 to 8500	4000 7.5 mi	3650? 8.8 mi?	3100 10.8 mi	ENE	T 35 N } T 36 N } R 10 W
RUSH CREEK DRAINAGE						
Rush Creek	7500	4000 2.8 mi	3500 3.3 mi	—	E	T 34 N } T 35 N } R 10 W
CANYON CREEK DRAINAGE						
Big East Fork of Canyon Creek	7300	5250 1.0 mi	4900 1.4 mi	4700 1.5 mi	N	T 35 N, R 10 W
Canyon Creek	8500 to 8900	3350 7.8 mi	2800? 9.3 mi	2500? 10.5 mi	E and S	T 36 N } T 35 N } R 10 W
NORTH FORK OF TRINITY RIVER DRAINAGE						
Grizzly Creek	8500 to 8900	4650 4.1 mi	4450 4.6 mi	—	N to NNW	T 37 N, R 11 W
Rattlesnake Creek	8500 to 8900	4450 4.2 mi	3950 5.0 mi	—	NW	T 36 N, R 11 W

Canyon Creek glacier was the longest in the last two substages, and it also had the lowest terminal elevation in all three Wisconsin substages (table 6). This is attributed to a relatively large accumulation area at a comparatively high elevation, to the straight narrow nature of Canyon Creek, and to its relative steep longitudinal profile. The largest glacier by area during the Early (Alpine Lake) substage was in Swift Creek. It covered roughly 18 square miles compared to 16.7 and 9.2 square miles respectively for the Stuart Fork and Canyon Creek glaciers.

The record of glacier dimensions during the older phases of glaciation is necessarily incomplete as much of the evidence has been destroyed. Coffee Creek should have carried a relatively large ice stream in the Early (Alpine Lake) and Ancient (Swift Creek) phases, but no good evidence for this has been found. Likewise, the extent of Ancient stage glaciers in Canyon Creek and on Stuart Fork remains unknown.

In the Trinity Alps, length has varied much more than terminal elevation. The interval between mean terminal elevations for the 3 Wisconsin substages is essentially constant at about 700 feet, but the difference in length increases by a large factor with age.

TABLE 6  
Summary of lengths and terminal elevations of largest glaciers  
in Trinity Alps

Phase of glaciation	Longest glacier		Lowest Terminal elevation		Mean elevation of terminus	Mean length
	Length in miles	Valley occupied	Elevation in feet	Valley occupied	In feet, number of glaciers in parentheses	In miles, number of glaciers in parentheses
Late (Morris Meadow)	7.8	Canyon Cr.	3350	Canyon Cr.	4615 (30)	3.1 (30)
Middle (Rush Cr.)	9.3	Canyon Cr.	2800	Canyon Cr.	3900 (23)	4.3 (23)
Early (Alpine Lake)	11.3	Swift Cr.	2500	Canyon Cr.	3240 (6)	7.2 (6)
Ancient (Swift Cr.)	13.7(?)	Swift Cr.	2450(?)	Swift Cr.	2450 ? (1)	13.7 ? (1)

#### SPECIAL FEATURES

##### *Debris Flows*

Deposits of debris-flow material, indistinguishable from till, greatly complicate the determination of glacial boundaries in those parts of the Trinity Alps where serpentine is the principal bedrock. Serpentine is a notoriously ready participant in mass movements, a tendency which becomes accentuated when the material is finely ground and supplied with abundant water. Thus, highly mobile debris flows formed at the snouts of glaciers carrying principally

serpentine detritus and extended several miles down valley. Successive flows built up thick deposits not unlike outwash trains but markedly different in constitution. Perhaps, accumulations of glacially supplied flow debris should have a specific name other than Hartshorn's (1958) flowtill, a similar but more localized deposit derived from superglacial material.

Trinity Alps flow debris contains abundant boulders of serpentine and a few of other lithologies, mostly no larger than 4-6 feet in diameter but in some instances up to 10 feet across (plate 2B). These and numerous smaller stones are firmly embedded in a copious greenish-gray matrix rich in silt and clay. In large exposures an indistinct stratification is expressed by beds 5 to 30 feet thick with occasional intercalated layers or lenses of water-laid gravel, sand, and silt. These layers dip 3 to 5 degrees downstream, and a general lack of weathering along contacts between them suggests relatively rapid deposition. In most exposures the flow debris is so hard, tough, and compact that it stands in vertical banks, forms the beds of stream channels, and fragments of it compose abraded boulders in modern stream gravels.

In most respects this flow debris looks more like till than till itself. The resemblance is strengthened by inclusion of glacially striated stones, so that a distinction in small exposures is virtually impossible. The layering seen in large exposures, the location and distribution, the nearly continuous exposure along a stream, and surface morphology were the only criteria of much help in distinguishing flow debris from till.

Deposits of this origin are particularly extensive on lower Deer and Swift creeks. A succession of flows filled the narrow canyon of Deer Creek to a depth of at least 330 feet in the Middle substage and about 500 feet in the Early substage. These deposits have been largely slushed out by Deer Creek, but patches still cling to the valley walls and sit atop the narrow bedrock ridge between lower Deer Creek and Stuart Fork.

On lower Swift Creek debris-flow deposits are exposed to a thickness of 100 feet in stream-cut banks, and other relations suggest a maximum thickness approaching 400 feet. These thicker accumulations compose broad rounded ridges on both sides of the stream, that may be subdued lateral moraines or huge mudflow levees. Ridges of this type formed during both the Early and the Ancient glaciations (fig. 8).

Probably each phase of glaciation sent its share of debris flows surging down Swift Creek. On the east side of lower Swift Creek inside the Early lateral ridge at the big bend are three distinct benches at 75, 90 and 160-170 feet above the creek. The upper bench is 200-300 feet wide, but the others are narrower. These benches may represent remnants of accumulated flow debris of the Late, Middle and Early substage of glaciation.

The difficulty of distinguishing flow debris from till complicates the accurate definition of the extent of Early and Ancient glaciers on lower Swift Creek. The terminal position of the Early glaciation (fig. 8) is shown with reasonable confidence, but the terminus indicated for the Ancient glacier may be too far downstream. It seems likely that Hershey (1900, p. 48), Ferguson (1914, pl. II) and Hinds (1933, pl. III) were earlier confused by outcrops of flow debris in this same area.

Tributaries of lower Swift Creek were ponded as glacial and flow debris accumulated along the trunk stream. Cement Creek presumably derived its name from pond deposits of light-colored silt and clay that compose its bed and banks just outside the Early lateral ridge on the north side of Swift Creek. Along Gratten Creek are similar well-bedded clay and silt deposits lying between debris-flow deposits of the Early and Ancient glaciations.

Patches of till-like material containing much serpentine detritus occupy protected niches on the walls of Coffee Creek several hundred feet above the canyon floor at its junction with Union Creek. Similar material is not found along Coffee Creek above or below this site, so the detritus probably came down Union Creek. The deposits may well be glacial since there is an Early substage lateral moraine high on the east side of lower Union Creek, but the possibility of debris flowage contributes a degree of uncertainty. Likewise, it is difficult to determine whether till-like deposits high on the spur north of the mouth of Salt Creek, an east side tributary of Stuart Fork, represent flow debris from Salt Creek, from Deer Creek, or till laid down by the Stuart Fork glacier.

Need for recognizing flow debris as such is further demonstrated in places where materials of this origin could have had no relation to glaciers. An example in point is provided by small patches of serpentine-rich flow debris on Stuart Fork at the mouth of Elk Gulch, three-quarters of a mile above Trinity Alps Resort. This material came down Elk Gulch from an unglaciated area of serpentine bedrock on the south flank of Red Mountain. A misidentification as till could lead to a wholly erroneous conclusion as to the size of the Stuart Fork glacier. Crandell and Waldron (1954) found that deposits formed by huge debris flows from the flanks of Mt. Rainier were previously misidentified as till.

### *Stream Terraces*

Remnants of terraces at several levels along streams in the Trinity Alps have attracted early attention because of associated auriferous gravels (Hershey, 1902, 1903a, 1903c, 1904; Diller, 1914; Averill, 1933). Terrace remnants are largest and most abundant along tributary canyons in the mountains and in wide parts of the major river valleys known by the local name "bar". Most terraces consist of a gently sloping rock surface mantled by bouldery stream gravel 8 to 15 feet thick and locally attaining 45 feet. Where the local setting is suitable, a coverhead of weathered slopewash, a few to 20 feet thick, has formed on top of the stream gravels. Placer workings provide good exposures of the deposits, the rock-gravel contact, and the bedrock surface. The latter in many instances displays an impressively rough microtopography of knobs, ridges, channels, and closed depressions in haphazard arrangement on a relief-scale of 10 feet.

In early phases of this work considerable effort was devoted to the study and mapping of terraces in hopes that they would provide a means of linking the glacial sequence of the Trinity Alps to Pacific coastal terraces, a possibility earlier perceived by Hershey (1903a, p. 431). This expectation was dashed by the lack of marine terraces at the mouth of Klamath River, but the stream ter-

ances remain worthy subjects of attention in their own right. They afford a possible means of extending the glacial chronology into unglaciated areas and are important reference horizons and recorders of Pleistocene history.

Correlation of terrace remnants was principally by height above present grade, supplemented by the nature and weathering of overlying deposits. Heights were determined by hand leveling on low terraces and by Paulin altimeter on higher surfaces. The figures are good to within 10 percent; even less for the higher levels. In view of irregularities in the terrace surfaces and other considerations, more accurate measurements would not be significant.

Canyon Creek contains some of the more numerous, well preserved, and best exposed terrace remnants of the Trinity Alps. Since they were studied in detail, a brief description is given as representative of the area. The remnants are scattered along the course of Canyon Creek downstream from its glaciated reach (fig. 15). Ignoring small intermediate surfaces and rounding off the figures within the accuracy of measurement, the principal terrace levels along Canyon Creek can be said to lie at 10, 20, 40, 90, 160 and 300 feet above the present stream. These figures are for the height of the bedrock surface which is the datum most easily and accurately determined. The upper surface of the gravel is usually 8 to 15 feet higher and in some ways would be a better datum since it probably comes closer to the level of the original stream channel in average discharge but in most places it has been removed by placering. Near the limit of glaciation, the bedrock surface is not always exposed, and in some other places both the rock and gravel surfaces were measured (fig. 15).

Since the terraces are essentially bedrock surfaces, there is no immediate reason to conclude that they must be genetically related to glaciation. It could be argued that the streams were in a cycle of down cutting when glaciation occurred flooding the canyons with great quantities of outwash and causing the streams to erode laterally thus creating the gently sloping rock surfaces that constitute the present terraces. Down cutting could presumably be renewed in the interglacial intervals. The gravel mantles on terraces, locally as much as 45 feet thick, give some support to this idea, but the argument is tenuous at best and lacks other means of direct confirmation.

A direct relation with glaciation could be established by tracing a terrace directly to the terminal position of a glacier and showing that it does not continue farther up stream. Much time and effort were expended in attempting to do this on Canyon Creek without complete satisfaction. However, the 10-foot rock terrace fulfills these requirements reasonably well for the Late substage of glaciation, and the 20-foot terrace bears a similar relation to the Middle substage. Remnants of the 40-foot rock terrace also lie down stream from the estimated terminal position of the Early substage of glaciation (fig. 15).

In terms of chronological relations, the correlations indicated in table 7 appear reasonable. This does not imply that the terraces are genetically related to glaciation but only that they are of about the same age. Reasons for considering the 300-foot level as possibly older than any of the glaciations identified have already been presented. This view is also supported by the fact that deposits on the 90-foot and higher terraces are mantled by debris more deeply

and extensively weathered than anything seen on glacial deposits except those of the Ancient stage on lower Swift Creek.

TABLE 7  
Suggested chronological relations between episodes of glaciation  
and rock terraces on Canyon Creek

Mean height of Rock Terrace in Feet	Episode of Glaciation
10	Late glaciation
20	Middle glaciation
40	Early glaciation
90	Ancient glaciation
160 } 300 }	Still older glaciation?

#### *Ice Carapaces and Schrund Lines*

In the central high country of the Trinity Alps are extensive glaciated rock surfaces on sloping valley walls far above the level of the former ice streams partly filling these valleys (plate 3). Similar surfaces are found in place of cirques (fig. 16) at the heads of many canyons, Devils Canyon and Granite Creek for example. Surfaces of this type are better developed in the Trinity Alps than in most other glaciated mountain ranges of western United States. They are well displayed throughout the headwaters of Canyon Creek and the Stuart and North forks of the Trinity River where they caught the attention of Cox (1956, p. 109-110).

Striae, scoured and plucked rock surfaces, and *Schrund* lines show that the valley walls in these areas had a mantle or carapace of ice, possibly no more than 200 to 300 feet thick, that flowed toward the valley axis. The situation is pictured to have been about as sketched in figure 16. Ice bodies of this type have been observed repeatedly in areas of existing glaciers in Alaska. It is important that the work they did should not be credited to the ice streams flowing in the valleys, as this would lead one to attribute much too great a thickness to the valley glaciers.

Two factors probably contributed to the development of these ice carapaces. First, a suitable valley wall of modest slope had formed by normal weathering and erosion of the dioritic rocks composing much of the central core. Secondly, the climatic environment of the glacial age had enough of a maritime flavor to produce wet, sticky snow which accumulated on the sloping valley walls until it attained a thickness great enough to flow.

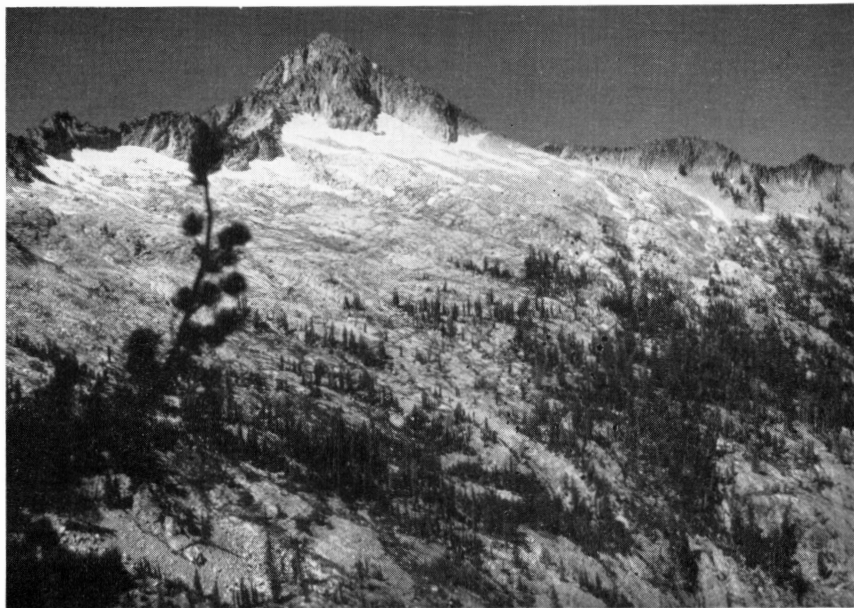
Accompanying features of interest are the prominent *Schrund* lines which in many places define the upper and lateral limits of the ice carapaces. *Schrund* lines are found not only along the base of ragged crested divides but also along the edges of lateral spurs projecting into the valleys and separating adjacent carapaces. These lines presumably mark the mean location of the perennial

crevasse or *Bergschrund* near the edge of the ice where exceptional excavation of bedrock occurred. The cliffs defining such *Schrund* lines are usually 50 to 300 feet high.

*Existing Glaciers*

Two small vestigial bodies of glacier ice remain in the area. One lies at the head of Grizzly Creek on the north side of Thompson Peak (8936 feet). The other occupies an adjacent cirque at the head of Thompson Creek on the north side of a high unnamed peak (8800 feet) on Sawtooth Ridge 0.6 mile east of Thompson Peak (plate 3). For identification the first is called Grizzly glacieret and the second Thompson glacieret.

PLATE 3



Looking west-southwest to unnamed peak on Sawtooth Ridge. Thompson glacieret under snow at base. Sloping rock surfaces scoured by former carapace of ice. Sharp ragged peaks and ridges rise above. August 6, 1950.

Such bodies cover 5 or 6 acres, lie at elevations between 8200 and 8500 feet, display crevasses, and consist of somewhat dirty ice in crystals up to one inch in diameter. When visited on September 1, 1956, a year of considerable residual snow, they were mostly snow-covered. Views from a distance in other, drier years suggest that at times 30 to 40 percent of the ice may be exposed during summer. A short distance beyond the margins of both bodies are fresh bouldery moraines indicative of greater size and activity in the immediate past.

The Trinity Alps may contain other vestigial glaciers as not all large snow banks were visited to see if they concealed ice, but possibilities seems light except perhaps above Lake Josephine. Hershey (1903a, p. 431) states that the "Alps" contained 3 small glaciers in 1903, but he does not locate or identify

them. The glacierets of the Trinity Alps are easily the lowest existing glaciers in California. They appear to have a reasonably good prospect of survival with a continuation of the climatic conditions of the early and mid 1950's.

#### *Snowline Relations*

Elevations of Pleistocene climatic and orographic snowline in the Trinity Alps can be estimated from the available data. Readers interested in background details concerning snowline types and their determination should inspect Charlesworth's (1957, p. 11-13) informative discussion.

The approximate limits of climatic snowline can be defined by altitudes of the lowest glaciated peaks and the highest unglaciated summits. In the Trinity Alps, peaks above 8000 feet almost without exception had glaciers on their north, northeast, and east slopes. Most peaks above 7500 feet show some evidence of glaciation, and specific isolated summits as low as 7100, 6900 and 6800 feet carried small glaciers on north and northeast slopes. Lower peaks are all unglaciated. Allowing for local topographic situations, one can say that the elevation of climatic snowline during the Wisconsin in this area was probably in the neighborhood of 8000 feet.

Cirque elevations have been used to determine the approximate altitude of orographic snowline. A compilation shows that cirque elevations in the Trinity Alps range between 6050 and 7500 feet. Many of the most reliable examples are at 6500 feet. This looks like a good mean value for Wisconsin orographic snowline, and it is reasonably compatible with Davis' (1958, p. 626) study of cirque elevations in northern California. Actually, local topography, exposure and other factors exert so much influence on cirque elevation that one might do better to speak of an orographic snow zone which in this area would extend from 6000 to 7000 feet. Cirques facing north, northeast, and northwest have a mean elevation of about 6500 feet. Cirques exposed to the east are 500 feet higher (7000 feet) and those facing west are still higher by 300 to 400 feet. The cirques lie 500 to 2400 feet below the bordering peaks and ridges, the interval being generally greater the larger the cirque. The direction of exposure of Trinity Alps cirques is; 45 percent north, 20 percent northeast, 15 percent northwest, 10 percent west, 10 percent east, and none to the south.

In the Trinity Alps climatic snowline appears to have been about 1500 feet higher than mean orographic snowline during the Wisconsin. Perennial snowbanks suggest that orographic snowline is at present in the neighborhood of 7500 feet. Unless the interval between climatic and orographic snowline has changed considerably, climatic snowline should now lie close to 9000 feet.

Brief inspection of glaciated sites on Mt. Lassen was made in order to compare the elevation of Wisconsin orographic snowline there and in the Trinity Alps. Mt. Lassen attains an elevation of 10,453 feet and lies 85 miles inland in an east-southeasterly direction. The data obtained suggest a mean elevation for Wisconsin orographic snowline in the Mt. Lassen area of 8000 feet, compared to 6500 feet in the Trinity Alps. Thus, the inland rise of Wisconsin orographic snowline in northern California at about Latitude 41° N. is roughly 18 feet per mile. This rise is probably due both to decreasing winter

precipitation and increasing summer ablation inland, a view supported by analysis of present-day climatic conditions (Davis, 1958, table 1, p. 621-622).

*Diversion of the Headwaters of Coffee Creek*

Any geologist working in this area who fails to report the diversion of the former headwaters of Coffee Creek into the South Fork of Salmon River at Big Flat will be characterized by his successors as totally blind. The present headwaters of the Salmon are so clearly a continuation (fig. 4) of the upper part of Coffee Creek that one scarcely needs the added confirmation afforded by the underfit condition of upper Coffee Creek, its wide gravel-floored valley that hangs above the Salmon, the sharp elbow in the Salmon, and the narrow bedrock gorge by which it passes out of the former Coffee Creek drainage.

The diversion most likely occurred during glaciation when ice rose high enough against the low divide between Coffee Creek and the Salmon River to permit a marginal meltwater stream to overflow the divide and to descend steeply into the Salmon River drainage. This stream cut down rapidly and was able to maintain its course during shrinkage of the glacier. When the ice had disappeared upper Coffee Creek was permanently diverted into the South Fork of the Salmon, a conclusion formerly reached by Hershey (1900, p. 46-48).

It would be convenient to think of this event as occurring during the Late substage of glaciation, for the terminal moraine of this advance is 1.75 miles down Coffee Creek from the point of diversion (fig. 4). However, the elevation of lateral moraines on the west wall of the Coffee Creek-Salmon River valley and the depth of the rock gorge followed by the present drainage would require at least 750 feet of stream-cutting in relatively resistant metamorphic rock during and since the Late substage. This requirement and the relatively open nature of the gap in the former Coffee Creek-Salmon River divide suggest that diversion occurred during some earlier episode of glaciation. One might therefore expect that the Coffee Creek-Salmon River glacier in the Late substage had a bifurcated tongue with one lobe extending down Coffee Creek and the other projecting into the South Fork of Salmon River below Big Flat. Conclusive evidence for the Salmon River lobe has not been found. Coarse granitic debris on the walls and in the bottom of the South Fork gorge is not obviously morainal, and the morphology of the gorge in no way suggests occupation by ice. Perhaps ice did not project far down the South Fork gorge because of the right-angle turn at the point of diversion (fig. 4), or because a dam of morainal debris partly choked the gap. Regardless of when it occurred, this is as good an example of glacially controlled stream diversion as could be desired (Hershey, 1900, p. 47).

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REFERENCES

- Averill, C. V., 1933, Gold deposits of the Redding and Weaverville quadrangles: Calif. Jour. Mines and Geology, v. 29, p. 2-73.

- Birman, J. H., 1954, Pleistocene glaciation in the upper San Joaquin Basin, Sierra Nevada: Calif. Div. Mines, Bull. 170, chap. 5, p. 41-44.
- , 1957, Glacial geology of the upper San Joaquin drainage, Sierra Nevada, California: Univ. Calif., Los Angeles, Ph.D. thesis, 237 p.
- Blackwelder, Eliot, 1931, Pleistocene glaciation in the Sierra Nevada and Basin Ranges: Geol. Soc. America Bull., v. 42, p. 865-922.
- Charlesworth, J. K., 1957, The Quaternary era: London, Edward Arnold, v. 1, 591 p.
- Cooper, W. S., 1958, Terminology of post-Valders time: Geol. Soc. America Bull., v. 69, p. 941-945.
- Cox, D. P., 1956, Geology of the Helena quadrangle, Trinity County, California: Stanford Univ. Ph.D. thesis, Doctoral Dis. Ser., Publ. 17, 710, University Microfilms, Ann Arbor, Mich.
- Crandell, D. R. and Waldron, H. H., 1954, Recent mudflow of exceptional dimensions from Mt. Rainier, Washington (abst.): Geol. Soc. America, v. 65, p. 1337.
- ✓ Davis, S. N., 1958, Glaciated peaks in the northern Coast Ranges, California: AM. JOUR. SCI., v. 256, p. 620-629.
- Diller, J. S., 1911, The auriferous gravels of the Trinity River basin, California: U. S. Geol. Survey Bull. 470, p. 11-29.
- , 1914, Auriferous gravels in the Weaverville quadrangle, California: U. S. Geol. Survey Bull. 540, p. 11-21.
- Ferguson, H. G., 1914, Gold lodes of the Weaverville quadrangle, California: U. S. Geol. Survey Bull. 540, p. 22-79.
- Hartshorn, J. H., 1958, Flowtill in southeastern Massachusetts (abst.): Geol. Soc. America Bull., v. 69, p. 477-482.
- Hershey, O. H., 1900, Ancient alpine glaciers of the Sierra Costa Mountains in California: Jour. Geology, v. 8, p. 42-57.
- , 1901, Metamorphic formations of northwestern California: Am. Geologist, v. 27, p. 225-245.
- , 1902, Neocene deposits of the Klamath region, California: Jour. Geology, v. 10, p. 377-392.
- , 1903a, The relation between certain river terraces and the glacial series in northwestern California: Jour. Geology, v. 11, p. 431-458.
- , 1903b, Some evidence of two glacial stages in the Klamath Mountains in California: Am. Geologist, v. 31, p. 139-156.
- , 1903c, Certain river terraces of the Klamath region, California: AM. JOUR. SCI., v. 16, p. 240-250.
- , 1904, The river terraces of the Orleans Basin, California: Univ. Calif. Dept. Pub., Geol. Sci. Bull., v. 3, p. 423-475.
- Hinds, N. E. A., 1932, Paleozoic eruptive rocks of the southern Klamath Mountains, California: Univ. Calif. Pub., Dept. Geol. Sci. Bull., v. 20, p. 375-410.
- , 1933, Geologic formations of the Redding-Weaverville districts, northern California: Calif. Jour. Mines and Geology, v. 29, p. 76-122.
- , 1935, Mesozoic and Cenozoic eruptive rocks of the southern Klamath Mountains, California: Univ. Calif. Pub., Dept. Geol. Sci. Bull., v. 23, p. 313-380.
- , 1940, Paleozoic section in the southern Klamath Mountains, California: Sixth Pacific Sci. Cong. Proc., v. 1, p. 273-287.
- MacDonald, D. F., 1910, The Weaverville-Trinity Center gold gravels, Trinity County, California: U. S. Geol. Survey Bull. 430, p. 48-58.
- Matthes, F. E., 1930, Geologic history of the Yosemite Valley: U. S. Geol. Survey Prof. Paper 160, 137 p.
- , 1939, Report of the committee on Glaciers: Am. Geophys. Union Trans., p. 518-523.
- , 1940, Committee on glaciers: Am. Geophys. Union Trans., p. 396-406.
- , 1942, Glaciers, chap. 5 in Hydrology, Physics of the Earth: New York, McGraw-Hill Book Co., Inc., v. 9, p. 149-219.
- Maxson, J. H., 1933, Economic geology of portions of Del Norte and Siskiyou counties, northwesternmost California: Calif. Jour. Mines and Geology, v. 29, p. 123-160.
- Nelson, R. L., 1954, Glacial geology of the Frying Pan River drainage, Colorado: Jour. Geology, v. 62, p. 325-343.